ASSESSMENT OF UPPER LIMB MYOELECTRIC PROSTHESES

by

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Abstract

In recent years, many new prosthetic devices have entered the marketplace claiming to be easy to use and to significantly improve the functional outcomes of the amputees. This research study aimed at establishing evidence and providing tools to rehabilitation professionals and funding agencies for use in appropriate prescriptions of prostheses to amputees who lost their upper limbs from work-related injuries.

The thesis started with a review of published literatures on upper limb myoelectric prostheses. The review focused on critical factors affecting successful prescriptions, current standards governing design and safe use, guidelines and practice for testing, performance evaluation, and outcome measurements. To understand the current practice and state of technology, an overview of upper limb functions, amputation characteristics, residual limb management, prosthetic intervention, and current prosthetic technologies was included.

A retrospective data analysis was performed on case files of upper limb amputee prosthetic users. The analysis first looked at the profile of the amputees, characteristics of prosthetic prescriptions, and levels of prosthetic utilization. Based on the claim files from prosthetists, the reliability, maintenance requirements, as well as the acquisition and operating costs of different prosthetic devices were studied. Results of the analysis such as prosthetic abandonment rates, mean time between failures, average maintenance service intervals, and life-cycle cost of ownerships were presented.

A survey was performed to collect information on safety issues relating to prosthetic use. Base on a survey results and risk management standards on medical devices, a

systematic process to perform risk assessment on upper limb prostheses was formulated. This process took into consideration the functional activities and employment needs from the users' and caregivers' perspectives.

An assessment platform for upper limb externally-powered prostheses was developed. The platform consisted of a hardware EMG signal acquisition module, an analog I/O module, virtual instrument (VI) modules, and a number of custom-built transducer circuits. The platform was designed to assess the functional performance of myoelectric prostheses and to verify technical specifications of prosthetic components. Two commercial myoelectric prosthetic terminal devices were used to validate the platform.

Preface

The following publications are based on the work from this research study. The thesis author prepared the manuscripts and was the main contributor of these publications.

1. Some preliminary work in chapter 6 was presented in this refereed conference podium presentation:

   Chan, A., Kwok, E. and Bhuanantanondh, P. An Assessment Platform for Upper Limb Myoelectric Prosthesis, *The 34th Canadian Medical and Biological Engineering Society Conference*, Toronto, Canada, June 2011.

2. A paper based on part of the work in chapter 6 has been accepted for publication in the Journal of Medical and Biological Engineering (with permission):

   Chan, A., Kwok, E. and Bhuanantanondh, P. Performance Assessment of Upper Limb Myoelectric Prostheses using a Programmable Assessment Platform, *Journal of Medical and Biological Engineering*, 32(4): 259-264, 2012.

3. A version of chapter 5 was accepted as a refereed poster paper in the RESNA 2011 conference:

   Chan, A., Kwok, E. and Bhuanantanondh, P. Development of a Risk Assessment Process for Upper Limb Myoelectric Prostheses. *The 2011 Annual Conference of the Rehabilitation Engineering and Assistive Technology Society of North America*, Toronto, Canada, June 2011.

Under a "confidentiality agreement" with WorkSafeBC (dated July 7, 2011), twenty eight amputee workers' case history files between the year 2004 and 2010 were obtained from WorkSafeBC. No direct or indirect contact was made with the amputee workers.

Approval (UBC BREB Number: H12-02040) was granted by the UBC Office of Research Services, Behavioural Research Ethics Board. The results of this retrospective analysis are presented in chapter 4 of the thesis. All names of the workers have been removed from the thesis.

To obtain expert opinion regarding risk assessment in prosthetic applications, a questionnaire was sent via emails to the ULPOM Group − a professional group comprising of occupational therapists, physiotherapists, prosthetists, manufacturer's representatives, engineers and researchers interested in outcome measurements of upper limb prostheses. The responses from the questionnaire are discussed in chapter 5 of the thesis. A risk management framework is formulated and proposed for upper limb prostheses in the chapter.

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List of Abbreviations

ADL	Activities of daily living
ALARA	As low as reasonably achievable
BP	Body powered
ED	Elbow disarticulation
EV	Evoked potential
FQ	Forequarter amputation
IADL	Instrumental activities of daily living
ICF	International classification of functioning, disability and health
EMG	Electromyographic
GUI	Graphical user interface
MTBF	Mean-time-between-failures
Myo	Myelectric
SD	Shoulder disarticulation
sEMG	Surface myoelectric
TC	Transcarpal amputation
TR	Transcarpal amputation
TH	Transhumeral
TMR	Targeted muscle reinnervation
ULPOM	Upper limb prosthetic outcome measures
VI	Virtual instrument
WD	Wrist disarticulation
WHO	World Health Organization
WSBC	WorkSafe BC

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Last but not least, I am indebted to my wife, Elaine and my daughters, Victoria and Tiffany who had been missing much of my attention during the past several years while I was immersed in this endeavor.

To

my family, my mother,

and

in memory of my father

Chapter 1: Introduction

1.1 Background

A false toe made of wood and leather (Figure 1.1) unearthed in 2000 is considered by scientists to be the world's oldest functional prosthesis. It was found on the foot of a 3,000-year-old mummified body of an Egyptian noblewoman in a tomb near the ancient city of Thebes [Choi, 2007]. Today, prostheses are commonly prescribed therapeutic devices for functional or cosmetic reasons to substitute missing body parts, such as an arm, a leg, an eye, or a tooth.

(Image of "A prosthetic toe in the Cairo Museum" courtesy of Live Science - http://www.livescience.com/4555-world-prosthetic-egyptian-mummy-fake-toe.html, assessed April 20, 2012)

Figure 1.1 World's Oldest Functional Prosthesis

An external limb, or external extremity, prosthesis is an externally-applied medical device consisting of a single component or an assembly of components to replace entirely, or partly, any absent or deficient limb segment. It may be used to restore some functions of a healthy limb or used solely for cosmetic purposes. Prostheses for functional restoration of a compromised limb can be body-powered or externally-powered. A body-powered (or conventional) prosthesis relies on intentional body motion of the amputee to create functional activities. An externally-powered prosthesis uses signals produced by the amputee to control actuators in the prosthesis to create functional activities. An externally-powered prosthesis using myoelectric signals from the patient as control input is generally referred to as a myoelectric prosthesis. Electric motors and batteries are common actuators and power sources for externally-powered prostheses. A block diagram of a typical myoelectric prosthetic system is shown in Figure 1.2.

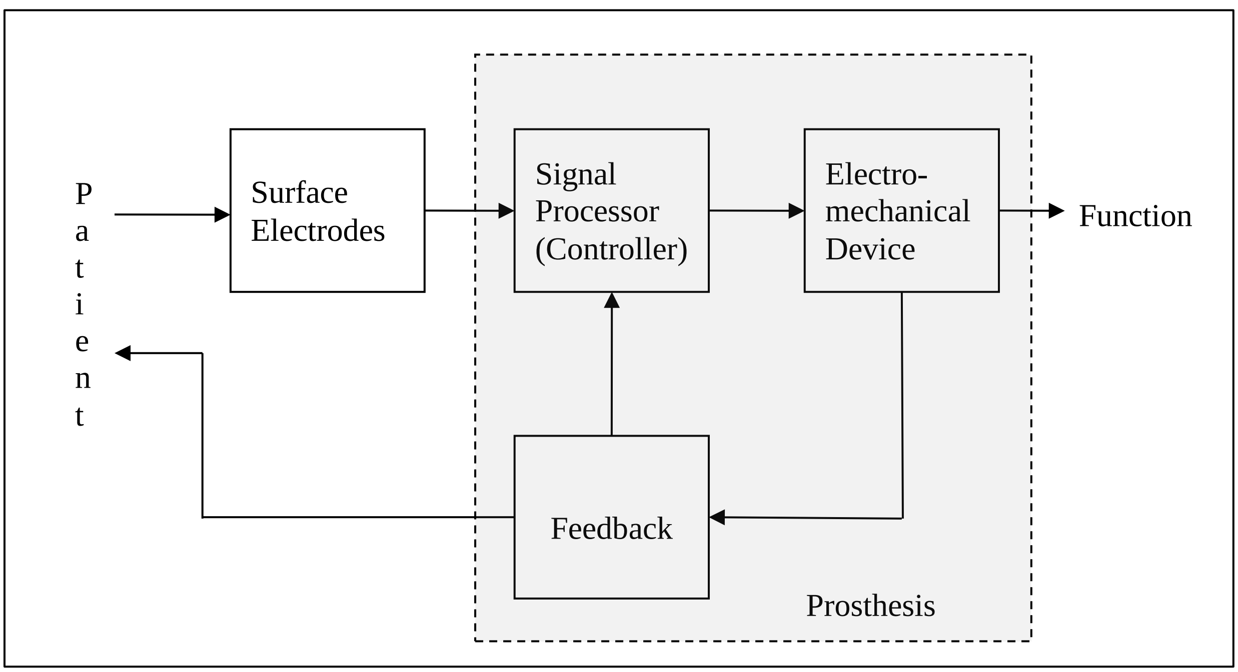


Figure 1.2 Block Diagram of a Typical Myoelectric Prosthesis

In a typical system, the patient voluntarily activates groups of skeletal muscle in sequence to perform certain tasks (or functions). Electrodes (usually surface electrodes) are applied on the patient to pick up the myoelectric signals. These myoelectric signals, which are usually of very small amplitude and mixed with other biopotential signals and noise, are processed before they can be used to control the prosthetic device. Multiple activations in sequence are usually required to perform a task (such as opening a door). Visual feedback is often used to guide the patient in completing the desired task. Some prostheses generate feedback signals to the patient to achieve better control.

The capability and fluency of performing tasks for an amputee fitted with a myoelectric prosthesis depend on the following factors:

- Initial surgical preparation and condition of the residual limb
- The engineering design of the prosthesis
- The interface between the prosthesis and the patient (electrodes, sockets, and harnesses)
- The quality of the myoelectric signals
- The availability and quality of rehabilitation and ongoing support
- The ability and motivation of the patient to learn and master the process.

The Artificial Limb Manufacturers and Brace Association (ALMBA) was founded in 1917 in anticipation of the needs for braces and artificial limbs by the soldiers during and after World War I. ALMBA later became the American Orthotic and Prosthetic Association (AOPA). About the same time, craftsmen making prosthetic arms and legs were started to be viewed as professionals. After World War II, improving prosthetic devices became an attractive field among researchers leading to rapid improvement of prosthetic technology. From the start of the anti-terrorist wars in October 2001 to August 2008, there were 1,214 US military amputees from Afghanistan and Iraq. This surge in war-related amputations prompted the US Defense Advanced Research Project Agency (DARPA) to infuse over $71.2 million US into the Revolutionizing Prosthetics 2009 (RP2009) Program for prosthetic arm research [Adee, 2009]. The Canadian Association for Prosthetics and Orthotics (CAPO) was established in 1955 as a professional organization to represent the interests of the growing number of practitioners in the field. The Upper Limb Prosthetic Outcome Measures (ULPOM) Group was formed in 2008 by an international group of prosthetists, physiotherapists, occupational therapists, biomedical engineers, researchers, and manufacturing representatives [Hill, 2009]. The goal of the ULPOM Group is to adopt and develop a set of systematic outcome measurement tools for upper limb prostheses. Although many companies around the world manufacture and sell prosthetic products for various applications, there are very few international standards guiding the design, development, sales, and use of myoelectric prosthetic components.

1.2 Motivation of Research

In recent years, new prosthetic components with increasing complexity and sophisticated technologies have entered the marketplace claiming to be easy to use and to significantly improve the functional outcomes of the amputees. Examples of emerging upper limb myoelectric prosthetic components include the “Dynamic Arm” from Otto Bock Healthcare GmbH and the “i-LIMB Hand” from Touch Bionics. Due to the short history and limited number of installations of these new prosthetic components, there has been little life-cycle documentation and inadequate understanding of their performance, reliability, and potential hazards. In addition, expensive componentry as well as high abandonment rates of myoelectric prostheses are of concern to caregivers and funding agencies.

The advancement of prosthetic technology has led to expanded use of prostheses in non-traditional areas such as recreational activities, competitive sports, and demanding employment situations. Such functional activities and their related environment are pushing the design limits and may create hazardous situations for and impose risks on the prosthetic device users as well as others who are in close proximity. Other than compensation and overuse injuries, an amputee can be put at risk due to defects, failures, or inappropriate use of prosthetic components. There have been anecdotal reported incidents of injuries to amputees wearing upper limb myoelectric prostheses yet no study was published on assessing risks associated with these devices.

Health care providers and insurance agencies often hold mandates to fund the provision, training, and ongoing maintenance of prostheses for injured workers. Keeping up with the latest technology and determining which prosthesis is appropriate for an individual amputee and at a reasonable cost becomes a growing challenge for case managers of these organizations. This research study is focused on upper limb prostheses prescribed to adult workers who underwent upper limb amputations subsequent to work-related injuries. In most cases, they are unilateral upper limb amputees with the majority of them suffering from transradial (TR) or transhumeral (TH) amputations.

1.3 Research Objectives

The main objectives of this research study are to identify patterns and critical factors affecting successful prescriptions and reliable use of upper limb prostheses in the adult worker population who have lost their upper limbs from work-related injuries. The study will attempt to develop tools and provide solutions/recommendations to resolve some of the challenges described in Section 1.2. The approach to achieve the research objectives is described below:

1. Conduct a retrospective review and life-cycle analysis of prostheses prescribed to workers who lost their upper limbs from work-related injuries.

2. Explore potential hazards on upper limb amputees from using prosthetic devices and propose a risk assessment process to be used in the early phase of prosthetic prescription.

3. Design and develop a graphical user interface assessment platform to objectively evaluate the functional performance of myoelectric prostheses.

1.4 Potential Contributions

This thesis offers a critical review of upper limb prosthetic planning and intervention of adult amputee workers. It identifies patterns, critical factors, and key areas of gaps in current upper limb prosthetic prescription practice. A study of risk associated with the use of prostheses in daily living and work environment is conducted. Solutions are proposed to address deficiencies and to enhance appropriate selection and safe use of upper limb prostheses. Information on life-cycle costs and service patterns of body-powered and myoelectric prostheses from amputee patient records are analyzed and presented. In addition, a unique assessment platform is developed to enable objective evaluation of the functional performance of myoelectric prosthetic components and systems. These findings, proposals, and tools will eventually benefit prosthetic researchers, manufacturers, rehabilitation professionals, funding agencies and, ultimately, amputees who are users of the prosthetic devices.

1.5 Thesis Organization

Chapter 1 of the thesis provides an introduction to the research work and highlights the research objectives. Chapter 2 documents the result of the literature review which focused in the following areas: prosthetic componentry and control, criteria for selection, factors affecting acceptance and replacement, prosthetic functional assessment, life-cycle analysis and safety, guidelines and standards. It summarizes published research works and identified gaps in these areas. Chapter 3 provides a critical review of upper limb functions, amputation characteristics, residual limb management, prosthetic intervention, and current prosthetic technologies. It allows one to understand and appreciate the challenges to achieve successful prosthetic prescriptions and rehabilitation, identify critical processes, as well as lays the background for this research study. Chapter 4 presents the retrospective data analysis performed on upper limb amputee case files acquired for this research. Specific information on amputee profiles, prosthetic prescription characteristics, levels of prosthetic utilization, prosthetic reliability, and life-cycle cost of ownership is reported. Chapter 5 highlights potential risks associated with use of upper limb prostheses. Based on a well-recognized medical device risk management standard, a risk assessment process including risk analysis, risk evaluation, and risk control is proposed for prosthetic devices. Chapter 6 describes the conceptualization, design, development, and validation of an assessment platform for objective evaluation of the functional performance of upper limb myoelectric prostheses. Chapter 7 draws conclusions of this research study and suggests directions for future research.

Chapter 2: Literature Review

2.1 Introduction

This literature review explores published research works on upper limb myoelectric prostheses focusing on the research objectives. Its purpose is to understand the state of the technology, critical factors for successful prescriptions, current standards governing design and safe use, guidelines and practice for testing, performance evaluation and outcome measurements.

Publications retrieved from keyword searches of online databases (e.g., PubMed, EMBASE), professional journals, conference proceedings, book chapters, and those suggested by researchers and professionals working in the field were reviewed. As this study is on prostheses use by amputees suffering from traumatic injuries, publications related to pediatric and congenital amputations were excluded. The review was focused on recent studies, primarily those published within the last decade. However, some classical publications were included. A summary of the review findings is included at the end of this chapter. Publications in this chapter are grouped under the following specific headings:

- Prosthetic Componentry and Control
- Criteria for selection of Prostheses
- Factors Affecting Acceptance and Abandonment
- Assessment of Outcomes and Performance
- Life-cycle Analysis, Safety, and Reliability
- Guidelines and Standards

2.2 Prosthetic Componentry and Control

The book *Powered Upper Limb Prosthesis: Control, Implementation and Clinical Application* by Musumdar offers a historical development of myoelectric control of the upper limbs and presents problems related to myoelectric prosthetic components following amputations of the upper limbs. It describes the fittings and interface design, myoelectric signal acquisition and processing, prosthetic components' characteristics, therapy and assessment, as well as provides an overview of available commercial myoelectric prosthetic components [Musumdar, 2004]. Pettenburg, in his book *Upper extremity prosthetics*, *Current Status and Evaluation*, introduces prostheses and prosthetic components to overcome arm defects, their means of control, and their sources of power. The author also explores the actual use of prostheses and basic requirements needed for each type of prosthetic components. [Pettenburg, 2006].

Lake and Dodson described the desired characteristics of different socket designs: an anatomic-contoured socket is fitted to the muscles of the residual limb and maintains a suspension that incorporates the benefits of the mediolateral and anterior-posterior contours of the limb; flexible socket designs distribute force globally, resulting in better overall weight bearing on the residual limb. In order to achieve active motions, electrodes must be securely positioned and in contact with the skin to receive the signals from the muscle; roll-on suction suspension liner, or roll-on-sleeve, has gained acceptance in lower limb prosthetics and is being used more frequently in upper limb prosthetics [Lake, 2006]. In a roll-on-sleeve, electrodes are installed into the liner which is then rolled over the limb to achieve a snug, form-fitted shape. A roll-on-sleeve is an excellent way to achieve superior suspension and greater range of motion as well as providing a consistent positioning of electrode sites and maintaining good electrode skin contact [Daly, 2000]. A new breathable liner is made of spacer fabrics in combination with partial silicon coating for suspension. It is designed to be permeable to gas and moisture and prevent skin breakdown by providing a cushion effect to reduce pressure peaks and shear force [Bertels, 2011].

A myoelectric prosthesis is usually activated by electromyographic (EMG) signals from the residual muscle groups in the amputee's stump. EMG signals are usually collected by surface electrodes installed in the fitting socket. The lecture *Introduction to Surface EMG* by De Luca explored the various uses of surface EMG signals in the field of biomechanics. It started with a review of the technical consideration for recording EMG signals. Topics include factors affecting the EMG signals and force produced by a muscle, detection and processing of the EMG signals, the activation timing of muscles, and the relationship between force and EMG signals. Recommendations are made to provide assistance for the proper detection, analysis, and interpretation of the EMG signals. Problems and challenges to advancing the field of surface electromyography are put forward for consideration [De Luca, 1997].

Muscle sites for electrode placements are selected primarily on the level of amputation and socket design and typically include the pectoralis, anterior deltoid, biceps, wrist flexors, posterior deltoid, infraspinatus, teres major, triceps, and wrist extensors [Lake, 2006]. The EMG signals picked up by electrodes from the muscle sites are amplified and band-pass filtered, and then processed by electronic circuits. The processed signals are then used to activate the electric motors in the myoelectric prosthesis to produce the desired motions. The myoelectric control scheme is generally based on the sequential activation of the prosthetic articulations one at a time, resulting in a not very natural motion [Troncossi, 2007].

Proportional control (versus on-off control) is used in more recent prosthetic devices such as producing variable grip force in myoelectric hands. The intensity of a myoelectric signal is used to control the grip force produced by the prosthesis. A study published in 2005 describes a series of experiments to determine the validity of using surface EMG signals from forearm muscles to predict hand grip forces. The surface EMG signals acquired from six forearm muscles of eight healthy male subjects were measured simultaneously with their handgrip forces. The handgrip forces were measured using a custom-made strain gauge force transducer. The EMG signals were recorded with disposable Ag/AgCl surface electrodes. The EMG signals were amplified, band-pass filtered (10 to 400 Hz), digitized, full-wave rectified and low-pass filtered (5 Hz) before being used to calibrate against the measured grip forces. Subsequent experiments were performed to verify the force prediction accuracy. The results showed that absolute differences between observed and predicted grip forces were small [Hoozemans, 2004].

Ohnishi and Goto applied a quality engineering technique to investigate the factors in installing EMG sensors for generating on-off activation control signal. Eight influential factors on fitting surface EMG electrodes for prosthetic hand control were selected, and a multifactor experiment was conducted as a pilot test on a single, able-bodied subject. The results showed that i) a sensor in-line with the muscle fiber direction is most effective on improving the sensitivity and signal-to-noise ratio of the EMG control function; ii) the proper determination of the cut-off frequency of the low-pass filter and the assigned activation threshold level are important parameters; and iii) electrode contact pressure and envelope window size have a minimum influence [Ohnishi, 2008]. Another article published by Schulz provides an overview of the sensor options as an alternative to EMG sensors for prosthesis activation. The characteristics of a number of commonly-used sensors (including Flexbend-Sensors and Touch-Pad force sensing resistors) and their applications in a partial hand prosthetic configuration are discussed [Schulz, 2011].

2.3 Criteria for Selection of Prostheses

Inappropriate prescription of upper extremity prosthetic components is a concern for both clinicians and manufacturers. Selection of the most appropriate prosthetic components and controls requires knowledge of options available and the ability to predict which systems will most benefit the user. However, the most important factor to consider in fitting high-level bilateral arm amputees is the user [Uellendahl, 2008]. Troncossi, in his book *Rehabilitation Robotics*, stated that sufficient functionality, reliable performance, and pleasant appearance are good qualities of a prosthesis. Other critical aspects that need to be addressed are the weight and the volume of the physical structure, as well as intricate control [Troncossi, 2007].

Sears presented a vector approach (quantitative approach) to match devices with patient needs. From the five basic needs, which are function, comfort, cosmesis, reliability and convenience, and low cost, he created a vector score to suggest the most appropriate terminal device (e.g., body power or myoelectric, hook or hand) for the patient. The basic needs were weighed to represent the needs variation among different patients. He suggested that although the quantitative approach may predict what type of devices to prescribe, intangible criteria such as motivation, body image, and expectation will determine whether or not the patient is going to use the device. He further suggested that trial fitting is a practical and reliable approach to assess these intangible criteria [Sears, 1991].

Matching a limb that meets both the requirements of daily living and future workplace duties can be seen as the ultimate challenge to any prosthetic fitter. The Prosthetist's Assistant for Upper Limb Architecture (PAULA) software is a tool developed by Otto Bock HealthCare GmbH to guide certified prosthetists through the whole prosthetic rehabilitation process and help them to choose the best components and improve the outcome of the fitting. PAULA was designed for both myoelectric and body-powered prostheses for all levels of amputation as well as for passive arm prostheses [Eichinger, 2008].

When financial consideration is put aside, the condition of the residual limb, control constraint, and performance expectations are major determining factors for prosthetic component prescriptions. In general, the longer the residual limb, the easier it is for a patient to operate a body-powered or electrical prosthesis. However, the harness, which is required for functionality and suspension of a body-powered prosthesis, limits the range of motion and functional envelope of the individual. Such limitations make it difficult for the patient to operate a terminal device without having to use gross body motion. For a higher level amputation, such as transhumeral and glenohumeral levels, an electrical prosthesis has been proven to be a more functional option over its body-powered counterpart. In a body-powered prosthesis, the harness operates with a pull to apply tension to a cable to create the prosthetic motion or actuate a switch to release or apply a lock on the prosthesis. The user can feel the cable tension during a grasping motion and adjust accordingly. The motion triggering the harness will result in additional movements from locations near the harness attachment point that may feel or look awkward [Lake, 2006].

Body-powered prostheses are usually more durable and able to provide sensory feedback to the patient when compared to myoelectric devices. However, it is less cosmetically pleasing than a myoelectric device and requires more gross limb movements to operate [Martinez, 2011]. On the other hand, a myoelectric device comes with additional weight and is more expensive. In some cases, combining the precision of a myoelectric device with a body-powered terminal device can create a hybrid that is particularly useful for hand users [Andrew, 2002]. Body-powered prostheses are less sensitive to the environmental conditions where foreign materials and moisture may compromise use and require additional maintenance [Brenner, 2008].

Uellendahl outlined the prosthetic management of a traumatic bilateral shoulder disarticulation amputee over a period of 19 years (1989−2008). He concluded that a hybrid approach combining both external and body-powered prostheses has merit. Body-powered prostheses offer proprioceptive feedback through the cable and harness and, therefore, is favored by the user for fine manipulation while electrically powered prostheses offer higher grip strength and lift capabilities [Uellendahl, 2008].

Another study on bilateral transradial amputees in performing activities of daily living (such as drinking from a cup and opening a door) concluded that “a body-powered prosthesis allowed for greater range of elbow flexion but required more shoulder flexion to complete the tasks that required continuous grasp. While using myoelectric prostheses, the user was able to compensate for limited elbow flexion by flexing the shoulder" [Cary, 2009].

In a study of using intelligent hierarchical control to reduce the need for visual feedback in grasping process automation, the authors concluded that body-powered systems provided more speed and accuracy by enabling the wearer to sense device actuation through cable tension and harness position. Although myoelectric prostheses do not provide the tactile feedback that a body-powered device does, the electric motor in a myoelectric device do provide more proximal function for upper humeral amputation patients and also produce greater grip strength. However, grasping decisions will have to be based solely on visual feedback requiring the user to continuously monitor the prosthesis [Light, 2002].

As an alternative to myoelectric control, externally-powered prostheses that utilize small switches, rather than muscle signals, to operate the electric motors are options to be considered. Typically, these switches are enclosed inside the socket or incorporated into the suspension harness of the prosthesis. A switch can be activated by the movement of a remnant digit, or part of a bony prominence against the switch, or by a pull on a suspension harness similar to a movement a patient might make when operating a body-powered prosthesis [Kelly, 2011].

Bhuanantanondh et al. conducted a survey of prosthetists to identify key factors for fitting upper limb amputees. The results showed that the main advantages of the body-powered prostheses include lower cost, lighter weight, and usable in more hostile conditions. Myoelectric prostheses provide greater grip force, closer to normal physiological control, and a wider functional envelope. An important consideration in prosthesis selection is matching functional needs to capabilities of prosthetic system such as range of motion, weight, grip strength, environment, as well as the patient's motivation [Bhuanantanondh, 2011].

A study by Heckathorne and Waldera reported the results of interviews conducted with 23 farmers and ranchers with lower limb amputations and 17 with upper limb amputations. Of the 17 farmers with upper limb amputations, 13 had amputations caused by accidents involving farm equipment. One had a partial hand amputation, one had a wrist disarticulation, ten had transradial amputations, four had tranhumeral amputations, and two had shoulder disarticulations. All of the farmers with transradial amputations were using a prosthesis. Only one out of a total of six farmers with transhumeral or higher level amputations was using a prosthesis. All farmers using prostheses in their farm work were using cable-actuated, body-powered devices. Seven of the farmers had experience with myoelectric prostheses but did not use them in farming activities. The most important problem identified by both farmers and prosthetists was durability. Concern about durability was the most common reason cited for not using an electric-powered device for farm work. Another reason preventing the use of electric-powered devices in farming is the requirement of washing the entire prosthesis with soap and water to remove dirt and contaminants [Heckathorne, 2011].

2.4 Factors Affecting Acceptance and Abandonment

A questionnaire was used to retrospectively evaluate the use of body- and externally- powered prostheses of 314 adult, upper limb amputees at the Ontario Workers' Compensation Board. Follow-up ranged from 1 to 49 years with a mean of 15 years. Sixty-nine out of the 83 amputees (83%) indicated complete or useful acceptance of an electrically-powered prosthesis; 199 of 291 amputees (68%) used the cable operated hook, 57 of 291 (20%) used the cable-operated hand and 40 of 83 (48%) used the cosmetic prosthesis. The majority of amputees used more than one prostheses for their functional needs and, therefore, should be fitted with more than one type of prosthesis. Acceptance rate of an upper-limb prosthesis was 89% (196/220) for below-elbow amputees, 76% (56/74) for above-elbow amputees and 60% (12/20) for high level amputees. These figures indicate that for most upper limb amputees, their prostheses are well used and essential to their personal and employment activities [Millstein, 1986].

Silcox et al. conducted a study to examine acceptance and usage of myoelectric prostheses of 61 amputees at the Emory University affiliated hospitals from January 1972 through December 1989. With 14 patients lost to follow-up, one dead, and two with less than two years of experience (violated inclusion criterion), 44 remained in the study group. Of the remaining 44 patients, the mean age at prosthesis fitting was 38 years; 91% of the amputations were trauma related; 68% were distal to the elbow and 6% were wrist disarticulations; forty patients had a conventional prosthesis and nine had a cosmetic prosthesis besides their myoelectric prostheses. Among the 40 patients who owned a conventional prosthesis before being fitted with a myoelectric prosthesis, 83% had been using their prosthesis for an average of eight years. The authors utilized a standardized questionnaire to determine prosthetic usage patterns, reasons for rejection, training received, and the amputee perception of sensory feedback. Amputees were asked to quantify the time they spent wearing their various prostheses at home, at work, and for social activities. The results showed that 22 patients (50%) rejected the myoelectric prosthesis completely; thirteen (32%) of the 40 patients who also had a conventional prosthesis rejected the conventional prosthesis completely. There was no association between myoelectric prosthesis acceptance and training by an occupational therapist; there was no significant association between acceptance of myoelectric prosthesis and length of prior experience with a conventional prosthesis. The author also found no correlations between the use of any type of prosthesis with age/sex of the amputee, reason for amputation, length of time until the prosthesis fitting, or prosthesis type preferred. The patients who used the myoelectric device the least were employed in occupations that required higher physical demands. Amputees whose job required light demands (desk or supervising jobs) from their prosthesis found sensory feedback good and the ones with high prosthesis demand jobs (manual labor) found sensory feedback poor. The reasons for not utilizing a myoelectric prosthesis were its heavy weight, low durability, and relative slowness. The most common reason for usage of a myoelectric prosthesis was its cosmetic appearance [Silcox, 1993].

An evaluation by questionnaires on patterns of use of prostheses by 135 upper limb amputees showed that between 38% and 50% of users discontinued use of their prostheses [Wright, 1995]. A study in 2004 using a self-administered postal questionnaire and medical records to collect data showed similar results [Datta, 2004]. A more recent survey of 266 patients in 2007 to investigate the roles of predisposing characteristics showed that rates of rejection for myoelectric hands, passive hands, and body-powered hooks were 39%, 53%, and 50% respectively. It also showed that enabling resources including availability of health care, cost, and quality of training did not have significant influence on prosthesis rejection. Whereas fitting time frame, involvement of clients in prosthesis selection, state of availability of technology, perceived need, and comfort are opposing factors in abandonment. The study concluded that "An improvement in comfort, particularly prosthesis weight, is considered of high priority for individuals of all ages and wearers of all types of prostheses. Design priorities reflect consumer goals for prosthesis use: wearers of passive/cosmetic hands desire a more life-like appearance, while those wearing body-powered hooks desire functional enhancements, and individuals wearing electric hands desire a mixture of both. Tracking user satisfaction is vitally important to providing consumer-centered prostheses" [Biddiss, 2007]. Lake stated that an amputee will eventually reject a prosthesis if it does not fulfill their basic personal requirements. These personal requirements are related to function, cosmetics, psychological factors, initial prosthetic experience, comfort, weight, and tactile sensation. If any of the above conditions are left unfulfilled, they may lead to abandonment or result in overuse syndrome [Lake, 2006].

A retrospective cohort study examined 935 persons with amputation in the registry maintained by the Amputee Coalition of America. Among the 362 (38.7%) persons who lost their limbs from trauma injuries, 75 (20.7%) were upper and 287 (79.3%) were lower limb amputees. Together with data collected on the use and satisfaction with prosthetic devices, the study revealed that "the frequency of prosthesis use and satisfaction with the device were significantly higher among those with shorter timing to first prosthesis fitting" [Pezzin, 2004]. A survey questionnaire to explore factors in prosthesis acceptance revealed that individuals fitted within two years of birth (congenital) or six months of amputation (acquired) were 16 times more likely to continue their prosthetic use. The survey concluded that to increase the rate of prosthesis acceptance, clinical directives should focus on timely, client-centered fitting strategies, and the development of improved prostheses and health care for individuals with high level or bilateral limb absence [Biddiss, 2008].

The socket is a custom-built device to interface the prosthesis with the residual limb of the patient. The physical characteristics of the residual limb affect the fit of the socket and, therefore, are considered an important factor in the design of a prosthetic socket. Acceptance and successful long-term usage of an upper-limb prosthesis is primarily dependent on its comfort and perception of the amputee [Andrew, 2002; Brenner, 2008]. A major failure of the prosthesis or end of its useful life provides an opportunity to re-evaluate the patient's functional goals and re-consider the design of the prosthesis. Factors to consider are improved fabrication techniques and materials, new components, and better control schemes [Uellendahl, 2008].

A report on a survey of literature on upper limb prosthetic devices focused on myoelectric hands by WorkSafe BC in 2011 identified factors related to successful prosthetic use/acceptance included: job/work conditions, level of amputations, type/properties of prostheses, time between amputation and prosthesis fitting, and availability/continuity of vocational and rehabilitation services [Martin, 2011].

2.5 Assessment of Outcomes and Performance

Despite the increased interest in research and development, existing prosthetic technology is not sufficiently advanced to match the human's pre-amputation ability. Unlike lower limb prosthetics which can benefit from the effects of gravity and ground reaction forces to enhance involuntary prosthetic function, upper limb amputees must consciously control each separate movement of their prostheses. The ability to replace upper limb functions with a prosthesis (especially involving a high level trans-humeral, shoulder-disarticulation or intra-scapular-thoracic amputation) is limited by the prosthetic components and control systems available at the time [Brenner, 2008].

Drummey summarizes published studies that examined functional upper limb range of motion of normal and impaired patients. It highlights that interface designs, harnesses, and prosthetic types are some of the potential limitations that affect the functional outcome of treatments and their progression [Drummey, 2009].

Standardized measurements are important to assessment of any intervention. Pasquina included three areas in his outcome measures in amputee care. They are mobility, function, and quality of life (QOL) [Pasqiina, 2006]. The World Health Organization's (WHO) International Classification of Functioning, Disability, and Health (ICF) Framework is structured around three components: body function and structure, basic functional skills, and participation. These are factored into some outcome measurement tools [World Health Organization, 2002].

The most typical type of prosthetic assessment is task completion tests or performance tests. In these tests, the ability of the user to perform specific tasks related to practical daily activities and the time required for task completion are used as assessment criteria. An example is the Southampton Hand Assessment Procedure (SHAP) which is a clinically-validated hand function test made up of eight abstract objects and 14 activities of daily living (ADL). The time to complete a particular task is used as a quantitative parameter in the assessment [Light, Chappell & Kyberg, 2002]. The Michigan Hand Outcomes Questionnaire (MHQ) is another hand-specific outcome instrument that is used to assess a patient's general hand function with conditions of, or injury to, the hand or wrist. The MHQ contains six distinct scales which cover overall hand function, activities of daily living (ADLs), pain, work performance, aesthetics, and patient satisfaction with hand function [U-M Medical School−MHQ, retrieved 2009].

Metcalf et al published a practical overview of studies by clinicians and researchers involved in assessing upper limb function. The article considers 25 upper limb assessments used in musculoskeletal care and presents a simple, straightforward comparative review of each. The World Health Organization International Classification on Functioning, Disability and Health (WHO ICF) model was used to provide a relative summary of purpose between each assessment [Metcalf, 2007].

The Upper Limb Prosthetic Outcome Measures (ULPOM) Group published a "ULPOM Reference List" with 29 assessment tools and their related publications. The assessment tools identified include: ABILHAND, ABILHAND-Kids, ACMC, Life-H, AMPS, AHA, AMAT, ASK, Box and Blocks, CAPP-FSU, CAPP-FSIP, CAPP-FSIT, CAPP-PSI, CHQ, COPM, DASH, DASABLIDS, GAS, Jebsen Taylor Test of Hand Function, OPUS, PEDI, PedsQL, PODCI, PUFI, Purdue Pegboard, QUEST, SFA, TAPES, WHOQOL-BREF [Hill, 2009].

Wright conducted a systematic literature search including electronic databases from 1970 to 2009 and performed a structured review on peer-reviewed publications related to outcome measurements with upper limb amputees. Of the 660 publications identified from the search, 25 met all of the inclusion criteria for full review. In those publications, seven adult and nine pediatric distinct outcome measures were found. Several of the measures were identified with greatest psychometric promise for use in upper limb prosthetics. These include ACMC, UEFS module of the OPUS, DASH, and TAPES. Wright concluded that "the use of standardized outcome measures with adult upper limb amputees is sparse in the published studies of this clinical population, and validation work with the measures that have been used is in its early stages across all components of the ICF" [Wright, 2009].

The assessment of capacity for myoelectric control (ACMC) has been gaining popularity for use to assess the capacity of control of prosthetic users. It is administered and scored based on clinical observations of the myoelectric prosthesis user when he or she is performing everyday tasks. Any task, easy or difficult, can be used as long as the task requires active use of both hands. It is to evaluate the person's capacity to control the myoelectric prosthesis, not the person's independence or quality of task performance. An occupational therapist assesses the capacity for control of the myoelectric prosthesis by rating the amputee's performances on items representing different aspects of quality of myoelectric control. The 30 items in the ACMC are classified into four groups: 1-Gripping (12 items), 2-Holding (6 items), 3-Releasing (10 items), and 4-Coordinating between hands (2 items). Each person's performance is rated with scores ranging from 0 to 3. From not capable (= 0), sometimes capable (= 1), capable on request (= 2), to spontaneously capable (= 3). Some examples of the items are: adjust grip force without crushing, holds with no visual feedback, release with arm supported, coordinate grips using both hands [Hermansson, 2004].

Millstein et al. conducted a study using mailed questionnaires from more than 1,000 industrial amputees at the Ontario Workers' Compensation Board. The study investigated the current employment status of amputees and the factors that influenced successful return-to-work. At the time of review 51% of the amputees were full-time employed, 5% part-time employed, 25% retired, and 8% unemployed. The remainder were engaged in a vocational activity, still recovering, or were not seeking work. Among upper limb amputees, the unemployment rate varied by the level of amputation; 22% (highest) in above-elbow, 18% in partial hand amputations and 10% (lowest) in below-elbow. Subjects who reported more frequent prosthetic use were more likely to be employed. The data revealed that amputees typically returned to jobs that were less physically demanding. Factors including prosthetic use, vocational services, and a younger age at the time of amputation were identified as being positively associated with a return to work. Those factors that were negatively related to successful employment included dominant hand lost, stump and phantom limb pain, and multiple limb amputations. The study concluded that the majority of the amputees reviewed were successful in returning to work. Although they did not assess the psychological state of the amputees, the authors emphasized the importance of psychological circumstances as a factor influencing the success of a rehabilitation program, including the rate of return-to-work. The authors further suggested that amputees benefit from treatment programs that include medical, prosthetic, and vocational services [Millstein, 1985].

Scheme and Englehart developed a MATLab-based virtual environment to facilitate rapid prototyping and testing of real time prosthetic control schemes. The virtual environment includes multiple-channel signal acquisition, signal processing, and output control configuration. The ability to visualize raw signals and control signal outputs enables researchers to study prosthetic controls with the user-in-the-loop. This application has been used as a research and clinical tool helping to verify the viability of existing (such as dual site configuration) and proposed (such as pattern recognition-based) myoelectric control strategies [Scheme, 2008].

2.6 Life-Cycle Analysis, Safety and Reliability

To identify costs associated with assistive devices, a study was conducted with veterans from the Vietnam conflict (1961−1973) and servicemembers from the OIF/OEF (Operation Iraqi Freedom/Operation Enduring Freedom) conflicts (2000−2008). Those with at least one major traumatic amputation were surveyed. Two hundred and ninety eight (65%) from the Vietnam conflicts and 283 (59%) from the OIF/OEF responded to the surveys. The 2005 Medicare prosthetic device component prices were applied to current prosthetic and assistive devices. Projections were made for 5-year, 10-year, 20-year, and lifetime costs based on Markov models. Assistive-device replacements for the Vietnam group are lower than for the OIF/OEF cohort due in part to use of fewer and less technologically-advanced prosthetic devices and higher frequency of prosthetic abandonment. For the Vietnam group and OIF/OEF cohort, 5-year projected unilateral upper limb average costs are $31,129 and $117,440, unilateral lower limb costs are $82,251 and $228,665, and multiple limb costs are $130,890 and $453,696 respectively [Blough 2010].

In the literature review published by WorkSafeBC in 2011, the author stated that "in the 1990s, for a below-elbow amputee, the cost of a myoelectric prosthesis was about six times higher than the cost of a body-powered prosthesis including an opening or closing terminal device. In 1997, in Canada, the average price of a below-elbow myoelectric prosthesis was $9,000 USD and repair costs of approximately $800 USD annually. The prosthesis would need replacing every 4−5 years. In 2008, in Canada, the cost of a myoelectric hand ranged from about $7500 to $29500 CAD, whereas a conventional body-powered prosthesis might cost around $5500 CAD." [Martin, 2011]

A group of researchers evaluated the functional outcomes of two new myoelectric terminal devices (i-LIMB hand and DMC plus hand) in a case study with a 45-year-old male unilateral upper limb amputee. The evaluation covered all functional levels of the International Classification of Functioning and Health (ICF) framework using a number of function outcome assessment tools such as SHAP and TAPES. The authors found no significant difference between the two terminal devices. [Van der Niet Otr, 2010].

The risk factors of overuse injury found in the amputee population include repetition, high force, awkward joint posture, direct pressure, vibration, and prolonged constrained posture. Examples of common upper limb overuse injuries include rotator cuff tendonitis and tears, shoulder impingement and bursitis, lateral and medial epicondylitis, carpal tunnel syndrome, and tendonitis of the forearm extensors [Verdon, 1996].

Jones and Davidson studied the occurrence of overuse injuries in the sound limbs of unilateral upper limb amputees in an Australian hospital between 1994 and 1997 and found that 50% reported symptoms of overuse injury. They stated that no unilateral upper limb amputee is immune to overuse injuries and, therefore, patients must be counselled about the risk of overuse injuries. Furthermore, prosthetists and rehabilitation therapists should not place their clients at risk by encouraging them to do the same level of activities they were doing before amputation [Jones, 1999].

2.7 Guidelines and Standards

The International Classification of Functioning, Disability and Health, known more commonly as ICF, provides a standard language and framework for the description and classification of disability and health. This framework has been adopted by many in the assessment and outcome measurements of limb prostheses [World Health Organization, 2002].

The following standards on upper limb prostheses were located:

- ISO 8548-3:1993. Prosthetics and orthotics − Limb deficiencies − Part 3: Method of describing upper limb amputation stumps
- ISO 13405-1:1996. Prosthetics and orthotics − Classification and description of prosthetic components − Part 1: Classification of prosthetic components
- ISO 13405-3:1996. Prosthetics and orthotics − Classification and description of prosthetic components − Part 3: Description of upper-limb prosthetic components
- BS EN12182:1999. Technical aids for disabled persons − General requirements and test methods
- ISO 22523:2006(E). External limb prostheses and external orthoses – Requirements and test methods

The ISO 22523:2006(E) is a combined level 2 and 3 standard dealing with technical aids for disabled persons. It specifies requirements and test methods for external limb prostheses and external orthoses covering “strength, materials, restrictions on use, risk and the provision of information associated with the normal conditions of use of both components and assemblies of components" [ISO 22523:2006(E)].

External limb prosthetic components, according to the US Food and Drug Administration Code of Federal Regulations Title 21, are classified as Class I medical devices under "physical medicine devices" [US FDA 21CFR890.3420, 2011]. Mechanical or powered hand, hook, wrist unit, elbow joint, and cables are listed under external limb prosthetic components in this section. Class I devices are not subjected to the rigorous review processes required for medical devices in higher classifications. Performing hazard analysis during prosthetic product development and its documentation are not required. Although some manufacturers included hazard analysis in their development process, they are not required to disclose such information.

ISO 13485 is a standard stipulating the requirements for a comprehensive management system for the development and manufacturing of medical devices [ISO 13485:2003]. ISO 14971 is a risk management standard for medical devices. It provides a basic process on risk analysis, risk evaluation, and risk control [ISO 14971:2007]. Compliance of these standards is enforced by medical device regulatory agencies such as Health Canada and the US FDA.

The Upper Limb Prosthetic Outcome Measures (ULPOM) Group was formed in 2008 by an international group of prosthetists, physiotherapists, occupational therapists, engineers, researchers, and manufacturer representatives. The goal of the group is to adopt and develop systematic outcome measurement tools for upper limb prostheses based on the WHO ICF model. The group believes that a unified approach throughout the profession would identify a set of validated tools already in existence and discover gaps within the set that need additional attention [Hill, 2009].

At the American Academy of Orthotists and Prosthetists' Ninth State of Science Conference on upper limb prosthetic outcome measures held in March 2009, a group of engineers, prosthetists, and therapists reviewed and discussed the report by Wright on the evidence-based review of upper limb prosthetic outcome measures [Wright, 2009], the report by Hubbard on pediatric upper limb outcome measurement [Hubbard, 2009] and the work by the ULPOM group [Hill, 2009]. The group concluded that "there was no one 'gold standard' outcome measure identified that covered all related components and would work in all fields of application (i.e., research or patient care)." At the conference, the group classified existing outcome measurement tools into three categories: recommended, to consider, and excluded [Miller, 2009]. To suggest how these tools might be used on human subjects, the group further classified them into three fields of applications: development research, clinical research, and patient care. Quoted below are seven research priorities summarized from the gaps identified in the discussions:

1. *How should outcome measures be disseminated to the various stakeholders along the continuum? That is, what are the best methods to enable all of the stakeholders to use outcome measures on a routine basis?*
2. *What are appropriate and recommended measures that can be identified across the continuum from research and development through community integration and across all the ICF-related components?*
3. *How can we leverage multidisciplinary, multicenter, longitudinal, and collective studies to answer the interest questions of the various stakeholders?*

4. *What measures are sensitive enough to evaluate acceptance and rejection of prosthetic devices?*
5. *How does the team approach influence upper limb prosthetic outcomes? (multidisciplinary, experience, specialty groups or specialized training, and complexity of the case [bilateral and/or higher levels of amputation, other comorbidities, etc]).*
6. *What are the contributing factors to overuse injury in upper limb deficiency and is there a difference in injury incidence and severity for those who do or do not use an upper limb prosthesis?*
7. *How are overall clinical upper limb outcomes related to individualized interventions or decisions?*

Despite the lack of standards in the industry, there is significant interest among manufacturers and researchers to develop standards to facilitate compatibility of prosthetic components. The Institute of Biomedical Engineering at the University of New Brunswick (UNB) developed a Prosthetic Device Communicated Protocol (PDCP) which is a digital serial communication bus based on the Control Area Network (CAN) widely used in the industry (e.g., automobile) [Losier, 2010]. The PDCP is implemented in the controller area network bus in the myoelectric control unit of a new modular multiple degree of freedom myoelectric hand currently being developed at UNB [Losier, 2011]. Another group is in the process of designing a universal coupler for modern powered prostheses to allow interchangeability of terminal devices, as well as to meet the demands for strength, durability, communication, and power transfer requirements [Sutton, 2011].

2.8 Conclusions: Review Findings and Identified Gaps

The literature review shows that rehabilitating an amputee to become independent in their activities of daily living and allow them to return to work involves many complicated and interrelated factors and processes. Although the history of functional prostheses could be dated back to thousands of years, due to their low volume and lack of commercial incentive, little advancement was achieved until recently. Without established industry standards and recognized performance guidelines, the academic, industry and rehabilitation communities are struggling to explore criteria for prosthetic prescriptions, maintain system compatibility (both backward and cross platforms), and improve prosthetic functional capabilities. Specifically, the following subsections highlight the key findings and gaps identified from the literature review:

2.8.1 Review Findings

- The functionality and motion fluidity of prosthetic devices are still very primitive when compared to those of the natural upper limbs.
- Many studies attempted to evaluate the acceptance of myoelectric prosthetics and to discover factors for successful prescriptions. The majority of them focussed on analyzing activities of daily living without paying much attention to work/vocational requirements.
- Tools available to measure outcomes of upper limb prostheses are centered on qualitative observations and are often questionnaire based.
- Most of these studies were qualitative, requesting patients or their caregivers to provide subjective responses to the questions.

- There is keen interest to adopt existing outcome measurement tools and to standardize outcome measurements of upper limb prostheses based on the WHO ICF model [World Health Organization, 2002].

2.8.2 Identified Gaps

- There is a lack of study on optimizing prescription of prostheses to job-specific needs.
- No standard or guideline was published on upper limb myoelectric prostheses in areas of performance evaluation or outcome measurements.
- Publications on laboratory (devices not fitted on patients) evaluation of functional performance of upper limb myoelectric prostheses were sparse.
- Some tools for use in prosthetic testing and simulation are available from manufacturers. However, they are restricted to be used on their own devices. No commercial product is available to objectively evaluate the functional performance of prosthetic components and systems.
- There are very few reported studies on life-cycle analysis, maintenance requirements, and reliability of upper limb prosthetic use.
- There is no published study on potential hazards arising from prosthetic use except those leading to collateral or overuse injuries. Risk analysis in prosthetic planning and prescriptions was not systematically performed or documented by practitioners.

Chapter 3: Prosthetic Management and State of Technology

3.1 Introduction

This chapter is based on information collected from the literature review in Chapter 2, discussions with experts and rehabilitation professionals (including prosthetists, occupational therapists, physiotherapists, prosthetic manufacturers, research engineers, and insurance case managers), observation of prosthetic fittings, assessments, and amputee training. It provides an overview of upper limb functions, amputation characteristics, residual limb management, and current prosthetic technologies. In addition, current practices in prosthetic management and intervention are categorized, presented, and critiqued. Overall, it lays the background for one to understand and appreciate the challenges in appropriate prosthetic prescriptions and successful amputee rehabilitation.

3.2 The Human Upper Limbs

The human upper arm includes three joints: the wrist, elbow, and shoulder and provides seven mechanical degrees of freedom. The shoulder complex (including the clavicle) provides three degrees of freedom, the elbow joint provides two, and the wrist provides two. For most activities, the arm provides reach and support for the hand to carry out the intended functions. A number of studies were conducted to quantify the upper extremity motions during activities of daily living [Magermans, 2005]. In a very simple model, the ranges of motions of the upper arm are tabulated in Table 3.1. It is important to note that the quantitative ranges listed in the table are for reference only as these values are different for different individuals. When considering a prosthetic prescription, it is often more important to allow the amputee to achieve desirable functional outcomes than to replicate the ranges of motions before amputation.

Table 3.1 Range of Arm Motion and Prosthetic Replacement

Joint	Motion	Range (Degrees)	Prosthetic Replacement Examples
Wrist	Flexion/Extension	0−60/0−60	friction wrist
	Radial/Ulnar Deviation	0−20/0−30	
Elbow	Flexion/Extension	90−140/0−90	BP elbow with lock; electric elbow
	Pronation/Supination	0−80/0−80	friction wrist; electric wrist rotator
Shoulder	Flexion/Extension	0−180/0−50	mainly passive prostheses
	Abduction/ Adduction	0−180/0−50	
	Internal/External Rotation	0−90/0−90	

The functional activities of the hand are extensive but can be categorized into prehensile and non-prehensile activities. Non-prehensile activities include pressing, tapping, lifting, pushing, stirring, touching, feeling, etc. Prehensile activities are grips which can be grouped into precision and power grips. A precision grip involves the radial side of the hand with involvement of the thumb, index, and middle fingers to form a jaw chuck. An example of a precision grip is holding a ball (Figure 3.1-left), or holding a scalpel in precise cutting. A power grip involves the ulnar side of the hand; all fingers including the little and ring fingers are recruited in a power grip. The thumb plays an important role in this grip. A typical power grip is the cylindrical grip. An example of such is holding the handle of a tool in which all fingers are flexed maximally (Figure 3.1-middle). When more power is needed in the power grip, the thumb is wrapped around the flexed fingers (Figure 3.1-right).

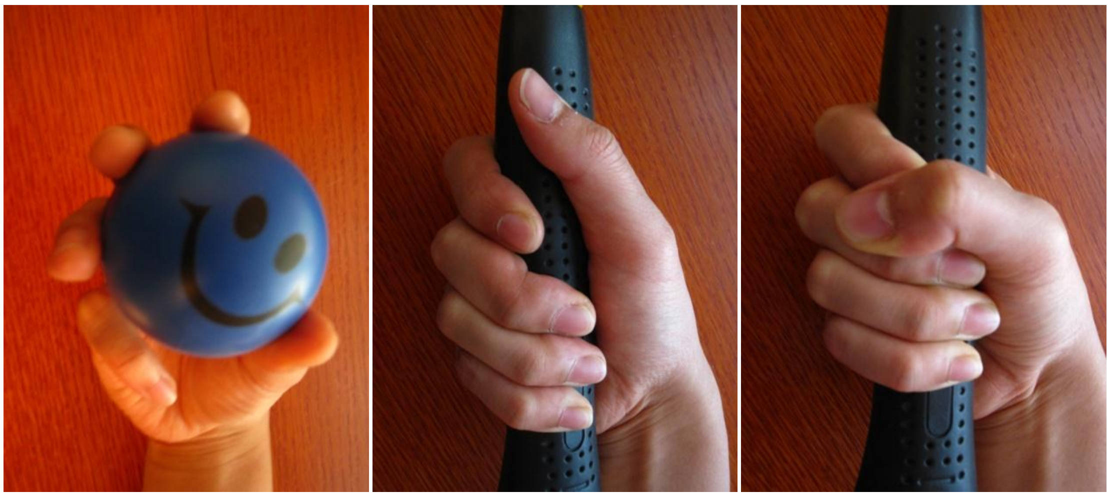


Figure 3.1 Prehensile Grip Patterns

3.3 Functional Activities

The upper limbs allow an individual to engage in various kinds of activities including activities of daily living (ADL), instrumental activity of daily living (IADL), work, play, gesture, etc. Below is the list of activities published in the "Occupational Therapy Practice Framework: Domain and Process" in the *American Journal of Occupational Therapy* [Roley, 2008].

3.3.1 Activities of Daily Living (ADL)

Activities that are oriented toward taking care of one's own body, including:

- Bathing, showering

- Bowel and bladder management
- Dressing
- Eating
- Feeding
- Functional mobility
- Personal device care
- Personal hygiene and grooming
- Sexual activity
- Toilet hygiene

3.3.2 Instrumental Activities of Daily Living (IADL)

Activities to support daily life within the home and community, including:

- Care of others
- Care of pets
- Child rearing
- Communication management
- Community mobility
- Financial management
- Health management and maintenance
- Home establishment and management
- Meal preparation and cleanup
- Religious observance
- Safety and emergency maintenance

- Shopping

3.3.3 Rest and Sleep

Activities related to obtaining restorative rest and sleep, including:

- Rest
- Sleep
- Sleep preparation
- Sleep participation

3.3.4 Education

Activities needed for learning and participating in the environment, including:

- Formal educational participation
- Informal personal educational needs or interests exploration
- Informal personal education participation

3.3.5 Work

Activities needed for engaging in remunerative employment or volunteer activities, including:

- Employment interests and pursuits
- Employment seeking and acquisition
- Job performance
- Retirement preparation and adjustment
- Volunteer exploration
- Volunteer participation

3.3.6 Play

Any spontaneous or organized activity that provides enjoyment, entertainment, amusement, or diversion, such as:

- Play exploration
- Play participation

3.3.7 Leisure

Non-obligatory activity that is intrinsically motivated and engaged in during discretionary time, such as:

- Leisure exploration
- Leisure participation

3.3.8 Social Participation

Organized patterns of behavior that are characteristic and expected of an individual or a given position within a social system including:

- Community
- Family
- Peer, friend

While the purpose of a prosthesis may be aimed at replacing functional activities for the amputee, a prosthesis may also return the appearance or provide cosmetic restoration of the missing limb. Ideally, a prosthesis should serve both purposes. Unfortunately, functional performance and cosmetic appearance are often contradicting features in current prosthetic devices. For example, a cosmetic hand can be made to look exactly like the amputated hand but will not allow the amputee to perform much practical hand function. On the other hand, a body-powered hook will enable the amputee to carry out a wide range of functional activities but it does not resemble his/her natural limb.

3.4 Amputation and Residual Limb Management

3.4.1 Amputation

An amputation may be performed as a result of trauma or disease conditions. It is part of the rehabilitation plan that includes surgical reconstruction, therapy, and prosthetic fitting to help the amputee to recover successfully. In general, the surgeon will try to save as much of the residual limb as possible while taking into consideration the rehabilitation plan. Listed below are the levels of amputation and their descriptions [Kelly, 2012]:

- Transcarpal (TC) – including transmetacarpal and carpal disarticulation (CD)
- Wrist disarticulation (WD) – at the wrist joint
- Transradial (TR) – also refers to as below elbow (BE) amputation
- Elbow disarticulation (ED) – at the elbow joint
- Transhumeral (TH) – also refers to as above elbow (AE) amputation
- Shoulder disarticulation (SD) – at the shoulder joint
- Forequarter (FQ) – removal of the entire upper extremity including the scapular and clavicle

Figure 3.2 illustrates their anatomical positions. Different amputation levels require different rehabilitation plans including therapy and prosthetic solutions.

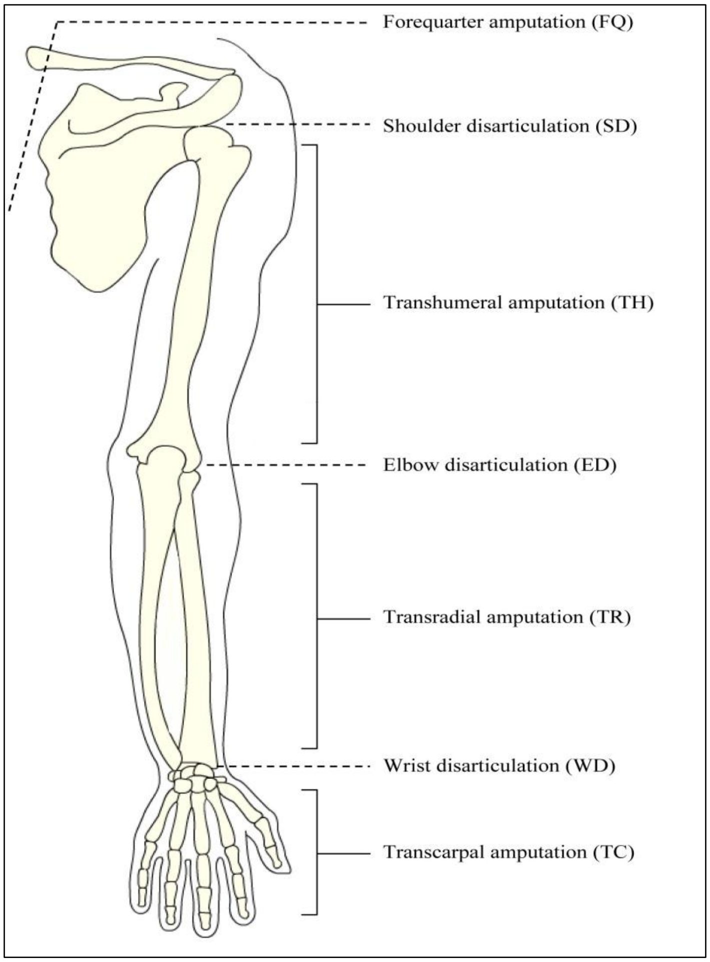


Figure 3.2 Levels of Amputation

The surgical procedure of amputation involves damaged tissue removal, bone beveling, residual nerve fiber transection, and muscle preparation (myodesis or myoplasty). In the procedure, an extra flab of skin is retained to close off the wound of the residual limb. After the surgery, a protective dressing will be applied to protect and gently compress the residual limb. A drainage tube may be placed initially to remove fluid from within the bandage. Once the initial dressing is removed, a shrinker sock or elastic bandaging will be applied to decrease swelling and promote shaping for future prosthetic fitting. The residual limb will continue to change shape and decrease in size over a period of six to twelve months before it will be stabilized. Repeated adjustments and refitting of prosthetic sockets are common during this period of stabilization.

3.4.2 Pain and Sensations Management

The injury from amputation involves severing and disturbance of nerve fibers. Until they are completely healed, the nerve endings will be extra sensitive. Minor triggering by a bump, pressure, or touch can cause pain. Such residual limb pain will gradually subside as the limb heals. Most new amputees experience phantom sensations such as twisting, itching, tingling, warm or cold feelings, movement, or even pain at where the amputated limb used to be. These sensations are common among amputees and typically will fade away within a few months after amputation. However, some amputees may experience phantom pain for years. Treatment options for phantom pain range from desensitization therapy (such as massaging, tapping, and vibration), adjustment and padding of prosthesis, acupuncture, medication, nerve blocks to surgical intervention. Prevalence of phantom pain and sensation will impact prosthetic utilization and may lead to abandonment of the prosthesis.

3.4.3 Pre-prosthetic Assessment

Shortly after surgery (ideally after injury and before surgery), a rehabilitation team (physiotherapist, occupational therapist, prosthetist, etc.) will conduct a clinical assessment of the amputee before commencing treatment planning. Some of the factors to consider include level of amputation, anatomical alignment, range of motion of the residual limb, stump condition (skin, muscle strength, shape, and pain), health status, home environment, family support, access to prosthetic rehabilitation facilities, prosthetic technical services, vocational considerations, recreational needs, psychological status, personal attitude and motivation, and funding sources. From the results of these assessments, the rehabilitation team will prescribe therapy in preparation for prosthetic fitting and rehabilitation. This pre-prosthetic therapy may include stretching and exercising to maintain flexibility, desensitization of pain and sensations, and education regarding body posture and exercise in order to prevent compensation injuries and overuse injuries.

3.5 Prescription Intervention

Fitting of the prosthesis will begin once the wound on the residual limb has healed and is no longer swollen, tender, or sensitive. This usually takes about four to six weeks after the surgery. Before prosthetic intervention, the prosthetist will:

1. assess the level of amputation and shape of the residual limb.
2. evaluate the range of motion and physical limitations.
3. discuss with the patient to identify functional and cosmetic needs, activity levels, vocational and recreational goals.
4. identify and secure available funding.

Based on the above, the prosthetist will make a prosthetic proposal to the funding agency or physician-in-charge for approval. The following describes the different phases of prosthetic intervention:

3.5.1 Shape Capture

A positive replication of the residual limb is needed for prosthetic fabrication. A plaster cast of the residual limb is usually used to create the negative shape capture of the positive model. The positive model is then created from the negative shape capture. Minor rectification of the positive model is often required before it can be used to fabricate the socket.

3.5.2 Fabrication

A diagnostic (or test) socket is usually fabricated and tested on the patient before a definitive (or final) socket is made. Sockets are usually made of thermoplastic sheets of a resin matrix composite material. Heat and suction is then applied to produce a negative fit on the positive model. The control system elements (e.g., myoelectric electrodes) are embedded and attached to the socket before it is assembled with the other prosthetic components. The assembly is then formed to fit the residual limb and with the external appearance finished according to the desire of the patient.

3.5.3 Evaluation and Functional Alignment

In additional to evaluating the fit, the diagnostic socket is used to assess the function of the prosthesis. Gaps and pressure points, if any, are identified, and any parts that are obstructing motion of the residual limb are marked for revision. The myoelectric sites may need to be relocated if the electrodes fail to produce consistent and sufficient signal level for prosthetic activation. Such information is collected in order to revise the design before the definitive socket is fabricated.

3.5.4 Modification

It is important to obtain a well-fitted socket so that the prosthetic device can be attached without irritating the residual limb and decreasing its functionality. However, even a perfectly fitted socket will need to be modified or even refitted as the shape and volume of the residual limb will change over time. In addition, a new socket will need to be fitted after a revision surgery.

3.5.5 Maintenance

Proper routine maintenance by the amputee and qualified service professionals is critical to maintain the functional performance of the prosthesis, as well as the personal hygiene of the amputee. Routine maintenance includes daily cleaning, alignment checks, adjustment, and functional inspection by the prosthetist. Periodical inspection and preventive maintenance by a prosthetist can prevent catastrophic failures. Some externally-powered prosthetic components may need to be returned to the manufacturers for factory servicing.

3.6 Rehabilitation and Prosthetic Training

Rehabilitation often starts shortly after amputation. It plays a critical role in the transition of the amputee into independent living and to return to work. An assessment is done by the rehabilitation team shortly after amputation. The team members may consist of a physiatrist, a physiotherapist, an occupational therapist, a psychiatrist, and a prosthetist. The patient's medical history and pre-amputation activities will be reviewed. The amputee's physical condition, function, and strength of the residual limb will be assessed. With consideration of the goals of the patient, the team will discuss prosthetic options and treatment plan to allow the patient to be as independent as possible, and to prepare the amputee to return to work.

In the pre-prosthetic phase, rehabilitation treatment will focus on preserving strength and endurance of the residual limb, maintaining range of motion, as well as shaping and desensitizing the residual limb in preparation for the prosthesis. Once the prosthesis is fitted, the team will rehabilitate the amputee to perform functional activities using the prosthesis; the amputee will begin to learn proper donning and doffing, and operating of the prosthesis, as well as caring for the prosthesis. The rehabilitation process is aimed at allowing the amputee to progressively build tolerance, endurance, and strength in using the prosthesis to carry out functional activities. In case the amputee is planning to return to work, the team will arrange job site visits to assess the work location and occupational physical requirements. To prepare the amputee for returning to work, the team will formulate a rehabilitation plan including simulated work activities based on the identified work requirements. Workplace modifications and assistive aids are options to help the amputee in carrying out work activities.

For externally-powered prostheses, the proficiency of prosthetic control by the patient can be predicted in the early phase of rehabilitation before the prosthesis is prescribed [Smurr, 2008]. Skills of prosthetic control can be learned during pre-prosthetic training using simulation without the amputee actually being fitted with the prosthesis [Bouwsema, 2010]. This is important as studies have shown that early prosthetic use after amputation is important for motivation and linked to success with the prosthesis [Biddiss, 2007; Pezzin, 2004].

3.7 Post-amputation Injury

The human body is almost symmetrical along the sagittal plane. Missing an upper limb creates imbalance to the upper body. For a unilateral amputee, before being fitted with a functional prosthesis, the contralateral limb will need to take over all upper limb functions which used to be shared by both limbs. Even after prosthetic fitting, other parts of the body are often recruited in an unconventional way to operate the prosthesis. For example, to perform daily activities, a below elbow amputee will need to use shoulder movement repeatedly to open and close his/her body-powered hook. An above elbow amputee may need to tilt and bend his/her upper body to compensate for the lack of rotational motion in the arm. The above-described imbalanced and compensational movements will create stress and strain to the sound limb and other parts of the body. Injuries as a result of repetitive stress on the major joints, muscles, and tendons of the upper extremities are referred to as overuse syndrome. According to the *Team Physician's Handbook* [Mellion, 2002] an overuse injury is defined as "Microtraumatic damage to a bone, muscle, or tendon that has been subjected to repetitive stress without sufficient time to heal or undergo the natural reparative process. A diagnosis of overuse syndrome is usually indicated if there is persistent/recurrent musculoskeletal pain without immediate traumatic cause within the previous 6 weeks." Secondary injuries from overuse or compensational motion are referred to as collateral injuries.

The risk factors of overuse injury found in the amputee population include repetition, high force, awkward joint posture, direct pressure, vibration, and prolonged constrained posture. Examples of common upper limb overuse injuries include rotator cuff tendonitis and tears, shoulder impingement and bursitis, lateral and medial epicondylitis, carpal tunnel syndrome, and tendonitis of the forearm extensors [Verdon, 1996]. A new amputee often focuses on the loss of functional capabilities, but misses the importance of preservation of the sound limb and the remaining parts of the body. To avoid these injuries, amputees must be educated about the risks, to recognize symptoms at their onset, and to implement preventative measures. This responsibility lies with every member of the rehabilitation team including the physiatrists, physiotherapists, occupational therapists, and prosthetists.

3.8 Prosthetic Utilization and Abandonment

Successful selection of a prosthesis relies on accurate assessment of the characteristics and needs of the amputee by experienced and trained professionals. In addition to evaluating the functional capacities, a high level of prosthetic utilization implies successful prescription whereas an abandoned prosthesis indicates failure. There are many studies on prosthetic utilization and their rates of abandonment. A questionnaire survey of 266 amputees was done in 2007 to explore factors affecting abandonment of upper limb prostheses. Within the adult group (145 upper limb amputees), 21% rejected prosthetic use entirely. The rates of rejection for electric hands, passive hands, and body-powered hooks were 41%, 47%, and 65% respectively. The survey results also indicated that enabling resources including availability of health care services, cost, and quality of training did not have significant influence on prosthetic rejection. Whereas fitting time frame, involvement of clients in prosthesis selection, state and availability of technology, perceived needs, and comfort are opposing factors in abandonment [Biddiss, 2007]. An amputee will eventually reject a prosthesis if it does not fulfill his/her basic personal requirements. These requirements are related to functions, cosmetics, psychological factors, initial prosthetic experience, comfort, weight, and tactile sensation. If any of the above conditions are left unfulfilled, they may lead to abandonment or result in overuse syndrome [Lake, 2006].

Another survey questionnaire to explore factors in prosthesis acceptance revealed that individuals fitted within two years of birth (congenital) or six months of amputation (acquired) were 16 times more likely to continue their prosthetic use. The survey concluded that to increase the rate of prosthesis acceptance, clinical directives should focus on timely, client-centered fitting strategies. In addition, the availability of improved prostheses and better access to health care will increase the rate of acceptance for those with high level or bilateral limb absence [Biddiss, 2008]. A literature review published by WorkSafe BC in 2011 on upper limb prosthetic devices (specifically on myoelectric hands) identified work conditions, level of amputations, type of prostheses, time between amputation and prosthesis fitting, and availability of rehabilitation services to be factors affecting successful prosthetic acceptance [Martin, 2011].

Table 3.2 summarizes the desirable features of prostheses leading to successful prescriptions. These features are grouped under three categories: functionality, wearability, and technology. Other enabling factors which do not fall under these categories are listed in the last column of the table.

