MEASUREMENT OF UPPER EXTREMITY VOLUME IN WOMEN FOLLOWING AXILLARY DISSECTION FOR BREAST CANCER

by

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Abstract

Women who have been treated for breast cancer with axillary surgery and/or radiation are at an increased risk of developing lymphedema in the ipsilateral upper extremity. In order to ensure accuracy in the measurement of upper extremity volume, and thus provide appropriate treatment options for lymphedema, a reliable and valid measurement method must be determined.

The gold standard for clinical measurement of limb volume is water displacement volumetry, which can be time-consuming and unhygienic. The purpose of this research project was to determine if two methods of calculated upper extremity volume (using arm circumferences) could be substituted for measured water displacement volume in women after treatment for breast cancer. Inter-rater and test-retest reliability of circumferential measurements and water displacement volumetry were also examined.

The subjects were 23 women who were at risk for lymphedema, having undergone axillary lymph node dissection surgery for breast cancer. Seventeen of the women had additional radiation therapy. Subjects had circumference and volume measurements taken of bilateral upper extremities by two physical therapists on the first day, and one week later by one of the physical therapists.

Intraclass correlation coefficients (ICCs) were calculated to analyze circumferential and volume measurement reliability. Pearson product moment correlation coefficient (Pearson r) was used to evaluate the correlation between volumetry measurements and calculated volumes. Limits of agreement were calculated in order to determine the amount of agreement between the measurement methods. Upper
extremities ipsilateral to the breast surgery were compared separately to contralateral upper extremities.

Inter-rater and test-retest reliability ICCs for circumferential data were 0.99 and 0.99, for surgical upper extremities and contralateral upper extremities. Inter-rater and test-retest reliability ICCs for volumetric data were 0.99 and 0.99, for surgical upper extremities and contralateral upper extremities. Pearson-r values were 0.93 and 0.97 for the single truncated cone volume calculation and the summed truncated cone volume calculation respectively. Limits of agreement were (mean +/- 2sd) -52 +/- 334 mL, and -40 +/- 234 mL for single truncated cone calculation and summed truncated cone calculation respectively.

The results of this investigation suggest that calculated and volumetric measurements in this population are both reliable and closely related, but do not agree with each other, and thus can not be used interchangeably.
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1.1 Statement of the Research Problem

Women who have undergone axillary dissection surgery as a part of the medical management of breast cancer are at increased risk of developing lymphedema in the ipsilateral upper extremity. The addition of radiation therapy further increases the risk of lymphedema for these women. Although health care practitioners utilize techniques to treat lymphedema, evaluation of the effect of these treatments is not possible without an accurate, easy-to-use method for the quantification of arm size. To date, many researchers have examined the incidence of lymphedema following treatment for breast cancer, as well as possible treatments for lymphedema, but most researchers are using their own unique method for the measurement of the upper extremities, and the quantification of lymphedema.

A few researchers have used the water displacement method for upper extremity volume determination which is considered the 'gold standard' for measurement of limb volume. Others have used various methods involving upper extremity circumferences, which have not been determined to be valid or reliable in the determination of upper extremity volume in women after breast cancer treatments. The water displacement method for limb volume determination is time-consuming, not portable and can be unhygienic, which is why many researchers choose not to use this measurement tool. Determination of a valid and reliable outcome measure, which can be substituted for volumetry, is necessary for accurate diagnosis and effective monitoring of
lymphedema, and will provide an alternative measurement tool to researchers who are investigating the efficacy of treatments for this condition.

1.2 Significance of the Study

One woman in nine is expected to develop breast cancer in Canada, and approximately 15-20% of the women who have axillary lymph nodes removed in the management of breast cancer will develop lymphedema in the ipsilateral upper extremity. Lymphedema is defined by the International Society of Lymphology as an abnormal accumulation of tissue proteins, edema and chronic inflammation within an extremity. There are two types of lymphedema described in the literature. Primary lymphedema results from defects in the lymphatic system of congenital origin. Secondary lymphedema is acquired due to obstruction or interruption of the lymphatic system, usually occurring at proximal sites of lymph nodes.

In women with breast cancer, interruption of the lymphatic flow may be caused by surgery (i.e. axillary node dissection or mastectomy) or radiation therapy in the axillary region. Resection of a tumour may injure the lymphatic system due to the close proximity of the breast tissues and the axillary lymph vessels. In axillary dissection, increasing numbers of lymph nodes removed results in reduced lymph system effectiveness. Radiation therapy in the axillary region can cause fibrosis of the lymphatic structures, interfering with their function.

Incidence reports in the literature vary. Markowski et al. reported incidence rates ranging from 6.7 to 62.5% based on surveys of women who have undergone various treatments for breast cancer. They found that 15-20% of women who have axillary
lymph nodes removed will develop lymphedema in the ipsilateral extremity. Kissin and colleagues found that the incidence of lymphedema was greatest (i.e. 38%) among those who have had axillary surgery followed by radiation therapy. The development of lymphedema may occur soon after treatment, or may occur 30 years following the completion of treatment, making determination of incidence difficult. Also of concern is the fact that there is not yet a universally accepted definition of lymphedema.

The American Physical Therapy Association has suggested guidelines for a definition of lymphedema. It is one of the few definitions of lymphedema available, but is problematic. This scale defines mild lymphedema as a difference between the circumference of the affected and unaffected limb of three centimetres, moderate lymphedema as a difference between limbs from three to five centimetres, and severe lymphedema as greater than five centimetres difference between the limbs. Using an absolute scale such as this fails to account for the obvious size difference between upper extremities, as well as the variability in the size of women’s limbs. This scale does not outline where the measurements are to be taken on the limb. A difference in limb size at the level of the forearm will be proportionately greater than the same difference at the level of the upper arm. Due to dissatisfaction with definitions for lymphedema, many researchers are defining this condition using their own terms. This will affect the incidence rates reported by various researchers.

Lymphedema can be distressing to affected women, causing heaviness and discomfort in the affected upper extremity, impairments in function and unsatisfactory appearance. Large amounts of fluid in an extremity may cause restrictions in range of motion. Chronic lymphedema can compromise the health of subcutaneous tissues,
increasing the risk of developing infection in the tissues. Lymphangiosarcoma, while rare, is a malignant condition which has been associated with chronic lymphedema. Delaying intervention in reducing lymphedema may result in poor functional outcomes, as well as increasing emotional distress.

While much of the current research into breast cancer is focused on prevention and treatment of the cancerous lesion, little research has been directed toward important quality of life issues for women who have already developed and been treated for breast cancer. Physical therapists can offer conservative treatments for lymphedema. While a cure is not yet available, conservative treatment aims to reduce and control the amount of swelling in an affected limb, as well as restore the function and cosmesis of the extremity. Considering the medical and psychological complications of lymphedema, it appears critical that clinicians be able to identify whether lymphedema is developing. Unfortunately, without a valid or reliable method of measuring lymphedema, it is not possible to determine whether lymphedema is developing, nor to evaluate the effectiveness of treatment. While many methods to measure limb volume have been studied for the lower extremity after various orthopaedic conditions, only one method has been assessed for validity or reliability when used to measure volume of the upper extremity, but not specifically following treatment for breast cancer. An investigation of measurement techniques for the upper extremity following axillary node dissection treatment for breast cancer will begin to address the lack of available resources on this topic.
1.3 Definitions

Throughout the thesis, the following terms are used as defined below:

**Concurrent validity**: the extent to which a developing measure is comparable to a measurement standard

**Inter-rater reliability**: the consistency amongst different judges' ratings of the same object or response

**Intraclass Correlation Coefficient**: a statistical test that allows comparison of two or more repeated measures, often used for reliability analyses.

