SHOULD WE BE MOVING TOWARDS EARLY CONTROLLED MOBILIZATION OF EXTRA-ARTICULAR HAND FRACTURES IN BC?

by

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ABSTRACT

Should We Be Moving Towards Early Controlled Mobilization Of Extra-Articular Hand Fractures In BC?

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Hand fractures are the second most common fracture in both children and adults. They result in a considerable societal burden related to acute health care costs and lost socio-economic productivity due to a person's limited capacity to perform their normal functional activities throughout their recovery. Although early controlled mobilization (ECM) is commonly used following primary flexor tendon repairs and other equally fragile healing tissues in the hand, it is not commonly recommended for extra-articular hand fractures. There is scientific evidence to suggest that ECM of hand fractures has the potential to enhance early healing, improve regional hand soft tissue function and also lead to an improvement in a person's capacity to function throughout their recovery. However, ECM also may have a negative impact on healing and functional outcomes if introduced inappropriately. To date, the basic scientific and clinical literatures have not identified clear clinical parameters for the 'safe' introduction of ECM following an extra-articular hand fracture. Therefore, the overall objective of this research was to examine the potential clinical efficicacy of ECM following an extra-articular hand fractures as a possible alternative to acute post-fracture immobilization (IM) and to examine the implementation of ECM following an extra-articular hand fracture within the context of its application in the health care system in British Columbia (BC).

A series of research inquires were completed, including a five year retrospective review of BC Linked Health Datasets (BCLHD) to define the incidence, demographics and acute health care utilization trends for hand fractures treated in BC; a systematic review of the literature to define the current level of scientifically validated clinical evidence related to early motion following an extra-articular hand fractures; and a pre-clinical efficacy trial examining the effect of early controlled passive motion (ECPM) on 4-point bending structural properties, dorsal fracture alignment and regional mineralized tissue distribution during early fracture healing (initial 28 days) in a closed, extra-articular metacarpal (simulated hand) fracture in a rabbit model.

Between May 1, 1996 and April 30, 2001 there were 72,481 hand fractures identified in the BCLHD with an estimated 14,500 hand fractures occurring each year in BC with no significant trend for a change over time in number or type of fractures. The annual incidence rate for hand fractures in BC was 36 / 10,000 people. Males were at a 2.1 greater relative risk for sustaining a hand fracture and they sustained most of this risk from the ages of 15 to 40. As well, markedly more hand fractures occurred in the spring and in the Northern Health Authority. In BC, most hand fractures (70%) were initially treated by primary care physicians, with the initial point of contact into the medical care system being either a physician's office or an emergency room setting. Finally, people in BC with more complex hand fracture injuries were referred to and treated quickly by surgeon specialists with only a small percentage (10%) admitted to hospital for management of their hand fracture. Consistent findings from a qualitative synthesis of six Quasi-Randomized Clinical Trials (Q-RCT) indicated that early motion following a simple, closed, extra-articular metacarpal fracture may lead to faster recovery of mobility, strength and return to work without affecting fracture alignment. In addition, in a closed metacarpal fracture in a rabbit model, when compared to fractures treated with IM, fractures treated with ECPM showed significantly ($P < 0.05$) better gains in 4-point bending initial stiffness (29% difference at twenty eight days), maximum stiffness (21% difference at twenty eight days), failure load (17% difference at twenty eight days) and energy absorbed per unit area (21% difference at twenty eight days), as well as, showing a significant reduction in dorsal fracture angulation (33% difference at twenty eight days). ECPM also had an apparent influence on the mineralized tissue distribution in the callus at the 28-day time period, possibly explaining the superior mechanical properties found in the rabbit healing model at this time point.

Hand fractures are a common injury in BC, occurring most commonly in adolescent and young adult males during their most physically active and productive working years. Increased public awareness of hand fracture risk can lead to preventative measures that could reduce the incidence of hand fractures in BC. ECM following an extra-articular hand fracture warrants further randomized clinical investigation in humans as it has the potential to improve fracture healing and functional outcomes. Improved health outcomes following a hand fracture will reduce the socio-economic impact of this common injury in BC. Targeted education regarding the potential benefits of ECM following a hand fracture directed at clinicians treating hand fractures in BC will facilitate the recruitment of patients into future RCTs.

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CO-AUTHORSHIP STATEMENT and PUBLICATIONS ARISING FROM THIS THESIS

Sections of this thesis have been published or have been / or will be submitted for publication as multi-authored manuscripts in peer-reviewed journals and are indicated with a (* symbol) beside the publications listed below.

Authors' Contribution: In all cases, the author of this thesis was the first author of these manuscripts and was responsible for the original ideas behind the paper, the design and implementation of the experiment, the analyse and presentation of the findings, as well as the writing and editing of the original paper. All Co-authors contributed additional advice regarding the implementation of the experiments, as well as assistance with the interpretation of the results and editing of the manuscripts.

I agree with the stated contributions of the thesis author, as indicated above:

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3. ***Feehan LM**, Sheps S. Incidence and Demographics of Hand Fractures in British Columbia, Canada: A Population Based Study. J Hand Surg 2006; 31A(7):1068-1074.

4. ***Feehan LM**, Tang C, Oxland T. Early Controlled Passive Motion Improves Early Fracture Alignment and Structural Properties in a Closed Extra-articular Metacarpal Fracture in a Rabbit Model (*J Hand Surg 2007; In press*)

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1. ***Feehan LM**, Liu D, Oxland T. Effect of Early Controlled Passive Motion on Closed Fracture Callus Regional Tissue Distribution at 28-Days Post-Fracture: A pQCT and Histological Study In Rabbits (To be *Submitted to Journal of Orthopaedic Research, February, 2007*)

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1. **Feehan LM**, Liu D, Oxland T. Effect of Early Controlled Passive Motion on Closed Fracture Callus Regional Tissue Distribution at 28-Days Post-Fracture: A pQCT Study In Rabbits. Orthopedic Research Society, 53th Annual Meeting. San Diego, California. February 11-14, 2007. (Submitted August 2006).

2. **Feehan LM, Tang C, Oxland T.** Early Controlled Passive Motion Improves Early Fracture Stiffness and Alignment in a Rabbit Model. American Society for Hand Therapy (ASHT) 29th Annual Meeting, September 14-17, 2006. (*Conference Proceedings Abstract- Scientific Paper*).

3. **Feehan LM**, Oxland T, Tang C. Early Controlled Passive Motion Improves Early Fracture Alignment and 4-pt bending Structural Properties in a Rabbit Model. Orthopedic Research Society, 52th Annual Meeting. Chicago, Illinois. March 19-22, 2006 (*Conference Proceedings Abstract- Scientific Poster*)

4. **Feehan LM,** Oxland T, Liu D. A pQCT Scanner Can Provide Reliable and Valid Geometric Measures in Small Cortical Bone and Fracture Callus Specimens. Orthopedic Research Society, 52th Annual Meeting. Chicago, Illinois. March 19-22, 2006 (*Conference Proceedings Abstract- Scientific Poster*)

5. **Feehan LM,** Bassett K. Is There Evidence for Early Mobilization Following an Extra-Articular Hand Fracture? http://nhscrd.york.ac.uk/online/dare/20049807.htm (*DARE Structured Abstract*)

6. **Feehan LM.** Early Controlled Mobilization of Potentially Unstable Extra-articular Hand Fractures. Year Book of Hand Surgery, 2004:22. (*RA Berger MD, PhD – Reviewed, Summary Abstract*)

7. **Feehan LM**, Sheps S. Hand Fractures in BC: Incidence, Demographics and Acute Health Care Utilization Trends. IFSHT 2004: 6th Congress of the International Federation of Societies for Hand Therapy. June 28, 2004. Edinburgh, Scotland. (*Conference Proceedings Abstract - Scientific Paper*)

8. **Feehan LM**, Sheps S. Is there evidence for early motion following an extra-articular hand fracture. ASHT 26th Annual Meeting, October 11, 2003. (*Conference Proceedings Abstract- Scientific Paper*).

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CHAPTER 1: SHOULD WE BE MOVING TOWARDS EARLY CONTROLLED MOBILIZATION OF EXTRA-ARTICULAR HAND FRACTURES IN BC - AN INTRODUCTION

1.1 INTRODUCTION

Hand fractures are a common injury, accounting for up to 20% of all fractures in adults and children,[1,2] The long term morbidity associated with hand fractures, such as problems with healing or the persistent loss of regional hand tissue function is often minimal.[3-6] However, the initial functional burden for the person affected is significant, affecting their ability to use their hand for daily functional activities for up to three months post-fracture.[7] The common nature of hand fracture injuries can result in a considerable societal burden. This is evident in the provision of acute health care services for hand fractures, as well as with reduced socio-economic productivity due to the injured person's limited capacity to perform daily functional and vocational activities throughout their recovery.[8]

Early controlled mobilization (ECM) introduced before 3 weeks has the potential to enhance early hand fracture healing, [9,10] reduce the potential for joint stiffness, muscle weakness and restrictive adhesions associated with hand fracture immobilization. [5,6] It may also lead to an improvement in an individuals capacity to perform normal personal, recreational and vocational activities throughout their recovery.[7] However, to date the clinical / scientific literature does not specifically examine ECM in terms of its potential clinical efficacy or effectiveness following an extra-articular hand fracture. Therefore, clear clinical parameters for the 'safe' introduction of ECM interventions following and extra-articular hand fracture have not been defined.

The numbers and rates presented in the epidemiology literature related to hand fracture incidence and demographics vary markedly. [11-20] The probable reason for this variability is that none of these studies were true population based studies examining all occurrences of hand fractures within a whole population for a specified time period. Therefore, it is not possible to predict from the current epidemiological literature how many hand fractures may be occurring in British Columbia (BC) each year. Nor is it possible to clearly define who in BC may be most at risk for sustaining a hand fracture and, therefore, mostly likely to benefit from ECM following a hand fracture. Finally, there are no previous studies specifically examining acute health care utilization trends for people seeking treatment for a hand fracture. This makes it difficult to define who is likely to be providing the initial care for hand fractures in BC and in which medical setting. Both of these issues are important factors for defining how ECM might be implemented clinically in BC.

This thesis will provide a comprehensive overview of how ECM following an extra-articular hand fracture may impact the underlying fracture healing and an individual's functional recovery in BC. In addition, this thesis will provide an overview of who in BC is most at risk for sustaining a hand fracture, as well as identifying who in BC is likely to be initially treating hand fractures and in which medical setting. The relevant background for each of the research inquires in this thesis is presented in each chapter (Chapters 2 through 7), with additional supporting documentation presented in the thesis appendices.

1.2 CLINICAL AND BASIC SCIENTIFIC BACKGROUND

Simple closed extra-articular hand fractures are usually managed non-surgically with a closed reduction, followed in some instances by percutaneous pin fixation if the fracture remains unstable.[5,21-23] The advantage of a closed reduction, with or without percutaneous pin fixation, is the avoidance of additional surgical trauma. It is generally recommended that closed extra-articular hand fractures be 'immobilized' in a cast or a splint for at least 3 to 4 weeks to provide additional protection to the fragile healing fracture.[5,21-23]

Some closed hand fractures cannot be reduced in a closed manner, while others may remain intrinsically unstable or significantly mal-aligned following attempts at a closed reduction. In addition, some hand fractures present as more complex injuries; involving significant bone loss or comminution, articular disruption and / or presenting as an open injury often in conjunction with other regional tendon, nerve and vascular tissue trauma. In these circumstances it is usually recommended that an open surgical reduction be done with the addition of some form of stable or rigid fixation; ideally rigid fixation that provides direct fracture contact with some additional compressive load.[5,21-23] The rationale for rigid compressive fracture fixation is that it should provide enough structural strength or stability to allow for the consideration of early motion following fracture, while also facilitating direct fracture healing or remodeling across the fracture gap.[5,21-23] Unfortunately, the small size, brittle nature (high cortical to cancellous bone ratio) and contoured shape of hand bones, combined with the need for extensive regional soft tissue and periosteal disruption makes this option technically difficult to achieve. Therefore, it is not uncommon following an open reduction of a hand fracture for a surgeon to opt for a less stable form of fracture fixation. In these instances, it is again generally recommended that the hand fracture be immobilized for up to 4 weeks to provide additional protection to the healing fracture.[5,21-23]

There are many factors likely to influence functional outcome following a hand fracture, the most significant being the complexity of the initial hand fracture injury. Simple, non-displaced, closed hand fractures rarely have any associated long term morbidity.[3-6] However, the more complicated hand fracture injuries,

particularly open injuries that involve significant bone loss and / or other regional tendon or nerve injury can often lead to a delays in healing, multiple surgical and rehabilitation interventions, as well as long-term or permanent loss in regional hand tissue function. [3-6] Other factors associated with overall medical status of the individual affected, including their underlying bone health, will influence fracture healing. [24,25] Various medications, including nicotine and alcohol have also been shown to influence fracture healing. [26-28]

Factors related to the choice of medical management of the fracture are also known to influence outcome following an extra-articular hand fracture. In particular, clinical outcomes following internal plate and / or screw fixation of metacarpal and proximal phalangeal finger fractures remain less than ideal. [6,29-31] However, it is important to note that these reports are based on case series, rather than controlled clinical trials. Therefore, it is difficult to determine conclusively whether these poor functional outcomes are primarily related to the severity of the initial injury to begin with [5,6,29-32] and / or due to the additional trauma and scarring related to the surgery [32] and / or due to the potential negative impact of fixation implants on the underlying fracture healing process. [6]

Immobilization of regional hand, wrist and forearm tissues in a cast or splint will also affect all levels of an individual's capacity to function, as defined by the World Health Organization International Classification of Functioning, Disability and Health (ICF). [33] During the first month or so following a hand fracture when the hand is immobilized in a cast or splint, the capacity to participate in normal daily functional activities will be particularly compromised. In addition, when the cast or splint is removed, post immobilization complications in the hand such as muscle atrophy, weakness and fatigue, joint stiffness, loss of mobility, and loss of flexor and extensor tendon gliding function will also influence the capacity to return to normal functional activities. [3-6] These regional tissue complications associated with immobilization are often more evident following a surgical intervention and / or when immobilization of the hand exceeds four weeks, [35] leading to an increased likelihood of additional rehabilitation, medical and / or surgical interventions; an additional impact on health care service provision.

Experimental studies in animal models have shown that surgical disruption of the early fracture hematoma, periosteal tissues and the regional blood vessels affects normal fracture healing.[36-38] In addition, other studies have also shown that the additional introduction of metal fracture fixation devices such as pins, screws and plates also disrupts the regional bone vascular supply, as well as, the normal biologic and biomechanical integrity of healing fractures.[33,39] It has also been clearly shown in many animal studies that limited or controlled mechanical stimuli, in the form of micro-motion, introduced during the initial few days of

healing clearly influences the initial genetic and molecular expression in the callus. [40,41] This in turn also affects the initial cellular proliferation and differentiation, all of which ultimately influence the morphologic presentation and strength of the fracture throughout the early stages of healing. [42-64]

Based on these basic scientific studies in animals, during the last decade there has been a decided shift in the traditional philosophy related to the principles of long bone fracture fixation in humans. [65] The shift is away from the original concept of a direct (open) anatomic reduction and rigid compressive fracture fixation followed by immediate functional reactivation, to indirect (either a closed, percutaneous or limited open) near anatomic reduction combined with minimally invasive, limited contact flexible fixation methods, followed by early protected mobilization of the affected limb. [66,67] This newer concept is referred to as biologic or flexible long bone fixation and has been described by Perren SM (2002) [68] as finding a balance between maintaining the biologic integrity of the healing fracture while providing for an adequately stable mechanical environment to allow fracture healing to occur. Unfortunately, the current hand fracture clinical literature does not discuss the concept of biologic or flexible fracture fixation and its potential application in the management of an extra-articular hand fracture.

Early controlled mobilization is commonly used following primary flexor tendon repairs and other equally fragile or potentially "unstable" healing tissues in the hand,[69] but it is not recommended for potentially unstable extra-articular hand fractures. [5,21-23] The rationale for this clinical strategy in potentially 'structurally fragile' fractures is that early regional joint motion of any form may cause excessive motion at the fracture site and disrupt early fracture healing and / or alignment. [5,21-23] Interestingly, these were the same concerns expressed in the middle to late 1970s when surgeons and therapists were considering early controlled mobilization of potentially unstable or fragile healing primary flexor tendon repairs. However, despite these initial reservations, further research over the ensuing years has demonstrated that early controlled mobilization of healing primary flexor tendon repairs can lead to improved biologic healing, faster strength gains, no increased risk of structural failure (rupture) and better and faster functional recovery of the affected individual. [69-71]

1.3 SPECIALIZED HAND THERAPY RESOURCES IN BC

Physical Therapy (PT) and Occupational Therapy (OT) training across Canada currently involves an entry level professional Masters training program, offered as accredited programs in several universities across Canada. [72,73] The University of British Columbia offers an entry level Masters program in both Physiotherapy (MPT) and Occupational therapy (MOT). [74] To work in BC as either a Physical or an

Occupational Therapist requires licensure through either the College of Physical Therapists of BC [75] or the College of Occupational Therapists of BC. [76] In 2005, there were approximately 2400 registered Physical Therapists and 1450 registered Occupational Therapists in BC. [75,76]

Specialization in hand therapy or the specialization in rehabilitation of upper extremity / upper quadrant dysfunction is not a formally recognized area of clinical practice in either PT or OT in Canada. However, there are a number of therapists in Canada, both PT and OT, that tailor their clinical practice towards a specialization in upper extremity rehabilitation.[77] In August 2006, there were 65 Certified Hand Therapists working in British Columbia, accounting for 71% of all Certified Hand Therapists in Canada. [78] A Certified Hand Therapist (CHT) can be an occupational therapist or physical therapist who has a minimum of five years of clinical experience, including 4,000 hours or more in direct practice in hand therapy. In addition, a Certified Hand Therapist must have successfully passed a comprehensive test of advanced clinical skills and theory in upper quarter rehabilitation. [78]

The majority (46 of 65) of the CHTs in BC are working in the Vancouver Coastal and Fraser Health Authorities. [78,79] The Vancouver Island Health Authority has 12 CHTs in Campbell River, Nanaimo and Victoria, whereas, the Interior Health Authority has 7 CHTs working in Kamloops and Kelowna. There are no Certified Hand Therapists working in the Northern Health Authority. [78] In addition, there are also twenty Workers' Compensation Board of BC approved hand therapy providers in BC, providing specialized hand therapy rehabilitation services for injured workers with a traumatic injury in the upper extremity.[80] The WCB of BC approved hand therapy clinics provide both consultation and treatment services, with treatment provided either directly or under the supervision of a certified hand therapist. [80] BC is in a unique position in Canada, with a large number of therapists specializing in hand therapy, and thus well placed to be moving towards early controlled mobilization of extra-articular hand fractures, especially in the more populous urban areas in the province.