Table 3.2 Desirable Features of Prostheses

Desirable Prosthetic Features			Others enabling factors
Functionality	**Wearability**	**Technology**	
• Meet patient’s requirements and perceived needs • Highest possible functionality • Good performance (speed, forces, torques, etc.) • Efficient and easy to control • Designed for work environment	• Human-like appearance • Proper size and proportion • Light weight • Good comfort to wear • Low operating noise	• Robustness • Reliable • Sufficient energy source for extended use • Low cost • Timely technical support	• Timely fitting • Involvement of patient in selection • Patient-centered fitting strategy • Access to rehabilitation services • Sound psychological wellness

3.9 Functional Outcome Assessment

The human hands carry out diverse and sophisticate tasks which are impossible to be completely replaced by even the most sophisticated prostheses. To judge the successfulness of the rehabilitation of an amputee, many outcome measurement tools have been developed [Metcalf, 2007]. A few of them are quantitative, task-based assessment tools to assess selected motor skills while many are based on observation by rehabilitation professionals. The Southampton Hand Assessment Procedure (SHAP) is a clinically validated hand function test made up of eight abstract objects and fourteen activities of daily living (ADL). The time to complete a particular task, such as opening a door, is used as a quantitative parameter in the assessment [Light, 2002]. Figure 3.3 shows a picture of the SHAP assessment tool kit.

Figure 3.3 Southampton Hand Assessment Procedure (SHAP) Tool Kit

There are many assessment rating guides developed to evaluate the level of proficiency of upper limb amputees in performing functional activities [Smurr, 2008; Atkins, 1989]. These guides all use some forms of rating scales to rank the proficiency of unilateral upper extremity amputees in performing a selected list of activities. An example is one proposed by Smurr which uses a 4-point rating scale to assess the proficiency of activities of daily living [Smurr, 2008]. The ratings are: “0” – impossible; “1” – accomplished with much strain, or many awkward motions; “2” – somewhat labored or few awkward motions; “3” – smooth, minimum amount of delays and awkward motions. Activities in the guide are grouped into personal needs (e.g., set hair, don/doff prosthesis), eating and desk procedures (e.g. spread butter, sharpen a pencil), general and housing procedures (e.g., operate a door knob, cut vegetable), use of tools (e.g., hammer, screw drivers), and car procedures (open/close trunk, operate a vehicle).

Despite their common use, most rating guides rely on subjective evaluation and, therefore, may not be consistent between different evaluators.

3.10 Prosthetic Componentry and Current Technologies

3.10.1 Types of prostheses

There are three types of prostheses based on their activation mechanisms. They are:

1. cosmetic
2. body-powered
3. externally-powered.

The primary purpose of wearing a cosmetic prosthesis is to create the aesthetic look of a real limb. Cosmetic prostheses are not designed to provide much functional capability. However, an amputee may use a cosmetic prosthesis to assist the sound limb in carrying out some activities. Cosmetic prostheses require the least harnessing and are the most lightweight of the three types.

A body-powered prosthesis uses a cable and harness system to convey movement from another part of the patient's body to actuate the prosthesis. For example, in a body-powered cable hand system, pulling a cable attached to a lever on a prosthetic hand by shoulder exertion can open the prosthetic hand. Instead of using body power, an externally-powered prosthesis uses an external power source to produce the work. An example of an externally-powered prosthesis is a battery-powered electric elbow. A switch operates by the amputee will activate the electrode motor to create elbow flexion or extension. Externally-powered prostheses using electrical signals from skeletal muscle contractions as control signals are called myoelectric prostheses. Figure 3.4 shows two transhumeral amputees, one wearing a body-powered prosthesis and the other wearing an externally-powered prosthesis.

Figure 3.4 Transhumeral Amputee Fitted With: a Body-powered Prosthesis (left) and an Externally-Powered Prosthesis (right)

Both body-powered and externally-powered prosthetic systems have their advantages and disadvantages. Body-powered systems are usually lighter and more robust, but require more harnesses. Although it is not direct, pulling on the cable by a muscle group provides sensory feedback to the user. Externally-powered prostheses are often more aesthetic, require less harness, and have the advantage that their functional power is not restricted by their operating body movement. Their disadvantages are that they are usually heavier and cost more than body-powered prostheses. A hybrid prosthesis combines body-powered and externally-powered components. For example, a cable controlled elbow and an electric hook is a common combination of a functional hybrid prosthesis for transhumeral amputees. Prosthetic components replacing the hand functions are called terminal devices. Below are some common prosthetic components.

- Cosmetic finger, hand, and arm are passive prostheses to aesthetically replace the amputated part of the limb.
- Body-powered (or cable) hands and hooks are fitted for functional activities. Opening (or closing) of a BP terminal device is actuated by a cable-lever mechanism with the cable pulled by a healthy part of the body. Both BP hands and hooks have their voluntary opening or closing version. The prehensile grip force of a voluntary closing BP hook or hand is determined by the number of rubber bands installed on the lever mechanism. Depending on the intended tasks, different shapes, designs, and construction of hooks are available.
- Electric hands, hooks, or claws are available terminal devices for externally-powered prostheses. They can be controlled by a switch, a transducer, or myoelectric signals from the amputee. Control and operation of these terminal devices can be digital (on-off) or proportional (variable). For a digital terminal device, the closing (and opening) speed as well as the grip force is constant, whereas they are variable for a proportional device. A linear transducer or a myoelectric electrode may used to provide the variable input.

- A friction wrist is a body-powered prosthesis. In addition to providing rotation for wrist pronation and supination, some allow flexion and extension as well as radial and ulnar deviation. The position is usually held by friction.
- Similar to a friction wrist, an electric wrist offers pronation/supination, flexion/extension, and radial/ulnar deviation to the prosthetic terminal device. A proportional motorized wrist rotator with frictional flexion/extension capability is available in the market. A fully motorized wrist units is currently under development.
- A body-powered elbow allows flexion and extension of the prosthetic arm. The elbow can be moved by a cable or positioned by the sound limb and held in place by friction or by a locking mechanism. Some elbows can be fixed in a position by an electric-lock mechanism; the lock can be activated or deactivated by a toggle switch.
- An electric elbow allows flexion and extension of the forearm by a motorized gear mechanism. The speed and position is controlled by one or two linear transducers or myoelectric signals. Current devices in the market allow a transhumeral amputee to lift a five to ten kilogram load using the prosthesis.
- Shoulder prostheses currently available in the market are friction joints. Some electric shoulders are being developed in research labs.

3.10.2 Aids and Adaptive Devices

Current prostheses in the market, no matter how advanced and sophisticated, still do not come close to matching the functional performance of the real limbs that they are replacing. There are many different types of aids and adaptive devices to overcome some of these limitations. Pull rings for zippers, suction cup brush for bathing and cleaning, one-handed cutting board for food preparation, and built-up handles on toothbrushes for personal hygiene care are some examples of ADL aids. Advances in vehicle-adaptive technology allow many amputees to return to driving. Vehicle adaptive devices can be as simple as a spinner knob mounted on the steering wheel or as complex as a control console to replace turn signals, acceleration and brake pedals. Off-the-shelf and custom-built solutions are available to allow amputees to return to work after their injuries. Modified one-handed keyboard, adapted controls for forklift drivers, and a special hook for a butcher are examples of work place solutions for upper limb amputees. In addition, specialized adaptors on prostheses to allow quick-disconnect accessories are available for recreational activities such as gardening and golfing.

3.10.3 Anatomy of a Prosthesis

A typical upper extremity prosthesis has the following components:

- socket
- suspension
- socks, liners, and gloves
- control and actuation system.

The following sub-sections describe the functions, characteristics and construction of each.

3.10.3.1 Socket

Although many parts of a prosthesis are off-the-shelve components, the socket is a custom-built assembly which interfaces with the residual limb and serves as the scaffolding to hold the control mechanism (such as a myoelectrode) and functional components (such as an electric hand) of the prosthesis.

A dual wall designed socket has a rigid inner socket fabricated to fit anatomically with the patient residual limb. The outer wall which fits over the inner socket is designed to be the same length and have the same look as the sound limb. A flexible liner may be used to replace the rigid inner socket. A flexible inner socket is fabricated from soft and elastic materials (e.g., silicone and fabric) to provide appropriate contact and fit. Similar to the dual wall socket, an outer socket is used for structural support for other prosthetic components. Comfort of wearing the prosthesis and its functional performance relies on the fit of the inner socket.

3.10.3.2 Suspension

The function of the suspension system is to securely attach the prosthesis to the residual limb. As the prosthesis is usually worn for an extended period of time, its weight plus the load it is carrying should be appropriately distributed to reduce fatigue and avoid undue strain on the residual limb and other parts of the body. There are three types of suspension systems:

1. harness

2. self-suspending
3. suction

Figure 3.5 is a common harness system for transradial amputees. This common "figure-of-eight harness" was described as "a simple webbing loop that passes around the sound shoulder, the front portion being used for suspension, the back for attachment of the control cable." [Pursley, 1955]. Harnessed-based systems are the most commonly-used suspension systems for body-powered prostheses. They also provide attachments for the control cables. For heavier lifting, additional components such as a shoulder saddle with a chest strap are used.

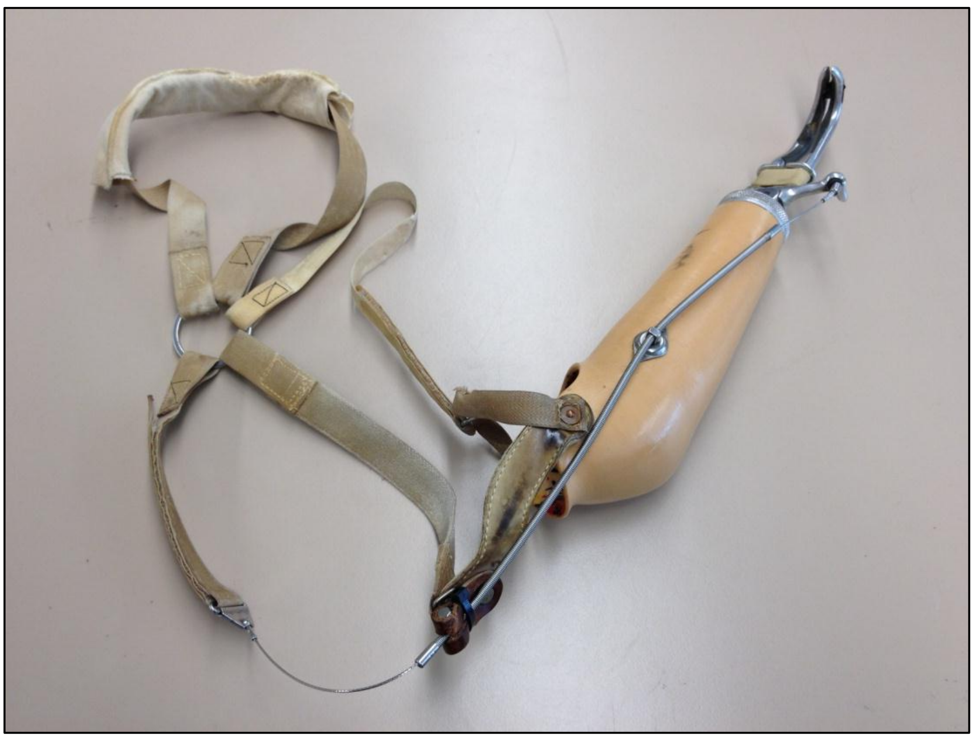


Figure 3.5 The Below-Elbow Figure-of-Eight Harness

Self-suspending and suction sockets are capable of providing adequate prosthetic suspension by themselves or in conjunction with harnesses for better suspension. In a self-suspending socket, the inner rigid socket is contoured to take advantage of the shape and bony prominences of the residual limb to hold the weight of the prosthesis. Good custom fitting of the socket provides better contact and pressure relief to the residual limb. Figure 3.6 is a picture of the inner socket of a transradial self-suspending socket.

Figure 3.6 Self-Suspending Transradial Socket

Suction suspension relies on negative pressure to hold the socket in place. A one-way valve on the skin-fit socket allows air to be pushed out during donning. The valve has a release button that breaks the suction for doffing. Conventional upper limb suction sockets require a total contact design. A residual limb with an irregular shape, excessive scarring, unstable volume, or sensitive skin is not suitable due to the air tightness requirement. Roll-on suction suspension liners have gained popularity in recent years. The liner is made of silicon material and is designed as a flexible tube to be rolled up on the residual limb to replace the rigid inner sockets. This design provides not only improved suspension but also better comfort and greater range of motion for the prosthesis. A locking liner uses a pin-locking mechanism to secure the outer socket to the liner. Figure 3.7 is a suction locking liner showing the locking pin at the end. Surrounding the flexible liner, a rigid frame is utilized for structural support and for attaching the necessary cables and joints as needed. Windows in the outer socket allow movement, permit relief over bony prominences, and enhance comfort.

Figure 3.7 Left: Suction Locking Liner Showing Roll-up Application (right)

3.10.3.3 Socks, Liners and Gloves

Socks and liners are interfaces between the skin of the amputee and the prosthesis. Prosthetic socks provide cushioning and serve to adjust the volume of the socket. Prosthetic socks protect the skin against pressure and friction in the skin-socket interface. They also absorb perspiration with a wick-like action and allow for ventilation. Prosthetic socks have different thicknesses and sizes and can be made of cotton, wool, and synthetics materials. By choosing socks with a certain thickness (denoted by a ply number), an amputee can adjust for changes in the size of his/her residual limb. Liners worn directly against the skin may replace socks or both may be worn together. Liners can provide skin protection against friction, allow more even pressure distribution and, in the case of a locking suspension liner, be used to attach a prosthesis to the stump. Liners are available in silicon, urethane, or as a mineral-oil derivative. They may or may not have a fabric backing.

Prosthetic gloves are covers on the prostheses. They provide the prosthesis with a more natural look and also protect the prosthetic components against dirt and moisture. Materials for cosmetic gloves range from durable Polyvinyl Chloride (PVC) production gloves to realistic looking high-definition custom silicon skin covers.

All socks and liners need to be cleaned or washed every day for hygienic reasons. A stretched sock or liner will lose its fit and fail to maintain suction. Gloves are subjected to stain and soiling as well as mechanical wear and tear. They all need to be replaced from time to time.

3.10.3.4 Control and Actuation Mechanisms

<u>Body-Powered Prostheses</u>

A Bowden-cable system is commonly found in body-powered prosthetic limbs to control prosthetic functions. It uses a cable-to-link movement from one part of the patient's body to the prosthesis. Movement of the humerus, shoulder, or chest is transmitted via the cable to activate the terminal device of the prosthesis. Figure 3.8 shows a control cable attached to a lever on a hook-type terminal device. Pulling the cable will open the hook, while relaxing the cable will allow the spring (or rubber band) to restore the hook to its closed position. The maximum holding or grip force for this body-powered hook is determined by the number of installed rubber bands. To obtain a greater grip force, a larger number of rubber bands are needed; however, the amputee will require a greater effort to open the hook. The control and actuation mechanism of an externally-powered prosthesis is very different and is discussed in the next section.

Figure 3.8 BP Prosthesis Suspension and a Bowden-Cable Hook

Externally-Powered Prostheses

A major limitation of body-powered prostheses is their total reliance on the movement of the patient to provide actuation. Externally-powered prostheses overcome this by using external power sources to power actuators to create prosthetic functional motions. In a typical externally-powered prosthesis, an electric motor, powered by a rechargeable battery, is connected to a mechanical gear system to actuate the moving parts of the prosthesis. The control signal can be from a switch, a linear transducer, or EMG signals. These control signals are created by the patient wearing the prosthesis and modified by signal processing circuits before being used to activate the prosthesis. Externally-powered prostheses using EMG signals as control input are called myoelectric prostheses. A picture of an electric hand (courtesy Otto Bock Health Care GmbH) with and without the cosmetic cover installed is shown in Figure 3.9 (left). A view of the same hand with the cover removed showing the motor and gear mechanism is shown in the middle. An electric claw (Otto Bock electric Greifer) is shown in the left of Figure 3-9.

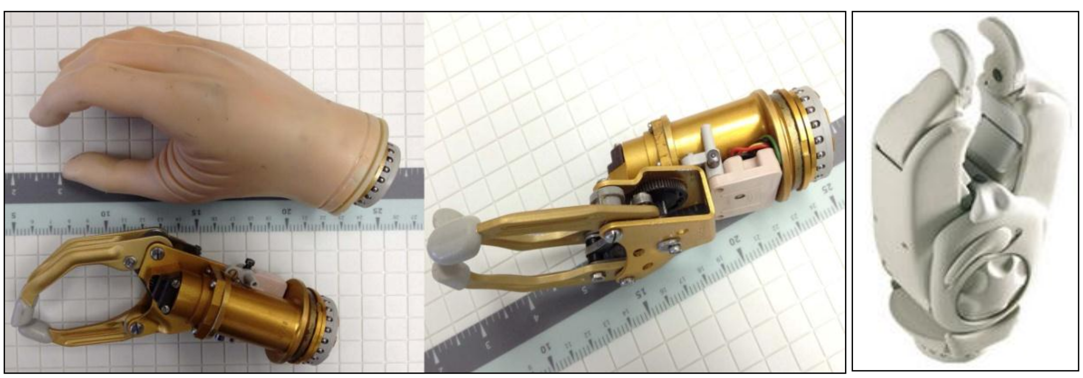


Figure 3.9 Electric Terminal Devices with and without Cosmetic Shell

The functional motion of an externally-powered prosthesis is similar to its body-powered version. However, much less effort and translational motion is required by the patient to operate the prosthesis as the patient’s motion is merely providing the activation signal; the motion and grip force are delivered by the electric motor. An externally-powered prosthesis can be controlled by a switch, linear transducer, or myoelectric signal. Figure 3.10 shows a linear transducer mounted on the harness of the transhumeral prosthesis at the back of the amputee. This setup allows the amputee to use shoulder exertion to control the terminal device.

Figure 3.10 Linear Transducer Used in Prosthetic Control

For a myoelectric prosthesis, EMG signals from contracting muscle groups are picked up by surface electrodes. These sEMG signals are amplified, rectified, and filtered to emulate muscle contraction [Disselhorst-King, 2009]. These processed EMG signals, also called myosignals, are employed to activate electromechanical actuators in the prosthesis. Figure 3.11 shows two EMG signals from muscle contractions captured by surface electrodes; the lower graph shows the corresponding myosignals.

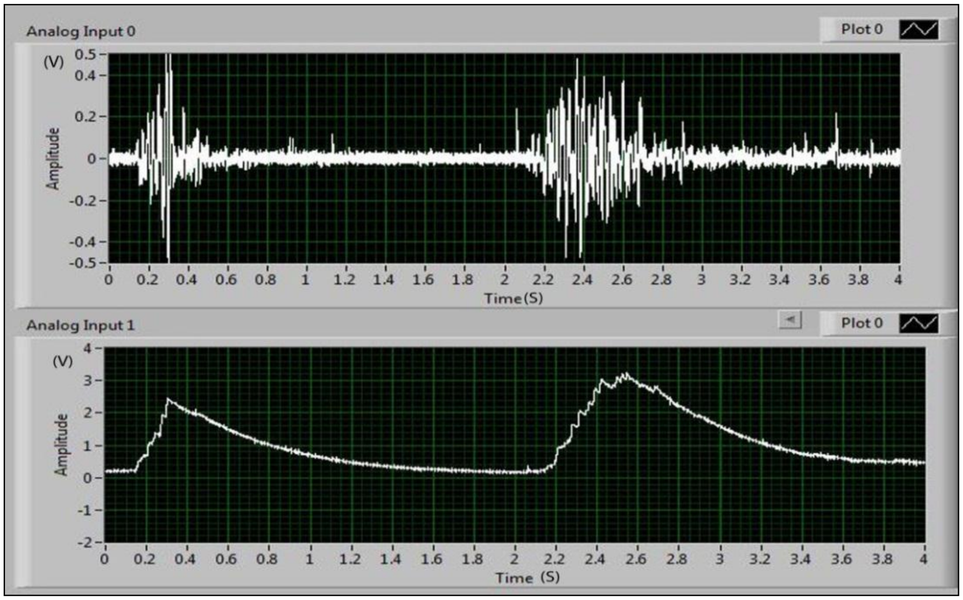


Figure 3.11 Surface EMG Signal and Myosignal

Figure 3.12 shows an example of a commercial myoelectrode manufactured by Otto Bock Healthcare GmbH for prosthetic applications. Signal processing circuits are built into the electrode package such that the output can be used for direct prosthetic activations. The left and right titanium contacts are connected to the differential input of the instrumentation amplifier inside the package. The central contact is for ground reference. According to the manufacturer, this myoelectrode provides an adjustable signal gain from 2,000 to 100,000 and has a bandwidth of 90 to 450 Hz. An opening on the inner socket allows the electrode to be placed in contact with the tissue of the amputee. In another prosthetic electrode configuration, metal electrodes are embedded in the inner flexible liner, snap-on cables are used to connect the electrodes to the EMG amplifier and processing circuits in the prosthesis but away from the electrode sites [Lake, 2006].

Figure 3.12 A Myoelectrode for Controlling Myoelectric Prostheses

To generate reliable control signals for prosthetic applications, the electrode sites must be carefully chosen to produce reliable EMG signals that are of significant amplitude. A pair of healthy antagonistic muscles in the residual limb is often chosen. Muscle sites for electrode placements typically include the pectoralis, anterior deltoid, biceps, wrist flexors, posterior deltoid, infraspinatus, teres major, triceps, and wrist extensors [Lake, 2006]. The preferred electrode location is in the midline of the muscle belly between the nearest innervation zone and the myotendonous junction [De Luca, 1997]. The strength and duration of muscle contraction have been shown to correlate with the amplitude and temporal characteristics of intramuscular EMG signals or EMG signals picked up from the skin surface of the patient [Hoozemans, 2005]. These myosignals derived from voluntary contractions of muscle groups by the amputee are used to control prosthetic activation. For example, a high amplitude myosignal sent to a myoelectric hand will produce a strong grip force. To perform an activity (such as drinking from a cup), a sequence of myosignals is needed to produce the desired functional motions. In most cases, patients rely on visual feedback to moderate their prosthetic motions. Some prostheses employ feedback control to enhance performance, such as detecting object slip under grip. Others have built sensors and actuators into the system to provide tactile feedback to the amputee [Boone, 2011].

Depending on the prosthetic design and the condition of the amputee, different control schemes may be selected. Amplitude and rate of increase (rising slope) of the myosignal are common control parameters. In a digital (on-off) control scheme, a threshold is established to differentiate control commands and noise. If only one control source is available, it is often used as a toggle switch. For example, the first muscle contraction will open the grip of the terminal device and the second contraction will close it. When there is more than one control signal source, more modes of control can be implemented. In a digital control scheme with two electrode sites, signals from one site are used to activate one function of the prosthesis, while signals from the other side are used to activate a second prosthetic function. An example is using the myosignals from the biceps electrode to flex an electric elbow and the triceps electrode to extend the elbow. In contrast to the digital control scheme which provides on-off signal control, the proportional control scheme is used to create variable output. For an electric elbow that supports proportional control, it can be programed so that an above threshold biceps signal will flex the elbow at a speed proportional to the signal's amplitude. The same approach can be used to control the variable grip force of an electric hook.

An amputee may have more than one prosthetic component. To control multiple prosthetic components, a sequential activation scheme using co-contraction (simultaneous activation) is commonly used. Figure 3.13 is a picture of the setup to illustrate such a control scheme for a transhumeral amputee fitted with an electric hand, an electric wrist rotator, and an electric elbow. Figure 3.14 displays the two sets of activation signals to activate the prosthesis to pick up a bottle, pour out its contents, and release the bottle. The control inputs and the corresponding motion sequence are described in Table 3.3. In this example, the prosthetic components are programed such that the signal amplitude (volt) controls the speed of motion and the signal pulse width controls movement duration.

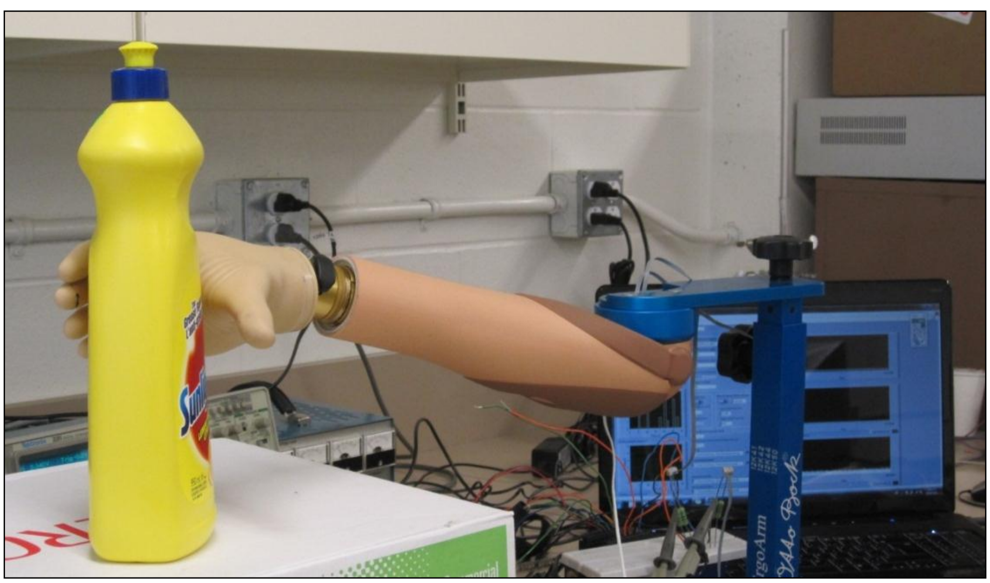


Figure 3.13 Transhumeral Prosthetic Test Setup

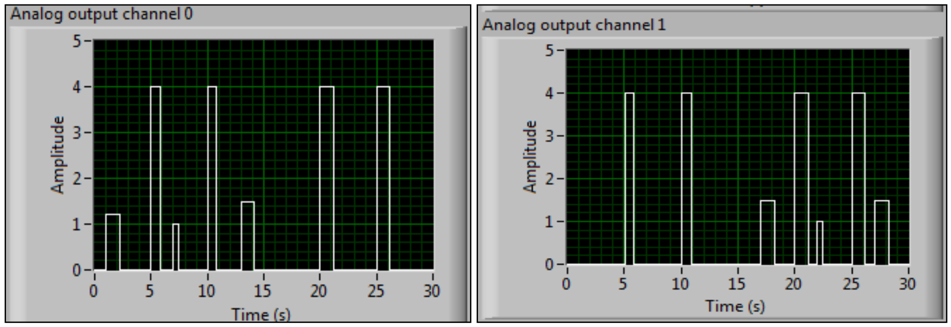


Figure 3.14 Prosthetic Activation Signals

Table 3.3 Dual Electrode Site Activation Control Signals

Left (V)	Right (V)	Component Under Control	Functional Outcome
1.2	0	Hand	Close hand
4.0	4.0	Co-contraction	Switch to elbow
1.0	0	elbow	Flex elbow
4.0	4.0	Co-contraction	Switch to wrist
1.6	0	Wrist	Rotate clockwise
0	1.6	Wrist	Rotate counter clockwise
4/0	4.0	Co-contraction	Switch to elbow
0	1.0	Elbow	Extend elbow
4.0	4.0	Co-contraction	Switch to hand
0	1.6	Hand	Open hand

The actuator of an externally-powered prosthesis is usually a brushless DC motor. The key design factors for prosthetic actuators are the size, power-to-weight ratio, noise, and energy efficiency. There are some research efforts to use alternative actuating mechanisms. Ultrasonic ceramic motors are promising alternatives. They provide high speeds and accelerations, quiet operation, have no heat generation, are self-locking when without excitation, and are non-magnetic. Pneumatic and hydraulic actuators are used in some experimental systems. Although pneumatic actuators are quiet to operate, they require compressed gas which is not readily available. Hydraulic actuators require bulky pumping mechanisms and are subject to fluid leakage.

Lithium-ion batteries are commonly used in current myoelectric prostheses. The capacity of 7.2-V Li-ion battery packs range from about 500 to 1,000 mAhr. Older prosthesis may use 6-V NiCd or NiMh batteries. Under normal usage, a fully-charged battery pack usually lasts for a day (or 8 hours) of use. Manufacturers often recommend users connect the prosthesis to its external charger when not in use. Some prostheses are designed so users can swap backup batteries for extended use.

3.10.4 Research and New Development

The Revolutionizing Prosthetics 2009 (RP2009) program, started in 2005 with a $71 million US budget, was aimed at developing a biologically-controlled prosthesis with sensory feedback on a quasi-open source hardware and software platform. It has met most of its set goals at the end of the program in 2009. One of the breakthroughs from the program was the invention of the targeted muscle reinnervation (TMR) surgery by Todd Kuiken, Director of the Rehabilitation Institute of Chicago's Neural Engineering Centre [Adee, 2009; Kuiken, 2009]. Another new development is implantable electrodes from which EMG signals can be wirelessly transmitted from the electrodes implanted under the patient's skin to the prosthetic devices. Multichannel implantable EMG sensors for cross talk free myoelectric control were developed and animal trialed [Schorsch, 2008].

The prosthetic socket and harness can cause significant discomfort and pain in the amputee. Osseointegration is a new method of attaching the artificial limb to the body. This new prosthetic suspension system works by surgically inserting a titanium bolt into the bone at the end of the stump. After several months the bone nit with the titanium bolt and an abutment is attached to it. The abutment extends out of the stump and the artificial limb is then attached to the abutment. Osseointegration allows the prosthesis to be worn for an extended period of time [Jonsson, 2011].

The RP2009 program has also spurred research in more life-like functional prostheses. An example is the MANUS-HAND project for the development of multi-functional upper limb prostheses. It includes a new thumb design that allows up to four grasping modes with just two actuators. The autonomous coordination and control system reduces the patient's participation in the control loop [Pons, 2004]. In addition, prosthetic manufacturers are striving to improve functional benefits on myoelectric prostheses without greatly increasing their weight or complexity. [Sears, 2008].

Pattern recognition is also applied in prosthetic design for deciphering movement intention of the patient from multiple channels of myoelectric signals [Seninger, 2008; Farrell, 2008; Scheme, 2011]. To reduce the cognitive burden placed upon the user in the control of multifunctional upper limb prostheses, Light et al. presented a hybrid controller to enable different prehensile functions to be initiated directly from the user's myoelectric signal to reduce the need for visual feedback by the patient. In the study, an artificial neural network was used to classify the myoelectric signals from a bipolar electrode pair placed over the biceps and triceps. Together with sensors mounted on the prosthesis, these control signals were used in automating the grasping process of a multi degree-of-freedom hand prosthesis. Limited success was reported in laboratory setting. [Light, 2002].

A shortcoming of a myoelectric prosthesis is the lack of tactile sensory feedback to the user. Boone et al. conducted a study to investigate fundamental issues relating to external vibro-tactile stimulation. These issues included optimal tactile feedback location on the upper arm, feedback signal type, skin desensitization, and the ability of feedback to assist in controlling grasping force [Boone, 2011].

3.10.5 Guidelines and Standards

The US Food and Drug Administration (FDA) classifies powered external limb prosthetic components and prosthetic accessories as Class I devices [US FDA, 2001]. According to Part 21 of the *Code of Federal Regulations*, "a Class I (general controls) device is exempt from the premarket notification procedures in subpart E of part 807 of this chapter, subject to the limitations in 890.9. The device is also exempt from the current good manufacturing practice requirements of the quality system regulation in part 820 of this chapter, with the exception of 820.180, regarding general requirements concerning records and 820.198, regarding complaint files." In Canada, medical devices are regulated by Health Canada's Therapeutic Products Directorate and are subject to the *Canadian Medical Devices Regulations* under the *Food and Drugs Act*. Artificial limbs are classified as Risk Class 1 Devices under the Regulations [Tan, 2005]. Risk Class 1 devices present the lowest potential risk and do not require a license. Different from higher risk class medical devices, Risk Class 1 devices are exempt from declaration of device safety and effectiveness, as well as other regulatory scrutiny before licensing and sale. In Europe, upper limb prosthetics are classified as Class 1 devices according to the classification criteria outlined in Appendix IX of the EU Council Medical Devices Directive 93/42/EEC [MDD:93/42/EEC].

Off-the-shelve upper limb prosthetic devices in Canada or the US are marketed as Class I or Risk Class I devices respectively. However, a finished prosthesis is often an assembly of multiple off-the-shelve devices in combination with custom fabricated component (e.g., sockets and connectors). As it is difficult to restrict the amputee to use the prosthesis in activities and environments within the labeled "intended use" of the individual devices, it is important for the prosthetist as well as the amputee to understand the functional requirements and the limitations to ensure safe prosthetic use.

The following are related standards on upper limb prostheses:

- ISO 8548-3:1993. Prosthetics and orthotics − Limb deficiencies − Part 3: Method of describing upper limb amputation stumps
- ISO 13405-1:1996. Prosthetics and orthotics − Classification and description of prosthetic components − Part 1: Classification of prosthetic components
- ISO 13405-3:1996. Prosthetics and orthotics − Classification and description of prosthetic components − Part 3: Description of upper-limb prosthetic components
- BS EN12182:1999. Technical aids for disabled persons – General requirements and test methods

- ISO 22523:2006(E). External limb prostheses and external orthoses – Requirements and test methods

ISO 22523:2006(E) is a combined level 2 and 3 standard dealing with technical aids for disabled persons. It specifies requirements and test methods for external limb prostheses and external orthoses covering “strength, materials, restrictions on use, risk and the provision of information associated with the normal conditions of use of both components and assemblies of components”.

Despite the lack of standards on powered prostheses in the industry, there is significant interest among manufacturers and researchers to develop standards to facilitate compatibility of prosthetic components. The Institute of Biomedical Engineering at the University of New Brunswick (UNB) developed a Prosthetic Device Communicated Protocol (PDCP) which is a digital serial communication bus based on the Control Area Network (CAN) widely used in the industry (e.g., automobile) [Losier, 2010]. The PDCP is implemented in the controller area network bus in the myoelectric control unit of a new, modular, multiple degree of freedom, myoelectric hand currently being developed at UNB [Losier, 2011]. Another group is in the process of designing a universal coupler for powered prostheses allowing interchangeability of terminal devices as well as meeting the demands for strength, durability, communication, and power transfer requirements [Sutton, 2011].

The International Classification of Functioning, Disability and Health, known more commonly as ICF, provides a standard language and framework for the description and classification of disability and health. This framework has been adopted by many in the assessment and outcome measurements of limb prostheses [World Health Organization, 2002].

The Upper Limb Prosthetic Outcome Measures (ULPOM) Group was formed in 2008 by an international group of prosthetists, physiotherapists, occupational therapists, biomedical engineers, researchers and manufacturer's representatives. The goal of the group is to adopt and develop systematic outcome measurement tools for upper limb prostheses based on the WHO ICF model. The group believes that a unified approach throughout the profession would assemble a set of validated tools from the many tools already in existence, and discover gaps within the set that need additional attention [Hill, 2009].

3.11 Summary of Key Findings

The above analysis illustrates that a successful upper limb prosthesis is one that is built with appropriate technology, is fitted comfortably on the residual limb, and meet the actual needs of the amputee. To achieve this goal, it is important for the rehabilitation team to perform a comprehensive patient assessment in order to come up with an appropriate rehabilitation plan including selection of the prosthesis. Initial and ongoing rehabilitation training and sufficient technical support to ensure reliable prosthetic performance are essential for successful prescription. The following are key findings in this chapter:

- There are three types of prostheses based on their activation mechanisms. They are: cosmetic, body-powered, and externally-powered. Both body-powered and externally-powered prosthetic systems have their advantages and disadvantages. A hybrid prosthesis combines body-powered and externally-powered components.

- A typical upper extremity prosthesis has the following basic components: socket, suspension, liners, control and actuation mechanism.
- The socket is a custom-built assembly which interfaces with the residual limb and serves as the scaffolding to hold the control and functional components of the prosthesis. Comfort of wearing the prosthesis and its functional performance relies on the fit of the inner socket.
- The function of the suspension system is to securely attach the prosthesis to the residual limb. As the prosthesis is usually worn for an extended period of time, its weight plus the load it is carrying should be appropriately distributed to reduce fatigue and avoid undue strain on the residual limb and other parts of the patient's body.
- Socks and liners are interfaces between the skin of the amputee and the prosthesis. They provide cushioning, protect the skin against pressure and friction, absorb perspiration, and serve to adjust the volume of the socket.
- The functional motion of an externally-powered prosthesis is similar to its body-powered version. However, much less effort and translational motion is required by the patient to operate the prosthesis as the patient's motion is merely providing the activation signal. Externally-powered prostheses using EMG as control signals are called myoelectric prostheses.
- A prosthesis may have more than one externally-powered components. To control these multiple prosthetic components, a sequential activation scheme using co-

contraction (simultaneous activation) to switch control from one component to another is commonly used.

- The successfulness of amputee rehabilitation relies on rehabilitation planning and prosthetic intervention which involves multiple disciplines and many complicated processes.
- Rehabilitation planning should start right after the injury and preferably before the amputation. It should take into consideration of the patient's physical condition, socio-economic situation, psychological status, and vocational needs. Prosthetic intervention as well as initial and ongoing rehabilitation training should be an integral part of the plan.
- Prevalence of phantom pain and sensation will impact prosthetic utilization and may lead to abandonment of the prosthesis and, therefore, should not be under looked.
- When considering a prosthetic prescription, it is more important to allow the amputee to achieve desirable functional outcomes than to replicate the ranges of motions.
- Ideally, a prosthesis should serve both cosmetic and functional purposes. Unfortunately, functional performance and cosmetic appearance are often contradicting features in current prosthetic devices.
- A well fitted socket and reliable prosthesis are important factors to avoid prosthetic abandonment.
- Proper maintenance is critical to maintain the functional performance of a prosthesis and improve its reliability.

- To prepare the amputee for returning to work, the rehabilitation plan should including simulated work activities based on the identified work requirements. Workplace modifications and assistive aids are useful to assimilate the amputee back to work.
- Skills of prosthetic control can be learned using simulation tools for pre-prosthetic assessment or training without the amputee actually being fitted with the prosthesis.
- A new amputee often focuses on the loss of functional capabilities, but misses the importance of preservation of the sound limb and the remaining parts of the body. To avoid collateral and overuse injuries, amputees must be educated about the risks, to recognize symptoms at their onset, and to implement preventative measures.
- Studies have shown high rejection rates of upper limb prostheses. Successful prescription relies on accurate assessment of the characteristics and needs of the amputee by experienced and trained professionals. The desirable features of prostheses are listed in Table 3.2.
- The human hands carry out diverse and sophisticate tasks which are impossible to be completely replaced by even the most sophisticated prostheses. Most of the outcome measurement tools developed to judge the successfulness of prosthetic intervention are qualitative based and rely on subjective observation.
- Recent new development in prosthetic technology includes: targeted muscle innervation, osseointegration, and signal pattern recognition.

- Despite the lack of standards on powered prostheses in the industry, there is significant interest among rehabilitation professionals, researchers and some manufacturers to develop standards to facilitate compatibility of prosthetic components.

Chapter 4: Amputee Case Files Review and Analysis

4.1 Introduction

Chapter 3 reviewed upper limb functions, amputation characteristics, residual limb management, prosthetic technologies and current practice in prosthetic intervention. It stresses the importance of comprehensive patient assessment, appropriate prescription and ensuring reliable prosthetic performance. To explore these characteristics in a real patient population, a retrospective data analysis was performed on the amputee case files provided by a local worker's compensation board. The analysis outcomes including profile of the amputees, prosthetic prescription characteristics, levels of prosthetic utilization, prosthetic reliability, and life-cycle cost of ownership are presented.

4.2 Study Inclusion Criteria

In Canada, amputees who suffered from work related injuries are insured by their provincial workers' compensation boards. Therefore, these insurance boards are logical sources of information to study adult upper limb prosthetic utilization and prescription practice. In the province of British Columbia, with a population of 4.5 million, WorkSafe BC (WSBC) is the provincial statutory agency on workers' compensation. Under a confidentiality agreement, twenty eight WSBC workers with upper extremity amputations between the year 2004 and 2010 were studied. The medical sections in the case files of these amputees documented from the time of injury to November 3, 2011 (record cut-off-date) were retrieved and analyzed.

4.3 Data Collection Methodology

The documents in the medical section provided by WSBC contain claim correspondences, long-term disability assessments, medical reports, treatment records and phone logs. Among the documents provided, the following records were the focus in extracting information for this project:

- physician reports
- physiotherapy reports
- rehabilitation assessment
- psychological assessment
- amputee multidisciplinary program assessment reports
- request of authorization for prosthetic services.

From each amputee case file, the worker's prosthetic profiles are summarized under the following headings:

- Date of birth
- Gender
- Injury date
- Causes and conditions of injury and amputation
- Amputation date
- Type (or level) of amputation (see description below)
- Dominant side before injury
- Occupation before injury (L/O/N − see description below)
- Retraining for employment information

- Occupation after amputation (L/O/N)
- Prosthetist ID
- Prostheses and accessories
- Frequency of prosthetic use
- Presence of phantom pain
- Driving after amputation (describe limitations and modification devices)
- Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthetic use, etc.)
- Recreational activities

Amputation level includes: transcarpal (TC), transradial (TR), transhumeral (TH), and shoulder-disarticulation (SD). Worker's occupations are encoded into three categories: laborer-type (L), office-type (O), and not working (N). Laborer-type work implies work which requires frequent lifting or moving of heavy objects. Office-type work are light duty work. The profile summaries of the amputees in the study group are reported in Appendix A.

In addition to the summary described above, pertinent information from the medical files in each prosthetic claim is condensed under the following headings:

- Amputee ID
- Prosthetist ID
- Level of Amputation
- Prosthesis (involved in the claim)
- Invoice/Request Date (dd/mm/yyyy)
- Approval Date (dd/mm/yyyy)

- Invoice Amount
- Type of Prosthesis (BP/Myo − see description below)
- Work Type (see description below)
- Work Nature (description of work)
- Description (description of the cost items)
- Quantity
- Unit Cost
- Total Cost
- Justification (rationale for the work in the claim)

To facilitate data analysis, the prosthetic types are consolidated into two categories: body-powered (BP) and myoelectric (Myo). BP prostheses include passive or cosmetic prostheses and conventional body-powered (cables and harnesses) prostheses. Myo prostheses include all externally-powered prostheses such as myoelectric as well as hybrid prostheses. The work type field is further divided into the following categories:

- Assess – pre-prosthetic assessment
- Initial – provide new prosthesis from socket up
- New – supply new components (e.g., a new terminal device)
- Refit – replace socket due to volume change, revision surgeries, etc.
- Adjust – minor changes to socket and harness (e.g., add padding, adjust cables)
- Replace – replace worn, ripped, torn, punctured, or stretched liners and gloves (not components)
- Modify – change to other configurations (e.g., change from pin-locked to suction suspension system)

- Repair – restore damaged or non-functional prosthetic components (e.g., replace bent fingers, fix broken hand)
- Supply – provide minor supplies (e.g., provide socks, lotions, hygiene care products)

In the prosthetic life-cycle analysis, “initial” and “new” are considered as prosthetic “componentry”, and “adjust”, “replace” and “repair” are grouped under “demand maintenance”. The summary of all prosthetic claims for each amputee from the provision of the first prosthesis until the study cut-off-date is stored in spreadsheet files. These files are the sources for data analysis.

4.4 Challenges in Data Collection

Initially, WSBC agreed to provide prosthetic claims (request of authorization for prosthetic services from prosthetists) for 20 recent amputees. These documents were pulled from worker case files by WSBC staff with the worker identifications manually removed by WSBC staff. This first batch of records was received in paper format in January 2011. After going through the files, it was found that many prosthetic claims were missing. In particular, records prior to November 2009 were not in this batch of documents. Upon inquiry, we were told that these records were not available in the current documentation system due to the transition of the WSBC record system from a paper-based to a computerized record management system in 2009. After some discussions, WSBC agreed to release complete medical section documentation (case files) under a confidentiality agreement. Eventually, documents of 28 amputees including the pre-2009 paper records were released for this study.

Despite receiving complete medical files from WSBC, there were many challenges encountered in extracting useful information from these documents. The main challenges include:

- Some records were missing (e.g., a reference to a document was mentioned in the "phone log" section but it could not be located).
- Some details in the prosthetic claims were missing (e.g., no breakdown was provided in a prosthetic claim).
- Information was not complete (e.g., for a worker with multiple prostheses, the prosthesis to which services were provided was not identified in the claim).
- Information was not reported in a consistent manner. There is no standardized classification of information (e.g., in describing the of level of prosthetic utilization, some documents describe "more than 4−hour use per day, another uses "frequent usage").
- In most cases, it is difficult to tell from the documents whether or not a prosthesis is still actively being used in particular when an amputee worker has been provided with multiple prostheses. For examples, if a BP prosthesis was not used for an extended period of time, it will not provide an accurate life-cycle cost.
- Among the 28 amputees, one passed away in 2011. As a result, his medical file was moved from active to archive and was no longer accessible. With no complete record, information from this amputee was not included in most of the analysis.

Missing and inconsistent data organization negatively impact on data analysis. Time consuming data mining and information threading were needed to organize the information.

4.5 Data Analysis

This section describes the analysis of data collected from these amputee case files. Information was extracted, compiled, categorized, and analyzed. The results were tabulated and graphed for presentation. Due to the relatively small sample size (28 amputees) and extensive data fluctuations, "Box and Whisker Plots" were used to present many of the data sets. Sample means as well as median values are shown in the data tables. "Student's t-tests" were used to evaluate statistical significance between differences in the sample means. Dependencies of data sets were evaluated using Pearson correlation coefficients.

Data extraction and interpretation are presented under the following headings:

- Amputee Profiles and Prosthetic Characteristics
- Prosthetic Utilization
- Reliability and Service Patterns
- Cost-of-Ownership Analysis

4.5.1 Amputee's Profile and Prosthetic Characteristics

Table 4.1 tabulates the characteristics of the 28 WSBC amputee workers in this study. Figure 4.1 shows the number of amputees per year from 2004 to 2010 as well as their levels of amputation. On average, over the seven-year data period, four WSBC workers per year suffered from injuries resulting in upper limb amputations.

The average age of the workers at the time of amputation was 43 years old. All workers received unilateral amputation.

Table 4.1 WSBC Amputee Worker's Profile

	Categories	Total	Percentage
Total Cases		28	100%
Gender	Male	22	79%
	Female	6	21%
Age	In 2011	mean 48, min 24, max 81, SD 13.9	
	At amputation	mean 43, min 22, max 75, SD 13.5	
Amputation Level	Transradial	14	50%
	Transhumeral	12	43%
	Transcarpal	1	4%
	Shoulder Disarticulation	1	4%
Lost Dominant Limb	Yes	16	57%
	No	11	39%
	Unknown	1	4%
Prosthesis Type	Both BP and Myo	23	82%
	BP only	2	7%
	Myo only	1	4%
	Others (1 deceased, 1 no prosth.)	2	7%
First Prostheses	BP	22	79%
	Myo	4	21%
Work Before Injury	Heavy duty (laborer type)	27	96%
	Light duty (office type)	1	4%
Return to Work After	No	11	39%
	Yes	17	61%
Returned to Work Type	heavy duty	8	47%
	light duty	9	53%
Driving After Amputation	Yes	13	46%
	No	15	54%

Of the 28 amputees, 6 (21%) are female and 22 (79%) are male. There are 14 (50%) workers with transradial amputation, 12 (43%) with transhumeral amputation, 1 (4%) with transcarpal amputation and 1 (4%) with shoulder disarticulation. The majority (23 or 82%) of the amputees received both body-powered and externally-powered prostheses, 2 (7%) have only body-powered (BP) prostheses, 1 (4%) has only externally-powered (myoelectric) prosthesis, and 1 (4%) is without any prosthesis. Of the 28 amputees, 22 (79%) were first given body-powered prostheses and 4 (21%) were provided first with externally-powered prostheses. Among the 17 (61%) amputees who has returned to work (full or part time) within the reporting period, 8 returned to laborer-type jobs and 9 to light-duty (e.g., office) jobs. Among all amputees, slightly less than half (46%) have returned to vehicle driving.

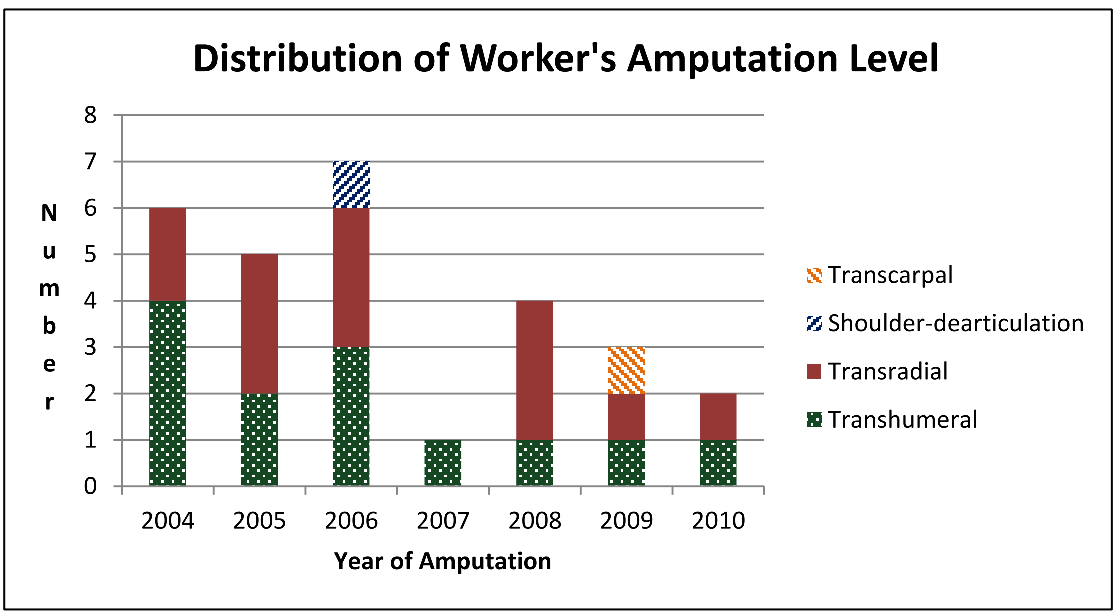
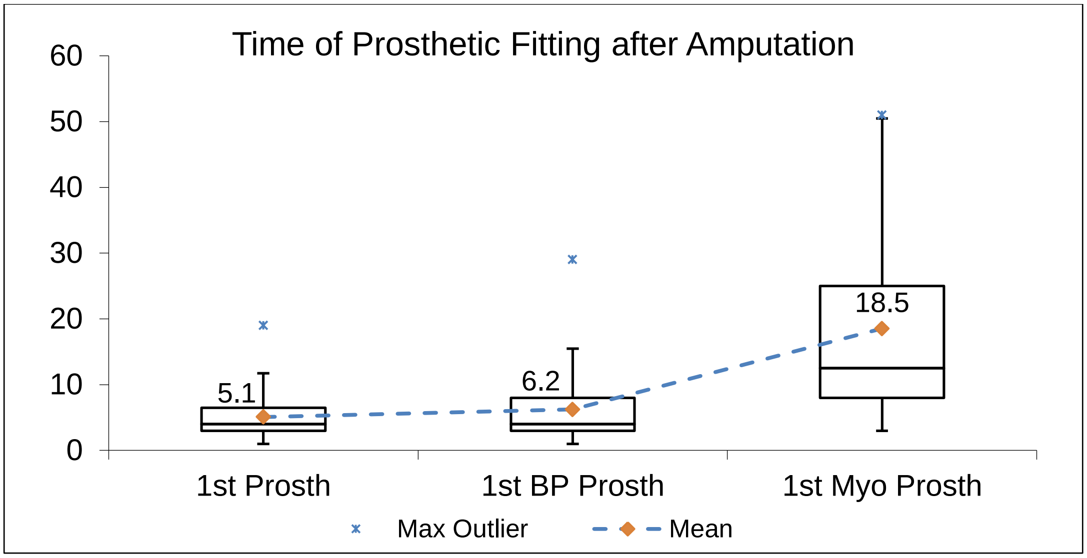


Figure 4.1 Worker’s Amputation Level in Study Group

The time elapsed for an amputee to receive his/her first prosthesis was calculated from the date of amputation to the date of the initial prosthetic claim. The times elapsed for the first prosthesis (BP or Myo), the first BP prosthesis and the first Myo prosthesis from amputation for all 28 amputees are compiled and presented in the "Box and Whisker Plot" (Box Plot) in Figure 4.2. Their statistical values (such as mean, max, etc.) are included in the data table below the plot.

In the Box Plot, the top and bottom levels of the box represent the third and first quartile values of the data; the middle line represents the median value. The length of the top or bottom whisker equals 1.5 times the interquartile range. The asterisks represent the maximum outliers of the data. In this study, the sample means are also computed and displayed on the plot. The standard deviation (SD), the standard error of the mean (SEM), and the sample size (n) of the data set are tabulated. The mean values are highlighted in the data table when their differences are statistically significant (Student's t-test, $p < 0.05$).



	1st (any) Prosthesis	1st BP Prosthesis	1st Myo Prosthesis
Min	1.0	1.0	3.0
Max	19.0	29.0	51.0
Median	4.0	4.0	12.5
Mean	5.1	6.2	18.5
SD	3.8	6.4	14.7
SEM	0.7	1.3	3.0
n	26	25	24

Figure 4.2 Time (# of months) of Fitting Prosthesis After Amputation

From Figure 4.2, on average, an amputee was provided with a body-powered (BP) prosthesis 6.2 ± 0.7 (Mean ± SEM) months after the amputation. An externally-powered or myoelectric (Myo) prosthesis was provided 18.5 ± 3.0 (mean ± SEM) months after the amputation. This 12 months difference between provision of Myo and BP prostheses is statistically significant according to the Student's t-test ($p < 0.01$). The "yellow" highlight in the data table signify the significance.

4.5.2 Prosthetic Utilization

The ultimate goal of rehabilitation of an amputee worker is for the individual to become independent and to return to employment. This section analyzes return to work patterns and the levels of prosthetic utilization of this study group.

4.5.2.1 Return to Work

One of the objectives of providing prosthesis and rehabilitation to an amputee is to facilitate the individual’s return to work. Among the cases in the data set, only one amputee was engaged in office type of work before amputation. Table 4.2 shows the return-to-work pattern between the types of work and the levels of amputation of the workers. Only TR and TH amputees are included. Note that under amputation level (headings TR and TH), the entry “Both” means that the amputee has both BP and Myo prostheses; “Myo” means that the amputee has a Myo prosthesis but may or may not have a BP prosthesis; similarly, “BP” means that the amputee has a BP prosthesis but may or may not have a Myo prosthesis. Figure 4.3 shows the work type before and after amputation for this amputee population.

Table 4.2 Return to Work Statistics – Work-type vs. Level of Amputation

Amputation Level			**TR**			**TH**			**Total Myo**	**Total BP**
Prosthetic Type		**Over-all**	**Both**	**Myo**	**BP**	**Both**	**Myo**	**BP**		
Returned to Work	Laborer Type	7	6	6	6	1	1	1	7	7
	Office Type	8	3	3	0	5	1	4	4	4
	Total Working	*15*	*9*	*9*	*6*	*6*	*2*	*5*	*11*	*11*
Not Working	*Total Not Working*	*10*	*4*	*4*	*4*	*6*	*4*	*3*	*8*	*7*
Total		***25***	***13***	***13***	***10***	***12***	***6***	***7***		

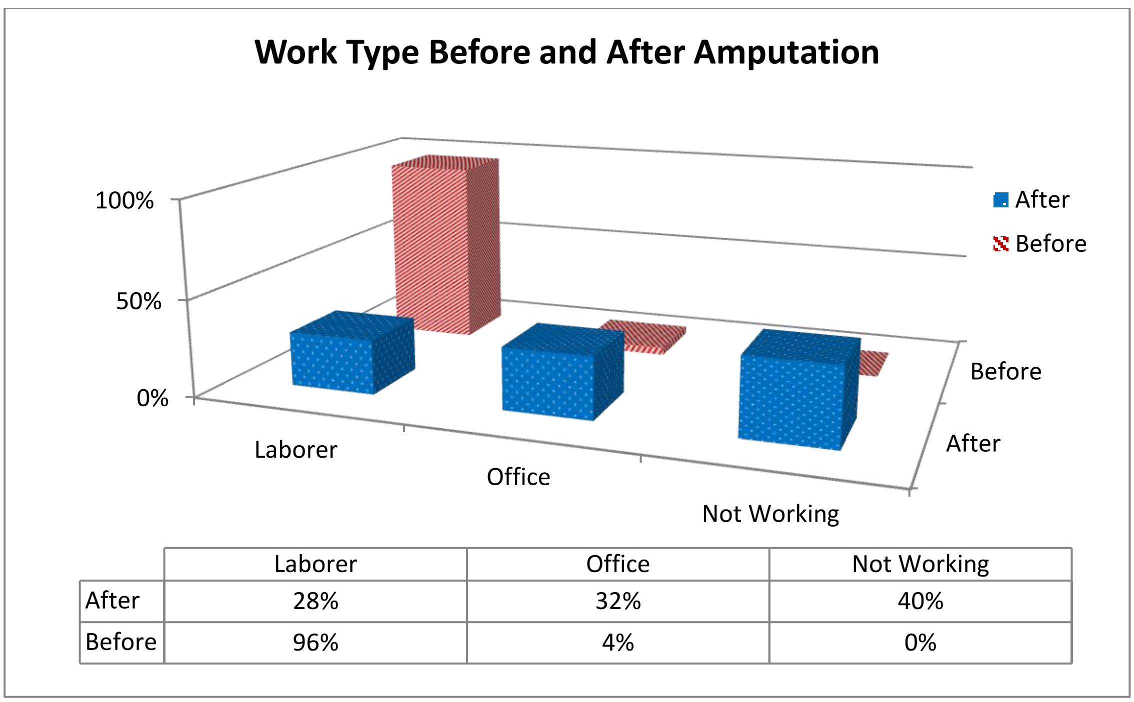
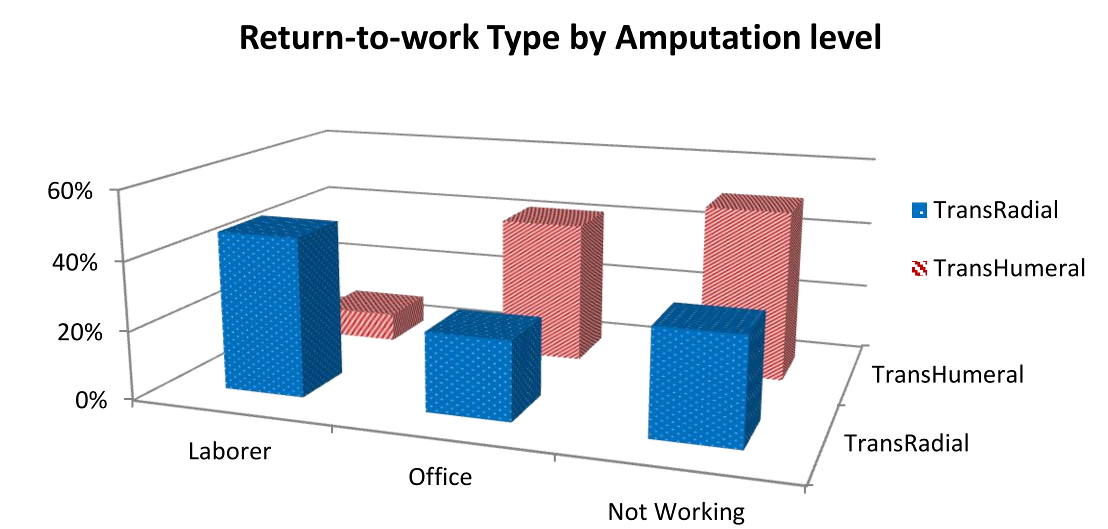


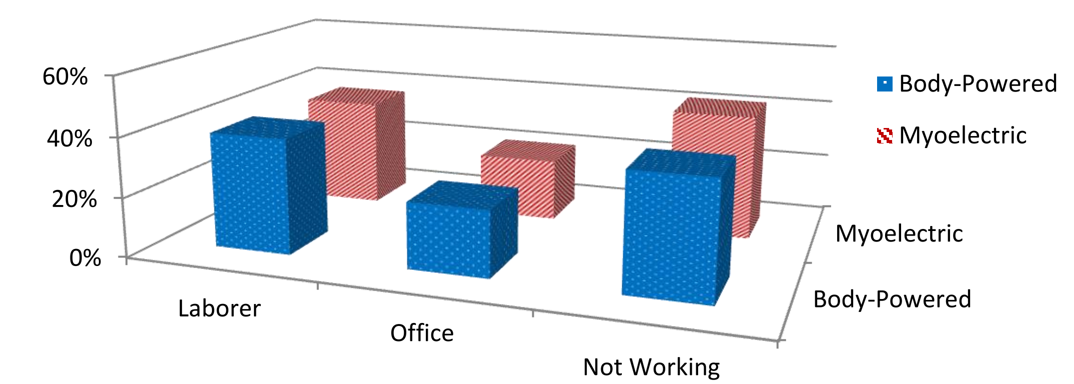
Figure 4.3 Work Type Before and After Amputation

To explain the fact that the majority of amputees (96%) were in heavy duty work before amputation, it is reasonable to expect a higher incident of serious injuries when the worker is carrying out heavy duty work than a worker in office work environment. As well, after their amputations, many of these amputee workers are no longer suitable to return to laborer type of work. The figures in Table 4.2 are converted into percentage values and are plotted in Figures 4.4, 4.5, and 4.6.



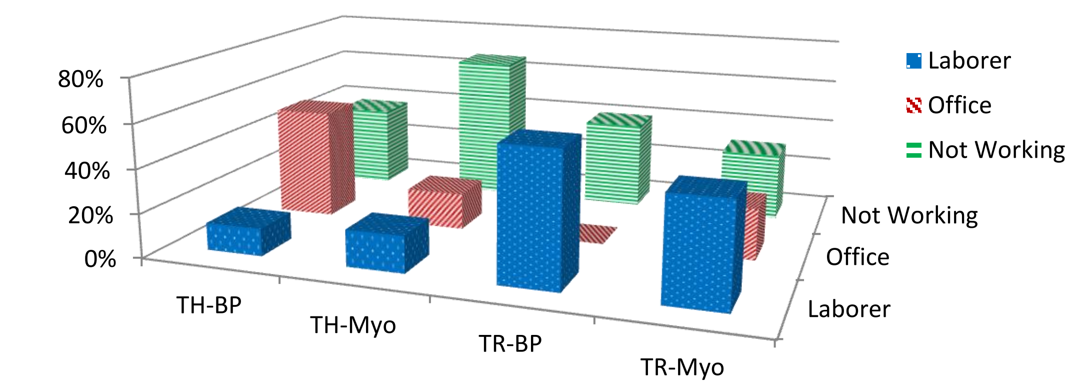
	Laborer	Office	Not Working
TransRadial	46%	23%	31%
TransHumeral	8%	42%	50%

Figure 4.4 Return-to-work Type by Amputation Level



	Laborer	Office	Not Working
Body-Powered	39%	22%	39%
Myoelectric	37%	21%	42%

Figure 4.5 Return-to-work Type by Type of Prosthesis



	TH-BP	TH-Myo	TR-BP	TR-Myo
Laborer	13%	17%	60%	46%
Office	50%	17%	0%	23%
Not Working	38%	67%	40%	31%

Figure 4.6 Return-to-work Type by Amputation Level and Type of Prosthesis

From the above figures (Figures 4.3 to 4.6), it is noticed that:

- Almost all workers (96%) who lost their upper limb were employed in laborer-type of work before their injuries.
- Of all TH and TR amputees, 40% did not return to work, and about half of those who returned to work have switched to light-duty jobs.
- From Figure 4.5, wearing a Myo or BP prosthesis does not appear to have much influence on whether or not the amputee will return to work, and does not affect what type of jobs they will return to.
- Those who have returned to more heavy duty work (laborer-type) tend to be TR amputees; and more TH amputees than TR amputees are not working.
- In Figure 4.6, the amputees are further segregated into the four categories (TH-BP, TH-Myo, TR-BP and TR-Myo) and plotted against the return-to-work types (L, O and N). It shows that most returned to laborer type of work are TR amputees. Although the plot shows some interesting trends, they are not statistically significant as the numbers in these categories are low.

4.5.2.2 Frequency of Use

One of the important parameters to indicate successfulness of prosthetic prescription is the frequency of prosthetic use by the amputee. Frequencies of prosthetic use were reported in various documents in the amputee's case files (e.g., medical reports, amputee clinic assessments, prosthetic claims, etc.). Unfortunately, there is no standardized reporting format among the WSBC documents for such an important parameter. Identifying the frequencies of prosthetic use of these amputees was attempted by reviewing the various documents in the case files. However, it is very difficult to reliably and accurately quantify this information as the descriptions and references in the documents were often ambiguous and disorganized. In most cases, references to prosthetic utilization were only made during the early stage of prosthetic use (e.g., during rehabilitation training). Nevertheless, a five-point numeric scale (shown in Table 4.3) was created to quantify the level of BP and Myo prosthetic utilization. When reviewing the overall prosthetic utilization, the higher of the BP and Myo prosthetic utilization values from the same amputee was taken to represent the overall prosthetic utilization of the amputee.

Table 4.3 Prosthetic Utilization Scale

Utilization Level	Description
5	active or > 5 hrs use per day
4	consistent or everyday
3	fair or few days per week
2	occasional
1	seldom or not used

The levels of prosthetic utilization in relation to different amputee characteristics are shown in the Box Plot in Figure 4.7. Although the differences in the mean values among the different categories are not statistically significant (t-test, $p > 0.05$), the analysis shows that:

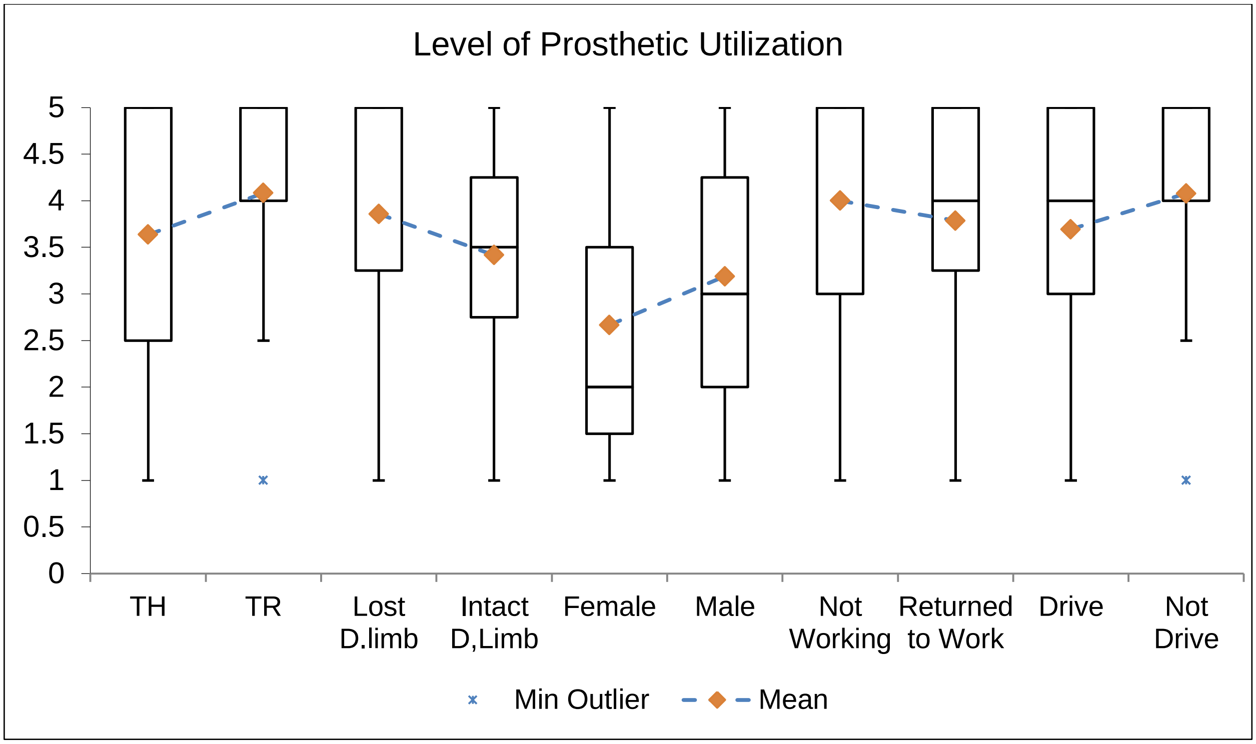
- TR amputees use their prostheses more than TH amputees.
- Workers who lost their dominant limb use their prostheses more than those who lost their non-dominant limb.

- Male amputees tend to have higher usage of prostheses than female amputees.
- Those who are not working have higher mean utilization usage than those who have returned to work.
- Those who continue to drive after amputation have lower prosthetic usage than those who no longer drive a vehicle.

To identify contributing factors affecting the level of prosthetic utilization, correlation tests were performed between the following five amputee worker profile parameters and the levels of prosthetic utilization.

1. Current age
2. Age at amputation
3. Time between first prosthesis and amputation
4. Frequency of repair
5. Cost of repair

With three utilization values (BP, Myo, and all) and five amputee profile parameters, 15 pairs of data sets were created for correlation assessment. However, no significant correlation could be established in any of the data pairs. As no significant correlation could be established, it is concluded that, from the samples in these case files, the levels of prosthetic utilization were not dependent on the above listed parameters. The poor correlation and insignificant differences are likely the results of the unreliable utilization values obtained from the case files.