**Limits of Agreement**: a statistical test that determines the amount of agreement between two measures

**Pearson Product Moment Correlation Coefficient**: a statistical test used to quantify the magnitude and direction of the linear relationship between two variables

**Test-retest Reliability**: the ability of a measurement to be repeated from one test occasion to another

**Validity**: the meaningfulness of test scores as they are used for specific purposes
1.4 Objectives of the Study

The goal of this study was to determine an accurate, reliable and cost-effective method for measurement of upper extremity volume that could be easily used in a clinical or research setting, as a substitute for water displacement volumetry. Specific objectives of the study are listed below.

1. Objective #1: The first objective of this research project was to investigate the inter-rater reliability of circumferential measurements of the upper extremity in women following treatment of breast cancer. Measurements of the upper extremities ipsilateral to the surgery were evaluated separately from measurements of the contralateral upper extremities in order to determine whether the measurement technique was reliable in both cases.

2. Objective #2: The second objective was to investigate the test-retest reliability of circumferential measurements of the upper extremity in women following treatment for breast cancer. Upper extremities ipsilateral and contralateral to the surgery were compared separately.

3. Objective #3: Thirdly, inter-rater reliability of volumetric measurements of the upper extremity in women following treatment for breast cancer was studied. Measurements of the upper extremities ipsilateral to the surgery and contralateral to the surgery were considered separately.

4. Objective #4: Objective four was to determine the test-retest reliability of volumetric measurements of the upper extremity in women following surgical treatment for...
breast cancer. Upper extremity measurements ipsilateral to the surgery were compared separately from measurements contralateral to the surgery.

5. Objective #5: The fifth objective was to determine the concurrent validity through correlation between volumetry, the gold standard technique for determination of extremity volume, and a method of calculating upper extremity volume using circumferential measurements (single truncated cone calculation).

6. Objective #6: The sixth objective was to determine the concurrent validity through correlation between volumetry and a second method for calculating upper extremity volume using circumferential measurements (summed truncated cone calculation).

7. Objective #7: The seventh objective was to investigate the level of agreement between volumetry and the single truncated cone calculation for arm volume in order to determine whether the two measurement techniques are interchangeable.

8. Objective #8: The eighth objective was to determine the level of agreement between volumetry and the summed truncated cone calculation for arm volume in order to determine whether the two measurement techniques are interchangeable.
CHAPTER II

LITERATURE REVIEW

A literature search was conducted in the areas of the lymphatic system and lymphedema, issues regarding measurement in research, and various methods to measure the volume of an extremity. This enabled the author to familiarize herself with the current literature on the association between breast cancer treatments and lymphedema, as well as the issues in the determination of upper extremity volume. After consideration of the literature, a research hypothesis was suggested for each study objective.

2.1 The Lymphatic System

Swelling in the ipsilateral upper extremity frequently occurs soon after axillary surgery for breast cancer and is thought to be due to lymphatic overload. Late lymphedema occurs approximately six months following surgery or radiation therapy of the axillary region, and is primarily thought to be due to obliteration of the lymphatic system vessels or nodes. Not all women treated with the same combinations of surgery and radiation therapy develop the same rates or severity of lymphedema.

The lymphatic system consists of a network of vessels throughout the body that converge at proximal sites in the form of sacs, or lymph nodes, which have a low internal hydrostatic pressure. Axillary lymph nodes are located in the axillary region, in close proximity to the breast and surrounding tissues. The low internal pressure of the lymph nodes and vessels, compared with a higher pressure outside the vessels, serves to promote
the passage of fluid and proteins into the lymphatic system's vessels. The function of the lymphatic system is then to return the lymph fluid and proteins from interstitial spaces to the circulatory system.\textsuperscript{23}

The flow of lymph throughout the vessels is driven by a mechanism similar to that of the venous system. Sequential contractions of smooth muscle produce the pumping action which moves the lymph fluid through the vessel network. Skeletal muscle that is in close proximity to the lymphatic system may also aid in compression of the vessels, further enhancing lymph flow through the system.\textsuperscript{24,25} Lymph vessels also contain a series of one-way valves similar to those of the venous system, thus permitting a forward flow of lymph fluid, and not allowing a backward flow.\textsuperscript{23}

\subsection*{2.2 Lymphedema after Treatment for Breast Cancer}

Lymphedema occurs when lymph fluid and proteins are not removed from interstitial spaces. The resulting accumulation of proteins and fluid in the affected tissues, causes edema and inflammation within the involved extremity.\textsuperscript{26} Surgical excision of a breast tumour may directly damage lymph vessels due to close proximity of the two structures. Direct injury to the lymphatic vessels can cause scarring, leading to obstruction in the lymphatic vessels and reduced efficiency of the lymphatic system to remove lymph from the extremity.\textsuperscript{1,11} Surgery may also include lymph node sampling, in which only some of the lymph nodes are removed in order to stage the breast cancer, or lymph node removal surgery, depending on the preference of the surgeon.\textsuperscript{27} Removal of some or all of the lymph nodes will reduce the efficiency, and effectiveness of the lymphatic system. In addition to axillary surgery, women may also have radiation

\textsuperscript{9}
therapy of the breast and axillary regions. Radiation can cause fibrosis of irradiated lymphatic tissues, again reducing the effectiveness of the vessels to perform their lymph removal task.  

Not all women who have been treated with the same combination of surgery and radiation develop lymphedema at the same rates. What creates this difference in amount of swelling and timing of lymphedema development? Despite damage or obliteration of lymphatic structures in the axillary region, there may still be remaining vessels which perform the task of lymph removal. In some patients, however, the remaining lymph system can become overwhelmed. Lymphatic function may be decreased over time due to advancing age, or local infection causing scarring and increased damage to the lymph system. Infection also brings extra fluid to the area, with the intention of fighting the local inflammation. In the case of a woman with previously damaged lymphatics, this increase in fluid could further overwhelm the system, potentially resulting in the development of lymphedema.

In order to determine whether lymphedema is developing, clinicians must be able to accurately measure the volume of the upper extremity. Lymphedema can be treated, and accurate measurement of upper extremity volume will give clinicians the ability to determine the effectiveness of treatment programs. The following section of the literature review outlines important concepts involved in measurement.

2.3 Measurement of Lymphedema

As increasing emphasis is being placed on reducing health care resources, health care professionals are being pressured to document effectiveness of treatments. Health
care consumers are increasingly demanding as well, appropriately expecting the best and
most successful treatments available. The documentation of effectiveness will allow for
determination of which treatments are best, and when to change treatment options.
Clinicians should choose reliable and valid outcome measures so that the worth of the
treatment program can be judged. Reliable and valid measures will enable accurate
judging of rehabilitation outcomes, which will ultimately improve treatment outcomes for
women who are being treated for lymphedema.

Measurement is a systematic process which allows differentiation between things
or items. "Measurement is not a random process, but one that proceeds according to rules
and guidelines." To be able to measure a phenomenon allows for determination of
whether the factor or item has changed. Determination of a clinically feasible, reliable
and valid measure of upper extremity volume is critical for several reasons. Firstly, the
capability to document upper extremity size will allow clinicians to instigate treatment of
lymphedema as soon as necessary. With more than one valid and reliable method from
which to choose, clinicians can decide on the method most suitable in particular
circumstances, whether they find a method less complicated, more portable, or more
hygienic. Secondly, a reliable method will allow comparison of treatment outcomes, to
determine the effectiveness of treatment, so that changes can be instituted as required.
Thirdly, a reliable and valid outcome measure can be used to answer research questions
regarding the effectiveness of treatments, or to investigate new treatments. Consistency
in outcome measures use will allow comparison among various research papers, which is
currently not possible due to the inconsistency of methods presently in use to document
upper extremity volume. A useful, dependable measurement tool, which is appropriate for clinical and research use, will demonstrate both reliability and validity.