1.4 RESEARCH OBJECTIVES

This thesis examines the introduction of early controlled mobilization (a novel intervention) into the management of extra-articular hand fractures, a possible alternative to acute post-fracture immobilization (standard care). As well, this thesis examines ECM following an extra-articular hand fracture in the context of its application in the health care system in BC.

The primary objective was to investigate the clinical question of: "Should we be moving towards early controlled mobilization of extra-articular hand fractures in BC?" This clinical question was examined through a series of research investigations derived from a number of research questions related to this primary clinical question. (See Figure 1-1)

The research questions addressed in this thesis were:

1. Can ECM be implemented clinically following an extra-articular hand fracture?
2. Is there any scientifically validated clinical evidence to support early motion following an extra-articular hand fracture?
3. Who is at risk of sustaining a hand fracture in BC?
4. Who is providing the initial care for hand fractures in BC and in what clinical setting?
5. How does Early Controlled Passive Motion (ECPM) affect the quality and rate of early bone healing in a rabbit model?

Each of the research inquiries conducted is presented as a separate manuscript-based chapter in this thesis. These research inquires included a comprehensive clinical overview of how ECM could be implemented following a potentially unstable extra-articular hand fracture (Chapter 2). In addition, a systematic review of the literature was conducted to examine the current state of scientifically validated clinical evidence related to early motion following any extra-articular hand fracture was completed (Chapter 3). As well, a two-part population based epidemiological study was done involving a five year retrospective review of all people identified in the BC Linked Health Datasets (BCLHD) [81] as having sustained a hand fracture in BC between May 1, 1996 and April 30, 2001. The first part of epidemiologic study defined annual incidence rates, demographics and seasonal and geographic variations for hand fractures BC (Chapter 4). The second part of the epidemiological study identified which medical professionals were mostly likely to provide the initial medical care for hand fractures in BC and in which medical setting (Chapter 5). A final pre-clinical, efficacy trial was done in a rabbit, closed, 3rd metacarpal extra-articular fracture healing model examined the effect of ECPM on early fracture alignment and 4-point bending structural properties (Chapter 6). The efficacy trial also looked at the effect of ECPM on closed fracture callus regional tissue distribution at 28-days post-fracture (Chapter 7). In the final chapter (Chapter 8), there is a brief summary of the key findings from each of the research inquires followed by a discussion of why, based on these findings we should be moving towards ECM following an extra-articular hand fracture in BC. The thesis ends with recommendations for educational and research initiatives that could be implemented in an effort to be moving forward with ECM for extra-articular hand fractures in BC.

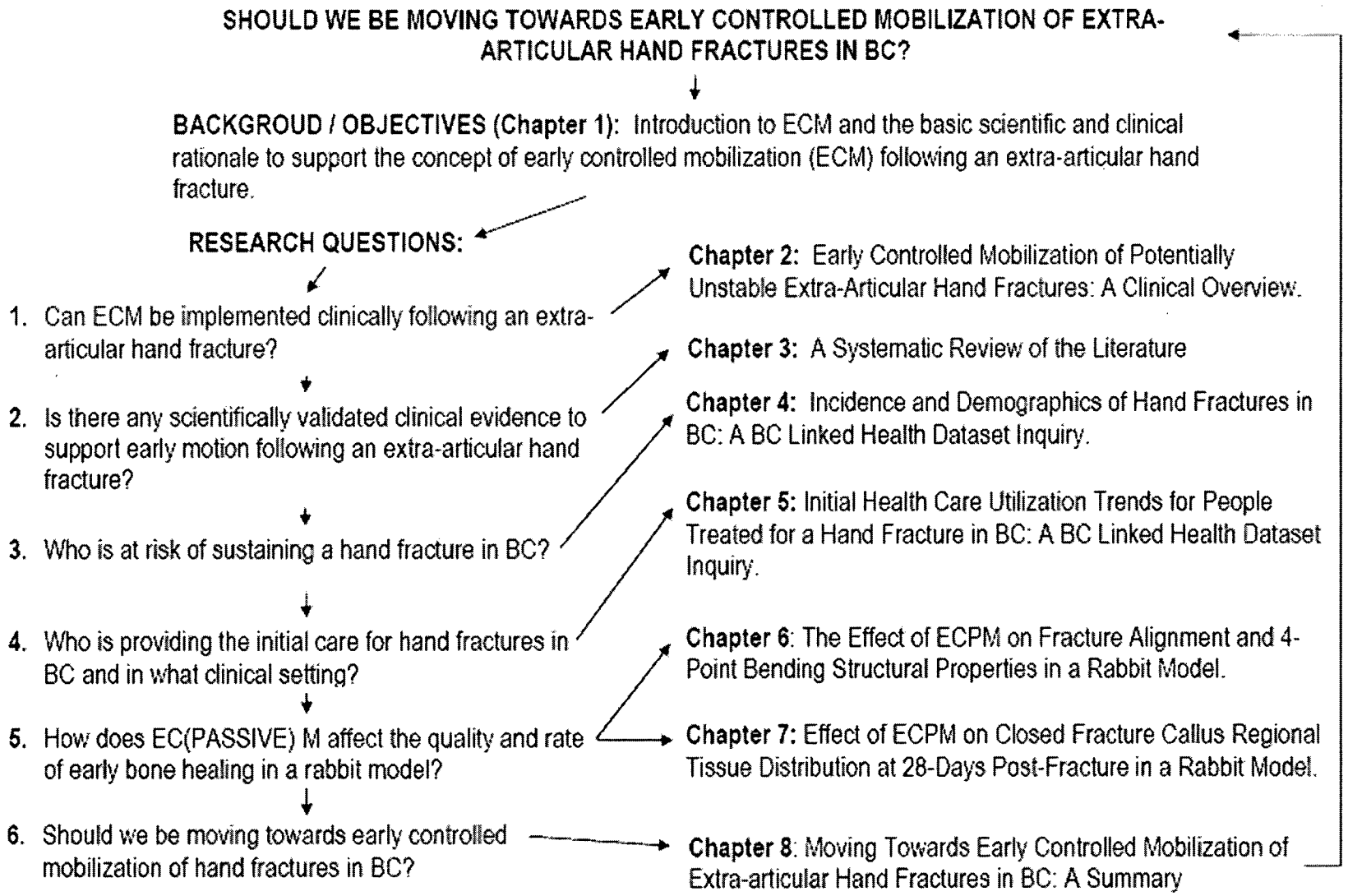

Figure 1-1: Dissertation Overview

CHAPTER 1: REFERENCES

1. Cooper C, Dennison EM, Leufkens HG, Bishop N, van Staa TP. Epidemiology of childhood fractures in Britain: a study using the general practice research database. J Bone Miner Res. 2004;19(12):1976-81.
2. Johansen A, Evans RJ, Stone MD, Richmond PW, Lo SV, Woodhouse KW. Fracture incidence in England and Wales: a study based on the population of Cardiff. Injury. 1997;28(9-10):655-60.
3. Huffaker WH, Wray RC, Weeks PM. Factors influencing final range of motion in the fingers after fractures of the hand. Plast Reconstr Surg. 63: 82-87, 1979.
4. Strickland JW, Steichen JB, Kleinman WB, Flynn N. Factors influencing digital performance after phalangeal fractures (pp126-139). In: Stickland JW , Steichen JW (eds), Difficult Problems in Hand Surgery. St Louis, C.V. Mosby Co., 1982.
5. Freeland AE, Orbay JL. Extraarticular hand fractures in adults. A review of new developments. Clin Orthop Relat Res. 2006;445:133-145.
6. Ip WY, Ng KH, Chow SP. A prospective study of 924 digital fractures of the hand. Injury 1996; 27(4): 279-285.
7. Feehan LM, Bassett K. Is there evidence for early motion following an extra-articular hand fracture? J Hand Ther 2004; 17(2): 300-308.
8. Rosberg HE, Carlsson KS, Dahlin LB. Prospective study of patients with injuries to the hand and forearm: costs, function and general health. Scand J Plast Reconstr Surg Hand Surg. 2005;39(6):360-69.
9. Buckwalter JA. Effects of early motion on healing of musculoskeletal tissues. Hand Clin. 1996; 12(1):13-24.
10. Feehan LM. Early controlled mobilization of potentially unstable extra-articular hand fractures. J Hand Therapy 2003;16(2): 161-170.
11. Burke FD, Dias JJ, Lunn PG, Bradley M. Providing care for hand disorders: trauma and elective. The Derby hand unit experience (1989 – 1990). J Hand Surg 16B: 13-18, 1991.
12. Butt WD. Fractures of the hand. Statistical Review. Can Med Ass J 1962;85:775-779.
13. Chung KC, Spilson SV. The frequency and epidemiology of hand and forearm fractures in the United States. J Hand Surg [Am]. 2001 Sep;26(5):908-15
14. DeJonge JJ, Kingma J, van der Lei B, Klasen HJ. Phalangeal fractures of the hand. An analysis of gender and age-related incidence and aetiology. J Hand Surg 1994a;19B: 168-170.

15. DeJonge JJ, Kingma J, van der Lei B, Klasen HJ. Fractures of the metacarpals. A retrospective analysis of incidence and aetiology and a review of the English-language literature. Injury 1994b;25:365-369
16. Hastings H, Simmons BP. Hand fractures in children: A statistical review. Clinc Orthop Rel Res. 1984;188:120-130.
17. Hove LM. Fractures of the hand. Distribution and relative incidence. Scand J Plast Reconstru Surg Hand Surg. 1993;27:317-319.
18. Mahabir RC, Kazemi AR, Cannon WG, Courtemanche DJ. Pediatric hand fractures: a review. Pediatr Emerg Care. 2001 Jun;17(3):153-6.
19. van Onselen EB, Karim RB, Hage JJ, Ritt MJ. Prevalence and distribution of hand fractures. J Hand Surg [Br]. 2003 Oct;28(5):491-5.
20. Worlock P, Stower M. The incidence and pattern of hand fractures in children. J Hand Surg. 1986;11B(2):198-200.
21. Freeland AE, Lund PJ. Metacarpal and phalangeal fractures. In: Russell RC (ed.) Plastic Surgery: Indications, Operations and Outcomes. (Vol. 4 - Hand Surgery). Toronto, Mosby; 2000:1845-1864.
22. Purdy BA, Wilson RL. Management of nonarticular fractures of the hand. In: Mackin EJ, Callahan AD, Skirven TM, Schneider LH, Osterman AL (Eds.) Rehabilitation of the Hand and Upper Extremity (5th Edition). St. Louis: C.V. Mosby, 2002:382-395.
23. Stern PJ. Fractures of the metacarpals and phalanges. In: Green DP, (ed). Operative Hand Surgery (3rd ed). New York: Churchill Livingstone Inc. 1993:695-758.
24. Einhorn TA. The science of fracture healing. J Orthop Trauma. 2005 Nov-Dec;19(10 Suppl):S4-6.
25. Augat P, Simon U, Liedert A, Claes L. Mechanics and mechano-biology of fracture healing in normal and osteoporotic bone. Osteoporos Int. 2005;16 Suppl 2:S36-43.
26. Koester MC, Spindler KP. Pharmacologic agents in fracture healing. Clin Sports Med. 2006;25(1):63-73.
27. Hollinger JO, Schmitt JM, Hwang K, Soleymani P, Buck D. Related Articles, Impact of nicotine on bone healing. J Biomed Mater Res. 1999;45(4):294-301
28. Chakkalakal DA. Alcohol-induced bone loss and deficient bone repair. Alcohol Clin Exp Res. 2005; 29(12):2077-90.
29. Page SM, Stern PJ. Complications and range of motion following plate fixation of metacarpal and phalangeal fractures. J Hand Surg. 1998;23:827-832.
30. Fusetti C, Meyer H, Borisch N, Stern R, Santa DD, Papaloizos M. Complications of plate fixation in metacarpal fractures. J Trauma. 2002;52(3):535-9.

31. Kurzen P, Fusetti C, Bonaccio M, Nagy L. Complications after plate fixation of phalangeal fractures. J Trauma. 2006;60(4):841-3.
32. Trevisan C, Morganti A, Casiraghi A, Marinoni EC. Low-severity metacarpal and phalangeal fractures treated with miniature plates and screws. Arch Orthop Trauma Surg. 2004 ;124(10):675-80.
33. Chapman MW. The effect of reamed and nonreamed intramedullary nailing on fracture healing. Clin Orthop Relat Res. 1998;(355 Suppl):S230-8.
34. World Health Organization, International Classification of Functioning, Disability and Health (ICF) (http://www.who.int/classifications/icf/en)
35. Strickland JW, Steichen JB, Kleinman WB. Phalangeal fractures: factors influencing performance. Orthop Rev. 1982; 1: 39-50.
36. Ozaki A, Tsunoda M, Kinoshita S, Saura R. Role of fracture hematoma and periosteum during fracture healing in rats: interaction of fracture hematoma and the periosteum in the initial step of the healing process. J Orthop Sci. 2000;5(1):64-70.
37. Park SH, Silva M, Bahk WJ, McKellop H, Lieberman JR. Effect of repeated irrigation and debridement on fracture healing in an animal model.J Orthop Res. 2002;20(6):1197-204.
38. Claes L, Eckert-Hubner K, Augat P. The effect of mechanical stability on local vascularization and tissue differentiation in callus healing. J Orthop Res. 2002;20(5):1099-105
39. Farouk O, Krettek C, Miclau T, Schandelmaier P, Guy P, Tscherne H. Minimally invasive plate osteosynthesis: does percutaneous plating disrupt femoral blood supply less than the traditional technique? J Orthop Trauma. 1999;13(6):401-6.
40. Le AX, Miclau T, Hu D, Helms JA. Molecular aspects of healing in stabilized and non-stabilized fractures. J Orthop Res. 2001 Jan;19(1):78-84
41. Heiner DE, Meyer MH, Frick SL, Kellam JF, Fiechtl J, Meyer RA Jr. Gene expression during fracture healing in rats comparing intramedullary fixation to plate fixation by DNA microarray. J Orthop Trauma. 2006;20(1):27-38.
42. Ashhurst DE. The influence of mechanical conditions on the healing of experimental fractures in the rabbit: a microscopical study. Phil Trans R Soc Lond 1986; 313(B):271-302.
43. Bailon-Plaza A, van der Meulen M. Beneficial effects of moderate early loading and adverse effects of delayed or excessive loading on bone healing. J Biomech. 2003; 36:1069-1077.
44. Carter DR, Beaupre GS, Giori NJ, Helms JA. Mechanobiology of skeletal regeneration. . Clinical Orthop Related Research 1998; 355S:41-55.
45. Challis MJ, Welsh MK, Jull GA, Crawford R. Effect of cyclic pneumatic soft tissue compression on simulated distal radius fractures. Clin Orthop Relat Res. 2005;433:183-188

46. Chao EYS, Inoue N, Elias JJ, Aro H. Enhancement of fracture healing by mechanical and surgical intervention. Clinical Orthop Related Research 1998; 355S:163-178.
47. .Claes L, Eckert-Hubner K, Augat P The effect of mechanical stability on local vascularization and tissue differentiation in callus healing. J Orthop Res. 2002 ; 20(5):1099-105.
48. Claes LE, Heigele CA. Magnitudes of local stress and strain along bony surfaces predict the course and type of fracture healing. J Biomech 1999; 32(2): 255-266.
49. Egger EL, Gottsauner-Wolf F, Palmer J, Aro HT, Chao EY. Effects of axial dynamization on bone healing. J Trauma. 1993 Feb;34(2):185-92
50. Goodship AE, Cunningham JL, Kenwright J. Strain rate and timing of stimulation in mechanical modulation of fracture healing. Clinical Orthop Related Research 1998; 355S:105-115.
51. Hente R, Fuchtmeier B, Schlegel U, Ernstberger A, Perren S. The influence of cyclic compression and distraction on the healing of experimental tibial fractures. J Orthop Res. 2004; 22:709-715.
52. Hewitt JD, Narrelson JM, Dailiana Z, Guilak F, Fink C. The effect of intermittent pneumatic compression on fracture healing. J Orthop Trauma 2005; 19(6):371-376.
53. Klein P, Schell H, Streitparth F, Heller M, Kassi J, Kandziora F, Bragulla H, Haas N, Duda G. The initial phase of fracture healing is specifically sensitive to mechanical conditions. J Orthop Res. 2003;21:662-669.
54. Larsson S, Kim W, Caja V, Egger E, Inoue N, Chao E. Effect of early axial dynamization on tibial bone healing. A study in dogs. Clin Orthop Rel Res. 2001; 388:240-251.
55. Mark H, Nilsson A, Nannmark U, Rydevik B. Effects of fracture fixation stability of ossification in healing fractures. Clin Orthop 2004; 419:245-250.
56. Mark H, Rydevik B. Torsional stiffness in healing fractures: influence of ossification. An experimental study in rats. Acta Orthopaedica 2005;76(3):428-433.
57. Park SH, O'Conner K, McKellop H, Sarmiento A. The influence of active shear or compressive motion fracture healing. J Bone Jt Surg 1998; 80(6): 868-878.
58. Park SH, Silva M. Effect of intermittent pneumatic soft-tissue compression on fracture-healing in an animal model. J Bone Joint Surg 2003; 85A:1446-1453.
59. Park SH, Silva M. Neuromuscular electrical stimulation enhances fracture healing: results of an animal model. J Orthop Res 2004; 22(2):382-387.
60. Panjabi MM, White AA, Wolf JW. A biomechanical comparison of the effects of constant and cyclic compression on fracture healing in rabbit long bones. Acta Orthp Scand. 1979; 50:653-661.
61. Sarmiento A, Schaeffer JF, Beckerman L, Latta LL, Enis JE. Fracture healing in rat femora as affected by functional weight-bearing. J Bone Joint Surg Am. 1977; 59(3):369-375.