	TH	TR	Lost D.limb	Intact D.Limb	Female	Male	Not Working	Returned to Work	Driv-ing	Not Driving
Min	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Max	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Median	5.0	4.0	5.0	3.5	2.0	3.0	5.0	4.0	4.0	5.0
Mean	3.6	4.1	3.9	3.4	2.7	3.2	4.0	3.8	3.7	4.1
SD	1.9	1.6	1.7	1.6	2.2	1.7	1.8	1.7	1.9	1.3
SEM	0.6	0.5	0.4	0.5	1.2	0.4	0.6	0.5	0.5	0.4
n	11	12	14	12	3	16	9	14	13	13

Figure 4.7 Prosthetic Utilization by Amputee Profile

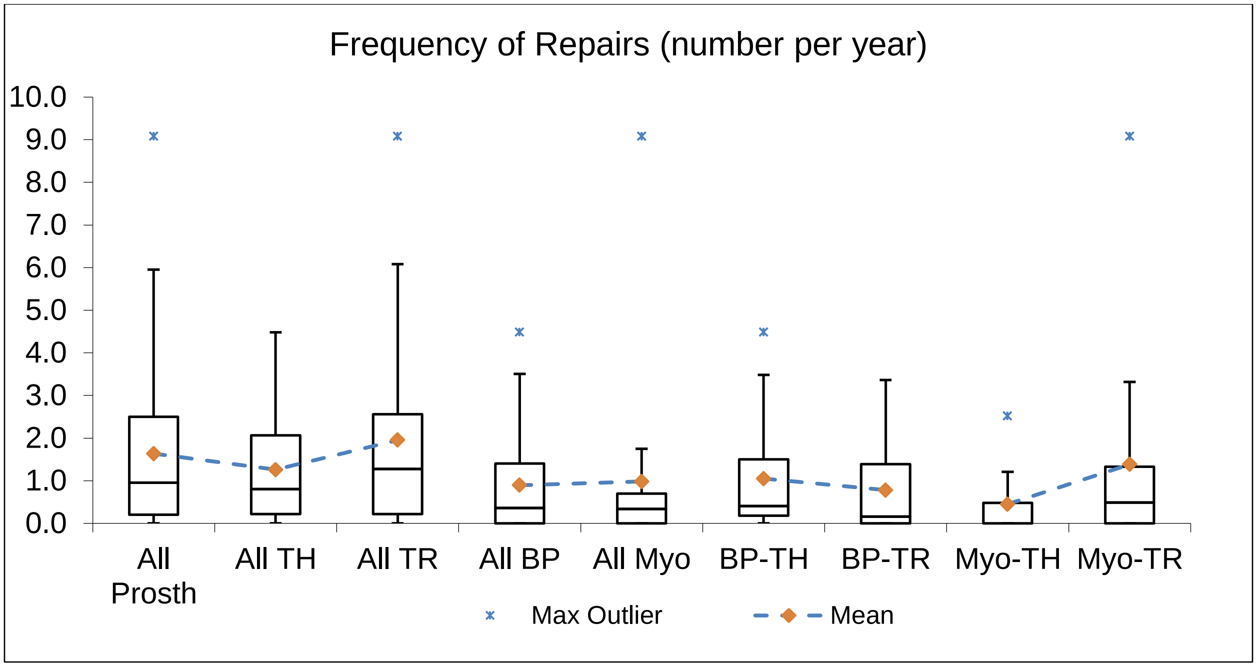
Vehicle driving is an instrumental activity of daily living (IADL). Adaptive devices (such as a steering wheel spinner knob and turn signal control switches) are often installed to facilitate prosthetic users to steer and control their vehicles. Table 4.4 tabulates the influence on driving by characteristics of amputation (TH versus TR, and workers who lost their dominant limb versus those with their dominant limb intact). The distribution shows that 67% of TH amputees have abandoned driving whereas 50% of TR amputees continued to drive after amputation. In addition, 63% of amputees who lost their dominant limb abandoned driving after amputations whereas only 36% of amputees with dominant limb intact abandoned driving.

Table 4.4 Effect of Amputation on Driving

	TH	TR	Lost dominant Limb	Dominant limb intact
Driving after amputation	4	7	6	7
Not driving after amputation	8	7	10	4

4.5.3 Reliability and Service Patterns

The repair rate of a prosthesis is considered to be affected by the work environment, frequency of use, and how it was used. Reliability is signified by the frequency of demand maintenance services due to malfunctioned parts, worn-out components and out of alignments. From each amputee case file, the number of repairs, adjustments, and replacements of worn out components are tallied. The costs associated with these services are also compiled. The annual frequency of repair is calculated by the total number of repairs divided by the number of years of possession of the prosthesis. The other service frequencies as well as their associated costs are similarly calculated. Figure 4.8 is the Box Plot of the annual repair frequencies of this study group arranged by the prosthetic types and levels of amputation.

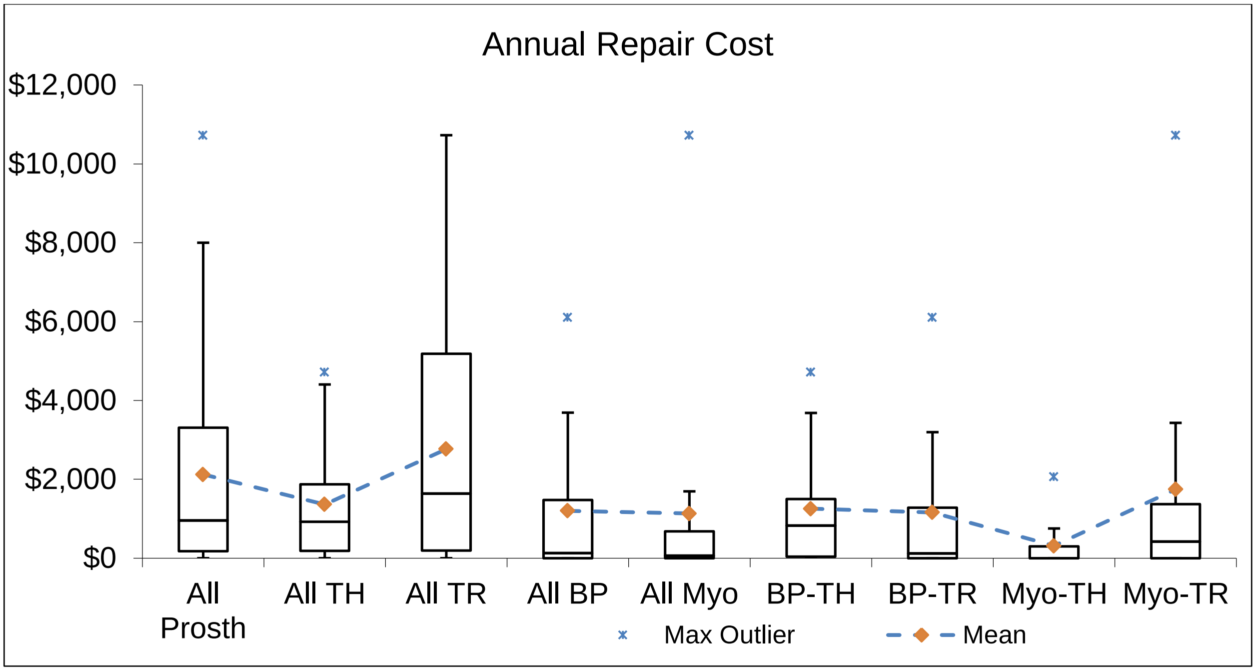


	All Prosth	All TH	All TR	All BP	All Myo	BP-TH	BP-TR	Myo-TH	Myo-TR
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max	9.08	4.49	9.08	4.49	9.08	4.49	3.37	2.52	9.08
Median	0.96	0.80	1.28	0.36	0.34	0.40	0.16	0.00	0.49
Mean	1.64	1.26	1.96	0.90	0.98	1.05	0.78	0.45	1.39
SD	1.06	1.06	1.33	0.69	1.06	0.69	1.23	1.06	0.77
SEM	0.22	0.32	0.37	0.14	0.23	0.22	0.34	0.35	0.22
n	24	11	13	23	21	10	13	9	12

Figure 4.8 Frequencies of Repair by Type of Prostheses

The Box Plot (Figure 4.8) shows that the mean frequencies of repairs for BP and Myo prostheses are 0.90 ± 0.14 (mean ± SEM) and 0.98 ± 0.23 (mean ± SEM) respectively. This translates to a mean-time-between-failures (MTBF) of approximately one year. On average, in the group of TR amputees, Myo prostheses require twice as much repair as BP prostheses (1.39 versus 0.78 times per year); whereas, for TH amputees the repair requirements are reversed (0.45 versus 1.05 times per year). It is also noted that the frequency of repair for TR Myo prostheses is over three times that of TH Myo prostheses (1.39 versus 0.45 times per year). However, these differences are not statistically significant. From Table 4.2, most amputees who returned to laborer-type of work were wearing transradial prostheses. We can, therefore, attribute the higher repair frequency to the use of transradial prosthesis in heavy duty work. It is interesting to notice that the median frequencies of repairs are much lower than their means. For example, the median repair frequency for all prostheses is 0.96 times per year and the mean is 1.64 times per year. This difference is due to the high repair rates in a couple of cases. In one case, an amputee was given a TR Myo prosthesis for moving heavy lumber at work causing frequent repeated damages to the prosthesis.

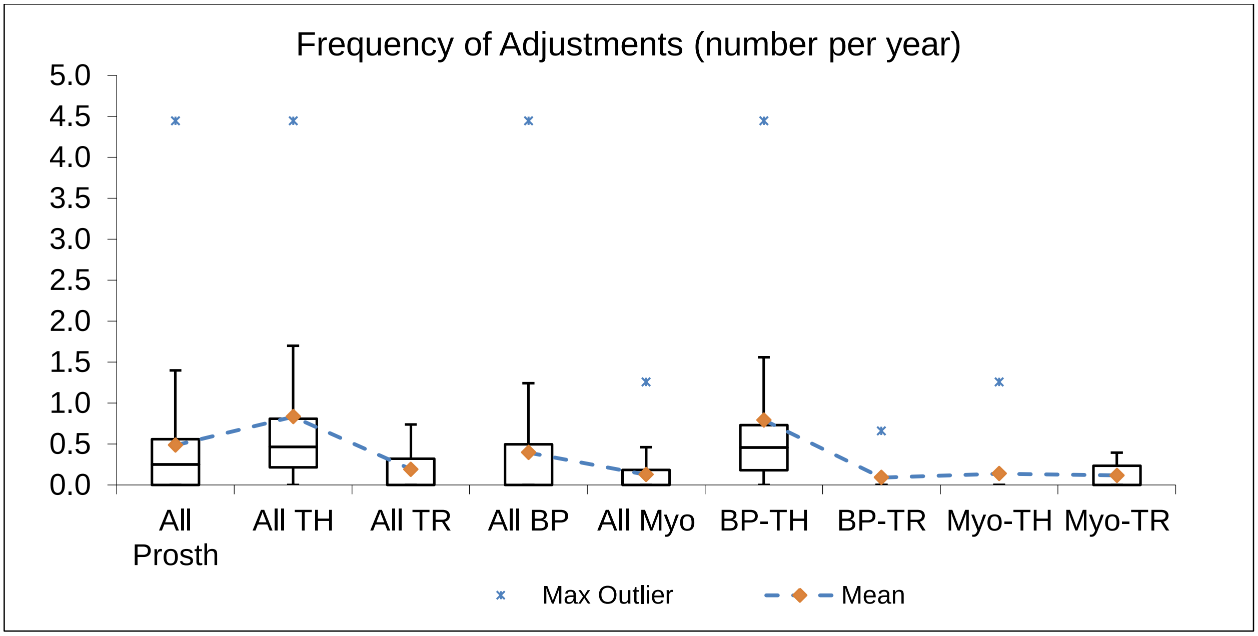
Figure 4.9 shows the annual repair cost of different types of prosthesis. It shares a similar pattern with the frequency of repair plot (Figure 4.8). Again, TR prostheses tend to incur higher annual repair costs. The average annual repair cost for a transradial prosthesis is about \$2,769 ± \$907 (mean ± SEM) whereas it is \$1,364 ± \$469 (mean ± SEM) for a TH prosthesis. It is interesting to note that there is not too much difference between the mean frequencies of repairs and the mean annual repair costs for BP and Myo prostheses.



	All Prosth	All TH	All TR	All BP	All Myo	BP-TH	BP-TR	Myo-TH	Myo-TR
Min	0	0	0	0	0	0	0	0	0
Max	10727	4719	10727	6109	10727	4719	6109	2066	10727
Median	953	923	1640	129	62	829	117	0	422
Mean	2124	1364	2768	1202	1133	1253	1162	314	1746
SD	2673	1555	3271	1891	2520	1609	2147	675	3202
SEM	546	469	907	394	550	509	595	225	924
n	24	11	13	23	21	10	13	9	12

Figure 4.9 Annual Repair Costs by Type of Prostheses

Other than repair work, prosthetic components require occasional adjustments (e.g., cable and harness adjustment for BP prosthesis) to maintain functional effectiveness. In addition, worn out components (parts and accessories such as gloves and liners) will need to be replaced. Figure 4.10 and Figure 4.11 show the annual adjustment frequencies and annual component replacement frequencies respectively for different types of prostheses.



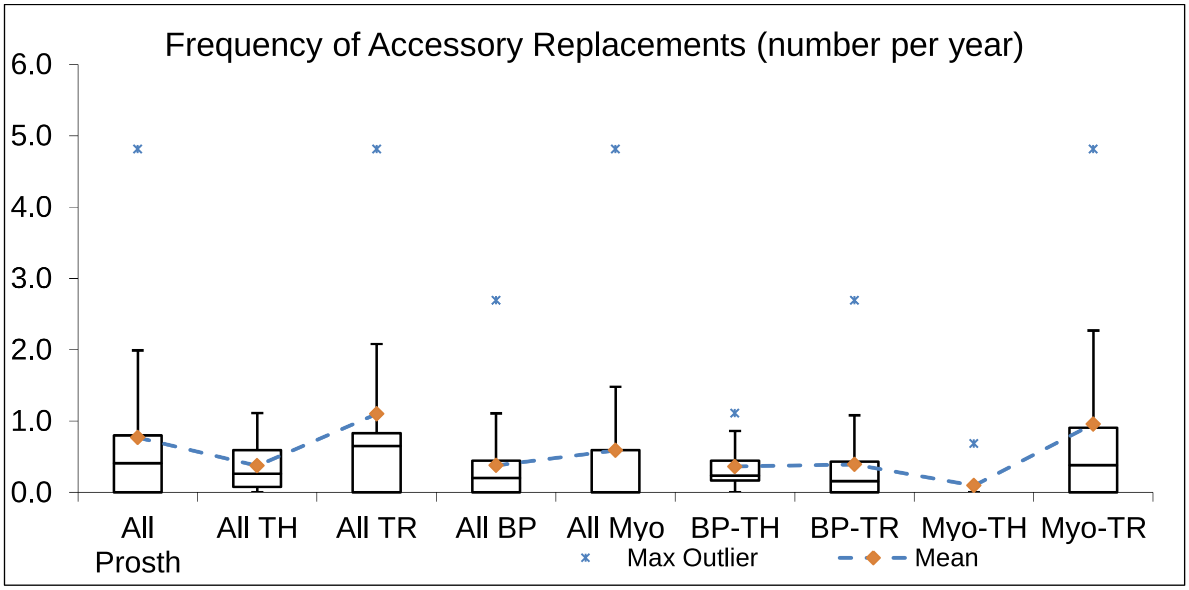
	All Prosth	All TH	All TR	All BP	All Myo	BP-TH	BP-TR	Myo-TH	Myo-TR
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max	4.44	4.44	0.74	4.44	1.26	4.44	0.66	1.26	0.40
Median	0.25	0.47	0.00	0.00	0.00	0.46	0.00	0.00	0.00
Mean	0.49	0.84	0.19	0.40	0.13	0.79	0.09	0.14	0.12
SD	0.46	0.46	0.16	0.32	0.56	0.32	0.00	0.56	0.17
SEM	0.09	0.14	0.05	0.07	0.12	0.10	0.00	0.19	0.05
n	24	11	13	23	21	10	13	9	12

Figure 4.10 Frequency of Adjustment by Type of Prostheses

Figure 4.10 shows that a prosthesis on average will need to be adjusted once every 2 years (frequency = 0.49 per year). The mean values, in general, are higher than the median values. Although the differences between the mean values are not statistically significant, the followings were noted from the Box Plots:

- Body-powered (BP) prostheses need more adjustments than externally-powered (Myo) prostheses.
- Transhumeral (TH) prostheses need more adjustments than transradial (TR) prostheses.

- Among the four mean categories (BP-TH, BP-TR, Myo-TH, and Myo-TR), BP-TH requires the most frequent adjustments.

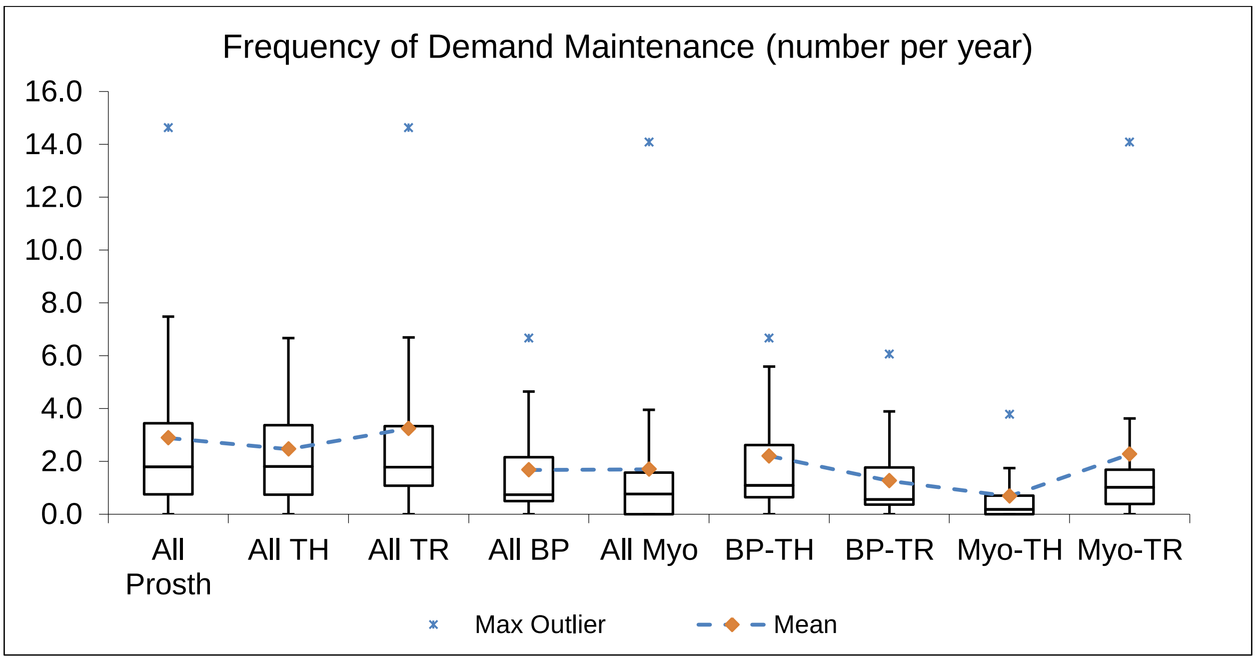


	All Prosth	All TH	All TR	All BP	All Myo	BP-TH	BP-TR	Myo-TH	Myo-TR
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max	4.81	1.11	4.81	2.69	4.81	1.11	2.69	0.68	4.81
Median	0.41	0.26	0.65	0.20	0.00	0.23	0.16	0.00	0.38
Mean	0.77	0.37	1.10	0.38	0.59	0.36	0.39	0.10	0.96
SD	0.28	0.28	1.07	0.19	0.31	0.19	0.99	0.31	0.29
SEM	0.06	0.09	0.30	0.04	0.07	0.06	0.27	0.10	0.08
n	24	11	13	23	21	10	13	9	12

Figure 4.11 Frequency of Accessory Replacement by Type of Prostheses

Replaced accessories are mainly items (such as gloves and liners) which suffer from wear and tear, and soiling. TR prosthetic users show a higher mean In particular, the mean accessory replacement frequency of Myo-TR prostheses (0.96 times per year) is almost 10 times that of the Myo-TH prostheses (0.1 times per year). The higher accessory replacement needs of TR prosthetic users may be an indicator that TR users are using their prostheses more often and in harsher environment than the TH users.

Figure 4.12 plots the frequencies of demand maintenance against different types of prostheses. Demand maintenance is the combination of repair, adjustment and replacement services. From the plot, a BP prosthesis requires 1.67 ± 0.20 (mean ± SEM) times of demand maintenance per year which is almost the same as a Myo prosthesis (1.70 ± 0.34). The average demand maintenance frequency of TR-Myo prostheses is about three times that of the TH-Myo prostheses (2.27 versus 0.69 times per year).

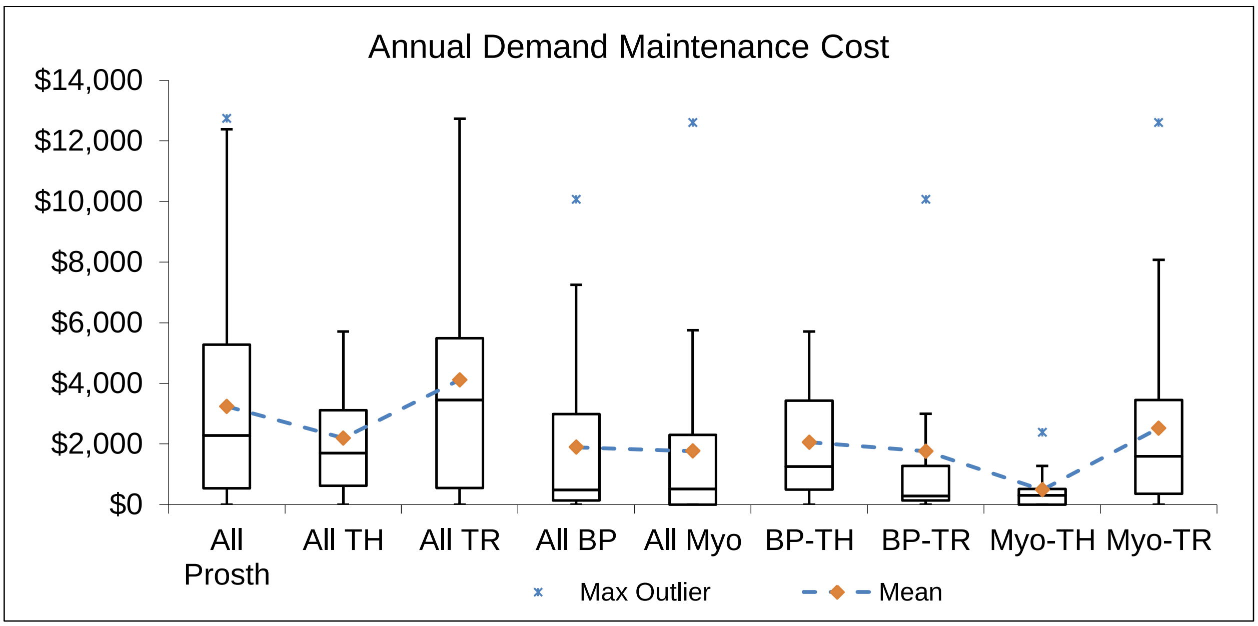


	All Prosth	All TH	All TR	All BP	All Myo	BP-TH	BP-TR	Myo-TH	Myo-TR
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max	14.63	6.66	14.63	6.66	14.08	6.66	6.06	3.78	14.08
Median	1.79	1.80	1.78	0.74	0.77	1.10	0.56	0.19	1.02
Mean	2.89	2.47	3.25	1.67	1.70	2.21	1.27	0.69	2.27
SD	1.45	1.45	2.15	0.94	1.58	0.94	2.16	1.58	0.84
SEM	0.30	0.44	0.60	0.20	0.34	0.30	0.60	0.53	0.23
n	24	11	13	23	21	10	13	9	13

Figure 4.12 Frequency of Demand Maintenance by Type of Prostheses

From Figures 4.8, 4.10, and 4.11, for BP prostheses, the average annual demand maintenance frequency (1.67 ± 0.20 times per year) is made up of 0.90 ± 0.14 times of repairs, 0.40 ± 0.07 times of adjustments, and 0.38 ± 0.04 times of replacements. For Myo prostheses, the average (1.70 ± 0.30) is made up of 0.98 ± 0.23 times of repairs, 0.13 ± 0.12 times of adjustments, and 0.59 ± 0.07 times of replacements.

Figure 4.13 shows the annual cost of demand maintenance. In general, TR prostheses cost twice as much to maintain than TH prostheses. Surprisingly, the average annual costs of repair for BP and Myo prostheses are about the same.



	All Prosth	All TH	All TR	All BP	All Myo	BP-TH	BP-TR	Myo-TH	Myo-TR
Min	0	0	0	0	0	0	0	0	0
Max	12736	5712	12736	10070	12598	5712	10070	2376	12598
Median	2278	1700	3447	485	512	1253	283	300	1587
Mean	3234	2193	4115	1888	1765	2056	1759	484	2515
SD	3348	2021	4030	2686	2902	2143	3120	761	3474
SEM	683	609	1118	560	633	678	865	254	964
n	24	11	13	23	21	10	13	9	13

Figure 4.13 Cost of Demand Maintenance by Type of Prostheses

Within the study group, with \$2,515 and \$484 per year respectively, Myo-TR prostheses cost 5 times as much to maintain as Myo-TH prsotheses ($p < 0.05$). The fact that TR prostheses require more maintenance than TH prostheses is likely the result of higher prosthetic utilization by TR amputees, as more wear and tear will happen to the prostheses when they are engaged in active and heavy duty work. In at least one case, it is apparent that the high breakdown frequency (leading to high service costs) was a result of the prosthetic components not designed to endure the specific work environment.

4.5.4 Cost-of-Ownership Analysis

When a worker is injured leading to upper limb amputation, there are many resources provided by insurance and funding agencies to assist the worker to recover from the injury, to return to independent living, and hopefully to return to work. Below is the collection of usual expenses provided by WSBC:

- Medical care – such as medical assessments, surgeries, medical and psychological consultations, etc.
- Rehabilitation and training − occupation therapy and physiotherapy including ADLs and prosthetic training, special driver’s training, and special on-the-job training.
- Reimbursements – such as wage loss, traveling and accommodation, domestic help expenses, etc.
- Modifications – such as home modifications, vehicle modifications, adaptive aids and tools, etc.

- Prosthetic service – including assessment, test sockets, liners, sockets fabrication and fitting, prosthetic components, ongoing maintenance and related supplies.

Although some of the above listed costs are related and may affect others, cost analysis in this study is mainly focused on the last item, i.e., prosthetic costs.

From the medical files, in particular from the prosthetic claims, the prosthetic history of each amputee is summarized in a spreadsheet file (Appendix B). For each amputee, the cumulative expenses of body-powered and myoelectric prosthesis as well as the combined prosthetic expenses are compiled and tabulated. These expenditures are normalized against the overall combined cumulative prosthetic costs and plotted against time. Figure 4.14 shows an example of such a plot. The horizontal axis is the year from the date of the first prosthesis. Each point on the graph is a prosthetic claim. In this example, worker #22 suffered from a TR amputation and received his first BP prosthesis in November 2005. The cumulative total cost over time of the BP prosthesis is represented by the red line (square labels). The date of amputation is indicated by the asterisk on the horizontal axis (in this case it was April 2005, 6 months before the first prosthesis). The worker was prescribed his/her first myoelectric prosthesis (green line with triangular labels) in January 2007, about 14 months after his BP prosthesis. The combined cumulative total prosthetic cost is represented by the blue line (diamond labels). As the first prosthesis was provided in November 2005, six years of history was recorded (record cut-off date was November 2011). At the cut-off date (November 2011), the total cumulative expenses on both BP and Myo prostheses were $52,029. From the reliability analysis in the previous section, the frequency of demand maintenance for a myoelectric prosthesis is 1.67 ± 0.20 (mean ± SEM) times per year which is one demand maintenance service every 7.2 ± 0.8 months. As there was no prosthetic claim on the myoelectric prosthesis for this worker in the last 3.6 years, it is reasonable to suggest that this worker has not been using his/her myoelectric prosthesis. On the other hand, the regular maintenance records of the BP prosthesis (shown in the claims) indicates that the amputee has been using the BP prosthesis consistently. We presumed that the amputee has abandoned his/her Myo prosthesis. Using this proposition, we postulate that a prosthesis has been abandoned when there was no maintenance activity for over two years.

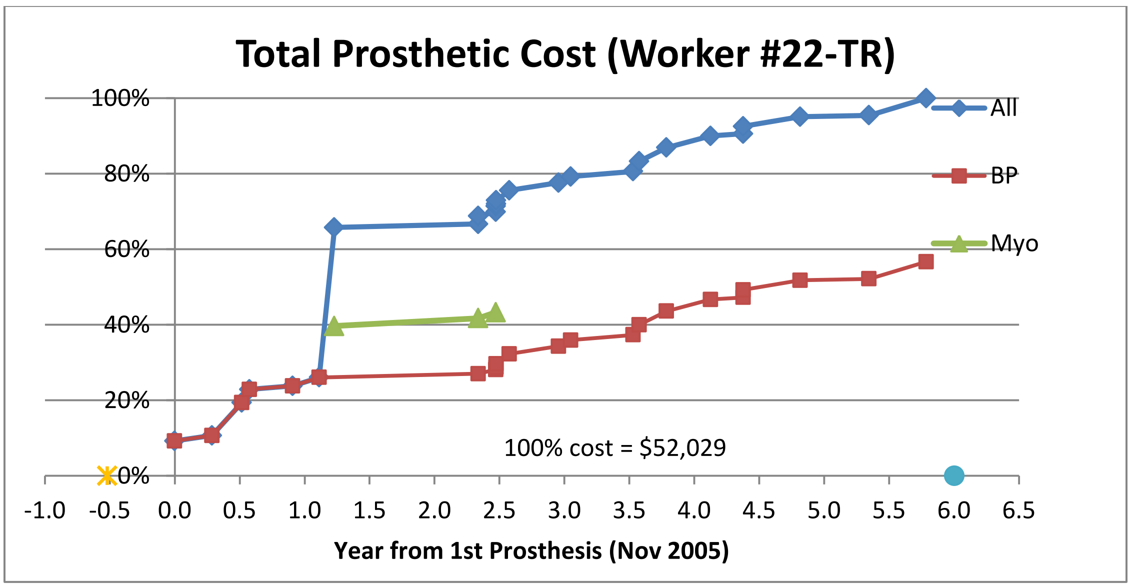
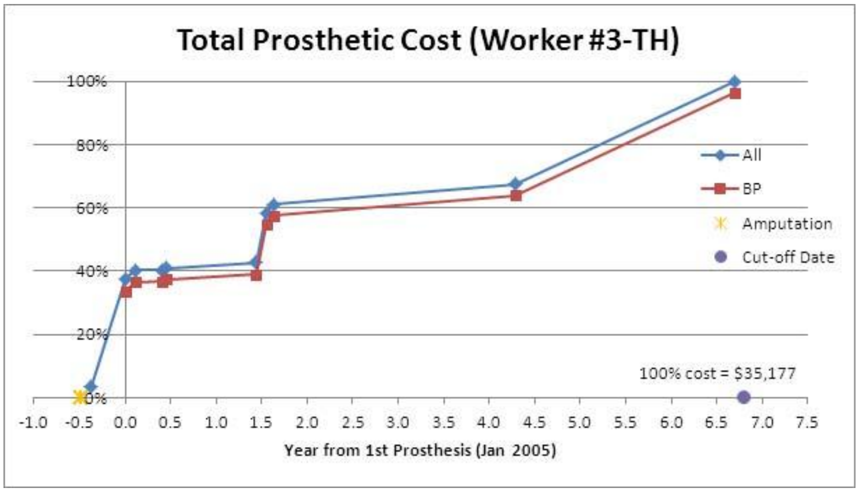
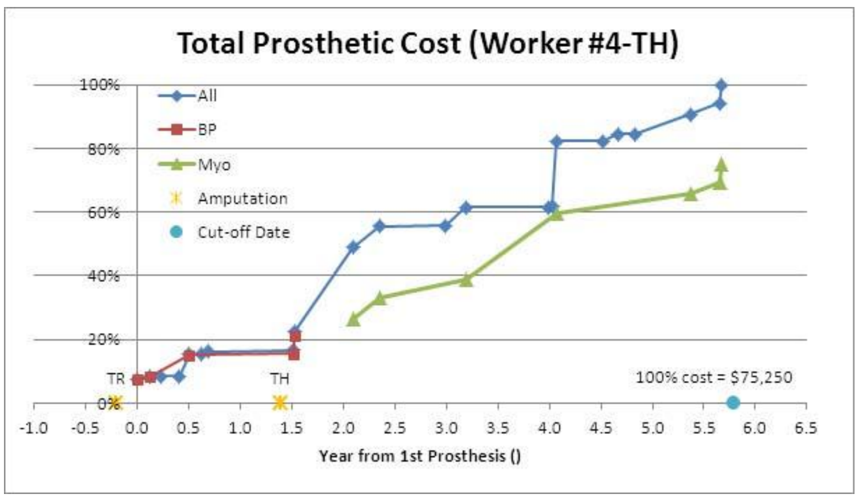


Figure 4.14 Example of Total Prosthetic Cost against Time

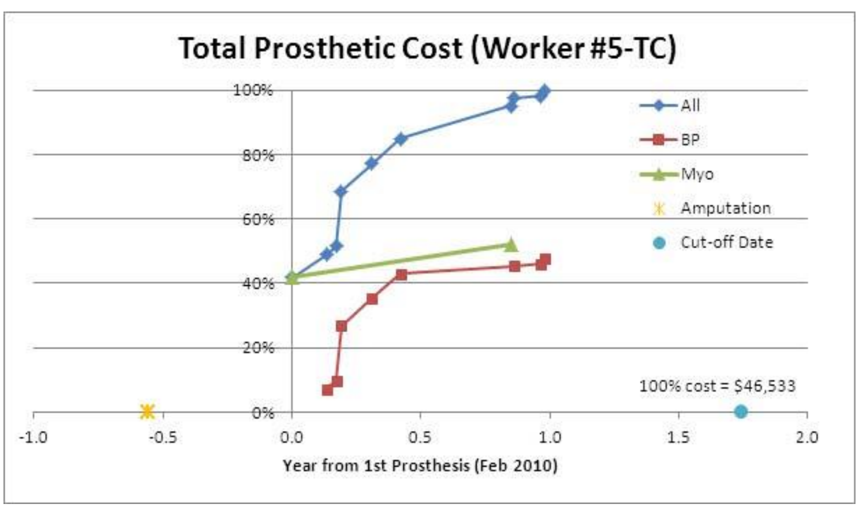
The total prosthetic cost plots for all amputees in this study are shown in Figures 4.15 - a to aa (for workers #3 to #29). As complete data is not available for the amputee worker who has passed away, only 27 cases are shown.



(a)

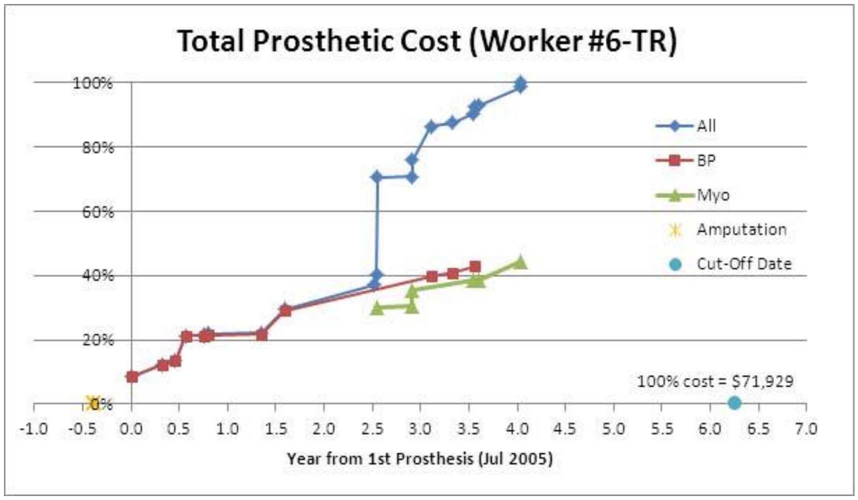


(b)

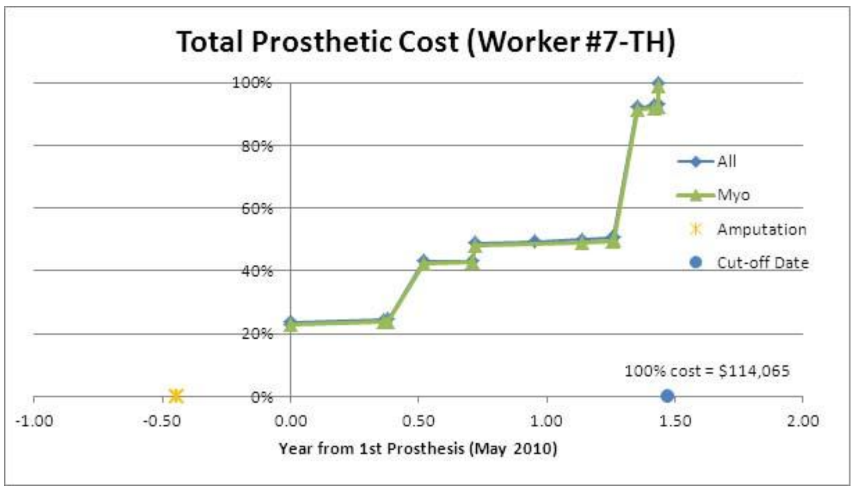


(c)

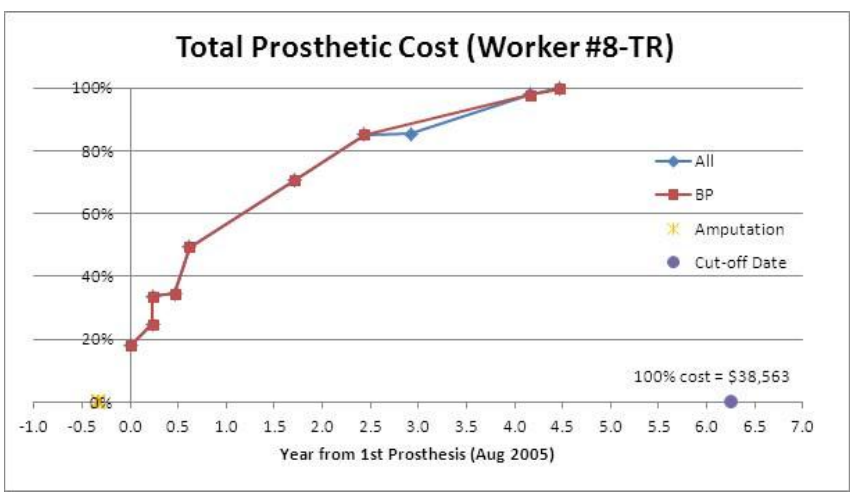
Figure 4.1 (a, b. c) Total Prosthetic Cost –Time Plot



(d)

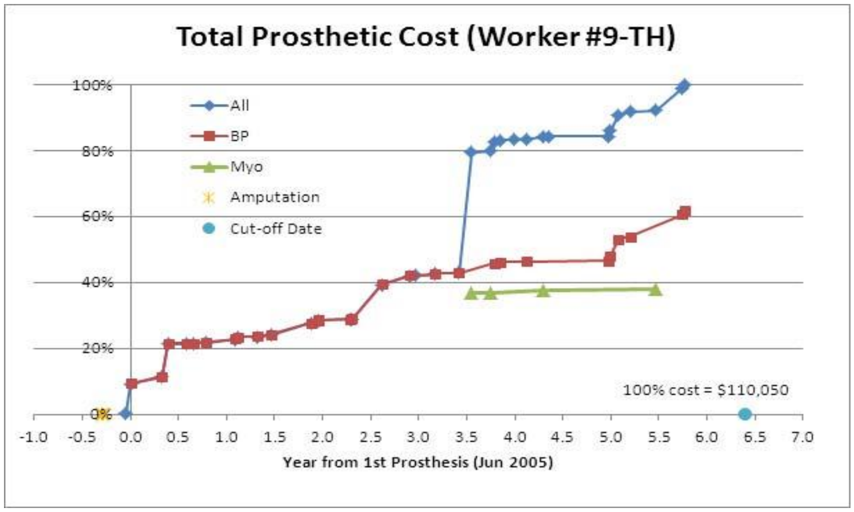


(e)

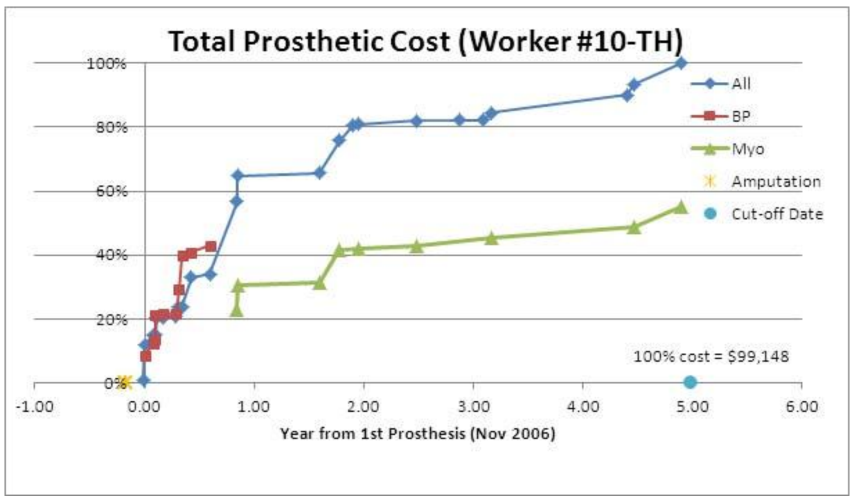


(f)

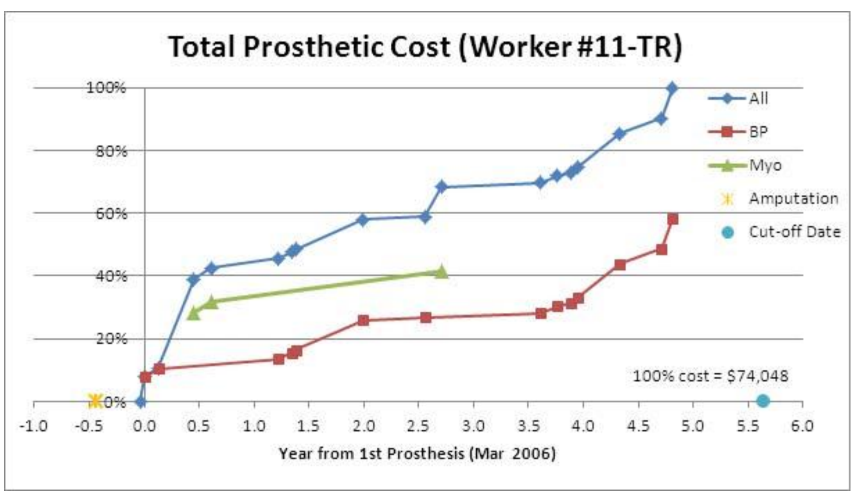
Figure 4.2 (d, e, f) Total Prosthetic Cost –Time Plot



(g)

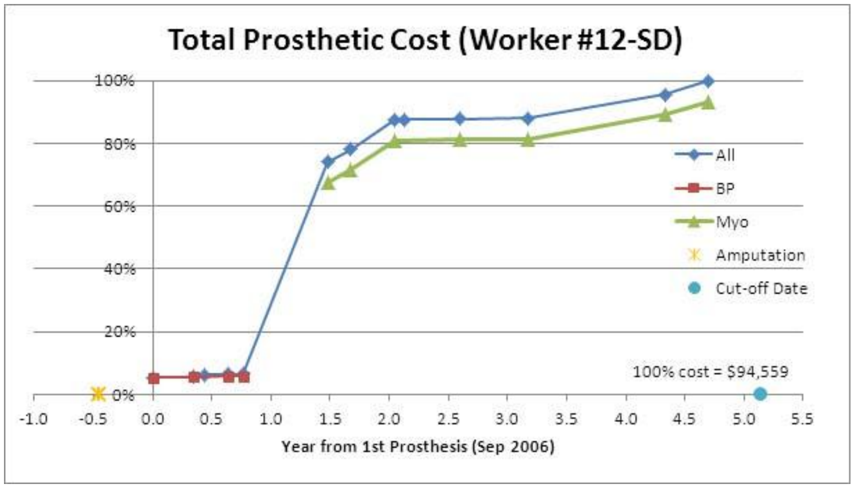


(h)

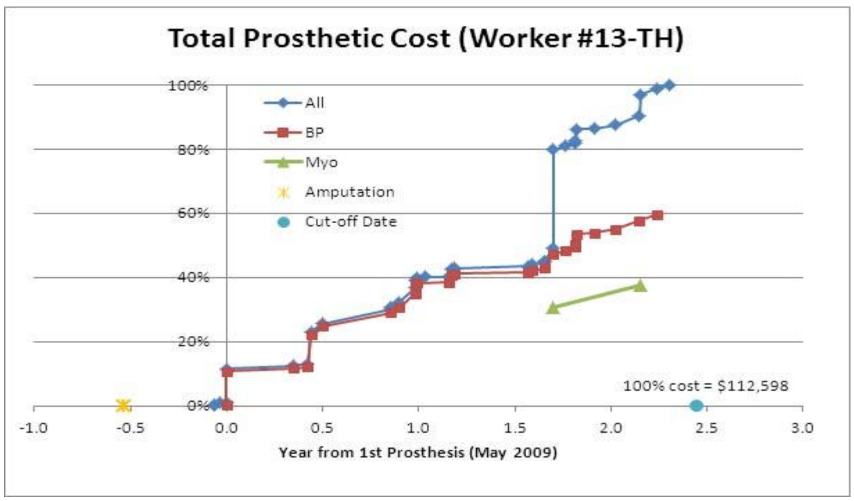


(i)

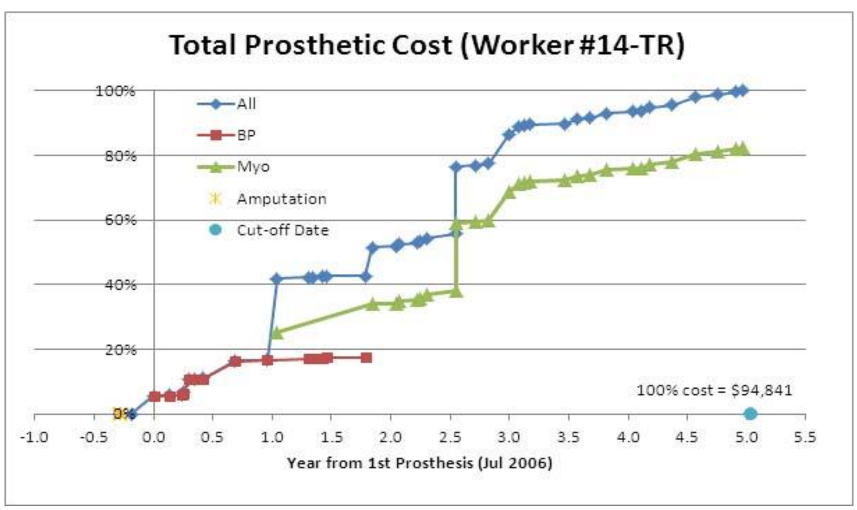
Figure 4.3 (g, h, i) Total Prosthetic Cost –Time Plot



(j)

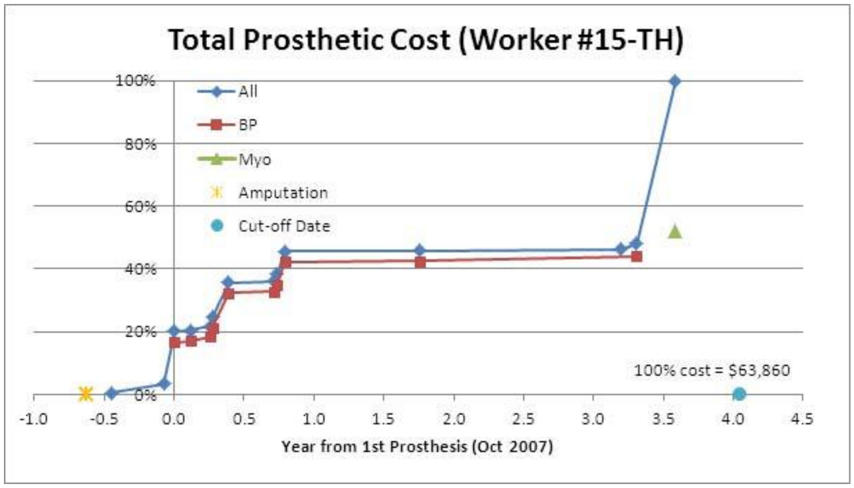


(k)

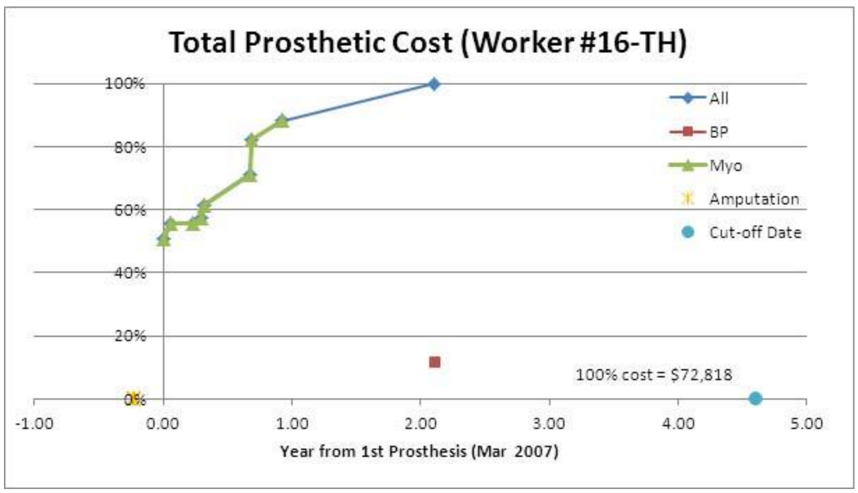


(l)

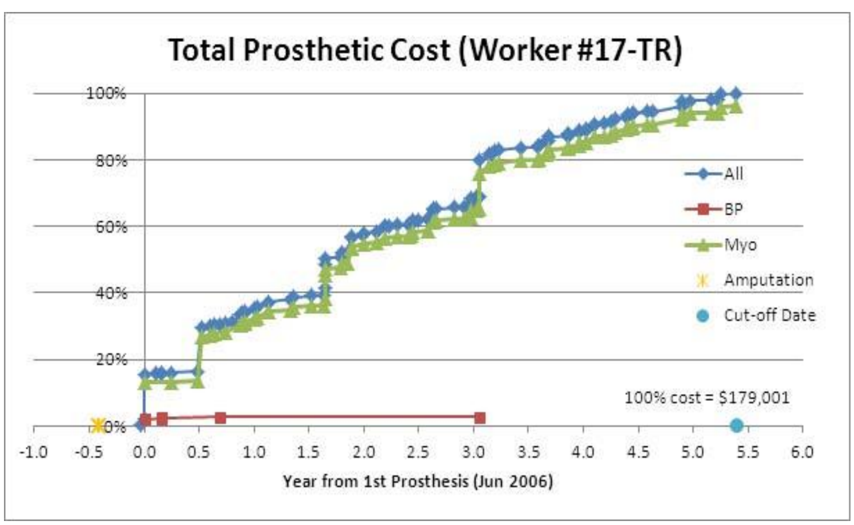
Figure 4.4 (j, k, l) Total Prosthetic Cost –Time Plot



(m)

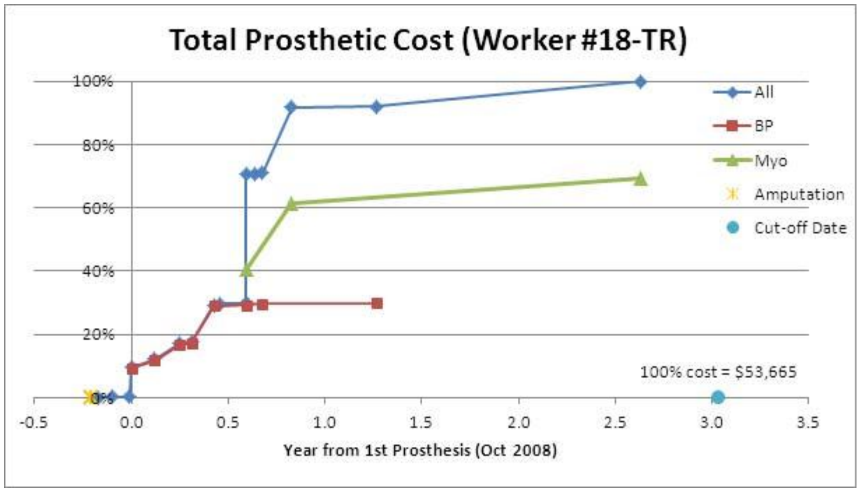


(n)

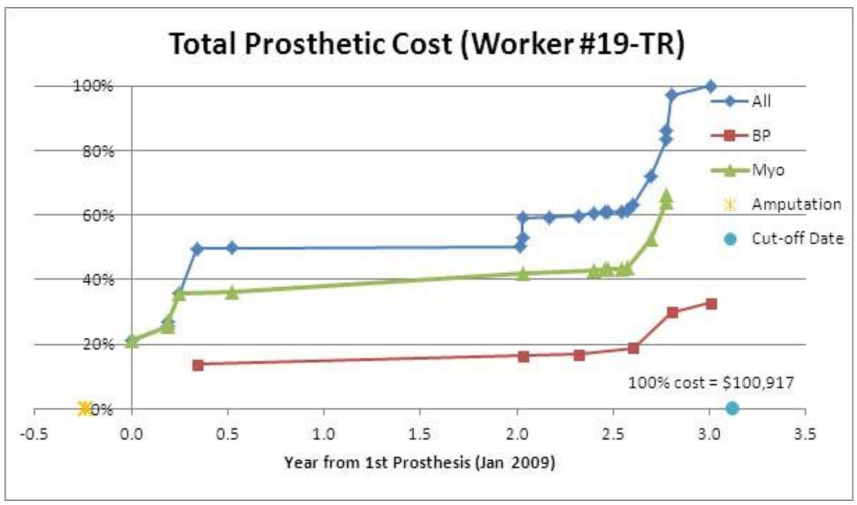


(o)

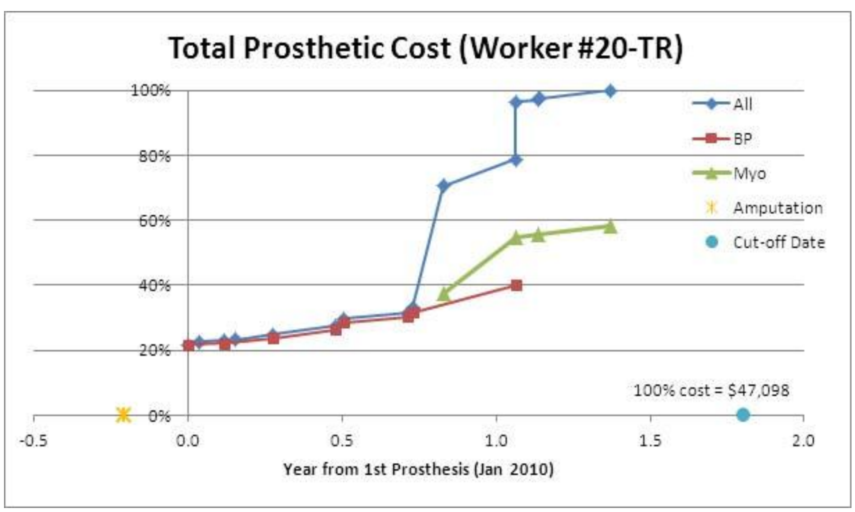
Figure 4.5 (m, n, o) Total Prosthetic Cost –Time Plot



(p)

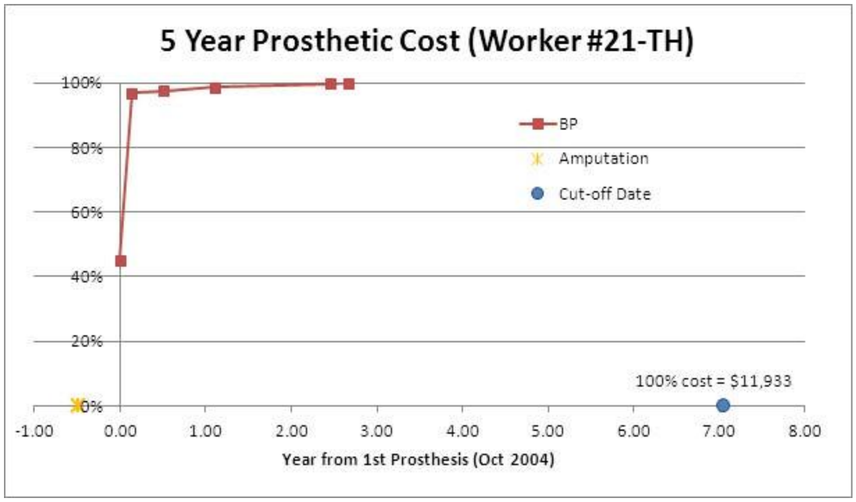


(q)

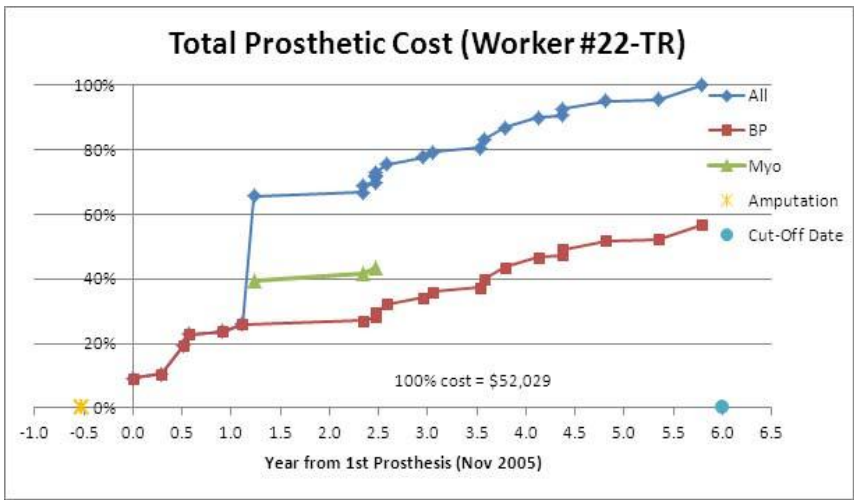


(r)

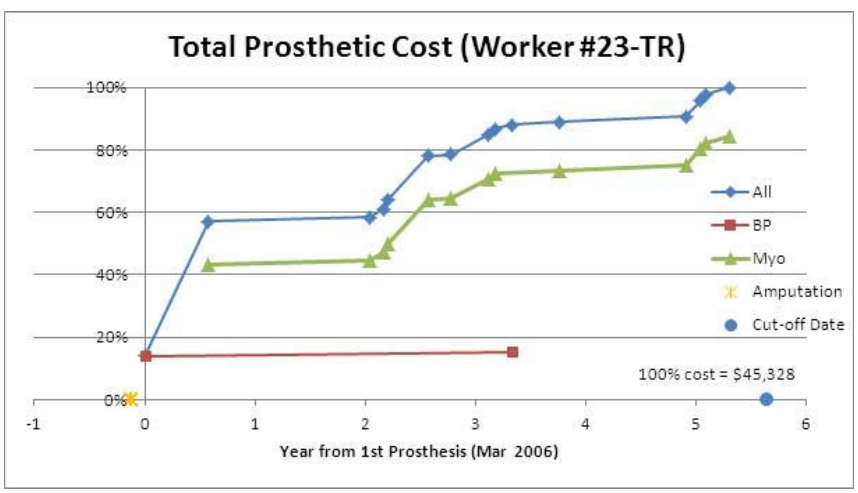
Figure 4.6 (p, q, r) Total Prosthetic Cost –Time Plot



(s)

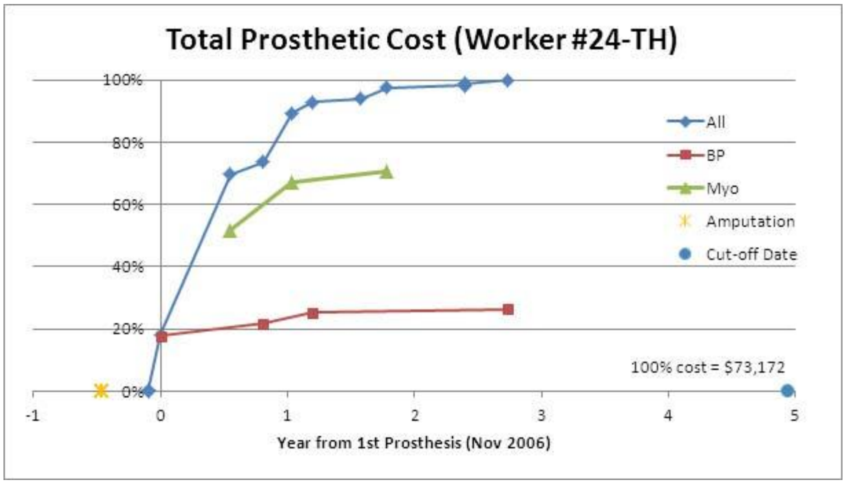


(t)

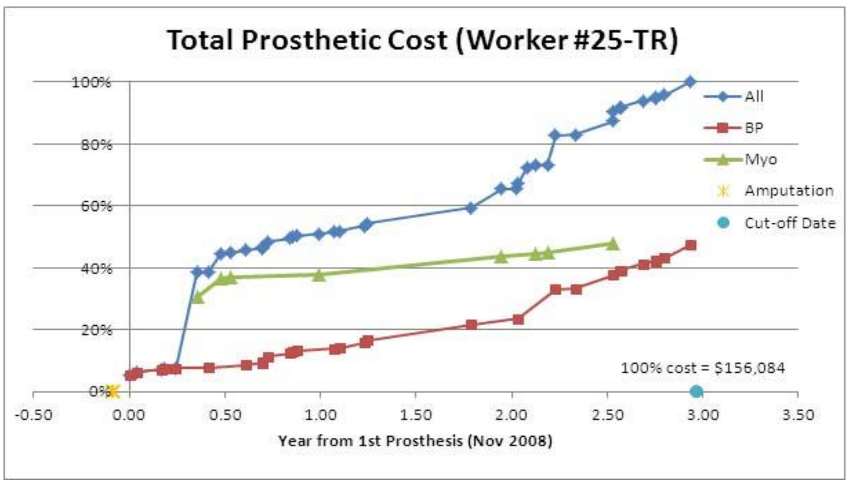


(u)

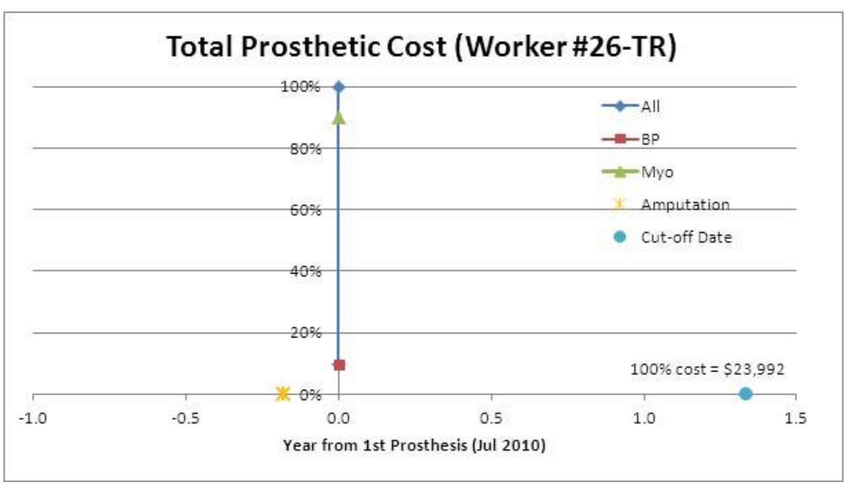
Figure 4.7 (s, t, u) Total Prosthetic Cost –Time Plot



(v)

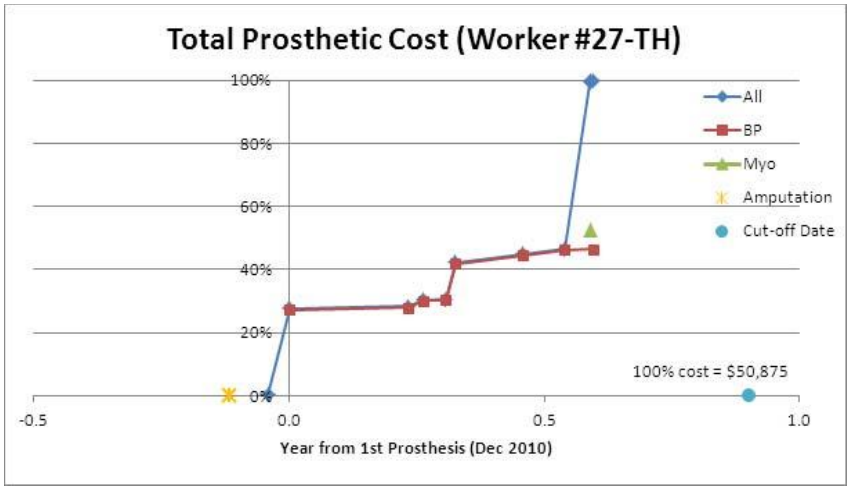


(w)

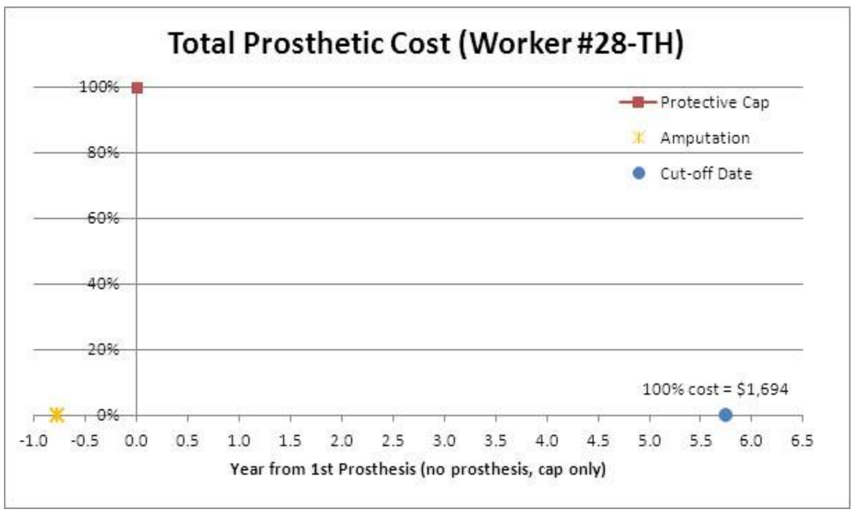


(x)

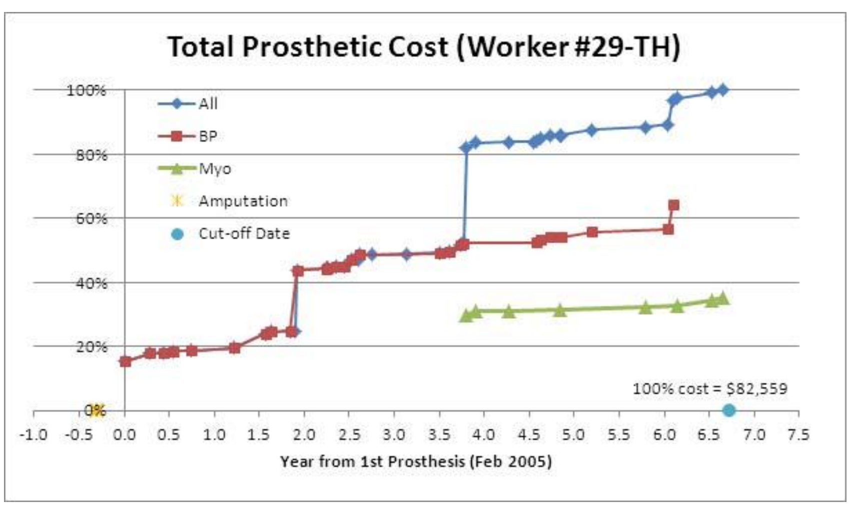
Figure 4.8 (v, w, x) Total Prosthetic Cost –Time Plot



(y)



(z)



(aa)

Figure 4.9 (y, z, aa) Total Prosthetic Cost –Time Plot

Of the cases, 74% (20 out of 27) of the amputees were given prostheses for over three years. Of these 20 amputees, 9 are TH, 10 are TR and 1 is SD. Twelve out of the 20 (60%) have not been using either or both of their prostheses (as there was no service activity for over two years). Table 4.5 shows the data of these 12 potential prosthetic abandoned cases. From the table, 4 out of 20 (20%) amputees (#6, #16, #21 and #24) have stopped using all prostheses. Among them, 3 out of 4 (75%) are TH amputees and 1 (25%) is a TR amputee. The percentage of TH amputees who stopped using all prostheses is 33% (3 out of 9) and the same figure for TR amputees is 10% (1 out of 10). Of the 12 who have abandoned their first prosthesis, 8 (67% out of 12) were BP prosthesis and 4 (33%) were Myo prosthesis.