2.4 Reliability

Reliability refers to the consistency or repeatability of measures.\textsuperscript{30} A measure is reliable if it consistently demonstrates similar scores on repeated application. Measurement of human attributes takes into account that a component of the value being measured is the actual variable of interest, but there are also other components to consider. In the instance of measuring upper extremity volume, scores may differ due to small changes in physiological properties related to circadian rhythms or levels of activity on particular days. Scores will also include an error component consisting of tester measurement error, and equipment error. It is important to control for as much variation as possible by ensuring that the test is reliable among raters, and over repeated administrations.

Types of reliability include intra-rater reliability, inter-rater reliability and test-retest reliability.\textsuperscript{30,31} Intra-rater reliability refers to the consistency of scores obtained by a single observer with repeated measurements. The variability in scores can be attributed to the observer’s errors, but may also be due to inconsistency in how the subject performs the test. Preferably, for scores obtained from observation of a skill or task, a subject’s performance can be videotaped, thus eliminating errors due to variable subject performance. The rater can then grade the same performance of the subject at two different times. In tests that are not observational, it is often difficult to determine the cause of any inconsistency.
Inter-rater reliability is the consistency of measurement scores between two or more separate observers who have assigned scores to the same item or performance.\textsuperscript{31} Again, in order to reduce errors due to subject performance or responses, observational measures can make use of videotaped performance, or watch and grade the performance at the same time. In the instance where performance can not be videotaped and a test must be applied, testers should apply the test closely in time.

Test-retest reliability consists of repeating a measure more than once over a sufficient period of time so that observers or raters do not remember the performance or parameters from the last test.\textsuperscript{31} There must not be so much time in between tests, however, that scores change due to significant changes in performance from elapsed time alone. In order to protect against variation in body measures due to circadian rhythms, tests should be performed at the same time of day. Test-retest reliability includes components of intra-rater and instrument reliability. In order to evaluate an outcome measure, inter-rater and test-retest reliability are sufficient to establish reliability.\textsuperscript{30} If either of these is poor, intra-rater reliability can be investigated in an attempt to determine the cause of the poor reliability.

### 2.5 Validity

Validity refers to whether a test is measuring what it is intended to measure.\textsuperscript{29} It helps to determine the appropriateness or usefulness of the test or measure. Reliability is an important component to validity. If a measure is unreliable it is also invalid, and therefore, is not a useful test.\textsuperscript{30} Reliability alone is not a sufficient condition for validity, however. In addition to being repeatable, a measure must also be valid. The
measurement tool must also measure what it is actually intended to measure, thus providing useful information. Measurement validity is divided into three categories: construct validity, content validity and criterion validity.

Construct validity refers to the appropriateness of the constructs that underlie the measure. In order to ensure construct validity, researchers must define the constructs that they wish to measure. For example, if a researcher wishes to measure strength in the hips of healthy subjects, strength must be defined within the context of the study, criteria which determine healthy subjects must be described, and the test itself described, allowing others to determine whether construct validity has been achieved. For the measurement of upper extremity volume in women at risk for lymphedema following treatment for breast cancer, the constructs of upper extremity volume, women at risk for lymphedema, and the application of the test would all have to be defined, to allow determination of the validity of the constructs being examined. Physical properties, such as the construct of volume, are readily observable and are defined by the actual measurements obtained through accepted methods, such as water displacement volumetry. The construct in this instance is an increase in volume due to swelling from lymphedema. An arm that is swollen will displace more water than one that is not swollen. In women with unilateral lymphedema, this would be demonstrated by assessing the contralateral upper extremity.

Content validity is the extent to which the measure captures the content of interest. This is more of a concern with self-report or observational tools. Activities of daily living measurement tools, and functional measurement scales may have questionable content validity if they do not include all items that some clinicians or
researchers consider important to the criteria that are being measured. A rationale for their validity must also be indicated.

Criterion validity is the amount to which a measure is related to another test measuring the same trait under study, ideally the 'gold standard'. Criterion validity may be predictive or concurrent in nature. Predictive validity determines the extent to which a test performed at one time is predictive of a future event. Concurrent validity is utilized when comparing the results of two measurement tools, which were performed at the same time. Concurrent validity is useful when comparing a new test to an established test which is measuring the same variable. If the measurements obtained by the new tool correlate closely to those of a widely accepted outcome measure, the new measure may be an appropriate substitute outcome measure.

One may ask whether it is worthwhile to examine a new test if another version already exists. In the instance that the new test is simpler, less expensive or less time-consuming, it is valuable to consider the new test. When measuring limb volume, water displacement volumetry is considered the 'gold standard'. Water displacement volumetry, however, is time-consuming, both in the set up of the equipment, as well as in the performance of the test. It is not a portable test, and with team sports that are performed at an outdoor site, the volumeter cannot easily be utilized. Further, with volumetry it is difficult and time consuming to maintain hygiene. If a client has open sores or wounds on the limb to be measured volumetry is not an option. A valid and reliable outcome measure, which could be substituted for volumetry, would be appropriate in this circumstance.
Historically, the calculation of a correlation coefficient was used to determine the extent of agreement between two measures which would signify concurrent validity. The Pearson product moment correlation coefficient is a statistical test used when wishing to determine the extent to which two instruments measure the same trait or quantity of a variable.  

Bland and Altman have suggested an alternative statistical test to determine agreement between two measurement methods. Calculation of the correlation coefficient quantifies the magnitude and direction of the relationship between two variables, and provides a measure of association, not agreement. For example, if two variables are highly correlated, as one increases in value, the other will increase in value, and similarly for decreases in value. High correlation between two measures does not necessarily mean that the two methods agree. For the condition of agreement to be met, values must not only be related, but equal in numerical value, or at least close enough to allow substitution of tests.  

Limits of agreement is a statistical test used to determine the amount of agreement there is between two test measures. The limits of agreement are determined by plotting the difference against the mean of the two measurement methods. If the difference diverges as the mean increases, this indicates that the measurement error will increase with the size of the measurement. This statistical function provides a more accurate determination of agreement between two measures.  

There are methods available to clinicians and researchers to measure limb volume. These measurement techniques have been investigated for reliability and validity in the lower extremity by numerous researchers and by one researcher in the upper extremity.
The following section outlines the current literature in the area of limb volume measurement.

2.6 Methods Available to Measure Upper Extremity Volume

Methods of upper extremity volume determination such as magnetic resonance imaging (MRI) and computed axial tomography are not feasible for frequent and routine clinical use, and thus will not be included in the discussion of available outcome measures. The fluid translocation method\textsuperscript{35}, and tonometry impression technique\textsuperscript{36,37} are also used in the assessment of lymphedema, but must be used in conjunction with volume determination methods since the information provided by them describes the quality of the swelling in the tissues, not the volume. These techniques were also not discussed in the following section.

2.7 Water Displacement Volumetry Reliability

The methods most frequently used to detect whether lymphedema exists in an extremity are water displacement volumetry and circumferential measurements. As described in the literature, the gold standard for volume measurement of a limb remains the water displacement or volumetry method.\textsuperscript{5} As discussed previously, the water displacement method of volume determination has problems, namely that it is time-consuming and is unhygienic if a client has an open sore or wound. Nevertheless, it has been found to be a valid and reliable method for measuring swelling in the lower extremity. In subjects with partial sprains of lateral ankle ligaments, reliability of
measurements by water displacement was found to be +/-15 mL on 20 trials, which corresponded to 1.2% variability in measuring the volume of the foot.

Swedborg examined the reliability of upper extremity measurements using a volumeter in healthy women. Intra-tester reliability was determined by performing the test on ten women three times in one day. Measurements were found to vary 0.2-0.7%. Test-retest reliability was determined by comparing measurements three days apart, and measurements ten days apart, on ten subjects. Over three days, measurements varied on average 1.7% and over ten days, measurements varied an average of 4.7%. More recently Karges et al investigated the reliability of water displacement volumetry in women with lymphedema of the upper extremity. Using the Intraclass Correlation Coefficient (ICC), reliability was found to be 1.0.