62. Smith-Adaline E, Volkman S, Ignelzi M, Slade J, Platte S, Goldstein S. Mechanical environment alters tissue formation patterns during fracture repair. J Orthop Rel Res. 2004; 22:1079-1085.
63. Thompson J, Miclau T, Hu D, Helms J. A model for intramembranous ossification during fracture healing. J Orthop Res 2002; 20:1091-1098.
64. Yamaji T, Ando K, Wolf S, Augat P, Claes L. The effect of micromovement on callus formation. J Orthop Sci 2001; 6:571-575.
65. Perren SM, Matter P. Evolution of AO philosophy. Acta Chir Orthop Traumatol Cech. 2003;70(4):205-6
66. Miclau T, Martin RE. The evolution of modern plate osteosynthesis. Injury. 1997;28 Suppl 1:A3-6.
67. Broos PL, Sermon A. From unstable internal fixation to biological osteosynthesis. A historical overview of operative fracture treatment. Acta Chir Belg. 2004;104(4):396-400.
68. Perren SM. Evolution of the internal fixation of long bone fractures. The scientific basis of biological internal fixation: choosing a new balance between stability and biology. J Bone Joint Surg Br. 2002 Nov;84(8):1093-110.
69. Pettengill KM. The evolution of early mobilization of the repaired flexor tendon. J Hand Ther. 2005; 18(2):157-68.
70. Lin TW, Cardenas L, Soslowsky LJ. Biomechanics of tendon injury and repair. J Biomech. 2004; 37:865-877.
71. Tang JB. Clinical outcomes associated with flexor tendon repair. Hand Clin. 2005; 21(2):199-210.
72. Accreditation Council for Canadian Physiotherapy Academic Programs (ACCPAP): http://www.accpap.ca
73. Canadian Occupational Therapy Association (CAOT): http://www.caot.ca
74. University of British Columbia, School of Rehabilitation Sciences: http://www.rehab.ubc.ca
75. College of Physical Therapists of BC (CPTBC): http://www.cptbc.org
76. College of Occupational Therapists of BC (COTBC): http://www.cotbc.org
77. Marcuzzi A, Kelly L, Chang M, Hannah S. A survey of Canadian hand therapists: demographics, roles, and educational needs. J Hand Ther. 1998 Jan-Mar;11(1):39-44.
78. Hand Therapy Certification Commission (HTCC): http://www.HTCC.org
79. British Columbia Government, BC STATS Service BC, Ministry of Labour and Citizens' Services. Health Authorities and Health Service Delivery Areas http://www.bcstats.gov.bc.ca
80. Workers' Compensation Board of British Columbia, WorkSafeBC, Rehabilitation Programs and Services, Hand Therapy Program: http://www.worksafebc.com
81. Center for Health Services and Policy Research (CHSPR) at the University of British Columbia. BCLHD – Data Services. http://www.chspr.ubc.ca/data

CHAPTER 2: EARLY CONTROLLED MOBILIZATION OF POTENTIALLY UNSTABLE EXTRA-ARTICULAR HAND FRACTURES: A CLINICAL OVERVIEW*

"Let anyone place a normal arm in splints for twenty-four hours a day and see what it is like at the end of a month. The result will be a useless limb."
J.W. Dowden (1924)[1]

2.1 RESEARCH QUESTION ADDRESSED IN THIS CHAPTER

Can Early Controlled Mobilization (ECM) be implemented clinically following a potentially unstable extra-articular hand fracture?

2.2 INTRODUCTION

For most patients with an extra-articular hand fracture, acute management follows the progression from injury to x-ray and closed reduction. Following a satisfactory closed reduction, percutaneous transfixing or intra-medullary Kirshner wire (K-wire) fixation may also be used to help maintain fracture alignment during initial healing. More complex fractures require more extensive surgical intervention to obtain satisfactory alignment and fracture fixation. [2-4]

Following these initial actions, a physician will likely consider two additional strategies for providing further support or protection to the fracture during the acute healing phase. The first of these is to consider a more 'stable' form of hardware fixation, allowing for earlier active motion of the regional joints. The second is to immobilize the joints proximal and distal to the fracture, with the assumption that unrestricted motion of these joints may cause displacement of the fracture during the acute phases of healing. [2-4] Unfortunately, these strategies of more extensive surgery and regional tissue immobilization can have negative functional consequences.[2-4]

This chapter reviews the clinical literature and describes 'early controlled mobilization' options for the management of potentially unstable extra-articular hand fractures. The intent is to have clinicians consider whether 'early controlled mobilization' can be utilized with a potentially unstable, extra-articular fracture. The challenge in deciding "to move or not to move" is in finding safe, efficacious and effective strategies for fractures that fall within the clinical 'Gray-Zone' of potentially unstable fractures. (See Figure 2-1).

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* A version of this chapter has been published. Feehan LM. Early controlled mobilization of potentially unstable extra-articular hand fractures. J Hand Ther. 2003;16:161-70.

2.3 EARLY CONTROLLED MOBILIZATION – WHO?

Currently there are two clinical situations where early 'unrestricted active' regional joint motion is considered an appropriate management option for extra-articular hand fractures. The first is an inherently stable fracture configuration, such as a closed minimally displaced inter-digitated fracture with no associated digital rotation (See Figure 2-1-A). [2-5] In this instance early-unrestricted active motion of the regional joints may be introduced, usually in combination with some form of external splint or brace stabilization of the fracture, commonly referred to as a functional fracture brace.[6] The second situation is when the internal or external fixation hardware (See Figure 2-1-C) provides sufficient 'structural stability' for the fracture to withstand early-unrestricted active motion of the regional joints. [2-4]

Early unrestricted active mobilization programs are generally not recommended for fractures that present in the 'Gray-Zone', pictured in Figure 2-1-B. [2-4] These fractures comprise oblique, spiral or comminuted fracture patterns known to be at risk for displacement. In addition, fractures managed with co-aptive pin or wire fixation methods that align but do not necessarily add strength to the fracture, would be considered in this 'Gray-Zone'. These types of fractures are generally thought to be potentially unstable and at a higher risk for losing their anatomic alignment or for having impaired healing if subjected to "too much stress" from unrestricted active motion. However, there are other early controlled mobilization options besides unrestrictive active motion, which can be considered as an alternative to 'immobilization' for these 'Gray-Zone' fractures.

2.4 EARLY CONTROLLED MOBILIZATION - WHY?

Although early controlled mobilization of tendon, nerve, articular and other hand injuries is considered part of good hand therapy practice, early controlled mobilization for most hand fractures is still not generally recommended during the first three to four weeks of healing. [2-4] The rational for this disparity in clinical practice is not clear. It may be that early mobilization, even when performed in a protected and controlled manner, is still generally considered by clinicians as either 'unsafe' (i.e. causing harm) or 'unnecessary' (i.e. providing no functional benefit) following an extra-articular hand fracture.

An alternative view is that early active and / or passive motion of one or both joints adjacent to a healing fracture will cause motion of the regional soft tissues and joints, reducing the potential for developing joint stiffness, muscle weakness and tendon glide tethering, all of which are commonly associated with

immobilization of hand fractures. [2-4] In addition, early limited or controlled joint motion may generate 'intermittent and limited cyclic compressive stresses or loads' across a healing fracture which has the potential to positively influence both the quality and rate of fracture healing. [7-14] Healing connective tissues, including bone, seem to do better with functional or physiologic stress during the early stages of healing. [15,16] Thus, in the case of potentially unstable hand fractures, early controlled mobilization choices may provide the safe, limited motion beneficial for both skeletal integrity and soft tissue mobility.

Despite recent clinical studies that advocate early motion, [5,19-23] from an evidence-based standpoint, [17,18] there is currently no defined evidence for either the efficacy or effectiveness of early mobilization for potentially unstable fractures. Therefore, the impact of early controlled motion on the quality and rate of hand fracture healing, as well as, on the rate of an individual's functional recovery clearly needs further study. (See Figure 2-2).

2.5 EARLY CONTROLLED MOBILIZATION – WHEN TO or WHEN NOT TO?

Wright (1968),[24] discussed the role of early mobilization following metacarpal and phalangeal hand fractures and remarked that "the stability of the fracture largely dictate(s) the type of immobilization required." He felt, as did James (1962),[25] that some 'stable' closed metacarpal and phalangeal fractures could safely be allowed immediate active motion. Tubiana [26] (1983) defined early mobilization of 'stable' hand fractures in terms of "beginning after the initial apprehension and pain disappear, usually towards the 3rd day."

In the case of 'less stable' fractures Wright [24] felt that there was a need for a period of immobilization, in which the hand should be placed "in the position of function, but there is no justification for immobilizing these fractures longer than three weeks." Barton (1984), [27] reiterated the importance of limiting the duration of immobilization for hand fractures to three weeks. Whereas, Strickland (1982) [28] considered that functional outcomes were not likely to be impacted until immobilization of the healing proximal phalanx fracture extended beyond four weeks.

In some cases, when the fracture is considered at 'high risk for displacement' the decision to immobilize may still be considered necessary or appropriate. In these instances, it is important to try to limit the duration of immobilization to less than three weeks, and to ensure that within the cast or splint the MCP

and IP joints are maintained in the position of function with flexion creases of non-involved joints cleared for movement.

The question of *when* to consider early controlled mobilization thus depends on when the healing fracture is considered 'strong enough' for this approach. This is essentially the same as asking whether a healing tendon is strong enough to withstand an early controlled tendon mobilization program. In both cases it would depend on what type of stresses or loads the healing tissue must withstand. In structural terms, this is akin to defining the specific load bearing potential or 'structural strength' of the tissue over time.

Defining the 'current structural strength' of any healing tissue at any point in time is a clinical decision dependent on a number of important clinical factors. In relation to early fracture healing, these factors are:[2,3]

- The location of the fracture (which bone, where in the bone) as this defines the regional 'static' and 'dynamic' forces that will likely compromise skeletal alignment. (See Table 2-1)
- The pattern of bone structural failure (the number and orientation of the fracture lines) and the degree of initial fracture displacement (amount of periosteal disruption) as this determines the inherent structural stability of the fracture.
- The type of fracture reduction (open vs. closed) and additional hardware fixation (none, co-aptive, stable, rigid) used. This will indicate how the underlying healing may be affected and how much additional 'structural stability' might be expected from the fracture fixation.
- The nature of any associated soft-tissue injury, from both the original injury and from the secondary surgical trauma, as this determines what other regional tissues need to be included in the rehabilitation plan.
- The daily functional demands of the affected person, as these determine the types of daily functional stresses the healing fracture will have to withstand.
- The timing or the stage of healing, as this determines the amount of additional 'structural strength' that may be provided by the underlying bone healing processes.

In clinical practice, progression of therapy and an individual's functional re-activation throughout recovery tend to correlate with gains in fracture 'structural strength'. (See Figure 2-2) However the timing of *when* to move or use a hand following a fracture can be highly variable. Therefore, individual modifications to

therapy programs must be tailored to each individual, taking into account the patient's clinical presentation, their specific personal needs and their daily functional demands. [29]

2.6 EARLY CONTROLLED MOBILIZATION - HOW?

Tubiana (1983), [26] described early mobilization in terms that "it must be gentle, never rough or painful, progressive, supervised and engage the active cooperation of the patient". He further states that the motion should be "in the arc through which the joint can be moved without risk of reproducing the displacement of the [reduced] fracture." In instances where full, free, unrestricted active motion of both joints adjacent to the fracture is not considered appropriate or safe, a number of limited or controlled motion options may still be possible.

Early controlled mobilization options for extra-articular hand fractures fall into two categories: external support and protection options; and early limited or controlled motion options. Figure 2-3 presents these early controlled mobilization options in a clinical decision algorithm that has been developed to be compatible with a similar physician clinical decision algorithm presented by Freeland (2000).[2] This rehabilitation clinical decision algorithm assumes that all extra-articular hand fractures are potentially unstable and it is just a matter of how unstable and / or under what physiologic or functional loading conditions they are likely to be disrupted. For example, a metacarpal fracture treated with a rigid compression plate is still at risk for disruption in the early stages of healing in a young male who plans to return to playing a contact sport such as football or hockey. In this case the fracture would require some additional external support or protection for return to sport.

This clinical algorithm also assumes that all extra-articular hand fractures will need some form of external support or protection during the early healing period (<3weeks), even if this support is only provided under limited conditions such as with work or sport. In addition, it assumes that all extra-articular hand fractures can be introduced to some form of limited or controlled motion before three weeks. For example in a fragile proximal phalangeal fracture, initiation of early motion may be limited to only one joint (Proximal Inter-phalangeal Joint - PIP), with a limited arc (< 30^0) of mid-range passive flexion and extension motion, repeated once or twice and only done once a day beginning on the 10^{th} day. (See Figure 2-3)

2.6.1 External Support or Protection Options – Modified Fracture Bracing

Fracture Bracing vs. Modified Fracture Bracing

A fracture brace can be defined as an external support (cast, splint or brace) providing direct, semi-flexible regional stabilization of the fracture while at the same time allowing for unrestricted mobility of the regional soft tissues and joints adjacent to the fracture. [6] Modified Fracture Bracing is a modified cast, brace or splint design that still provides an external direct, regional stabilization of the fracture while only allowing limited or controlled mobility at one or both joints adjacent to the fracture.

Fracture bracing, as a component of hand fracture management, is not a new clinical concept.[30,31] Colditz (2002), [6] provides an excellent overview of the history, theory and role of 'Functional Fracture Bracing' in the management of closed stable upper extremity fractures, including metacarpal and proximal phalanx fractures. Sarimento and Latta (1999), [32] and their various co-workers over the past 30 years are significant proponents of the use of fracture bracing in early fracture management. Latta (1980), [33] stated that Fracture Bracing is a philosophy rather than merely the use of orthotic devices; predicated on the belief that immobilization of the joints above and below the fracture is not necessary for secondary fracture healing.

The intent or purpose of the fracture brace is not to immobilize the fracture site, but to provide fracture alignment stability when regional joint motions occur. [6] This concept is based on the belief that motion of the joints surrounding the fracture generates limited functional or controlled stresses stimulating earlier bone formation in the peripheral region of the healing callus. It is thought that early bone deposition in the peripheral callus allows the healing fracture to bear functional loads earlier. [14,30]

Modified Fracture Bracing – Design Considerations

The key clinical considerations related to modified fracture brace design include: (See Figure 2-3)

- The Number of Joints Included at Rest - Limited Immobilization or Serial Reduction.
- The Position of the Joints at Rest – Position of Protection / "Static" Deforming Forces to be neutralized.
- Other considerations – Pins / Pressure Areas & "Dynamic" Deforming Forces to be neutralized.

Due to the potential negative consequences of immobilization, it is essential for clinicians to continue to

critically examine (or re-examine) their management choices in deciding which joints need to be immobilized and for how long. One option to complete regional tissue immobilization is to consider limiting the number of joints immobilized to 'one joint proximal and distal' to the healing fracture. [22] In instances where it is deemed necessary to initially immobilize 'more joints', another option is to consider a serial reduction of the cast or splint throughout the initial 3 to 4 weeks post-fracture in order to progressively reduce the number of joints contained in the splint. Figure 4 (Fig 2-4,A-C) presents one approach to 'Serial Splint Reduction' following a metacarpal fracture in which the initial resting splint has been cut down. The CMC is still included and the MCP is still held in flexion at rest, limiting the immobilization at rest to 'one joint proximal and one joint distal' to the fracture.

Figure 2-5,A-D compares a complete regional tissue immobilization splint design with a 'modified fracture brace' design for a patient with a proximal phalangeal fracture presenting with K-wires protruding dorsally adjacent to the MCP joints. Both splint designs would accommodate the protruding K-wires and protect the fracture from unwanted joint motion and other external forces that may displace the fracture at rest. Both splints position the MCP in flexion and the IP's in extension at rest in order to reduce the deforming force generated with intrinsic muscle tension. Both would allow access for wound care and pin care. Either of these splints could also be forearm based (including the wrist) for additional splint stabilization or they could be stabilized by 'figure-of-8' strapping around the wrist. The 'modified fracture brace' design has an additional 3-pt compression (apex volar) strapping over the proximal phalanx that adds additional stability to the fracture. In addition, the 'modified fracture brace' design allows for the optional release of the distal straps to introduce some form of early controlled mobilization of the IP joints. Alternately, this modified fracture brace splint could be serially reduced by cutting off the dorsal components that extend over the IP joints, with this option introduced as an intermediate step prior to removing the protective fracture brace completely.

2.6.2 Early Controlled / Limited Motion Options

The use of early controlled mobilization for potentially unstable fractures is dependent upon clinical factors or variables related to what motion would need to be controlled in order to maintain fracture structural integrity. These choices include: (See Figure 2-3).

- *Delaying* the initiation of motion until 10 to 14 days.
- Limiting the *number* of joints moved at one time.

- Controlling the *type* of motion (active and / or passive) allowed.
- Controlling the *arc* of motion (full or limited) allowed.
- Controlling the *frequency / duration* of motion (Number of sessions / repetitions) allowed.

Clearly, the decisions of when and how to control the motion requires that the physician, therapist and patient are all working together with a full understanding of the current strength or stability of the underlying fracture. One alternative is to consider a delayed 'early controlled mobilization' of one or both joints adjacent to the fracture, beginning at 10 to 14 days. For example, as depicted in Figure 2-4,D, a patient could release the strap holding the MCP in flexion at rest so that they can actively extend and abduct the fingers. This exercise is done while the patient provides some additional 3-point pinch stabilization force over the fracture with the non-involved hand to help neutralize the dynamic intrinsic muscle tension that is generated with motion of the MCP into an extended-abducted posture. (See Figure 2-4,D) This exercise could be delayed for one or two weeks but started prior to having the patient remove the protective splint at 3 to 4 weeks. This exercise could be performed while the patient is wearing the serially reduced splint (See Figure 2-4,D) or, alternatively, this exercise could be done even if the more comprehensive regional tissue resting splint design is chosen (Figure 2-4,A-B).