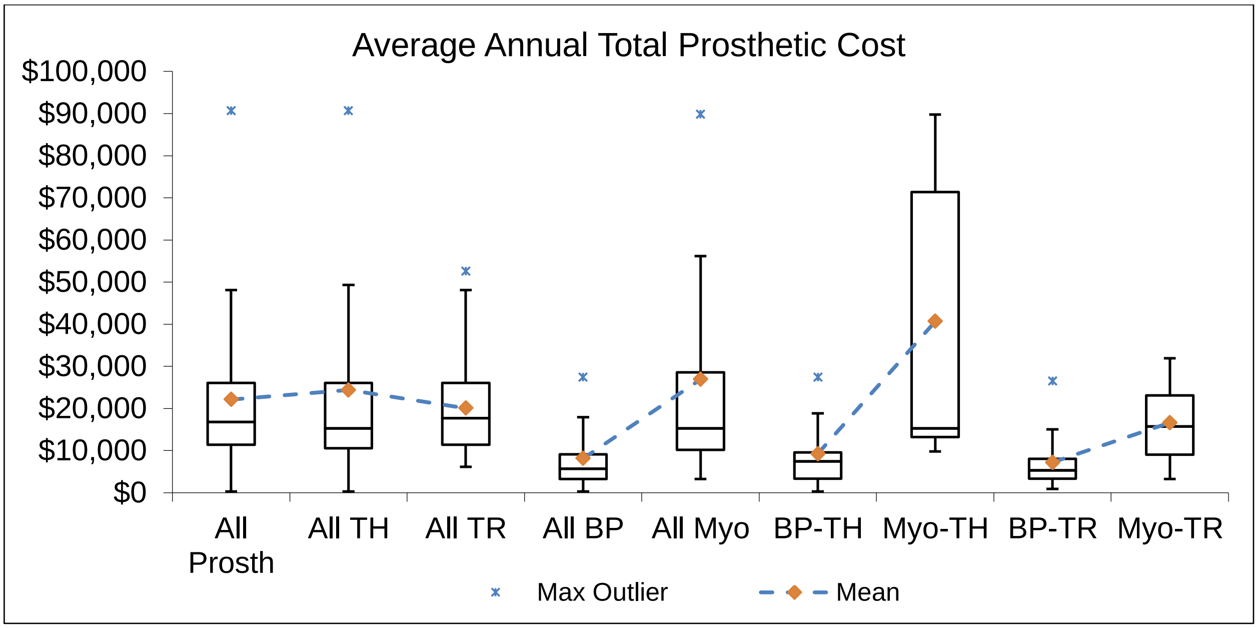
Table 4.5 Cases of Abandoned Prostheses

ID	Type	Initial Prosth	Overall Prosth Cost	1st Aban. Prosth	Year of no service	% of prosth cost	Potential cost saving	BP Util. Level	Myo Util. Level	Aban. All Prosth
6	TR	BP	$71,929	BP	2.7	43%	$30,929	5	4	y
21	***TH***	***BP***	***$11,933***	***BP***	***4.4***	***100%***	***$11,933***	***1***	***n/a***	***y***
10	TH	BP	$99,148	BP	4.4	43%	$42,634	5	5	
23	TR	BP	$45,328	BP	2.3	15%	$6,799	4	3	
4	***TH***	***BP***	***$75,250***	***BP***	***4.3***	***21%***	***$15,803***	***2***	***2***	
14	***TR***	***BP***	***$94,841***	***BP***	***3.3***	***18%***	***$17,071***	***1***	***5***	
12	***SD***	***BP***	***$94,559***	***BP***	***4.4***	***7%***	***$6,619***	***2***	***5***	
17	TR	Myo	$179,001	BP	2.4	3%	$5,370	?	4	
16	***TH***	***Myo***	***$72,818***	***Myo***	***3.7***	***88%***	***$64,080***	***1***	***1***	***y***
22	TR	BP	$52,029	Myo	3.7	43%	$22,372	2	5	
24	TH	BP	$73,172	Myo	3.2	71%	$51,952	1	5	y
11	***TR***	***BP***	***$74,048***	***Myo***	***2.9***	***41%***	***$30,360***	***4***	***2***	
Total Potential Cost Saving							**$305,922**			

When considering the costs of these abandoned prostheses, one can see that if these prostheses were not prescribed in the first place, \$305,922 could have been saved. This is an average saving of \$25,493 for each of these 12 amputees. The entries in the "utilization level" columns (columns 9 & 10) in Table 4.5 are obtained from utilization information reported in the amputee case files. When trying to correlate the reported utilization level to prosthetic abandonment, only 6 out of 12 cases (50%) have shown reasonable matching. These cases are highlighted in red (and in italic font) in the table.

The annual cost of owning a prosthesis was estimated by dividing the total prosthetic cost per amputee by the number of possession years of the prosthesis. The prosthetic possession year is calculated by subtracting the initial prescription date from the cut-off date (November 2011). Since the number of possession years varies from about 1 to 7, and the costs incurred in the earlier years were higher than that in the later years (see analysis further down in this chapter), this estimation of the average annual prosthetic cost may not be very accurate. Nonetheless, without a larger sample and more detailed data, this is still a fair indication of the average annual cost of ownership of the prosthesis. As there is only one TC and one SD amputee in the study population, these 2 categories of amputations are excluded from the analysis. Figure 4.16 is the Box Plot of the average annual prosthetic costs of TR and TH prostheses.

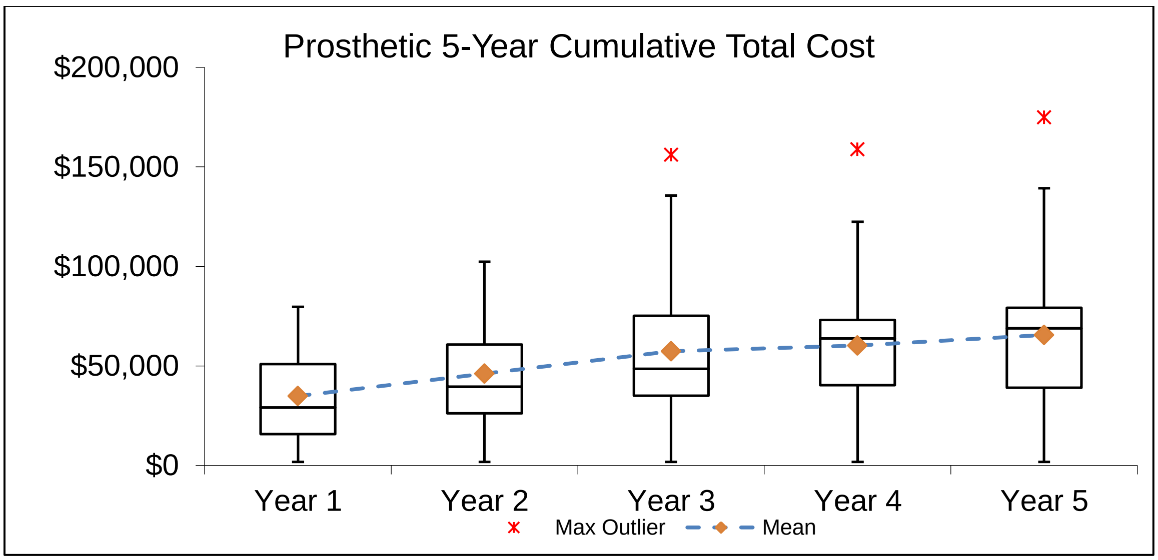
The average annual prosthetic cost per WSBC amputee was \$22,139 ± \$4,071 (mean ± SEM). Although the average annual prosthetic cost for TH prostheses was about 20% higher than TR prostheses, when the standard error of the mean (SEM) is taken into consideration, the difference is indistinguishable. On the other hand, the average annual prosthetic costs of Myo and BP users are \$26,923 ± \$5,687 (mean ± SEM) and \$8,128 ± \$1,595 respectively. When we further segregate the level of amputation, Myo-TH (\$40,674 ± \$11,542) and Myo-TR (\$16,609 ± \$2,773) prostheses cost more than BP-TH (\$9,247 ± \$2,777) and BP-TR (\$7,182 ± \$1,845) prostheses. These differences are statistically significant (t-test, $p < 0.05$).



	All Prosth	All TH	All TR	All BP	All Myo	BP-TH	Myo-TH	BP-TR	Myo-TR
Min	295	295	6168	295	3263	295	9783	927	3263
Max	90661	90661	52556	27388	89779	27388	89779	26481	31889
Median	16817	15295	17691	5721	15267	7420	15259	5287	15720
Mean	22139	24367	20082	8128	26923	9247	40674	7182	16609
SD	20357	26617	13033	7815	26063	9211	34626	6651	9607
SEM	4071	7684	3615	1595	5687	2777	11542	1845	2773
n	25	12	13	24	21	11	9	13	12

Figure 4.16 Average Annual Cost of Prosthesis

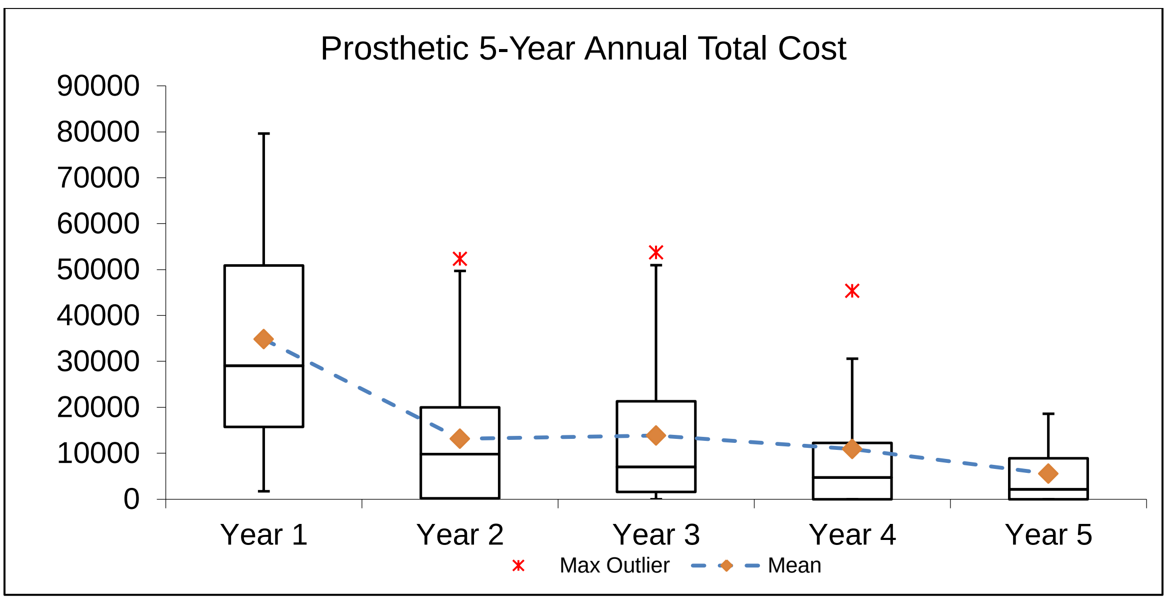
To provide a better picture of the prosthetic cost distribution with time, the cumulative total prosthetic cost for the first five years is plotted in Figure 4.16. Five year is generally considered to be the average life span of a myoelectric prosthesis. The analysis shows the average 5-year prosthetic cost-of-ownership is \$65,522 ± \$10,751 (mean ± SEM). From the graph in Figure 4.16, it is noted that 53% of the cumulative 5-year prosthetic cost was spent in the first year (Year 1 mean = \$34,212). As the amputation dates of the workers in the study population span from 2004 to 2010 and the cut of date is in November 2011, the number of amputees (n) in the table decreases from 25 in year one to 16 in year five. In another word, only 16 amputees in this study group are in possession of a prosthesis for over five years.



	Year 1	Year 2	Year 3	Year 4	Year 5
Min	1694	1694	1694	1694	1694
Max	79659	102347	156084	158866	174900
Median	29083	39564	48449	63860	68919
Mean	34840	46081	57319	60211	65522
SD	22204	29151	39978	36529	43002
SEM	4441	6215	8939	8860	10751
n	25	22	20	17	16
Mean/Yr5 Mean	53%	70%	87%	92%	100%

Figure 4.17 5-Year Cumulative Total Prosthetic Cost

By subtracting the cost of year i from that of year (i – 1), the above cumulative total prosthetic cost data was re-compiled to produce the annual total prosthetic cost. This data are then plotted in Figure 4.18. As shown the Box Plot, the average first year cost was substantially higher than the annual costs of the remaining years. For example, the first year cost ($34,840) is 66% more than the second year cost ($13,121), and is 53% of the total cumulative 5-year cost ($65,522). The differences between the average first year cost and those in the subsequent years are found to be statistically significant ($p < 0.01$).

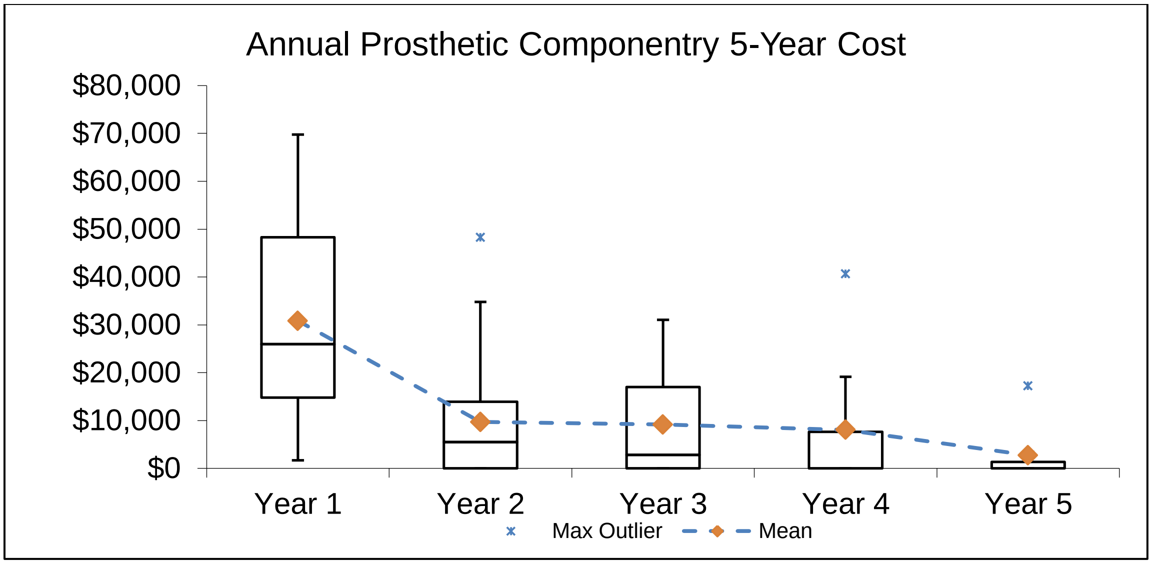


	Year 1	Year 2	Year 3	Year 4	Year 5
Min	1694	0	0	0	0
Max	79659	52294	53737	45373	18613
Median	29083	9815	6984	4681	2122
Mean	34840	13121	13847	10885	5539
SD	22204	14392	16421	15189	7085
SEM	4441	3068	3672	3684	1771
n	25	22	20	17	16

Figure 4.18 5-Year Annual Total Prosthetic Cost

The annual total prosthetic cost was broken down into the cost of the prosthetic componentry and the cost of operation. Prosthetic componentry cost includes the initial prescription cost and all subsequent purchases of prosthetic components. Operation cost encompasses the remaining costs which include all re-fitting, maintenance, repairs, and prosthetic supplies. The following two plots (Figure 4.19 and 20) represent the distribution of the prosthetic componentry and operation costs.

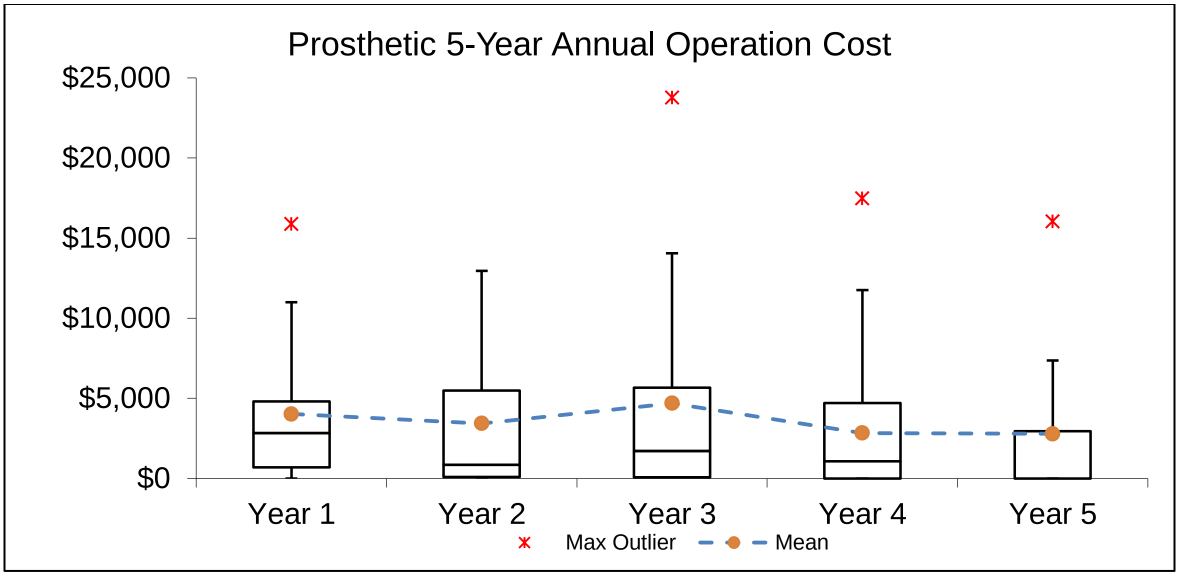
The average cost of the prosthetic componentry in year 1 was \$30,816 ± \$3,966 (Figure 4.19). It accounted for about 57% of the average cumulative 5-year prosthetic componentry costs (\$60,459) and is over 3 times of the subsequent annual costs. The differences between the first year cost and each of the remaining four years are statistically significant ($p < 0.01$). However, the year-to-year differences from year 2 to 5 are not.



	Year 1	Year 2	Year 3	Year 4	Year 5
Min	1694	0	0	0	0
Max	69734	48296	31047	40628	17240
Median	25936	5525	2827	0	0
Mean	30816	9692	9153	8046	2752
SD	19832	13007	11959	13324	5595
SEM	3966	2773	2674	3231	1399
n	25	22	20	17	16

Figure 4.19 5-Year Annual Prosthetic Componentry Cost

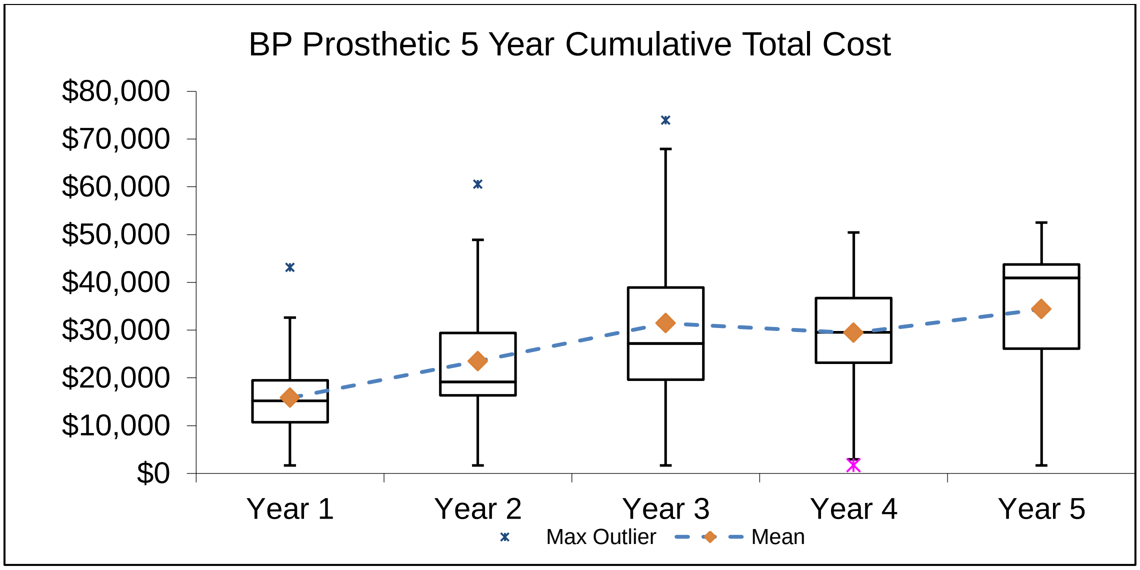
Figure 4.20 shows the annual prosthetic operating cost which is the total prosthetic cost minus the cost of prosthetic componentry. The graph shows that the mean annual operating cost is relatively steady over the years with an average of $3,555 and fluctuates between $2,788 and $4,694 (−22% and +32%). It is also noted that the median costs are less than the mean costs.



	Year 1	Year 2	Year 3	Year 4	Year 5
Min	0	0	0	0	0
Max	15888	12963	23767	17488	16034
Median	2603	842	1125	314	0
Mean	4024	3429	4694	2838	2788
SD	4676	4703	6791	4406	4766
SEM	935	1003	1518	1069	1192
n	25	22	20	17	16

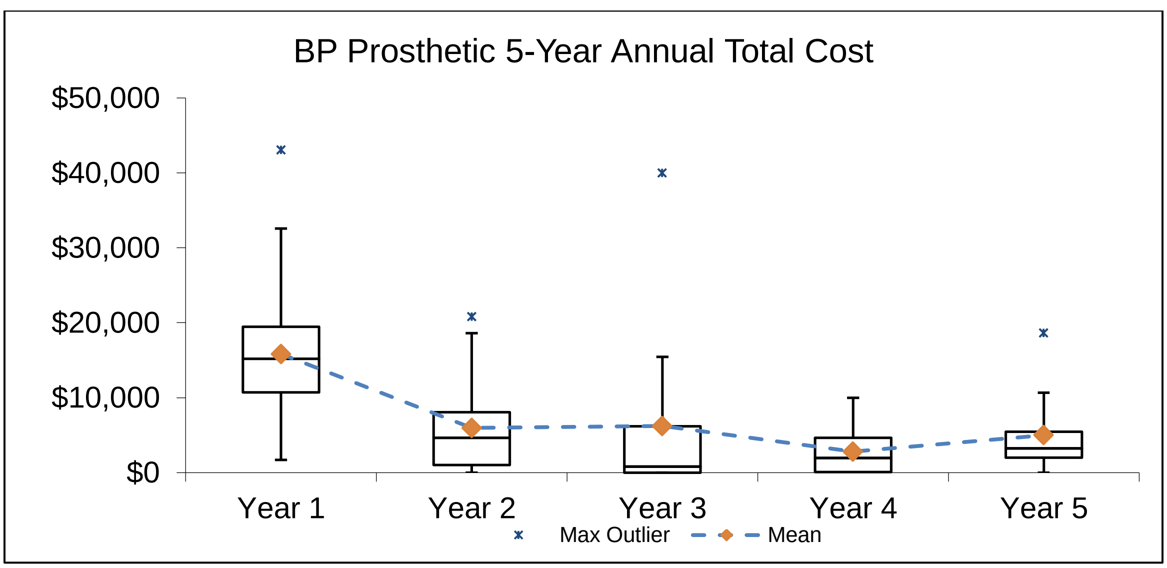
Figure 4.20 5-Year Annual Prosthetic Operating Cost

To study the differences between the types of prostheses, the following cost plots separate the prostheses into their BP and Myo groups. Figures 4.21, 4.22, 4.23, and 4.24 show the cumulative total cost, annual total cost, componentry cost, and operating cost respectively, for BP prostheses. When studying the BP and Myo graphs, one should understand that year one is the year when the prosthesis was first provided to the amputee. Therefore, even when a BP prosthesis was provided 3 years after the first Myo prosthesis, the initial prescription cost of the BP prosthesis is accounted for in year one in the BP cost plots.



	Year 1	Year 2	Year 3	Year 4	Year 5
Min	1694	1694	1694	1694	1694
Max	43088	60519	73916	50460	52536
Median	15198	19182	27184	29560	40920
Mean	15818	23481	31440	29411	34361
SD	9474	12745	19595	13404	16262
SEM	1934	2924	5059	4239	5750
n	24	19	15	10	8
%	46%	68%	91%	86%	100%

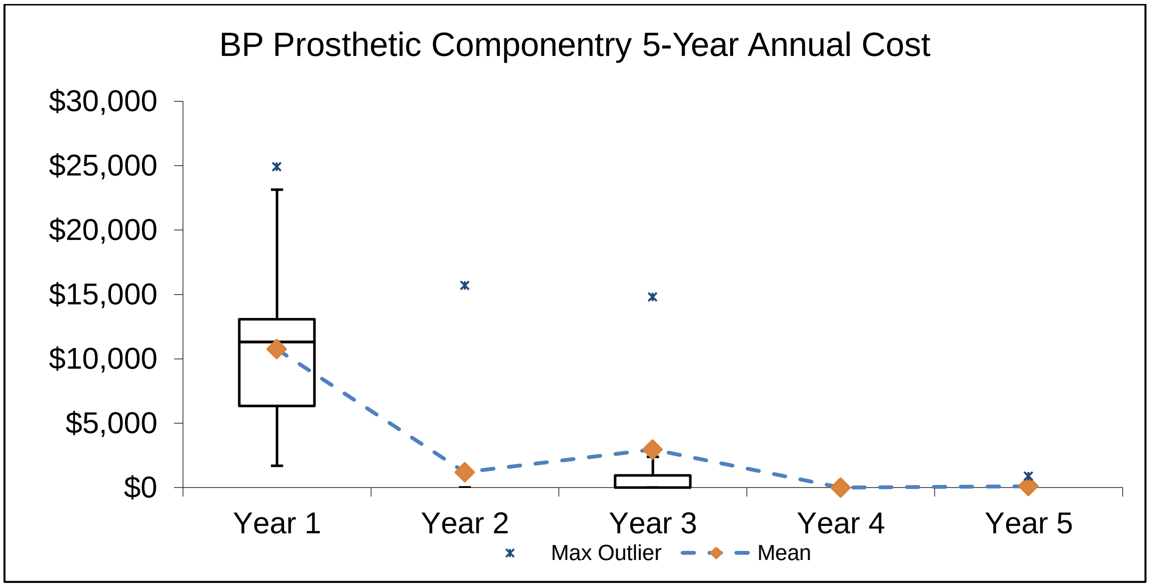
Figure 4.21 5-Year Cumulative Total Cost - BP Prosthetic



	Year 1	Year 2	Year 3	Year 4	Year 5
Min	1694	0	0	0	0
Max	43088	20807	39985	9966	18613
Median	15198	4621	809	1963	3248
Mean	15818	5949	6204	2793	4988
SD	9474	6035	10723	3249	5836
SEM	1934	1384	2769	1028	2063
n	24	19	15	10	8

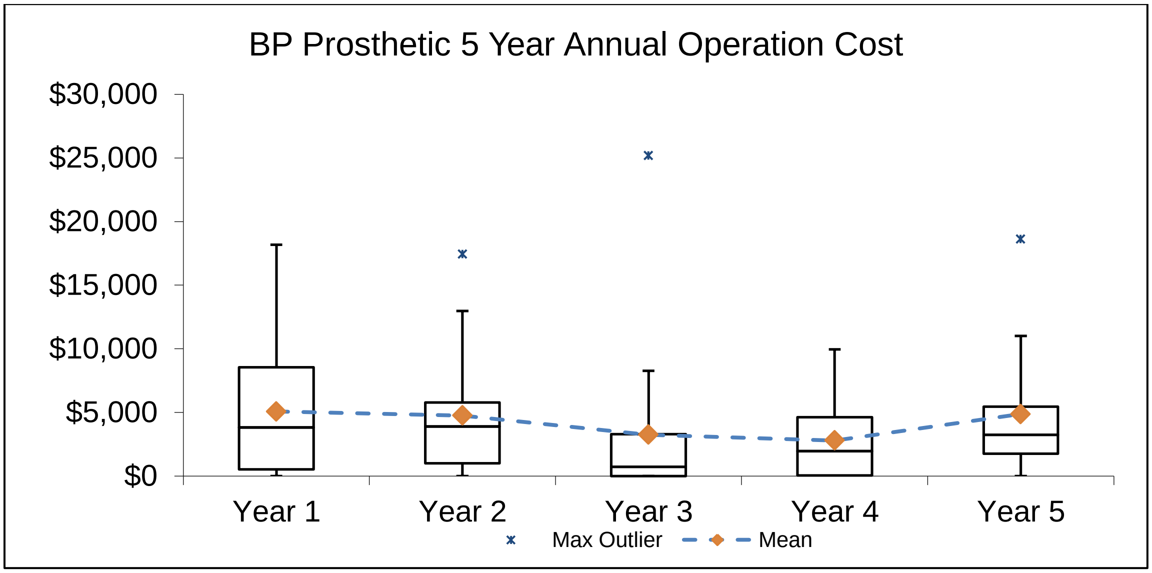
Figure 4.22 5-Year Annual Total Cost - BP Prostheses

It is noted that the trends of these plot are similar to those in Figures 4.17 and 4.18. In the BP group, 46% of the cumulative 5-year cost was spent in the first year. The average first year total annual cost is substantially higher than those of the remaining years.



	Year 1	Year 2	Year 3	Year 4	Year 5
Min	1694	0	0	0	0
Max	24909	15709	14800	0	898
Median	11319	0	0	0	0
Mean	10746	1189	2955	0	112
SD	5822	3771	5806	0	317
SEM	1188	865	1499	0	112
n	24	19	15	10	8

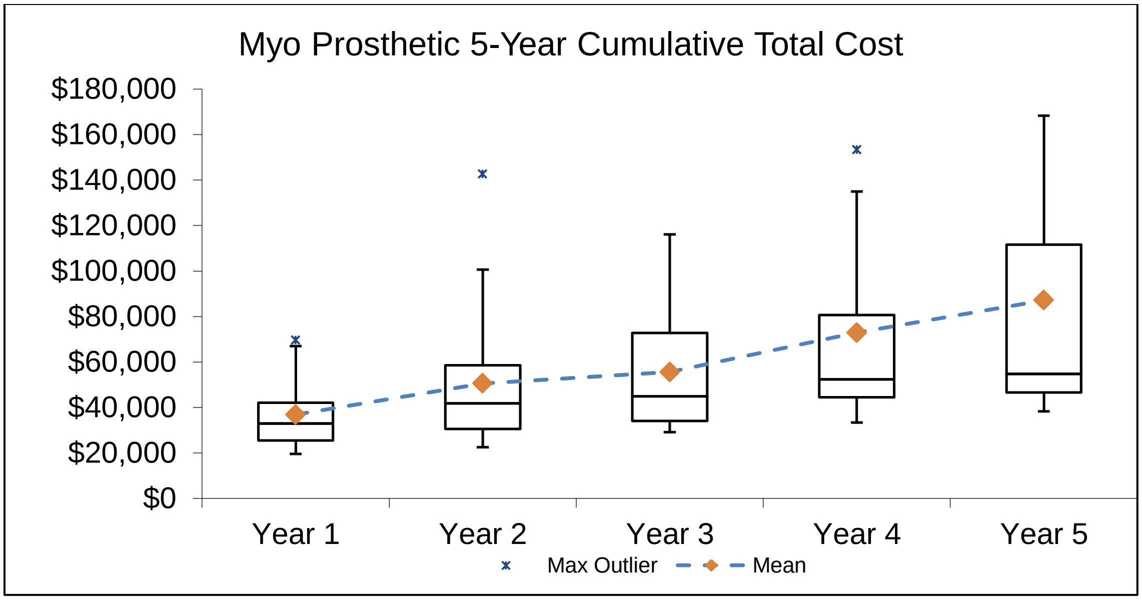
Figure 4.23 5-Year Annual Componentry Cost – BP Prostheses



	Year 1	Year 2	Year 3	Year 4	Year 5
Min	0	0	0	0	0
Max	18179	17431	25185	9966	18613
Median	3816	3903	720	1963	3248
Mean	5072	4760	3249	2793	4876
SD	5047	4818	6130	3196	5768
SEM	1030	1105	1583	1011	2039
n	24	19	15	10	8

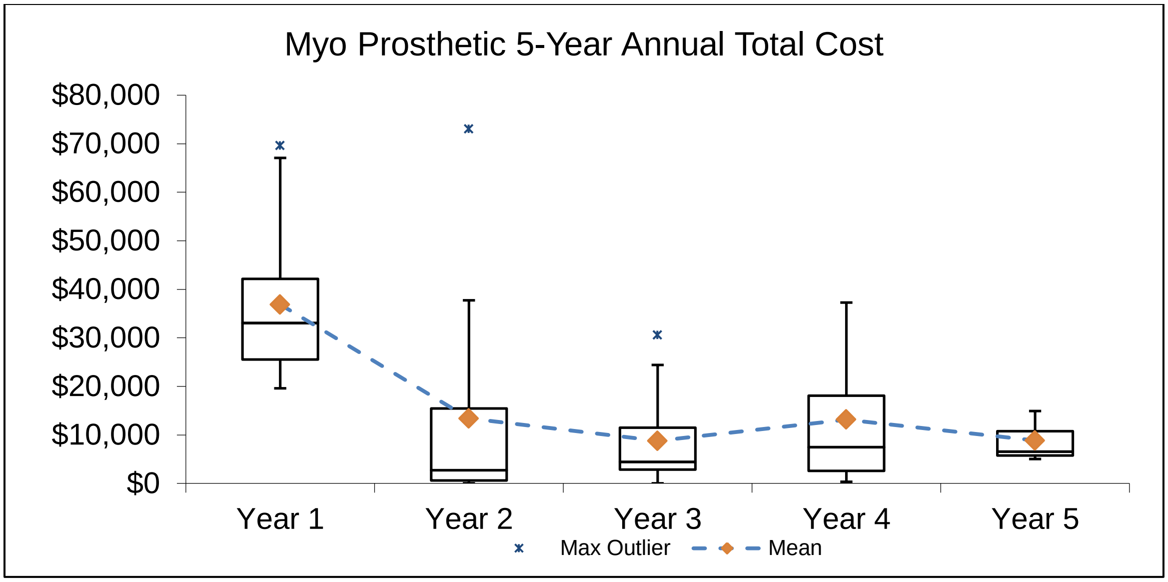
Figure 4.24 5-Year Annual Operating Cost - BP Prostheses

Figure 4.23 shows that majority of the BP prosthetic components was purchased in the first year. The mean annual operating costs (Figure 4.24) were steady over the 5-year span. Figures 4.25, 4.26, 4.27, and 4.28 show the cumulative total cost, annual total cost, componentry cost, and operating cost, respectively for Myo prostheses.



	Year 1	Year 2	Year 3	Year 4	Year 5
Min	19594	22530	29154	33328	38332
Max	69621	142663	116114	153393	168323
Median	33025	41839	44889	52374	54836
Mean	36851	50612	55590	72867	87164
SD	14993	32493	28020	54533	70769
SEM	3272	8390	8861	27266	40858
n	21	15	10	4	3
%	42%	58%	64%	84%	100%

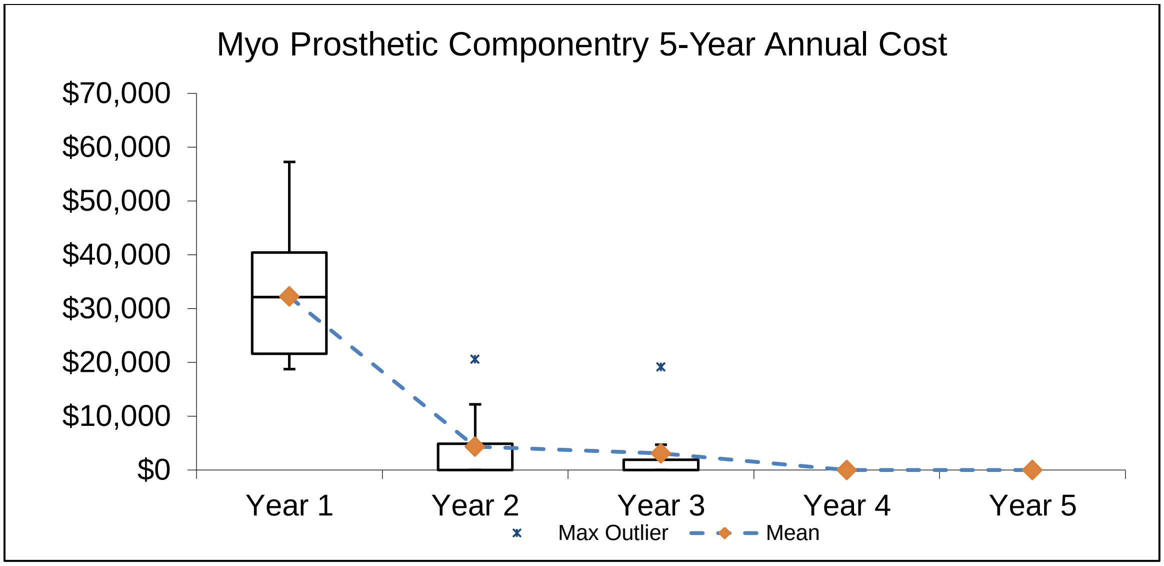
Figure 4.25 5-Year Cumulative Total Cost - Myo Prostheses



	Year 1	Year 2	Year 3	Year 4	Year 5
Min	19594	0	0	378	5004
Max	69621	73042	30595	37279	14930
Median	33025	2722	4456	7485	6566
Mean	36851	13391	8763	13157	8833
SD	14993	20800	9590	16777	5337
SEM	3272	5371	3033	8388	3082
n	21	15	10	4	3

Figure 4.26 5-Year Annual Total Cost - Myo Prostheses

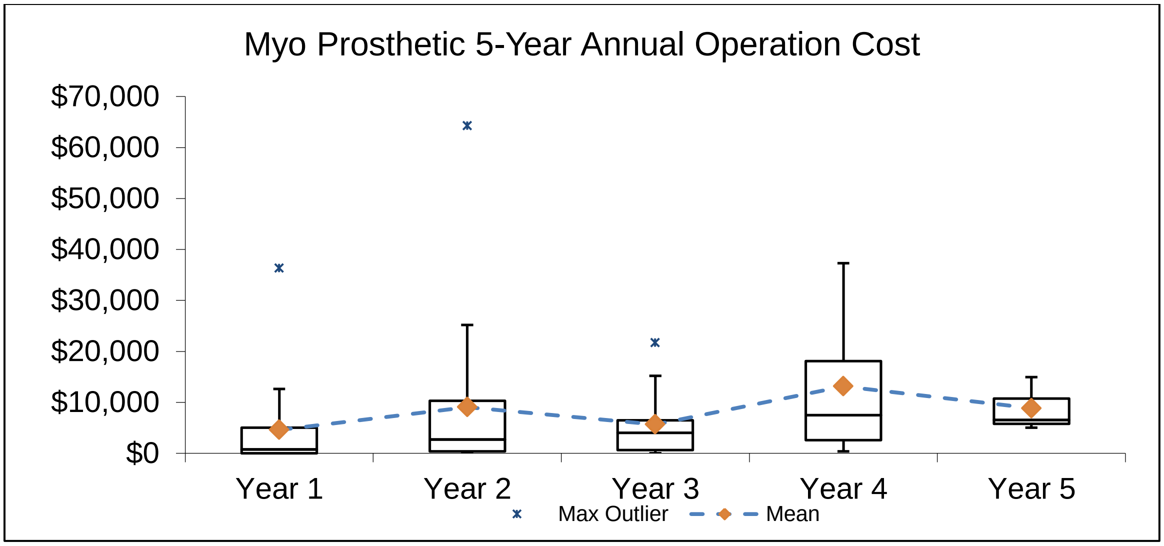
Again, the trends of these plot are similar to those in Figures 4.17, 4.18, 4.21, and 4.22 as well as in the BP group. In the Myo group, 42% of the cumulative 5-year cost was spent in the first year. The average first year total annual cost is substantially higher than those of the remaining years. The average cumulative 5-year prosthetic cost for Myo prostheses ($87,164) is 54% higher than the cost of BP prostheses ($34,361).



	Year 1	Year 2	Year 3	Year 4	Year 5
Min	18765	0	0	0	0
Max	57260	20575	19136	0	0
Median	32148	0	0	0	0
Mean	32233	4324	3095	0	0
SD	11246	7668	6279	0	0
SEM	2454	1980	1986	0	0
n	21	15	10	4	3

Figure 4.27 5-Year Annual Componentry Cost - Myo Prostheses

Similar to the BP cases, Figure 4.27 shows that majority of the Myo prosthetic components were purchased in the first year. The average first year componentry cost of Myo prostheses ($32,233) is 3 times that of BP prostheses ($10,746).



	Year 1	Year 2	Year 3	Year 4	Year 5
Min	0	0	0	378	5004
Max	36353	64255	21721	37279	14930
Median	746	2722	4060	7485	6566
Mean	4618	9067	5667	13157	8833
SD	9114	16440	6890	16777	5337
SEM	1989	4245	2179	8388	3082
n	21	15	10	4	3

Figure 4.28 5-Year Annual Operating Cost - Myo Prostheses

The mean annual operating costs (Figure 4.28) are steady but with a minor upward trend over the 5-year span. This upward trend over the 5-year span is more obvious with the median values. Comparing to the same parameter for BP prostheses (Figure 4.25), it may indicate that Myo prostheses are not as durable or reliable as BP prostheses.

The average annual total prosthetic cost, the average annual prosthetic componentry cost, and the average annual prosthetic operating cost for the different types of prostheses are compared in Figures 4.29, 4.30, and 4.31 respectively.

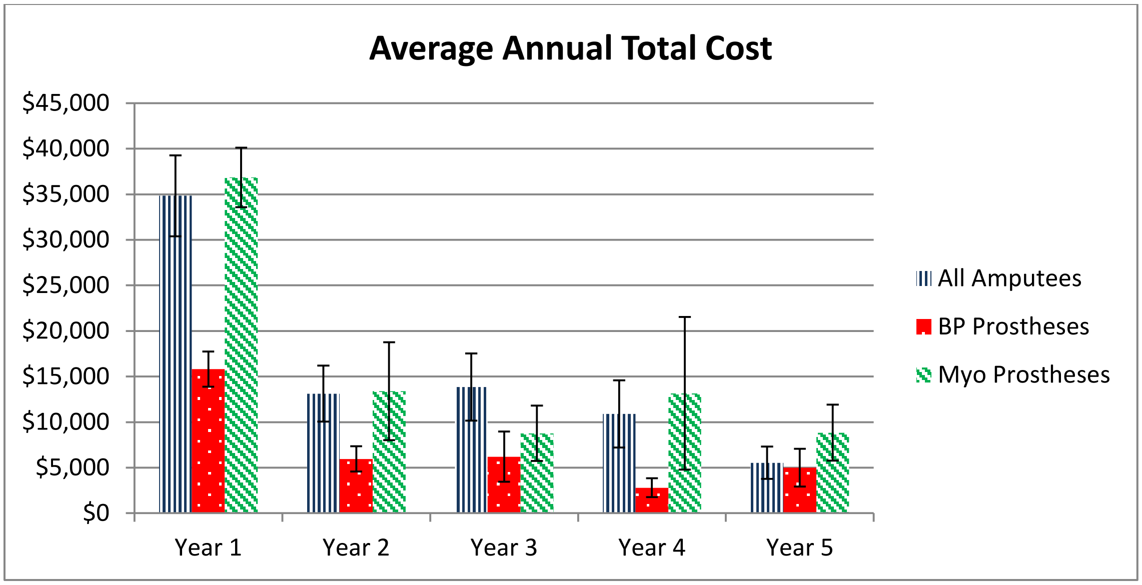


Figure 4.29 Average Annual Total Prosthetic Cost

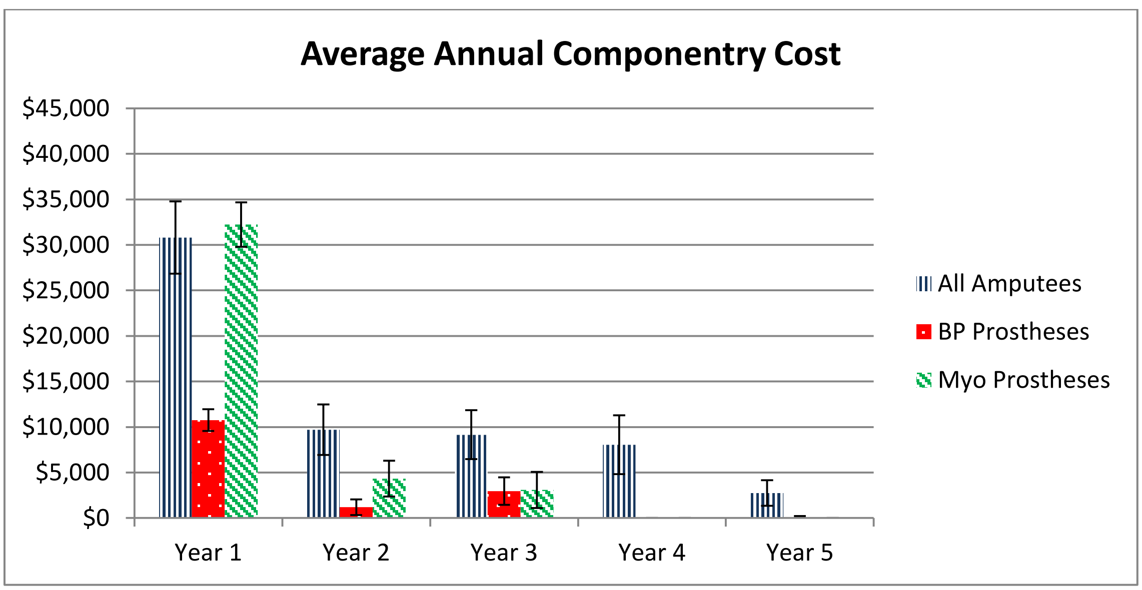


Figure 4.30 Average Annual Prosthetic Componentry Cost

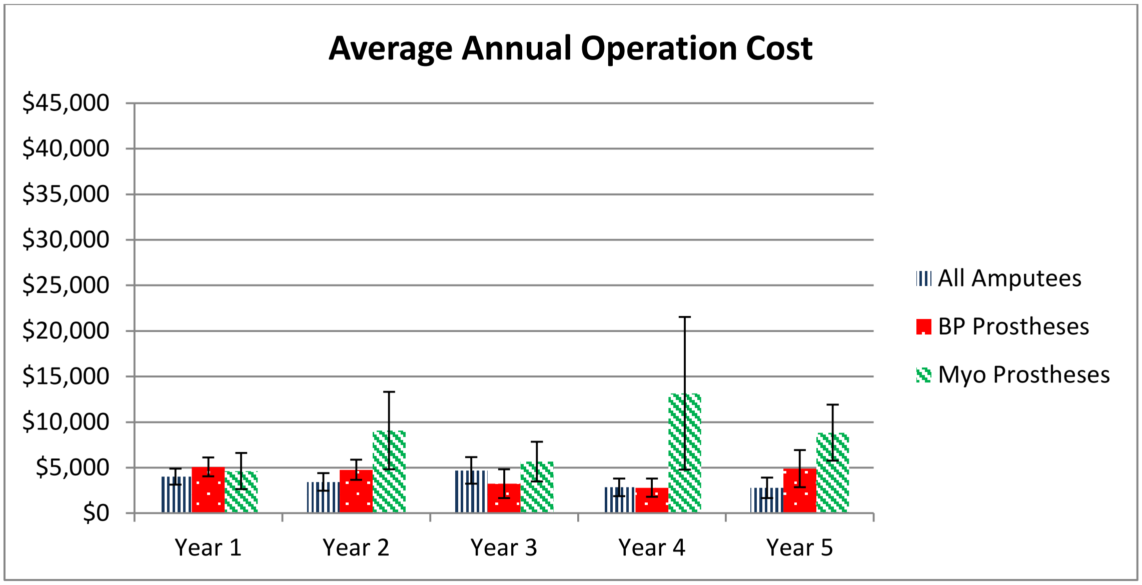


Figure 4.31 Average Annual Prosthetic Operating Cost

The above bar graphs clearly show that, among this group of amputees, the 5-year life-cycle costs including the componentry and operating costs is much higher for myoelectric (Myo) prostheses than that of body-powered (BP) prostheses.

4.6 Summary of Key Findings

Difficulties were encountered when trying to extract information from the amputee worker case files (see Section 4.4 in this chapter). These documents include reports submitted by different organizations and professionals. Tracking amputee progress, compiling life-cycle cost information, and assessing levels of prosthetic utilization would have been much easier if the documentation system was designed for progress monitoring and outcome review, and was consistently followed.

Listed below are summary of findings from the analysis of the upper limb amputee case files supplied by WSBC. They are grouped under 3 sub-headings.

4.6.1 Worker's Profile and Prosthetic Characteristics

- Between 2004 and 2010, there were 28 workers who lost their upper limbs from work injuries; 21% are female and 79% are male; there are 50% workers with transradial amputation, 43% with trans-humeral amputation, the remaining are trans-carpal and shoulder disarticulation.
- 82% of the amputees received both body-powered and externally-powered prostheses; 8% has only body-powered prostheses; 4% has only externally-powered prostheses; and 4% without any prosthesis.
- 79% were first given body-powered prostheses; 14% were provided first with externally-powered prostheses. On average, a BP prosthesis was provided six months after amputation and a Myo prosthesis was provided twelve months after the provision of a BP prosthesis. This time sequence is in line with the WSBC practice (learned from discussions with WSBC case managers). In general, an amputee will first be fitted with a BP prosthesis and a Myo prosthesis will be provided after twelve months of observation and evaluation.

4.6.2 Prosthetic Utilization and Reliability

- Almost all workers (96%) who lost their upper limbs were working in laborer-type of work before their injuries. Of all the TH and TR amputees, 40% did not return to work. About half of those who returned to work have switched to light-duty or office-type work.

- Wearing a Myo or BP prosthesis has no influence on whether or not the amputee will return to work; and does not affect the type of jobs that the amputee will return to.
- There are more TH amputees than TR amputees who are not working are amputation. Those who have returned to heavy duty work (laborer-type) tend to be TR amputees. This is understandable as labor-intensive work demands higher strength and a wider range of motion of the upper limbs; a TR amputee often suffers from these limitations.
- In terms of prosthetic utilization, TR amputees use their prostheses more frequently than TH amputees. This make sense as TH amputees have less functional capability and, hence, tend to use their prostheses less for functional activities. Workers who lost their dominant limb use their prostheses more than those who lost their non-dominant limb. Male amputees tend to have higher usage of prostheses than female. From the case file history, it was not able to establish correlation between prosthetic utilization level and factors such as age of worker, time between amputation and first prosthesis, frequency and cost of repairs.
- Among the group of amputees who have been given prostheses for over three years, 60% of them have not been using one or both of their prostheses, 20% have stopped using all prostheses. This high prosthetic abandonment rate finding agrees with the result from a questionnaire survey conducted with a similar group of subjects [Silcox, 1993]. From Table 4.5, over $300,000 was spent on these abandoned devices. This represents an average saving of $25,493 for each

amputee. The percentage of TH amputees who stopped using all prostheses is 33% and the same figure for TR amputees is 10%.

- A BP prosthesis requires 1.67 ± 0.20 (mean ± SEM) times of demand maintenance (repair, adjustment, and replacement) per year and a Myo prosthesis requires 1.70 ± 0.34 times of demand maintenance per year.
- The repair frequencies of BP prostheses and Myo prostheses are about the same with a mean-time-between-failures (MTBF) of about one year. For TR amputees, Myo prostheses require twice as many repairs as BP prostheses do; whereas, for TH amputees, the repair requirements are reversed; this may indicate workers fitted with TH-Myo prostheses were using less of their prostheses than those who were fitted with TH-BP prostheses. It is also noted that the frequency of repair for TR-Myo prostheses is three times over that of TH-Myo prostheses.
- The average annual repair cost of a TR prosthesis ($2,768) is twice that of a TH prosthesis ($1,364). They are about the same for Myo and BP prostheses ($1,133 and $1,202 respectively).
- TH prostheses need more adjustments than TR prostheses. TH-BP prostheses need the most adjustments among all prostheses. TR prosthetic users wear out more liners and gloves than TH prosthetic users.
- TR prosthetic users show a much higher accessroy replacement frequency than TH users (1.10 versus 0.37 times per year).
- The average frequency of demand maintenance of a BP prosthesis is similar to a Myo prosthesis (about 1.7 times per year). The average demand maintenance

frequency of TR-Myo prostheses is about three times that of the TH-Myo prostheses (2.27 versus 0.69 times per year).

4.6.3 Cost of Ownership

- For the entire study population, the average annual total prosthetic cost per WSBC amputee is \$22,139 ± \$4,071 (mean ± SEM). The average annual total Myo and BP prosthetic componentry cost per WSBC amputee is \$26,923 ± \$5,687 and \$8,128 ± \$1,595 respectively. When we separate that by level of amputations, Myo-TH (\$40,674 ± \$11,542) and Myo-TR (\$16,609 ± \$2,773) prostheses cost more than BP-TH (\$9,247 ± \$2,777) and BP-TR (\$7,182 ± \$1,845).
- The average 5-year prosthetic cost-of-ownership is \$67,230 ± \$10,291 (mean ± SEM) per amputee. An amount of \$34,840 ± \$4,441 (mean ± SEM) was spent in the first year which is 53% of the total prosthetic cost. The average 5-year cost-of-ownership of a Myo prosthesis is about 2.5 times that of a BP prosthesis. A study reported that the 5-year projected average cost of US veteran amputees with unilateral upper limb amputation was \$117,440 [Blough, 2010]. One possible reason for this reported higher cost is that every US veteran amputee from the Gulf War was automatically provided with all three types of prostheses (cosmetic, BP, and Myo) shortly after amputation.
- The average cost of prosthetic componentry (initial prostheses and other new components) in the first year after amputation is \$30,816 ± \$3,966. This first year cost consumes 56% of the total 5-year componentry cost (\$53,950). The average annual operating cost is relatively steady at about \$3,432 per year. A

similar trend applies when we look at the costs of the BP and Myo prostheses separately.

4.7 Suggestions for Improvement

The following propositions are drawn from the results of the analysis:

- Due to the frequent maintenance and service requirements, it is important for prosthetic users to have quick access to technical support, preferably local services.
- The type of prosthesis (BP or Myo) prescribed has no influence on whether or not an amputee worker will return to work. Instead, the higher the level of amputation (e.g., TH amputation), the less likely the amputee will return to work or engage in laborer type of work.
- About 60% of amputees are not using one (Myo or BP) of the provided prosthesis or have abandoned all prostheses. This creates an opportunity that resources could be saved if appropriate prostheses were provided in the first place. In addition, early provision of the right kind of prostheses could potentially reduce time and frustration of the amputee.
- Myoelectric prostheses are more expensive than body-powered prostheses primarily due to the expensive componentry. The average first year prosthetic componentry cost for Myo prostheses is 3 times that of BP prostheses ($32,333 versus $10,746). The average 5-year total cost of ownership of Myo prostheses is 2.5 times that of BP prostheses yet the analysis shows that BP were preferred by

some amputees over Myo prostheses. There is a need to review and improve the current prosthetic selection process.

- Better documentation by funding agencies and rehabilitation professionals will help in tracking prosthetic outcomes and provide better information for rehabilitation improvement.
- The analysis shows high prosthetic failure (repair) rate (once per year) and high demand maintenance frequency (1.7 times per year). This high maintenance requirement is likely due to the practice of non-standardized individualized fabrication which combines many off-the-shelve components and custom components. Inappropriate use of the prosthesis beyond its designed capability is another contributing factor. Establishing product standards, practice guidelines, and prescription protocols will improve the reliability of the prostheses.

Chapter 5: Risk Assessment

5.1 Introduction

The advancement of prosthetic technology has led to expanded use of prostheses in non-traditional areas such as recreational activities, competitive sports, and demanding employment situations. Such activities and their related environment may create hazardous situations and impose risks on the prosthetic device users as well as others who are in close proximity. There have been anecdotal reported incidents of injuries on amputees wearing upper limb myoelectric prostheses, yet no study was published on assessing risks associated with these devices.

External limb prosthetic components, according to the US Food and Drug Administration (FDA) Code of Federal Regulations Title 21, are classified as Class I medical devices under “physical medicine devices” [US FDA 21CFR890.3420, 2011] and, therefore, are not subjected to the rigorous review processes required for medical devices in higher classifications, performing hazard analysis during prosthetic product development and its documentation are, therefore, not required. Although some manufacturers included hazard analysis in their development process, they are not required to disclose such information. In prosthetic practice, upper limb prostheses are custom designed and fabricated for individual amputees. The prosthetic components supplied by manufacturers are only part of the entire prosthesis and may be from different manufacturers. An upper limb transradial myoelectric prosthesis, for example, consists of a custom-fabricated socket that fits on to the residual limb of the amputee with a myoelectric hand attached to the socket. The socket is designed to hold the myoelectric electrodes, control electronics and batteries, as well as to replace the missing arm and provide support for the prosthetic hand. In addition, depending on the activities of the amputees, prosthetic devices may be used in unconventional applications which are not foreseeable by their manufacturers. There is currently no risk management standard specific to upper limb prostheses. Hazard analysis is not a common consideration in prosthetic prescription or in prosthetic education and training.

In the medical devices industry, risk management is an important process in medical device development. The Standard ISO 14971:2007(E) - Application of Risk Management to Medical Devices is the worldwide adopted risk management standard for medical device developers. This chapter applies ISO 14971:2007(E) to formulate a process of risk management for upper limb myoelectric prostheses from the users and caregivers perspectives within the scope of functional activities and employment needs.

5.2 Risk Assessment Process

The elements of risk assessment adopted from the Standard ISO 14971:2007(E) are summarized below. The references in brackets refer to the clauses or sub-clauses in the above-mentioned Standard. The remainder of this section describes the process.

1. <u>Risk Analysis</u> *(4.0)*
    - 1.1. Determine intended use and reasonably foreseeable misuse *(4.2)*
    - 1.2. Identify characteristics related to safety *(4.2)*
    - 1.3. Identify hazards (potential sources of harm) *(4.3)*
    - 1.4. Estimate risks (probability of occurrence of harm and severity of that harm) for each hazardous situation *(4.4)*

2. Risk Evaluation *(5.0)*

    2.1. Determine risk criteria and the acceptability of risk

    2.2. Assign values to risks (risk index)

    2.3. Compare estimated risks to the risk criterion for each hazardous situation

    2.4. Identify unacceptable risks

3. Risk Control *(6.0)*

    3.1. Determine available risk control options *(6.2)*

    3.2. Evaluate risk control options *(6.2)*

    3.3. Implement or propose risk control measures *(6.3)*

    3.4. Perform residual risk evaluation *(6.4)*

    3.5. Analyze and evaluate risks arising from control measures *(6.6)*

4. Evaluation of Residual Risk *(7.0)*

    4.1. Perform risk-benefit analysis

5. Documentation *(8.0)*

5.3 Risk Analysis

Analysis of risk starts at determining the intended use of the device. For all amputees, the prostheses are prescribed to assist them to perform basic activities of daily living (ADLs) including activities such as donning/doffing of prosthesis, grooming, or eating, and various levels of instrumental ADLs such as housekeeping or driving a vehicle [Roley, 2008].

The first step to identify characteristics related to safety is to review the intended use of the prosthetic device published by the manufacturer. The manufacturer often publishes the device's applications, conditions of use, safety precautions and may list activities that are counter indicated. However, this labeling may be too general or non-specific. Figure 5-1 is an example of an "Intended Use" statement quoted from the instruction manual of an electric arm (Otto Bock Dynamic Arm User Manual, Otto Bock (647G152-04-1006). In the first bullet, it stated that the device should not be subjected to intense smoke, dust, mechanical vibration, shocks or high temperatures but does provide clear definitions of these stated conditions.

For an amputee who is returning to work or going to participate in recreational activities, identifying intended use and foreseeable misuse of the prosthesis must include these functional requirements. It is especially important to recognize the environmental conditions under which these activities are being performed. For example, water resistant prosthetic components are required if an activity is intended to be performed in an outdoor environment.

Patient Information

- *The DynamicArm® should not be subjected to intense smoke, dust, mechanical vibrations, shocks or high temperatures.*
- *Do not allow debris or liquids to get into the DynamicArm®.*
- *Avoid staying near high-tension power lines, transmitters, transformers or other sources of strong electromagnetic radiation (such as security systems for goods in department stores), as this can lead to malfunction of the DynamicArm®.*
- *In case of malfunction as well as when turned off, the DynamicArm® can be locked and unlocked by means of a mechanical cable control. Particular caution is required when unlocking the DynamicArm® while lifting heavy loads! Manual unlocking of the DynamicArm® while bearing a load should take place with great caution only, since there is a risk of injury to the patient.*
- *The DynamicArm® has been developed for everyday use and must not be used for unusual activities such as extreme sports (free climbing, paragliding, etc.). Careful handling of the prosthesis and its components not only increases their service life but, above all, ensures the patient's personal safety! Should the prosthesis be subjected to unusual stresses (such as a fall), immediately contact your prosthetist and have the prosthesis inspected for any damage. If necessary, the responsible prosthetist will pass the prosthesis on to the Otto Bock Myo-Service.*
- *Pay attention to the fact that fast lifting of objects entails a risk of injury.*
- *The DynamicArm® and DynamicArm® components may be opened or repaired only by certifed Otto Bock Myo-Service technicians.*
- *Do not use or wear the prosthesis during the charging process.*
- *Follow the recommended service intervals.*
- *Check the DynamicArm® for any visible damage before every use.*

Driving a Vehicle

- *An upper extremity amputee's ability to drive a vehicle is determined on a case-by-case basis. Factors include the type of fitting (amputation level, unilateral or bilateral, residual limb conditions, design of the prosthesis) and the amputee's abilities. All persons are required to observe their country's national and state driving laws when operating vehicles. For insurance purposes, drivers should have their driving ability examined and approved by an authorized test centre. For maximum safety and convenience, Otto Bock recommends that, at the very least, a specialist evaluate the need for any adaptations to the car (such as by installing a steering fork). It is indispensable to ensure that the driver is able to operate the vehicle without any risk with the DynamicArm® turned off. Driving with the DynamicArm® turned ON may present a risk if the DynamicArm® inadvertently moves due to unintentional muscle contraction or other causes.*
- *Attention: Before an arm prosthesis with a quick-disconnect mechanism can be used to drive a vehicle, the System Electric Hand or System Electric Greifer must be positioned in such a way that a slight turn of the Hand or Greifer, which can occur during steering, cannot disconnect the Hand or Greifer from the prosthesis!*

Service Information

- *Since all moving mechanical parts are subject to some wear and tear, yearly service check-ups are required.*
- *During the service visit, the entire DynamicArm® will be inspected by Otto Bock Myo-Service and any necessary adjustments or replacements of worn parts will be performed.*

(source: Otto Bock Dynamic Arm User Manual, Otto Bock · 647G152-04-1006)

Figure 5.1 Device Intended Use Statement

In addition to the manufacturer's published safety precautions, efforts should be made to understand known use hazards. There is currently no publication on known prosthetic use hazards. Such knowledge was accrued when caregivers or service providers (such occupational therapists) spoke to or treated prosthetic users who encountered adverse incidents. To collect examples of these adverse incidents related to upper limb prosthetic use, a questionnaire was created and sent to the Upper Limb Prosthetic Outcome Measures (ULPOM) Group in October 2010 to solicit responses. The ULPOM Group was formed in 2008 by a group of professionals who are interested in creating a common set of outcome measurement tools for upper limb prosthetic users. The Group uses "Google Group" as the primary online communication platform. Over one hundred members including physiotherapists, occupational therapists, prosthetists, biomedical engineers, and researchers from North America and Europe subscribed to the Google Group. According to the ULPOM Group founders "the Upper Limb Prosthetic Outcome Measures (ULPOM) group was created for increased communication among health care professionals in the field of upper limb prosthetics. The main goal is to establish a Golden Standard of outcome measures for upper limb prosthetics" [Hills, 2008]. The survey request with the questionnaire is shown in Appendix C. A reminder of the request was sent after two weeks of the first request. An example of a completed questionnaire is shown in Figure 5-2. Eight responses containing 7 incidents were received. The survey responses are tabulated in Appendix D. The reported incidents and their causes of injuries are listed in Table 5-1. It is interesting to note that among the seven reported cases, five were related to "failure to release hand grip" even though a prosthetic hand is designed to provide a firm grip of the object. Harm could be avoided or reduced if appropriate risk assessment was conducted and followed up starting at the initial stage of prosthetic prescription.

Risk Survey of Upper Limb Prostheses

The questions below are to identify risks to clients or others from using upper limb body-powered or myoelectric prosthetic components. The components involved may be terminal device, wrist or elbow. Please also use this same questionnaire to provide information about potential risks that you think may happen to clients or others. Please use a separate page for each incident.

1. Are you aware of any incident that has resulted in injury (or damage) to your clients or other people?

   Yes __X__, No _____

2. Is this a true incident or a potential risk? Incident ____X___, Potential Risk ________
3. Describe the prosthetic component(s) involved:

   Right above elbow amputee with myoelectric hand, friction wrist rotator, body-powered elbow

4. Describe the cause(s) of the injury (or damage):

   Patient riding a bicycle tripped on a mountain trail; myoelectric hand was in closed position on the bike handle; was not able to release myoelectric hand from the handle; patient fell together with the bike.

5. Describe the injury (and/or damage):

   Bruises on various parts of the body; cuts on arm and legs from the bike and gravels. Bike destroyed.

   Rate the severity of the injury: Severe _____, Moderate ___X___, Minor ______
6. Describe the method of mitigation (e.g. replacement of components, training, etc.):

   Nothing was done to this patient's prosthetic devices after the injury. Perhaps could install a quick release of the right hand to be activated by the left sound arm.

7. What is the probability of this incident to happen on another patient under similar situation?

   High _____, Medium __X__, Low _____
8. Other comments:

Risk_questionnaire_examples.doc Sept 24, 2010 UBC-AYC

Figure 5.2 Incident Survey Questionnaire

Table 5.1 Reported Prosthesis Related Incidents

Case	Component Involved	Causes of Injury
1	Otto Bock Sensor Speed Hand	While driving, the auto grasp feature activated, hand gripped hard on steering wheel preventing car from turning around a corner.
2	Boston Elbow, LTI electrodes (no longer in use)	Electrochemical burns to client's upper arm in area of the electrode placement over a period of three months.
3	Otto Bock DMC hand	Client was riding her mountain bike while wearing her myoelectric prosthesis. Her hand was turned on and grasping the handle bar when she fell. The bike landed on her as she rolled down an incline.
4	Boston Elbow	The client was at a store trying to write something on a counter surface when the arm started going into extension and continued into hyper-extension.
5	Voluntary closing hook with locking mechanism	Patient was rowing a boat that overturned while paddling. Subject was unable to release paddle causing him difficulty in swimming
6	Proportional control myo Greifer	Patient was changing diaper on a baby and inadvertently pinched child. Greifer (electric claw) would not release tissue trapped, bruising child.
7	TRS (Therapeutic Recreation Systems) terminal device	The incident occurred on a kayaking trip where the TRS TD was in the locked mode "holding on" to a kayaking oar. Rough white water was encountered by the transradial amputee wearing the TRS device and he could not quickly release.

It was noted from communicating with rehabilitation professions during the course of the survey that risk management is not within their practice and is not official included in the prosthetic intervention process. However, many confirmed that they had encountered or were aware of incidents related to prosthetic use. In general, most agreed that a formalized process written in the standards of practice will help to reduce these risks.

Based on the examples of hazards listed in Annex D of the Standard−ISO 14971:2007(E), a list of general potential sources of harm (hazards) applicable to amputees fitted with upper limb myoelectric prostheses is presented in Table 5-2. The list also takes into consideration the incidents collected from the survey, the amputee's activity requirements and the characteristics of the prosthetic components. These hazards are grouped under four categories: energy, operational and environmental, biological and chemical, and information.

The list (Table 5.2) can be used as an initial check or a starting point for prosthetic risk analysis. Note that depending on the type and nature of the prosthetic components and configurations, some of the hazards in the list may not be applicable. On the other hand, specific hazards will need to be added after the individual patient's profile, device characteristics, functional and environmental requirements are considered.

Table 5.2 List of Potential Hazards

Energy Hazards	**Operational and Environmental Hazards**	**Biological and Chemical Hazards**	**Information Hazards**
• Line voltage • Leakage current • Electromagnetic field • High temperature • Drop impact • Shock and vibration • Weight (on patient) • Battery (heat and explosion) • Force (load on prostheses) • Force (created by prostheses) • Moving parts (entrapment) • Contact with sharp objects	• Water/moisture • Heat/fire • Operating cycles • Unintentional terminal device open/close • Unintentional elbow flexion/extension • Unintentional wrist pronation/ supination • Excessive force (created by prosthesis) • User errors (mistakes, slips, lapses) • Battery failures • Material weakness and failure • Component failure • Donning and doffing • Stress and strain from overuse • Stress and strain from postural compensation	• Bacterial, fungus and virus • Allergens • Cleaning & disinfection agents • Corrosive chemicals (e.g., from battery)	• Incomplete use instruction • Incomplete installation instruction • Inadequate description of performance • Inadequate specification of intended use • Inadequate pre-use check instructions • Inadequate specification of service and maintenance requirements • Inadequate disclosure of side-effects, limitations and hazards • Inadequate user training

The next step in risk analysis is risk estimation. Risk is defined as "a combination of the probability of occurrence of harm and severity of that harm" [ISO 14971:2007(E)]. A hazard only will create harm when one or more events leading to a hazardous situation has occurred. The probability of occurrence of harm is the product of the probabilities of occurrences of all the foreseeable events. However, unless there are sufficient historical data, it is difficult to establish the exact values of these probabilities. In practice, these probabilities are often estimated and divided into different levels such as high, medium, low, and extremely low (H, M, L and E). A hazard may create multiple hazardous situations and each may have its own level of harm severity. Severity of harm may also be conveniently divided into levels such as 0, 1, 2, and 3 representing respectively negligible, marginal, significant, and catastrophic harm. To illustrate this approach in risk analysis, a few hazard examples with the sequences of events leading to these hazardous situations are shown in Table 5-3. Sample entries of the probability of occurrence (P) and its severity of harm (S) for each hazard using the above-mentioned level scales are also shown.

Table 5.3 Hazard Table

ID	Hazard	Foreseeable sequence of Events	Hazardous Situation	Harm	P	S
H1	Line voltage	1. Patient wearing prosthesis while battery is being charged 2. Electrical insulation failed	Line voltage applied to patient via electrode	Electric shock Skin burn	E	3
H2	Batteries (Lithium-ion)	1. Overcharging or short circuit 2. Patient wearing prosthesis	Battery overheated, fire	Skin burn	L	2
H3	Unintentional opening of terminal device	1. Patient carrying heavy object 2. Terminal device opened	Heavy object fall under gravity	Impact injury	M	1
H4	Unintentional closure of myoelectric hand	1. Myoelectric hand used in driving 2. Hand grasped on steering wheel and could not be released	Patient cannot effectively steer and control vehicle	Vehicle crash injury	M	3

5.4 Risk Evaluation

For each identified hazardous situation, one must make a judgment on whether or not the risk can be tolerated. For example, a risk of low probability of occurrence (P = L) and negligible harm (S = 1) will be tolerated; whereas a risk that may inflict serious injuries (S = 4) and occur frequently (P = H) must be avoided or mitigated. Two methods are commonly used in risk evaluation. One is to plot the severity of harm (S) against the probability of occurrence (P). Figure 5-3 shows such a plot for the example in Table 5-3. A line may be drawn to delineate acceptable risk from intolerable risk. From the risk analysis, the P and S values of each hazardous situation are plotted on the graph. Those above the line will need to be mitigated so that either its risk is reduced and/or its frequency of occurrence is lowered until the risk moves inside the acceptable region. In one of the hazard examples, unintentional closure of the myoelectric hand (ID:H4) while the amputee is driving falls outside the acceptable region and, therefore, will need to be mitigated. For the line voltage hazard (ID:H1), although the probability is low, the harm from electrocution cannot be ignored; it is, therefore, not acceptable.