2.8 Circumferential Measurement Reliability and Validity

Circumferential measurements of limbs have been used to estimate the extent of swelling or edema in an extremity. Soderberg and colleagues have examined the intra-tester and inter-tester reliability of performing circumferential measurements on the lower extremity following anterior cruciate ligament reconstruction. Using nine subjects within months of surgery, intra-tester ICCs ranged from 0.82 to 1.0. Inter-tester ICCs were found to range from 0.72 to 0.97. Karges et al investigated the reliability of circumferential measurements of the upper extremities in women with lymphedema. ICCs for girth measurements ranged between 0.96 and 0.99.
2.8.1 Estimating Limb Size

Circumferential measurements have been used in research to compare an involved extremity to the contralateral side. In much of the research investigating lymphedema after treatment for breast cancer, the size of the upper extremities was monitored by directly comparing the circumferential measurement of the involved and uninvolved limbs at one or more sites.\textsuperscript{6,7} While this method may demonstrate a difference in the limbs, it can not be used to estimate the volume of the limb. Further, since researchers use a variable number and different locations of circumferential sites to measure, comparison between the various results in the literature is difficult if not impossible.

2.8.2 Calculating Volume - Disk Method

Circumferential measurements may be used to calculate the volume of the limb. By dividing the limb into disks three centimetres high, the volume of each disk can be calculated based on circumference, and then the volumes of the disks summed to estimate the entire limb volume. The calculation used is as follows:
Fig. 1 Disk

\[ V = \Sigma \left( \frac{C^2}{4\pi^2} \right) \times h, \]

Where \( V \) = volume  
\( C \) = circumference  
\( h \) = height

This method has been tested only on the lower extremity, but was found to correlate to volume measurement by water displacement, with a correlation coefficient of greater than 0.99.\(^5\) The volume of the foot was excluded from both the volumeter value and the calculated value. Bunce et al\(^40\) used a similar method of dividing the limb into disks, but increased the height of each disk to 10 centimetres, thus reducing the number of measurements needed. While the authors suggested that this was an adequate method to calculate limb volume, they did not comment on the reliability or concurrent validity of this method.

2.8.3 Calculating Volume – Truncated Cone Calculation

Another indirect method which is used to calculate limb volume is called the frustrum sign method. In this calculation, the limb is visualized to be in the shape of a truncated cone. The circumference of the extremity at the proximal and distal limits of
the segment, together with the length between them, are used to calculate the volume of
the segment.  

\[ V = \frac{1}{12} \pi x h (C^2 + Cc + c^2) \]

Where:
- \( V \) = volume
- \( C \) = proximal circumference
- \( c \) = distal circumference
- \( h \) = height

Stranden\textsuperscript{21} found good correlation \((r = 0.98)\) between the frustrum sign method
and water displacement volumetry. Nine subjects with unilateral leg edema following
femoropopliteal bypass grafting were measured with both the water displacement
volumetry method and frustrum sign method. The author concluded that the frustrum
sign method could be substituted for water displacement for determination of lower
extremity volume. Kaulesar Sukul et al\textsuperscript{5} also compared the frustrum sign method of
lower extremity limb volume determination with water displacement volumetry. Only
two circumferences, the lower-most and upper-most circumferences, were incorporated
into the calculation of lower extremity volume. Using two circumferences, a single
truncated cone value was calculated. The correlation coefficient was found to be 0.93.
Despite the high correlation between the two methods, the authors did not recommend
that the frustrum sign method be substituted for volumetry. After inspection of the limits
of agreement, the frustrum sign method demonstrated limits of agreement which were too large to determine agreement between the methods.

Karges et al\textsuperscript{21} were the first researchers to investigate the concurrent validity of the frustrum calculation with water displacement volumetry in the upper extremities. The subject population consisted of fourteen women with lymphedema. Using Pearson r, correlations of 0.99 and 0.99 for both affected and unaffected upper extremities were found, and thus it was concluded that the frustrum calculation method could be substituted for volumetry in this population. The authors did not investigate the limits of agreement between the two methods of measurement, however, which may have changed their conclusions.

From the review of the literature of limb volume measurement methods and measurement issues, the current investigation was designed. While researchers have investigated measurement methods for the lower extremity, as well as the upper extremity in women who have lymphedema, there are no published studies investigating measurement methods to determine upper extremity volume in women after lymph node dissection treatment for breast cancer. The following section outlines the details of the methodology utilized in order to address the overall goal and specific objectives of this thesis, outlined in Chapter I.
CHAPTER III

METHODOLOGY

The methodology was designed based on a review of the literature of measurement in research and current studies investigating measurement of extremity volume. The following section outlines the methodology of data collection and the process of data management and analysis used in order to meet the specific objectives of the study. Finally, a research hypothesis is suggested for each study objective.

3.1 Participants:

Power analysis revealed that at least 17 subjects were required for the investigation (see Appendix A). Subjects were included from two sources. The research project “Effects of Progressive Resistive Exercises and Stretching on Shoulder Range of Motion, Upper Extremity Strength and Lymphedema Following Axillary Dissection and Radiation Therapy” (Principal Investigator Susan Harris, funded by the Canadian Breast Cancer Foundation (CBCF)) began in January, 1997. Included in the CBCF study were 21 women volunteers who had had previous treatment for breast cancer, including axillary node dissection and in some cases, breast and/or axillary radiation. Subjects were at risk for lymphedema following the treatment for breast cancer, but did not necessarily have lymphedema. Subjects were recruited by radiation oncologists, surgeons and other oncology health care professionals in the Greater Vancouver area. Due to the nature of the study and the exercise component involved, only women with Stage I-III
cancer were included. Excluded from the study were women with metastases or those who were currently undergoing additional treatments for breast cancer (e.g. chemotherapy). As a descriptive component to the investigation, the subjects involved had circumferential and volume measurements of both upper extremities taken at initial entry into the research project and again one week later. To provide additional reliability and validity data, seven other subjects were recruited from breast cancer survivor support groups in the Greater Vancouver Area.

3.2 Subject Characteristics

Twenty-three subjects from the two groups met inclusion criteria for this study. These subjects had been diagnosed with unilateral breast cancer, and had had lymph node removal surgery. None of the subjects had open lesions on either upper extremity at the time of testing. From the original twenty-eight subjects, data from three subjects who had been treated for bilateral breast cancer were omitted from the data analysis. Medical history information, as to the affected side of breast cancer and axillary dissection, was not obtained for two subjects, and their data were also omitted. Data from 23 subjects were included in the final analyses.

Ages of the 23 subjects ranged from 35 to 67 years. Seven had been treated for breast cancer on the right side and 16 were treated for breast cancer on the left. All 23 of the subjects were treated surgically with axillary node dissection. Nine subjects had had a total mastectomy, and 14 had had a partial mastectomy. Twelve of the subjects had radiation therapy to the breast only in addition to surgery. Five subjects were treated with radiation to the breast and axillary nodes, and six subjects had no radiation treatment.
The time elapsed since the end of treatment ranged from 2 to 19 months. Thirteen subjects had undergone chemotherapy as a component of treatment. (See Appendix B)

### 3.3 Materials

A volumeter was used to displace water in order to measure the volume of the upper extremities (see Appendix C). A one litre graduated cylinder and a 250 mL graduated cylinder, with accuracy of 50mL and 10mL respectively, were used to measure the volume of the displaced water, which then represented the volume of the upper extremity that was measured.

A plastic tape measure with an accuracy of one millimetre was used to measure the circumference and length of the upper extremities.