Another option is to consider limiting the *number of joints* for which motion is allowed. For example, the 'modified fracture brace' depicted for the proximal phalangeal fracture patient in Figure 2-5,C-D would allow for the introduction of some form of early controlled motion *only* at the IP joints. In addition, with this splint design early controlled motion of the DIP joint could be introduced immediately, whereas, the introduction of some form of PIP motion could be delayed for a week or two.

A third option is to consider controlling the *type of motion* allowed, that is active versus passive motion. For example, if either active flexion and / or extension were considered to be unsafe at one or both joints possibly controlled passive motion would be acceptable. Figure 2-6,A-B shows a modified fracture brace design for a middle phalangeal fracture that holds the IP joints in extension and provides significant fracture protection at rest. With this splint design, the strap over the proximal phalanx can be released (Figure 2-6,C) so the patient can isolate and *passively* flex and extend the PIP joint. In addition, the patient can again add 'pinch' stabilization with the non-involved hand over the middle phalanx in order to 'neutralize' the dynamic deforming forces that could be generated with tension in FDS and central slip.

This exercise could be followed by releasing the strap over the distal phalanx and having the patient isolate and *actively* flex and extend the DIP while stabilizing the middle phalangeal fracture (See Figure 2-6,D).

A fourth option is to consider controlling the *arc of motion* allowed, that is full versus a limited arc. In this instance, if a full arc of joint motion were considered to be unsafe at one or both joints, possibly limiting the arc of joint motion would be acceptable. Figure 2-7,A-B, shows how the more complex modified fracture brace (shown in Figure 2-5,C-D) allows for an almost complete 'arc' of composite flexion and extension motion at the IP joints when both the distal straps are released. This same splint design could also be easily modified so that the volar thermoplastic fracture stabilization component is extended slightly more distally, crossing over into the PIP flexion crease, limiting the available arc of inner range flexion in the PIP joint even more. In addition to controlling the 'arc of motion', the 'type of motion' could also be controlled by instructing the patient to do *only passive* flexion and / or extension exercises of PIP and / or DIP, similar to early passive exercises done with acute flexor tendon repairs.

Figure 2-7, C-D shows a simpler design for a proximal phalangeal fracture brace, which is a modification of a buddy strap that incorporates a fracture stabilization C-ring held in place by the proximal buddy strap. The C-ring encroaches volarly onto the PIP flexion creases, effectively limiting the inner range of active and passive PIP flexion. This modified buddy strapping could be used acutely for the initial management of a 'more stable' proximal phalangeal fracture, or alternately, used as a progression following removal of a more protective modified fracture brace. The final controlled motion option is to consider controlling the *frequency and duration* for when joint motion is allowed, by allowing only intermittent and / or supervised motion (not shown).

These clinical variables are essentially the same types of variables that physicians and hand therapists consider prior to implementing any early controlled mobilization program for other types of fragile healing hand injuries. The advantage of making this clinical determination early in the fracture healing process is that it is then possible to move from categorizing a fracture as either 'clinically stable' (able to tolerate unrestricted active motion) or 'clinically unstable' (unable to tolerate unrestricted active motion), to thinking instead of what clinical factors or variables would need to be controlled in order to maintain fracture structural integrity and still allow for some form of early joint motion.

2.7 SUMMARY

One of the biggest challenges following hand fractures is in helping the affected person overcome the adverse effects of immobilization. [29] Immobilization can contribute, along with the injury, to temporary and sometimes permanent limitations in the capacity to use the hand functionally. [34] Early controlled mobilization of the soft tissues and joints adjacent to a fracture reduces the potential for stiffness, weakness and restrictive adhesions. The limited and intermittent cyclic compressive stresses that can be generated across the healing fracture with regional joint motion have a positive influence on the quality of fracture healing.

However, these benefits would be negated if motion caused fracture-healing problems of mal-union or non-union to occur. The planning, design and timing for safe implementation of an early controlled mobilization program for potentially unstable fractures does require that the hand therapist and physician communicate and work in partnership. Decisions as to 'if' and 'when' a fracture is ready for limited motion, as well as, which parameters of support and mobility may be safely manipulated, are variables that can be used to determine appropriate rehabilitation of hand fracture patients.

The goal of fracture management from a rehabilitation perspective is to protect and maintain the integrity of the fracture reduction / alignment during healing, using techniques of protective support and early controlled motion that allow for safe, pain free, progressive motion. This concept opens the door for clinicians to consider early controlled motion for potentially unstable acute hand fracture patients.

Table 2-1: Summary of Primary Deforming Forces and Common Patterns of Mal-union for Extra-articular Hand Fractures

	METACARPAL	PROXIMAL PHALANX	MIDDLE PHALANX
Primary Deforming Forces:	• *Intrinsic Muscle Tension:* Causes the distal fragment to flex.	• *Intrinsic Muscle Tension*: Causes the proximal fragment to flex. • *Extensor Mechanism Tension*: Causes the distal fragment to extend.	Proximal 1/ 3: (Apex Dorsal) • *Central Tendon Tension:* Causes the proximal fragment to extend. • *FDS Tension:* Causes the distal fragment to flex Distal 1/3 (Apex Volar): • FDS Tension: Causes the proximal fragment to flex. • *Extensor Mechanism Tension:* Causes the distal fragment to extend. Middle 1/3 (Apex Dorsal or Volar): • Depending on whether *FDS or Extensor Mechanism* is dominant influences the distal fragment.
Common Patterns of 'Mal-union':	*Apex Dorsal* Fracture Angulation, Functional Bone Shortening + / - Digital Rotation or Lateral Angulation Distal to Fracture.	*Apex Volar* Fracture Angulation, Functional Bone Shortening + / - Digital Rotation or Lateral Angulation Distal to Fracture.	*Apex Volar* (proximal or middle 1/3) *or Apex Dorsal* (middle or distal 1/3) Fracture Angulation, Functional Bone Shortening + / - Digital Rotation or Lateral Angulation Distal to Fracture.

CHAPTER 2: FIGURES

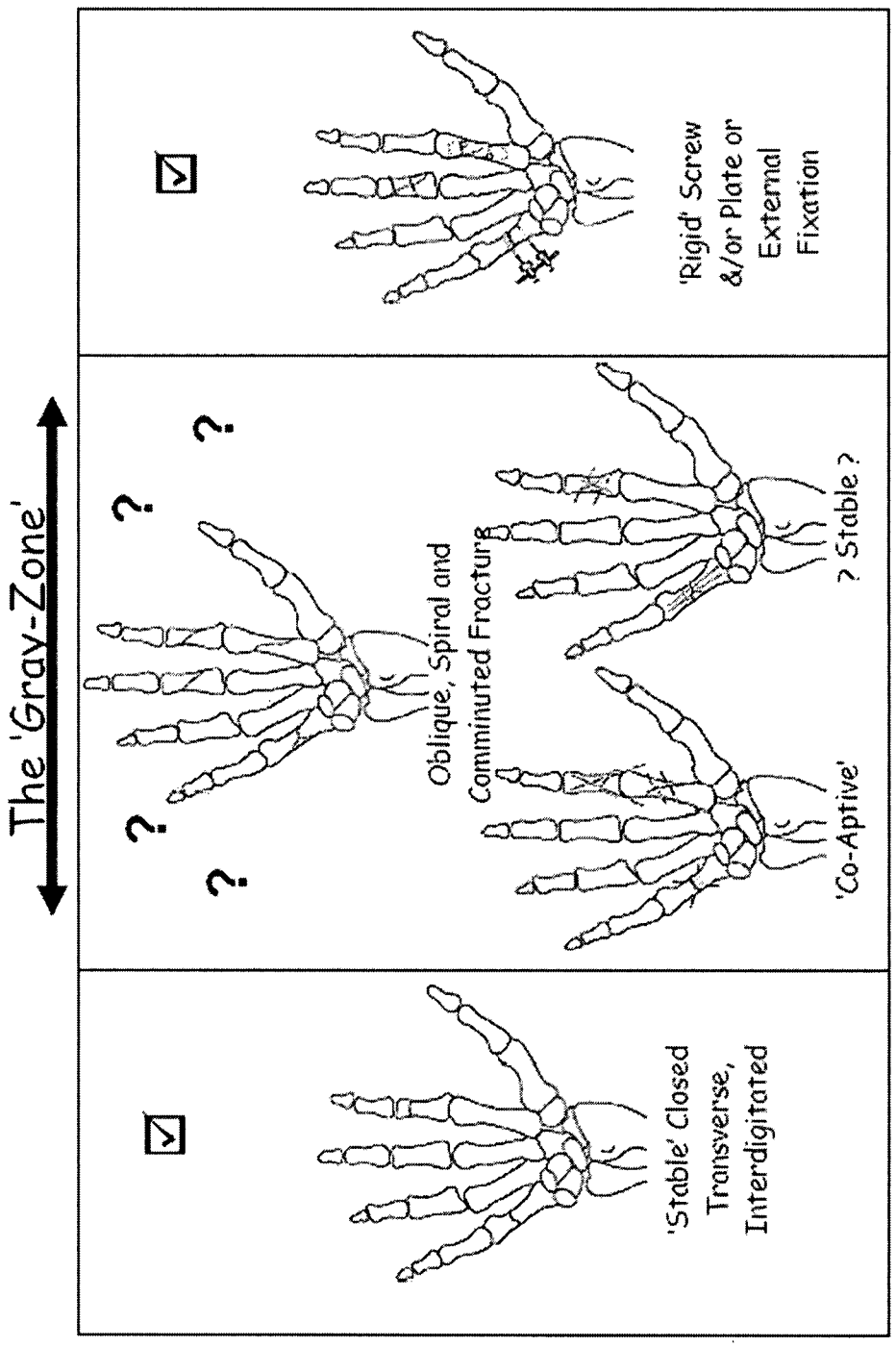

Figure -2-1: To Move of Not to Move?

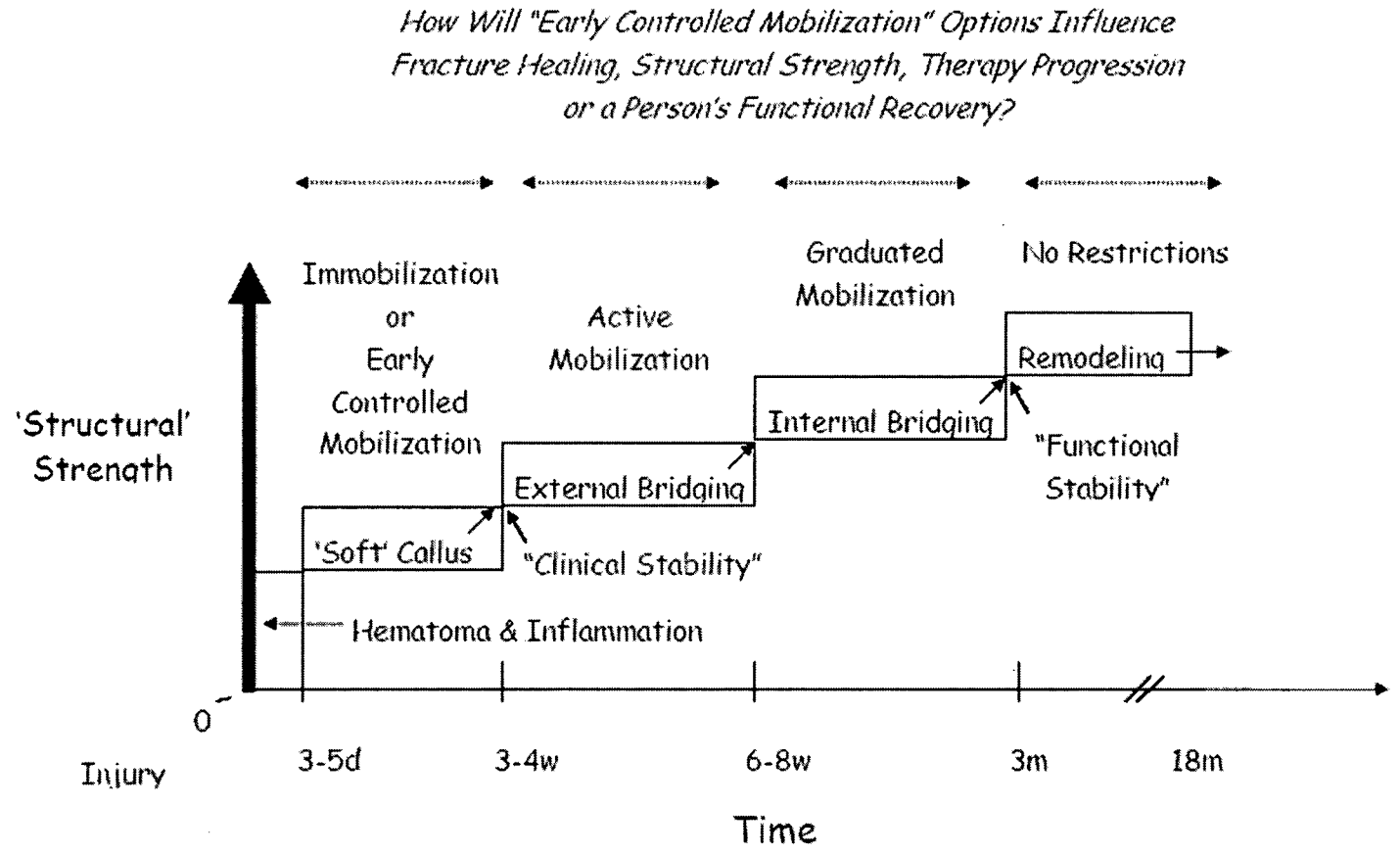

Figure -2-2 : Evidence-based practice: How will early controlled mobilization affect health outcomes?

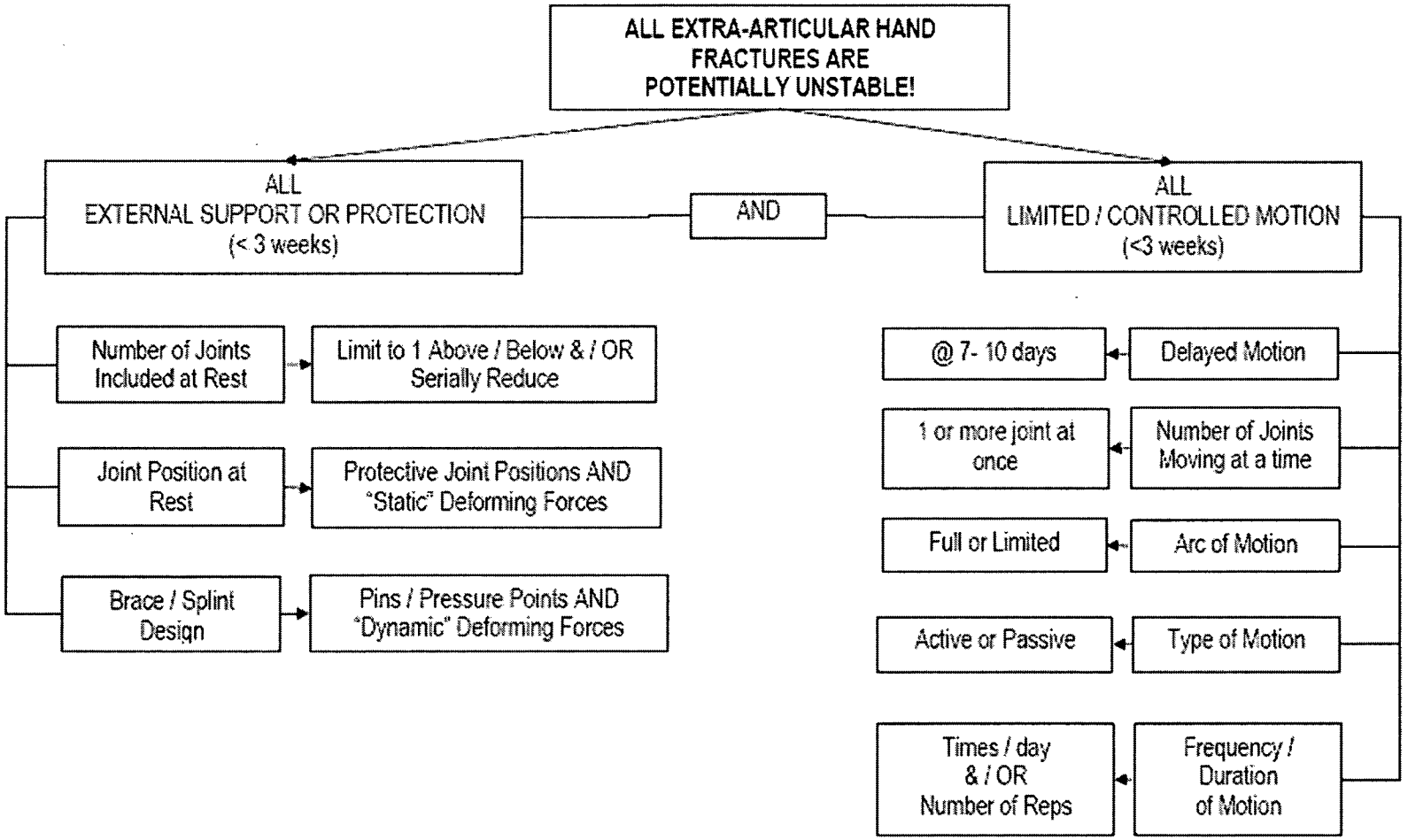

Figure -2-3 Rehabilitation clinical decision algorithm developed to be compatible with a similar physician decision algorithm presented by Freeland (2000) [2]