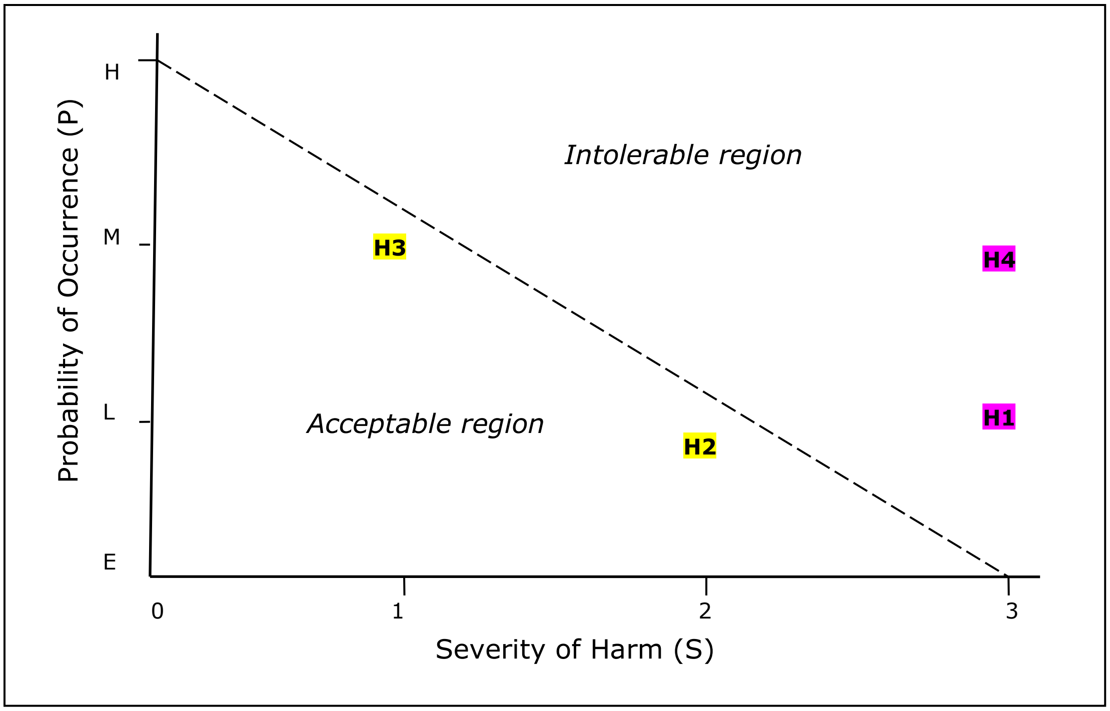


Figure 5.3 Risk Diagram

Another method to evaluate risk is to create a risk table (Table 5-4) so that each combination of probability of occurrence (P) and severity of harm (S) is assigned a risk score or risk index (RI). A threshold value, commonly referred to as the acceptability criterion, will need to be determined so that any hazardous situation with RI above this value is considered to be unacceptable. The RI of each hazardous situation will then be looked up from the table using the identified values of P and S. In our example (Table 5-3), if we use a value of 13 as the acceptable criterion, from the risk table; the hazard H4-"unintentional closing of myoelectric hand while patient is driving" is unacceptable. Moreover, this acceptable criterion will turn the hazard H1-"line voltage" into acceptable.

In fact, it is a challenge to come up with reasonable risk indices for different hazardous situations as the probability of risk occurrence is difficult to estimate.

Likewise, the impact of risk (harm) is difficult to quantify. Nonetheless, RI and the acceptable criterion are established by manufacturers or organizations when conducting risk assessment. In performing risk assessment on upper limb prosthesis, one must understand its limitations [Youssef, 2009] and believe in the merit that risk assessment provides a systematic process to analyze hazards which leads to risk minimization.

Table 5.4 Risk Index Table

	Severity of Harm (S)			
Probability of Occurrence (P)	**3**	**2**	**1**	**0**
H	16	14	11	6
M	15	13	9	4
L	12	10	7	2
E	8	5	3	1

5.5 Risk Control

For each hazardous situation, if the risk exceeds the acceptable level, risk control measures will need to be implemented to reduce the risk. There are three categories of risk mitigations. In order of their effectiveness, they are:

1. Mitigation is embedded in the design
2. Mitigation is an alarm
3. Mitigation is based on labeling

These available options will need to be evaluated and selected so that an acceptable RI may be achieved within reasonable deployment of resources. Using the hazardous situation “unintentional closing of myoelectric hand while patient is driving” (Table 5.3: H4) as an example, one possible mitigation is for the user to turn off the myoelectric hand and use it as an assistant to the dominant hand while driving. However, if the user does not follow this instruction (mistake) or forgets (lapse) to turn off the hand, the hazardous situation remains and harm may occur. A better approach is to install a modification to the steering wheel of the vehicle so that the prosthetic hand can be engaged in driving but still able to be disconnected quickly from the steering wheel when needed. Installing a spinning knob on the steering wheel shown in Figure 5-4 is an example of this driving modification. Such mitigation will reduce the probability of occurrence so that the risk will fall within the acceptable region. In the case of the “line voltage” hazard (Table 5.3: H1), a myoelectric arm may be designed such that it needs to be removed from the amputee before it can be connected to the power line battery charger.

Not all risk may be reduced to an acceptable level. For example, a transradial amputee who is fitted with a myoelectric arm shall not be climbing on a high ladder as the socket will not be able to withhold the weight of the amputee. In case there is a slip, even though the prosthetic hand is gripping on the ladder, the amputee will suffer a fall injury as the prosthetic arm will be detached from the residual limb. In this case, a practical approach is to warn the amputee (in the device labeling) that such activity must not be performed. Alternatively, if “climbing a ladder” is a required job function of the amputee, a specially designed prosthesis and/or extra safety harness are possible solutions to reduce the probability of occurrence (P) or the severity of harm (S).

Figure 5.4 Spinning Knob (pointed by arrow)

In risk control and mitigation, one has to bear in mind that any risk may pose harm. Therefore, an “as low as reasonably achievable (ALARA)” approach must be adopted. If a reasonable risk reduction measure is available, it should be implemented to reduce the risk even though the risk index may be within the acceptable criterion.

5.6 Evaluation of Residual Risk

After the initial risk mitigation, risk analysis and evaluation should be performed on each modified situation to determine if the residual risk level is acceptable and if the method of mitigation will create other new risks. It is not always possible that the risks of all hazardous situations can be lowered to an acceptable level. In such cases, risk-benefit analysis should be performed to determine if the benefit will outweigh the risk. For a bilateral above elbow amputee fitted with prostheses, driving should be prohibited as the risk of losing control leading to serious injuries is quite high. A modified vehicle with foot steering and foot control may be an option if driving is a necessity for the amputee.

5.7 Summary

From the survey information, it is confirmed that a prosthetic device can be hazardous and may cause injuries to the user or others. Currently, conducting risk assessment is not a part of the professional practice in amputee prosthetic prescription. However, there appears to be some keen interest from the professional community to explore this topic and most agreed that a formalized process written in the standards of practice will help to reduce risk. A systematic approach to assess risk of upper limb myoelectric prostheses taking into consideration their intended use is established in this chapter. This approach is based on ISO 14971:2007(E) which is a recognized risk management standard in medical device development.

The purpose of risk assessment is to identify hazards and minimize risks. Risk assessment should be included as a required component in the selection, prescription, fabrication, and use of prosthetic components and systems. The process established in this chapter identified a list of potential hazards applicable to prosthetic use. It takes into consideration the amputee’s characteristics, environmental conditions, activity (including work) requirements, and the functional limitations of the prosthetic components. Furthermore, risk evaluation strategies are proposed to delineate whether or not risk arising from these potential hazards can be tolerated.

In summary, a risk assessment framework specifically designed for upper limb myoelectric prostheses taking into consideration their intended use is formulated and proposed in this Chapter.

Chapter 6: Development of Prosthetic Assessment Platform

6.1 Introduction

Chapter 3 presented a critical review of current prosthetic technology and practice. The summary of key findings (Section 3.11) identified, among others, the lack of objective assessment tools, and recognized keen interest in the professional community to create tools and standards for prosthetic outcome assessment.

A prosthesis for functional restoration of a compromised limb can be body-powered or externally-powered. Externally-powered prostheses are electromechanical devices that replace some functions of a lost limb segment. Upper limb externally-powered prostheses include electric elbows, wrist rotators, and terminal devices such as electric hooks or hands [Troncossi, 2007]. The activation control signals of an externally powered prosthesis may be derived from a switch or a linear potentiometer operated by the patient, or more commonly, from the patient's electromyographic (EMG) signals [Herberts, 1973]. The strength and duration of muscle contractions have been shown to correlate with the amplitude and temporal characteristics of intramuscular EMG signals or EMG signals picked up from the skin surface of the patient [Ray, 1983; Hoozemans, 2006]. Myoelectric prosthetic devices are often controlled by surface EMG (sEMG) signals initiated by the patient. EMG signals captured using surface electrodes from healthy muscle groups in the amputee's stump are often used to derive the activation signals. Muscle sites for electrode placements typically include the pectoralis, anterior deltoid, biceps, wrist flexors, posterior deltoid, infraspinatus, teres major, triceps, and wrist extensors [Lake, 2006]. The selection of desirable sites usually depends on the level of amputation and socket design. The sEMG signals are rectified and filtered to emulate physical muscle contractions. These processed EMG signals, also called myosignals [Disselhorst-King, 2009], are used to activate electromechanical actuators in the prosthesis. For example, a higher amplitude myosignal will produce a stronger grip force from a myoelectric hand. To perform an activity (such as drinking from a cup), a sequence of myosignals is needed to produce the desired functional motions. Some prostheses employ closed-loop feedback control to enhance performance, such as detecting the slipping of an object under grip. Others have built sensors and actuators into the system to provide tactile feedback to the amputee [Boone, 2011]. In general practice, patients rely on visual feedback to control their prosthetic motions.

For amputations at high levels, such as transhumeral and glenohumeral levels, an electrical prosthesis has been proven to be more functional than its body-powered counterpart [Lake, 2006]. Prosthetic components with increasing complexity and advanced technologies have been developed. A prosthetic hand may incorporate delicate sensors for detecting digit position, grip force, slip, and temperature [Chappell, 2011]. These devices often claim to be easy to use and provide significant improvement to the patient's functional outcomes. Despite much higher costs [Uellendahl, 2008; Blough, 2010], studies have shown that, in some patient groups or activities, myoelectric prostheses may not be appropriate nor perform better than body-powered prostheses [Biddiss, 2007]. In addition, the high abandonment rate [Dakpa, 1997] and poor durability [Wright, 2009] of myoelectric prosthetic devices are of concern to caregivers and funding agencies. There have been ongoing discussions among practitioners and researchers on the development of standardized tools and guidelines for evaluating a patient's functional outcomes when fitted with these devices [Hill, 2009; Lindner, 2010; Dillingham, 2002]. Furthermore, due to their short history and limited number of fittings [Biddiss, 2007], very few technical reports have been published about their technical capability, device reliability, and functional performance.

Two of the most significant factors affecting the use or rejection of prostheses are established needs and available prosthesis technology [Lovely, 2004]. Established needs are determined from interviews, discussions, and activity studies to identify the intended usage and desired activities of the patient. When new prosthesis technology becomes available, practitioners and funding agencies must rely on the claims and published specifications from the manufacturer since there is no standard and few tools available for objectively evaluating the technical performance of such prosthetic devices. Based on this need, an assessment platform for upper limb myoelectric prostheses that integrates the following features is designed and constructed:

1. Capture, analyze, process, and record sEMG signals
2. Create prosthetic activation signals from simulated or captured waveforms
3. Activate the prosthesis under test with consistent and repeatable inputs
4. Measure, record, and analyze the functional characteristics of the prosthesis

This Chapter describes the development of the assessment platform and the results of its application to the functional evaluation of myoelectric prosthetic terminal devices in the market.

6.2 Market Scan

A search of available tools in the market was conducted to see if there were commercial products available to serve the above objectives. From literature review, Web search, and contact with manufacturers and service providers, there is not a single platform available that can provide all of the above listed functions. Individual manufacturers have created tools for their own products. These tools are for pre-prosthetic evaluation, patient training, and system adjustment. Some examples of these tools are listed below.

- Otto Bock MyoBoy
- Otto Bock ElbowSoft
- Otto Bock Myosimulator
- Motion Control MyoLab

The functional characteristics of these products are listed in Table 6.1. We can see that none of them can carry out all the required functions. As well, these tools are not able to create an arbitrary activation signal sequence or to measure and record functional output parameters from the prosthesis under test. The following sections describe the assessment platform developed and tested in the study.

Table 6.1 Characteristics of Available Assessment Tools

	Device Application	Capture, Analyze, and Process EMG	Custom Create Myoelectric Activation Signal	Generate Consistent and Repeating Activation Signal	Measure Prosthesis Output Characteristics
Otto Bock MyoBoy	Muscle training, electrode site selection	Acquire sEMG, general myosignal; display signal strength	Real time signal from patient only	Activate virtual hand (Computer simulation of Otto Bock hands) or prosthesis (when connected to the test adaptor) by real time patient signal	Measurement functions not available Only visual observation of prosthesis response
Otto Bock Elbow-Soft	Parameter settings of Otto Bock prosthetic components	Display activation signals to prosthesis; display signal strength	Real time signal from patient only	Activate prosthesis with patient signal	Measurement functions not available Only visual observation of prosthesis response
Otto Bock Myo-simulator	Test functioning of prosthetic assembly	N/A	Internally generate activation signal	Two channels of single pulse internal generated signal (e.g., open and close hand); single or repeating activation	Measurement functions not available Only visual observation of prosthesis response
Motion Control MyoLab	Parameter settings of Motion Control prosthetic components	Display activation signals to prosthesis; display signal strength	Real time signal from patient only	Activate prosthesis with patient signal	Measurement functions not available Only visual observation of prosthesis response

6.3 Requirement Specifications

The functional requirements and performance specifications of the assessment platform are formulated in this section:

6.3.1 Signal Acquisition and Pre-processing

Objective: To acquire sEMG signals from the patient using metal or Ag/AgCl electrodes

Function:

- Signal input level: 10 μV to 1 mV
- Selectable band pass filter: f_L = 0.5 or 90 Hz and f_H = 480 or 1,600 Hz
- Variable amplification: up to 50,000 times
- CMRR: greater than 100 dB

6.3.2 Signal Post Processing

Objective: To analyze, process, create, and record signal waveforms for prosthetic activation

Function:

- Input: real time amplified sEMG signal or signal waveform from a stored file
- Display: raw and processed signal waveform and their power frequency spectra
- Signal processing: amplify, filter, power-frequency rejection, level shift, envelope detect, inject noise (power frequency and Gaussian)
- Construct a signal train from imported, processed, or simulation waveforms
- Store processed waveforms or activation signal train for use by other modules

6.3.3 Retrieve and Display Waveforms

Objective: To display a stored waveform file

Function:

- Retrieve waveform from a stored file
- Display waveform

6.3.4 Prosthetic Device Activation and Measurement

Objective: To activate a prosthesis; to acquire, process, and record functional outputs from the prosthesis under test

Function:

- Load a maximum of four waveforms (channels 0 to 3) from stored files
- Output a maximum of four channels of prosthetic activation waveforms
- Select number of test cycles
- Capture a maximum of four analog input channels for data logging

6.3.5 Analog Input and Analog Output

Objective: To activate a prosthesis with real time input signals

Function:

- Two analog real time input channels: 10 μV to 1 mV
- Selectable band pass filter: 0.5 to 1 kHz
- CMRR: greater than 100 dB
- Signal processing parameters: amplify, filter, rectification, envelope detection, DC level shift
- Output two real time analog channels to activate a prosthesis

6.4 System Architecture

The architectural diagram of the assessment platform based on the objectives and functional requirements is shown in Figure 6.1. EMG signals picked up by surface electrodes are amplified and bandwidth limited by the “signal acquisition” module. In the “signal capture” module, the acquired signals are digitized and processed. Amplification, filtering, and rectification can be performed in this module. The processed signal waveforms are saved in files in the “waveform storage” module for later use or further analysis. The function of the “programmable signal generator” is to build a train of signal waveforms for prosthetic activation. The “activation and measurement” module amplifies and outputs the signal waveform train to activate the prosthesis under test. The responses of the prosthesis to the activation signals are captured by the transducer circuits and recorded in a spreadsheet file.

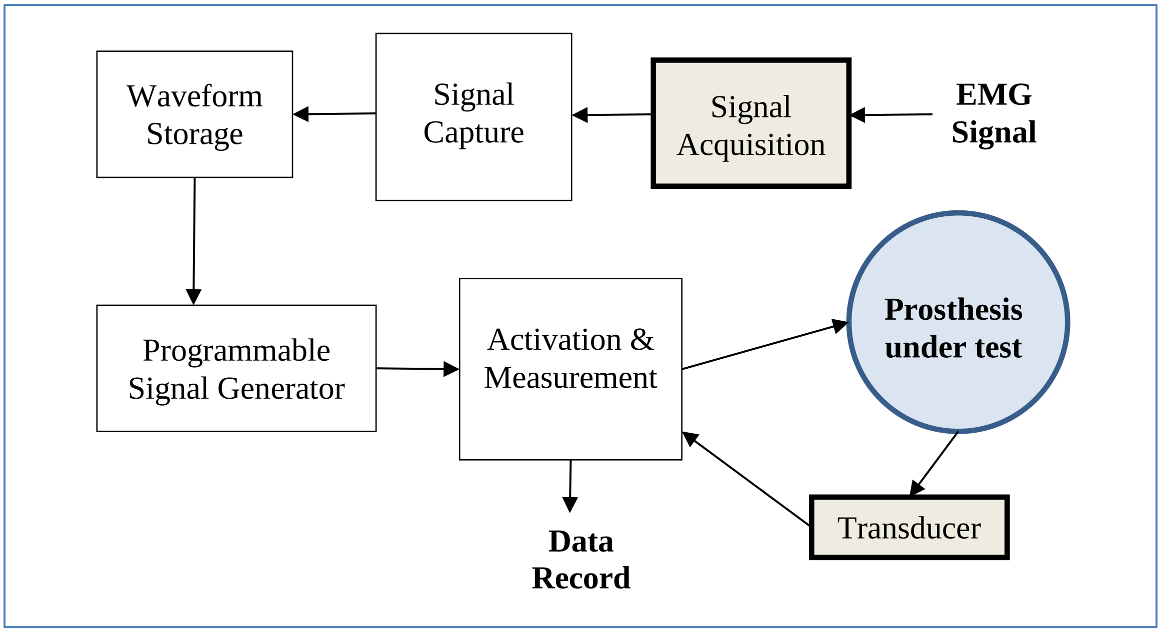


Figure 6.1 Assessment Platform Architectural Diagram

The acquisition module and transducer circuits are built with analog electronic hardware components. The remaining modules are implemented on a National Instruments (NI) LabVIEW data acquisition platform and run on a Microsoft Windows-based computer connected to the input-output (I/O) hardware. An NI 9215 four-channel, ±10-V, 16-bit analog voltage input module and an NI 9263 four-channel, ±10-V, 16-bit analog voltage output module are used as the I/O interface between the hardware and software environment. This combination provides four simultaneous differential analog input channels and four analog output channels with sampling rates of up to 100 kS/s. This sampling frequency is more than 50 times that of the EMG frequency bandwidth. The following sections describe the four functional modules of the assessment platform

6.5 EMG Signal Acquisition Module

The control signals for myoelectric prostheses are, in general, derived from the EMG signals acquired by a pair of surface electrodes placed on two antagonistic muscles such as the brachialis and the triceps brachii. The amplitude, duration, and rate of change of the myosignals (processed EMG signals) are common control parameters of myoelectric prostheses [Boone, 2011].

The acquisition module is a battery-powered (two replaceable 9-V batteries) instrumentation amplifier with analog-signal processing circuits designed to pick up sEMG signals in the order of 10 μV. It was custom-built using a low-power high-common-mode-rejection differential amplifier (Analog Devices AD620). The module provides a 10 GΩ input impedance with a variable gain of up to 50,000 times to the input signals. An analog band pass filter is used to limit the bandwidth and remove noise from the signal before it is digitized by the signal capture module. The upper cut-off frequency can be selected to either 480 Hz or 1,600 Hz and the lower cutoff frequency can be selected to be 0.4 Hz or 90 Hz. Additional signal filtering may be performed in the signal capture module. An envelope detector consists of a precision rectifier (no conduction threshold voltage) and a 3 Hz low pass filter converting the EMG signals into myosignals. There are two outputs from this module, one produces the EMG signal (V_{EMG}) and the other the myosignal (V_{MYO}). Figure 6.2 shows the schematic diagram of the signal acquisition module. Below is a description of the circuit.

U1 (Analog Devices AD620) is a low-power high common mode rejection differential amplifier with 10-GΩ input impedance. The gain G of this amplifier stage is given by:

$$G = \frac{49.4\ k\Omega}{R_G} + 1$$

Where R_G is the external resistance across pins 1 and 8 of the operational amplifier.

When J1 is at the indicated position, R_G can be adjusted from 5 kΩ to 50 Ω by the 5-kΩ user-adjustable potentiometer which will provide a variable gain from 10 to 1,000. The 2-kΩ variable resistor is an internal resistor to provide a pre-set gain when J1 is at the other position. The diodes D3 to D6 limit the input voltage to ±0.6 V to protect the amplifier from damage by high voltage such as static electricity.

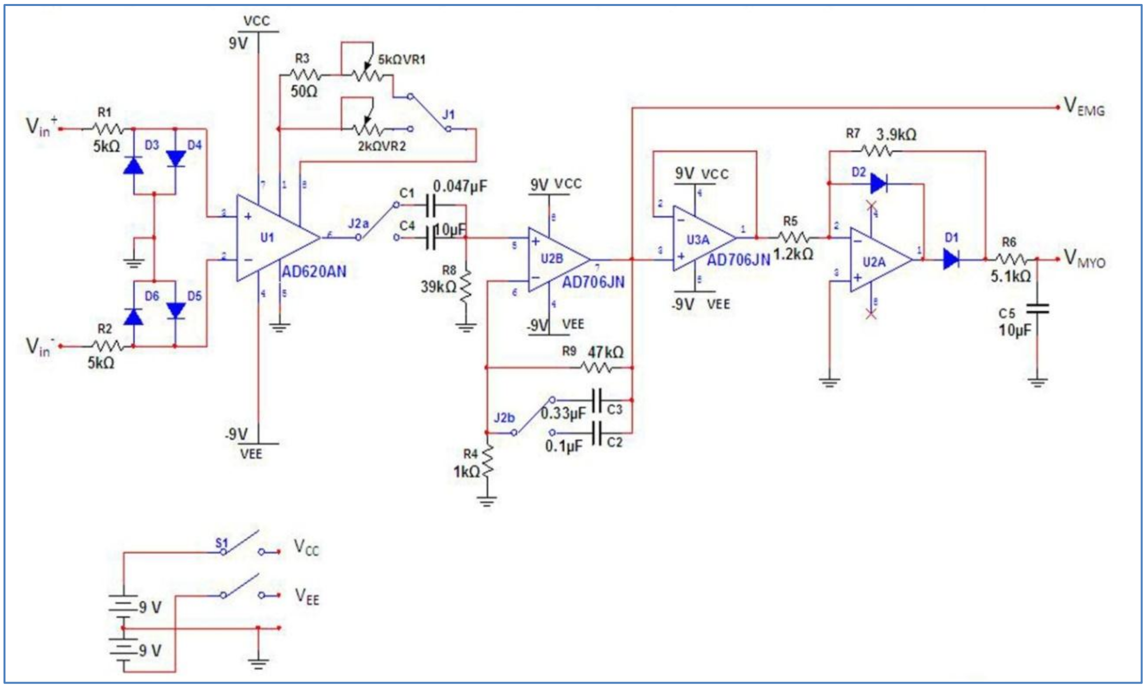


Figure 6.2 Schematic Diagram of the Signal Acquisition Module

U2 and U3 are low power, bipolar op amps (AD706). J2 is a double-pole-double-throw (DPDT) switch. At the position indicated, the signal pass band is from 90 to 480 Hz; when at the other position, it is from 0.4 to 1,600 Hz. The former bandwidth is commonly used for EMG signal capture in myoelectric prosthetic applications. The latter bandwidth is suitable to capture full EMG signals for analysis. The op amp circuit of U2B provides a mid-band gain of 48. Together with the first stage gain (10 to 1,000), the module amplifies the input signal ($V_{in}^{+} - V_{in}^{-}$) by 480 to 48,000 (at the V_{EMG} output). The circuit with U2A is a half-wave precision rectifier for the EMG signals. The RC circuit at the amplifier output provides a 3 Hz low pass filter to convert the rectified EMG signals to their myosignals at the output terminal (V_{MYO}). A picture of this hardware signal acquisition module is shown in Figure 6.3.

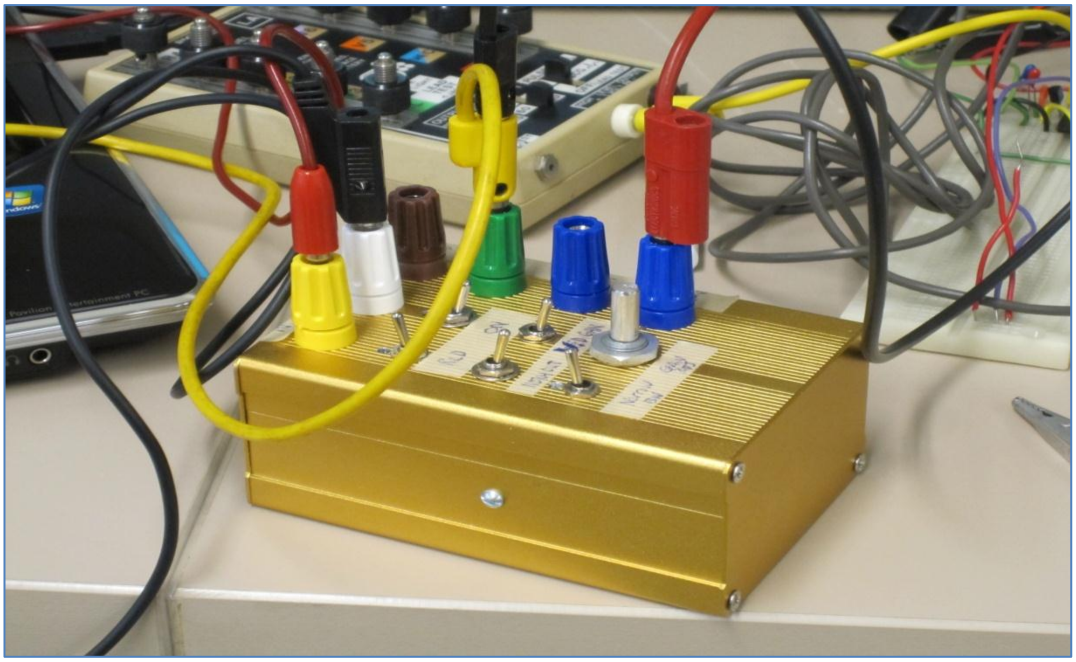


Figure 6.3 Signal Acquisition Module

6.6 Signal Capture Module

The signal capture module captures EMG signals or other waveforms from the acquisition module. Figure 6.4 is the graphical user interface (GUI) of this module. It allows the user to view a four second segment of the waveform in real time. A "FREEZE" function allows the user to freeze the time-varying waveform for inspection. The upper window shows the EMG signals in real time and the other shows the corresponding myosignals. A power-frequency spectrum of the signal is displayed next to each of the input waveforms. When the "SAVE" button is clicked, twelve seconds of the waveform is saved in a binary file (including four seconds prior to and four seconds after the waveform shown on the display). These waveform files can be imported into the programmable signal generation module for further analysis and processing.

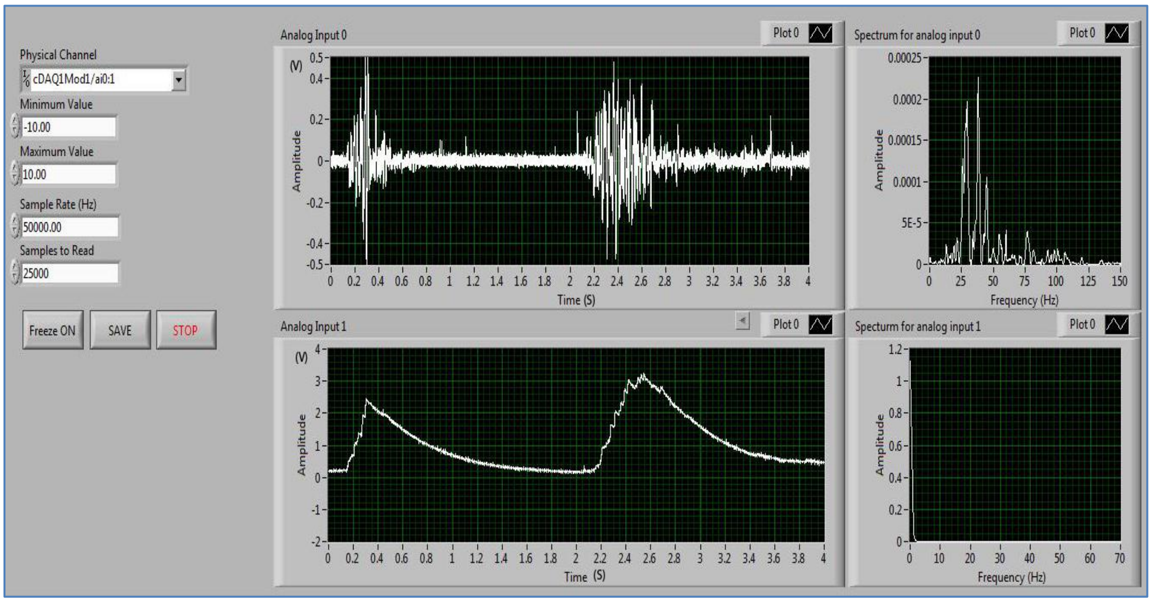


Figure 6.4 GUI of Signal Capture Module

6.7 Programmable Signal Generation Module

The programmable signal generation module consists of a signal conditioner sub-module and a waveform builder sub-module. Signal conditioning functions, namely amplification, attenuation, level shifting, filtering, and envelope detection, are built into this module. Power frequency (60 Hz) and Gaussian noise of adjustable amplitude can be added to the waveform to simulate sEMG signals acquired in a noisy environment. The imported (raw) and processed waveforms and their respective power-frequency spectra are displayed on the front panel of the LabVIEW GUI.

The main function of the waveform builder sub-module is to compose a train of signals for activating myoelectric prostheses. A captured waveform from the signal capture module can be used as a building block for the activation signal train. Alternatively, signals with various amplitudes, durations, and rise and fall times may be created using this sub-module. A mixture of captured myosignals and simulated signals can be combined to create an activation signal train of up to 30-second duration. This activation signal train, when applied to a prosthesis, will activate the prosthesis to produce a sequence of preprogrammed functional motions.

Figure 6.5 shows the GUI of this module. Signal processing functions (filtering, rectification, etc.) can be selected and applied to the imported signal. In the figure, the imported signal (sEMG) is displayed in the upper window and the process signal (myosignal) is displayed in the middle window. The frequency-power spectra of the waveforms are displayed on the right. The lower window displays the 30-second signal train built for prosthetic activation. A pair of cursors selects a waveform segment in the middle window. This segment can be directly copied to the lower window, or manipulated (level shifted, time shifted, etc.) before being copied. Alternatively, a signal waveform may be created in the lower window by drawing straight lines of variable lengths and slopes. Power frequency and Gaussian noise can also be added to the signal. With these combinations, activation signals of any shape and form can be created. The lower window in Figure 6.5 shows six activation signals created to illustrate this capability. The first two waveforms were composed using the slope and straight line tools. The third waveform is a copy of the selected segment of the processed signal from the middle window. The fourth waveform is a level-shifted (+ 0.25 V) version of the third waveform. The fifth and sixth waveforms have 60-Hz noise and Gaussian noise added, respectively. This module can be used to simulate various input signal conditions (such as a noisy EMG signal, electromagnetic interference, etc.). The created signal train can be saved and later used to evaluate the performance of prosthetic devices under various conditions. An example of an activation signal train (with only simulated rectangular pulses) created from this module is shown at the top of Figure 6.6.

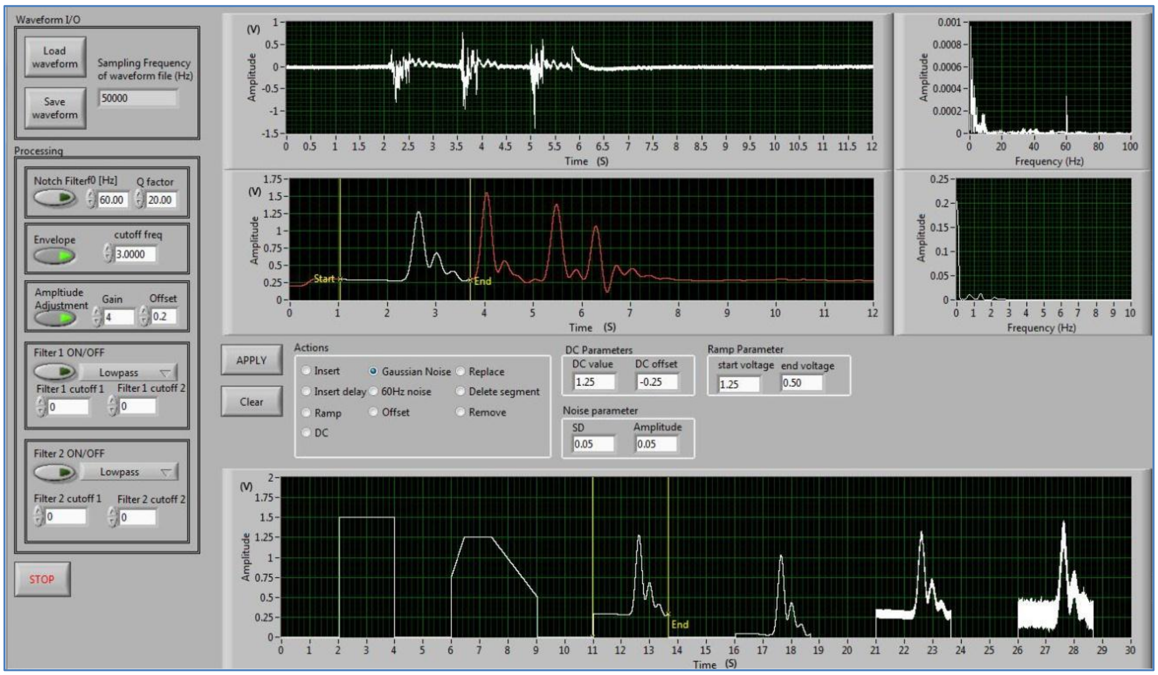


Figure 6.5 GUI of Programmable Signal Generation Module

6.8 Activation and Measurement Module

One of the functions of the activation and measurement module is to activate the prosthesis with the signal train created by the programmable signal generation module. To activate the myoelectric prosthesis, activation signal trains are loaded into the output channels to create a single sequence of motions. Figure 6.6 shows the prosthetic configuration of a transhumeral amputee and the activation signals. The setup consists of a myoelectric hand, an electric wrist rotator, and a powered elbow. Below is the description of a common scheme to activate these three components using myosignals from two electrode sites:

- A momentary muscle contraction (myosignal) from one site will activate the prosthetic component to move it in one direction (e.g., hand open).
- Another momentary muscle contraction (myosignal) from the other site will activate in the opposite direction (e.g., hand close).
- A "co-contraction" (simultaneous muscle contractions at both sites) switches the control from one prosthetic component to another.

The transhumeral prosthetic setup was programmed for sequential activation from two input control channels. The two 30-second activation signal trains shown in Figure 6.6 (top) were synchronized and sent via the output interface to the control inputs of the prosthesis. Note that the 4-V rectangular pulses are programmed "co-contraction" while the pulses with lower amplitudes are activation signals.

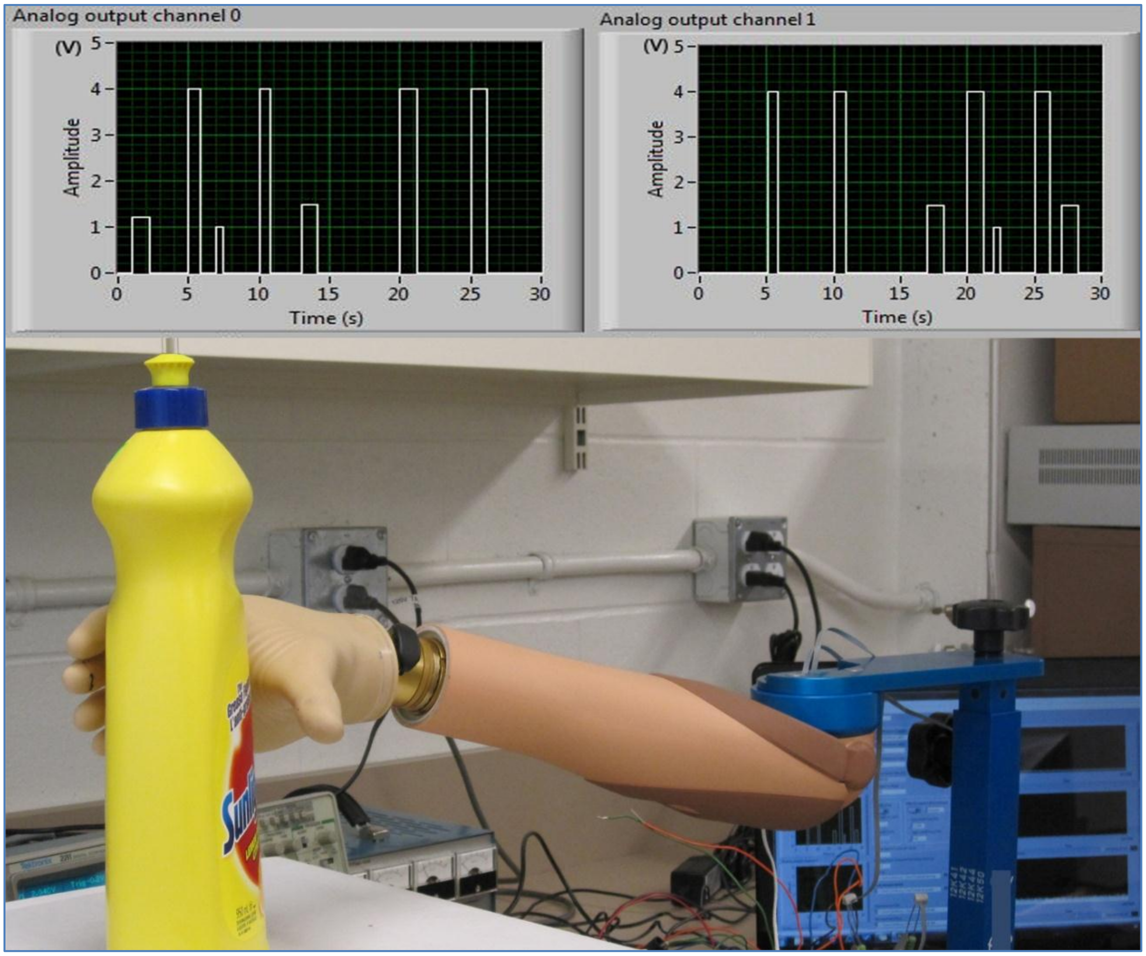


Figure 6.6 Transhumeral Prosthesis: Activation Signals (top) and Test Setup

The amplitude and duration of the activation signals are selected to control the intensity (e.g., hand closing speed) and duration (e.g., time of hand closing action) of the activation. In this setup, the prosthetic activation signal train produces a single motion sequence: grasp the bottle (hand closed), lift it up (elbow flexed), pour out its content (wrist rotated), return the bottle to its initial position (wrist counter rotated and elbow extended), and release the bottle (hand opened). The motion sequence of this setup in response to the activation signal train is listed in Table 6.2. In addition to producing a single sequence of motions, the module can be programmed to repeat the activation signal train for a selected number of cycles; or to loop continuously until it is manually interrupted.

Table 6.2 Prosthetic Activation Signal and Motion

Start Time (s)	Action Sequence	Function
1	Close hand	Grasp bottle
5	Switch control to arm (co-contraction)	
7	Raise arm	Lift bottle from table
10	Switch control to wrist (co-contraction)	
13	Rotate wrist	Pour bottle content
17	Rotate wrist	Return bottle to upright position
20	Switch control to arm (co-contraction)	
22	Lower arm	Place bottle on table
25	Switch control to hand (co-contraction)	
27	Open hand	Release bottle

The measurement function in this module captures the responses of the prosthesis being driven by the activation signal. Four data acquisition channels are available to simultaneously acquire analog voltage signals from external transducers. These acquired signals are processed (e.g., peak measurement, time detection) and stored for further analysis. Depending on the prosthetic component and the functional parameter to be measured, a transducer circuit will need to be built and interfaced with the input data acquisition channel of the assessment platform. An example of using this test platform to verify the specifications of myoelectric terminal devices is described in the next section.

6.9 Verification of Myoelectric Terminal Device Specifications

The grip force and the closing speed are considered two of the most important functional parameters of a myoelectric hand [Pylatiuk, 2007]. An advantage of myoelectric hands over body-powered hands is the ability to generate higher grip force to hold heavy objects [Lake, 2006]. Fast hand closing speed is also an advantage. To measure the grip force, a transducer circuit was built using a Tekscan Flexiforce A210-100 flexible membrane force sensor [Tekscan, 2009]. To convert the grip force to a voltage signal, the force-to-voltage circuit suggested in the user manual of the force sensor was used (Fig. 6.7). A 5 V negative voltage regulator (79L05) was used to supply a constant reference voltage for V_T. A 200-kΩ variable resistor is used for R_T. To improve repeatability, the transducer was sandwiched between two strips of 4 mm thick Plexiglas. A circular puck, slightly smaller than the sensing area of the transducer, was placed on top of the sensor (Figure 6.8). This arrangement allowed better force distribution on the sensor from the three-point grip (grip produced by the thumb, index, and middle fingers) of the prosthetic hand. The force sensing setup was calibrated using a set of ANSI/ASTM E617 Class 4 [ASTM, 2008] calibration masses (±2% within the range of 0 to 10 kg). The analog output voltage from the sensor was recorded via the measurement module of the assessment platform.

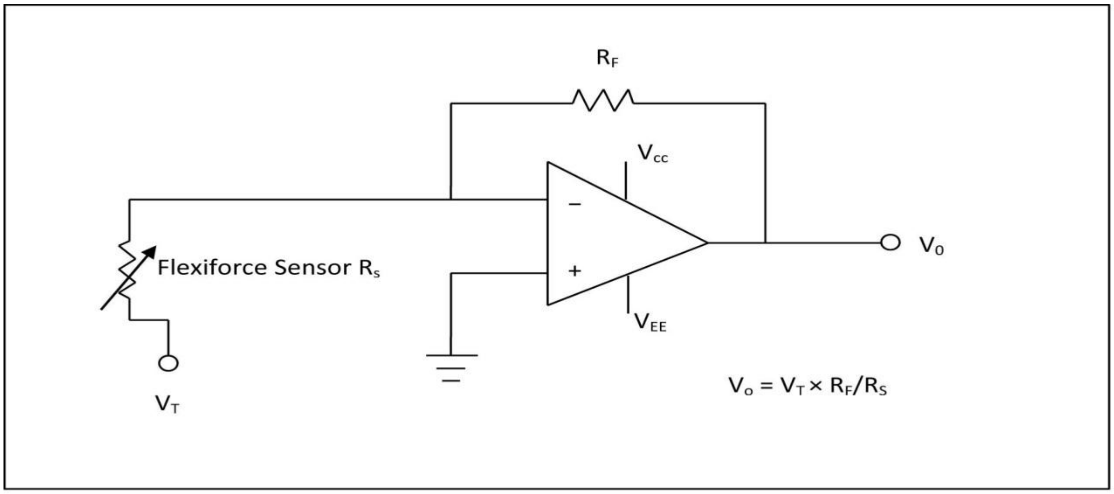


Figure 6.7 Flexiforce Force-to-Voltage Transducer Circuit

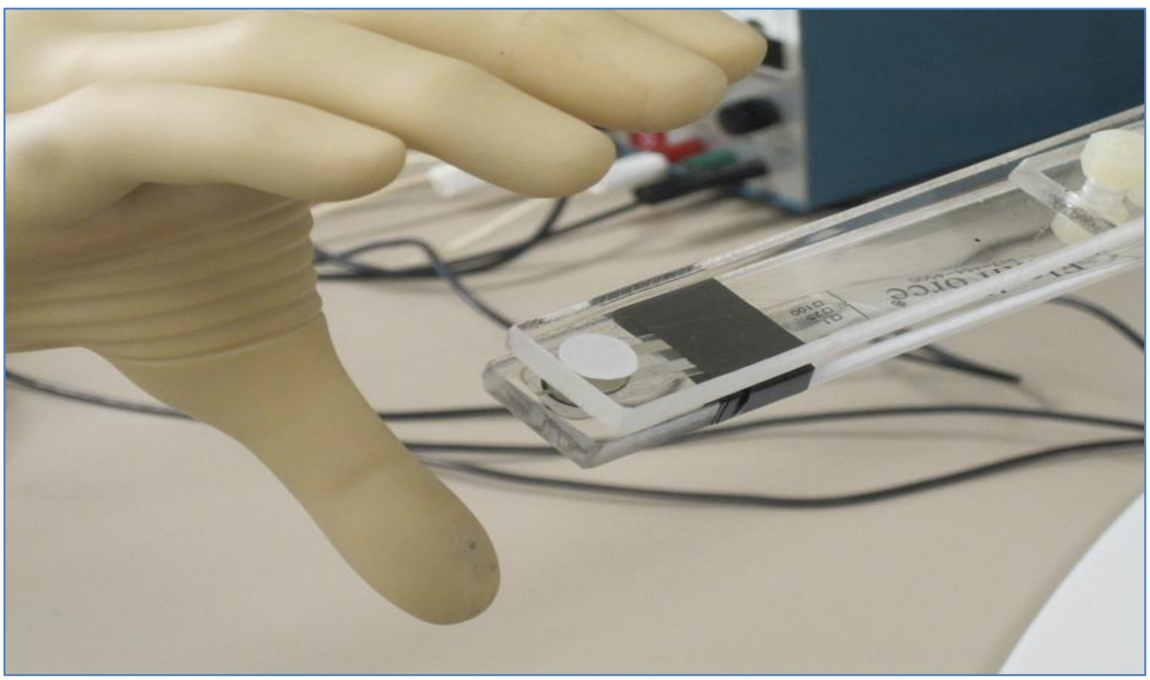


Figure 6.8 Grip Force Measurement Setup

To measure the hand's opening and closing speed, a pair of Honeywell HOA6972 optical sensors were interfaced to the input channels of the assessment platform. The setup is shown in Figure 6.9. The dimension of the gap between the thumb and middle finger of the hand was measured using a caliper when the lower sensor was triggered. The same was measured when the upper sensor was triggered. The distance of travel between the thumb and middle finger (the grip opening) was calculated from the difference of these measurements. During each activation cycle, the time interval between the triggering of the two optical sensors was captured by the assessment platform. The hand speed was then calculated by dividing the distance of travel by the measured time interval. The optical sensor trigger circuit is shown in Figure 6.10. The anode of the infrared light-emitting diode (LED) is connected to a 7.2-V power supply (V_{cc}) via a 270-Ω resistor. A 1-kΩ pull-up resistor is connected between V_o and V_{cc}. The trigger circuit sends a 7.2-V pulse to the analog input of the activation and measurement module of the test platform when the sensor is interrupted.

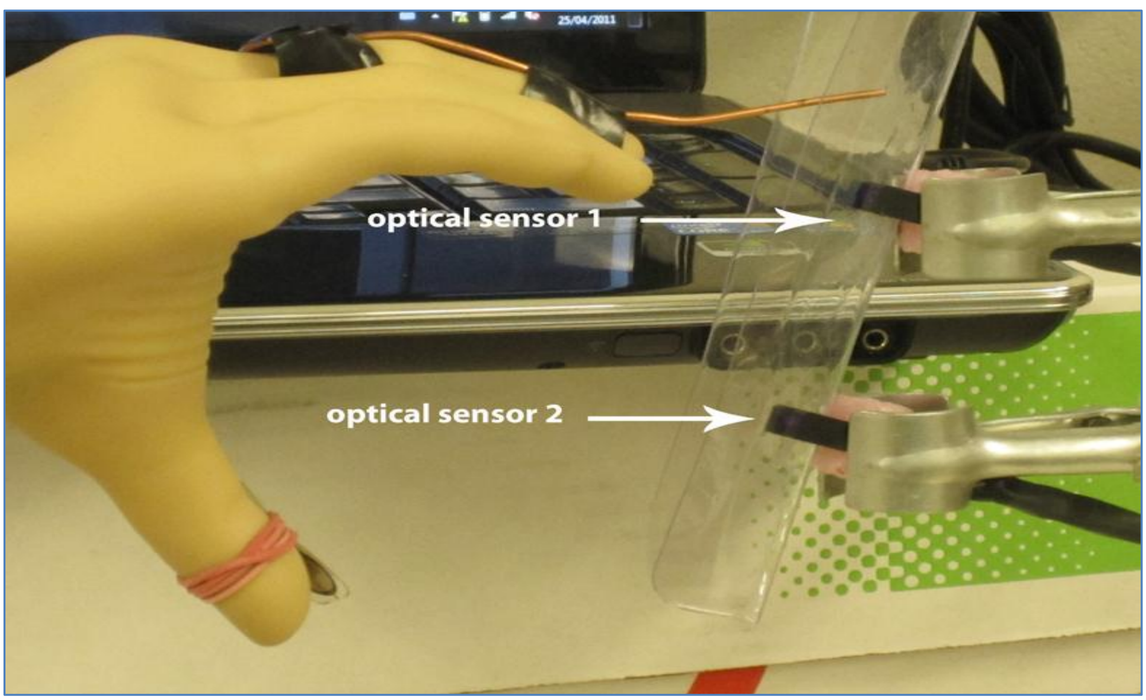


Figure 6.9 Hand Speed Measurement Setup

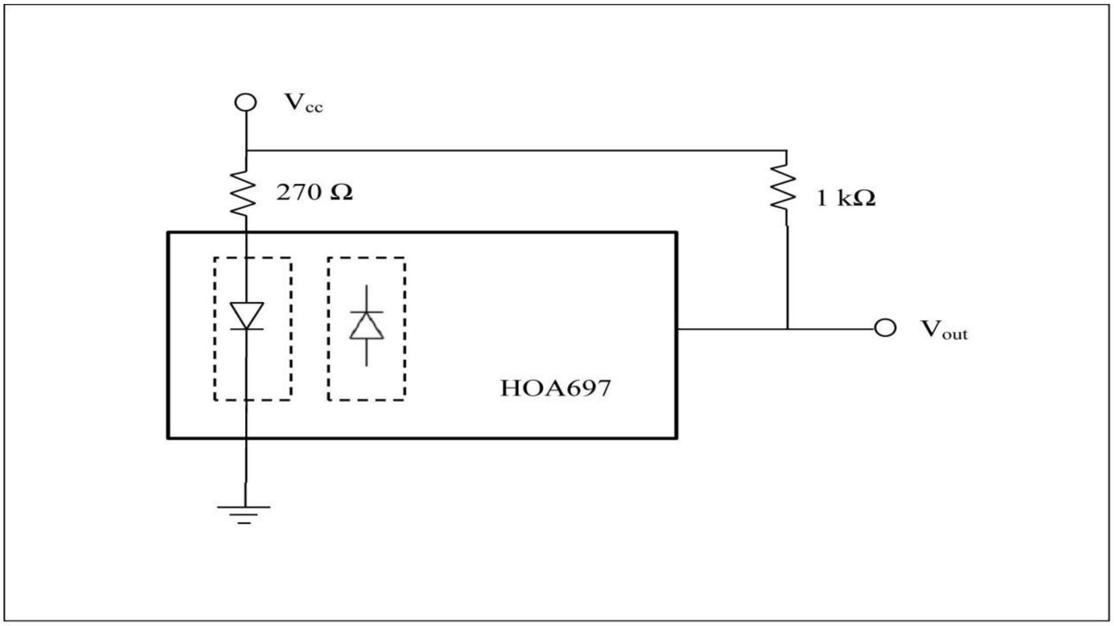


Figure 6.10 Optical Sensor Trigger Circuit

The accuracies of the force and speed measurements of the assessment platform, taking into consideration the transducer setup, I/O interface, sampling, and quantization error, were determined to be ±8% and ±3%, respectively.

Figure 6.11 is the screen capture of the GUI of the activation and measurement module in this experiment. The waveform in the upper left window is to open the hand and the waveform in the middle left window is to close it. These activation signals are sent via the analog output interface to activate the myoelectric hand. The top and middle windows on the right display the outputs from the upper and lower optical sensors. The screen capture displays a triggered output pulse from the lower optical sensor. The bottom window displays the output of the pressure transducer which measures the grip force produced by the myoelectric hand. During the test, activation signals were repeatedly sent to the prosthetic hand. The corresponding output waveforms were stored in waveform files. The grip force, and opening and closing times captured were appended to a spreadsheet file.

The grip force, opening and closing speed of a myoelectric hand (Otto Bock SensorHand Speed, S/N: 201019801) and a myoelectric claw (Otto Bock DMC Greifer, S/N: 201039908) were measured to demonstrate the capability of this module.

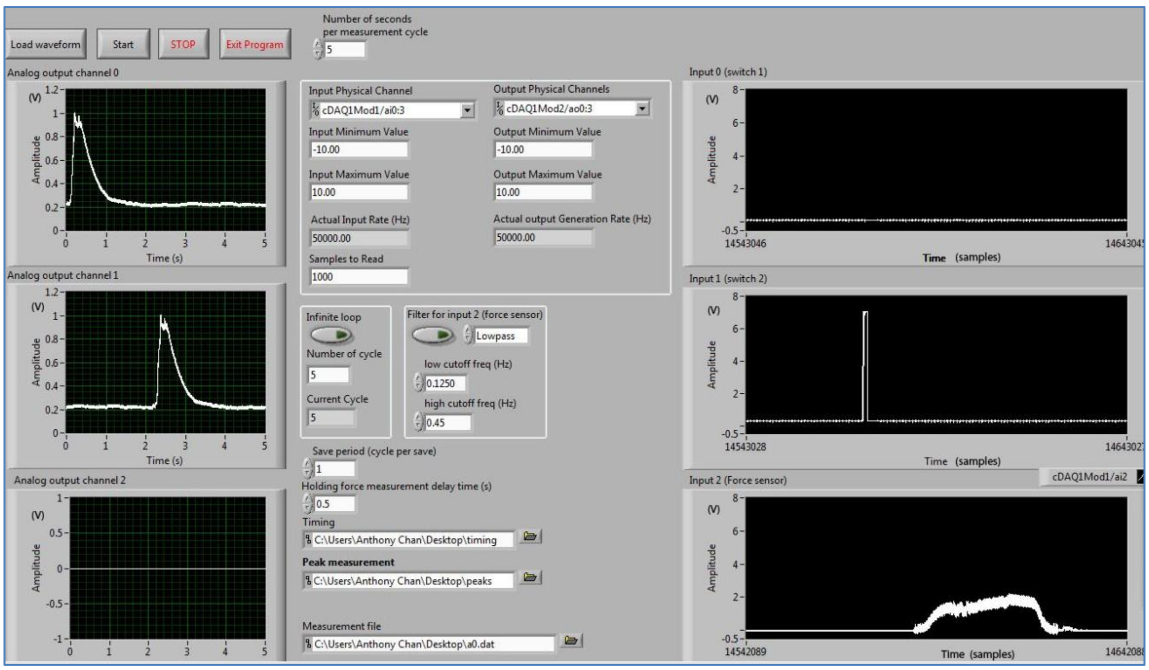


Figure 6.11 Activation and Measurement Module

6.10 Results and Discussions

The grip forces of a myoelectric hand and a myoelectric claw on loan from a supplier were evaluated using the assessment platform. The maximum grip forces of the hand and claw quoted in the product specifications were 100 N and 160 N respectively. The tolerances of these parameters were not published.

Table 6.3 shows five sets of measurements of the myoelectric hand exported to a spreadsheet file. The holding force (0.5 seconds after the peak grip force) was also recorded. The waveform of the force sensor output from 20 activations of the electric hand is shown in Figure 6.12. The lower diagram is a single-cycle time-expanded waveform showing the grip force profile from activation to deactivation. Figure 6.13 shows a plot of the maximum grip force in each cycle from 50 identical consecutive activations of the two prosthetic terminal devices. From the test data, the prosthetic hand (lower graph) produced a mean grip force of 91.5 N with maximum, minimum, and standard deviation values of 95.5, 83.0, and 3.3 N respectively. For the myoelectric claw (upper graph), these values are 155, 160, 151, and 1.6 N respectively. The error of measurements is ±8%.

Table 6.3 Grip Force Measurement Output File

Cycle	Closing Time(s)	Opening Time (s)	Grip Force (N)	Holding Force (N)
1	0.123	0.127	95.5	94.0
2	0.123	0.129	95.2	93.9
3	0.123	0.128	95.5	92,2
4	0.123	0.128	95.2	90.7
5	0.124	0.133	90.5	84.5

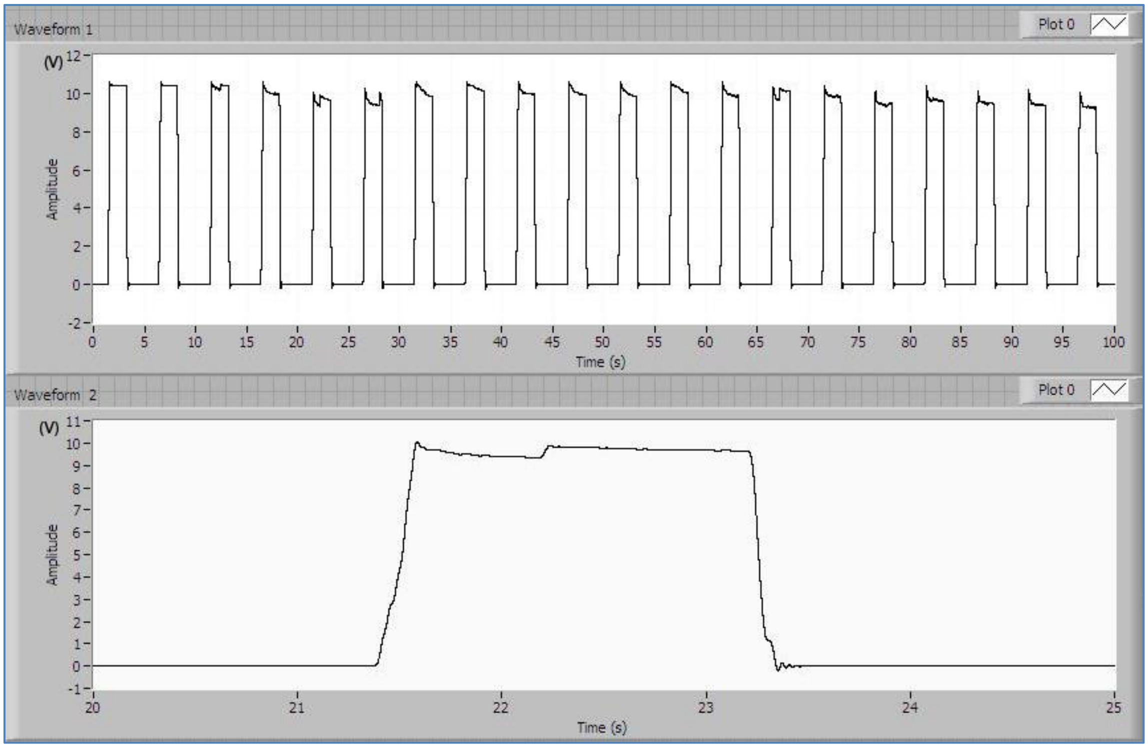


Figure 6.12 Grip Force Waveforms

Figure 6.14 is a plot of the opening and closing hand speeds of the terminal devices determined from 100 identical activations. The maximum hand and claw speeds quoted in the product specifications are 300 and 200 mm/s respectively. The tolerances of these specified speeds were not published. The average closing hand speed calculated from the measurement was 461 mm/s with maximum, minimum, and standard deviation values of 476, 434, and 9.1 mm/s respectively. The corresponding values of the myoelectric claw were 255, 262, 243, and 3.7 mm/s. The error of measurements is ±3%.

The results from the verification tests show that the grip forces were within 10% of the product specifications. However, the measured hand closing speed was more than 50% higher than that specified by the manufacturer. The measured closing speed of the claw was 28% higher than the specifications. In a discussion with the manufacturer, it was revealed that the hand speed was determined by measuring the hand opening and closing times between fully open and fully closed positions. The manufacturer's published speed was calculated by dividing the maximum hand open width by the measured time. The published value, therefore, included the acceleration and deceleration times of the hand from its fully open to fully closed positions, making the specified hand speed (300 mm/sec) much lower than the experimental result (461 mm/sec) obtained from the assessment platform.

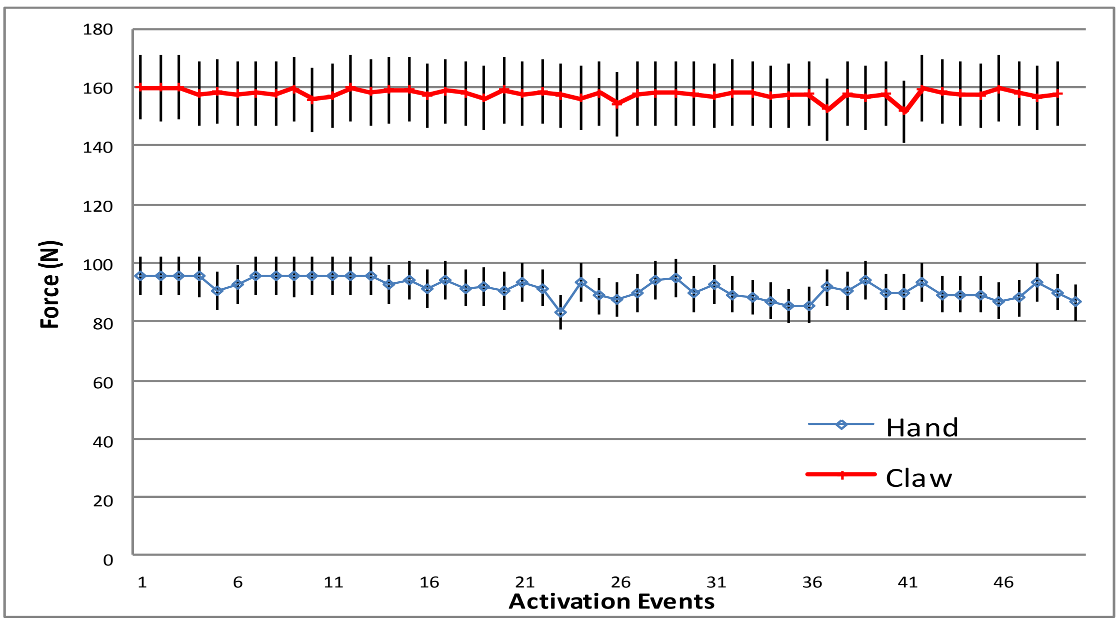


Figure 6.13 Maximum Grip Force of Electric Hand and Claw

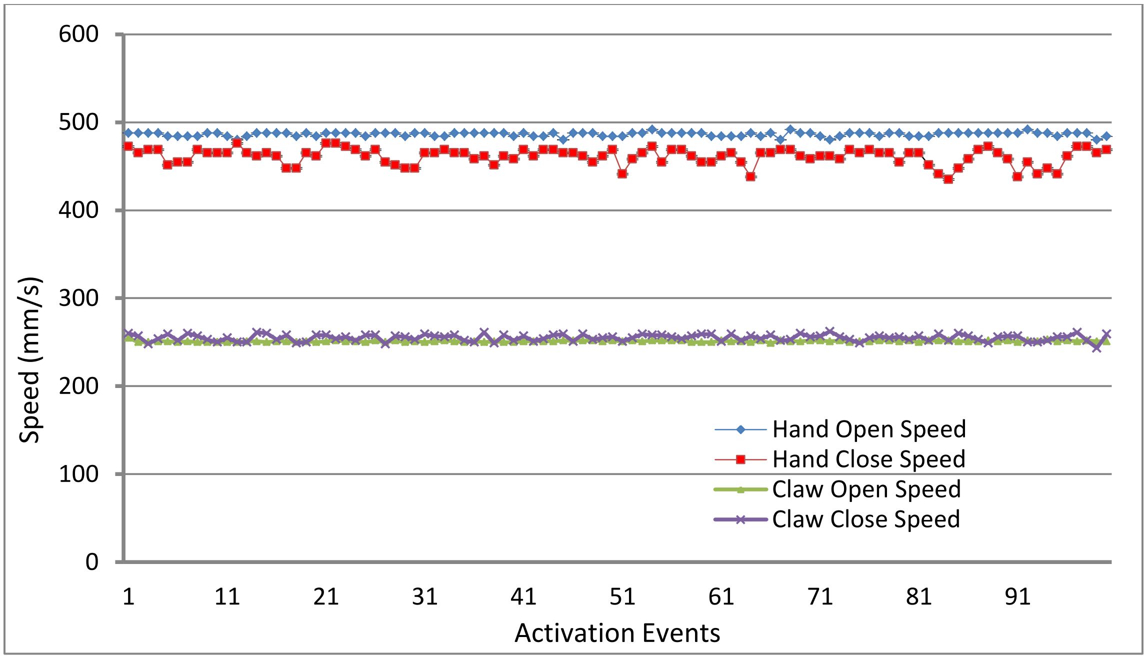


Figure 6.14 Open/Close Speed of Electric Hand and Claw

An experiment conducted on the electric claw according to the method used by the manufacturer confirmed this explanation. In the manufacturer's method, the power supply current waveform during activation of the terminal device is recorded. To measure the supply current, a 1 Ω sampling resistor is placed in series with the positive power supply wire to the electric claw; the voltage across the sampling resistor is recorded using the measurement module of the assessment platform. Figure 6.15 is the current waveform recorded in an attempt to reproduce the opening/closing time measurement of the electric claw using the manufacturer's method. The first waveform corresponds to claw opening and the second to claw closing. The start of the claw opening time is noted (the first arrow) when the current started to rise. The actuation motor stalled when the claw hit the full open mechanical limit. Stalling an electric motor creates a sharp rise in motor supply current which in this experiment is marked by the second arrow in the figure. The electric claw open time is, therefore, the time between the two arrows. The opening speed is calculated by dividing the maximum jaw open dimension of the electric claw (95 mm from manufacturer's specifications) and the time measured (0.45 s from the waveform in Figure 6.15). The open and close speeds of the electric claw from this set of experiment were respectively found to be 210 and 220 mm/s which are within 10% of the specified values.

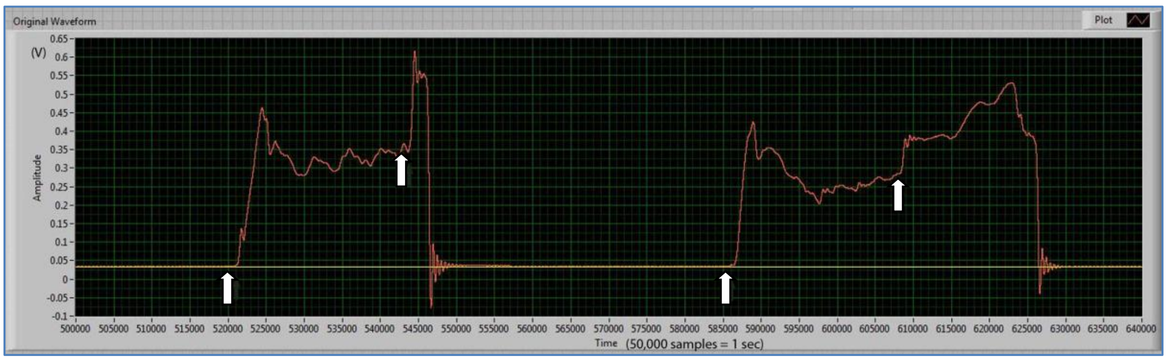


Figure 6.15 Power Supply Current of Electric Claw

6.11 Summary

An assessment platform for evaluating the technical performance of upper limb myoelectric prostheses was developed using the NI LabVIEW virtual instrument (VI) development system. The platform consists of an EMG signal acquisition module designed and built with analog electronic components. The module captures muscle biopotential signals from surface electrodes, amplifies the signals, and processes them to become myosignals for prosthetic device activation. The signal capture module VI imports the EMG signals or myosignals stored for future use. The programmable signal generation module VI creates a sequence of prosthetic activation signals from stored myosignal samples or from the built-in arbitrary waveform generator. The activation and measurement module VI outputs the signal train from the programmable module to activate the myoelectric prosthesis. In conjunction with external transducer circuits, prosthetic functions in response to activation signals can be measured and recorded.

The assessment platform was tested and validated by using it:

1. To create a 30-second prosthetic activation signal train and use it to activate a transhumeral prosthesis consisting of an electric elbow, wrist rotator, and electric hand. The signal train was programmed to activate the prosthetic arm such that it grasps a bottle, pours out its content, and returns it to the original position. The same signal train was programmed to be repeated and sent to the prosthesis. The prosthesis repeated the motion sequences according to the activation.
2. To verify the technical specifications of two myoelectric terminal devices: an electric hand and an electric claw. The terminal device was activated repeatedly by the same activation signal created from the programmable signal generation module. In the experiments with each of the terminal devices, the maximum grip force and the grip force waveform were measured and recorded. In addition, the opening and closing speeds of the prosthetic terminal device was determined and recorded.

The results confirmed that the assessment platform is a useful tool for evaluating the performance of upper limb myoelectric prostheses.

Chapter 7: Conclusions and Directions for Future Research

This research is a classical technology management (clinical engineering) study. It delivers an in-depth understanding of the technology and its clinical applications, evaluates related professional practices, investigates problems, identifies gaps, and offers solutions and new ideas for improvement.