### 3.4 Data Collection

#### 3.4.1 Process

As subjects were entered into the CBCF study, initial volume and circumference measurements were taken independently by two physical therapists blinded to the affected/unaffected or dominant/non-dominant upper extremity. One week later, one of the physical therapists, the author of this thesis, repeated the volume and circumference measurements, without reviewing the previous week’s measurements.
3.4.2 Procedures

Circumferential Measurements

The procedures used were designed to emulate a typical clinical situation. For circumferential measurements, subjects were placed in the supine position on a plinth with arms resting comfortably at the sides with forearms in the pronated position (see Appendix C). This position enabled easy access to the ulnar styloid process for measurement. The right upper extremity was measured first in each subject. Circumferential measurements were taken at the centre of the ulnar styloid process, and every three centimetres along the length of the upper extremity, ending fifteen centimetres proximal to the lateral epicondyle. An adjustment was made at the elbow so that measurements for each subject ended at 15 centimetres proximal to the elbow. The length of the subject’s forearm, from ulnar styloid to lateral epicondyle, was also recorded, in order to calculate the length of the frustrum between the most distal forearm measurement and the lateral epicondyle. Care was taken not to make an indentation in the superficial skin while taking measurements. This procedure was then repeated on the left upper extremity.

Volumetric Measurements

The volumeter was initially full, but not overflowing, with water at room temperature. Subjects were in a sitting position for volume measurements (see Appendix C) and were asked to remove jewelry. Using a body marker, subjects were marked at the levels of the ulnar styloid process and fifteen centimetres proximal to the lateral epicondyle on both upper extremities prior to measurement with the volumeter. The right
upper extremity was measured first in each subject. Initially, the volume of the hand was measured. The palm and volar surface of the arm were positioned against the inside of the volumeter, with the water level at the centre of the ulnar styloid process, until water flowed at a rate of one drop per second or less. This displaced water was then measured with the graduated cylinders to determine the volume of the hand. For reading, the graduated cylinders were placed on a flat surface and read at eye level. In order to measure the volume of the entire arm, the same upper extremity was then lowered into the volumeter with the elbow straight, and the palm and volar surface of the arm held flush against the inside of the cylinder. Once the subject’s arm was sufficiently lowered so that the water level reached 15 cm proximal to the lateral epicondyle, the arm was held there until water flowed at a rate of less than one drop per second. The arm was then removed and dried. The procedure was repeated on the left upper extremity.

3.5 Data Management and Analysis

The following section describes the process for data management and analysis in order to answer each objective of the thesis.

3.5.1 Objective #1
Inter-rater Reliability for Circumferential Measurements

In order to assess inter-rater reliability, the circumference measurements from the two physical therapists from the initial subject visit were used. The results from the upper extremity ipsilateral to the surgery were compared separately from results of the
contralateral upper extremity, in order to determine if there was a difference in the reliability of measurements where there was an increased risk of lymphedema.

Data analysis was performed using the Intraclass Correlation Coefficient (ICC) (see Appendix A). This is a reliability coefficient which is indicated for reliability analysis of continuous data, when two or more repeated measures are to be analyzed. The Intraclass Correlation Coefficient utilizes analysis of variance in the calculation, examining the sources of variability between and within scores. This makes it a more appropriate test to use than the Pearson product moment correlation coefficient. The Intraclass Correlation Coefficient assumes that the two samples are drawn from normally distributed data with the same variance. When R = 0.80 or greater, correlation is considered to be good.

3.5.2 Objective #2
Test-retest Reliability for Circumferential Measurements

In order to evaluate test-retest reliability, the measurements from the initial visit and the visit one week later, all completed by the same physical therapist, were compared. The results from the upper extremity ipsilateral to the surgery were compared separately from results of the contralateral upper extremity, in order to determine if there was a difference in the reliability of measurements where there was an increased risk of lymphedema. For the same reasons as for inter-rater reliability, ICC was calculated. Correlation is considered good if R is greater than 0.80.
3.5.3 Objective #3  
*Inter-rater Reliability for Volumetry Measurements*

In order to determine inter-rater reliability, the volumetric measurements from the two physical therapists from the initial subject visit were used. The results from the upper extremity ipsilateral to the surgery were compared separately from results of the contralateral upper extremity, in order to determine if there was a difference in the reliability of measurements where there was an increased risk of lymphedema. ICC was calculated.

3.4.4 Objective #4  
*Test-retest Reliability for Volumetry Measurements*

As for circumferential measurements, in order to evaluate test-retest reliability, the volumetric measurements from the initial visit and one week later, all completed by the same physical therapist, were used. The results from the upper extremity ipsilateral to the surgery were compared separately from results of the contralateral upper extremity, in order to determine if there was a difference in the reliability of measurements where there was an increased risk of lymphedema. ICC was calculated.

3.4.5 Objective #5  
*Concurrent Validity for Volumetry and Single Truncated Cone Calculation*

Water displacement volume was the gold standard for volume determination of a limb in this investigation. The water displacement volume of each upper extremity from the ulnar styloid process to 15 cm proximal to the lateral epicondyle was used as a comparison to two separate methods for calculating upper extremity volume. The
volume of the upper extremity was determined by subtracting the volume of the hand from the volume of the entire upper extremity.

Single Truncated Cone Calculation

Upper extremity volume was calculated using the following formula for calculation of a frustrum, which is the formula to calculate the volume of a truncated cone.

\[ V = \frac{\pi}{3} \times (R^2 + Rr + r^2) \]
\[ R = \frac{C}{2\pi} \]
\[ r = \frac{c}{2\pi} \]

\[ V = \frac{\pi}{3} \times h((\frac{C}{2\pi})^2 + (\frac{C}{2\pi} \times \frac{c}{2\pi}) + (\frac{c}{2\pi})^2) \]

\[ V = \frac{\pi}{12\pi^2} \times h(C^2 + Ce + c^2) \]

Where:
- \( V \) = volume
- \( R \) = proximal radius, \( C \) = proximal circumference
- \( r \) = distal radius, \( c \) = distal circumference
- \( h \) = distance between circumferences

In order to determine the single truncated cone volume, two circumferential values were used for the calculation: the circumference at the ulnar styloid process and the circumference at the level 15 cm proximal to the lateral epicondyle. These circumferences represented the most proximal and distal measurements of the upper extremity.
Concurrent Validity for Single Truncated Cone Calculation

The water displacement method of measuring arm volume represented the gold standard of limb volume measurement. The relationship between water displacement volumetry and the single truncated cone calculated volume was evaluated using Pearson Product-Moment Correlation coefficient (Pearson r) (See Appendix A). This calculation is used when wishing to determine the relationship between two continuous variables. It provides information regarding the direction and strength of the relationship. The Intraclass Correlation Coefficient assumes that data are drawn from two populations with the same variance, and thus cannot be used in this circumstance. The Pearson r calculation does not assume the same variance, and is appropriate for use in this calculation. If r = 0.80 or greater, this demonstrates good correlation.32
3.5.6 Objective #6
Concurrent Validity for Volumetry and Summed Truncated Cone Calculation

Summed Truncated Cone Calculation

For the summed truncated cone calculation, the same equation as in the single truncated cone calculation was used to calculate the volume of the upper extremity. In the summed truncated cone calculation, each of the circumferential measurements spaced three centimetres apart, from the ulnar styloid process to the final circumference (15 cm proximal to the lateral epicondyle), were also included. Each set of two adjacent circumferential measurements was used to calculate the volume of the mini-frustrum. All of the frustrum volumes were next summed to create a single volume for the entire upper extremity.

Fig. 4 Summed truncated cone volume calculation
Concurrent Validity for Summed Truncated Cone Calculation

The relationship between water displacement volume and the summed truncated cone calculation method for calculation of upper extremity volume was evaluated using Pearson r.