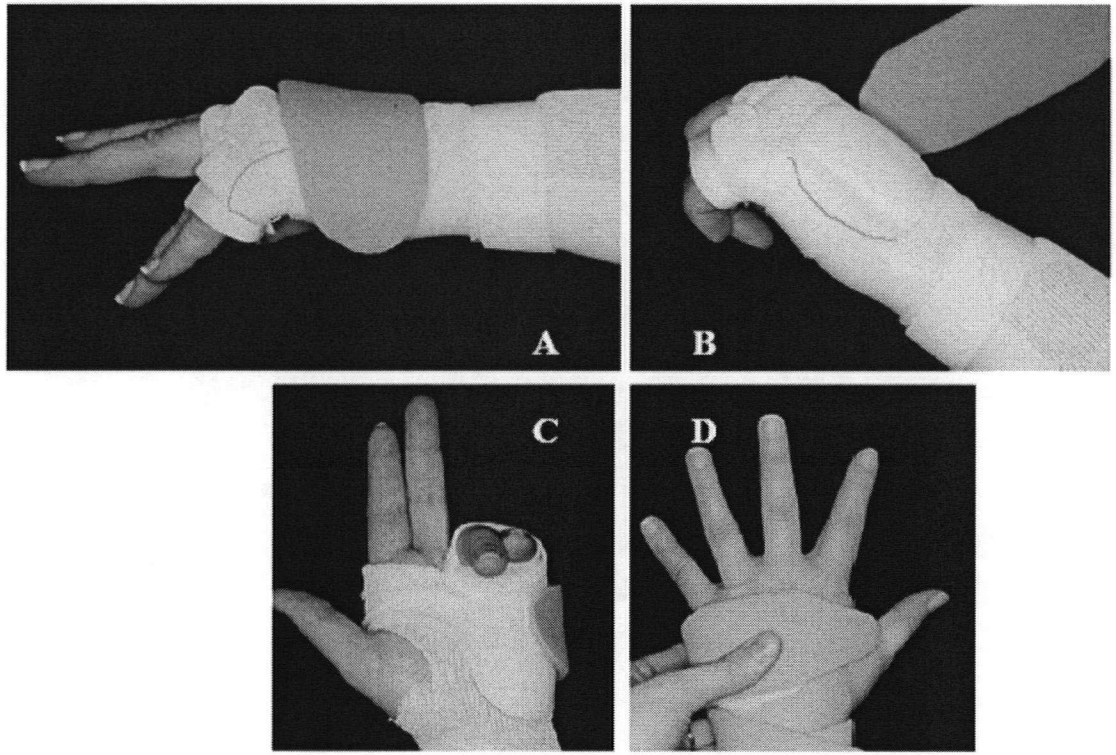

Figure -2-4: Fifth Metacarpal Fracture - Serial Splint Reduction and / or Modified Fracture Brace Design. **A:** Volar Forearm Based "Immobilization/ Resting" splint, proximal strap over P1 holds the affected fifth finger MCP joint in flexion at rest. **B:** A separate molded and padded thermoplastic compression insert is placed dorsally under the hand strap. The dorsal strapping / compression can be adjusted with variations in swelling. **C:** Serial reduction of the splint. The CMC is still included and the MCP is still held in flexion at rest, limiting the immobilization at rest to 'one joint proximal and one joint distal' to the fracture. Proximal 'Figure-of-8' stabilization strap not shown. **D:** Active composite finger extension and abduction exercise performed in the modified fracture brace while the patient adds additional 3-pt 'pinch' stabilization for the fracture. The proximal 'figure-of-8' splint stabilization strap is partially shown.

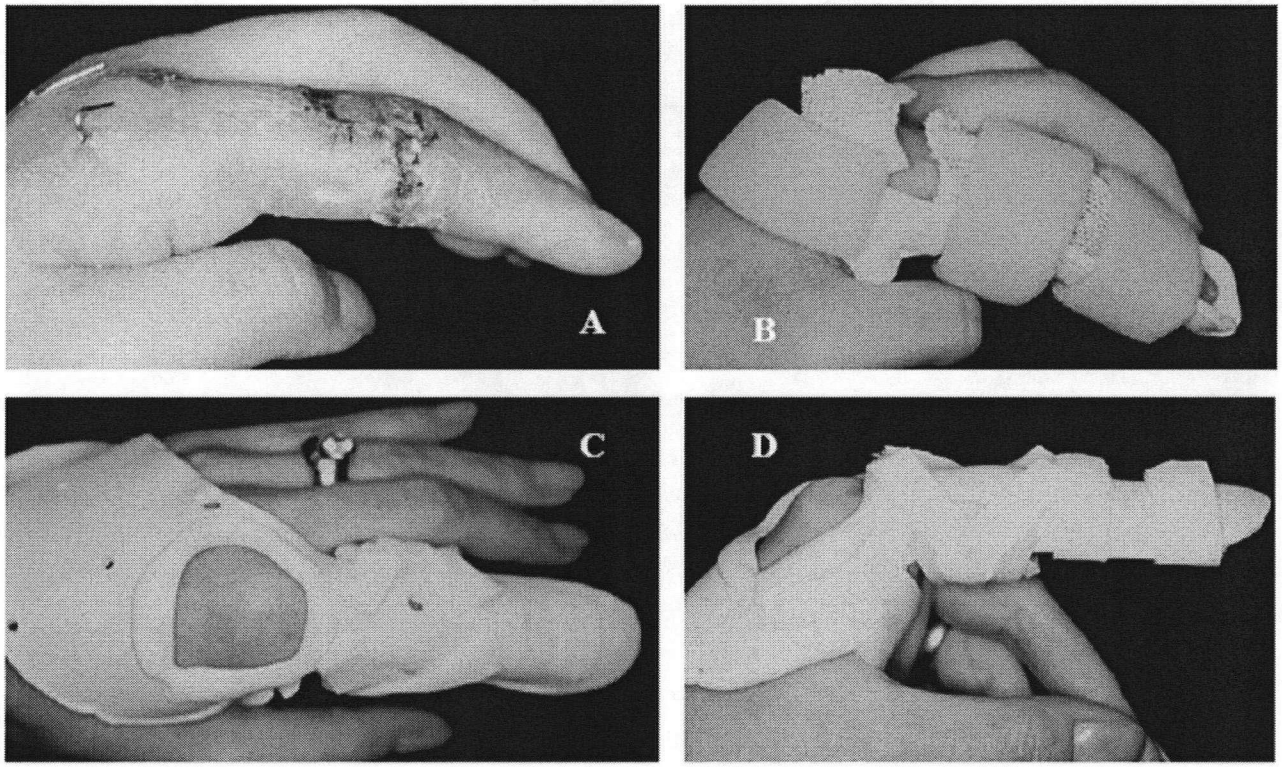

Figure -2-5: 'Unstable' Proximal Phalangeal (P1) Fracture – Early 'Immobilization' vs. 'Modified Fracture Brace' Splint Designs. **A:** Lateral View of the patient, showing K-wire fixation and healing incisions for unstable P1 fracture **B:** 'Complete Immobilization' splint for protection of this 'unstable' fracture from all potential deforming forces, allowing access only for wound and pin care. **C:** Dorsal View - Alternate Modified Fracture Brace Design, allows for the same protection at rest, access for pin and wound care and accommodation for K-wires. **D:** Lateral View – Shows the '3-pt' (apex volar) strapping option. This volar strapping component is made with a molded thermoplastic volar fracture stabilization component, held in place over P1 with bilateral 'V-shaped' strapping.

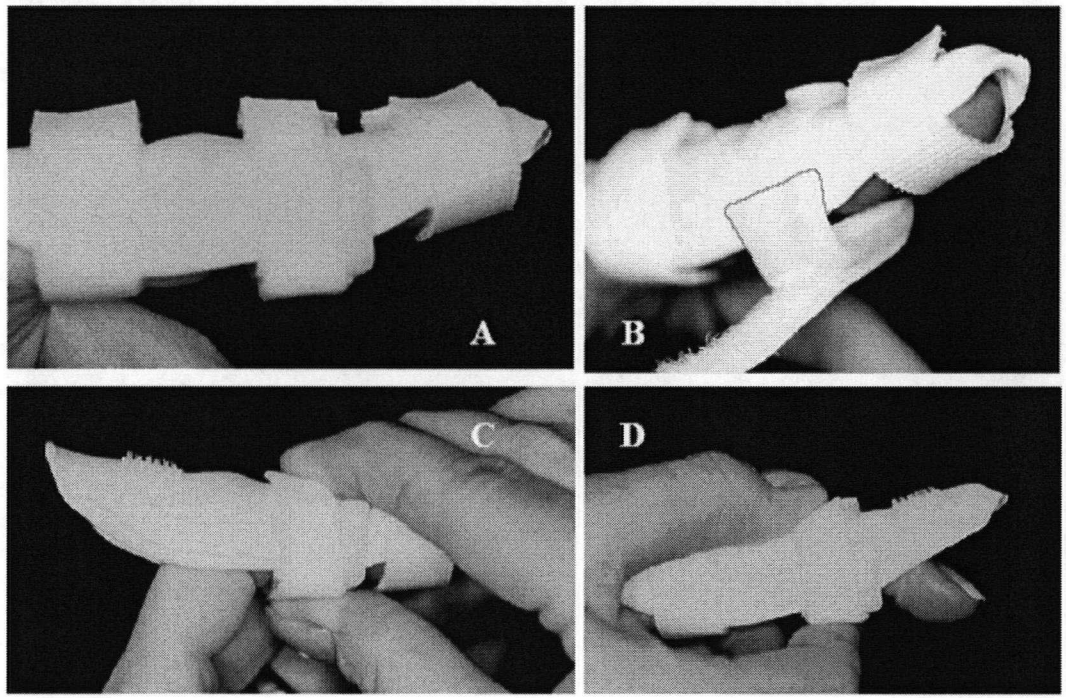

Figure 2-6: Middle Phalangeal (P2) Fracture – Early Control of 'Type' of Motion **A**: Lateral View –Resting Splint, provides maximal protection. Shows 'Dorsal Prominence' to accommodate PIP motion and the volar molded thermoplastic insert under the P2 volar strap to provide additional compression over fracture. **C:** Proximal strap over P1 can be released for isolated *passive* PIP flexion and / or extension exercises while the patient also provides additional 'pinch' stabilization of the fracture. **D:** Lateral View – Shows additional 'pinch' pressure provided by patient while performing isolated *active* DIP flexion and extension exercises.

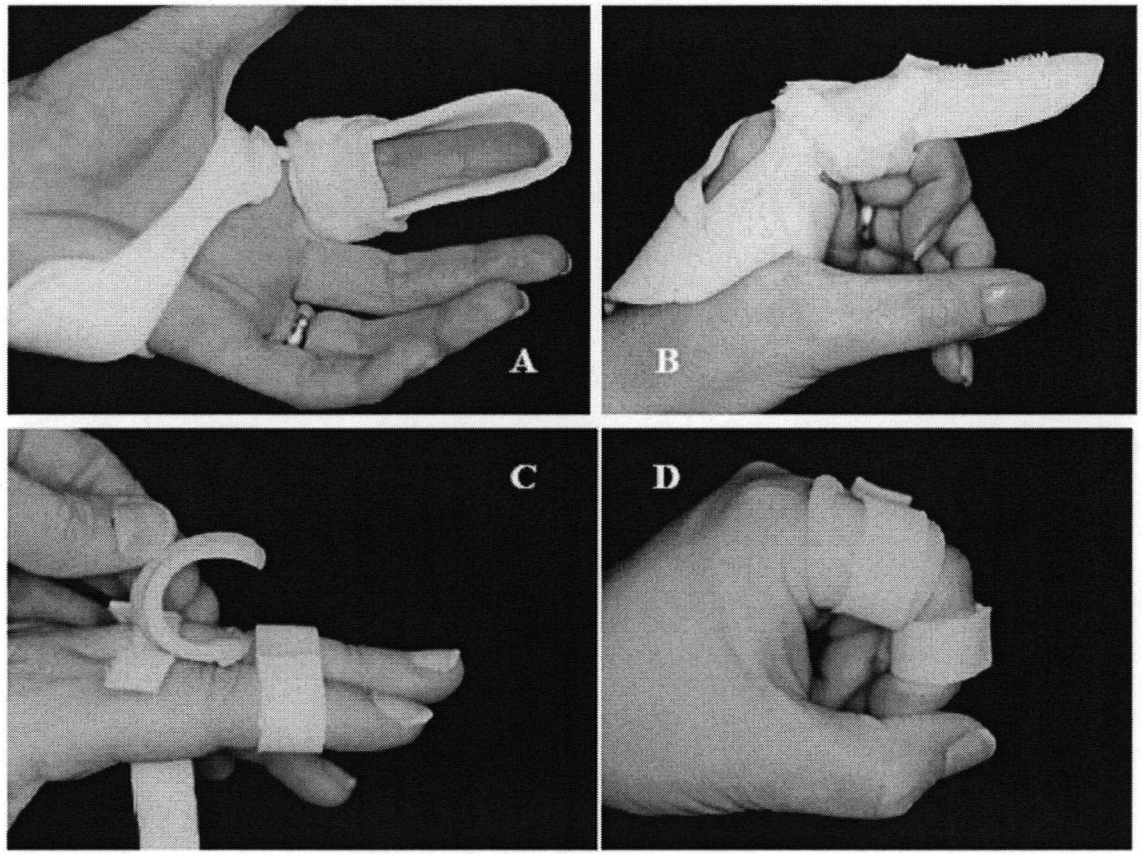

Figure 2-7: 'Unstable' Proximal Phalangeal (P1) Fracture – Early Control of 'Arc' of Motion **A:** Volar view of same P1 splint depicted in Figure 4.c and d. The distal straps are removed allowing the patient access to do almost full composite arc of IP joint motion. **B:** Lateral view same splint, no distal straps, shows active composite IP flexion demonstrating a slight limitation in inner 'arc' of PIP flexion. The patient could also add additional 'pinch' compression during this exercise (not shown). **C:** Alternate Design for P1 Modified Fracture 'Buddy-strapping'. In this case a 'Fracture Stabilization C-Ring' is molded over the proximal phalanx and held in place with the proximal buddy strap. **D:** Lateral View 'Modified Buddy Strap – Shows 'limited arc' of composite active motion flexion allowed in this splint.

CHAPTER 2: REFERENCES

1. Dowden JW (1924) . The principles of early active movement in treating fractures of the upper extremity. Reprinted in: Clinical Orthop Rel Res 1980; 146: 4-8.
2. Freeland AE, Lund PJ. Metacarpal and phalangeal fractures. In: Russell RC (ed.) Plastic Surgery: Indications, Operations and Outcomes. (Vol. 4 - Hand Surgery). Toronto, Mosby; 2000:1845-1864.
3. Purdy BA, Wilson RL. Management of nonarticular fractures of the hand. In: Mackin EJ, Callahan AD, Skirven TM, Schneider LH, Osterman AL (Eds.) Rehabilitation of the Hand and Upper Extremity (5th Edition). St. Louis: C.V. Mosby, 2002:382-395.
4. Stern PJ. Fractures of the metacarpals and phalanges. In: Green DP, (ed). Operative Hand Surgery (3rd ed). New York: Churchill Livingstone Inc. 1993:695-758.
5. Ip WY, Ng KH, Chow SP. A prospective study of 924 digital fractures of the hand. Injury 1996; 27(4): 279-285.
6. Colditz JC. Functional fracture bracing. In: Mackin EJ, Callahan AD, Skirven TM, Schneider LH, Osterman AL (Eds.) Rehabilitation of the Hand and Upper Extremity (5th Edition). St. Louis: C.V. Mosby, 2002:1875-1886.
7. Ashhurst DE. The influence of mechanical conditions on the healing of experimental fractures in the rabbit: a microscopical study. 1986; Phil Trans R Soc Lond 313(B):271-302.
8. Carter DR, Beaupre GS, Giori NJ, Helms JA. Mechanobiology of skeletal regeneration. . Clinical Orthop Related Research 1998; 355S:41-55.
9. Chao EYS, Inoue N, Elias JJ, Aro H. Enhancement of fracture healing by mechanical and surgical intervention. Clinical Orthop Related Research 1998; 355S:163-178.
10. Claes JE, Heigele CA. Magnitudes of local stress and strain along bony surfaces predict the course and type of fracture healing. J Biomech 1999; 32(2): 255-266.
11. Goodship AE, Cunningham JL, Kenwright J. Strain rate and timing of stimulation in mechanical modulation of fracture healing. Clinical Orthop Related Research 1998; 355S:105-115.
12. Park SH, O'Conner K, McKellop H, Sarmiento A. The influence of active shear or compressive motion fracture healing. J Bone Jt Surg 1998; 80(6): 868-878.
13. Panjabi MM, White AA, Wolf JW. A biomechanical comparison of the effects of constant and cyclic compression on fracture healing I rabbit long bones. Acta Orthp Scand. 1979; 50:653-661.
14. Sarmiento A, Schaeffer JF, Beckerman L, Latta LL, Enis JE. Fracture healing in rat femora as

affeacted by functional weight-bearing. J Bone Jt Surg 1977;59A:107-113.