To a person who lost an upper extremity from a work injury, the goal of the rehabilitation team (clinicians, practitioners, etc.) is to assist this individual to return to independent living and eventually back to work. A major challenge to an amputee and the rehabilitation team is to satisfactorily replace the natural limb functions with an artificial limb. To achieve this goal, the team needs to provide the amputee with an effective, safe, and reliable prosthesis to perform tasks of daily living, recreational activities, and work. In addition to providing appropriate rehabilitation training and ongoing support, the team strives to minimize the aggravation and frustration of the amputee during the learning phase of prosthetic intervention. The purpose of this research study is to identify factors pertaining to successful prosthetic prescription and help the rehabilitation team and funding agencies understand the functional capabilities and cost implications of upper limb myoelectric prostheses.

The literature review suggested that most tools developed to measure outcomes of upper limb prostheses are centered around qualitative observations on fulfilling activities of daily living. There is a lack of published standards on technical evaluation of upper limb myoelectric prostheses. Except studies relating to collateral injuries, there is no published literature on assessing risk of prosthetic use in daily activities, recreational undertakings, and in work environments. Very few studies were conducted on life-cycle cost of ownership, maintenance requirements, and reliability of upper limb prostheses.

In this research study, a retrospective analysis of amputee case files was performed on WSBC workers who suffered from amputations between 2004 and 2010. The study reviewed the profiles of these amputees as well as their prosthetic histories. Some characteristics and factors leading to successful prosthetic prescriptions were identified. Information on service history, reliability, and cost of ownership was analyzed and summarized from the prosthetic claims. An online questionnaire survey was conducted to collect information on prosthetic-related incidents. A risk assessment framework for upper limb prostheses was proposed and discussed. This framework was developed based on guidelines of medical device risk assessment standards and practice, the results from the survey, and understanding of the technologies and applications. In addition, an assessment platform to evaluate the performance of myoelectric prostheses was conceptualized, designed, built, tested, and validated. This engineering platform provides a practical tool to objectively verify functional specifications of myoelectric prosthetic components and assess their performance under a controlled laboratory environment.

The following sections highlight the outcomes from different parts of this research study. The significance of the research findings and suggestions on future direction for research are also discussed.

7.1 Prosthetic Management and State of Technology

A successful upper limb prosthesis is one that is built with appropriate technology, is fitted comfortably on the residual limb, and meets the actual needs of the amputee. To achieve this goal, it is important for the rehabilitation team to perform a comprehensive patient assessment in order to come up with an appropriate rehabilitation plan including selection of the prosthesis. Initial and ongoing rehabilitation training and sufficient technical support to ensure reliable prosthetic performance are essential for successful prescription. Some of the significant findings are listed below:

- The successfulness of amputee rehabilitation relies on rehabilitation planning and prosthetic intervention which involves multiple disciplines and many complicated processes.
- Rehabilitation planning should start right after the injury and preferably before the amputation. It should take into consideration of the patient’s physical condition, socio-economic situation, psychological status, and vocational needs. Prosthetic intervention as well as initial and ongoing rehabilitation training should be an integral part of the plan.
- The socket of a prosthesis is a custom-built assembly which interfaces with the residual limb and serves as the scaffolding to hold the control and functional components of the prosthesis. Comfort of wearing the prosthesis and its functional performance relies on the fit of the socket. Despite the challenges of coping with ongoing shape and volume changes of the residual limb and patient condition, maintaining a well fitted socket and reliable functional performance are important factors to avoid prosthetic abandonment.
- Light weight, human-like appearance, and quiet operation are some of the key desirable features of a prosthesis.

- Simulation tools are useful for pre-prosthetic assessment and control skill training without the amputee actually being fitted with the prosthesis.
- Most of the outcome measurement tools developed to measure the successfulness of prosthetic intervention are qualitative based and rely on subjective observation.
- Despite the lack of standards on powered prostheses in the industry, there is significant interest among rehabilitation professionals, researchers and some manufacturers to develop standards to facilitate outcome assessment and component's compatibility of prosthetic devices.

7.2 Amputee Case Files Review and Analysis

From the analysis of the medical case files of adult workers who lost their upper limbs from traumatic injuries, some significant findings are listed below:

- In the WSBC study group, about 82% of amputee workers were given both Myo and BP prostheses; 79% were first given a BP prosthesis. On average, a Myo prosthesis was provided to an amputee 12 months after the first BP prosthesis. This reflects the current prescription practice for WSBC patients.
- About 40% of workers who lost their upper limbs did not return to work. There were more TR than TH amputees returning to work after amputation. TH amputees were less likely to return to heavy duty work. These findings are expected as prostheses in the market are still far from matching the functional performance of natural limbs and are difficult to control; a TH prosthesis can only provide limited functions and is especially difficult to manipulate.

- Wearing a Myo or BP prosthesis had no influence on whether or not the amputee would return to work.
- Enabling factors for high prosthetic utilization by unilateral amputees are lower level of amputation (TR rather than TH), lost dominant limb, and male workers.
- Within the study group, 33% of TH and 10% of TR amputees abandoned all of their prostheses. 60% of the amputees who were prescribed with prostheses for more than three years were not using at least one type (BP or Myo) of prostheses. From Table 4.5 (Chapter 4), over $300,000 was spent on these abandoned devices. Significant cost could have been saved if these prostheses were not provided in the first place. It is, therefore, important to be able to determine the most appropriate type of prosthesis at the time of the initial prescription. The common practice of first providing a BP prosthesis to a new amputee should be reviewed.
- A typical prosthesis has a repair frequency of about once per year and required 1.7 demand maintenance services per year. These values were roughly the same for BP and Myo prostheses. When considering only services due to component failures, a TR prosthesis in general needs more repairs than a TH prosthesis. This is probably due to more wear and tear on the prostheses as TR amputees are usually more active in using their prostheses than TH amputees. Factors affecting the frequency of demand maintenance services include the nature of work, frequency and duration of prosthetic use, and the work environment.
- For this group of amputees, the average annual total prosthetic cost (total prosthetic cost divided by the number of possession years) was about $22,000

per amputee. The same cost for a Myo prosthesis was three times that of a BP prosthesis ($27,000 versus $8,000).

- The average 5-year prosthetic cost of ownership was about $67,000 per amputee. About 50% of this was spent in the first year after amputation. The average 5-year prosthetic cost of ownership of a Myo prosthesis was roughly 2.5 times that of a BP prosthesis ($87,000 versus $34,000).

The analysis identified some contributing factors and revealed that there is room to improve prosthetic utilization and worker’s satisfaction. The prosthetic utilization characteristics, support and service patterns, and life-cycle cost information revealed from this study will be useful information for rehabilitation professionals and funding agencies in rehabilitation planning and policy formulation.

7.3 Risk Assessments

The survey conducted in this research study confirmed that a prosthetic device can be hazardous and impose harm on the user. Judging from the survey and other information collected, it is important to include risk management in the process of prosthetic prescription. A risk assessment framework specifically designed for upper limb myoelectric prostheses taking into consideration their intended use is proposed. This systematic approach to assess risk includes the following processes:

- Risk analysis
- Risk evaluation
- Risk control

An example was used in the thesis to illustrate these processes. In risk analysis, the process reviews the device intended use and identifies potential hazards. As a starting point, an inventory of hazards relevant to basic upper limb prosthetic applications was formulated. A sample hazard table with assigned values of probability of risk and severity of harm was created as an exercise. Two methods of risk analysis (risk diagram and risk table) were introduced together with the concept of compiling risk scores and assigning threshold value.

Currently, risk assessment is not a component in the process map of professional practice in upper limb amputee prosthetic management. However, the professional community has expressed keen interest in this topic. From the awareness introduced by this work, it is expected that hazardous situations related to prosthetic use from activities and environmental conditions will be studied and documented. Together with performance characteristics of myoelectric prostheses, a list of critical safety requirements will eventually be developed for each category of employment and functional activities. Rehabilitation professionals should be convinced to adopt risk assessment into their professional practice and to create a set of risk assessment protocols and templates taking into consideration the amputee’s profile, activity (including work and recreational) requirements, environmental conditions, and prosthetic characteristics and limitations.

7.4 Upper Limb Prosthetic Assessment Platform

An assessment platform for evaluating technical performance of upper limb myoelectric prostheses was developed. The platform consists of a hardware EMG signal acquisition module, an analog I/O module, three programmable graphical user interface (GUI) virtual instrument (VI) modules, and a number of custom-built transducer circuits. Its performance was verified and validated by running it on a number of prosthetic components. The results from the experiments verified that the assessment platform is a useful tool in evaluating technical performance of prosthetic devices.

It was noted in the literature review (Chapter 2) that there is a lack of standard on performance evaluation of myoelectric prostheses. In addition, the rehabilitation professionals have expressed interest to identify or create a set of outcome measurement tools for upper limb prostheses. When the assessment platform was used to verify the functional specifications of two myoelectric terminal devices (a hand and a claw), it was discovered that the definition of hand speed used by the manufacturer was different from the one used in this study's experiments. This discovery signifies that without standardized definitions and harmonized measurement protocols, inconsistent reporting of functional parameters is inevitable and may lead to confusion and/or create problems.

With its programmable feature and data logging capabilities, the assessment platform can also be used to study consistency of prosthetic functional performance in response to repeated activation inputs and to determine the reliability and durability (such as failure rate) of prosthetic components and systems. In addition, the platform can be used to optimize myoelectrode placements in prosthetic planning, as well as in amputee pre-prosthetic assessment and training.

7.5 Summary and Suggestions for Future Work

This research study presented a critical review of upper limb prosthetic planning and intervention, and identified common factors affecting successful prescriptions of upper limb prostheses in the adult worker population who have lost their upper limbs from work-related injuries. A risk assessment framework for safe prosthetic prescription and use was developed and proposed. Collaboration among rehabilitation professionals is needed to further develop and affirm the framework so that it will become a standard of practice in prosthetic intervention. From a collection of amputee worker case files, prosthetic utilization characteristics, technical support and service patterns, and life-cycle cost of ownerships were compiled and presented. In addition, an assessment platform to evaluate the performance of myoelectric prostheses was conceptualized, designed, built, and validated. These outcomes will benefit prosthetic researchers, manufacturers, rehabilitation practitioners, funding agencies and, ultimately, amputees who are users of prosthetic technologies. Below are some specific suggestions for future work.

It is obvious that prosthetic devices currently available in the market are still far from reaching the functional level of a natural human limb. In addition to using the assessment platform in evaluating existing prosthetic devices, the assessment platform developed can be reconfigured for use in studying myoelectric signals, in signal processing research to improve prosthetic control (e.g., multiple signal pattern recognition and simultaneous activation), and in new prosthetic user assessment and bio-feedback training. It can also be modified for other biopotential signal applications, such as evoked potential (EP) studies.

The risk assessment framework for prosthetic prescription is a prototype that needs to be enhanced and validated. More works are required such as expanding the hazard table and developing templates for the various processes. Currently, risk assessment is not a required component in the professional practice of upper limb amputee prosthetic management. The proposed framework and its protocols will need to be reviewed and accepted by practicing rehabilitation professionals and preferably in conjunction with professional associations such as the Canadian Association of Prosthetics and Orthotics.

The amputee case study revealed the prosthetic cost of ownerships and their life-cycle cost distributions. It also provided knowledge in prosthetic utilization as well as technical service and support. This information will definitely benefit rehabilitation practitioners and funding agencies in appropriate deployment and ongoing support of prosthetic devices to amputee workers. The findings are from data mining 28 amputee case files supplied by WSBC. Recruiting additional subjects into this study will improve the statistical relevance of the findings. One approach to increase the sample size is to analyze and compare similar data sets from other workers' compensation boards within the same period of time. Alternatively, earlier WSBC case files (pre-2004) can be included to increase the sample size. Funding agencies such as WSBC should be convinced to implement consistent data reporting structure in order to collect reliable and consistent indicators for ongoing quality improvement purposes (e.g., tracking prosthetic utilization level).

Based on the findings in this study, a practice framework to enhance successful prosthetic prescription is conceptualized in Figure 7.1. The key elements of the process are listed below.

Key Elements of Prosthetic Intervention Process

I. Amputee demographic information (e.g., age, gender)

II. Injury and amputation information (cause of injury, injury date, dominant limb, amputation level, length of stump, skin condition)

III. Physical conditions (range of motion, myosignal strength)

IV. Medical and psychological assessment (medical history, phantom pain, stress, sleep disorder)

V. Amputee goal and motivation evaluation (vocational, social, recreational)

VI. ADL/IADL list (activities required to be performed by prosthesis)

VII. Work information (activities, duration, environment)

VIII. Insurance coverage and funding sources

IX. Scoring table of prosthetic requirements and weighted desirable features

X. Prosthetic specifications and functional performance assessment

XI. Prosthetic Options (list in order of ranks)

XII. Rehabilitation, training and support (type, location, level, cost)

XIII. Life-cycle cost and reliability estimation

XIV. Service locations

XV. Risk assessment (hazard table, mitigations)

XVI. Prosthetic decision, enabling accessories and rehabilitation provisions

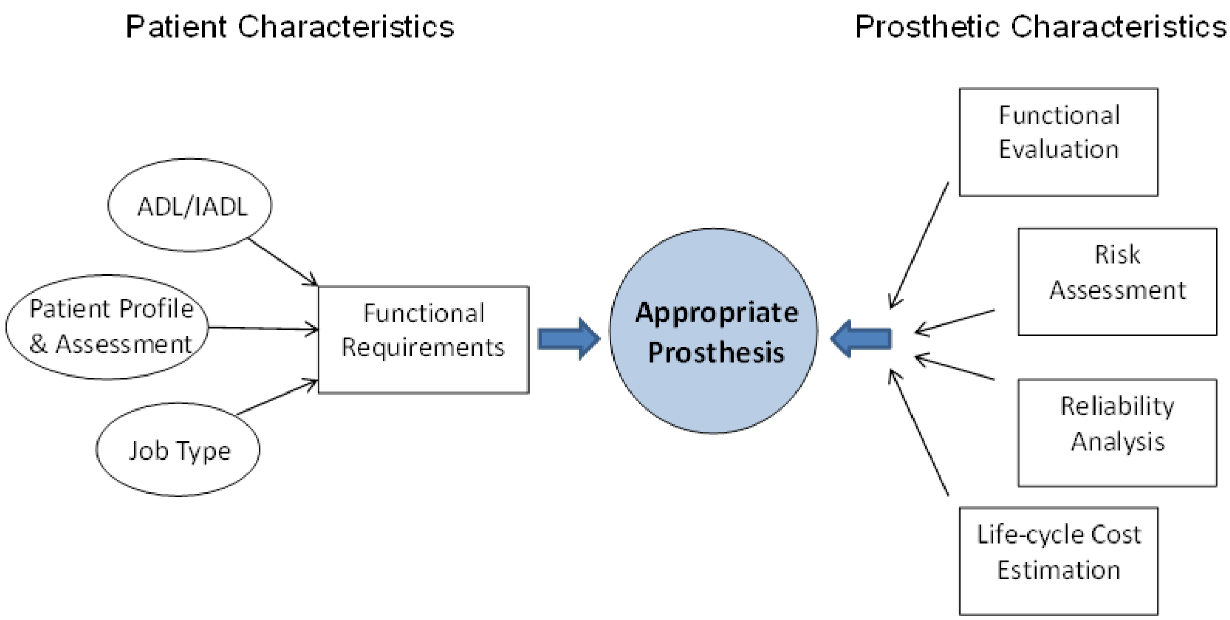


Figure 7.1 Prosthetic Prescription Framework

On the left side of Figure 7.1 are the functional requirements of the prosthesis identified through systematic assessment of the amputee. The assessment will consider the amputee's profile such as gender and age (Key Element I), medical and psychological condition (IV), pre-injury activity level (II), and expectation of recreational activities and future work (V). The functional expectation of the amputee will be categorized alongside with the conditions of the residual limb (III). Should there be an intention to prescribe myoelectric prosthetic components, the amputee's myoelectric signal quality will also be measured and documented (III). Depending on the level of amputation and the amputee's profile, the ADL/IADL (activities of daily living/instrumental activities of daily living) are itemized (VI). Activities related to the type of work that the amputee will return to and the perceived work environment will also need to be studied and documented (VII). The prosthetic functional requirements as well as desirable features of the prosthesis are derived and itemized from the above information. To differentiate the levels of importance, weighing factors are assigned to the desirable features (IX).

Available prosthetic components (XI) are evaluated against the identified requirements and desirable features. The functional performance of these devices should meet the amputee’s functional requirements. For example, if the amputee is intended to return to work in a fish processing plant, the prosthesis must be able to perform the required work activities and to function in wet environment. Prosthetic components not meeting one or more of the requirements will be eliminated. In case the performance of the device is questionable or not published in the manufacturer’s specifications, the device should be tested using a calibrated assessment platform (X). A scoring system based on the weights assigned to each of the desirable features will need to be developed to allow ranking of available prosthetic components (IX). The choice of prosthesis should also include factors such as the amputee’s physical and psychological conditions, and personal motivation (III, IV, and V). Estimation of the prosthetic life-cycle costs (XIII) should also be performed. These cost estimations should encompass initial and ongoing costs including those from service and maintenance, as well as from training requirements (XII). The life-cycle cost estimation should consider the effect of activity level and work requirements on prosthetic service frequency and reliability (XIII and XIV). The funding agency should be consulted for preliminary approval (VIII). After the prosthetic components are selected, the preliminary design will need to go through a hazard analysis (XV). A hazard table will have to be developed according to the prosthetic functions and its intended operating environment. All hazards identified with unacceptable risks will need to be mitigated. For example, an upper limb amputee will need to use a steering wheel knob installed in order for him/her to safely drive a vehicle.

It is important to involve all the stakeholders including funding agencies (VIII) and the amputee in the process and that the amputee is allowed to participate in all phases especially in the final prosthetic selection (XVI). This proposed framework will serve as a starting point for discussion. It will need to be reviewed, studies, discussed, modified, refined and adopted by the rehabilitation professionals.

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Appendices

Appendix A Amputee Profile Summaries

ID#: 26

Date of Birth: May 4, 1988

Gender: Female

Injured date: Apr 28, 2010

Cause and condition of injury/amputation: apron caught in a meat grinder while trying to pull out bones which stuck in the grinder. Switch went on from brushing against it, right arm got caught and tried to grab it with left arm.

Amputation date: Apr 28, 2010, follow up surgery on May 26, 2010

Type of Amputation: right short (5 cm distal to elbow) transradial and left partial hand (mid 3 fingers and partial pinkie) amputation

Dominant side before injury: right hand

Occupation before injury: meat wrapper & customer service at Cliffview Meat & Sausage Ltd.

Retraining for employment: studying Bachelor of Arts to be a teacher

Occupation after amputation: studying since Sep 2011 to become a teacher

Prosthetist: ML

Prostheses: myo DMC Plus Greifer (July 2010); cosmetic/passive (July 2010)

Prostheses use frequency/duration (BP & Myo): wears cosmetic daily for 4 to 5 hrs per day; not using myo arm due to weight, discomfort ,cold sensitivity and pain when wearing. Fixed elbow flexion which makes arm not too functional.

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices): went through driver's evaluation and able to drive with adaptation (spinner knob and atternate hand control) to the car. Still needs modifications with the signal levers and high/low beam switch?

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): concern of collateral injury to the left upper extremity due to overuse of left hand.

Recreational Activities: swimming, yoga, dance, hiking and roller blading. Can no longer play piano or ride a bicycle. Was a gymnastic before her heart attack at age 14.

Worker has a pacemaker and defibrillator implanted at age 14 after a heart attack. Another heart attack at age 17.

ID#: 4

Date of Birth: Feb 2, 1960

Gender: Female

Injured date: Oct 31, 2003

Cause and condition of injury/amputation: arm caught in a saw

Amputation date: Nov 4, 2005 transradial, due to pain and loss of function in the left hand - Jun 8. 2007 transhumeral

Type of Amputation: left transhumeral

Dominant side before injury: right

Occupation before injury: upper deck block sorter

Occupation after amputation: return to work to the East Fraser Fiber Joint Plant as a trainer

Prosthetist: DH

Prostheses: BP with hooks (Jan 06); 1st myo with Greifer ETD (Apr 08); 2nd myo with MC ETD hook & flex wrist on non-articulating elbow

Prostheses use frequency/duration (BP & Myo): happy with how prostheses are working out. Typically not wearing her prosthesis as she tends to get pinching at the anterior socket.

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices):

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): right carpal tunnel syndrome, neuroma on left residual limb

Recreational Activities:

ID#: 25

Date of Birth: Apr 21, 1979

Gender: male

Injured date: Sep 13, 2008

Cause and condition of injury/amputation: received a high voltage shock while installing a power line resulted in amputation of left arm, electrical burn to right arm and to electrical burn to right hand involving nerve damage to right hand. Debridement and wound caring surgical procedures on Sep 13, Sep 19, Oct 2, & Oct 23, 2008 and Jan 29, Apr 14, 2009, Amputation of left hand on Oct 30, 2008 and revision surgery on Apr 13, 2010. Limited range of motion on right hand and wrist (only very loose claw grip).

Amputation date: Oct 30, 2008

Type of Amputation: left below elbow

Dominant side before injury: right hand

Occupation before injury: BC Hydro linesman

Retraining for employment: will take course in Occupational Health & Safety (2 yrs distant program) in Jan 2012

Occupation after amputation: not working

Prosthetist: SC & DB

Prostheses: 4 sets: Left T/R body powered prosthesis: Otto Bock Movo wrist flex unit (Aug 2010), Otto Bock 8K23 Hand (Dec 2009) replaced with Hosmer Mechanical Hand (Aug 2011). Left T/R myo prosthesis: greifer (May, 2009), i-Limb Hand (May 2010). Recreational prosthesis: socket and terminal devices for baseball, basketball, hockey, kayaking, fishing, hunting, golfing & biking (May 2010). Bathing prosthesis provided in Nov 2008.

Prostheses use frequency/duration (BP & Myo): BP prosthesis 8-10 hr/day, myo about 20 min at a time due to weight.

Phantom pain?: minor

Driving after amputation (describe limitations and modification devices): yes with modification: button touch pad, turn signal buttons and wiper washer buttons, spinner knob

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.):

Recreational Activities: hockey, golf, weight lifting, etc. with recreational prosthesis

ID#: 11

Date of Birth: Jul 5, 1962

Gender: Male

Injured date: Oct 6, 2005

Cause and condition of injury/amputation: caught in granulator

Amputation date: Oct 7, 2005

Type of Amputation: left transradial

Dominant side before injury: ambidextrous

Occupation before injury: Fork lift (clamp truck) driver and relief lead hand

Occupation after amputation: work in his farm (orchard)

Prosthetist: RK

Prostheses: BP prosthesis with grip hand (Mar 2006); myo with SensorHand Speed (Aug 06); BP work prosthesis wotj TLO terminal device (Feb 2011)

Prostheses use frequency/duration (BP & Myo): Typically use BP, use myo device more intermittent

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices): nil

Driver rehab recommended spinner knobs. nil

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): In August 2010, he fell down and land on his prosthesis, he fractured his distal humerus. Required new prosthesis.

Recreational Activities: nil

ID#: 22

Date of Birth: Dec 21, 1978

Gender: male

Injured date: April 18, 2005

Cause and condition of injury/amputation: worker was in a vehicle which went off the road and flipped over an embankment. Worker suffered multiple fractures in the right arm and resulting radioulnar joint instability, fractured neck, cervical vertebrae and displaced C6. Underwent fasciotomies of the left forearm on April 18; Left forearm below elbow amputation and fixation on the right arm on Apr 26. A second surgery in Dec 2005 for bone graft due to non-union.

Amputation date: April 26, 2005

Type of Amputation: left below elbow

Dominant side before injury: ?

Occupation before injury: Pipeline construction labourer and self employed carpenter

Retraining for employment: would like to return to be an equipment operator

Occupation after amputation: carpenter

Prosthetist: AD

Prostheses: BP hook with friction wrist (Apr 2005), myo SensorHand Speed hand (Apr 2007)

Prostheses use frequency/duration (BP & Myo):

Phantom pain: occasional, minimal if working

Driving after amputation (describe limitations and modification devices):

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): reduced function of the right forearm and wrist and has pain with repetitive activities from initial injury; subsequent surgery

Recreational Activities: fishing, skating and boating; used to play hockey before injury

ID#: 23

Date of Birth: Nov 25, 1931

Gender: male

Injured date: Mar 22, 1990

Cause and condition of injury/amputation: overalls and sleeves caught in a saw blade dragging his left hand into the saw. Sustained significant lacerations to his left hand (severed left index and middle fingers) with nerve damage, skin necrolysis did not heal resulting in 12 subsequent surgical operations culminating in an amputation of the left forearm

Amputation date: Feb 1, 2006

Type of Amputation: left below elbow transradial (19cm from antecubital fossa crease)

Dominant side before injury: right hand (but told physician he is left handed in 2008 when requesting i-Limb Hand)

Occupation before injury: truck driver/saw operator

Retraining for employment:

Occupation after amputation: retired, has not returned to work since initial incident

Prosthetist: GH

Prostheses: BP with hook, hand (Mar 2006), thumb and finger pulley prosthesis; Myo with OB DMC myoelectric hand (Feb 2007)

Prostheses use frequency/duration (BP & Myo): able to perform ADL; use BP prosthesis most of the time, use myo hand part of the time.

Phantom pain?: no

Driving after amputation (describe limitations and modification devices): yes using an unmodified auto shift vehicle with his hook

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): hot burning pain on stump and electric shock to elbow.

Recreational Activities: socializing and helping his son with renovations. May go back to bowling.

ID#: 16

Date of Birth: Feb 24, 1961

Gender: male

Injured date: Jun 21, 2006

Cause and condition of injury/amputation: worker was completing a concrete cutting job when a load of angle iron fell on top of him. Worker sustained severe injury: severe left arm compound fracture involving humerous and elbow joint and left hand leading to left above elbow amputation; adhesive capsulitis right shoulder, fractures of T6 and L1 vertebra; fractures of the right transverse processes through L5; compound left tibia-fibula fracture.

Amputation date: Jan 5, 2007

Type of Amputation: left above elbow amputation with 20 cm stump

Dominant side before injury: left hand

Occupation before injury: concrete cutting worker

Retraining for employment: no training, switched to scanning concrete using ground penetrating radar

Occupation after amputation: returned to work in Aug 2008 (worker is the proprietor of his concrete finishing company) performing administrative work and with ground penetrating radar equipment

Prosthetist: DB (worker not happy, decided to switch); RK

Prostheses: Above elbow myoelectric prosthesis (Jun 2007) with ErgoArm, DMC Greifer, wrist rotator (worker insisted to start with a myoelectric prosthesis, no BP); BP for holding (Jun 2009)

Prostheses use frequency/duration (BP & Myo): rarely use. Prosthesis falling off due to short stump. Myo prosthesis difficult to operate and sensitive to wet condition that is common with his work

Phantom pain?: constant phantom pain affecting left arm

Driving after amputation (describe limitations and modification devices): driving with automatic transmission and custom controls

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): injured right shoulder from fall when being transferred in the hospital.

Recreational Activities: hunting, hiking, fishing and camping, had given up guitar and driving ATV. Tries to do some hunting but cannot hike for long distance on rough terrain

ID#: 13

Date of Birth: Jan 18, 1976

Gender: Male

Injured date: Nov 7, 2008

Cause and condition of injury/amputation: working as a flagman when a tandem rig came along and one of the metal arm caught him on the left hand side.

Amputation date: Nov 7, 2008

Type of Amputation: transhumeral, right

Dominant side before injury: right

Occupation before injury: work as a diamond driller on the rig

Occupation after amputation: not work

Prosthetist: DR

Prostheses: BP with ErgoArm and hook (Jun 2009), BP2 with ErgoArm and hook,(Nov 2009) mechanical hand (Apr 2010), myo hand with Greifer & Variplus speed hand (Feb 18/2011)

Prostheses use frequency/duration (BP & Myo): he is very diligent of becoming a strong prosthetic user. Using his prosthesis but prosthesis would break or give way on him. Not able to use myo more than 15-20 min due to significant loss of suspension and operation (Jul 2011 – Amp. Multidiscipline Program Report).

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices): N/A

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): Lt. shoulder anterior instability (July 2009)

Recreational Activities: nil

ID#: 5

Date of Birth: Apr 8, 1953

Gender: Male

Injured date: July 14, 2009

Cause and condition of injury/amputation: slipped on a wet area of the workplace floor and placed his left arm out to catch himself. His left hand was caught in the saw resulting him losing the fingers of his left hand.

Amputation date: July 14, 2009

Type of Amputation: trans carpal, left

Dominant side before injury: right

Occupation before injury: mill laborer

Occupation after amputation: not work

Prosthetist: DR

Prostheses: Myo with transcarpal hand (Mar 2010); BP with quick disconnect, hook (Jun 2010) & tools adaptor (Dec 2010); Cosmetic with transcarpal silicon passive hand (Apr 2010)

Prostheses use frequency/duration (BP & Myo): use consistently; cosmetic -3 to 4 times/wk, BP & Myo – 2 to 3 times/wk as it was not working consistently (reported Nov 2010)

Phantom pain?: Yes

Driving: Feb 28, 2011 (got driver license), do not need any modification.

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): neuroma

Recreational Activities: nil

ID#: 29

Date of Birth: Aug 4, 1957

Gender: Male

Injured date: Oct 23, 2004

Cause and condition of injury/amputation: trapped in a machine, crushed right upper extremity, leading to distal humeral amputation of the right arm.

Amputation date: Oct 23, 2004

Type of Amputation: right transhumeral

Dominant side before injury: right

Occupation before injury: bailer/operator/labourer (Waste Controller) at Crown Forest Products

Occupation after amputation: operating a toggle switch

Prosthetist: DR

Prostheses: BP prosthesis with hook and mechanical hand (Feb 2005); myoelectric prosthesis with MC ProHand, flex wrist and a re-use ErgoArm (Dec 2008)

Prostheses use frequency/duration (BP & Myo): active BP user for work, less Myo as it is heavier, more unwieldy to don precisely and had suspension issue

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices): steering knob on left side of steering wheel

Driver rehab recommended spinner knobs. Got driver license on May 28, 2005.

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.):

Carpal tunnel symptom on left side – Jun 13, 2005

Recreational Activities: nil

ID#: 20

Date of Birth: Jan 12, 1960

Gender: Male

Injured date: Aug 14, 2008

Cause and condition of injury/amputation: he was loading his truck with a power jack when it slipped and he had a torquing injury to his left wrist that was also pinned.

Amputation date: Oct 28, 2009

Type of Amputation: left transradial

Dominant side before injury: right

Occupation before injury: truck driver/warehouse worker

Occupation after injury: Not work

Prosthetist: DR

Prostheses: BP: Movowrist, mechanical hand, mechanical Al. and steel hooks (Jan 2010) modified to cosmetic in Apr 2011; Hybrid: electric hook (ETD Motion Control), linear transducer & flexion wrist (Nov 2010); Myo (modified from Hybrid on Apr 2011

Prostheses use frequency/duration (BP & Myo): often use mechanical hook before myo.

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices): nil

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): neuroma

Recreational Activities: nil

ID#: 19

Date of Birth: May 11, 1950

Gender: Male

Injured date: Jun 23, 2008

Cause and condition of injury/amputation: caught in the conveyor belt

Amputation date: Jun 23, 2008

Type of Amputation: transradial, right

Dominant side before injury: right

Occupation before injury: Metal sorter

Retraining for employment:

Occupation after amputation: labour full time

Prosthetist: DR

Prostheses: myo with MC ProHand (Oct 2008), Greifer (Jan 2009), replace MC hand with Ob Vari Speed Hand (Aug 2011); BP with 2 hooks (Mar 2009), BP2 with hook for work (Aug 2011)

Prostheses use frequency/duration (BP & Myo): BP- consistent and adept user, another BP was prescribed for work. Myo – occasional use of Greifer but not using MC ProHand much due to problem with inconsistent control & too slow.

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices):

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.):

Recreational Activities:

ID#: 18

Date of Birth: Feb 9, 1983

Gender: Male

Injured date: Aug 7, 2008

Cause and condition of injury/amputation: caught in a saw

Amputation date: Aug 7, 2008

Type of Amputation: transradial, left

Dominant side before injury: right

Occupation before injury: Lathe saw operator

Occupation after amputation: dry chain operator

Prosthetist: DH

Prostheses: BP with hook and hand (Nov 2008); Myo with EDT hook & ProHand (Jun 2009)

Phantom pain?: yes

Prostheses use frequency/duration (BP & Myo): use consistently

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices): Mar 9, 2009 got driver license. Use a spinner knob and resting arm at the 6 o'clock position at red lights/stops

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): musculoskeletal problem at shoulder

Recreational Activities: nil

ID#: 15

Date of Birth: Jan 27, 1952

Gender: Male

Injured date: Mar 1, 2007

Cause and condition of injury/amputation: caught in rock crusher

Amputation date: Mar 1, 2007

Type of Amputation: transhumeral, right

Dominant side before injury: right

Occupation before injury: a crusher operator

Occupation after amputation: not work

Prosthetist: GH

Prostheses: body powered elbow with ErgoArm, hook and tool adaptor (Nov 2007); myo with ErgoArm and VariPlus Hand (Jun 2011)

Prostheses use frequency/duration (BP & Myo): use BP 2-4 hours/day, just received (June 2011?) myo device (ErgoArm and Variplus Speed Hand), trying to use 4-6 hrs per day

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices): nil

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.):

Carpal tunnel symptom on left side

Recreational Activities: nil

ID#: 14

Date of Birth: Dec 10, 1956

Gender: Male

Injured date: Jul 11, 2006

Cause and condition of injury/amputation: caught at opening of a large silo and the silo gate unexpectedly striking the rt. arm

Amputation date: Jul 11, 2006

Type of Amputation: right transradial

Dominant side before injury: right

Occupation before injury: Labourer

Retraining for employment:

Occupation after amputation: a machine operator, but recently has been transferred to more office duties

Prosthetist: LJ

Prostheses: BP with hook and hand (Oct 2006); BP2 with hook and hand for ADL (Nov 2007); Myo with OB DMC Plus System Hand (Nov 2007), Greifer (Sep 2008) and Myo2 for ADL with DMC Plus Hand (Jun 2009)

Prostheses use frequency/duration (BP & Myo): Use Myoelectric during work (up to 12 hrs.), rarely use body-powered

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices): N/A

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): left lateral epicondylitis, left carpal tunnel syndrome

Recreational Activities: skiing

ID#: 9

Date of Birth: Dec 15, 1946

Gender: Male

Injured date: Feb 23, 2005

Cause and condition of injury/amputation: Right arm caught in a pulley (conveyor belt), amputating it at the elbow. There was soft tissue avulsion from the distal upper arm, a revision was performed Feb 25, 2005.

Amputation date: Feb 23, 2005

Type of Amputation: right transhumeral

Dominant side before injury: right

Occupation before injury: Loader operator in a gravel quarry

Retraining for employment:

Occupation after amputation: Heavy equipment operator/front end loader (full time)

Prosthetist: BS

Prostheses: 3 sets: Conventional primary RTAE prosthesis with Ergo Elbow, OB system hand, Hosmer SS hook, N-Abler II terminal syste (Jun 2005); Back up BP with Ergo Arm (Feb 2008); myo with ErgoArm, electric wrist rotator and Greifer (Jan 2009)

Prostheses use frequency/duration (BP & Myo): 16 hours/day (body powered prosthesis with an Otto Bock Ergo Arm Plus),no data yet with myo

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices): N/A

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): N/A

Recreational Activities:

ID#: 8

Date of Birth: August 1, 1979

Gender: Female

Injured date: Apr 4, 2005

Cause and condition of injury/amputation: caught Rt. forearm in a molding machine

Amputation date: Apr 4, 2005

Type of Amputation: right transradial

Dominant side before injury: right

Occupation before injury: Furniture packer

Retraining for employment:

Occupation after amputation: conveyancer at a notary public office

Prosthetist: LJ

Prostheses: body-powered with mechanical hand & Aluminum hook (Aug 2005); cosmetic prostheses (Nov 2005)

Prostheses use frequency/duration (BP & Myo): initially not wearing Body-powered prosthesis due to weight, appearing and discomfort, increased wearing time as found to be useful. Now wears BP and cosmetic prosthesis majority of the day (14hr/day).

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices): N/A

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): underwent a neurolysis and transposition of a neuroma of the lateral cutaneous of forearm

Recreational Activities: sedentary

ID#: 3

Date of Birth: Sept 14, 1979

Gender: Male

Injured date: May 14, 2004

Cause and condition of injury/amputation: arm caught in a conveyor belt

Amputation date: July 29, 2004

Type of Amputation: right transhumeral

Dominant side before injury: right

Occupation before injury: laborer

Retraining for employment: N/A

Occupation after amputation: security

Prosthetist: LW

Prostheses: BP, ErgoArm, mechanical hook, work hook and hand (Jan 2005)

Prostheses use frequency/duration (BP & Myo): 6 hrs/day when he is out. Does not wear when at home.

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices): N/A

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): N/A

Recreational Activities: sedentary

ID#: 27

Date of Birth: Jul 10, 1981

Gender: Female

Injured date: Jan 13, 2007

Cause and condition of injury/amputation: accident on a school ski trip at Whistler, found unconscious 10 feet below an ice block on the ski hill. Sustained severe head trauma, multiple fractures of spine, vertebral artery occlusion, a complete right tracheal plexus disruption, fractures from C5-C2, and multiple rob fractures; unconscious for several days. Paralysis of right arm. Performed a brachial plexus exploration surgery on Jul 9, 2007. Amputated in Oct 2010 to relief ongoing pain.

Amputation date: Oct 26, 2010

Type of Amputation: right transhumeral

Dominant side before injury: right hand

Occupation before injury: science teacher

Retraining for employment: completed master's degree

Occupation after amputation: pending to be hired as a teacher

Prosthetist: DD

Prostheses: body powered prosthesis (Dec 2010) with functional cosmetic hand and hook (OB12K42 elbow unit, 8K23 Hand and a Hosmer 88K hook), hybrid prosthesis (Aug 2011) with ErgoArm elbow, VariPlus Speed Hand, shoulder pull switch control, linear transducer; myo being planned.

Prostheses use frequency/duration (BP & Myo): BP prosthesis never use due to limited shoulder motion to overcome hook grip tension, limited function and pain.

Phantom pain? Severe ongoing

Driving after amputation (describe limitations and modification devices):

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.):

ID# (from old entry): 7

Date of Birth: Jul 13, 1979

Gender: Male

Injured date: Nov 26, 2009

Cause and condition of injury/amputation: electrocuted on the job site and suffered significant injuries, 4th degree burn to his left arm and 3rd degree burn to right leg including a left proximal humeral amputation on Nov 26 and right above knee amputation on Nov 28. Multiple debridement procedures on Dec 1, 3 & 6; last procedure in Nov, 2010

Amputation date: Dec 3, 2009

Type of Amputation: Left high transhumeral amputation & right above knee leg amputation

Dominant side before injury: right

Occupation before injury: Journeyman Lineman

Retraining for employment: Field Safety, crane operator, software

Occupation after amputation: continue to work for existing employer on modified duties

Prosthetist: RC (lower limb), DR (upper limb)

Prostheses: 2 sets of myo prostheses (one for work and the other for general purpose). First one in July 2010 and modified in Jan 2011 - with ErgoArm (first linear transducer, then stump switch control, then harness switch), Greifer (2 myo electrode) and ATP Hand. 2nd in Nov 2011 – with Dynamic Arm, wrist rotator, dual myo site control and can be fitted with existing Greifer

Prostheses use frequency/duration (BP & Myo): fair usage with some fitting problem

Phantom pain?: ongoing but not bad with medication (Lyrica)

Driving after amputation (describe limitations and modification devices): may pursue Class 3 or 5 license, will need adaptation: control pads, spinner knob & left foot accelerator.

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): overuse injury to right shoulder and arm.

Recreational Activities:

ID#: 24

Date of Birth: Apr 26, 1979

Gender: Male

Injured date: Jun 9, 2006

Cause and condition of injury/amputation: working doing maintenance on a harvester machine with his right hand in the machine. The operator turned the switch on and worker's arm was pulled into the cutter, resulting in a complete amputation of the right upper arm and multiple bruises and lacerations to the right upper torso. Underwent irrigation, debridement with revision surgery of the amputation on Jun 9, 2008. Worker also had the distal tip of the left index finger amputated in the mid phalanx with a log splitter in 1995.

Amputation date: June 9, 2006

Type of Amputation: right above elbow

Dominant side before injury: left

Occupation before injury: farm equipment operator

Retraining for employment: not able to return to previous work due to limitation from injury, currently studying to become an agricultural engineer

Occupation after amputation: not working since injury

Prosthetist: DB & ML (did not provide any prosthesis) and WH

Prostheses: 2 sets of prostheses: a BP prosthesis approved on Oct 27, 2006; and a hybrid prosthesis with Otto Bock ErgoArm Electronic Elbow, a SensorHand Speed and a Digital twin Hand approved May 09, 2007 plus a Greifer approved on Nov 30, 2007

Prostheses use frequency/duration (BP & Myo): myo all time, rarely use BP

Phantom pain?: initially intermittent and severe, currently occasional, not limiting his range of motion

Driving after amputation (describe limitations and modification devices): yes, got driver license in Switzerland, must drive an automatic with a steering wheel knob

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): bilateral shoulder range motion limitation (not injury) due to wearing left T/H prosthesis

Recreational Activities: hiking, used to biking (now afraid of falling)

ID#: 6

Date of Birth: May 17, 1966

Gender: Male

Injured date: June 14, 2004

Cause and condition of injury/amputation: Arm caught and crushed by the lift on the truck and the truck frame

Amputation date: June 14, 2004 to March 8, 2005 several surgeries attempting to reconstruct left forearm and hand but was not successful. Left just below elbow amputation on March 9, 2005.

Type of Amputation: left below elbow, transradial

Dominant side before injury: left

Occupation before injury: off-highway logging truck driver

Retraining for employment: took web designer course

Occupation after amputation: tried return to work on May 9, 2005 but not successful. Took course to

Prosthetist: DH & SC

Prostheses: body powered prosthesis with hook & hand (Aug 2005); myo with greifer (Feb 2008); protective socket (Feb 2008)

Prostheses use frequency/duration (BP & Myo): BP – consistent user, use up to 6 hrs of heavy work per day. Greifer use exclusively for work, not used much outside work

Phantom pain?: constant pain to arm and elbow

Driving after amputation (describe limitations and modification devices): class 5 driver license with restriction. Drives 1.5 hr to work everyday

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.):

Recreational Activities:

ID#: 21

Date of Birth: Oct 24, 1954

Gender: Male

Injured date: Apr 21, 2004

Cause and condition of injury/amputation: arm got caught in a chain-drive, the arm was pulled in and ripped off

Amputation date: Apr 21, 2004 and subsequent debridement and reconstruction due to infection on Jun 26, 2004

Type of Amputation: left high level transhumeral

Dominant side before injury: left

Occupation before injury: sawmill labourer including piling lumber and clean up duties

Retraining for emloyment: nil

Occupation after amputation: tried return to work on May 9, 2005 but not successful

Prosthetist: SS (initial), DH (repair)

Prostheses: Cosmetic with humeral/forearm and passive hand (Oct 2004); BP with mechanical elbow, quick release wrist & work hook (Dec 2004).

Prostheses use frequency/duration (BP & Myo): does not use much, does not find helpful

Phantom pain?: mild phantom sensation, occasional shooting, sharp pain but no last for any significant time

Driving after amputation (describe limitations and modification devices):

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.):

Recreational Activities:

ID#: 10

Date of Birth: Dec 22, 1947

Gender: male

Injured date: Sep 8, 2006

Cause and condition of injury/amputation: while working at construction, right arm smashed by a pile-driver resulted in crushed type amputation at the distal humerus.

Amputation date: Sep 8, 2006

Type of Amputation: right transhumeral

Dominant side before injury: left hand

Occupation before injury: construction worker

Retraining for employment: working with Vocational Rehab Consultant in Aug 2008

Occupation after amputation: nil

Prosthetist: DR

Prostheses: BP prosthesis with ErgoArm and hook (Nov 2006); cosmetic with system hand (Dec 2006); Myo with ErgoPlus Elbow & Greifer (Oct 2007), MC Hand & flex wrist (Aug 2008)

Prostheses use frequency/duration (BP & Myo): active user

Phantom pain?: yes, daily, awaken him 2 -3 times per week

Driving after amputation (describe limitations and modification devices): yes with spinning knob

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): discomfort in non-work injured left shoulder (impringement and biceps tendinopathy) due partly due to age and pre-existing condition as well as repetitive work and awkward postures.

Recreational Activities: fly-fishing, playing pool & racket ball; hobbies – cooking, gardening, repairing & maintenance of appliances & vehicles

ID#: 17

Date of Birth: Feb 12, 1958

Gender: Male

Injured date: Feb 2, 2004

Cause and condition of injury/amputation: on Feb 2, 2004, involved in a work related accident where his right arm got caught in a feed roll machine. He lost his thumb and portion of index and long fingers. After his initial surgeries, he went on to develop contractures of the 4^{th} and 5^{th} fingers. Went on to have tendon and joint release procedures done, but unfortunately this was also complicated by infections. Recommended for transradial amputation.

Amputation date: Jan 13, 2006

Type of Amputation: right transradial

Dominant side before injury: right

Occupation before injury: Working for a mill working as a tongue and groove operator

Retraining for employment:

Occupation after amputation: loader

Prosthetist: DH

Prostheses: Cosmetic arm (Jun 2006); Myo with SensorHand Speed (Aug 2006); Myo2 with Sensor Hand Speed (Feb 2007), SensorHand Speed (Feb 2008) & Greifer (May 2008); Myo3 with MC ProHand (Jul 2009)

Prostheses use frequency/duration (BP & Myo): Use myo consistently

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices): N/A

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.):

Lt, carpal tunnel syndrome, deQuervain's tenosynovitis

Recreational Activities:

ID#: 12

Date of Birth: Nov 20, 1960

Gender: Female

Injured date: Mar 25, 2006

Cause and condition of injury/amputation: got her coat sleeve caught in a chain and sprocket

Amputation date: Mar 31, 2006

Type of Amputation: right shoulder disarticulation

Dominant side before injury: right

Occupation before injury: cleanup at a sawmill (at time of injury)

Occupation after amputation: 3 days/week as youth co-ordinator

Prosthetist: DM

Prostheses: BP: external shoulder joint, manual elbow, TD hook (Nov 2006); Dynamic Arm, wrist rotator, SensorHand Speed (Jul 7, 2008) and Greifer (Oct 2008)

Prostheses use frequency/duration (BP & Myo): wearing myo prosthesis for the majority of the day on daily basis during the week. Leave the prosthesis off over the weekend. BP is used occasionally, eg wet.

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices): drive using a mini-touch spinner knob system with 6 control switches.

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): neuroma

Recreational Activities: biking, snow mobiling

ID#: 28

Date of Birth: Nov 2, 1954

Gender: Female

Injured date: Sept 18, 2004

Cause and condition of injury/amputation: On Sep 18, 2004, worker was leaving a walk-in cooler when the door swung back and hit her left arm. The top part of the prosthesis (artificial elbow) which she had implanted 20 years ago broke through her fresh as a result of a motor vehicle accident. Reconstruction was not successful. She underwent removal of the prosthesis and left with a left transhumeral amputation.

Amputation date: Apr 23, 2005

Type of Amputation: Left transhumeral

Dominant side before injury: right

Occupation before injury: dishwasher

Prosthetist: LJ

Prostheses: nil

Prostheses use frequency/duration (BP & Myo): n/a

Phantom pain?: yes, severe every 2 to 3 days

Driving after amputation (describe limitations and modification devices): not driving a vehicle (no license)

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): Over use injury to the right arm. Jan 30, 2006 diagnosed with right rotator cuff tendonitis. Impingement syndrome of the right arm. Arthroscopic subacromial decompression surgery done on May 29, 2008 & Mar 22, 2011

Recreational Activities: gardening, swimming

ID#: 1

Date of Birth: Jan 10, 1957

Gender: Male

Injured date: Oct 13, 2004

Cause and condition of injury/amputation: hit left hand against a plane head and sustained a traumatic forearm amputation proximal to the left non-dominant wrist. Underwent debridement of the forearm.

Amputation date: Oct 13, 2004

Type of Amputation: Short left below elbow transradial amputation

Dominant side before injury: left

Occupation before injury: Planeman

Retraining for employment: taking a course to upgrade his lumber grader ticket

Occupation after amputation: will require to install a Shark Fin Board Turner ($17,000 + $1,7000 installation) to allow him to return to a Lumber Grader position

Prosthetist: LJ

Prostheses: body powered hook with locking wrist, SensorHand Speed and Greifer

Prostheses use frequency/duration: mainly myo, frequently damaging hand due to heavy use; may not be using greifer

Phantom pain?: yes

Driving after amputation (describe limitations and modification devices): spinner knob with 4 function switch (turn signals, R/L and wipers on/off), plus floor mounted head lamp dimmer (high/low beam). Knob later changed to steering palm grip.

Driver rehab recommended/modifications:

Injuries after amputation (collateral/overuse injury, injury from hazard arising from prosthesis, etc.): depressed; right wrist overuse injury required surgery.

Recreational Activities: nil

Date of Death: Dec 17, 2009

Reason of Death: ruptured aorta caused by blunt force trauma from motor vehicle incident

Phantom Pain: yes, **Contralateral Pain:** right metacarpal pain - overuse syndrome

Appendix B Prosthetic Claim History Spreadsheets

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
6 (KT)	**14/06/2004**	**09/03/2005**								
	11/08/2009	25/08/2009	$4,135	Myo	refit	replace myo socket due to volume change	1	$290	$290	T/R diagnostic socket
							1	$2,300	$2,300	T/R socket
							1	$205	$205	electric arm technique
							1	$60	$60	electrode assessory kit
							1	$67	$67	electrode accessory for Definitive Socket
							1	$738	$738	battery mounting set
							1	$475	$475	cosmetic finish
	11/08/2009	25/08/2009	$1,000		new	protective socket without prosthesis	1	$1,000	$1,000	Modified T/R socket
	03/03/2009	04/03/2009	$226	Myo	repair	replace finger tip cover	1	$226	$226	Finger tip cover for greifer
	18/02/2009	19/02/2009	$1,569	BP2	repair	replace damaged locking hinge	1	$1,509	$1,509	Flail arm hinge
							0.5	$120	$60	Install hinge
	13/02/2009	19/02/2009	$2,050	Myo	repair	replace battery and charger	1	$1,025	$1,025	Energy pack
							1	$1,025	$1,025	battery charger
	26/11/2008	02/12/2008	$731	BP	repair	replace damaged hook	1	$731	$731	55012 5XA Hook
	04/09/2008	29/10/2008	$7,666	BP2	initial	replace BP prosthesis and downgrade existing to backup	1	$290	$290	check socket
							1	$2,300	$2,300	socket procedure
							1	$250	$250	double laminate
							1	$1,652	$1,652	Flail arm hinge
							1	$767	$767	quick change wrist
							1	$195	$195	harness
							1	$150	$150	tricep cuff
							1	$175	$175	control cable
							1	$475	$475	cosmesis exoskeletal
							1	$1,148	$1,148	hook 7L0L
							12	$22	$264	soft sock
	25/06/2008	14/07/2008	$130	Myo	adjust	Emerg adjustment of prosthesis due to lost residual volume	1	$70	$70	Tec sticky spot
							1	$60	$60	adjust socket fit
	25/06/2008	14/07/2008	$3,662	Myo	refit	replace socket for myo due to volume change	1	$290	$290	check socket
							1	$2,300	$2,300	socket procedure

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
6 (KT)	**14/06/2004**	**09/03/2005**								
							1	$57	$57	electrode assessory kit
							1	$64	$64	electrode assessory kit
							1	$226	$226	battery mounting set
							1	$475	$475	cosmesis exoskeletal
							1	$250	$250	double laminate
	14/02/2008	26/02/2008	$21,772	Myo	initial	provide new myo prosthesis	1	$2,300	$2,300	socket WCB, BE
							1	$290	$290	check socket
							1	$200	$200	double laminate forearm shell fo myo
							2	$2,054	$4,108	electrode
							2	$140	$280	electrode cable
							2	$64	$128	electrode assessory kit
							1	$226	$226	battery mounting set
							1	$120	$120	battery cable
							1	$165	$165	lamination ring
							1	$72	$72	coupling piece
							1	$350	$350	coaxial plug
							1	$7,671	$7,671	electric Greifer DMC Plus
							2	$1,025	$2,050	battery
							1	$1,156	$1,156	Lithium ion battery charger
							1	$304	$304	connection cable
							1	$120	$120	tricep cuff
							1	$1,562	$1,562	Flail arm hinge
							1	$195	$195	Figure 8 harness
							1	$475	$475	cosmesis exoskeletal, BE
	12/02/2008	15/02/2008	$2,300		new	provide protective socket	1	$2,300	$2,300	socket, BE
	01/02/2008	05/02/2008	$5,440		supply	1SP1RGXS	6	$22	$132	supplies
	02/03/2007	09/03/2007	$5,308	BP	repair	replace elbow and repair BP	1	$5,308	$5,308	no request found
	05/12/2006	07/12/2006	$180	BP	repair	repair damaged hook	1	$180	$180	repair badly damaged hook. The aluminu
	19/05/2006	08/06/2006	$154	BP	repair	repair damaged elbow	1	$27	$27	emergency repair to damaged elbow loc
							1	$7	$7	
							1	$120	$120	
	01/05/2006	29/05/2006	$60	BP	repair	repair damaged elbos	0.5	$120	$60	labour to install lock mechanism
	02/05/2006	21/05/2006	$269		supply	socks and hygiene supplies	6	$28	$168	soft sock
							1	$31	$31	Derma clean
							1	$35	$35	Derma prevent
							1	$35	$35	Derma repair

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
6 (KT)	**14/06/2004**	**09/03/2005**								
	20/02/2006	22/02/2006	$5,541	BP	refit	replace prosthesis	1	$2,000	$2,000	socket, BE
							1	$290	$290	Thermolyn stiff check socket
							1	$1,650	$1,650	Flail arm hinge locking 50989
							1	$479	$479	Friction wrist FW500
							1	$240	$240	Hotronic unit
							1	$295	$295	harness
							1	$175	$175	control cable
							1	$12	$12	tricep cuff
							1	$400	$400	Lamination
	12/01/2006	24/01/2006	$799	BP	new	provide Al hook and stump shrinker	1	$681	$681	Aluminum hook, 5XA
							1	$41	$41	wrist insert
							1	$18	$18	compressogrip shrinker, 3x18
							0.5	$120	$60	labour to install & fit
	25/11/2005	28/11/2005	$2,769	BP	refit	provide tigher socket	1	$2,769	$2,769	Dr Willms requested tigher socket for thi
	29/07/2005	08/08/2005	$6,168	BP	initial	initial BP prosthesis	1	$2,000	$2,000	socket
							1	$175	$175	check socket
							2	$735	$1,470	Locking liners, Ossur
							1	$468	$468	Lock
							1	$489	$489	step up hinge 51500
							1	$148	$148	tricep cuff, custom leather
							1	$440	$440	Wrist, quick change J2128 w/ss insert
							1	$728	$728	SS Hook -55009, 5X
							1	$165	$165	Figure 8 harness, custom
							1	$85	$85	cable, 32N, HD-custom

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
22 (TH)	**18/04/2005**	**26/04/2005**								
	15/08/2011	19/08/2011	$2,351	BP	replace	replace worn wrist unit	3	$100	$300	labour
							1	$892	$892	components to repair wrist unit
							1	$788	$788	custom liner
							5	$74	$371	filler socks
	07/03/2011	21/03/2011	$208	BP	repair	repair broken riveton tricep cuff	1	$100	$100	labour
							6	$15	$89	filler socks (6)
							1	$19	$19	repair to replace broken tricep cuff
	25/08/2010	26/08/2010	$1,321	BP	repair	repair worn out wrist unit	1.5	$100	$150	labour
							1	$294	$294	components to repair wrist unit
							6	$15	$89	filler socks (6)
							1	$788	$788	custom liner
	18/03/2010	23/03/2010	$1,024	BP	modify	replace flex wrist with fixed unit	6.5	$100	$650	labour
							1	$285	$285	replace wrist unit and relaminate
							6	$15	$89	filler socks (6)
	18/03/2010	23/03/2010	$306	BP	repair	repair wrist unit	0.5	$100	$50	labour
							1	$256	$256	components to repair wrist unit
	16/12/2009	21/12/2009	$1,593	BP	repair	repair flex wrist	1	$605	$605	repair to prosthetic arm - wrist componer
							1	$749	$749	custom liner
							6	$15	$89	filler socks
							1.5	$100	$150	labour
	14/08/2009	22/09/2009	$1,888	BP	repair	overhaul of BP prosthetic arm	1	$307	$307	overhaul of prosthetic arm
							1	$442	$442	hook, ss neoprene grip
							1	$788	$788	custom liner
							3.5	$100	$350	labour
	13/05/2009	08/06/2009	$731	BP	repair	repair of flexion wrist	1	$379	$379	flex wrist with swivel base
							12	$15	$178	filler socks
							1	$23	$23	elbow bushing
							1.5	$100	$150	labour
	30/05/2009	30/10/2008	$1,389	BP	repair	repair of flexion wrist and replace liner	1	$788	$788	Custom liner, Ossur
							6	$15	$89	Filler socks
							1	$411	$411	flex wrist parts to repair
							1	$100	$100	labour
	18/11/2008	18/11/2008	$838	BP	replace	replace ripped liner	1	$788	$788	custom liner
							0.5	$100	$50	labour

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
22 (TH)	**18/04/2005**	**26/04/2005**								
	15/10/2008	30/10/2008	$1,053	BP	repair	replace arm warmer	1	$265	$265	custom footwarmer
	30/05/2008	30/10/2008	$1,389	BP	repair	repl. worn liner & repair wrist unit	1	$788	$788	Custom liner, Ossur
							6	$15	$89	filler socks
							1	$411	$411	flex wrist parts to repair
							1	$100	$100	labour
	22/04/2008	23/04/2008	$578	BP	repair	repair BP prosthesis	2	$50	$99	Flex wrist lever lock
							2	$2	$5	strap twin loop
							6	$20	$119	sheath
							6	$15	$89	filler socks
							1	$20	$20	clean wrist unit & loop
							2	$48	$96	heavy duty cable
							1.5	$100	$150	labour
	22/04/2008	30/04/2008	$809	myo	replace	replace worn liner	1	$784	$784	custom liner
							0.5	$50	$25	labour
	23/04/2008	30/04/2008	$463	BP	repair	repair wrist unit	1	$50	$50	flex wrist - lever lock
							1	$194	$194	flex unit swivel base
							6	$20	$119	sheath
							1	$100	$100	labour
	03/03/2008	11/03/2008	$1,080	myo	replace	replace worn liner	1	$784	$784	Custom liner, Ossur for myo
	23/04/2008	30/04/2008	$297	BP	repair	repair wrist unit	1	$84	$84	wrist unit insert
							1	$50	$50	flex wrist lever lock
							1	$13	$13	washers and bushings
							1	$150	$150	labour
	03/03/2008	11/03/2008	$500	BP	new	supply hook for older arm	1	$442	$442	hook, 5XA
							1	$8	$8	rubber bands
							0.5	$100	$50	labour
	24/01/2007	12/04/2007	$20,641	Myo	initial	provide 1st myo prosthesis	1	$20,641	$20,641	single site myo prosthesis with SensorHar
	12/12/2006	15/12/2006	$1,168	BP	replace	replace liner and heater	1	$1,168	$1,168	locking liner and Hotronic heat unit
	29/09/2006	15/12/2006	$484	BP	repair	repair cables	1	$484	$484	repair cables
	30/05/2006	15/12/2006	$1,809	BP	repair	repair/adjustment	1	$1,809	$1,809	
	09/05/2006	15/12/2006	$4,550	BP	refit	replace BP prosthesis due to volume change	1	$4,550	$4,550	replacement of BE prosthesis
	14/02/2006	15/12/2006	$742	BP	repair	repair BP prosthesis	1	$742	$742	repairs to BE prosthesis
	01/11/2005	15/12/2006	$4,820	BP	initial	new BE first prosthesis	1	$4,820	$4,820	new BE prosthesis

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
10 (DO)	**08/09/2006**	**08/09/2006**								
	28/09/2011	18/10/2011	$6,566	Myo	refit	refit socket due to volume change	1	$2,880	$2,880	T/H Socket Procedure
							1	$350	$350	T/H Diagnostic Procedure
							1	$300	$300	Suction Socket Procedure
							1	$475	$475	T/H Exoskeletal Finish
							1	$350	$350	Double Lamination Procedure
							1	$376	$376	Lamination Ring, 13Z47
							2	$99	$198	Electrode Accessories, 13E206
							1	$89	$89	Power Pull Sock
							1	$1,387	$1,387	Wiring Harness. 13E187
							1	$161	$161	Mag Valve, 21Y15
	26/04/2011	16/05/2011	$3,310	Myo	refit	replace newer myo electrode	2	$1,655	$3,310	Electrode, 13E202=60
	31/03/2011	16/05/2011	$5,408	BP	refit	refit socket due to weight gain	1	$2,880	$2,880	T/H Socket Procedure
							1	$350	$350	T/H Diagnostic Procedure
							1	$80	$80	Valve P12-320-1000
							1	$375	$375	Lamination Ring, 13Z47
							1	$475	$475	T/H Exoskeletal Finish
							1	$195	$195	Harness
							1	$175	$175	Control Cable
							2	$89	$178	Pull Sock 3M-PP10-SM
							1	$350	$350	Double Lamination Procedure
							1	$350	$350	Cosmetic Re-Lam of Radial part of
	06/01/2010	approved?	$2,307	Myo	new	supply/install computer and software	1	$1,073	$1,073	computer interface
							1	$100	$100	serial port adaptor
							1	$894	$894	T-cable
							2	$120	$240	install software and train client
	09/12/2009	20/04/2010	$197	BP	repair	repair & replace arm parts	1	$95	$95	hook to hand cable
							1	$42	$42	arm terminal
							0.5	$120	$60	replace parts
	23/09/2009	01/10/2009	$89		supply	supply pull sock	1	$89	$89	power pull sock
	30/04/2009	22/07/2009	$990	Myo	new	replace battery	1	$990	$990	lithium battery 757B21
	03/10/2008	31/10/2008	$4,848	BP	refit	replace socket due to volume change	1	$290	$290	T/H Diagnostic Procedure
							1	$2,880	$2,880	T/H Socket
							1	$290	$290	Mag Valve, 21Y15
							1	$350	$350	Lamination Ring, 13Z47
							1	$368	$368	Alignment Kit 743A23

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
10 (DO)	**08/09/2006**	**08/09/2006**								
							1	$195	$195	Harness
							1	$475	$475	Cosmetic finish
	18/10/2008	21/10/2008	$367	Myo	repair	adjust socket size, realign electrodes	1	$87	$87	Nylon Pull Sock
							2	$20	$40	Shrinker, 2H0B0S18
							2	$120	$240	Labout to adjust socket volume &
	18/08/2008	28/08/2008	$9,935	Myo	new	supply Motion Control hand, flex wrist and controller	1	$4,505	$4,505	MC Hand
							1	$2,380	$2,380	Multiflex Wrist
							1	$2,380	$2,380	Prohand Option (controller)
							1	$550	$550	Short Hand Option
							1	$120	$120	Labout to install & setup
	12/06/2008	23/06/2008	$876	Myo	repair	replace finger tips (Greifer?)	1	$876	$876	replace finger tips of Greifer
	13/09/2007	22/10/2007	$7,931	Myo	new	supply Greifer	1	$7,931	$7,931	DMC Plus System Electric Greifer &
	11/09/2007	22/10/2007	$22,554	Myo	initial	supply myo T/H prosthesis	1	$2,880	$2,880	AE Socket
							2	$290	$580	AE Check Socket
							1	$475	$475	Flexible Inner Socket
							1	$368	$368	Alignment Kit
							1	$7,126	$7,126	Ergo Plus Elbow Unit (electronic)
							1	$230	$230	Coding plus set
							2	$2,054	$4,108	Electrode
							2	$136	$272	Electrode Cable
							2	$57	$114	Electrode Accessories
							2	$956	$1,912	Battery energy pack
							1	$712	$712	Battery mount set
							1	$1,156	$1,156	Lithium Ion Battery Charger
							1	$265	$265	Lamination Ring
							1	$72	$72	Coupling Piece
							1	$350	$350	Coaxial Plug
							1	$120	$120	Battery Cable
							1	$775	$775	Quick Connect Myo Wrist Adapt
							1	$100	$100	Valve
							1	$195	$195	Harness
							1	$175	$175	Bowden Control Cable
							1	$94	$94	Easy Proth Yellow
							1	$475	$475	AE Cosmesis Exoskeletal
	12/06/2007	14/06/2007	$1,079	BP	replace	replace liner	1	$791	$791	Locking liner
							1	$288	$288	Distal Cup

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
10 (DO)	**08/09/2006**	**08/09/2006**								
	11/04/2007	17/04/2007	$9,017	BP	refit & new	replace BP socket with supply new tool adaptor	1	$2,880	$2,880	AE Socket
							1	$290	$290	AE Check Socket
							1	$200	$200	Double wall socket
							1	$26	$26	FAB Ring w/oring
							1	$344	$344	Lamination Ring
							1	$368	$368	Alignment Aid for ErgoArm
							1	$3,641	$3,641	N-Abler Teminal Device
							1	$164	$164	N-Abler Quick Disconnect (to wrist
							3	$168	$504	Texas Assist Device (to tools)
							1	$425	$425	Custom Leather Shoulder Saddle
							1	$175	$175	Bowden Control Cable
	12/03/2007	15/03/2007	$275	BP	repair	replace broken cable	1	$175	$175	Control Cable
							0.5	$120	$60	Labour to convert hook to hand ac
							2	$20	$40	Shrinker, 2H0B0S18
	01/03/2007	23/02/2007	$2,765	BP	new	replace liner, provide hook and wrist adaptor	1	$791	$791	Ossur Liner
							1	$1,314	$1,314	#7 LO Hook
							2	$330	$660	Wrist Adaptor
	21/02/2007	28/02/2007	$383	BP	adjust	adjustment and supplies	1	$180	$180	protective glove, leather
							2	$21	$42	recievers
							1	$31	$31	50372 & 50378
							0.5	$120	$60	labour
	07/01/2007	17/01/2007	$100	BP	adjust	add pressure relief pad	1	$70	$70	Tec sticky spot
							0.25	$120	$30	labour
	17/12/2006	22/12/2006	$4,904	BP	new	provide forearm & wirst insert	1	$4,099	$4,099	Enabler 8 Style Forearm & Wrist
							2	$165	$330	wrist insert
							1	$475	$475	Relaminate forearm
	07/12/2006	20/12/2006	$2,890	Cos	initial	mechanical cosmetic hand & 2nd liner	1	$1,672	$1,672	System hand
							1	$228	$228	Cosmetic cover short sleeve
							1	$790	$790	Iceross liner
							1	$80	$80	Attach Pin Ratchet STD.
							1	$120	$120	Labour to install hand and glove
	12/12/2006	18/12/2006	$75	BP	adjust	add shoulder suspension strap	1	$75	$75	Strap
	13/12/2006	20/12/2006	$312	BP	adjust	adjust chest harness	2	$20	$40	volume pad
							4	$38	$152	socks
							1	$120	$120	labour

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10 (DO)	**08/09/2006**	**08/09/2006**								
	07/11/2006	14/11/2006	$11,097	BP	initial	supply first prosthesis	1	$2,500	$2,500	AE Socket
							1	$792	$792	Iceross locking liner
							1	$290	$290	AE Check Socket
							1	$473	$473	Iceross Ratchet
							1	$4,473	$4,473	ErgoArm Plus
							1	$371	$371	Quick Change Wrist
							1	$615	$615	5X Hook
							1	$58	$58	Hook Band Applier
							1	$195	$195	Harness Upper Extremety
							1	$175	$175	Bowden Control Cable
							1	$205	$205	Shuttle Lock Proceduer
							1	$475	$475	EXO Finish to Humeral Section
							1	$475	$475	EXO Finish to Forearm Section
	03/11/2006	07/11/2006	$873		new	liner for volume control	1	$873	$873	Ossur Locking Liner

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21 (PR)	**21/04/2004**	**21/04/2004**								
	28/03/2007	30/03/2007	$120	BP	repair	replace worn suspension sleeve	1	$60	$60	protector for Anatech shoulder
							0.5	$120	$60	labour (1/2 hr)
	13/06/2007	15/06/2007	$39	BP	repair	replace Axilla loop	1	$39	$39	replace Axilla loop
	21/11/2005	23/11/2005	$120	BP	adjust	labour to RE&RE suspension	1	$120	$120	revision to suspension for better donnnin
	20/04/2005	21/04/2005	$90	BP	adjust	labour to adjust	0.75	$120	$90	labour to adj lock system and socket
	02/12/2004	09/12/2004	$6,164	BP	initial	provide 1st work prosthesis	1	$2,500	$2,500	socket, carbon acrylic
							1	$250	$250	check socket
							1	$1,451	$1,451	Mechanical Elbow w forearm (E200)
							1	$436	$436	Friction wrist w quick disconnect
							1	$1,272	$1,272	Work hook, 3X, stainless steel Model 8 55
							1	$254	$254	Figure 8 & Bowden cable
	15/10/2004	25/10/2004	$5,401	cos	initial	provide 1st cosmetic arm	1	$2,500	$2,500	socket, carbon acrylic
							1	$250	$250	check socket
							1	$888	$888	hand, passive
							1	$1,266	$1,266	humeral/forearm, modular
							1	$347	$347	finish, foam cover & glove
							1	$150	$150	suspension, custom harness/chest strap