3.5.7 Objective #7

Level of Agreement between Volumetry and Single Truncated Cone Calculation

High correlation between two measures does not necessarily mean that the two measures agree. For the condition of agreement to be met, values must not only be related, but equal in numerical value, or at least close enough to allow substitution of tests. Limits of agreement are used to determine the amount of agreement there is between two test measures. For this reason, limits of agreement were calculated to compare water displacement volumetry with the single truncated cone calculation method for upper extremity volume determination. The relationship between the difference and the means of the two methods was graphed.

Appropriate limits for the limits of agreement are based on clinical judgement and not a standard calculation. The agreement must be appropriate for a particular purpose. One definition of lymphedema proposed by Swedborg is that upper extremities differ in volume by 150 mL or greater. This definition of lymphedema was considered when choosing appropriate limits for agreement. In order to ensure that differences seen in measurements are due to true differences in limb volume, as opposed to measurement error, the agreement limit between the two measurement methods must not approximate the quantitative definition of lymphedema. For this thesis project, it was determined that
an appropriate limit of agreement would be 100 mL or less, or that the two methods of volume determination would be within 100 mL of each other.

3.5.8 Objective #8
Level of agreement between Volumetry and Summed Truncated Cone Calculation

Limits of agreement were calculated to compare water displacement volumetry with the summed truncated cone calculation method for upper extremity volume determination, and the relationship of difference versus mean of the two methods was graphed. An acceptable limit of agreement was determined to be 100 mL or less.

3.6 Research Hypotheses

The following null hypotheses were developed based on the specific objectives of the research project, as well as the review of literature of measurement.

**Hypothesis 1:** $H_0$: Inter-rater reliability for circumferential measurements (R) will be less than 0.80.

**Hypothesis 2:** $H_0$: Test-retest reliability for circumferential measurements (R) will be less than 0.80.

**Hypothesis 3:** $H_0$: Inter-rater reliability for volumetric measurements (R) will be less than 0.80.

**Hypothesis 4:** $H_0$: Test-retest reliability for volumetric measurements (R) will be less than 0.80.
Hypothesis 5: $H_0$: The correlation coefficient ($r$) for the relationship between volumetry and single truncated cone calculated volume will be less than 0.80.

Hypothesis 6: $H_0$: The correlation coefficient ($r$) for the relationship between volumetry and summed truncated cone calculated volume will be less than 0.80.

Hypothesis 7: $H_0$: Limits of agreement for the relationship between volumetry and single truncated cone calculated volume (2 standard deviations from the mean) will be greater than 100mL.

Hypothesis 8: $H_0$: Limits of agreement for the relationship between volumetry and summed truncated cone calculated volume (2 standard deviations from the mean) will be greater than 100mL.
CHAPTER IV

RESULTS

The results from the data analysis are presented in this chapter. Data were collected from 21 subjects from the concurrent research study "Effects of Progressive Resistive Exercises and Stretching on Shoulder Range of Motion, Upper Extremity Strength and Lymphedema Following Axillary Dissection and Radiation Therapy" as well as seven additional subjects recruited from the Greater Vancouver area. From these 28 initial subjects, data were included for 23 subjects. Subject characteristics (Appendix B) were included in Methodology, Chapter III.

4.1 Subject Data (see Appendix D)

Volumes for the upper extremities from volumeter data and calculated volume values are presented in Appendix D. Within this section, the upper extremity which was on the same side as the breast cancer is referred to as the surgical upper extremity, and the other upper extremity is referred to as the contralateral upper extremity.

4.2 Results of Data Analysis

Hypotheses from Chapter III were tested individually, and the results follow.
4.2.1 Inter-rater reliability for circumferential measurements

Hypothesis #1: \( H_0 \): Inter-rater reliability for circumferential measurements will be less than 0.80.

In testing Hypothesis 1, inter-rater reliability for circumferential measurements was evaluated using the Intraclass Correlation Coefficient. Inter-rater reliability ICC for surgical upper extremities was \( R=0.99 \), and for contralateral upper extremities, \( R=0.99 \). The null hypothesis is rejected for both surgical and contralateral upper extremities since both ICCs are greater than 0.80, demonstrating good reliability.

4.2.2 Test-retest reliability for circumferential measurements

Hypothesis 2: \( H_0 \): Test-retest reliability for circumferential measurements will be less than 0.80.

Hypothesis 2 was evaluated using the Intraclass Correlation Coefficient. ICCs for test-retest reliability were \( R=0.99 \) for both surgical and contralateral upper extremities. The null hypothesis is rejected in both cases, since both ICCs are greater than 0.80, demonstrating good reliability.

4.2.3 Inter-rater reliability for volumetric measurements

Hypothesis 3: \( H_0 \): Inter-rater reliability for volumetric measurements will be less than 0.80.

In testing hypothesis 3, inter-rater reliability for volumetry measurements was evaluated using the Intraclass Correlation Coefficient. For both surgical and contralateral upper extremities, \( R=0.99 \). The null hypothesis is rejected for surgical and contralateral
upper extremities, since ICCs are greater than 0.80 in both cases, demonstrating good reliability.

4.2.4 Test-retest reliability for volumetric measurements

Hypothesis 4: $H_0$: Test-retest reliability for volumetric measurements will be less than 0.80.

The Intraclass Correlation Coefficient was used to evaluate test-retest reliability for volumetric measurements. $R=0.99$ for surgical upper extremities and 0.99 for contralateral upper extremities. The null hypothesis is rejected in both cases, demonstrating good reliability.

4.2.5 Concurrent validity between volumetry and single truncated cone calculation

Hypothesis #5: $H_0$: The correlation coefficient for the relationship between volumetry and single truncated cone calculated volume will be less than 0.80.

Concurrent validity for the relationship between volumetry and the single truncated cone calculated volume was evaluated using the Pearson Product Moment Correlation coefficient. Pearson $r$ was found to be 0.93 for surgical upper extremities (see Figure 5), and $r=0.95$ for contralateral upper extremities (see Figure 6). The null hypothesis is rejected in each case since Pearson $r$ is greater than 0.80, demonstrating good correlation.
Fig. 5 Correlation between volumetry and single truncated cone volume calculation for surgical upper extremities

Fig. 6 Correlation between volumetry and single truncated cone volume calculation for contralateral upper extremities
4.2.6 Concurrent validity between volumetry and summed truncated cone calculation

Hypothesis #6: $H_0$: The correlation coefficient for the relationship between volumetry and summed truncated cone calculated volume will be less than 0.80.

In testing Hypothesis #6, the Pearson Product Moment Correlation coefficient was used. Pearson $r$ for surgical upper extremities was found to be 0.97 (see Figure 7), and for contralateral upper extremities $r=0.98$ (see Figure 8). The null hypothesis is rejected in each case, demonstrating good correlation.

Fig. 7 Correlation between volumetry and summed truncated cone volume for surgical upper extremities.
Fig. 8 Correlation between volumetry and summed truncated cone volume for contralateral upper extremities.

4.2.7 Limits of agreement between volumetry and single truncated cone calculation

Hypothesis #7: $H_0$: Limits of agreement for the relationship between volumetry and single truncated cone calculated volume (2 standard deviations from the mean) will be greater than 100mL.

The limits of agreement between volumetry and the single truncated cone calculated volume were determined by graphing the data, as well as calculating means and standard deviations for the two methods of volume determination. Ninety-five percent of the data will fall in between two standard deviations from the mean, which are the limits of agreement between the two methods. For surgical upper extremities, the mean difference between volumetry and single truncated cone volume calculation was -52 mL, which states that the single truncated cone volume calculation over-estimates
volume by 52 mL on average. The calculated standard deviation was 167 mL. Ninety-five percent of the data, falls in between the values of 282 mL and -386 mL (see Figure 9). Since the limit of agreement is two standard deviations, or 334 mL, the null hypothesis can not be rejected in this case.