15. Cry LM, Ross RG. How controlled stress affects healing tissues. J Hand Ther. 1998; 11(2): 125 – 130.
16. Slade JF, Chou KH. Bony Tissue Repair. J Hand Ther 1998; 11(2): 118 – 124.
17. McClure P. Critical literature reviews. J Hand Ther 2001; 14:53.
18. Mulrow C, Cook D (eds). Systematic Reviews: Synthesis of best evidence for health care decisions. Philadelphia (PA); American College of Physicians. 1998.
19. Ebinger T, Erhard N, Kinzl L, Mentzel M. Dynamic treatment of displaced proximal phalangeal fractures. J Hand Surg 1999; 24A:1254-1262.
20. Gonzalez MH, Hall RF. Intramedullary fixation of metacarpal and proximal phalangeal fractures of the hand. Clinical Orthop 1996; 327: 47 – 54.
21. Hansen PB, Hansen TB. The treatment of fractures of the ring and little metacarpal necks: A prospective randomized study of three different types of treatment. J Hand Surg 1998; 23B 2: 245 – 247.
22. Motta, P., Mariotti, U., and Cettina, R. [Brace for orthopaedic treatment of fifth metacarpal fractures] Ortesi per il trattamento incruento dell fratture del v metacarpo. Minerva Ortop Traumatol 1994; 45[5], 179-185.
23. Kuokkanen HO, Mulari-Keranen SK, Niskanen RO, Haapala JK. Treatment of subcapitate fractures of the fifth metacarpal bone: prospective randomized comparison between functional treatment and reposition and splinting. Scand J Plast Reconstr Surg Hand Surg 1999; 33:315-317.
24. Wright TA. Early mobilization in fractures of the metacarpals and phalanges. Can J Surg. 1968; 11:491-498.
25. James JIP. Fractures of the proximal and middle phalanges of the fingers. Acta Orthop Scand 1962; 32: 401- 410.
26. Tubiana R. Early mobilization of fractures of the metacarpals and phalanges. Ann Chir Main 1983; 2(4): 293-297.
27. Barton NJ. Fractures of the hand. J Bone Jt Surg. 1984; 66B: 159-167.
28. Strickland JW, Steichen JB, Kleinman WB. Phalangeal fractures: factors influencing performance. Orthop Rev. 1982; 1: 39-50.
29. Feehan LM, Hardy MA. Therapeutic Management of Hand Trauma In: Russell RC (ed.) Plastic Surgery: Indications, Operations and Outcomes. (Vol. 4 - Hand Surgery). Toronto, Mosby; 2000: 1705-1733.

30. Ferraro MC, Coppola A, Kippman K, Hurst LC. Closed functional bracing of metacarpal fractures. Orthop Rev. 1983; 12(8):49-56.
31. Thomine JM, Gibon Y, Benjjeddou MS, Biga N. Functional brace in the treatment of diaphyseal fractures of the proximal phalanges of the last four fingers. Ann Chir Main 1983; 2:298-306.
32. Sarmiento A, Latta LL. Functional fracture bracing. J Am Acad Orthop Surg 1999; 7(1): 66-77.
33. Latta LL, Sarimento A, Tarr RR. The rationale of functional bracing of fractures. Clin Orthop Rel Res 1980; 146:28-36.
34. World Health Organization.ICIDH-2 International classification of functioning, disability and Health. Geneva: 2001 (www.who.int/icidh/)

CHAPTER 3: SYSTEMATIC REVIEW OF THE LITERATURE*

3.1 RESEARCH QUESTION ADDRESSED IN THIS CHAPTER

Is there scientifically validated clinical evidence for early mobilization following an extra-articular hand fracture?

3.2 INTRODUCTION

A systematic review and critical appraisal provides an unbiased and comprehensive synthesis of the best available scientific evidence related to a clinical issue of interest.[1-3] Findings from systematic reviews provide clinicians with an opportunity to examine this clinical evidence and its potential utility in the management of their own patients.[4,5]. Evidence-based practice decisions are traditionally based on scientifically validated evidence obtained from either high quality systematic reviews / meta-analysis of all randomized clinical trials (RCTs) [Level I evidence] or from one or more high quality RCTs [Level II evidence] [6,7] Evidence obtained from a synthesis of poor quality RCTs (Quasi-randomized Clinical Trials – Q-RCTs) or a prospective non-randomized controlled trials (Controlled Clinical Trial – CCTs) [Level III evidence] help to clarify future research directions.[6,7] (See Figure 3-1.)

As noted in Chapter 2, early active motion is generally considered an appropriate management option for extra-articular hand fractures in two clinical situations.[8] The first is when internal or external fixation hardware provides enough 'structural stability' for the fracture to withstand early motion. [9-11] The second is when the fracture presents with an inherently stable fracture configuration (eg: in non-displaced, simple, closed fractures). [12-17] The assumption being that early motion has the potential to improve healing and functional outcomes. [8] Conversely, early mobilization programs are generally not recommended for extra-articular hand fractures that present with inherently unstable fracture configurations (eg: displaced spiral, oblique, comminuted fractures) or in instances when the fracture has been managed with some form of less structurally rigid internal or external hardware fixation. [8-11] In these clinical situations the assumption is that 'too much stress' may have a negative impact on healing outcomes. [8]

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* An earlier version of this chapter has been published. Feehan LM, Basset K. Is there evidence for early motion following an extra-articular hand fracture? J Hand Ther 2004; 17(2): 300-308. This publication was also peer reviewed and published on-line as a DARE structured abstract. http://nhscrd.york.ac.uk/online/dare/20049807.htm (See Appendix 3-1). This chapter contains an updated literature review.

Clinically, it remains unclear when earlier mobilization of the affected hand can be considered safe (causing no harm) or necessary (providing clinically meaningful functional benefit) following an extra-articular hand fracture. [8] The intent of this study was to conduct a systematic review and critical appraisal of the clinical literature to establish if there is scientifically valid evidence (level I or II evidence) related to the effect of early motion on fracture healing or functional status following an extra-articular hand fracture.[6,7] The specific research question was: Does the introduction of early (< 21 days) motion of joints adjacent to a fracture affect fracture healing and functional outcomes in people with extra-articular metacarpal or phalangeal fractures compared with people treated with post-fracture immobilization?

3.3 METHODS

3.3.1 Study Inclusion Criteria

Study Design: The study had to be a prospective controlled (CCT), quasi-randomized controlled (Q-RCT) or randomized controlled (RCT) clinical trial.

Intervention of Interest: The trial had to compare complete post-fracture immobilization of both joints proximal and distal to the fracture, to motion of one or both joints adjacent to the fracture. Joint motion had to be initiated in the first 21 days post-fracture or reduction. Additional interventions were allowed as long as both groups received the same co-intervention(s) (eg: medications, strengthening exercises).

Study Participants: Participants could be of any age or gender presenting with an open or closed extra-articular hand fracture(s) in any digit. Fractures managed with any form of reduction and / or additional hardware fracture fixation was allowed. Excluded were studies (subgroups) with intra-articular metacarpal or phalangeal fractures. Also excluded were studies (subgroups) with associated regional soft-tissue trauma that would require an additional surgical intervention (eg: tendon, nerve, artery, significant skin loss).

Health Outcomes of Interest: The health outcomes of interest were determined apriori, and were sub-grouped into either a 'Healing status' or 'Functional Status' measure. The primary and secondary health outcomes of interest are outlined in Table 3-1.

3.3.2 Search Strategy

Medical bibliographic databases were searched via a Basic Index DIALOG search of MEDLINE; EMBASE; Biosis Previews(R); SciSearch(R). Occupational medicine databases were searched in OSH-ROM. In addition, a comprehensive fugitive literature search was undertaken to identify materials published in in-house and commercial databases, as well as, unpublished materials found in conference proceedings,

theses, and clinical trials in progress. There was no specific language or date limit for any search. (See Tables 3-2 and 3-3 for further details of the search strategy and sources searched)

3.3.3 Study Selection

Two independent reviewers, one content expert (LF) and one methodology expert (KB) conducted this systematic review. One or both reviewers screened all titles and references retrieved in any search strategy. Any unique study title or reference identified by either reviewer as possibly meeting the inclusion criteria went on for a formal review of the abstract. Both reviewers then independently assessed all abstracts to define which articles should be retrieved for further review. Finally, both reviewers independently reviewed all retrieved articles using a standardized to determine if the articles met the specific inclusion criteria. [18,19] Reviewers resolved any disagreement by consensus.

3.3.4 Methodological Quality and Validity Assessment

Both reviewers independently evaluated the methodological quality of all included studies using a standardized and pre-tested form with pre-defined operational criteria for rating. (See Appendix 3-2) The methodological quality assessment form was modified from previously published sources. [18,19] Eighteen items within five domains of interest (Patient Selection, Interventions, Protocol Violations, Outcome Evaluation, and Analysis) were evaluated. Any disagreement between reviewers in the rating of any item was discussed and resolved by consensus decision. An 'overall quality assessment score' (OQA) and an 'internal validity' (IVS) percentage score was determined. [18,19] A score of 70% or higher was needed to achieve a good rating.

3.3.5 Data Extraction

One reviewer (LF) extracted 'Study Characteristic' and 'Health Outcome' data using standardized forms. The second reviewer (KB) checked all extracted data for accuracy.

3.4 RESULTS

3.4.1 Trial Flow

Approximately 1000 clinical trial study titles or references related to extra-articular hand fractures were screened. A total of 344 abstracts were formally reviewed. The total number of abstracts excluded at this stage was 334 (Kappa = .769; Substantial Agreement for selection). [20] Ten abstracts were selected for retrieval and review of the full text. An additional four studies were excluded at this stage (Kappa = 1.0;

Complete Agreement for inclusion / exclusion). Six studies met the inclusion criteria for this systematic review.

3.4.2 Excluded Studies

Both reviewers agreed to exclude 330 studies based only on the abstract review. Four additional abstracts (Hurov, 1999; Randall 1992; Stassen 1994; Trabelis, 2001) were excluded following reviewer discussion. [21-24] Both reviewers also agreed to exclude an additional four studies (Harding, 2001; Jones, 1995; Motta, 1994; Viegas, 1987) following the review of the full text. [25-28] The two primary reasons for exclusion at any level were inadequate study design (eg: case reports or series, uncontrolled studies) or the reported outcomes were not specifically described for the sub-group of extra-articular hand fractures.

3.4.3 Study and Fracture Characteristics

See Table 3-4 for further details regarding the study characteristics; including study design, comparisons made, sample sizes and patient demographics, as well as further details regarding the included fracture characteristics. Six studies met the minimum inclusion criteria for this systematic review of the literature. [Braakman,1998(n=50); Hansen,1998 (n=105); Konradsen,1990 (n=100); Kuokkanen,1999 (n=29); McMahon, 1994 (n=42); Sorenson,1993 (n=133)]. [29-34] The included studies reported on health and functional outcomes in a total of 459 patients (numbers included in the study ranged from 29 to 133 patients) all with simple, closed, metacarpal fractures occurring in the second through fifth digits. The included fractures were managed with or without a closed reduction. The age range potentially included in all the studies was 10 to 80 years old. Of the four studies reporting mean-age (Braakman, 1998; Konradsen, 1990; Kuokkanen, 1999; McMahon 1994), the mean-age ranged from 22 to 31 years old. In the three studies reporting gender (Braakman, 1998; Kuokkanen, 1999; Sorenson, 1993) the percentage of men ranged from 84 – 90%

All six studies were published in English in peer-reviewed journals from 1990 to 1999. All were single center studies. Five of the studies were conducted in a Scandinavian country and one was conducted in the United Kingdom. All six studies compared traditional plaster cast immobilization [including the forearm, wrist, carpal-metacarpal (CMC), metacarpal-phalangeal (MCP) + / - the inter-phalangeal (IP) joints] to some form of early unrestricted active motion of one or both joints immediately adjacent to the healing metacarpal fracture (CMC and / or MCP). The duration of immobilization ranged from two weeks in one study (McMahon, 1994), to three weeks in another study (Konradsen, 1990) to four weeks in the remaining four studies (Braakman, 1998; Hansen, 1998; Kuokkanen, 1999; Sorenson, 1993).

Three of the studies (Braakman, 1998; Kuokkanen, 1999; McMahon, 1994) compared cast immobilization to some form of non-restrictive external support (taping, compression glove or compression bandage) that allowed full, unrestricted motion in all joints in the affected hand. Two studies (Konradsen, 1990; Sorenson, 1993) compared cast immobilization to some form of functional fracture brace that potentially restricted motion in the affected digit CMC joint, but allowed for full, unrestricted motion of the affected digit MCP joint. Hansen (1998), compared cast immobilization to two different early motion options: compression bandaging and functional fracture bracing. Of the three studies that utilized functional fracture-bracing options (Hansen, 1998; Konradsen, 1990; Sorenson, 1993), two utilized materials that allowed the fracture brace to be custom-molded on the affected hand (Hansen, 1998; Konradsen, 1990). Sorenson (1993), utilized a commercially available 3-point pressure metacarpal fracture brace.

No prospective controlled clinical trials were found that involved extra-articular phalangeal fractures. As well no studies were identified that included any extra-articular hand fracture requiring an open reduction and / or additional hardware fracture fixation.

3.4.4 Methodological Analysis

All six were reported as randomized clinical trials (RCTs). However, following review they were re-categorized as quasi-randomized controlled clinical trials (Q-RCT) This was based on pre-established criteria defining 'quasi-randomization' as random treatment allocation that was unclear or inadequate in terms of a showing a truly random treatment allocation in combination with no evidence of adequate concealment of treatment allocation.

All six studies were rated as poor quality. Figure 3-2 outlines the results of the 'Overall Quality' (OQS) and 'Internal Validity' (ICS) scores for the included studies. The mean OQS for all included studies was poor at 10.2 / 18 (56.5%) with a range from 8-12 / 18 (44.4% - 66.7%). The ICS score for all included studies was also poor at 5.8 / 11 (53.0%) with a range from 4-7 / 11 (36.4% - 63.6%).

3.4.5 Health Outcome Date Synthesis

Health outcome data could not be pooled in a quantitative meta-analysis because of the poor methodological quality of the trials, the heterogeneous nature of the early mobilization interventions, the diversity of health outcome reported and the incomplete reporting of outcome data. A qualitative analysis

was completed. See Table 3-4 for further details of the extracted health and functional outcome data. The following is a summary of the key findings.

Primary Healing and Functional Health Outcomes of Interest: No study reported on either a standardized measure of time to clinical or boney union or a score on a standardized hand function test or health related quality of life test instrument.

Secondary Healing Health Outcomes of Interest: Three studies (Konradsen, 1990; Kuokkanen, 1999; Sorenson, 1993) examined change in fracture alignment or 'malunion' over the duration of the study. All three reported no statistically significant change from baseline fracture angulation for any group throughout the study.

Sorenson (1993) reported many more secondary medical problems related to adverse skin reactions in the early motion group that used a commercially available 3-point pressure metacarpal fracture brace. In this group there were fifteen pressure sores and two necrotic areas (17 / 65) as compared to no reported skin problems in the cast group (n=68). Two other studies compared metacarpal fracture braces that were custom molded on the affected hand with cast immobilization (Hansen, 1998; Konradsen, 1990). Both these studies state that there were no pressure sore or necrosis skin problems observed in any subject in any group.

Secondary Functional Health Outcomes of Interest: All six included studies reported on some aspect of the affected digit's mobility as a health outcome measure. However they used different ways to operationalize and report their mobility data, making mobility outcome comparisons between studies difficult. All six studies report statistically better mobility immediately following the period of immobilization in the 'mobilized groups' as compared to the 'immobilized group'. All six studies reported essentially no difference in mobility for any groups at final follow-up (minimum of three months), with all participants achieving full or less than a 10-degree loss of mobility in the affected digit.

Three studies (Braakman, 1998; Konradsen, 1990; Kuokkanen, 1999) report on strength as a functional outcome. All three report a statistically greater grip strength measure in the 'mobilized group' as compared to the 'immobilized group' immediately post-immobilization. Two studies (Konradsen, 1990; Kuokkanen, 1999) report the immobilized groups as having approximately 65% of normal grip strength as compared to

approximately 85% of normal grip strength in the mobilized groups immediately after the period of immobilization. The third study (Braakman, 1998) did not report specific values for grip strength. All three report that all participants had regained at least 90% of normal grip strength at final follow-up (minimum 3 months).

One study (Konradson, 1990) discusses time to return to work as an outcome. In this study time (in days) until return to work was compared between the groups. Each group was subdivided into four different work categories (student, white-collar worker, light-equipment operators, road-construction workers). In all four of the work categories examined the early mobilization (functional brace) group returned to work in a significantly faster time than the immobilized (cast) group. The 'mobilized group' returned to work on average two-thirds faster than the 'immobilized group'. All participants had returned to work by 3 months.

3.5 DISCUSSION

This systematic review examined clinical evidence regarding the impact of early motion interventions on fracture healing and functional status following early mobilization of extra-articular hand fractures. These health outcomes are relevant to two clinical issues. The first relates to whether or not early motion of one or both joints adjacent to a healing extra-articular hand fracture would cause harm to either the quality or rate of fracture healing. The second relates to whether or not early regional joint motion would provide any clinically meaningful functional benefit. Based on these two clinical issues, the primary and secondary health outcomes of interest were defined and critically examined in this review.

Scientifically valid clinical trial evidence in this area remains weak. Our review found no Level I (evidence from high quality systematic review or meta-analysis of RCTs) or Level II (evidence from one or more high quality RCT) evidence related to the effect of early motion interventions on either fracture healing or functional outcomes following any extra-articular hand fracture. [6,7] The most consistent study findings, based on six poor quality, quasi-randomized studies (Level III evidence) [6,7] suggest that early motion following a simple, closed, metacarpal fracture in the second to fifth digit managed without an open reduction and / or additional fracture hardware fixation has the potential to: 1) result in earlier recovery of mobility and strength, 2) facilitate an earlier return to work and 3) not affect fracture alignment. Findings also indicate that skin pressure problems are not associated with custom-molded metacarpal fracture braces.

Our study contrasts to another review article, published in German by Prokop et al (1999), which discusses clinical outcomes following a metacarpal fracture. [35] This article reviewed 16 clinical studies of mixed clinical trial design, included a separate examination of outcomes from three prospective controlled clinical trials involving 163 people comparing cast immobilization to early motion. All three of the studies examined were also included in our systematic review. The authors concluded that early mobilization following a metacarpal fracture would provide good to excellent results (not specifically defined) in 95% of the cases. However, they also caution that there is potential for a high failure rate because of local bruising and necrosis from the use of a metacarpal fracture brace. This caution is based on the findings from the study conducted by Sorenson (1993), in which commercially available non-custom molded 3-point metacarpal fracture brace was used. We also report the high instance of skin pressure related problems found in the Sorenson study. However, our systematic review also included two additional studies that used custom-molded metacarpal fracture braces (Hansen, 1998; Konradsen, 1990). In both these additional studies there were no reports of any skin pressure related problems. These inconsistent findings related to secondary skin pressure problems associated with the use of a metacarpal fracture brace are easily explained by differences in fracture brace design. A fracture brace that is custom-molded to fit directly on the affected hand will provide a more consistent pressure over a larger skin surface area and will be far less likely to cause skin pressure related problems.