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23 (EC)	**22/03/1990**	**01/02/2006**								
	02/07/2011	25/07/2011	$1,050	Myo	repair	replace of DMV+ myo hand	1	$837	$837	repair cost of DMC+ Myoelectric Hand 8E
							1	$34	$34	shipping charge
							1.5	$120	$180	labour to disassmble, package and ship
	16/04/2011	28/04/2011	$846	Myo	replace	diagnostic liners (wih request below)	1	$798	$798	T/R diagnostic silicon suspension liner
							1	$48	$48	Pin for suspension liner
	28/03/2011	31/03/2011	$2,345	Myo	refit	replace T/R liner due to change in volume and sugery	1	$1,895	$1,895	BA Custom T/R silicone locking liner
							1	$140	$140	Modifications to cas for silicone liner
							1	$310	$310	Lycra cover
	08/02/2011	12/02/2011	$762	Myo	refit	redo and adjust due to surgery	1	$120	$120	labour - examination and testing to deter
							4.5	$120	$540	labour-dismantle and reconstruct socket t
							1	$42	$42	electrode mount supplies
							0.5	$120	$60	laobur or reassessment and training of pa
	17/12/2009	21/12/2009	$378	Myo	replace	replacement of glove and inner shell	1	$258	$258	Otto Bock System Inner Hand shell
							1	$120	$120	labour to disassemble, torn glove and inn
							1	$0	$0	Regal silicone glove - warranty
	13/07/2009	15/07/2009	$654	Cos	replace	replace torn glove	1	$654	$654	Regal Silicone Cosmetic Glove
	18/05/2009	08/06/2009	$809	Myo	repair	repair DMC+ hand and hand shell	1	$528	$528	Cost to repair & service DMV+ Hand and I
							2	$120	$240	labour to remove, ship, reinstall & test
							1	$17	$17	freight for 3rd party repairs (out)
							1	$24	$24	freight for 3rd party repairs (return)
	27/04/2009	08/06/2009	$2,840	Myo	refit	replace T/R socket due to volume change	1	$2,300	$2,300	Left T/R socket
							3	$120	$360	Electric arm technique
							1.5	$120	$180	lock procedure
							1	$0	$0	reuse existing Otto Bock DMC+ electric ha
	23/12/2008	30/12/2008	$226	Myo	adjust	supply Iceflex balance sleeve	2	$113	$226	Iceflex Balance Sleeve, F-101035
	08/10/2008	10/10/2008	$6,417	Myo	replace	redo socke and change suspension liner system	1	$798	$798	T/R silicon test liners
							1	$1,695	$1,695	Custom T/R silicone liner
							1	$280	$280	Lycra cover
							1	$120	$120	modifications to cast for silicone liner

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23 (EC)	**22/03/1990**	**01/02/2006**								
							1	$305	$305	Radial test socket
							1	$2,300	$2,300	T/R laminated socket, including fitting
							1	$585	$585	Myoelectric socket design and integratior
							2	$0	$0	reuse existing Otto Bock DMC+ electric ha
							1	$70	$70	coupling piece
							1	$264	$264	Lamination Ring for size 7 3/4 hand
	27/05/2008	02/06/2008	$1,313	Myo	adjust	replace with thiner liner (1mm) to enhance fit	1	$1,193	$1,193	Iceross locking liner
							1	$120	$120	labour to modify shuttle lock and adapt t
	14/05/2008	21/05/2008	$1,153	Myo	refit	replace liner due to volume change	1	$913	$913	Iceross locking liner, 3mm
							2	$120	$240	labour to modify socket interior to accom
	01/04/2008	03/04/2008	$598	Myo	repair	replace split glove	1	$598	$598	Regal left glove for Otto Bock hand
	12/10/2006	12/02/2007	$19,594	Myo	initial	provide first myo prosthesis	1	$19,594	$19,594	first conventional prosthesis
	16/03/2006	20/03/2006	$0	BP	initial	first BP prosthesis				missing prosthetic request

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24 (NSc)	**09/06/2006**	**09/06/2006**								
	19/08/2009	?	$809	BP	repair	replace/repair worn out components	1	$315	$315	shoulder bandage
							1	$90	$90	pull stocking
							1	$126	$126	pull cable
							1	$278	$278	montage, cleaning
	15/04/2009	16/04/2009	$476	?	?		1	$476	$476	
	15/04/2009	16/04/2009	$428	?	?		1	$428	$428	
	05/09/2008	08/09/2008	$2,712	?	replace	replace socket for Myo?	1	$2,712	$2,712	
	21/06/2008	18/07/2008	$829	?	?		1	$829	$829	
	04/02/2008	11/04/2008	$2,577	BP	replace	replace socket due to volume change/weight gain	1	$2,357	$2,357	upper arm shaft made of cast resin
							1	$135	$135	replacement of pull cable
							1	$85	$85	disassembly. Cleaning, assembly
	06/12/2007	13/12/2007	$11,343	Myo	new	supply Greifer?	1	$11,343	$11,343	Greifer?
	?	14/09/2007	$2,914	BP	repair	repair damaged mechanical UE prosthesis	1	$2,914	$2,914	
	15/07/2006	12/06/2007	$37,834	Myo	initial	initial myo prosthesis	1	$37,834	$37,834	provision of hybrid prosthesis
		24/11/2006	$13,000	BP	initial	initial BP prosthesis	1	$13,000	$13,000	provide initial BP prosthesis
	20/10/2006	29/11/2006	$120			myoelectric assessment & testing	1	$120	$120	myoelectric assessment & testing
	20/10/2006	27/10/2006	$130		supply	supply stump shrinker	2	$65	$130	stump shrinker

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16 (DT)	**21/06/2006**	**05/01/2007**								
	04/05/2009	14/06/2009	$8,519	BP	initial	provide prosthesis	1	$2,880	$2,880	T/H socket
							1	$350	$350	diagnostic socket
							1	$930	$930	comfort sleeve Iceross
							1	$686	$686	suspension pin Icerock
							1	$205	$205	procedure for installation of suspension p
							1	$451	$451	wrist unit WD400S
							1	$360	$360	North Western suspension (3 hrs)
							1	$1,247	$1,247	terminal device
							1	$1,050	$1,050	cosmetic finish
							1	$360	$360	operating cable (3)
	27/02/2008	25/02/2008	$4,400	Myo	repair	replace previously damaged electrodes	2	$2,054	$4,108	electrodes, 13E200=60
							2	$146	$292	cable, 13E124=60
	26/11/2007	28/11/2007	$6,999	Myo	replace	replace prosthesis due to non-functional	1	$2,880	$2,880	AE socket
							1	$1,040	$1,040	test socket
							1	$1,654	$1,654	definitive liner with fabric
							1	$455	$455	finishing
							1	$400	$400	suspension strap modifired with pull
							1	$570	$570	Ice Lock pin system
	18/07/2007	19/07/2007	$3,173	myo	replace	replace torn liner	1	$798	$798	diagnostic liner
							1	$1,415	$1,415	silicone liner
							1	$360	$360	embedded electrode
							1	$240	$240	embedded wire
							1	$240	$240	anti-elongation strip
							1	$120	$120	labour
	13/7/1007	13/07/2007	$1,256	myo	replace	replace lost battery	1	$1,025	$1,025	battery
							1	$231	$231	battery mounting set
	03/12/2007	05/05/2008	$8,027	myo	refit	replace unfit/failed liner	1	$2,880	$2,880	T/H socket
							1	$350	$350	Flexible inner socket
							1	$100	$100	laminated humeral section
							1	$798	$798	custom liner diagnostic procedure
							1	$468	$468	Alps silicon locking liner
							1	$468	$468	Alps custom cushion liner
							1	$1,285	$1,285	Ossur comfort locking liner
							2	$166	$332	electrode cables
							1	$354	$354	coaxial plug
							1	$272	$272	coaxial bushing

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16 (DT)	**21/06/2006**	**05/01/2007**								
							6	$120	$720	labour for fitting, installing & removing el
	19/06/2007	19/06/2007	$60	myo	adjust	fit adjustment	1	$60	$60	labour for adjustment
	16/04/2007	18/04/2007	$3,506	myo	initial	supply 4-channel processor	1	$3,506	$3,506	four channel processor
	26/03/2007	26/03/2007	$36,878	myo	initial	provide T/H myo prosthesis	1	$500	$500	dynamic test socket
							1	$2,880	$2,880	T/H socket
							1	$1,285	$1,285	Ossur upper liner
							1	$440	$440	shuttlelock
							1	$350	$350	Flexible inner socket
							2	$77	$154	custom made stump shrinkers
							1	$100	$100	laminated humeral section
							1	$8,650	$8,650	Ergo Elbow electric
							2	$2,054	$4,108	electrodes
							2	$138	$276	electrode cables
							1	$854	$854	switch
							1	$171	$171	connection cables
							1	$8,981	$8,981	DMC Griefer
							1	$3,465	$3,465	Wrist rotator
							2	$1,025	$2,050	batteries
							1	$712	$712	battery mounting set
							1	$1,156	$1,156	charger
							1	$126	$126	battery connection cable
							1	$270	$270	wrist unit
							1	$350	$350	finishing

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25 (CM)	**13/08/2008**	**13/10/2008**								
	01/09/2011	02/09/2011	$1,462	BP	repair	replace liner and adaptor	1	$1,062	$1,062	seal-in liner 5X
							1	$280	$280	Movo wrist adaptor
							1	$120	$120	labour to fit and trim liner
	16/08/2011	02/09/2011	$482	BP	modify	lengthen arm to fit Hosmer hand (to replace Otto Bock hand, Hosmer Hand is shorter)	1	$25	$25	Perlon cable
							1	$31	$31	cable housing
							1	$4	$4	clamp sleeve
							1	$62	$62	Dorrance Hand Stud
							3	$120	$360	labou
	16/08/2011	18/08/2011	$1,136	3athing P	repair	replace frayed liner	1	$1,010	$1,010	Ossur locking liner
							1	$126	$126	upper X shuttle pin
	22/07/2011	02/08/2011	$3,413	BP	repair	replace damaged Otto Bock Hand with Hosmer Hand	1	$2,158	$2,158	Hosmer Dorrance Mechanical Hand
							1	$280	$280	Movo wrist adaptor
							1	$120	$120	labour to integrate hand and glove
							1	$855	$855	Regal Glove
	09/06/2011	17/06/2011	$224	BP	repair	replace hand chassis due to stripped thread on threaded stud	1	$104	$104	Otto Bock Chassis for hand
							1	$120	$120	labour to disassemble & reassemble hanc
	08/06/2011	17/06/2011	$1,863	BP	replace	replace torn glove and supply spare grove and spare liner	1	$885	$885	Regal Glove
							1	$918	$918	Ossur locking liner
							0.5	$120	$60	labour to trim and fit liner
	26/05/2011	13/06/2011	$4,668	Myo	replace	refit failed liner	1	$1,516	$1,516	Ossur custom double seal-in liner
							1	$1,035	$1,035	Otto Bock custom liner diagnostic
							1	$1,877	$1,877	Custom liner with Lycra and side pin susp
							2	$120	$240	labout to cast and fit diagnostic and custc
	26/05/2011	13/06/2011	$6,902	BP	repair	replace broken BP prosthesis	1	$2,396	$2,396	Movo wrist
							2	$288	$576	Terminal device adaptor
							1	$230	$230	System Inner Hand
							1	$2,255	$2,255	Custom Skinergy Arm cover
							2	$130	$260	Casting silicone
							1.5	$120	$180	Labour for cast and fit

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25 (CM)	**13/08/2008**	**13/10/2008**								
							1	$885	$885	Regal Glove
							1	$120	$120	Labour for disassemble arm and repari an
	14/03/2011	21/03/2011	$403	BP	repair	replace worn Auxilla loop	2	$40	$80	Axilla Pads
							1	$135	$135	terminal device cable
							3	$20	$60	ball receivers
							1	$8	$8	ball terminal
							1	$120	$120	labour
	04/02/2011	25/05/2011	$14,800	BP	new	supply high definition cosmetic glove	1	$14,800	$14,800	high definition cosmetic glove-life art cus
	21/01/2011	26/01/2011	$163	Myo	shipping	shipping charge for wrong iLimb Hand	1	$163	$163	shipping charge
	28/12/2010	18/01/2011	$1,440	Myo & BF	refit	additional suspension and supply liner	1	$378	$378	Proseal Ring Set (Otto Bock)
							1	$1,062	$1,062	Iceross 5X Seal-in Liner
	13/12/2010	01/02/2011	$7,411	Rec	refit	replace unfit recreational prosthesis due to arm too large	1	$2,300	$2,300	Transradial Procedure
							1	$350	$350	flexible inner socket
							1	$920	$920	Ossur Liner
							1	$280	$280	Shuttle lock
							1	$171	$171	Lynn valve
							1	$878	$878	wrist unit
							8	$177	$1,416	wrist inserts
							1	$100	$100	Laminated forearm
							2	$210	$420	suspension sleeve Dermaflex short
							1	$226	$226	swagging tool
							1	$350	$350	finish
	23/11/2010	24/11/2010	$70		supplies	supply clean and disinfection product	1	$70	$70	3 pack set Clean& Simple
	25/11/2010	10/11/2010	$2,981	BP	pair & supply T	repair BP prosthesis and supply terminal devices	1	$214	$214	Otto Boch System Inner Hand
							1	$1,064	$1,064	Iceross 5X Seal-in Liner 5X
							3	$270	$810	Terminal device to wrist adaptors
							1	$863	$863	Regal High Definition Cosmetic Glove
							0.5	$60	$30	labour to replace inner hand and don glo
	20/10/2011	10/11/2010	$6,319	bathing	refit	provide new bathing prosthesis to replace unfit bathing prosthesis	1	$2,300	$2,300	T/R procedure

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25 (CM)	**13/08/2008**	**13/10/2008**								
							1	$500	$500	Dynamic TDS procedures
							1	$350	$350	flexible inner socket
							1	$100	$100	carbon fiber epoxy lamination
							1	$484	$484	Shuttle lock
							1	$88	$88	Shuttle pim
							1	$1,285	$1,285	Ossure upper X liner
							1	$406	$406	WD Quich change wrist unit
							1	$214	$214	passive hand
							1	$242	$242	cosmetic glove
							1	$350	$350	finish
	25/10/2010	10/11/2010	$9,551	Myo	modify	refit myo socket for iLimb	1	$2,300	$2,300	T/R procedure
							1	$500	$500	TDS procedure
							1	$1,064	$1,064	Iceross seal-in linner 5X
							1	$350	$350	flexible inner socket
							1	$171	$171	Lynn valve
							1	$310	$310	split battery packs (iLimb)
							2	$2,258	$4,516	suction electrodes
							1	$100	$100	Laminated forearm
							2	$120	$240	labout to disassemble existing arm and in
	27/08/2010	27/09/2010	$7,835	BP	refit	redo BP prosthesis due to not fit & supply flex wrist	1	$2,300	$2,300	T/R procedure
							2	$500	$1,000	Transparent diagnostic procedure
							1	$350	$350	flexible inner socket
							1	$178	$178	Iceross expulsion valve
							1	$100	$100	laminated carbon fibre epoxy - forearm
							1	$340	$340	bicep cuff
							1	$275	$275	Dacron/leather hinges (1 pr)
							1	$135	$135	heavy duty terminal device cable & housi
							1	$180	$180	Figure 9 harness
							1	$2,329	$2,329	Movo wrist (Otto Bock)
							1	$298	$298	Adaptor (Otto Bock)
							1	$350	$350	finish
	11/02/2010	25/02/2010	$1,308	BP	replace	replace stretched liner	1	$1,308	$1,308	Ossur seal-in X5 suspension liner
	04/02/2010	26/02/2010	$2,805	BP	refit	redo BP prosthesis due to stump change	1	$350	$350	T/R diagnostic socket
							1	$2,300	$2,300	B/E prosthesis
							1	$155	$155	harvast & resue wrist and valve
	10/12/2009	16/12/2009	$880	BP	repair	replace broken hand	1	$880	$880	replacement BP hand

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25 (CM)	**13/08/2008**	**13/10/2008**								
	19/12/2009	16/12/2009	$309	BP	repair	attempt to repair mechanical hand	2	$155	$309	labour to attempt to repair mechanical ha
	10/11/2009	16/11/2009	$1,023	Myo	replace	replace torn cosmetic glove due to volume gain	1	$560	$560	cosmetic glove
							1	$463	$463	iLimb skin covering
	24/07/2009	30/07/2009	$842	bathing	replace	replace stretched bathing arm liner	1	$842	$842	Iceross suspension liner
	30/09/2009	02/10/2009	$433	BP	repair	provide spare Axilla loop and harness	3	$39	$117	Axilla loop
							2	$158	$316	Figure 9 harness
	21/09/2009	30/09/2009	$869	bathing	replace	new silicone glove for bathing arm	1	$560	$560	cosmetic silicone glove
							2	$155	$309	labour
	16/09/2009	01/09/2009	$1,591	BP?	replace	replace liner and valves	1	$1,191	$1,191	Iceross seal-in liner for full suction susper
							2	$200	$400	expusion valve
	05/08/2009	07/08/2009	$2,609	BP	refit	replace socket due to volume change	1	$2,300	$2,300	replacement socket
							1	$155	$155	suction procedure U/E
							1	$155	$155	labour to harvest and re-use wrist unit
	24/07/2009	29/07/2009	$842	bathing	replace	replace stretched liner	1	$842	$842	Iceross upper-x suspension liner
	23/06/2006	25/06/2009	$1,402	BP	replace	replace stained and frayes glove, and worn liner	1	$560	$560	cosmetic glove silicon
							1	$842	$842	silicon suspension liner
	13/04/2009	14/04/2009	$242	BP	replace	replace soiled cosmetic glove	1	$242	$242	cosmetic glove
	25/05/2009	?	$574	Myo	refit	refit myo prosthesis due to volumr change	1	$574	$574	check socket & temp set-up
	06/05/2009	16/06/2009	$9,100	myo	initial	livingskin high definition glovefor i-limb	1	$9,100	$9,100	livingskin HD glove for iLimb
	23/03/2009	00/04/2009?	$48,168	myo	initial	provide 1st myo with iLimb hand and griefer	1	$5,333	$5,333	digital greifer
							1	$28,992	$28,992	iLimb hand
							1	$464	$464	iLimb skin covering
							2	$184	$369	electrode cable
							1	$2,703	$2,703	wrist rotator
							1	$184	$184	battery cable
							2	$1,361	$2,722	Myoblock electrode
							1	$441	$441	wrist unit

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
25 (CM)	**13/08/2008**	**13/10/2008**								
							1	$2,618	$2,618	Four channel processor
							1	$264	$264	adjustment cap
							1	$1,766	$1,766	T/R socket
							1	$574	$574	check socket
							1	$1,738	$1,738	exo-finish
	14/01/2009	15/01/2009	$1,040	BP	refit	refit prosthesis to accommodate volume change	1	$574	$574	check socket
							1	$234	$234	cosmetic glove (Otto Bock)
							1.5	$155	$232	labour to harvest lock & wrist
	09/02/2009	10/02/2009	$234	?	?	?	1	$234	$234	
	20/01/2009	22/01/2009	$668	?	?	?	1	$668	$668	
	28/11/2008	03/12/2009	$1,781	?	?	?	1	$1,781	$1,781	
	13/11/2008	18/11/2008	$8,243	BP	initial	provide 1st BP prosthesis	1	$8,243	$8,243	Ossur Iceross upper-x locking liner
									$0	OB Volunteering Open System Hand (8K2
						bathing prosthesis?			$0	Figure 9 harness
									$0	Socket
									$0	Check socket

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7 (MR)	**26/11/2009**	**02/12/2009**								
	20/10/2011	Approved?	$9,787	Myo2	new	provide 2nd Griefer and program tool	1	$8,874	$8,874	Electric Greifer DMV Plus 8E33=9
							1	$913	$913	Myoelectric Tool 757T13
	20/10/2011	31/10/2011	$568	myo	repair	replace electrode cable and pads	1	$161	$161	Electrode Cable
							1	$99	$99	Electrode accessories
							1	$8	$8	hanger
							2.5	$120	$300	labour
	13/10/2011	18/10/2011	$804	myo2	repair	repair work arm and replce liner tansducer switch and other	1	$134	$134	battery cable
							5	$120	$600	labour
							1	$20	$20	materials
							1	$50	$50	shipping to client
	20/09/2011	31/10/2011	$59,618	Myo2	initial	provide new (2nd) Myo with Dynamic arm & electric wrist	1	$2,880	$2,880	T/H Socket Procedure
							1	$350	$350	T/H Diagnostic Procedure
							1	$350	$350	Thermoplastic flexibel insert
							1	$475	$475	T/H exosketal finish
							1	$350	$350	Double lamination procedure
							2	$1,655	$3,310	Suction socket electrode
							2	$161	$322	Electrode Cable
							1	$161	$161	Electrode Cable
							1	$3,622	$3,622	Myotronic
							1	$3,637	$3,637	Electric wrist rotator
							2	$88	$176	Electrode accessories
							1	$1,998	$1,998	4-step transducer
							1	$40,432	$40,432	Dynamic Arm
							1	$195	$195	Upper extremety Harness
							3	$120	$360	Labour to make custom humeral connecti
							1	$110	$110	4-hole adaptor
							1	$146	$146	4-hole coupling plate
							1	$218	$218	Male pyramid socket adaptor
							1	$526	$526	Tube Adaptor Angled Aluminum
	17/08/2011	24/08/2011	$354	Myo	adjust	adjustment of finger tip for Greifer	1	$234	$234	Finger tip cover
			$998				1	$120	$120	labour

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
7 (MR)	**26/11/2009**	**02/12/2009**								
	16/08/2011	23/08/2011	$967	Myo	repair	factory repair of Greifer	1	$878	$878	Repairs to Otto 12K50 Bock Elbow Unit
							1	$29	$29	Shipping to Otto Bock
							0.5	$120	$60	Re & Re
	04/07/2011	07/07/2011	$944	Myo	repair	replace linear transducer with harness switch	1	$824	$824	Harness Switch (9x14)
							1	$120	$120	labour
	26/04/2011	05/05/2011	$542		supply	custom Farabloc garment to relieve phantom pain	1	$470	$470	custom Farabloc for T/H
							0.5	$120	$60	install chest strap
							1	$12	$12	shippling cast to supplier
	31/01/2011	25/11/2011	$8,177	Myo	modify	provide new prosthesis with 2 electrode sites	1	$2,880	$2,880	T/H Socket Procedure
							1	$350	$350	T/H Diagnostic Socket
							1	$350	$350	Carbon laminated frame
							1	$475	$475	T/H exosketal finish
							1	$350	$350	Flexible inner socket
							1	$1,655	$1,655	Suction socket electrode
							1	$161	$161	Electrode Cable
							1	$198	$198	Electrode accessories
							1	$28	$28	Pull tube
							1	$99	$99	Socket attachment
							1	$936	$936	Greifer Tips
							1	$500	$500	Tube adapter
							1	$195	$195	UE harness
	27/01/2011	03/02/2011	$140	Myo	adjust	modify harness system	1	$120	$120	labour to adjust
							1	$20	$20	materials
	19/11/2010	26/01/2011	$26,690	myo	modify	provide 2nd myo prosthesis (modified from 1st)				
							1	$2,880	$2,880	T/H Socket Procedure
							1	$350	$350	T/H Diagnostic Socket
							1	$475	$475	T/H exosketal finish
							1	$3,300	$3,300	LTI locking shoulder joint
							1	$1,037	$1,037	Sierra Nudge Switch
							1	$530	$530	Lock release
							1	$210	$210	Spoke Mounting plate
							1	$1,000	$1,000	Custom machinned Humeral section
							1	$3,280	$3,280	Elbow w/ Forearm
							1	$4,755	$4,755	ATP Hand

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
7 (MR)	**26/11/2009**	**02/12/2009**								
							3	$1,516	$4,548	Quick disconnect
							1	$280	$280	lamination ring
							1	$79	$79	coupling piece
							1	$380	$380	coaxial plug
							1	$120	$120	custom lamination procedure
							1	$90	$90	Attach plate w/ strap
							1	$2,026	$2,026	Linear transducer
							1	$166	$166	Electrode Cable
							1	$246	$246	battery mounting set
							1	$209	$209	Female Pyramid tube clamp
							1	$400	$400	Pyramid Adaptor
							1	$134	$134	battery cable
							1	$195	$195	Upper Extremity harness
	30/09/2010	05/10/2010	$470	Myo	modify	reforming thermoplastic socket due to relocation of electrode placement	1	$350	$350	T/H flexible inner socket
							1	$120	$120	labour to fit and install
	24/09/2010	01/10/2010	$876	myo	modify	replace longer finger tips to improve functions	1	$876	$876	Finger tip set
	14/05/2010	28/06/2010	$33,268	Myo	initial	provide first prosthesis for evaluation	1	$2,880	$2,880	T/H Socket Procedure
							1	$350	$350	Flexible inner Liner
							1	$205	$205	Electric arm technique
							1	$2,299	$2,299	Suction electrode
							2	$161	$322	electrode cables
							1	$8,519	$8,519	ErgoArm
							1	$394	$394	Alignment Aid
							1	$290	$290	wrist 10S1=50
							1	$79	$79	coupling piece
							1	$380	$380	coaxial plug
							1	$1,232	$1,232	battery charger
							2	$1,020	$2,040	battery
							1	$134	$134	battery cable
							1	$200	$200	connection cable
							1	$778	$778	battery mounting set
							1	$8,874	$8,874	Greifer 8E33=9
							1	$475	$475	Exoskeletal finish
							1	$700	$700	universal tool holder UHH02

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7 (MR)	**26/11/2009**	**02/12/2009**								
							2	$142	$284	wrist inserts
							1	$704	$704	QDME myo adaptor
							1	$1,979	$1,979	Linear transducer 9x25
							1	$150	$150	chest strap
	14/05/2010	28/06/2010	$860		new	provide diagnostic socket and myoelectric assessment	2	$250	$500	T/H Diagnostic Socket
							3	$120	$360	labour for testing

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26 (CMo)	**28/04/2010**	**28/04/2010**								
	02/07/2010	14/07/2010	$2,370	Cosmetic	initial	provide cosmetic passive prosthesis	1	$600	$600	second socket on same cast
							1	$475	$475	B/E Exo finish
							1	$1,113	$1,113	high definition long cosmetic glove & adju
							1	$182	$182	friction wrist
	02/07/2010	18/07/2010	$21,623	Myo	initial	provide first myoelectroc prosthesis	1	$2,300	$2,300	T/R procedure
							1	$350	$350	B/E myoelectric
							1	$475	$475	B/E finish
							1	$8,118	$8,118	Greifer DMC plus
							2	$2,155	$4,310	electrodes 13E.200.60
							2	$161	$322	electrode cable
							1	$290	$290	lamination ring
							1	$79	$79	1054 coupling
							1	$350	$350	coaxial plug
							1	$274	$274	connection cables
							2	$1,092	$2,183	lithium energy pack
							1	$1,232	$1,232	Li-Ion battery charger
							1	$1,092	$1,092	High definition cosmetic silicone glove
							1	$248	$248	battery mounting set

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27 (RB)	**13/07/2007**	**26/10/2010**								
	13/07/2011	15/07/2011	$120	BP	adjust	adjust harness to gain better control of terminal device	1	$120	$120	labour
	11/07/2011	26/08/2011	$220		supply	provide Farabloc limb coverto reduce pain	1	$220	$220	Custom Farabloc limb cover
	11/07/2011	31/08/2011	$26,817	Myo	initial	provide first myo prosthesis	1	$2,800	$2,800	T/H Socket
							1	$730	$730	laminated Humeral Section
							1	$8,868	$8,868	Ergo Arm Electronic
							1	$284	$284	glove
							1	$186	$186	connection cable
							1	$130	$130	battery cable
							1	$368	$368	coaxial plug
							1	$250	$250	harness system
							1	$5,881	$5,881	VariPlus Speed Hand
							1	$2,038	$2,038	Linear Transducer
							1	$800	$800	harness pull switch
							1	$77	$800	Coupling piece.
							1	$240	$77	Battery mount
							1	$280	$280	lamination ring
							2	$1,062	$2,124	batteries
							1	$1,202	$1,202	battery charger
	23/06/2011	28/06/2012	$858	BP	adjust	repair and adjust of BP prosthesis	1	$195	$195	harness
							1	$175	$175	control cable
							1	$54	$54	forear, lift assembly
							1	$14	$14	Axilla Pad
							3.5	$120	$420	Access & adjustment
	24/05/2011	27/05/2011	$1,322	BP	replace	replace torn liner	1	$60	$60	Fit and trim new liner
							1	$1,162	$1,162	Ossur Iceross upper X liner
							1	$100	$100	Attachment Pin for liner
	06/04/2011	24/05/2011	$5,923	BP	refit	replace socket with new	1	$2,800	$2,800	T/H Socket
							1	$650	$650	Flexible thermoplastic inner socket
							1	$350	$350	test socket
							1	$730	$730	laminated Humeral Section
							1	$205	$205	lock procedure
							1	$438	$438	Ossur upper X shuttle locks
							1	$384	$384	Otto Bock laminating ring
							1	$250	$250	harness system

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27 (RB)	**13/07/2007**	**26/10/2010**								
							1	$64	$64	lamination protection cover 13Z59
							1	$52	$52	lamination protection cover 13Z55
	30/03/2011	24/05/2011	$120	BP	adjust	adjust/trim socket for easier donning	1	$120	$120	labour
	03/03/2011	17/03/2011	$300	BP	adjust	modification of socket to allow easier donning	2.5	$120	$300	labour
	14/03/2011	21/03/2011	$1,065	BP	new	supply BP hook and modification of harness	1	$630	$630	#55036 hook
							1	$65	$65	cable extension
							1	$120	$120	labour
							1	$250	$250	new harness system
	08/12/2010	17/01/2011	$13,921	BP	initial	provide first conventional prosthesis	1	$2,880	$2,880	A/E Suction socket
							1	$450	$450	test socket
							1	$195	$195	Seattle System Valve
							1	$730	$730	laminated Humeral Section
							1	$5,117	$5,117	Elbow and forearm OB 12k42=45
							1	$260	$260	Wrist Hosmer WD400
							1	$550	$550	Flexible thermoplastic socket
							1	$250	$250	harness systems
							1	$880	$880	Hand OB 8k23=R7 1/4
							1	$284	$284	Glove OB
							2	$1,162	$2,325	Ossur Seal-in liners
	23/11/2010	17/11/2010	$198		suppy	supply prosthetic shrinker	2	$99	$198	Custom made Shrinker Socks for transhur

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28 (BB)	**18/09/2004**	**23/04/2005**								
	02/02/2006	06/02/2006	$1,694	n/a	initial	provide left shoulder cap			$1,600	shoulder cap/socket

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3 (AW)	**14/05/2004**	**19/07/2004**								
	31/08/2004	03/09/2004	$1,280		supply	supply 1st shrinker			$1,250	alpha cushion
									$30	1/4 hr labour
	14/01/2005	17/01/2005	$11,858	BP	initial	provide 1st BP prosthesis			$2,875	rt. Above elbow
									$1,550	alpha lock liners
									$4,585	elbow &forearm
									$605	lock pin & extra pin
									$250	test socket
									$300	shuttle lock technique
									$265	wrist
									$830	hand
									$228	glove
									$175	AE harness
									$195	Bowden cable system
	24/02/2005	01/03/2005	$1,023	BP	new	provide hook to BP prosthesis			$920	hook
									$55	wrist insert
									$48	hook to hand cable adaptor
	14/06/2005	17/06/2005	$60	BP	adjust	adjust & clean			$60	clean and adjust
	30/06/2005	12/10/2005	$228	BP	replace	warranty repair of malfunctioned elbow/ replace glove			$228	glove
	22/06/2006	27/06/2006	$569	BP	replace	replace glove, adjust socket, repair cable & harness			$3	1/2 Ft teflon
									$8	ball terminal
									$228	glove
									$175	harness
									$7	4 bar buckle
									$150	1.25 hr labour
	03/08/2006	31/08/2006	$5,529	BP	refit	replace BP prosthesis due to poor fit	1	$2,500	$2,500	T/H procedure
							1	$500	$500	test socket
							1	$48	$48	test socket 13S8=67
							1	$300	$300	lock technique
							1	$485	$485	century lock
							2	$661	$1,321	alpha liner
							1	$375	$375	exo finish
	31/08/2006	06/09/2006	$961	BP	new	supply work hook	1	$829	$829	#7 Work hook

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3 (AW)	**14/05/2004**	**19/07/2004**								
							1	$132	$132	wrist insert
	27/04/2009	09/06/2009	$2,252	BP	replace	replace torn and worn components	2	$738	$1,476	Alpha locking liners
							2	$100	$200	pins
							1	$242	$242	glove
							1	$214	$214	handshell
							1	$120	$120	1hr. Labour
	27/09/2011	11/10/2011	$11,417	BP	epair & replac	replace broken and unfit prosthesis	1	$2,300	$2,300	TH procedure
							1	$500	$500	test socket
							1	$503	$503	P20191 10-ossur
							1	$88	$88	extra pin
							1	$205	$205	lock technique
							1	$5,168	$5,168	OttoBock ErgoArm 12K42=50
							2	$580	$1,161	Alpha locking liners
							1	$54	$54	13G8=67 lamination collar
							1	$393	$393	WD4005 wrist unit
							1	$351	$351	fihure of 8 harness
							1	$195	$195	teflon lined control cable
							1	$500	$500	exoskeletal finishing

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
No patient prosthetic file (before 2009 and after 2010) provided as patient has deceased.										
1 (GP)	**13/10/2004**	**10/13/2004**								
	06/01/2010		$8,699	myo	repair	replacement myo hand	1	$8,355	$8,355	8E36-6 DMC plus hand
							1	$284	$284	cosmetic glove
							1	$60	$60	labour to install glove and hand
	19/11/2009		$1,650	myo	repair	non-warrany repair of myo hand	1	$1,490	$1,490	8E38=8-L7; replace damaged thumb sens
							1	$100	$100	loaner myo hand
							1	$60	$60	labour to assess and change hands
	01/10/2009		$646	myo	replace	replace glove and repair inner hand shell	1	$90	$90	labour to change gloves and repair inner l
							1	$556	$556	myo clean cosmetic glove
	05/08/2009		$1,010	myo	repair	replace battery and missing screw	1	$20	$20	labour to replace missing screws
							1	$990	$990	myo battery 757B21
	03/07/2009		$676	myo	adjust	increase socket size	1	$120	$120	labour to increase socket size and refinish
							1	$556	$556	myo clean cosmetic grove
	05/05/2009		$856	myo	replace	replace inner hand shell and glove	1	$258	$258	inner hand shell 8X18-L7 3/4
							1	$538	$538	myo clean glove 8S11C=210X78L6
							1	$60	$60	labour to install inner shell and change gl
	02/06/2009		$628	myo	adjust	adjust tight socket and replace teared glove	1	$90	$90	labour to adjust myo socket (May 25)
							1	$538	$538	myo clean glove (May 25)
	?		$430	myo	replace	replace glove and supply shrinker	1	$284	$284	myo cosmetic glove (June 1)
							1	$60	$60	labour to install glove (June 1)
							2	$43	$86	stump shrinkers (June 1)
	14/01/2009		$38		supply	provide Derma Prevent	1	$38	$38	Derma Prevent
	01/06/2006		$5,586	myo	refit	refit due to physical change & replace lost battery	1	$2,000	$2,000	trans radial socket
							1	$250	$250	myo procedure check socket
							1	$262	$262	laminating ring (reuse all remaining comp
							1	$640	$640	double wall exo finish for arm
							1	$1,006	$1,006	battery
						new glove and work hook	1	$228	$228	cosmetic glove
							1	$1,200	$1,200	left 7L0 work hook
						initial filling date and cost?			$0	

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
29 (IS)	**23/10/2004**	**23/10/2004**								
	10/02/2005	17/02/2005	$12,700	BP	initial	provide first BP prosthesis	1	$12,700	$12,700	BP prosthesis (breakdown missing)
	26/05/2005	30/05/2005	$2,110	BP	refit	replace socket due to volume change	1	$2,110	$2,110	replace unfit BP socket
	19/07/2005	25/07/2005	$198	BP	adjust	revise harness, replace wrist cap and spring	1	$67	$67	wrist cap
							1	$11	$11	spring
							1	$120	$120	labour hour
	26/08/2005	29/08/2005	$275	BP	repair	repair sticky lock mechanism	2	$120	$240	labour hour
							1	$35	$35	materials
	09/11/2005	10/11/2005	$142	BP	repair	adjust harness system	0.5	$120	$60	repair
							1	$82	$82	glove cleaner
	01/05/2006	19/06/2006	$734	BP	replace	replace stretched locking liner	1	$734	$734	locking liner
	05/09/2006	08/09/2006	$3,753	BP	refit	provide new socket for existing system	1	$3,753	$3,753	new socket (breakdown missing)
	28/09/2006	12/10/2006	$523	BP	refit	socket for existing system		$290	$290	flexible inner socket
								$200	$200	lamination
								$26	$26	cable
								$7	$7	hanger
	14/12/2006	18/12/2006	$88	BP	adjust	modify harness	1	$12	$12	axilla loop pad
							2	$38	$76	ply socks
	03/01/2007	09/01/2007	$22		supply	supply lotion		$22	$22	ALPS lotion
	11/01/2007	19/01/2007	$15,709	BP2?	initial?	breakdown missing			$15,709	
	10/05/2007	16/05/2007	$385	BP	replace	replace dirty harness		$385	$385	custom chest strap - prototype 3 hrs. labc
	19/05/2007	24/05/2007	$90	BP?	adjust	relocate Elbow lock cable	0.75	$120	$90	repairs labour
	18/06/2007	21/06/2007	$295	BP	repair	replace PVC glove	1	$235	$235	glove
							0.5	$120	$60	install glove
	25/07/2007	26/07/2007	$54	BP	repair	repair VO hand	1	$24	$24	steel cable
							0.25	$120	$30	install
	20/08/2007	21/08/2007	$1,667	BP	repair	repair VO mechanical hand	1	$200	$200	inner hand
							1	$235	$235	glove
							1	$1,112	$1,112	mech. Hand
							1	$120	$120	install
	19/09/2007	17/09/2007	$37		supply	supply TEC spot	1	$37	$37	TEC spot
	20/09/2007	24/09/2007	$1,410	BP2?	new	provide spare liner for new prosthesis	1	$1,285	$1,285	Upper liner
							1	$125	$125	pin

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29 (IS)	**23/10/2004**	**23/10/2004**								
	13/11/2007	15/11/2007	$66		supply	supply gel roll on	1	$66	$66	gel roll on
	31/03/2008	04/04/2008	$132		supply	supply gel roll on	1	$66	$132	distal roll on
	15/08/2008	15/08/2008	$400	BP?	repair	repair prosthesis	1	$24	$24	perlon cable
							1	$21	$21	ball receiver
							1	$235	$235	PVC glove
							1	$120	$120	assess and install components/glove
	19/09/2008	22/09/2008	$297	BP?	repair	replace broken parts	2	$132	$132	distal roll on pad
							1	$19	$19	tongue cap
							2	$43	$86	cable with fitting
							0.5	$120	$60	install cable and cap
	04/11/2008	17/11/2008	$1,805	BP?	repair	modify liner system	1	$1,415	$1,415	OttoBock custom liner
							1	$270	$270	Lycra cover
							1	$120	$120	cast modifications
	18/11/2008	25/11/2008	$433	BP?	repair	repair ErgoArm	1	$363	$363	factory repair to ErgoArm
							0.5	$120	$60	Assess ErgoArm for function
							1	$11	$11	Postage
	28/11/2008	30/12/2008	$24,572	myo	initial	first myoelectric prosthesis with reuse ErgoArm electronics	2	$290	$580	T/H diagnostic Socket
							1	$2,880	$2,880	T/H Socket
							1	$318	$318	Socket variation & distal roll on
							1	$649	$649	icelock ratchet
							1	$205	$205	lock procedure
							1	$1,815	$1,815	OB custom locking liner w/Lycre cover
							2	$2,054	$4,108	13E200 elecrode
							1	$1,470	$1,470	electrode acc, cables, plugs, battery mour
							1	$370	$370	control cable & harness
							1	$9,790	$9,790	motion control prohand w/Flaxwrist & co
							1	$475	$475	T/H cosmetic finish
							2	$956	$1,912	batteries
	06/01/2009	08/01/2009	$1,156	myo	new	provide battery charger for myo	1	$1,156	$1,156	757L20 battery charger
	21/05/2009	11/06/2009	$107	myo?	supply	provide roll on pad and hook to hand adaptor	1	$62	$62	sillipos roll on pad
							1	$45	$45	hook to hand adaptor
	27/08/2009	01/09/2009	$62		supply	regular supply	1	$62	$62	1496 Silipos distalcup
	10/09/2009	28/09/2009	$346	BP?	new	try out new liner	1	$346	$346	ESP liner
	24/09/2009	29/09/2009	$650	BP	repair	repair forearm	5	$120	$600	repair forearm

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29 (IS)	**23/10/2004**	**23/10/2004**								
							1	$50	$50	lamination materials
	02/11/2009	05/11/2009	$637	BP	new	supply spare liner	1	$577	$577	BK18-6-SC ESP liner
							0.5	$120	$60	Fit&trim liners
	14/12/2009	18/12/2009	$120	myo	repair	adjust & repair myo	1	$120	$120	repair prosthesis
	16/12/2009	29/12/2009	$70	BP	repair	adjust prosthesis	0.5	$120	$60	labour adjust socket
							1	$10	$10	leather
	22/04/2010	29/04/2010	$1,386	BP&Myo	new	spare liners for both myo and BP	2	$577	$1,154	BK-18-6 liner
							2	$86	$172	L-192003 attachment pin
							0.5	$120	$60	Fit&trim liners
	25/11/2010	03/12/2010	$663	myo	replace	replace stretched suction liner	1	$517	$517	ESP-18-6SC liner
							1	$86	$86	L-192003 attachment pin
							1	$60	$60	Trim&fit liners
	24/02/2011	08/03/2011	$696	BP?	replace	replace torn liner	1	$577	$577	BK 14-8SC Aegis Locking Liner
							0.5	$120	$60	Trim&fit liners
							1	$59	$59	X-SPP-1 Short plunger pin
	15/03/2011	22/03/2011	$6,231	BP	refit	refurbish and upgrade existing socket due to volume reduction	1	$2,880	$2,880	T/H socket procedure
							1	$350	$350	T/H dynamic socket
							1	$376	$376	13Z47 lamination ring
							1	$577	$577	Aegis Liner
							1	$308	$308	L-621000 Icelock Ratchet
							1	$195	$195	Harness Upeer Extremity
							1	$175	$175	control cable
							1	$205	$205	shuttle lock procedure
							1	$690	$690	8S4N Movoskin glove
							1	$475	$475	Exoskeletal finish
	04/04/2011	06/04/2011	$488	myo	modify	work to fit new prosthesis	1	$420	$420	re-lamination of forearm & install of the f
							1	$28	$28	50724 Cable assembly
							1	$8	$8	50747 elbow lock cable hanger
							1	$32	$32	50408 Forearm lift assist
	18/08/2011	12/09/2011	$1,413	myo	replace	replace torn liner and glove with hole	1	$577	$577	Aegis streamline locking liner
							1	$86	$86	L-192003 attachment pin ratchet short
							1	$690	$690	8S4C=220x80R11 Movoskin clean glove
							1	$60	$60	Fit&trim liners

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29 (IS)	**23/10/2004**	**23/10/2004**								
	07/10/2011	14/10/2011	$637	myo	new	supply backup liner for myo prosthesis	1	$577	$577	Aegis streamline locking liner
							1	$60	$60	trim&fit liners

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8 (PB)	**04/04/2005**	**04/04/2005**								
	03/08/2005	08/09/2005	$6,916	BP	initial	provide 1st BP prosthesis	1	$2,000	$2,000	TR socket
							1	$1,600	$1,600	alpha liners-locking
							1	$400	$400	pin and lock
							1	$1,110	$1,110	VO hand and glove
							1	$649	$649	hook
							1	$410	$410	harness/cable/adapters
							1	$297	$297	quick change wrist
							1	$450	$450	exoskeleton finish
	26/10/2005	07/11/2005	$3,428	Cos	initial	provide 1st cosmetic prosthesis	1	$2,000	$2,000	TR socket
							1	$358	$358	laminated in locking system
							1	$350	$350	cosmetic lamination and finish
							1	$720	$720	cosmetic hand and glove with wrist
	26/10/2005	02/11/2005	$2,656	BP	refit	replace socket due to volume cha	1	$2,000	$2,000	TR socket
							1	$358	$358	laminated in locking system
							1	$298	$298	wrist unit
	20/01/2006	ıpproved (no date	$300	Cos	replace	replaced worn cosmetic glove	1	$240	$240	cosmetic glove
							0.5	$120	$60	remove and replace
	15/03/2006	20/03/2007	$5,713	Cos	refit	refit cosmetic prosthesis after su	1	$2,300	$2,300	socket
							1	$250	$250	check socket
							2	$700	$1,400	alpha liners-locking
							1	$205	$205	pin procedure
							1	$358	$358	pin system
							1	$480	$480	laminated finish
								$720	$720	cosmetic hand/glove
	18/04/2007	23/04/2007	$8,226	BP	refit	replace BP socket due to physical change		$2,300	$2,300	TR socket
								$400	$400	pin and lock
								$297	$297	quick change wrist
								$450	$450	exoskeleton finish
							1	$2,300	$2,300	socket
							1	$250	$250	check socket
							2	$593	$1,186	alpha liners-locking
							1	$205	$205	pin procedure
							1	$358	$358	pin system
							1	$480	$480	laminated finish
	10/01/2008	14/01/2008	$5,629	Cos	refit	refit cosmetic arm due to weight	1	$250	$250	check socket
								$2,550	$2,550	BE socket
							1	$1,991	$1,991	Alpha locking liners
							1	$838	$838	pin system laminated finish

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8 (PB)	**04/04/2005**	**04/04/2005**								
	01/10/2009	08/10/2009	$4,877	BP	refit	re-fit after surgery	1	$2,300	$2,300	below elbow pin suspension procedure
							2	$642	$1,284	Alpha locking liners
							1	$250	$250	check socket
							1	$205	$205	pin procedure
							1	$358	$358	Coyote pin system
							1	$480	$480	forearm laminated finish
	03/07/2008	03/07/2008	$86		supply	supply stump shrinker	2	$43	$86	stump shrinkers
	20/01/2010	22/01/2010	$733	Cos	repair	replace broken hand	1	$673	$673	Regal cosmetic hand
							1	$60	$60	labour to assess, temporary repair and ch

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9 (NS)	**23/02/2005**	**23/02/2005**								
	19/05/2005	26/05/2005	$260		supply	supply shrinker	1		$260	stump shrinker with chest strap
	07/06/2005	30/06/2005	$9,919	BP	initial	provide 1st BP prosthesis	1		$2,500	T/H socket fitting fee
									$310	check socket procedure
									$528	flexion wrist
									$1,580	heavy duty elbow
									$1,720	OB system hand
									$504	exoskeletal cosmetic finish (upper)
									$504	exoskeletal cosmetic finish (lower)
									$26	elbow locking cable
									$59	hook rubber band
									$190	OB cosmetic glove
									$384	forearm lift assist
									$199	northwestern ring
									$198	split cable
									$228	soft socks
									$845	hook rubber band
									$62	hook to hand adaptor
									$82	hanger, axilla loop
	04/10/2005	06/10/2005	$2,290	BP	new	provide additional TDs	1		$1,480	Hosmer 7L0 SS work hook
									$810	Hosmer 5X SS hook
	28/10/2005	07/11/2005	$10,952	BP	replace	BP prosthesis with Ergo Arm due to volume change	1		$2,500	TH socket fee
									$310	check socket procedure
									$642	flexible inner socket
									$138	silicone pad
									$1,008	exoskeletal cosmetic finish upper and low
									$199	NW ring harness
									$198	split cable
									$60	elbow locking cable
									$845	quick disconnect
									$4,655	Ergo elbow system
									$30	lift lower loop
									$367	suction and valve
	06/01/2006	10/01/2006	$84	BP	supply	supply wrist insert with spare hook	1		$84	wrist insert
	01/02/2006	03/02/2006	$125	BP	supply	supply prosthesis donner	1		$125	zipwhiz prosthesis donner
	23/03/2006	28/03/2006	$257	BP	adjust		1		$40	humeral rotation screws
									$107	wrist insert

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9 (NS)	**23/02/2005**	**23/02/2005**								
									$20	new leather
									$90	drill and tap screw to lock forearm rotatic
	12/07/2006	14/07/2006	$1,128	BP	new	supply & customize hook	1		$810	Hosmer hook stainless steel
									$318	customization to hook
	19/07/2006	21/07/2006	$663	BP	supply	supply assessories	1		$125	zipwhiz prosthesis donner
									$396	control cables
									$124	hand to hook adaptors
									$18	hook spring
	03/10/2006	03/10/2006	$169	BP	repair	repair valve	1		$169	small valve
	21/11/2006	22/11/2006	$615	BP	adjust	adjust BP prosthesis	1		$125	zipwhiz socket donner small
									$60	tighten A/P clamp on socket 0.5 hr
									$190	AE harness
									$110	special axilla padding
									$130	fiberglass A/P socket
	23/04/2007	26/04/2007	$3,915	BP	new	provide N-Abler II TD	1		$3,755	N-Abler II terminal device
									$160	quick disconnect insert
	23/05/2007	25/05/2007	$125	BP	supply	supply donner	1		$125	zipwhiz prosthesis donner
	23/05/2007	23/05/2007	$879	BP	new	provide new N-Abler hook	1		$78	hook to hand adaptor to accommodate TI
									$688	5X Hook
									$6	tension spring
									$107	wrist insert
	19/09/2007	21/09/2007	$225	BP	repair	repair hook and replace tension spring	1		$180	retread dorrance 5X hook and replace spr
									$15	shipping charges
									$30	ship labour
	27/09/2007	28/09/2007	$188	BP	repair	replace OB elbow lock cable	1		$48	elbow locking cable
									$140	shop labor to install
	17/01/2008	11/02/2008	$11,381	BP2	initial	supply hybrid prosthesis with ErgoArm and wrist	1		$2,880	T/H socket fitting fee
									$310	check socket procedure
									$642	flexible inner socket
									$138	silicone pad
									$504	exoskeletal cosmetic finish upper
									$504	exoskeletal cosmetic finish lower
									$199	Northwestern ring harness
									$198	split cable and housing teflon lined
									$198	suction
									$169	valve

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9 (NS)	**23/02/2005**	**23/02/2005**								
									$4,704	ergo plus elbow system
									$60	elbow locking cable
									$30	lift lower loop
									$845	Hosmer FM100 wrist
	01/05/2008	07/05/2008	$2,925	BP2	initial	provide a better wrist	1		$3,630	assistive device-5 function wrist model B
									$140	disconnect insert
									-$845	Hosmer FM100 wrist (replace FM100 wris
	27/05/2008	12/06/2008	$125		supply		1		$125	zipwhiz yellow
	05/08/2008	07/08/2008	$482	BP	repair	replace worn wrist insert	1		$76	replace worn wrist insert
							2	$198	$396	control cables
							5	$2	$10	rubber
	05/08/2008	06/08/2008	$150	BP2	adjust	provide custom sheepskin pad for new spare prosthesis			$150	custom pad (axilla pad)
	04/11/2008	04/11/2008	$328	BP2?	modify	supply franged insert for N-Abler II	2	$164	$328	flanged insert for RTAE prosthesis
	22/12/2008	27/01/2009	$40,348	Myo	initial	provide Myo prosthesis with ErgoArm, electric wrist rotator and DMC Plus Greifer			$2,880	T/H socket fitting fee
									$310	dynamic check socket procedure
									$642	flexible inner socket
									$138	silicone pad
									$198	suction
									$169	valve
									$552	myocharge
									$7,995	OttoBock ErgoArm
							2	$2,195	$4,390	suction socket electrodes
									$1,929	linear transducer
							2	$166	$498	elect cable straight plug
									$3,465	OttoBock electric wrist rotator
									$8,326	Greifer DMC plus
									$2,050	OttoBock energy pack
									$1,156	OttoBock Li-ion Batter charger
									$712	Battery mounting set
									$256	connection cables
									$125	battery cable
									$3,450	Myorotronic

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9 (NS)	**23/02/2005**	**23/02/2005**								
									$504	exoskeletal finish- upper
									$404	exoskeletal finish- lower
									$199	Northwestern ring harness
	04/03/2009	10/03/2009	$280	Myo	initial	addition to above	1	$280	$280	lamination ring
9	19/03/2009	01/04/2009	$3,264	BP2?	repair	repair forearm balance	1	$2,714	$2,714	automatic forearm balance 12K35
9	09/04/2009	15/04/2009	$396	BP	repair	replace cable	2	$198	$396	complete cables for old prosthesis
9							2	$62	$124	hook to hand adaptors
9							1	$30	$30	perma clean
9	03/06/2009	15/06/2009	$125		supply	supply donner	1	$125	$125	Zip Whiz prosthesis donner
9	22/07/2009	29/07/2009	$212		repair	replace worn out components	1	$124	$124	thread segment OB 13Z50
9							1	$28	$28	pressure lock OB 13Z57
9							0.5	$120	$60	ahop labour - installation
9	22/09/2009	28/09/2009	$746	Myo	repair	repair Griefer by Otto Bock	1	$586	$586	repair as per Otto Bock quote
9							1	$120	$120	shop labor to test and assess
9							1	$40	$40	shipping
9	13/10/2009	20/10/2009	$125		supply	replace prosthetic donner	1	$125	$125	Zip Whiz prosthesis donner
9	27/05/2010	04/06/2010	$90	BP2?	repair	replace strap & adjust fit on harness	1	$90	$90	replace strap on harness, adjust fit
9	04/06/2010	21/06/2010	$1,774	BP2?	repair	repair of AE prosthesis by Otto Bock	1	$1,374	$1,374	repair as per Otto Bock quote
9							3	$120	$360	shop labour to test and assess
9							1	$40	$40	shipping
9	05/07/2010	20/07/2010	$5,484	BP2	repair	replace ErgoArm	1	$4,866	$4,866	ErgoArm OB12K42
9							1	$189	$189	new harness
9							1	$120	$120	shop labor-install wrist unit and re-match
9							1	$309	$309	examination to socket
9	19/08/2010	25/08/2010	$918	BP2?	repair	replace inner liner and valve casing	1	$624	$624	flexible inner liner
9							1	$169	$169	valve
9							1	$125	$125	prosthetic donner ZipWhiz
9	25/11/2010	01/12/2010	$465	Myo	repair	replace worn out donner and adjust myo arm prosthesis	1	$125	$125	prosthetic donner ZipWhiz
9							1	$280	$280	adjust and re-program myo AE prosthesis
9							1	$60	$60	adjust harness on conventional arm prost
	04/03/2011	11/03/2011	$7,432	BP2	repar	repair ErgoArm	1	$642	$642	Flexible inner socket
							1	$504	$504	exoskeletal cosmetic finish lower

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9 (NS)	**23/02/2005**	**23/02/2005**								
							1	$199	$199	northwestern ring harness 51604
							1	$160	$160	re-initial wrist
							1	$190	$190	suction valve
							1	$5,267	$5,267	OB 12K42 Ergo arm
							1	$260	$260	Base plate bukle lift loop
							1	$120	$120	custom lamb wool axilla pad
							1	$90	$90	fitting and alignment carge
	15/03/2011	22/03/2011	$1,206	BP2	repair	adjust and reprogram ErgoArm	1	$198	$198	Split AE teflon lined cable and housing sys
							1	$504	$504	exoskeletal cosmetic finish upper
							1	$504	$504	exoskeletal cosmetic finish upper

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11 (KD)	**06/10/2005**	**07/10/2005**								
	01/03/2006	01/03/2006	$80		supply	supply stump shrinker	2	$80	$160	stump shrinker
	14/03/2006	23/03/2006	$5,768	BP	initial	provide 1st BP prosthesis		$2,000	$2,000	Lt B/E
								$530	$530	northwestern suspension
								$560	$560	wrist
								$350	$350	leather
								$120	$120	cable
								$560	$560	finishing
								$1,348	$1,348	terminal device
							12	$25	$300	socks
	01/05/2006	04/05/2006	$2,010	BP	new	provide BP hand		$1,354	$1,354	Becker lock grip hand
								$596	$596	silicone glove
								$60	$60	small cable for hand
	25/08/2006	30/08/2006	$21,088	myo	initial	provide 1st myo prosthesis		$350	$350	check socket
								$2,000	$2,000	Munster socket
								$840	$840	finishing
								$10,956	$10,956	sensor speed hand
								$266	$266	cosmetic glove
								$3,802	$3,802	myo bock electrode
								$228	$228	battery connection cable
								$226	$226	battery mounting set
								$448	$448	battery
								$142	$142	electrode cable
								$1,138	$1,138	battery charger
								$272	$272	lamination ring
								$72	$72	coupling piece
								$348	$348	coaxial plug
	23/10/2006	24/10/2006	$2,523	myo	replace	replace custom silicone liner		$2,283	$2,283	OttoBock charge
								$120	$120	1 hr. labour casting and shipping
								$120	$120	1 hr. fitting and teaching controls
	04/06/2007	05/06/2007	$2,244	BP	repair	replace broken BP hand		$530	$530	new suspension straps
							3	$120	$360	cable
								$1,254	$1,354	new Becker hand
	17/07/2007	19/07/2007	$1,557	BP	repair	repair and provide spare hand		$501	$501	repair and replacement labour
								$110	$110	materials
								$945	$945	Becker hand
	01/08/2007	02/08/2007	$639	BP	repair	replace broken cable		$509	$509	control cable
							4	$33	$130	labour

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11 (KD)	**06/10/2005**	**07/10/2005**								
	10/03/2008	17/03/2008	$6,964	BP	replace	replace socket due to stump shrinkage		$2,300	$2,300	Lt B/E
								$450	$450	leather and liner
								$450	$450	laminated munster socket
								$560	$560	finishing
								$560	$560	wrist unit
								$130	$130	wrist insert
								$530	$530	northwestern with triceps cuff
								$240	$240	cable
							12	$33	$390	socks
								$1,354	$1,354	Becker lock grip hand
11	02/10/2008	07/10/2008	$720	BP	supply	supply cables	6	$120	$720	cables
	26/11/2008	08/12/2008	$7,080	myo	replace	replace socket due to stump shrinkage	1	$2,300	$2,300	trans radial
							1	$2,285	$2,285	OttoBock custom silicone liner
							1	$266	$266	cosmetic glove
							1	$272	$272	lamination ring
							1	$226	$226	batterty mounting set
							1	$840	$840	finishing
							1	$686	$686	ice lock pin suspension
							1	$205	$205	lock procedure
11	19/10/2009	21/10/2009	$960	BP	supply	supply cables	8	$120	$960	cables
11	16/12/2009	18/12/2009	$1,642	BP	repair	replace broken hand	1	$1,354	$1,354	Becker lock grid hand
11							12	$24	$288	socks
11	01/02/2010	03/02/2010	$810	BP	epair & replac	replace liner, repair wrist and re-finish	1	$450	$450	new pelite liner with leather
11							1	$240	$240	re-finish prosthesis
11							1	$120	$120	repair wrist unit
11	24/02/2010	26/02/2010	$1,350	BP	repair	replace harness	1	$630	$630	Northwestern suspension with triceps cuf
11							6	$120	$720	cables
11	12/07/2010	26/07/2010	$7,762	BP	replace	replace T/R conventional prosthesis due to weight gain, quick disconnect wrist, suspension and lock grid hand	1	$2,300	$2,300	TR conventional prsothesis
11							1	$450	$450	muenster type
11							1	$450	$450	leather & pelite liner
11							1	$350	$350	diagnostic socket

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
11 (KD)	**06/10/2005**	**07/10/2005**								
11							1	$530	$530	figure 8 straps with triceps cuff
11							1	$560	$560	tricep cuff
11							1	$415	$415	wrist unit
11							1	$130	$130	insert
11							1	$455	$455	finishing lamination
11							4	$120	$480	cables
11							1	$1,354	$1,354	Becker lock grid hand
11							12	$24	$288	socks
11	26/11/2010	22/12/2010	$3,655	BP	replace	replace prosthesis due to stump change after injury, prosthesis will be used for socializing	1	$2,300	$2,300	TR conventional prosthesis
11							1	$450	$450	munster type
11							1	$450	$450	Pelite & leather liner
11							1	$455	$455	finishing lamination
11	03/01/2011	03/02/2011	$7,196	BP2	initial	provide work prosthesis due to stump change and replace damage terminal device	1	$2,300	$2,300	TR conventional
11							1	$450	$450	munster type
11							1	$450	$450	leather & pelite
11							1	$350	$350	diagnostic socket
11							1	$530	$530	figure 8 straps with triceps cuff
11							1	$415	$415	wrist unit
11							1	$130	$130	insert
11							1	$455	$455	finishing lamination
11							4	$120	$480	cables
11							12	$24	$288	socks
11							1	$1,348	$1,348	TLO terminal device

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
4 (DD)	**31/10/2004**	**4/11/2005 TR; 8/6/2007 TH**								
	17/01/2006	24/01/2006	$5,509	BP	Initial	provide 1st BP prosthesis	1		$2,000	socket
									$138	check socket
									$1,440	locking hinge medial
									$440	wrist
									$681	hook
									$27	forearm lift assy
									$53	hook band applicator
									$90	HD Bowden cable
									$200	triceps cuff
									$120	shrinkers
									$45	compress grip shrinker
									$276	regimed soft socket-3 ply
	01/03/2006	06/03/2006	$791	BP	new	provide work hook	1		$791	work hook
	11/04/2006	13/04/2006	$50			provide shrinker	1		$50	shrinkers
	15/06/2006	23/06/2006	$80			provide shrinker	1		$80	stump shrinker
	19/07/2006	03/08/2006	$5,132	BP	refit	replace unfit prosthesis	1		$2,000	BE socket
									$290	thermolyn rigid check socket
									$195	harness
									$175	control cable
									$149	tricep cuff
									$1,562	flail arm hinge
									$226	quick change wrist
									$60	modification to flail hinge 1/2 hour
									$475	exoskeletal finish
	30/08/3006	22/09/2006	$222		supply	provide shrinker	2	$81	$162	bk stump shrinkers
							0.5		$60	clinical time
	27/09/2006	24/10/2006	$440		supply	provide shrinker	6	$70	$420	shrinker with silicone beads
							1		$20	postage to Mackenzie
	24/07/2007	26/07/2007	$265	?		no info			$265	
	27/07/2007	03/08/2007	$4,357	?	refit?	no info			$4,357	
	20/02/2008	14/04/2008	$19,998	myo	initial	provide 1st myo prosthesis	1	$2,880	$2,880	AE socket procedure
							1	$320	$320	diagnostic procedure
							1	$57	$57	electrode accessory
							2	$2,054	$4,108	electrode
							2	$110	$220	electrode cable
							2	$64	$128	electrode assembly
							2	$1,025	$2,050	battery

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
4 (DD)	**31/10/2004**	**4/11/2005 TR; 8/6/2007 TH**								
							1	$226	$226	battery mounting set
							1	$120	$120	battery cable
							1	$1,156	$1,156	litium ion battery charger
							1	$265	$265	lamination ring
							1	$72	$72	coupling piece
							1	$350	$350	coaxial pug
							1	$7,571	$7,571	electric greifer DMC plus
							1	$475	$475	AE cosmesis exoskeletal
	23/05/2008	09/06/2008	$5,045	myo	refit	replace suction socket with suspension socket	1	$290	$290	AE check socket procedure
							1	$2,880	$2,880	AE socket procedure
							1	$200	$200	double wall lamination for myo
							1	$216	$216	expulsion valve
							1	$195	$195	harness UE
							1	$1,218	$1,218	quick disconnect adaptor
							2	$23	$46	compress grip shrinker
	14/01/2009	15/01/2009	$62		supply	provide shrinker	2	$26	$52	compress grip shrinker
							1	$10	$10	shipping
	26/03/2009	30/03/2009	$4,328	myo	refit	replace socket due to volume change	1	$290	$290	T/H diagnostic socket
							1	$2,880	$2,880	T/H socket
							1	$250	$250	Myo arm technique
							1	$238	$238	expulsion valve
							1	$475	$475	cosmetic finish
							1	$195	$195	harness
4	14/01/2010	?	$72		supply	provide shrinker	2	$26	$52	compressorgrip shrinker
4							1	$20	$20	shipping
4	26/01/2010	03/02/2010	$63		supply	provide shrinker	1	$26	$26	shrinker
4							1	$37	$37	derma prevent
4	11/02/2010	12/04/2010	$15,447	myo2	Initial	provide and fit 2nd myo prosthesis with a new terminal device - Motion Control hook	1	$2,880	$2,880	T/H socket
4							1	$238	$238	expulsion valve L-54200
4							1	$1,230	$1,230	potentiometer - Motion Control 3010546
4							1	$1,806	$1,806	internal battery
4							1	$79	$79	cable adpator

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
4 (DD)	**31/10/2004**	**4/11/2005 TR; 8/6/2007 TH**								
4							1	$404	$404	wire harness
4							1	$690	$690	coaxial connector
4							1	$368	$368	coaxial plug
4							1	$76	$76	coupling piece
4							1	$280	$280	wrist
4							1	$5,349	$5,349	ETD hook
4							1	$2,047	$2,047	flex wrist
4	26/07/2010	29/07/2010	$64		supply	supply shealth and fit suspension clip	1	$29	$29	supply one shealth and fit a suspension cl
4							1	$5	$5	
4							0.25	$120	$30	
4	15/09/2010	01/10/2010	$1,640		new	try out liner	1	$290	$290	T/H test socket procedure
4							1	$1,350	$1,350	seal-in liner
4	16/11/2010	18/11/2010	$26		supply	regular supply	1	$26	$26	socks
	31/05/2011	07/06/2011	$4,734	myo	refit	replace prosthesis with new liner system	1	$2,880	$2,880	T/H socket procedure
							1	$350	$350	T/H dynamic socket
							1	$300	$300	Suction socket procedure
							1	$378	$378	452A1=320 Proseal ring
							1	$630	$630	6Y81=280 Proseal SIL liner
							1	$196	$196	L551000 value
	11/09/2011	16/09/2011	$2,647	myo	refit	replace prosthesis with new Otto Bock Proseal liner system	1	$630	$630	Proseal SIL liner
							1	$248	$248	Battery mounting set
							1	$290	$290	lamination ring
							1	$79	$79	coupling piece
							1	$380	$380	coaxial plug
							1	$195	$195	T/H suspension harness
							1	$475	$475	T/H exoskeletal finish
							1	$350	$350	double laminatiom
	19/09/2011	21/09/2011	$4,279	myo2	refit	replace socket and outer frame	1	$2,880	$2,880	T/H socket procedure
							1	$475	$475	acrylic socket
							1	$350	$350	T/H double lamination procedure
							1	$378	$378	Proseal ring
							1	$196	$196	expulsion valve

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
14 (TB)	**11/07/2006**	**11/07/2006**								
	11/08/2006	15/08/2006	$46		supply	supply shrinker	2	$23	$46	shrinkers
	18/10/2006	23/10/2006	$5,212	BP	initial	provide 1st BP prosthesis	1	$2,000	$2,000	BE socket
							1	$250	$250	check socket
							1	$80	$80	stump shrinker
							1	$615	$615	hosmer hook
							1	$1,110	$1,110	VO hand and glove
							1	$410	$410	northwestern harness
							1	$297	$297	quick change wrist
							1	$450	$450	exoskeletal finish
	08/12/2006	14/12/2006	$154	BP	supply	replace sock and padding due to volume change			$10	1/2 hr. to pad socket within leather paddi
							6	$24	$144	3 ply socks
	12/01/2007	22/01/2007	$53	BP	repair	repair adaptor cable			$30	15 mins to replace adapter cable
									$16	triple swivel
									$6	ball terminal
									$1	4 inches cable
	18/01/2007	22/01/2007	$728	BP	new	provide work hook	1	$728	$728	work hook
	02/02/2007	07/02/2007	$3,877	BP	refit	replace socket due to volume change	1	$2,300	$2,300	TR socket
							1	$250	$250	check socket
							1	$297	$297	wrist
							1	$275	$275	northwestern harness
							1	$130	$130	flexible hinges/cuff
							1	$175	$175	control cable
							1	$450	$450	exo finish
	21/02/2007	28/02/2007	$295	BP	replace	replace cosmetic glove for BP hand	1	$235	$235	cosmetic glove
							0.5	$60	$60	1/2 hour to replace glove
	20/03/2007	04/04/2007	$53	BP	repair	replace broken cable			$16	triple swivel
									$6	ball terminal
									$1	4 inches cable
									$30	15 mins labour
	27/06/2007	29/06/2007	$5,132	BP2	initial	provide new BE arm for ADL (the other for work)	1	$2,000	$2,000	BE socket
							1	$250	$250	check socket
							1	$615	$615	hosmer hook
							1	$1,110	$1,110	VO hand and glove
							1	$410	$410	northwestern harness

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
14 (TB)	**11/07/2006**	**11/07/2006**								
							1	$297	$297	quick change wrist
							1	$450	$450	exoskeletal finish
	03/10/2007	04/10/2007	$285	BP	repair	retread hook			$285	hook retreading
	02/11/2007	26/11/2007	$23,831	myo	initial	provide 1st myo prosthesis			$23,831	Myoelectric T/R prosthesis with Otto Bocl
	07/02/2008	07/02/2008	$365	BP	replace	provide clean glove for work hand			$275	cosmetic glove
				BP?	repair	repair cable			$90	install glove and clean wrist unit
	20/02/2008	02/02/2008	$88						$9	hanger
									$15	ball receiver
									$3	cable
									$1	dacron tape
									$60	labour to repair
	20/03/2008	27/03/2008	$236	BP?	repair	adjust/change harness			$2	cable
									$16	triple swivel
									$9	hanger
									$1	grommet
									$1	dacron
									$27	axilla loop
									$180	labour to make harness
	04/04/2008	07/04/2008	$120	BP	supply	provide new stump socks			$24	3 ply sock
									$24	1 ply
									$72	cuddly soft socks
	30/07/2008	08/08/2008	$31	BP	repair	repair cable			$3	cable
									$16	triple swivel
									$9	hanger
									$2	dacron
									$0	rubber bands
	20/08/2008	02/09/2008	$8,317	myo	new	provide Greifer	1	$8,317	$8,317	Greifer 8E33=9
	12/11/2008	13/11/2008	$696	myo	repair	replace worn Greifer gripping pad	1	$606	$606	Greifer replacement pads
							0.75	$120	$90	labour to replace pads
	04/11/2008	12/11/2008	$335	myo	replace	replace cosmetic glove	1	$275	$275	cosmetic glove
							1	$60	$60	labour to switch gloves
	06/01/2009	12/01/2009	$335	myo	replace	replace soiled hand glove	1	$275	$275	myo cosmetic glove
							1	$60	$60	labour to switch gloves
	14/01/2009	19/01/2009	$335	myo	replace	replace torn and stained glove			$335	?
	05/02/2009	06/02/2009	$1,008	myo	repair	repair Greifer	1	$60	$60	labour to assess greifer and change to hai