![Graph showing limits of agreement for volumetry and single truncated cone calculated volume for surgical upper extremities.](image)

Fig.9 Limits of agreement for volumetry and single truncated cone calculated volume for surgical upper extremities.

For contralateral upper extremities, the mean difference between volumetry and single truncated cone calculated volume was -68 mL. The calculated volume overestimated the upper extremity volume by 68 mL on average. Standard deviation was 132 mL, creating a limit of agreement of 264 mL (see Figure 10). The limit of agreement is greater than 100 mL for the relationship between volumetry and single truncated cone calculated volume for contralateral upper extremities, and thus the null hypothesis can not be rejected.
Fig. 10 Limits of agreement for volumetry and single truncated cone calculated volume for contralateral upper extremities.

### 4.2.8 Limit of agreement between volumetry and summed truncated cone calculation

Hypothesis #8: H₀: Limits of agreement for the relationship between volumetry and summed truncated cone calculated volume (2 standard deviations from the mean) will be greater than 100mL.

For the relationship between volumetry and the summed truncated cone calculated volume for surgical upper extremities, the mean difference was -140 mL, reflecting that the calculated volume over-estimated upper extremity volume by 140 mL on average. Standard deviation was 117 mL, creating limits of agreement of 234 mL (see Figure 11).

For contralateral upper extremities, the mean difference between volumetry and summed
truncated cone calculation was -136 mL, and standard deviation was calculated to be 79 mL. The limit of agreement in this case was 158 mL (see Figure 12). The null hypothesis can not be rejected in these cases since the limit of agreement is greater than 100 mL for both surgical and contralateral upper extremities.

Fig. 11 Limits of agreement for volumetry and summed truncated cone volume for surgical upper extremities.
In summary, inter-rater and test-retest reliability of circumferential measurements and volumetric measurements were found to be good. Concurrent validity, as evaluated by correlation between volumetry and single truncated cone calculated volume, was found to be good for both surgical and contralateral upper extremities. The relationship between volumetry and summed truncated cone calculated volume was also good for surgical and contralateral upper extremities when evaluated using the Pearson r correlation coefficient. Volumetry and the single truncated cone calculated volume methods of volume determination do not agree with each other. The calculated volume consistently over-estimates volume of the upper extremity for both surgical and contralateral upper extremities, and the limits of agreement are too large to determine.
agreement between the two measurement methods. Similarly, the summed truncated cone calculated volume does not agree with volumetry. Summed truncated cone calculation consistently over-estimates calculated volume, and creates limits of agreement that are too large for agreement between the two methods of volume determination. In the following chapter the significance of these results and implications for future research will be discussed.
Despite advances in treatment for breast cancer, the development of lymphedema remains a very real and significant risk for survivors of breast cancer who have been treated with axillary node dissection. Treatments for lymphedema are available and do offer some hope to women who develop this condition. Treatment aims to control the extent of lymphedema in the involved upper extremity, which ultimately can improve the function and appearance of the arm. In order to monitor treatments and ensure that they are effective, it is critical that clinicians and researchers have access to valid and reliable measurement tools, so they can measure the volume of the upper extremity accurately. Considering the difficulties associated with water displacement volumetry, the search for alternative methods of extremity volume determination remains a worthwhile pursuit.

There are few published articles investigating limb volume measurement, and none of the articles have specifically investigated the upper extremities of women who are at risk for lymphedema following treatment for breast cancer. The results of this thesis investigation contribute important information in the area of extremity volume measurement, further expanding upon the existing literature. These results will provide guidance to researchers investigating treatments for lymphedema management.

According to the results of this thesis, circumferential measurements can not be used alternatively with volumetry to provide an estimate of upper extremity volume. The two different statistical tests of concurrent validity, Pearson r correlation coefficient and limits of agreement, provide different information. The Pearson r correlation coefficient
between volumetry and the two methods of calculating volume of the upper extremity was over 0.80 in each case, demonstrating good correlation. This suggests that as the volume of an upper extremity increases, both volumetry and calculated volume measurements will also increase. Volumetry and calculated volumes will change in the same direction, either increasing or decreasing in value together. As long as the researcher or clinician is interested in the direction of a change in volume, calculated volume can suffice to provide this information. Calculated volumes are not sufficient for use as an alternative to volumetry measurements, however, due to the poor agreement between the two methods.

The limits of agreement calculation contributes different information from that provided by the correlation coefficient. The limits of agreement calculation states how closely the two methods agree with each other in numerical value. Both calculated volumes, by the single or summed truncated cone methods, over-estimate the volume of the upper extremity. If a clinician or researcher is interested in the exact volume of the upper limb, calculated volume can not be used as an accurate estimate. Volumetry would have to be utilized if the actual volume of the upper extremity was required.

While water displacement volumetry is a time-consuming and difficult test to perform, it is the only easily accessible method currently available to clinicians that can provide the volume of an entire extremity. Lymphedema may occur in the hand, and circumferential measurements of the arm will miss this presentation. The water will accommodate the irregular features of a hand or foot, which circumferential measurements will not capture.
According to the results of this study, volumetry is the only method that can be used for accurate determination of upper extremity volume in women following axillary node dissection surgery for breast cancer. At times, however, volumetry is not an option, whether due to the time required, or the unhygienic nature of the test. In these instances, circumferential measurements can be substituted, but only to monitor the direction of change in limb size, not to provide an accurate volume value. Once volumetry is an option for the particular client, it can then be performed if it is desirable to know the exact volume of the arm.

While there have been few research studies on this topic, comparison with the available previous published literature demonstrates many similarities. Only one researcher has investigated the calculated volume method for the upper extremity. The conclusions reached by Karges and colleagues parallel those of this thesis. Karges et al investigated the concurrent validity between volumetry and the summed truncated cone calculated volume in women who had lymphedema in one or both upper extremities. The authors did not state the cause of the lymphedema. Similar to results of the current investigation, Karges and colleagues found good reliability in performing circumferential and volumetric measurements, although the specific type of reliability was not specified. These authors also found good concurrent validity between volumetry and the calculated volume, and concluded that the two methods were equivalent. The authors did not, however, calculate the limits of agreement between the two methods, which is considered a preferred method for determination of equivalency between two tests. Calculation of the limits of agreement may have changed the conclusions reached in their investigation.
Other authors have investigated measurement of limb volume with the lower extremity. Stranden calculated the volume of lower extremities using the single truncated cone method. The relationship between this calculated method of volume determination and volumetry was investigated using Pearson product moment correlation coefficient. Stranden found good correlation between the two methods of volume determination, and concluded that calculated volume could be substituted for volumetry. Similar to Karges et al., Stranden did not investigate the limits of agreement between the two methods. The conclusions derived by this author may have changed had the agreement between the two methods been calculated.

Kaulesar Sukul and colleagues investigated the relationship between volumetry and calculated lower extremity volume using the single truncated cone method. Similar to the results of this thesis, the authors found good correlation between calculated volume by the single truncated cone calculation and volumetry. The authors did calculate the limits of agreement between volumetry and the calculated volume. The results found paralleled the results of this thesis. The limits of agreement between volumetry and the single truncated cone calculated volume were too large (mean +/- 2sd = 521 +/- 238 mL) to be considered good agreement. The authors did not recommend that calculated volume, by the single truncated cone method, be substituted for volumetry.

Kaulesar Sukul and colleagues did not calculate volume of the lower extremity using the summed truncated cone method, but instead used the summed disk method, with disks three centimetres in height. Extremity volume by calculation was found to correlate well with volumetry, and further investigation of the limits of agreement demonstrated that the limits (mean +/- 2sd = -45 +/- 78 mL) were sufficient for
substitution of this method for volumetry. The results from the summed volume
calculation method cannot be compared to the results of this thesis, since Kaulesar Sukul
and colleagues\textsuperscript{5} used only the summed disk method of volume determination, not the
summed truncated cone volume calculation.