Poolman et al, have also submitted a protocol to the Cochrane Collaboration Musculoskeletal Injuries Review group entitled "Conservative treatment for closed fifth (small finger) metacarpal neck fractures in adults." [36] Findings from this review have yet to be published. Our systematic review was much broader including any prospective controlled clinical trial that compared 'early motion' with 'immobilization' following any type of extra-articular hand fracture. Ultimately we only found trials involving closed, metacarpal fractures in the second through fifth digits. It will be of interest to compare the findings and conclusions from these two similar, but independently conducted, systematic reviews. (See Additional Related Comments)

3.6 REVIEWER CONCLUSIONS

There are no well-conducted, randomized controlled clinical trials that study early motion of joints surrounding any extra-articular hand fracture. Therefore, the impact of early motion on either the healing status of the fracture or the functional status of the affected person has not been clearly established. Well-conducted, randomized controlled clinical trials (RCTs) are needed before any definitive conclusions can be

drawn regarding either the efficacy or effectiveness of early motion interventions for any healing extra-articular hand fracture.

3.7 CLINICAL RELEVANCE

Based on the findings from this systematic review, there is currently a lack of scientifically valid clinical evidence (level I or II evidence) to either support or refute the use of early regional joint motion following any extra-articular hand fracture. However, further trials in this area are warranted as findings to date show a consistent potential for benefit with no significant risk of harm when early regional joint motions are incorporated into the management of closed, extra-articular, finger metacarpal fractures. It has not been established if early motion interventions will have similar effects on health outcomes following a closed, extra-articular fracture in a thumb metacarpal or any digital phalangeal bone. Nor has the effect of early motion interventions on health outcomes been established in any extra-articular hand fracture managed with an open reduction and / or additional fracture hardware fixation.

3.8 ADDITIONAL RELATED COMMENTS

Since the publication of a version of this chapter in early 2004, two additional studies have been subsequently published that relate directly to this systematic review. As mentioned above, the Poolman et al Cochrane review (2005) [37] has been completed and published. The stated purpose of this review was to compare functional treatment (early motion) with immobilization and to compare different periods and types of immobilization for the treatment of closed fifth metacarpal fracture in adults. Their review included five studies involving 252 people.

Two of the studies in the Poolman et al [37] review were also included in our review (Braakman 1998 and Kuokkanen 1999). They also included two other studies (n=100, all closed 5th metacarpal neck fractures) that would have met our inclusion criteria. One that was published by Statius Muller et al (2003) [38] [n=40] after the completion of our study and another detailed conference abstract found in the 1999 American Academy of Orthopedic Surgeons conference proceeding by Anand et al (1999) [39] [n=60] that we missed and that is no longer directly accessible on-line. Both of these studies compared cast immobilization to a non-restrictive compression bandage and found faster functional recovery in the fractures managed with early motion. [37-39] As well, they included one study (Harding 2001) that did not meet our inclusion criteria because it did not compare early motion alternatives to immobilization, but rather compared two different early motion alternatives (buddy taped and molded fracture brace). Not surprisingly, given the similarity of their review and this systematic review they came to a similar conclusion. Specifically they concluded that

no studies reported on their primary outcome of interest (a validated measure of hand function), that the included studies were of limited quality and size and that there was heterogeneity between the studies. Therefore, they could not recommend one non-surgical treatment option as superior to another in the treatment of closed fifth metacarpal neck fractures and that further research is definitely warranted.

The subsequent formal inclusion and independent review of the two additional poor quality studies (n=100) that would have met our inclusion criteria is not warranted as it would not change our overall finding that there is currently a lack of scientifically valid clinical evidence (level I or II evidence) to either support or refute the use of early regional joint motion following any extra-articular hand fracture. However, these two additional studies do add further strength to our original statement that further trials in this area are warranted as findings to date (in now 8 independently conducted Q-RCTs) show a consistent potential for benefit with no significant risk of harm when early regional joint motions are incorporated into the management of closed, extra-articular, finger metacarpal fractures.

CHAPTER 3: TABLES

Table 3-1: Primary and Secondary Health Outcomes of Interest

	Fracture Healing Status	Functional Status
Primary	Time to Union – a standardized measure of time to clinical or bony union.	Test Score - Standardized Hand Function Test or Health Related Quality of Life Test Instrument.
Secondary	Mal-union - rotational, angular, shortening. Non-union - > 6 months with no evidence of solid bony union. Secondary Medical Interventions - Repeat closed reduction, analgesic prescription, antibiotic prescription, secondary wound care. Secondary Surgical Interventions - Secondary open reduction, Osteotomy + / - bone graft, Capsulotomy, Tenolysis.	Mobility (hand, fingers, thumb). Functional Strength (grip, pinch). Pain. Swelling. Cosmetic Appearance. Patient Satisfaction. Personal Activities of Daily Living (ADL). Instrumental Activities of Daily Living (IADL). Time to Return to Normal Activity (Work, Sport). Health Care Costs.

Table 3-2: Electronic Databases Searched

Search Strategy	Databases
DIALOG - Basic Index Search (No limit Year / Language)	MEDLINE 1966-2002/JAN; EMBASE 1974-2001/Dec; Biosis Previews(R) 1969-2001/Dec; SciSearch(R) Cited Ref Sci 1990-2001/Dec
OSH-ROM: databases searched	RILOSH; MHIDAS; HSELINE; CISDOC; NIOSHTIC2 .

Table 3-3: Fugitive Literature Sources

Search Strategy	Databases / Sources
In-house database / Directory	Centre for Health Services & Policy Research Library Catalog; HealthCare Standards (ECRI Directory)
Commercial databases	Cochrane Library; LILAC Database; PEDro Database; HSRProj (NLM); Dissertation Abstracts; HTA Database; National Research Register; Current Controlled Trials, metaRegister; TRIP database
Web library catalogues	AMICUS (National Library of Canada); Australian National Library Catalog; British National Library; National Library of Medicine LocatorPlus; CISTI Library Catalog
Expert and Trialist (e-mail and / or fax contact)	Clinician (surgeon and therapist) experts in the area of fracture management. Corresponding authors for registered clinical trials identified as potentially related to this review.
Internet peer-reviewed sites	OMNI, Medical Matrix
Internet search engines	Google, Alta Vista
Hand Search (1990 – 2001)	Reference List review – Related Hand Therapy and Surgery: Clinical Articles / Chapter / Narrative reviews; Conference Proceedings (AAHS, ASSH, ASHT, IFSHT)
In-house database / Directory	Centre for Health Services & Policy Research Library Catalog; HealthCare Standards (ECRI Directory)

Table 3-4: Detailed Summary of Study and Fracture Characteristics and Reported Health / Functional Outcomes

STUDY CHARACTERISTICS	FRACTURE CHARACTERISTICS	REPORTED HEALTH OUTCOMES
Kuokkanen (1999) **Design:** Q-RCT **Comparison:** Plaster Cast Vs. Elastic Compression Bandage **Immobilization Duration:** 4wks **Enrolled:** N = 29 (14 / cast; 15 / elastic compression) **Completed:** 29 @ 4wks & 3 mths (100%) **Ages:** 11-68 (mean 29) **Males:** 26 (90%); **Females:** 3 (10%)	**MC (subcap):** 100%, *D5:* 100% **Fractures Included:** Single, closed, < 70 degrees, no lateral or rotational deformity **No Reduction:** 48% (all elastic) **Closed Reduction:** 52% (all cast) **Baseline Alignment:** Elastic (48^0) > cast (35^0) P<0.02.	**Time to union:** no difference @ *4 wk and 3 mths.* **Mal-union:** No change either group over time (0 – 3 weeks). **Mobility:** (MCP and PIP joints). ***@ 4 wks:*** Elastic > Cast group. *MCP:* Elastic 81^0 (45-90) > Cast 57^0 (10-100). P = 0.02; *PIP:* Elastic 95^0 (85-105) > Cast 85^0 (65-100). P = 0.02 ***@ 3 mths:*** No difference. All ~ 100%. **Strength:** Grip dynamometer (% - affected / healthy side). ***@ 4 wks:*** Elastic (84%) > Cast (62%). P= 0.002; ***@ 3 mths:*** No difference. All > 90%.
Braakman (1998): **Design:** Q-RCT **Comparison:** Ulnar Gutter Cast Vs. Taping (buddy taped fingers / tape strapping around hand) **Immobilization Duration:** 4wks **Enrolled:** N = 50 (25 / 2 groups) **Completed:** 48 (96%) @ 6 mths. **Ages:** 14-44 (mean 26). **Males:** 43 (90%); **Females:** 5 (10%)	**MC:** 100% Location not reported. **D5:**100% **Fractures Included:** closed, single, <4 fragments. **No Reduction:** 44 (92%) **Closed Reduction:** 4 (8%) **Baseline Alignment:** Same	**Mobility:** (Deficit - composite digital motion) ***@ 1wk:*** *Extension deficit,* cast (12.5^0) > tape (2.7^0); P<0.0002; ***@ 4 wk:*** *Extension deficit,* cast (8.2^0) > tape (0^0) P< 0.009; ***@ 3mths and 6 mths:*** No difference. (3mth ~ 80%; 6 mths ~100%). **Strength:** *(Six strength measures – data points not reported)* ***@ 1wk:*** All (except pronation torque). Tape > cast. P< 0.01; ***@ 4 wks:*** All. Tape > cast. P < 0 .002; ***@ 3mths and 6 mths:*** No difference. All ~ 80% @ 3-mths and ~100% @ 6-mths.

Table 3-4: Detailed Summary of Study and Fracture Characteristics and Reported Health / Functional Outcomes (con't)

Hansen (1998): **Design:** Q-RCT **Comparison(s):** Ulnar Gutter Cast Vs. Elastic Compression Bandage Vs. Semi-Rigid Custom-molded Fracture Brace **Immobilization Duration:** 4wks **Enrolled:** N = 105 (35 / 3 groups) **Completed:** 85 @ 4wks (81%); 79 @ 3 mths (75%) **Ages / Sex:** Not reported	**MC (neck):** 100% **D4 and D5:** proportion not reported. **Fractures Included:** closed, single, <60 degrees. **No Reduction:** 100% **Baseline Alignment:** not reported	**Mobility:** (Mean loss MCP joint motion) ***@ 4wks:*** Cast (20^0), > Elastic (10^0) > Brace (0^0) P< 0.05. ***@ 3 mths:*** Elastic (10^0) > Cast (0^0) = Brace(0^0). P <0.05 **Pain:** VAS (0-10). ***@ 4 wks:*** Elastic (2.7) > Brace (1.8) and Cast (1.5). P < 0.05; ***@ 3 mths:*** Not measured. **Fracture Tenderness:** (0-3). ***@ 4 wks:*** No difference; ***@ 3 mths:*** Not measured. **Patient Satisfaction:** ***@ 4 wks:*** Not measured; ***@ 3 mths:*** 92-98% all three groups either Satisfied or Fully Satisfied.
McMahon (1994) **Design:** Q-RCT **Comparison:** Plaster Slab Vs. Snug-fitting Compression Glove **Immobilization Duration:** within week 2 (mean 9 days, range 6-13 days) **Enrolled:** N = 42 (21 / 2 groups) **Completed:** 42 @ 2, 3, & 4 wks: (100%) **Ages:** 18-80 (mean 27 / cast; 35 / elastic compression) **Sex:** Not reported	**MC (shaft):** 100% *D2-5:* proportion not reported **Fractures Included:** Single, closed, stable (<50% displacement, < 40 degrees). **No Reduction:** 100% **Baseline Alignment:** not reported	**Mobility:** (Deficit - compared to norm of 270^0) Clinical significance = 30^0 difference between groups ***@ week 2:*** 28^0 difference (95% CI 10-46 difference) Cast > Elastic. P = 0.0036; ***@ week 3:*** 23^0 difference (95% CI 10-35 difference) Cast > Elastic. P = 0.001; ***@ week 4:*** 8^0 difference (95% CI –3-20) Cast > Elastic. Significance not reported **Swelling:** (PIP circumference and Hand Volume) ***@ week 2:*** *PIP circumference:* 2.3 mm difference (95% CI 0.5 – 4.1). Cast > elastic. P = 0.019; *Hand Volume:* 23 ml difference. (95% CI 3-43). Cast > Elastic P = 0.029 ***@ week 3:*** No difference.; ***@ week 4:*** No difference.

Table 3-4: Detailed Summary of Study and Fracture Characteristics and Reported Health / Functional Outcomes (con't)

Sorenson (1993) **Design: Q-RCT** **Comparison:** Plaster Cast Vs. Commercial 3-point Metacarpal Fracture Brace. **Immobilization Duration:** 4wks **Enrolled:** N = 133 (68 / cast; 65 / brace) **Completed:** 82 @ 4wks & 3 mths (62%). **Ages:** 10-20 = 40%; 21-30 = 26% ; > 31 = 36% (mean not reported). **Males:** 112 (84%); **Females:** 21 (16%)	**MC:** (n=140) 100% 8% - base; 43% -shaft; 49% - neck / head D2 - 10% ; D3 - 11%; D4 - 28%; D5 - 51% **Fractures Included:** Single and multiple, closed. **No Reduction:** 83% overall (69% brace, 93% cast) **Closed Reduction:** 17% overall (31% brace, 7% cast) **Baseline Alignment:** Brace 21° (range 0-60) > Cast 11° (range 0-45). P < 0.05	**Mobility:** (% of group with deficit - data points or ranges not reported). **@ *4 wks:*** 4% Brace Vs 31% Cast had reduced mobility. P < 0.01; **@ *3mths:*** No difference, all ~ 100% **Patient Satisfaction:** **@ *4 wks:*** Not reported; **@ *3 mths:*** No difference. 72 - 89% satisfied or very satisfied. **Drop-outs (Excluded from analysis) :** *Total Drop-outs:* Brace 38 / 65 (58%) > Cast 13 / 68 (19%). P < 0.01; *Subgroup – Skin Pressure Problems:* Brace 17 / 65 (26%) > Cast 0 / 68 (0%). Significance not reported *Subgroup – other drop-outs (non-compliance, secondary surgical, poor fit):* Brace 21 / 65 (32%) Vs. Cast 13 / 68 (19%) Significance not reported.
Konradsen (1990) **Design:** Q-RCT **Comparison:** Immobilization Cast Vs. Plaster Fracture Brace (molded around hand / metacarpals)	**MC (shaft or neck):** 100% D2: 8%; D3: 10%; D4: 22%; D5: 60% **Fractures Included:** Single, closed **No Reduction:** 23%	**Malunion:** No change either group over time (0 – 3 weeks). **Mobility:** Mean loss - Wrist, MCP and PIP joints. **@ *3wks:*** All joints - Cast > Brace.(P< 0.05). *Wrist:* Cast 56% with mean loss of 25° > Brace 8% with mean loss of 10°; *MCP:* Cast 48% with mean loss of 20° > Brace 28%

Table 3-4: Detailed Summary of Study and Fracture Characteristics and Reported Health / Functional Outcomes (con't)

Immobilization Duration: 3wks **Enrolled:** N = 100 (50 / 2 groups) **Completed:** 100 @ 3 wks (100%) 93 @ 3 mths (93%) **Ages:** 12-22 (mean 22) **Sex:** Not reported	**Closed Reduction:** 77% **Baseline Alignment:** Cast (27º) > Brace (18º). P<0.01.	with mean loss of 20º; *PIP:* Cast 32% with mean loss of 10º > Brace 4% with mean loss of 10º ***@ 3mths:*** Significance not reported. *Wrist and PIP*: both groups full mobility; *MCP*: Cast 10% with mean loss of 10º > Brace 0 % with loss of mobility. **Strength:** % of contra-lateral side. ***@ 3wks:*** Cast (66%) < Brace (81%). (P <0.01). ***@ 3mths:*** No difference, all ~ 100%. **Time to RTW:** Mean days until return to workplace (student, white-collar, light-equipment, heavy-construction). ***Results:*** Brace < Cast (P <0.05) All four work categories, brace returned to work ~2/3 faster. *Student:* 1 (1-3) < 7 (1-21) days. *White Collar:* 7 (1-10) < 21 (14-27) days. *Light- equipment:* 10 (1-28) < 24 (21-30) days. *Heavy – construction:* 8 (7-21) < 21 (10-27) days. **Cosmetic Appearance:** Cast (36%) > Brace (12%) report poor cosmetic appearance. Significance not reported.