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14 (TB)	**11/07/2006**	**11/07/2006**								
							1	$948	$948	Non-warranty thirde party repairs as per
	06/05/2009	08/06/2009	$19,603	myo2	initial	provide 2nd set of prosthesis for social use	1	$2,300	$2,300	below elbow socket procedure
							1	$350	$350	check socket
							1	$205	$205	pin procedure
							1	$485	$485	forearm cosmetic finish
							1	$8,125	$8,125	myo hand DMC plus 8E38=6
							2	$2,085	$4,170	myo bock electrode 13E200=60
							1	$76	$76	coupling
							1	$284	$284	cosmetic glove
							1	$368	$368	coaxial plug
							1	$278	$278	lamination ring
							2	$156	$312	electrode cables
							2	$1,062	$2,124	battery 757B20
							1	$240	$240	battery mounting set
							1	$160	$160	Coyote lock
							1	$126	$126	battery cable
	06/05/2009	08/06/2009	$1,385	myo	repair	repair greifer and replace cosmetic gloves	2	$284	$568	cosmetic glove
							2	$60	$120	labour to switch gloves
							1	$457	$457	non-warranty griefer repairs as per Otto B
							2	$120	$240	labour to reinforce myo socket
	03/07/2009	08/07/2009	$384	myo	replace	new cosmetic glove and padding	1	$284	$284	cosmetic glove
							1	$90	$90	labour to pad socket due to volume loss
							1	$10	$10	leather padding
	14/08/2009	28/08/2009	$602	myo	replace	replace inner hand shell and glove	1	$284	$284	myo cosmetic glove
							1	$258	$258	inner hand shell
							1	$60	$60	labour to change glove and hand shell
	14/10/2009	23/10/2009	$8,370	myo	refit	replace non-functional socket and liner due to physical change	1	$2,300	$2,300	T/R procedure
							1	$3,038	$3,038	custom silicone locking liner Otto Bock
							1	$350	$350	diagnostic socket
							1	$800	$800	electric arm technique + forearm switch
							1	$231	$231	battery housing
							1	$723	$723	wrist unit 10S4 10S1=50, 9E169

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14 (TB)	**11/07/2006**	**11/07/2006**								
							1	$485	$485	forearm finish
							1	$205	$205	pin procedure
							1	$238	$238	Coyote lock system
	13/11/2009	24/11/2009	$2,256	myo	repair	repair Griefer by Otto Bock	1	$2,196	$2,196	non-warranty griefer repairs as per Otto E
							1	$60	$60	labour to assess griefer ans send away
	30/11/2009	02/12/2009	$344	myo	replace	replaced soiled & broken glove	1	$284	$284	cosmetic glove
							1	$60	$60	labour to install glove
	21/12/2009	24/12/2009	$344	myo	replace	replaced soiled glove	1	$284	$284	cosmetic glove
							1	$60	$60	labour to install glove
	06/04/2010	09/04/2010	$354	myo	replace	replaced soiled & broken glove	1	$294	$294	cosmetic glove
							1	$60	$60	labour to install glove
	12/05/2010	18/05/2010	$1,300	myo	repair	replace battery charger	1	$1,300	$1,300	battery charger 75L20
	22/06/2010	25/06/2010	$354	myo	replace	replace broken & soiled glove	1	$294	$294	cosmetic glove
							1	$60	$60	labour to change glove
	11/08/2010	17/08/2010	$1,311	myo	repair	repair myo electic hand and replace cosmetic glove	1	$957	$957	labour to repair myo electric hand as per
							1	$294	$294	cosmetic glove
							1	$60	$60	labour to install new glove
	03/11/2010	08/11/2010	$515	myo	repair	replace glove, padding and battery & repair broken retention for battery and cable	1	$42	$42	battery receptacle
							1	$45	$45	cable retention piece
							1	$294	$294	cosmetic glove
							1	$15	$15	leather for padding
							1	$120	$120	labour to pad socket and repair prosthesi
	26/11/2010	14/12/2010	$60	myo	repair	repair wiring	1	$60	$60	labour to repair prosthesis
	22/12/2010	30/12/2010	$1,102	myo	repair	repair myo hand	1	$718	$718	repair to hand as per Otto Bock Invoice
							1	$294	$294	cosmetic glove
							1	$90	$90	labour to change glove and assess proble
	03/03/2011	08/03/2011	$869	myo	repair	repair myo hand	1	$779	$779	Non warranty hand repairs as per Otto Bc
							1	$90	$90	Labour to assess hand issues and install g
	11/05/2011	13/05/2011	$2,279	myo	replace	replace soiled glove	1	$306	$306	cosmetic glove
							1	$6	$6	leather
							1	$90	$90	labour to change glove and pad socket

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14 (TB)	**11/07/2006**	**11/07/2006**								
	20/07/2011	21/07/2011	$644	myo2	replace	replace soiled and punctured hand glove	1	$306	$306	cosmetic glove 8S11=210X78R6
							1	$278	$278	inner hand shell 8X18=R 73/4
							1	$60	$60	labour to change hand shell and glove
	16/09/2011	20/09/2011	$867	myo2	repair	repair myo hand	1	$827	$827	Non warranty hand repairs as per Otto Bo
							1	$40	$40	labour to assess hand and send away for
	06/10/2011	11/10/2011	$366	myo	replace	replace soiled and torn cosmetic glove	1	$306	$306	cosmetic glove
							1	$60	$60	labour to change glove

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12 (JP)	**25/03/2006**	**31/03/2006**								
	13/09/2006	20/09/2006	$5,018	BP?	initial?	provide first BP prosthesis?			$5,018	
	18/01/2007	22/01/2007	$240	BP	repair		2	$120	$240	2 hours to take apart tighten screw and p
	20/02/2007	29/07/2007	$600		assess	looking for myo sites	2	$120	$240	looking for sites
							2	$120	$240	working on site and control
							1	$120	$120	final check using mock up electrodes and
	02/05/2007	07/05/2007	$200	BP	repair	replace broken cable	1	$200	$200	SD Cable assembly
	19/06/2007	21/06/2007	$120	BP	repair	remove foam from arm	1	$120	$120	labour
	07/03/2008	01/04/2008	$63,846	myo	initial	provide first myo prothesis	1	$3,570	$3,570	SD procedure
							1	$620	$620	myo procedure
							1	$188	$188	chest harness
									$59,469	total from page 2
	15/05/2008	26/05/2008	$3,767	myo	initial	missing items in Apr 1, 2008 approval	1	$3,059	$3,059	manual locking shoulder joint
							1	$506	$506	spring loaded lock release
							1	$202	$202	spoke mounting plate
	29/09/2008	14/10/2008	$8,981	myo	new	supply greifer	1	$8,981	$8,981	griefer terminal device 8O33=9
	29/10/2008	31/10/2008	$66		supply	supplies - conduction gel	1	$49	$49	ProComfort gel 250 gm
							1	$17	$17	
	20/04/2009	27/04/2009	$240	myo	repair	repair shoulder and re-program elbow	1.25	$120	$150	labour to replace strap & repair shoulder
							0.75	$120	$90	labour to re-program elbow: boost on elb
	16/11/2009	23/11/2009	$259	myo	adjust	re-padded loose socket and re-programed arm	0.75	$120	$90	labour to pad socket
							1	$20	$20	padding materials
							1	$29	$29	ProComfort gel - consummable
							1	$120	$120	labour to re-program Dynamic Arm
	10/01/2011	28/01/2011	$7,128	myo	refit	replace socket due to physiological change	1	$3,570	$3,570	SD procedure
							1	$720	$720	myoelectric technique procedure
							2	$500	$1,000	dynamic check sockets
							1	$700	$700	flexible inner socket
							1	$188	$188	chest strap type harness
							1	$950	$950	exoskeletal finishing
	25/05/2011	08/06/2011	$4,093	myo	repair	repair hand and elbow	2	$120	$120	labour
							2	$120	$120	labour
							1	$1,224	$1,224	repair/service 8E38=8=R7 3/4 hand
							1	$2,602	$2,602	repair/service 12K100 elbow
							1	$27	$27	freight to ship arm to OttoBock

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12 (JP)	**25/03/2006**	**31/03/2006**								
	09/06/2011	approval?	$12,925	rec	initial	rec arm for biking and snowmobiling	1	$3,570	$3,570	SD procedure
							1	$700	$700	flexible liner
							1	$7,155	$7,155	bike elbow and wrist
							1	$1,500	$1,500	shoulder joint

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17 (RC)	**02/02/2004**	**13/01/2006**								
	24/11/2005	30/11/2005	$210		assess	initial prosthetic assessment	1.75	$120	$210	
	15/12/2005	15/12/2005	$99		supply	provide compressogrip	1		$92	1 box compressogrip
									$7	postage
	30/05/2006	10/04/2006	$57		supply	provide shrinker			$57	shrinkers
	11/06/2006	12/06/2006	$3,905	cos	initial	provide 1st passive/cosmetic prosthesis	1		$3,905	cosmetic prosthesis
	11/06/2006	03/08/2006	$23,741	myo	initial	provide 1st myo prosthesis	1		$23,741	myoelectric prosthesis with sensor hand
	18/07/2006	19/07/2006	$40		supply	provide shrinker after surgery	2	$20	$40	shrinkers
	08/08/2006	30/08/2006	$288	cos	replace	provide new glove			$228	glove
							0.5	$120	$60	install
	09/08/2006	30/08/2006	$292	cos	supply	supplies			$92	arm sleeve
									$70	sticky spot
									$130	derma kit
	08/09/2006	08/09/2006	$180	myo	replace	replace torn suspension sleeve	2	$90	$180	suspension sleeve
	05/12/2006	08/12/2006	$793	myo	replace	replace worn out sleeves, inner hand and glove	2	$91	$182	suspension sleeve
							1	$267	$267	glove
							1	$224	$224	inner hand for myo
							1	$120	$120	install glove and inner hand 1 hour
	18/01/2007	25/01/2007	$344	myo	repair	labour to remove and ship hand for repair	1	$120	$120	labour
							1	$224	$224	inner hand
	29/01/2007	01/02/2007	$627	myo	repair	repair of sensor hand	1	$567	$567	see manufacturer quote for repairs
							0.5	$120	$60	labour
	19/02/2007	21/02/2007	$379	cos	replace	replace torn glove and suspension sleeve	1	$228	$228	glove
							1	$91	$91	suspension sleeve
							0.5	$120	$60	labour
	18/12/2006	22/02/2007	$23,741	myo2	initial	provide 2nd myo work prosthesis	1		$23,741	myoelectric prosthesis with sensor hand
	09/03/2007	23/03/2007	$1,025	myo2	new	provide spare batteries	1	$1,025	$1,025	litium battery
	30/03/2007	03/04/2007	$182		replace	provide Silipos suspension sleeves	2	$91	$182	suspension sleeve
	26/04/2007	07/05/2007	$4,154	myo2	refit	replace socket due to volume reduction			$4,154	

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17 (RC)	**02/02/2004**	**13/01/2006**								
	26/04/2007	07/05/2007	$240	myo2	replace	replace worn suspension sleeve	2	$120	$240	H/D suspension
	01/05/2007	07/05/2007	$335	myo2	replace	replace glove from wear & tear	1	$275	$275	glove
							0.5	$120	$60	labour
	11/05/2007	15/05/2007	$284	myo	repair	workplace damage, replace inner hand	1	$224	$224	inner hand
							0.5	$120	$60	labour
	11/05/2007	17/05/2007	$559	myo2	repair	repair damage hand to OB	1	$224	$224	inner hand
							1	$275	$275	glove
							0.5	$120	$60	labour
	13/06/2007	15/06/2007	$1,919	myo	repair	repair sensor hand by OB			$1,919	repairs
	20/06/2007	21/06/2007	$335	myo2	replace	replace hand glove	1	$275	$275	glove
							0.5	$120	$60	labour
	27/07/2007	02/08/2007	$3,045	myo2	repair	repair damaged myo hand	2	$120	$240	suspension sleeve
							1	$2,685	$2,685	repairs
							1	$120	$120	labour
	31/07/2007	01/08/2007	$23	myo	repair	courier hand	1	$23	$23	courier charges
	10/10/2007	19/10/2007	$1,309	myo	repair	repair broken prosthesis			$1,309	OB repair
	18/10/2007	23/20/2007	$1,439	myo2	repair	non-warranty repair of myo hand	1	$1,319	$1,319	repairs
							1	$120	$120	labour
	21/12/2007	21/12/2007	$512	myo	repair	ship damaged myo hand for repair			$392	see attached quote from manufaturer
							1	$120	$120	labor to un-install and re-install unit
	30/01/2008	01/02/2008	$447	myo2	repair	ship damaged myo hand for repair			$327	repairs
							1	$120	$120	labour to un-install and re-install hand
	04/02/2008	12/02/2008	$3,394	myo2	refit	replace socket and forearm shell			$3,394	
	04/02/2008	11/02/2008	$4,106	myo	refit	replace socket and forearm after revision surgery			$4,106	
	04/02/2008	12/02/2008	$12,344	myo2	new	provide sensor hand as backup			$11,949	sensor hand 8E38=8 (S/N 200749818)
									$275	glove
									$120	labour
	25/03/2008	27/03/2008	$571	myo?	replace	replace suspension sleeve and glove	2	$118	$236	suspension sleeve

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17 (RC)	**02/02/2004**	**13/01/2006**								
							1	$275	$275	glove
							0.5	$120	$60	labour
	28/03/2008	31/03/2008	$2,113	myo	repair	repair of myo hand by OB			$2,023	quote attached for cost of repairs
									$30	postage to and from manufacturer
							0.5	$120	$60	labour
	15/04/2008	21/04/2008	$118	myo?	replace	replace suspension sleeve	1	$118	$118	suspension sleeve
	29/04/2008	02/05/2008	$8,231	myo2	new	provide Greifer	1	$8,171	$8,171	Greifer (s/n 200817910)
							0.5	$120	$60	labour
	30/04/2008	01/05/2008	$829	myo2	repair	repair myo hand by OB	1	$829	$829	OttoBock for cost of repair
	06/06/2008	09/06/2008	$305		supply	supplies	1	$35	$35	derma prevent
							1	$34	$34	EDAP crème
							2	$118	$236	silipos suspension sleeve
	12/06/2008	18/06/2008	$1,248	myo	repair	repair myo hand by OB			$1,128	repairs to Myo hand
							1	$120	$120	labour
	22/07/2008	25/07/2008	$1,036	myo2	repair	repair myo hand by OB			$966	OB repairs
							1	$120	$60	labour
									$10	postage
	19/08/2008	22/08/2008	$236		replace	provide suspension sleeve	2	$118	$236	silipos suspension sleeve
	04/09/2008	09/09/2008	$236		replace	provide suspension sleeve	2	$118	$236	silipos suspension sleeve
	19/08/2008	10/09/2008	$2,461	myo	repair	repair myo hand by OB			$2,321	Repairs see attached
							1	$120	$120	labour
									$20	postage
	01/10/2008	07/10/2008	$373	myo	repair	repair sensor hand by OB	1	$298	$298	factory repair to Myo hand (see attached
							0.5	$120	$60	assess myo function
							1	$15	$15	shipping
	13/11/2008	24/11/2008	$140	myo?	adjust	add padding	2	$70	$140	TEC sticky spot
	18/11/2008	24/11/2008	$2,050	myo	repair	replace battery	2	$1,025	$2,050	batteries
	04/11/2008	16/11/2008	$483	myo?	replace	replace suspension sleeve and glove	2	$104	$208	suspension sleeve
							1	$275	$275	glove
	08/12/2008	17/12/2008	$208		replace	provide suspension sleeve	2	$104	$208	suspension sleeve
	07/01/2009	29/01/2009	$451	myo	repair	repair myo hand	0.5	$120	$60	assess myo function
							1	$1,931	$376	factory repair
							1	$15	$15	shipping
17	07/01/2009	15/01/2009	$455	myo2	repair	ship Greifer to OB for repair	0.5	$120	$60	assess myo hand for function
17							1	$375	$375	factory repair
17							1	$20	$20	shipping

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17 (RC)	**02/02/2004**	**13/01/2006**								
	06/02/2009	06/02/2009	$335	myo	replace	replace ripped cosmetic glove	1	$275	$275	glove
							0.5	$120	$60	install glove
	28/01/2009	11/02/2009	$288	myo2	repair & adjust	repair broken cable and refit socket due to volume change	0.75	$120	$90	diagnose and repair myo problem
							0.5	$120	$60	adjust socket
							1	$138	$138	electrode cable
	28/01/2009	11/02/2009	$4,543	myo2	refit	replace socket due to volume change	1	$290	$290	TR diagnostic socket
							1	$2,300	$2,300	TR socket
							1	$250	$250	Myo socket variation
							2	$58	$116	electrode
							2	$65	$130	electrode accessory
							1	$712	$712	battery mount set
							1	$270	$270	lamination ring
							1	$475	$475	cosmetic finish
	09/04/2009	14/04/2009	$582	myo2	repair	repair myo hand	1	$502	$502	repairs to Myo hand
							0.5	$120	$60	inspect and assess for damage
							1	$20	$20	shipping
	11/05/2009	25/05/2009	$314	myo2 ?	replace	replace ripped cosmetic glove	1	$284	$284	cosmetic glove
							0.25	$120	$30	install glove
	25/05/2009	10/06/2009	$523	myo2	repair	repair myo hand by OB	0.5	$120	$60	assess hand and prep for shipping
							1	$20	$20	shipping
							1	$443	$443	OB repair cost
	01/06/2009	10/06/2009	$3,473	myo2	repair	repair 3rd sensor speed hand	0.5	$120	$60	assess hand for proper function
							1	$3,393	$3,393	repairs
							1	$20	$20	shipping
17	01/06/2009	10/06/2009	$603	myo	repair	repair myo hand (OB)	0.5	$120	$60	assess hand & prep for shipping
17							1	$20	$20	shipping
17							1	$523	$523	OB repair cost
17	18/06/2009	approval?	$523	myo2	repair	repair myo hand (OB)	0.5	$120	$60	assess hand & prep for shipping
17							1	$20	$20	shipping
17							1	$443	$443	OB repair cost
17	25/06/2009	14/07/2009	$344	myo2	replace	replace ripped cosmetic glove	1	$284	$284	cosmetic glove

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17 (RC)	**02/02/2004**	**13/01/2006**								
17							0.5	$120	$60	install glove
17	29/06/2009	14/07/2009	$19,136	myo3	initial	supply new hand, adjust socket and supply shrinker	1	$290	$290	T/R diagnostic socket
17							1	$2,300	$2,300	T/R socket
17							1	$205	$205	electric arm technique
17							1	$1,953	$1,953	dual site preamps
17							2	$35	$70	preamp dummies
17							1	$338	$338	electrodes, high profile
17							1	$1,927	$1,927	internal battery
17							1	$278	$278	lamination ring
17							1	$76	$76	coupling piece
17							1	$690	$690	coaxial connector
17							1	$5,031	$5,031	Pro Hand 5010029
17							1	$2,310	$2,310	flexion wrist option 3010441
17							1	$2,609	$2,609	Pro Hand 3010580
17							1	$200	$200	protective cover for wrist
17							1	$100	$100	auxilliary suspension
17							1	$475	$475	cosmetic finish
17							1	$284	$284	glove
17	29/06/2009	14/07/2009	$137	cos	adjust	adjustment of socket	1	$22	$22	stump shrinkers
17							0.75	$120	$90	make foam protective sheath
17							1	$25	$25	materials for sheath
17	29/06/2009	14/07/2009	$196	myo2	repair	disassemble and clean arm, replace cable and supplies	1	$37	$37	derma prevent
17							1	$37	$37	Derma Repair
17							1	$32	$32	Derma Clean
17							0.75	$120	$90	assess myo hand
17	01/08/2009	approval?	$3,473	myo2	repair	repair griefer	0.5	$120	$60	assess griefer for proper function
17							1	$3,393	$3,393	repair
17							1	$20	$20	shipping
17	11/08/2009	18/08/2009	$208		supply	regular supply	2	$104	$208	suspension sleeve
17	18/08/2009	03/09/2009	$1,253	myo	repair	repair myo hand (OB)	0.5	$120	$60	assess hand for function
17							1	$1,168	$1,168	factory repair
17							1	$25	$25	shipping
17	31/08/2009	03/09/2009	$603	myo2	replace	replace cut cosmetic glove and inner hand	1	$249	$259	inner hand
17							1	$284	$284	cosmetic glove
17							0.5	$120	$60	install inner hand & glove

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17 (RC)	**02/02/2004**	**13/01/2006**								
17	13/11/2009	02/12/2009	$1,295	myo2	repair	repair myo hand (OB)	0.5	$120	$60	inspect & assess hand
17							1	$1,220	$1,220	factory repair - Otto Bock
17							1	$15	$15	shipping
17	07/01/2010	14/07/2010	$593	myo?	replace	replace torn inner hand & glove	1	$249	$249	inner hand
17							1	$284	$284	glove
17							0.5	$120	$60	install hand/glove
17	13/01/2010	22/01/2010	$656	myo	repair	repair myo hand (OB)	0.5	$120	$60	inspect & assess hand
17							1	$571	$571	manufacturer repair
17							1	$25	$25	shipping
17	03/02/2010	approval?	$2,150	myo3?	repair	replacement of finger tips	2	$1,030	$2,060	finger tips
17							0.75	$120	$90	fit and modify
17	15/02/2010	19/02/2010	$1,937	myo2	repair	reapir myo hand (OB)	0.5	$120	$60	inspect & assess hand
17							1	$1,862	$1,862	factory repair - Otto Bock
17							1	$15	$15	shipping
17	15/02/2010	19/02/2010	$544	myo	repair	repair myo hand (OB)	0.5	$120	$60	inspect & assess hand
17							1	$469	$469	factory repair - Otto Bock
17							1	$15	$15	shipping
	16/02/2010	19/02/2010	$106	myo3	repair	motion concepts pro hand	2	$8	$16	finger tips
							0.75	$120	$90	fit & modify finger tips
17	20/04/2010	26/04/2010	$354	myo?	replace	repair worn out suspension	2	$26	$52	shrinker
17							1	$107	$107	suspenstion sleeve
17							1	$195	$195	harness
17	20/04/2010	04/05/2010	$583	myo3	replace	replace torn inner hand & glove	1	$229	$229	inner hand Motion Control 3010387
17							1	$294	$294	cosmetic glove 8S11
17							0.5	$120	$60	replace inner hand & glove
17	22/04/2010	07/05/2010	$510	myo2	repair	repair myo hand (OB)	0.5	$120	$60	inspect and assess hand
17							1	$435	$435	factory repair - Otto Bock
17							1	$15	$15	shipping
17	26/05/2010	09/06/2010	$1,121	myo	repair	repair arm and replace inner glove	1	$120	$120	labour
17							1	$380	$380	coaxial plug
17							1	$79	$79	coupler
17							1	$248	$248	battery box
17							1	$294	$294	glove
17	26/05/2010	09/06/2010	$902	myo2	repair	repair myo hand (OB)	0.5	$120	$60	inspect & assess hand for function
17							1	$827	$827	factory repair - Otto Bock

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17 (RC)	**02/02/2004**	**13/01/2006**								
17							1	$15	$15	shipping
17	18/06/2010	07/07/2010	$500	myo2	repair	repair OB arm B	1	$380	$380	coaxial plug
17							1	$120	$120	replace coax
17	18/06/2010	02/07/2010	$130	myo	repair	repair OB arm A	1	$120	$120	rear brim, replace strap
17							1	$10	$10	strap material
17	15/07/2010	19/07/2010	$104		supply	regular supply	1	$104	$104	suspension sleeve
17	15/07/2010	20/07/2010	$2,445	myo	repair	reapir myo hand (OB)	0.5	$120	$60	inspect & assess hand
17							1	$2,373	$2,373	factory repair - Otto Bock
17							1	$12	$12	shipping
17	17/08/2010	01/09/2010	$648	myo2&3	replace	replace cosmetic gloves	2	$294	$588	cosmetic glove 8S11
17							0.5	$120	$60	install glove
17	10/09/2010	30/09/2010	$732	myo2	repair	repair myo hand (OB)	0.25	$30	$8	inspect & assess hand
17							1	$710	$710	manufacturer repair
17							1	$15	$15	shipping
17	24/09/2010	15/10/2010	$1,753	myo2	repair	repair myo hand (OB)	0.5	$120	$60	inspect and assess
17							1	$1,673	$1,673	factory repair - Otto Bock
17							1	$20	$20	shipping
17	01/11/2010	17/10/2010	$839	myo2?	epair & replac	replace broken lever of battery box and replacement of outer and inner gloves	1	$61	$61	engaging lever
17							0.5	$120	$60	fit and align lever
17							1	$104	$104	suspension sleeve
17							1	$166	$166	inner hand
17							2	$194	$388	cosmetic glove
17							0.5	$120	$60	labour to install gloves
17	04/11/2010	17/11/2010	$1,166	myo3	repair	repair myo hand (MC)	1	$1,116	$1,116	repair to Motion Control hand
17							1	$50	$50	shipping
17	16/11/2010	23/11/2010	$326	myo	repair	repair myo hand OB)	0.5	$120	$60	inspect & assess hand
17							1	$241	$241	repair of myo hand (Otto Bock)
17							1	$25	$25	shipping
17	22/11/2010	29/11/2010	$583	myo3	replace	replace cosmetic glove and inner hand	1	$294	$294	cosmetic glove 8S11
17							0.5	$120	$60	install glove
17							1	$229	$229	inner hand Motion Control 3010387
17	10/01/2011	25/01/2011	$680	myo2	replace	replace cosmetic glove and inner hand	1	$294	$294	cosmetic glove
17							1	$266	$266	inner hand (Otto Bock)

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17 (RC)	**02/02/2004**	**13/01/2006**								
17							1	$120	$120	install
	27/01/2011	03/02/2011	$121	myo2?	repair	repair broken battery box	1	$61	$61	engagin lever
							0.5	$120	$60	labour
	05/05/2011	24/05/2011	$3,042	myo	repair	repair myo hand by OB	1	$120	$120	inspect and assess hand
							1	$2,897	$2,897	OttoBock repair of hand
							1	$25	$25	shipping
	02/05/2011	06/06/2011	$2,659	myo2	repair	reapir myo hand (OB)	1	$2,514	$2,514	repair of myo hand
							1	$25	$25	shipping
							1	$120	$120	Re&Re
	01/06/2011	06/06/2011	$306	myo	replace	replace punctured cosmetic glove for myo	1	$306	$306	8S11 Cosmetic glove
	09/08/2011	11/08/2011	$208	myo?	replace		2	$104	$208	S1310 suspension sleeve
	11/09/2011	16/08/2011	$3,257	myo2	repair	repair myo hand by OB	0.5	$120	$60	inspect hand
							1	$3,157	$3,157	manufaturer repair of myo hand
							1	$40	$40	shipping
	31/08/2011	06/09/2011	$100	myo?	supply	provide suspension straps for myo prosthesis	2	$50	$100	suspension strap
	28/10/2011	?	$227	myo	repair	repair myo hand by OB	0.5	$120	$60	inspect hand
							1	$142	$142	manufaturer repair of myo hand
							1	$25	$25	shipping

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15 (MZ)	**01/03/2007**	**01/03/2007**								
	03/05/2007	10/05/2007	$277		supply	supply shrinker	3	$59	$177	stump shrinkers
							5	$8	$40	narrow short 1-ply socks
							2	$8	$16	Rolls FWRAP
							2	$4	$8	Mepore bandage
							1	$5	$5	intra site gel
							1	$16	$16	polyethylene posterior spline for humeral
							1	$15	$15	sock stretching donning tube
	19/09/2007	24/09/2007	$1,850		supply	supply shrinker and supplies	1	$856	$856	iceross comfort locking liner
							1	$120	$120	customization of iceross liner
							1	$169	$169	chest strap harness, acrylic bridge, with v
							1	$308	$308	icelock ratchet lock set with lock pin
							1	$45	$45	customized forearm extension to aid in si
							1	$35	$35	Ointment with A & D
							1	$22	$22	liner cleanser
							5	$59	$295	stump shrinkers
	15/10/2007	15/11/2007	$10,710	BP	initial	provide 1st BP prosthesis	1	$425	$425	TH test socket with suction suspension
							1	$2,880	$2,880	TH socket fabrication and fit
							1	$800	$800	humeral shell, double walled with elbow j
							1	$5,123	$5,123	ErgoArm plus, with forearm shell
							1	$196	$196	wrist unit
							1	$642	$642	hook
							1	$192	$192	fitting accessories and pull socks
							1	$452	$452	soft shoulder suspension and chest strap
	27/11/2007	28/11/2007	$272		supply	replace customized liner due to weight gain	2	$35	$70	prosthetic ointment
							1	$22	$22	ALPS lotion
							1	$35	$35	Derma repair
							1	$25	$25	iceross liner
							1	$120	$120	labour
	16/01/2008	17/01/2008	$792		?				$792	
	24/01/2008	07/02/2008	$1,780	BP	new	provide mechanical hand, N-Abler wrist and tool adaptor	1	$124	$124	wrist insert, stainless steel
							1	$854	$854	Ottobock system hand, VO
							1	$598	$598	silicone glove for mech hand
							2	$102	$204	short control cable adapters
	05/03/2008	13/03/2008	$7,067	BP	new	privde accessories for N-Abler System	1	$3,470	$3,470	N-abler five function wrist

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15 (MZ)	**01/03/2007**	**01/03/2007**								
							1	$178	$178	steak knife adapter
							1	$2,990	$2,990	N-abler tool adapter
							3	$143	$429	N-abler wrist insert with flange
15	02/07/2008	09/07/2008	$318	BP	adjust	enlargement of socket	2	$120	$240	enlarge medial wall of laminated socket
15							1	$38	$38	acrylic resin and fibreglass patch
15							2	$20	$40	replace velcro straps for chest harness
	10/07/2008	11/07/2008	$1,371	BP	replace	replace damaged glove	1	$1,101	$1,101	Regal glove with integral zipper
							2	$135	$270	modified stump shrinkers with belt adapt
15	29/07/2008	11/08/2008	$4,646	BP	refit	rebuild socket, suction suspension due to volume change	1	$445	$445	Right T/H test socket
15							1	$2,880	$2,880	Right T/H laminated socket with thermop
15							2	$120	$240	adaptation of existing prosthetic harness
15							2	$412	$824	silicone liner Evolution EOC-5
15							1	$182	$182	slide valve
15							1	$75	$75	original silicone liner, test (postage only)
15	16/07/2009	23/07/2009	$228	BP	adjust	adjustment of prosthesis & supply lotion	1	$120	$120	cleaning and reassembly of T/H elbow tur
15							2	$24	$48	prosthetic lotion
15							0.5	$120	$60	report to Dr. Rhonda Willms re progress a
15	23/12/2010	30/12/2010	$314		supply	supply & modify shrinkers after surgery	2	$67	$134	stump shrinkers
15							1.5	$120	$180	adaptation, modification an fitting of stur
	04/02/2011	08/02/2011	$991	BP	refit	replacement	4	$120	$480	assessment of TH socket fit and function a
							1	$259	$259	axilla bypass shoulder harness
							1	$144	$144	excursion multiplier
							1	$77	$77	control cabling
							1	$31	$31	Teflon lining Fairlead cable
	16/05/2011	06/06/2011	$33,244	myo	initial	provide first myo prosthesis	1	$445	$445	TH suction test socket with electrodes
							1	$2,880	$2,880	TH laminated socket procedure
							1	$182	$182	Lyn RV slide suction valve
							1	$999	$999	laminated double walled humeral proced
							1	$1,042	$1,042	pressure switch for elbow lock activation
							1	$190	$190	connection cable for elbow lock
							2	$1,655	$3,310	suction socket electrode
							2	$161	$322	electrode cable
							1	$8,243	$8,243	ErgoArm
							1	$394	$394	alignment aid for ErgoArm

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
15 (MZ)	**01/03/2007**	**01/03/2007**								
							1	$248	$248	battery mounting
							2	$770	$1,540	Li-ion battery
							1	$1,380	$1,380	battery charger
							1	$130	$130	battery connection cable
							1	$348	$348	coaxial plug
							1	$264	$264	lamination ring
							1	$10,000	$10,000	Variplus speed hand w quick disconnect
							1	$690	$690	myoskin natural glove
							1	$90	$90	glove cleaner
							2	$55	$110	procomfort gel
							1	$309	$309	Figure 8 harness assembly for elbow moti
							1	$128	$128	coupling piece, installed and adjusted

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
18 (VM)	**07/08/2008**	**07/08/2008**								
	09/06/2011	17/2011	$4,244	myo	refit	replace socket due to volume change	1	$2,300	$2,300	T/R socket procedure
							1	$350	$350	T/R diagnostic procedure
							1	$350	$350	double lamination procedure
							2	$62	$62	electrode accessories
							1	$475	$475	exoskeletal finish
							1	$290	$290	lamination ring
							12	$22	$264	soft sock
	26/01/2010	29/01/2010	$153	BP	supply	supply wrist inserts	3	$51	$153	wrist inser
	19/08/2009	16/09/2009	$11,198	myo	new	supply myo hand for non-work use	1	$5,246	$5,246	Pro Hand 5010028
							1	$2,679	$2,679	Pro Hand Option 3010589 (ProControl 2)
							1	$2,679	$2,679	multiflex wrist option 4050157
							1	$70	$70	protective cover for wrist
							1	$284	$284	glove 8S11
							2	$120	$240	install components/glove & setup myo ha
	11/08/2009	approved?	$10,614	BP?	new	supply adaptor aids	1	$627	$627	guitar pick adaptor
							1	$500	$500	pool cue adaptor
							1	$1,445	$1,445	weight lifting adaptor
	25/06/2009	06/07/2009	$144	BP	adjust	install pad to cushion	3	$38	$114	TEC Spots
							0.25	$120	$30	install pads
	25/05/2009	25/06/2009	$21,827	myo	initial	supply new myo prosthesis	1	$290	$290	T/R diagnostic socket
							1	$2,300	$2,300	T/R socket
							1	$250	$250	myo arm technique
							1	$368	$368	coaxial plug
							2	$60	$120	electrode assembly
							2	$2,107	$4,214	electrode 13E200=60
							1	$76	$76	coupling piece
							1	$280	$280	lamination ring
							1	$475	$475	cosmetic finish
							1	$6,386	$6,386	ETD Hook 5010032
							1	$2,395	$2,395	flex wrist 3010485
							1	$2,380	$2,380	Prohand Feature 3010599
							2	$67	$134	electrode assembly
							1	$2,080	$2,080	internal battery charger 3010596
							1	$0	$0	wire harness
							1	$0	$0	AC adaptor
							1	$79	$79	coax connector

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18 (VM)	**07/08/2008**	**07/08/2008**								
	12/06/2009	22/06/2009	$24		supply	supply stump shrinker	1	$24	$24	stump shrinkers
	25/05/2009	15/06/2009	$155	BP	adjust	replace rubber band with spring and replace cable	6	$10	$60	hook tension spring
							1	$95	$95	control cable
	06/04/2009	08/04/2009	$156		supply	supply liner sock	6	$26	$156	liner sock
	26/03/2009	08/04/2009	$6,300	BP	refit & new	replace BP socket that no longer fit, provide a work hook	1	$290	$290	TR diagnostic socket
							1	$2,300	$2,300	TR socket
							1	$38	$38	TEC spot
							1	$203	$203	wrist
							1	$475	$475	cosmetic finish
							1	$2,474	$2,474	work hook
							1	$195	$195	harness
							1	$175	$175	control cable
							1	$150	$150	triceps cuff
	12/02/2009	13/02/2009	$300	BP	repair	replace worn out components	0.5	$120	$60	repair cable
							1	$12	$12	hanger
							1	$6	$6	base plate
							1	$2	$2	rubber disc
							1	$150	$150	triceps cuff
							1	$70	$70	TEC pads
	19/01/2009	20/01/2009	$2,640	BP	refit	replace socket due to volume change	1	$290	$290	TR diagnostic socket
							1	$2,300	$2,300	TR socket
							2	$25	$50	flexible hinge
	04/12/2008	11/12/2008	$1,373	BP	new	provide grip hand and cosmetic lamination	1	$1,195	$1,195	Becker lock grip hand
							1	$20	$20	triple swivel
							1	$38	$38	wrist insert
							3	$120	$120	laminate wooden section
	19/08/2008	19/08/2008	$92		supply	supply shrinker	4	$23	$92	Stump shrinker
	15/09/2008	16/09/2008	$40		supply	supply shrinker	2	$20	$40	Stump shrinker
	18/10/2008	20/10/2008	$40		supply	replace worn shrinker	2	$20	$40	Stump shrinker
	21/10/2008	14/11/2008	$4,969	BP	initial	provide first BP prosthesis	1	$290	$290	TR diagnostic socket
							1	$2,300	$2,300	TR socket
							1	$250	$250	triceps cuff

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
18 (VM)	**07/08/2008**	**07/08/2008**								
							1	$203	$203	wrist
							2	$175	$350	control cable
							1	$195	$195	harness
							1	$475	$475	cosmetic finish
							1	$642	$642	5XA hook
							12	$22	$264	soft sock

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
19 (KC)	**23/06/2008**	**23/06/2008**								
	20/09/2011	22/09/2011	$2,828	BP	supply	provide spare liners & dispossable supplies	2	$1,285	$2,570	Iceross upper X liner
							6	$23	$138	ply arm sock
							20	$2	$60	surgical tubing per ft.
							1	$60	$60	fit & trim liner
	08/07/2011	24/08/2011	$11,304	BP2	initial	provide new work BP prosthesis; existing BP will be refurbished for outside work use	1	$2,300	$2,300	T/R socket procedure
							1	$350	$350	T/R diagnostic socket
							1	$1,285	$1,285	Iceross upper X liner
							1	$484	$484	Icelock ratchet
							1	$205	$205	shuttle lock procedure
							1	$352	$352	hinge single axis LG
							1	$3,576	$3,576	B-style wrist
							1	$133	$133	quick disconnect insert
							1	$1,215	$1,215	hook
							1	$220	$220	bicep half cuff
							2	$175	$350	UE control cable
							1	$195	$195	UE harness
							1	$14	$14	Neoprene axilla loop pad
							1	$625	$625	T/R carbon exoskeletal finish
	29/06/2011	12/08/2011	$11,639	myo	repair	replacement MC Hand with OttoBock Hand	1	$11,027	$11,027	myohand vari plus speed
							1	$260	$260	cosmetic glove for men
							1	$232	$232	inner hand shell
							1	$120	$120	labour
	29/06/2011	12/08/2011	$2,458	myo	repair	repair	1.25	$120	$150	labour
							4	$2	$8	washer
							1	$9	$9	bearing
							1	$133	$133	quick disconnect wrist insert
							1	$2,158	$2,158	flexion unit assembly
	30/05/2011	08/06/2011	$8,874	myo	new	provide 2nd Greifer for work backup	1	$8,874	$8,874	Greifer
	26/04/2011	29/04/2011	$2,001	BP & myc	new	provide 2nd hook for outside work use	1	$812	$812	#7 hook
							1	$133	$133	quick release
							1	$936	$936	Greifer Tips

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19 (KC)	**23/06/2008**	**23/06/2008**								
							1	$120	$120	Re & Re
	14/04/2011	19/04/2011	$237	myo	repair	replacement	1	$152	$152	repairs to Greifer
							1	$25	$25	shipping to Ottobock
							0.5	$120	$60	inspect and Assess
	04/04/2011	07/04/2011	$90	myo	adjust	adjust wrist and recalibrate Greifer	1	$90	$90	adjustments
	09/03/2011	15/03/2011	$120	myo	repair	calibrate Greifer	1	$120	$120	Re & Re
	03/03/2011	09/03/2011	$200	myo	repair	install MC loaner hand	1	$150	$150	install, test, calibrate loaner hand and rep
							1	$25	$25	shipping to Motion Control
							1	$25	$25	Shipping loaner hand back to Motion Con
	11/02/2011	23/02/2011	$901	myo	repair	repair Greifer	1	$816	$816	repairs to Greifer
							0.5	$120	$60	Labour
							1	$25	$25	shipping to Ottobock
19	14/01/2011	20/01/2011	$359	BP?	repair	repair and supplies	1	$175	$175	control cable
19							2	$2	$4	washers
19							2	$12	$24	Socks Dillon Law
19							1	$22	$22	triple swivel
19							1	$14	$14	hanger 1"
19							1	$120	$120	assemble
19	19/11/2010	21/02/2011	$350		supplies	provide 2nd arm sleeve	1	$350	$350	custom Farabloc arm sleeve
19	29/09/2010	19/10/2010	$6,076	myo	refit	refit of existing myo prosthesis due to volume change	1	$290	$290	T/R diagnostic socket
19							1	$2,300	$2,300	T/R socket procedure
19							1	$400	$400	flexible inner liner
19							1	$205	$205	electric arm technique
19							4	$70	$280	electrode accessory
19							4	$62	$248	electrode accessory
19							1	$280	$280	wrist 10S1=45
19							1	$475	$475	exoskeletal finish
19							1	$28	$28	pull tube
19							1	$1,200	$1,200	hand motor upgrade
19							1	$370	$370	battery holder
19	29/09/2010	19/10/2010	$2,792	BP	refit	replace liner due to volume change	3	$26	$78	3Ply sock
19							6	$12	$72	sheath
19							24	$1	$12	hook tension band
19							2	$1,285	$2,570	Ossur liner I-813116

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19 (KC)	**23/06/2008**	**23/06/2008**								
19							0.5	$120	$60	fit & trim liners
19	24/09/2010	30/09/2010	$350		supply	supply Farabloc sleeve for phantom pain	1	$350	$350	custom Farablock Arm Sock
19	27/03/2009	02/04/2009	$275	myo	repair	repair of flexion switch of Greifer	0.5	$120	$60	install & test
19							1	$215	$215	flexion switch
	20/01/2009	10/02/2009	$13,844	BP	initial	provide 1st prosthesis -BP	1	$290	$290	TR diagnostic socket
							1	$2,300	$2,300	TR socket
							1	$649	$649	Icelock, Ratchet, Fabrication ring and spar
							1	$205	$205	lock procedure
							2	$1,010	$2,010	Icecross liner
							1	$300	$300	side joints
							1	$1,157	$1,157	bicep cuff, harness, bowden cable, wrist c
							1	$4,427	$4,427	B-version wrist and insert
							1	$717	$717	5X hook
							1	$1,314	$1,314	7 LO hook
							1	$475	$475	cosmetic finish
	18/12/2008	20/01/2009	$9,202	myo	new	provide Greifer	1	$8,326	$8,326	Greifer
							1	$876	$876	Long finger tips for Greifer
	26/11/2008	05/12/2008	$1,301	myo	supply	supplies for prosthesis	1	$82	$82	glove cleaner
							1	$13	$13	spary bottle for cleaner
							1	$538	$538	Movaskin cosmetic glove
							1	$560	$560	pincer for myo hand
							1	$48	$48	procomfort gel
							0.5	$120	$60	install glove
	26/11/2008	05/12/2008	$4,292	myo	replace	refit of existing myo prosthesis due to volume change	1	$290	$290	TR diagnostic socket
							1	$2,300	$2,300	TR socket
							1	$350	$350	flexible socket liner
							1	$250	$250	myo socket variation
							1	$27	$27	pull tube
							2	$65	$130	electrode accessory
							1	$280	$280	battery box
							2	$58	$116	electrode accessory
							1	$74	$74	wrist
							1	$475	$475	TR cosmetic finish
	18/09/2008	03/10/2008	$21,424	myo	initial	provide 1st prosthesis - myo	1	$290	$290	TR diagnostic socket

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19 (KC)	23/06/2008	23/06/2008								
							1	$2,300	$2,300	TR socket
							1	$400	$400	inner socket for myo
							1	$344	$344	lamination ring and coupling piece
							1	$4,748	$4,748	plug, cable (2), electrodes (2)
							1	$9,815	$9,815	motion control hand prohand
							1	$275	$275	glove
							1	$2,012	$2,012	battery set
							1	$202	$202	cable adaptor
							1	$500	$500	aegis liner
							3	$21	$63	shrinkers
							1	$475	$475	TR exoskeletal finish

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13 (SG)	**07/11/2008**	**07/11/2008**								
	10/09/2011	21/09/2011	$1,217	?					$1,217	no prosthetoc request
	17/08/2011	29/08/2011	$2,143	BP2	supply		1	$306	$306	Myoskin clean glove
							2	$560	$560	wrist insert for 10V39
							0.5	$120	$60	labour
							1	$869	$869	Iceross locking liner
							1	$288	$288	silicone distal cup
							1	$60	$60	fit and trim liner
	14/07/2011	25/08/2011	$3,096	BP2	repair	replace worn wrist	1	$2,696	$2,696	Movowrist
							1	$120	$120	Re & Re
							1	$280	$280	adapter for 10V39
	17/07/2011	25/08/2011	$3,637	myo	new	provide wrist rotator	1	$3,637	$3,637	electric wrist rotator
			$3,622				1	$3,622	$3,622	myorotonic
			$240				2	$120	$240	labour to install and calibrate
	30/05/2011	08/06/2011	$1,398	BP2	new	replace OB mechanical hand with voluntary close hand	1	$1,278	$1,278	voluntary hand
							1	$120	$120	labour to install hand
	19/04/2011	03/05/2011	$280	BP	repair	replace cracked wrist unit	1	$280	$280	wrist unit adapter
	17/03/2011	28/03/2011	$3,827	BP	refit	replace with custom silicone liner due to volume/shape change	1	$798	$798	trial fit liner
							1	$292	$292	distal connector
							1	$134	$134	Ottobock modifications
							1	$1,465	$1,465	T/H silicone liner
							1	$616	$616	custom design pad
							1	$292	$292	cover
							1.5	$120	$180	casting procedure, alignment, mold set
							2	$25	$50	shipping to Ottobock
	15/03/2011	21/03/2011	$764	BP	repair	repair broken wire on harness	1	$704	$704	wiring harness
							0.5	$120	$60	install
	15/03/2011	21/03/2011	$1,219	BP	refit	cast and fit test socket	3	$350	$1,050	test socket fittings
							1	$80	$80	valve
							1	$89	$89	pull sock
	24/02/2011	07/03/2011	$1,214	BP	refit	replace too loose liner	2	$577	$1,154	Aegis locking liner
							0.5	$120	$60	trim and fit liners
	31/01/2011	18/02/2011	$34,673	myo	initial	provide first myo prosthesis	1	$2,880	$2,880	T/H socket procedure
							1	$350	$350	T/H diagnostic socket
							1	$175	$175	control cable

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13 (SG)	**07/11/2008**	**07/11/2008**								
							2	$1,655	$3,310	suction socket electrode
							2	$161	$332	electrode canble
							2	$99	$198	electrode accessories
							1	$1,232	$1,232	lithium battery charger
							1	$248	$248	battery mounting kit
							2	$730	$1,460	battery energy pack
							1	$130	$130	battery cable
							1	$290	$290	lamination ring
							1	$79	$79	coupling piece
							1	$380	$380	coaxial plug
							1	$195	$195	UE harness
							1	$8,874	$8,874	electrogreifer DMC plus
							1	$936	$936	Greifer tips
							1	$556	$556	movaskin clean
							1	$11,027	$11,027	Variplus speed hand
							4	$120	$480	install collar
							1	$120	$120	install auxillary lanyard strap
							1	$870	$870	Iceross original liner
							1	$76	$76	alpha gel cups
							1	$475	$475	exoskeletal finish
	31/01/2011	17/02/2011	$4,624	BP	refit	replace socket with suction socket and adjust length	1	$2,880	$2,880	T/H socket procedure
							1	$350	$350	T/H diagnostic procedure
							1	$154	$154	Mag valve
							1	$376	$376	lamination ring
							1	$89	$89	pull sock
							1	$475	$475	T/H exoskeletal finish
							1	$300	$300	suction socket electrode
13	14/01/2011	20/01/2011	$900	BP	repair	refit locking liner for assessement	1	$870	$870	locking liner
13							0.5	$60	$30	trim & fit liners
13	14/01/2011	20/01/2011	$140	BP	repair	warranty repair of elbow still has problem	1	$120	$120	Re & Re Elbow unit
13							1	$14	$14	shipping to Otto Bock
13							1	$6	$6	elbow lock hanger
13	14/01/2011	20/01/2011	$133	BP	repair	warranty repair of elbow	1	$120	$120	Re & Re Elbow unit
13							1	$13	$13	shipping to Otto Bock

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13 (SG)	**07/11/2008**	**07/11/2008**								
13	23/12/2010	30/12/2010	$620	BP/BP2	replace	replace broken and deformed inserts	2	$280	$560	wrist insert 10A30=1/2-20
13							0.5	$120	$60	install insers
13	14/12/2010	17/12/2010	$527	BP	adjust	service & adjustment	1	$27	$27	cable
13							1	$8	$8	elbow hanger
13							1	$39	$39	axilla loop pad
13							2	$120	$240	exchange harness and replace elbow lock
13							1	$195	$195	figure 8 harness
13							1	$18	$18	Neoprene axilla loop pads
13	27/07/2010	03/08/2010	$145	BP	repair	adjustment and servicing	1	$120	$120	repair/adjust
13							1	$25	$25	repair materials
13	27/07/2010	03/08/2010	$175	BP	repair	inspect elbow and sent for warranty repair	0.5	$120	$60	inspect & assess elbow unit
13							1	$11	$11	shipping
13							4	$26	$104	soft sock
13	23/07/2010	03/08/2010	$2,739	BP	new	install wrist unit to improve functionality	1	$2,329	$2,329	wrist flex 10V38=50 MOVO
13							3	$120	$360	install & laminate
13							1	$50	$50	lamination materials
13	16/07/2010	20/07/2010	$124	BP	repair	install exisiting hand to primary prosthesis	0.75	$120	$90	install & modify
13							1	$20	$20	ball receiver
13							2	$7	$14	ferrule
13	03/06/2010	10/06/2010	$190		supply	supplies for prosthesis	2	$26	$52	soft sock
13							6	$23	$138	#ply sock
13	17/05/2010	31/05/2010	$860	BP2	repair	repair elbow unit	0.5	$120	$60	assess elbow for function
13							1	$778	$778	factory repair - Otto Bock
13							1	$12	$12	shipping to Otto Bock
13							1	$10	$10	shipping to client
13	14/05/2010	31/05/2010	$2,780	BP2	modify	convert suction to locking suspension	1	$308	$308	ratchet lock
13							1	$870	$870	Ossure liner
13							2	$76	$152	distal gel cup
13							1	$364	$364	laminating ring
13							1	$686	$686	5X hook
13							1	$280	$280	wrist adaptor
13							1	$120	$120	install components

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
13 (SG)	**07/11/2008**	**07/11/2008**								
13	14/05/2010	31/05/2010	$4,953	BP	repair	replace socket with locking liner system due to volume change	1	$290	$290	T/H diagnostic socket
13							1	$2,880	$2,880	socket procedure
13							1	$364	$364	lamination ring
13							1	$26	$26	fabrication ring
13							1	$54	$54	list assit
13							1	$394	$394	alignment aid
13							1	$475	$475	exoskeletal finish
13							1	$295	$295	harness
13							1	$175	$175	control cable
13	14/04/2010	Approved?	$4,810	rec	initial	specialty design Trans Humeral prosthesis for golfing	1	$290	$290	T/H diagnostic socket
13							1	$2,880	$2,880	T/H socket
13							1	$438	$438	wrist 52128 WD-400S
13							1	$26	$26	fabrication ring
13							1	$1,176	$1,176	GolfPro terminal device
13	14/04/2010	27/04/2010	$1,775	BP2	new	new 2nd mechanical hand	1	$150	$150	MAG valve 21Y15
13							1	$880	$880	hand 8K23
13							1	$280	$280	wrist adaptor
13							1	$250	$250	cosmetic glove
13							1	$95	$95	hook to hand cable
13							1	$120	$120	modify cable
13	29/03/2010	06/04/2010	$4,927	BP2	refit	refit prostheses due to weight gain	1	$290	$290	T/H diagnostic socket
13							1	$2,880	$2,880	T/H socket
13							1	$350	$350	flexible socket liner
13							1	$150	$150	MAG valve 21Y15
13							1	$205	$205	suction procedure
13							1	$475	$475	cosmetic finish
13							1	$195	$195	harness
13							2	$175	$350	control cable
13							1	$32	$32	lift assist
13	29/03/2010	06/04/2010	$918		new	supply cushion liner	1	$888	$888	cushion liner Ossur G-040318
13							0.5	$60	$30	fit & trim liners

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
13 (SG)	**07/11/2008**	**07/11/2008**								
13	18/11/2009	26/11/2009	$2,910	BP2	modify	replace friction controlled wrist unit with multifunction wrist unit	1	$2,280	$2,280	wrist unit Movowrist Flex 10V39
13							1	$270	$270	wrist adaptor
13							3	$120	$360	replace wrist of existing prosthesis
13	28/10/2009	20/11/2009	$11,254	BP2	initial	revise prosthetic prescription to improve function	1	$290	$290	T/H diagnostic procedure
13							1	$2,880	$2,880	T/H socket procedure
13							1	$1,195	$1,195	seal-in wave liner I-366318
13							1	$475	$475	cosmetic finish
13							1	$4,502	$4,502	Ergoarm 12K42=50
13							1	$293	$293	wrist
13							1	$350	$350	lamination ring
13							1	$54	$54	forearm lift
13							1	$83	$83	wrist insert
13							1	$762	$762	5XA hook 55013
13							1	$195	$195	harness
13							1	$175	$175	control cable
13	22/10/2009	27/10/2009	$461	BP	modify	revise existing harness and install new elbow control cable	2	$76	$152	Alpha gel caps
13							2	$8	$16	elbow hanger
13							2	$7	$14	ferrule
13							2	$6	$12	cable housing anchor
13							1	$27	$27	cable assembly
13							2	$120	$240	fabricate and install cable
13	24/09/2009	29/09/2009	$1,218	BP	replace	replace liner and volume control distal cup after surgery	1	$288	$288	distal cup
13							1	$870	$870	locking liner Ossur
13							0.5	$120	$60	trim & fit liners
13	21/05/2009	10/06/2009	$70	BP	adjust	supply pad to improve fit	1	$38	$38	TEC pad
13							1	$32	$32	Sillpos end pad
13	21/05/2009	10/06/2009	$11,880	BP	initial	fit first T/H BP prosthesis	1	$290	$290	T/H diagnostic socket
13							1	$2,880	$2,880	T/H socket
13							1	$308	$308	ratchet lock
13							1	$205	$205	lock procedure

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
13 (SG)	**07/11/2008**	**07/11/2008**								
13							1	$76	$76	distal pad
13							1	$870	$870	Iceross locking liner
13							1	$5,130	$5,130	Ergoarm hybrid plus elbow unit 12K44=5(
13							1	$522	$522	flexion wrist 51100
13							1	$195	$195	harness
13							1	$175	$175	control cable
13							1	$56	$56	forearm lift
13							1	$475	$475	cosmetic finish
13							1	$640	$640	hook 555
13							1	$58	$58	hook band applicator
13	07/05/2009	10/06/2009	$888		supply	supply compression garment	1	$888	$888	cushion liner Ossur I-040318
13	27/04/2009	?	$48		supply		2	$24	$48	B/K shrinker
13	27/04/2009	?	$9				1	$9	$9	shipping

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
20 (RM)	**14/08/2008**	**28/10/2009**								
	27/05/2011	02/06/2011	$1,161	Myo	new	supply extra charger	1	$642	$642	pulse charger
	03/03/2011	12/04/2011	$350	Myo	repair	reduce friction of EDT quick disconnect	1	$350	$350	motion control invoice
	04/03/2011	08/03/2011	$169		supply	supply pull sock	1	$89	$89	pull sock
							0.5	$120	$60	clinical time
							1	$20	$20	shipping to client
	04/02/2011	12/04/2011	$3,903	BP	modify	modify BP to Cosmetic prosthesis	1	$2,300	$2,300	T/R socket procedure
							1	$350	$350	T/R diagnostic socket
							1	$475	$475	T/R exoskeletal finish
							1	$28	$28	pull tube
							1	$336	$336	passive hand
							1	$250	$250	glove
							1	$75	$75	hand adapter
							1	$89	$89	pull sock
	04/02/2011	13/04/2011	$8,284	Myo	modify	revise hybrid to myo	1	$2,300	$2,300	T/R socket procedure
							1	$350	$350	T/R diagnostic socket
							1	$475	$475	T/R exoskeletal finish
							1	$350	$350	double lamination procedure
							1	$290	$290	lamination ring
							2	$1,655	$3,310	suction socket electrode
							2	$88	$198	electrode accessories
							1	$161	$161	electrode cable
							1	$88	$88	battery mounting set
							1	$634	$634	battery
							1	$100	$100	battery connection cable
							1	$28	$28	pull tube
20	10/11/2010	22/11/2010	$17,604	hybrid	initial	provide hybrid prosthesis to replace BP sytem	1	$350	$350	T/R diagnostic socket
20							1	$2,300	$2,300	T/R socket procedure
20							1	$475	$475	exoskeletal finish
20							1	$634	$634	battery 757B15
20							1	$100	$100	battery connection cable
20							1	$88	$88	battery mounting set
20							1	$2,026	$2,026	linear transducer 9X52
20							1	$161	$161	electrode cable
20							1	$5,415	$5,415	EDT Motion Control TD, left 5010032
20							1	$2,555	$2,555	ProHand Feature 3010599

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
20 (RM)	**14/08/2008**	**28/10/2009**								
20							1	$2,121	$2,121	flexion wrist attachment 3010485
20							1	$290	$290	lamination ring
20							1	$380	$380	coaxial plug
20							1	$260	$260	heater pad
20							1	$25	$25	heater mounting bracket
20							3	$26	$78	3Ply wool sock
20							6	$12	$72	stretch spacer socks
20							1	$195	$195	figure nine harness
20							1	$79	$79	coupling piece
20	05/10/2010	13/01/2011	$202		supply	supply compression sock	1	$190	$190	Relax compression sock
20							1	$12	$12	safe soap
20	05/10/2010	29/10/2010	$634	BP	replace	supply stain resistance glove	1	$574	$574	Movoskin glove 8S4C
20							0.5	$120	$60	install glove
20	29/09/2010	29/10/2010	$830	BP	modify	supply & install heating pad for pain relief	1	$250	$250	Hotronic heating system
20							1	$220	$220	Bicep cuff w/ hinges
20							3	$120	$360	install heater & cuff
20	15/07/2010	20/07/2010	$1,045	BP	new	supply tool adaptors	1	$750	$750	custom tool adaptor
20							1	$280	$280	wrist adaptor
20							1	$15	$15	shipping
20	05/07/2010	08/06/2010	$1,251	BP	new	modify prosthesis after surgery	1	$747	$747	5X hook 55010
20							1	$280	$280	wrist adaptor
20							2	$22	$44	3Ply sock
20							1.5	$120	$180	assess and supply
20	22/04/2010	Approved?	$720	BP	new	supply adaptor for recreation	1	$440	$440	Hustler Pool cue adaptor
20							1	$280	$280	wrist insert
20	24/02/2010	09/04/2010	$250	BP	supply	supply temporary sheaths	2	$125	$250	Silipos double cushion sheath
20	09/03/2010	25/03/2010	$78		supply	supply volume control socks	3	$26	$78	3 Ply sock
20	25/01/2010	26/01/2010	$376		supply	supply cushion liner	1	$346	$346	Aegis cushion liner
20							0.5	$60	$30	fit & trim liners
20	12/01/2010	21/01/2010	$10,241	BP	initial	provide 1st BP prosthesis	1	$290	$290	T/R diagnostic socket
20							1	$2,300	$2,300	T/R socket
20							1	$308	$308	distal lock L-621000
20							1	$205	$205	lock procedure
20							1	$1,062	$1,062	Iceross locking liner I431322

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
20 (RM)	**14/08/2008**	**28/10/2009**								
20							1	$2,280	$2,280	MovoWrist 10V39=50
20							2	$270	$540	wrist adaptor 10A30
20							1	$475	$475	cosmetic finish
20							1	$880	$880	mechanical hand 8K23
20							1	$242	$242	cosmetic glove
20							1	$700	$700	5XA hook 55012
20							1	$352	$352	side hinges 51856
20							1	$237	$237	bicep cuff
20							1	$195	$195	harness
20							1	$175	$175	control cable

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
5 (SS)	**14/07/2009**	**14/07/2009**								
	27/01/2011	10/02/2011	$842	BP	new	provide tools for prosthesis	1	$700	$700	universal handle holder
							1	$142	$142	quick release
	21/01/2011	10/02/2011	$304	BP?	repair?		2	$142	$284	quick disconnect
							1	$20	$20	mailing
	14/12/2010	31/12/2010	$1,124	BP	modify	replacement wrist inserts & tool shank adaptor	4	$210	$840	tool shank adaptor
							2	$142	$284	quick release wrist inserts
	10/12/2010	31/12/2010	$4,751	Myo	refit	replace exsiting socket,new laminated forearm shell & transfer existing myoelectric components.	1	$2,650	$2,650	T/C socket procedure
							1	$350	$350	T/C diagnostic socket
							1	$475	$475	T/C exoskeletal finish
							1	$350	$350	double lamination procedure
							1	$856	$856	lamination plate
							1	$70	$70	electrode assembly
	07/07/2010	09/08/2010	$3,546	BP	new	additional terminal device & tools for exisitng body power prosthesis	1	$1,061	$1,061	work hook
							3	$148	$444	insert
							1	$175	$175	garden heo
							1	$333	$333	tool cradle
							1	$175	$175	cultivator
							1	$758	$758	passive hook
							1	$175	$175	spade
							1	$425	$425	chef knive
	14/04/2010	16/04/2010	$7,896	cos	initial	supply cosmetic custom silicone hand	1	$7,856	$7,856	passive silicone hand
							1	$40	$40	shipping
	07/04/2010	13/04/2010	$1,237	BP	initial	parts for conventional (BP) prosthesis in progress	1	$846	$846	Aluminum hook
							1	$195	$195	harness
							1	$95	$95	control cable
							1	$39	$39	axilla loop pad
							1	$62	$62	hook band applicator
	24/03/2010	06/04/2010	$3,319	cos	assess	prototype custom silicone hand prosthesis	1	$2,796	$2,796	prototype silicone hand prosthesis
							4	$120	$480	cast, fit and assess

Client	Request Date (dd/mm/yyyy)	Approval Date (dd/mm/yyyy)	Invoice	Type	Work Type	Work Nature	Qty	Unit Cost	Total Cost	Description
5 (SS)	**14/07/2009**	**14/07/2009**								
							1	$43	$43	shipping
	27/05/2010	09/06/2010	$4,021	BP	initial	provide 1st conventional arm prosthesis with quick disconnect style wrist	1	$290	$290	T/C diagnostic procedure
							1	$2,650	$2,650	T/C procedure
							1	$400	$400	flexible inner liner
							0	$523	$0	Alpha custom liner (removed 2010-05-27)
							1	$413	$413	transcarpal adaptor
							1	$148	$148	quick disconnect insert
							6	$20	$120	2 ply sock
	03/02/2010	03/03/2010	$19,492	Myo	initial	provide 1st myoelectric trans carpal hand	1	$290	$290	T/C diagnostic procedure
							1	$2,650	$2,650	T/C procedure
							1	$400	$400	flexible inner liner
							1	$240	$240	electric arm technique
							2	$2,170	$4,340	electrode
							2	$68	$136	electrode assembly
							2	$138	$276	electrode cables
							1	$1,000	$1,000	internal battery
							1	$1,200	$1,200	battery charger
							1	$166	$166	switch block
							1	$8,500	$8,500	trans carpal hand
							1	$294	$294	cosmetic glove

Appendix C Incidence Survey Request and Questionnaire

From: Anthony Chan
Subject: [ULPOM_All] Risk Assessent of UL Prostheses
To: ulpom
Date: Wednesday, October 13, 2010, 12:04 PM

Hello Everyone
I am a biomedical engineer associated with the British Columbia Institute of Technology and the University of British Columbia. I am currently working on a project with a team of researchers and rehabilitation professionals sponsored by the WorkSafe BC (the workers' compensation board of the province of British Columbia in Canada). The purpose of the project is to optimize the selection of prostheses for upper limb amputees from work-related injuries with the intention that these amputees will return to their original or alternative jobs. A task of this project is to develop risk assessment protocols for upper limb prostheses under different environments based on the International Standard ISO 14971 (Application of Risk Management to Medical Devices).
The first phase of the task is to collect and review available safety-related information on upper limb prostheses in use. Such information includes known and potentially hazardous situations, the harm incurred (to patients, caregivers, and others) under each hazard, and its risk control measures.
I am hoping to get your help by completing and returning to me the attached short questionnaire (hopefully by the end of October). I have also attached an example.
Please send your responses directly to me. I will share the results collected with those who are interested.
Your assistance will be very much appreciated.

Anthony Chan, PEng, CCE

(See attached file: Risk_Questionnaire_example.doc)(See attached file: Risk_Questionnaire.doc)

Risk Survey of Upper Limb Prostheses

The questions below are to identify risks to clients or others from using upper limb body-powered or myoelectric prosthetic components. The components involved may be a terminal device, wrist or elbow. Please also use this same questionnaire to provide information about potential risks that you think may happen to clients or others. Please use a separate page for each incident.

1. Are you aware of any incident that has resulted in injury to your clients or other people?

   Yes ____, No _____

2. Is this a true incident or a potential risk? Incident _______, Potential Risk ________
3. Describe the prosthetic component(s) involved:
4. Describe the cause(s) of the injury (and/or damage):
5. Describe the injury (and/or damage):

   Rate the severity of the injury/damage: Severe _____, Moderate ______, Minor ______
6. Describe the method of mitigation (e.g. replacement of components, training, etc.):
7. What is the probability of this incident to happen on another client under similar situation?

   High _____, Medium _____, Low ______
8. Other comments:

Risk_questionnaire.doc Sept 24, 2010 UBC-AYC

Appendix D Prosthesis Related Incident Survey Results

Case	Source/ Profession	Incident/ Potential Risk	Components Involved	Causes of Injury	Description of Injury (Severity)	Method of Mitigation	Probability of Occurrence	Other Comments
1	OT	Incident	Otto Bock Sensor Speed Hand	Auto grasp feature was turned on and client was using his hand to drive. As he tried to turn the steering wheel, the auto grasp feature activated and the hand gripped the wheel harder preventing him from turning around a corner	The client is an experienced user and was able to release the hand before any damage was done, but it scared him and we disabled the auto grasp feature after this incident (minor)	We discussed locking the hand in an open position while driving to prevent this from happening, but also disabled the auto grasp feature to ensure it wouldn't happen again	High	
2	OT	Incident	Boston Elbow, LTI electrodes (no longer in use)	Electro-chemical burns to clients upper arm in area of the electrode placement over a period of three months	There was a small voltage leak through the system that resulted in burn marks and blistering of the skin on the clients residual limb exactly where the electrodes were located (moderate)	Arm was sent to LTI for repairs and replacement of components	low	This happened about 10 years ago and many of the components in question are no longer in use, however, the potential is always there to have voltage leakage and electro-chemical burns resulting

Case	Source/ Profession	Incident/ Potential Risk	Components Involved	Causes of Injury	Description of Injury (Severity)	Method of Mitigation	Probability of Occurrence	Other Comments
3	OT	Incident	Ottobock DMC hand	Client was riding her mountain bike while wearing her myoelectric prosthesis. Her hand was turned on and grasping the handle bar when she fell. The bike landed on her as she rolled down and incline	She had many bumps and bruises on her face and arms. She was knocked unconscious and later had a seizure. (moderate)	We discussed again the importance of always wearing a helmet, and always keeping the hand slightly open (and locked in position) when using a myo for riding a bike. We also provided her with a TRS bike attachment for use with her passive arm	High	Our clients are always instructed to keep the myo hand turned off and kept open when riding a bike so the hand will come off the bike in case of a fall. This particular client has issues with impulsive behaviour.
4	OT	Incident	Boston Elbow	The client was at a store trying to write something on a counter surface when the arm started going into extension and continued into hyper-extension	No physical injury but the client was embarrassed and then had difficulty getting in and out of his car, and di not want to take the arm off as he was at work and doesn't like to be in public without his prosthesis (minor)	The prosthesis needed to be sent back to the manufacturer for repairs. The calibration of the elbow continued to be a problem and we eventually decided to fit a different type of elbow (non-powered)	Low	
5	MD	Incident	Voluntary closing hook with locking mechanism	Patient was rowing a boat that overturned while paddling. Subject was unable to release paddle causing him difficulty to swim	Bruises in arm and legs (minor)	Avoid use of locking mechanism, implement fix, replace hook for voluntary opening or non locking system.	High	

Case	Source/ Profession	Incident/ Potential Risk	Components Involved	Causes of Injury	Description of Injury (Severity)	Method of Mitigation	Probability of Occurrence	Other Comments
6	MD	Incident	Proportional control myo griffer	Patient was changing diaper on a baby and inadvertently pinched child. Griffer would not release tissues trapped bruising child	Bruises in leg (moderate)	Failure reported to manufacturer, may consider an emergency release system	High	
7	OT	Potential Risk						I don't know of any incidents of injury to a user or others related to the use of any prosthesis. I think generally common sense guides prescription and training with prostheses and perhaps common sense prevails. Most amputee patients want desperately to return to driving and guidelines would be welcome because they would presumably support what therapists/prosthetists generally recommend.

Case	Source/ Profession	Incident/ Potential Risk	Components Involved	Causes of Injury	Description of Injury (Severity)	Method of Mitigation	Probability of Occurrence	Other Comments
8	OT	Incident	TRS (Therapeutic Recreation Systems) terminal device on transradial body-powered prosthesis	TRS (Therapeutic Recreation Systems) terminal device on transradial body-powered prosthesis	I don't believe there was any major injury; but there clearly could have been if the individual had not been quick thinking….He had to remove the entire prosthesis, over his head quickly, in order to release the oar and avoid injury as the kayak tipped over….(minor)	A change in the terminal device design to incorporate a quick release lock	Low	I am definitely interested in the results of your review and investigation of risks as it relates to upper limb components. This is an extremely interesting subject and one that will truly peak the interest of many clinicians in the field, manufacturers of upper limb components, the workers compensation insurance companies that not only have paid for these components for their claimants, but also may have been made aware of an incident that included an injury while wearing an upper limb prosthesis. An area where I am particularly interested, as it relates to the safety of individuals wearing upper limb electric components, revolves around the question of: "Is it safe to drive any type of vehicle while using a prosthesis, specifically one that is electric, where an electric malfunction may occur resulting in a car accident and personal injury, OR one where the reaction time of an individual is not related to the conscious thought process of locking or unlocking an electric elbow or hand….but rather the reflex reaction of what a individual *does* at the time of an accident to preserve their life and that of others. Has an electric locked elbow, or "grasping hand" of a steering wheel ever resulted in an accident, or caused an accident to occur? There are different "schools of thought" regarding this question, and different restrictions made by state's Department of Public Safety, as to whether upper limb prostheses are permitted to be worn while driving a car. Curious what rules in Canada exist as it relates to this topic?