In this thesis, only the truncated cone calculation was used to calculate volume.
The disk calculation is to be used when calculating the volume of a cylinder, or a disk
with equal circumferences at each end. When a cylinder has two different circumferences
on each end, the object is actually a truncated cone, and the volume calculation changes.
It was felt that the disk calculation was not an appropriate method to use for the
determination of the volume of a limb, which is more conical in shape.

5.1 Limitations

The subjects in this investigation were at risk for lymphedema due to the surgical
treatment that they had undergone for breast cancer. The subjects did not necessarily
have lymphedema. The results of this investigation do not provide answers as to whether
these measurement techniques are reliable or valid in a population of women who have
already developed lymphedema from breast cancer treatments. This limits the
generalizability of the results to a very specific population.

In order to evaluate test-retest reliability, only one of the physical therapists
repeated the test measures one week after the first assessment. The reliability of this
physical therapist was good ($r=0.99$ for surgical upper extremity and contralateral upper
extremity), but these results only demonstrate the ability of this one particular evaluator.
This does not necessarily demonstrate that the test has good test-retest reliability.
generally with many evaluators. Alternating physical therapists who would have performed the retest may have strengthened confidence in the results.

The temperature of the water in the volumeter was at room temperature, but was not monitored specifically with a thermometer, nor kept at a consistent temperature. In order to maintain a consistent temperature, a heating apparatus would have to be incorporated into the volumeter, which is not typical of the volumeters used in clinical settings. This may have altered the results. The temperature of the water may have had an effect on the amount of swelling in the upper extremity being measured. To what extent small changes in temperature can affect the volume of a limb is not known presently, but this issue warrants investigation.

Researchers were blinded to the surgical upper extremities and contralateral upper extremities, as well as the hand-dominance of the subjects. Surgery for breast cancer does, however, cause some scarring, which is apparent on the skin. Subjects were asked to wear short sleeve t-shirts, and to not disclose the surgical side, but at times, it was visibly apparent to the researcher. This may have caused a bias when taking measurements.

5.2 Implications and Suggestions for Future Research

The results of this investigation have demonstrated that the truncated cone calculation of upper extremity volume from circumferential measurements can not be used interchangeably with volumetric measurements. The calculated volume from circumferential measurements consistently over-estimates the volume of the limb. Circumferential measurements are much simpler to perform than volumeter
measurements. Further research should investigate ways that circumferential measurements can provide clinicians and researchers with useful information about the extent of swelling in an extremity.

Circumferential measurements have been used in other methods of size determination of upper extremities. Direct comparison of the circumference at varying sites on the arm has been used to monitor lymphedema.\textsuperscript{6,16} The validity or reliability of this method of extremity size determination has not been demonstrated. It may be worthwhile to investigate this method of limb size determination. If valid and reliable, this would be a simple method for measurement of limb size.

Edema of the trunk is a frequently reported finding of women who have been treated for breast cancer.\textsuperscript{43} Neither the water displacement method nor circumferential measurements will capture the amount or change in the amount of edema in the trunk. In order for evaluations of lymphedema to be complete, measurement of edema in the trunk will have to be incorporated. Currently, circumferential measurements have not been used to measure edema in the trunk. Investigation of methods to incorporate measurement of the trunk would be a worthwhile pursuit.

While swelling and increased volume of the upper extremity are common complaints of women with lymphedema, other subjective complaints include that the skin feels hard, and the arm is painful.\textsuperscript{18} Health care professionals who work with women with lymphedema are not only attempting to decrease the amount of swelling in the upper extremity, but also change the quality of the edema, reducing pain and decreasing the hardness in the limb tissues. Again, water displacement and circumferential measurements do not capture these qualities. Other tests, such as tonometry\textsuperscript{37} or
impression technique would have to be incorporated into the assessment of lymphedema, especially prior to its treatment, in order to document changes in these features. It may be helpful to investigate a test that would capture changes in both the quantitative and qualitative features of lymphedema.

Before measurements can be evaluated on women who already have lymphedema, a universal definition of lymphedema must be determined. This will allow appropriate inclusion criteria for subjects. The definition should include a volume difference between the two upper extremities. A definition based on an absolute volume difference does not appear to be appropriate, but a relative difference could be useful, since this will incorporate the varying sizes of women who develop lymphedema. Ideally, the definition of lymphedema would also incorporate more subjective findings as well, such as softness of skin, functional use of the arm and amount of pain, since these are all issues that concern women with lymphedema and clinicians who are treating lymphedema.

5.3 Summary and Conclusions

The results of this thesis provide important guidelines in the assessment of upper extremity volume. Previous studies looking at calculated volume of limbs compared with volumetry have demonstrated good correlation between the two methods, but few have also considered the limits of agreement, which provide important insight into the agreement between two measurements. This study examined concurrent validity of two calculation methods for determination of upper extremity volume compared with the gold standard water displacement volumetry. Inter-rater and test-retest reliability of both circumferential and volumetric measurements were also investigated in order to
determine the full value of the assessments in the population of women after axillary lymph node dissection surgery for treatment for breast cancer.

Inter-rater and test-retest reliability was appropriate for both circumferential measurements and water displacement volumetry. The same reliability was found for upper extremities ipsilateral to the lymph node surgery and contralateral to the surgery. Both the truncated cone calculation and the summed truncated cone calculation of upper extremity volumes were well correlated to water displacement volumetry, which is considered the gold standard measurement technique for limb volume determination. This demonstrates that as one measurement technique shows an increase in limb size, the other technique will also show an increase. Neither method was considered to be interchangeable with volumetry due to poor agreement, demonstrated by limits of agreement. Calculated volume consistently over-estimated the volume of the limb. While these findings do not exclude the use of circumferential measurements for limb volume determination, they do suggest caution in the results obtained from this measurement technique. Calculated volume from circumferential measurements will demonstrate an increase or decrease in arm volume as appropriate, which is important information for health care practitioners who are treating clients with lymphedema. If the actual value of the amount of volume change is required, however, calculated volume may not be accurate.

Circumferential measurements are easier to perform than water displacement volumetry, and have demonstrated acceptable inter-rater and test-retest reliability. Further research should be directed towards methods which incorporate circumferential
measurements in the determination of upper extremity size which could ultimately be
used in the evaluation of lymphedema in women after breast cancer treatment.
REFERENCES


APPENDIX A

List of Formulae

1. Formula for calculation of subject number\(^{44}\):

\[ \Delta = (\pi - \pi_0) / (1 - \pi_0), \]  
where \(\pi\) = correlation estimate, and \(\pi_0\) = null hypothesis value  
\[ \Delta = (.9 - .5) / (1 - (.9)(.5)) \]  
\(\Delta = .72\)

\(n = v + 2\)

\(v\) (with \(\Delta = .72\) and 90% power (from Kraemer\(^{44}\))) = 15

\(n = 17\)

2. Formula for Intraclass Correlation Coefficient\(^{45}\):

\[ P_{xx} = 1 - (M \Sigma_{\sigma T} / M \Sigma_{\sigma}) \]

where \(P\) = correlation coefficient, \(M \Sigma_{\sigma T}\) is the \(\sigma_3 T\) interaction and \(M \Sigma_{\sigma}\) is the mean square between subjects.

3. Formula for Pearson Product Moment Correlation Coefficient\(^{45}\):

\[ \rho = \sigma_{\sigma u} / \sigma_{\sigma} \]

where \(\rho\) = Pearson correlation coefficient, and \(\sigma\) = standard deviation
### APPENDIX B

#### Table 1
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Key:

MRM  Modified radical mastectomy (includes axillary node dissection)
PM  Partial mastectomy
AND  Axillary node dissection
APPENDIX C

Position for circumferential measurements

Volumeter
Position for volumetric measurements
## APPENDIX D

### Table 2 – Water displacement volumetry data

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