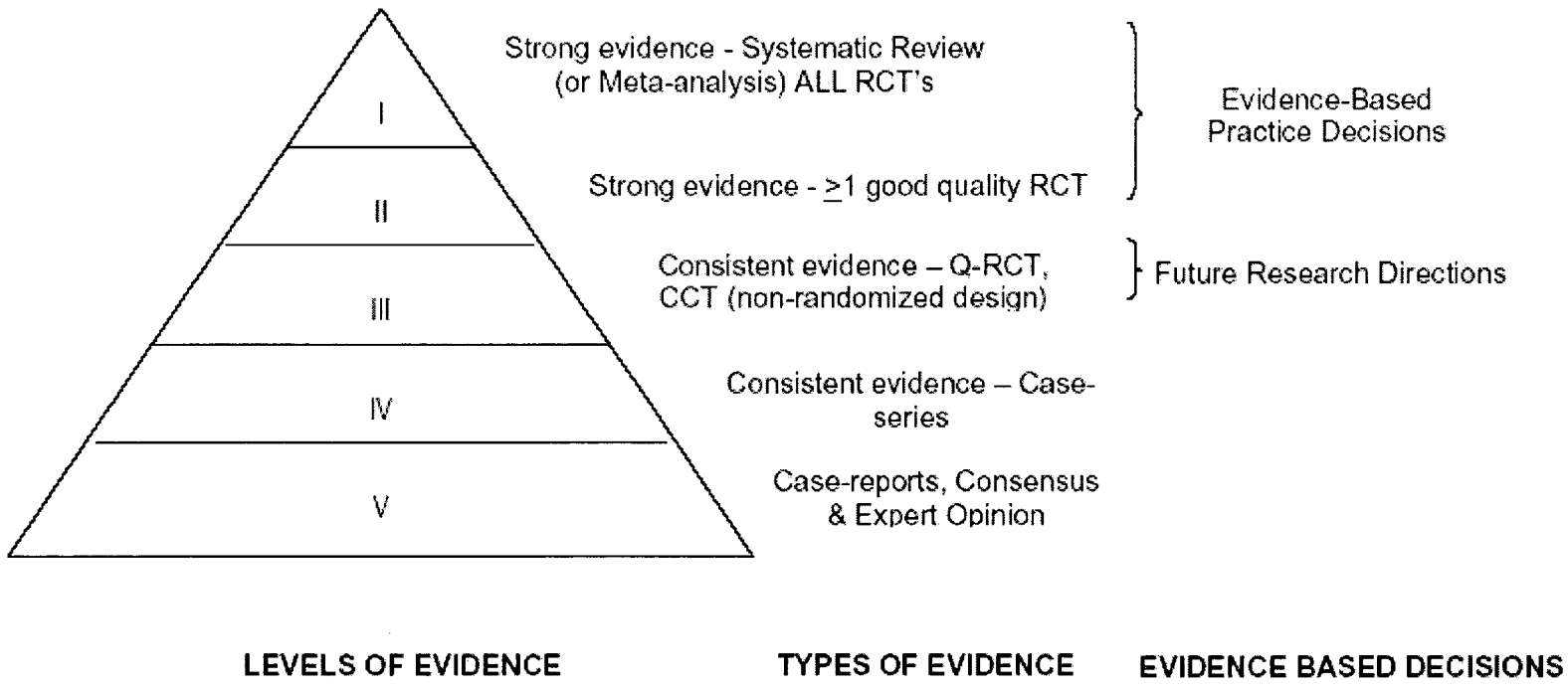

Figure 3-1: Levels and Types of Clinical Evidence: Evidence-based practice decisions are generally based on scientifically validated evidence derived from Level I or Level II clinical evidence. Level III evidence provides direction for future research [6,7]

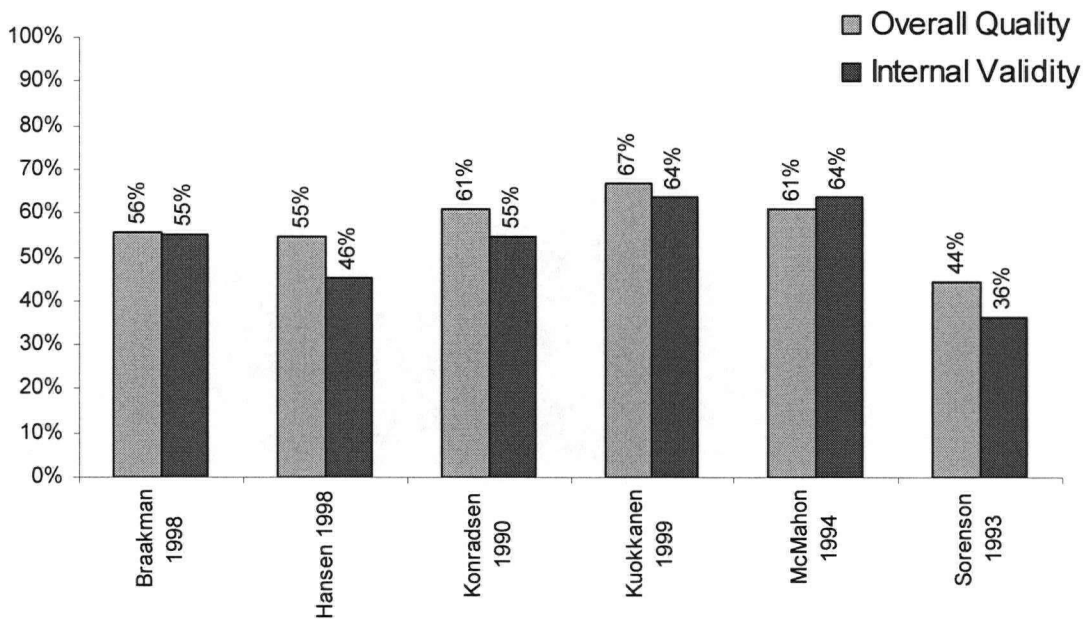

Figure 3-2: Overall Methodological Quality And Internal Validity Scores As Determined By An Evaluation Of 18 Study Design Items Within 5 Domains Of Interest (Patient Selection, Interventions, Protocol Violations, Outcome Evaluation And Analysis). Overall quality was based on all 18 items, whereas, internal validity was based on 11 of the 18 items. [18,19]

CHAPTER 3: REFERENCES

1. McClure P. Critical literature reviews. J Hand Ther 2001; 14:53.
2. Mulrow C, Cook D (eds). Systematic Reviews: Synthesis of best evidence for health care decisions. Philadelphia (PA); American College of Physicians. 1998.
3. Slavin RE. Best evidence synthesis: an intelligent alternative to meta-analysis. J Clin Epidemiol 1995;48(1):9-18.
4. Moher D, Cook DJ, Eastwood S, Olkin L, Rennie D, Stroup DF. Improving the quality of reports of meta-analyses of randomized controlled trials: the QUOROM statement. Lancet. 1999 Nov 27;354(9193):1896-900.
5. Sackett D. Rules of evidence and clinical recommendations on the use of antithrombotic agents. Chest. 1989; 95:2S-3S
6. Van Tulder MW, Koes BW, Bouter LM. Conservative treatment of acute and chronic nonspecific low back pain: a systematic review of randomized controlled trials of the most common interventions. Spine 1997; 22:2128-2156.
7. National Health and Medical Research Council (NHMRC) How to Use the Evidence: Assessment and Application of Scientific Evidence. AusInfo, Canberra, 2000.
8. Feehan, LM. Early controlled mobilization of potentially unstable extra-articular hand fractures. J Hand Therapy 2003; 16(2):161-170.
9. Freeland AE, Lund PJ. Metacarpal and phalangeal fractures. In: Russell RC (ed.) Plastic Surgery: Indications, Operations and Outcomes. (Vol. 4 - Hand Surgery). Toronto, Mosby; 2000:1845-1864.
10. Purdy BA, Wilson RL. Management of nonarticular fractures of the hand. In: Mackin EJ, Callahan AD, Skirven TM, Schneider LH, Osterman AL (Eds.) Rehabilitation of the Hand and Upper Extremity (5th Edition). St. Louis: C.V. Mosby, 2002:382-395.
11. Stern PJ. Fractures of the metacarpals and phalanges. In: Green DP, (ed). Operative Hand Surgery (3rd ed). New York: Churchill Livingstone Inc. 1993:695-758.
12. Ferraro MC, Coppola A, Kippman K, Hurst LC. Closed functional bracing of metacarpal fractures. Orthop Rev. 1983; 12(8):49-56.
13. Thomine JM, Gibon Y, Benjjeddou MS, Biga N. Functional brace in the treatment of diaphyseal fractures of the proximal phalanges of the last four fingers. Ann Chir Main 1983; 2:298-306.
14. Reyes FA, Latta LL. Conservative management of difficult phalangeal fractures. Clin Orthop Rel Res 1987; 214:23-30.
15. Burkhalter WE. Closed treatment of hand fractures. J Hand Surg. 1989; 14A: 390-393.

16. Ip WY, Ng KH, Chow SP. A prospective study of 924 digital fractures of the hand. Injury 1996; 27(4): 279-285.
17. Ebinger T, Erhard N, Kinzl L, Mentzel M. Dynamic treatment of displaced proximal phalangeal fractures. J Hand Surg. 1999; 24A:1254-1262.
18. Verhagen AR, de Vet HCW, de Bie RA, Kessels AGH, Boers M, Bouter LM, Knipschild PG. The delphi list: a criteria list for quality assessment of randomized clinical trials for conducting systematic reviews developed by the delphi consensus. J Clin Epidemiol 1998;51(12):1235-1241.
19. van Tulder MW, Assendelft WJJ, Koes BW, Bouter LM. Method guidelines for systematic reviews in the Cochrane collaboration back review group for spinal disorders. Spine. 1997;22(20):2322-2330.
20. Ker M. Issues in the use of kappa. Invest Radiol 1991;26:78-83.
21. Hurov JR, Concannon MJ. Management of a metacarpophalangeal joint fracture using a dynamic traction splint and early motion. J Hand Thera 1999;12(3):219-227.
22. Randall T, Portney L, Harris BA. Effects of joint mobilization on joint stiffness and active motion of the metacarpal-phalangeal joint. J Orthop Sports Phys Ther 1992;16(10):30-36.
23. Stassen LP, Logghe R, van Riet YE, van der Werken C. Dynamic circle traction for severely comminuted intra-articular finger fractures. Injury 1994;25(3): 159-163.
24. Trabelsi A, Dusserre F, Asencio G, Bertin R. Traitement orthopedique des fractures du col du cinquieme metacarpien: etude prospective. [Conservative treatment for the fracture of the fifth metacarpal neck: a prospective analysis.] Cirugie de la Main 2001; 20: 226-230.
25. Harding IJ, Parry D, Barrington RL. The use of a molded metacarpal brace versus neighbor strapping for fractures of the little finger metacarpal neck. J Hand Surg 2001;26[3], 261-263.
26. Jones AR. Reduction of angulated metacarpal fractures with a custom fracture-brace. J South Orthop Assoc 1995;(4): 269-76.
27. Motta P, Mariotti, U, Cettina, R. [Brace for orthopaedic treatment of fifth metacarpal fractures] Ortesi per il trattamento incruento dell fratture del v metacarpo. Minerva Ortop Traumatol 1994;45[5], 179-185.
28. Viegas SF, Tencer A, et al . Functional bracing of fractures of the second through fifth metacarpals. J Hand Surg 1987; 12A: 139-143.
29. Braakman M, Oderwald EE, Haentjens MHHJ. Functional taping of fractures of the 5th metacarpal results in a quicker recovery. Injury 1998;29(1): 5-9.
30. Hansen PB, Hansen TB. The treatment of fractures of the ring and little metacarpal necks: A prospective randomized study of three different types of treatment. J Hand Surg 1998;23B: 245-247

31. Konradsen L, Nielson PT, Albrecht-Beste E. Functional treatment of metacarpal fractures. 100 randomized cases with or without fixation. Act Ortho Scand 1990;61:531-534.
32. Kuokkanen HO, Mulari-Keranen SK, Niskanen RO, Haapala JK. Treatment of subcapitate fractures of the fifth metacarpal bone: prospective randomized comparison between functional treatment and reposition and splinting. Scand J Plast Reconstr Surg Hand Surg 1999;33:315-317.
33. McMahon PJ, woods DA, Burge PD. Initial treatment of closed metacarpal fractures. A controlled comparison of compression glove and splintage. J Hand Surg. 1994;19B:597-600.
34. Sorensen JS, Freund KG, Kejla G. Functional fracture bracing in metacarpal fractures: The Galveston metacarpal brace versus a plaster-of-paris bandage in a prospective study. J Hand Ther 1993;6:263-265.
35. Prokop A, Kulus S, Helling HJ, Burger C, Rehm KE. [Are there guidelines for treatment of metacarpal fractures? Personal results and literature analysis of the last 12 years] [Article in German] Unfallchirurg 1999;102(1): 50- 58.
36. Poolman R, Goslings C, Morton L, Statius Muller M, Steller F. Conservative treatment for closed fifth (small finger) metacarpal neck fractures in adults (Protocol for a Cochrane Review). In: *The Cochrane Library,* Issue 3, 2002. Oxford: Update Software.
37. Poolman R, Goslings C, Morton L, Statius Muller M, Steller F. Conservative treatment for closed fifth (small finger) metacarpal neck fractures in adults Cochrane Database Syst Rev. 2005; 20(3):CD003210
38. Statius Muller MG, Poolman RW, van Hoogstraten MJ, Steller EP. Immediate mobilization gives good results in boxer's fractures with volar angulation up to 70 degrees: a prospective randomized trial comparing immediate mobilization with cast immobilization. Arch Orthop Trauma Surg. 2003;123(10):534-537.
39. Anand N, Tannoury TY, Mey S, Weinstein RN. Boxer's fracture: a prospective randomized study comparing immediate mobilization to immobilization [abstract]. Conference Proceedings: *American Academy of Orthopaedic Surgeons Annual Meeting; 1999 Feb 4-8; Anaheim (CA)* [no longer accessible on-line]

CHAPTER 4: INCIDENCE AND DEMOGRAPHICS OF HAND FRACTURES IN BC: A BC LINKED HEALTH DATASET INQUIRY*

4.4 RESEARCH QUESTION ADDRESSED IN THIS CHAPTER

Who is at risk for sustaining a hand fracture in BC?

4.5 INTRODUCTION

Next to forearm fractures, fractures in the hand are the second most common fracture, accounting for up to 20% of all fractures.[1,2] There are many studies that discuss hand metacarpal and phalangeal fracture incidence and demographics.[1-24] However, the numbers presented for hand fracture incidence and demographics vary markedly. The reason for this variability is that none of these studies is a true population based epidemiologic study that specifically examines all instances of a hand fracture occurring within a whole population. Such a study would include hand fractures of all ages, treated in any medical setting, by any medical professional, within a large geographic area of diverse climactic and socio-economic regions.

The objective of this study was to identify population based hand fracture incidence rates and demographics from all occurrences of residents seeking treatment for a hand metacarpal or phalangeal fracture during the five year time period from May 1, 1996 to April 30, 2001 in British Columbia (BC), Canada. Our specific research goals were to identify: 1) the number of hand fractures occurring each year, 2) the age and gender distribution for hand fractures, 3) any seasonal variation, and 4) any geographic variation.

4.6 MATERIALS AND METHODS

This study was a population based epidemiologic study involving a five year, retrospective review, of all BC residents identified with hand fractures in the British Columbia Linked Health Database (BCLHD). The BCLHD contains comprehensive linked longitudinal population health and social service data for all BC residents. The data are maintained by the Center for Health Services and Policy Research (CHSPR). These data are available for Ministry of Health (MoH) approved applied health service and population

* A version of this chapter has been published. Feehan LM, Sheps S. Incidence and Demographics of Hand Fractures in British Columbia, Canada: A Population Based Study. J Hand Surg 2006; 31A(7):1068-1074. This chapter has also received Ministry of Health Approval.

health research projects.[25] This study was approved by the MoH and received institutional clinical research ethics approval. (See Appendix 4-1)

This study utilized extracted data records from the BCLHD Medical Service Plan (MSP), Hospital Separation (HS) and the MSP Registration (Registry) data sets. The MSP dataset contains records of all payments made to registered practitioners for medical services provided to BC residents. The HS dataset contains records for every hospital separation (acute, day-surgery, rehab, extended care). The Registry dataset includes individual demographic data, such as date of birth (yyyy, mm), gender (male, female) and regional geographic location (Health Authority). The Southwest corner of the province including the Vancouver Coastal and Fraser Health Authorities is mostly urban, and higher educational levels and a primarily service based industry. The Northern half (Northern Health Authority) is mostly rural, less affluent, and less educated, with a primarily resource based industry.[26]

All MSP and HS records from May 1, 1996 to April 30, 2001 including the International Classification of Disease, version 9 (ICD-9) codes for Metacarpal (815), Phalangeal (816) and Multiple (817) fractures were extracted, along with the individual registry demographic records linked to each hand fracture identified during this time period. The retrieved data included 7,460 [4460 - day-surgery; 3000 – acute] HS records, 232,608 MSP records and 72,481 Registry records. Each record in each of these three retrieved datasets contained a unique study identification code. This unique identification code was then used to re-structure, merge and re-organize the data contained in the three administrative datasets into one synthesized research database for further data extraction and analyses. The research database contained all the merged information for each hand fracture that occurred during the time period of this study. BC total population, including regional geographic age and gender demographic data for July 1st for all the years covered in this study (1996 to 2001). [26]

4.7 RESULTS

4.7.1 Annual Frequency and Incidence Rates

Over the five year time period, 72,481 (seasonally weighted and annualized to 86,911) metacarpal, phalangeal or multiple hand fractures were identified. Of these fractures 50% were phalangeal fractures, 42% were metacarpal fractures and 8% were identified as multiple hand fractures (see Appendix 4-1). The yearly mean frequency for all hand fractures from 1996 to 2001 was 14,485 / year [95% CI: 13,533 – 15,437]. The yearly mean frequency for metacarpal, phalangeal and multiple hand fractures for this same

time period were respectively; 6,060 / year [95% CI: 5,417 – 6,703]; 7205 / year [95% CI: 7,055 – 7,355] and 1,221 / year [95% CI: 947 – 1,495]. (See Table 4-1)

The overall mean yearly incidence rate for all hand fractures was 3.63 / 1000 [95% CI: 3.28 – 3.99]. Total population annual incidence rates for Phalangeal, Metacarpal and Multiple hand fractures were respectively, 1.81 / 1000 [95% CI: 1.72 – 1.89], 1.52 / 1000 [95% CI: 1.31 – 1.73] and 0.31 / 1000 [95% CI: 0.24 – 0.38]. (See Appendix 1) These data indicated a downward trend in annual incidence rate for hand fractures during this time period, specifically for metacarpal fractures (mean annual % change = - 3%). (See Figure 4-1) However, a Poisson regression analyses for a downward trend over the six years was not significant for any type of fracture. (Likelihood Ratio $\leq$ 0.03, p =.99)

4.7.2 Age Distribution / Incidence Rates

Age Distribution / Incidence Rates: The age range was less than one year old up to 106 years old with the average age for a hand fracture being 31 years of age (SD: +/- 19). The median age for the hand fractures was 27 years and the modal age was 14 years. (See Table 4-2) Age specific incidence rates show that there was a distinct unimodel and positively skewed distribution for hand fracture incidence rates, peaking in early adolescence [10 to14 (8.69 / 1000)] and remaining high throughout adolescence [15 to 19 (8.26 / 1000)]. After the age of twenty there was a progressive reduction in incidence rates over each decade until the age of 65 [65 to 69(1.82 / 1000] followed by a slight increase again after the age of 70. (See Figure 4-2)

Male vs. Female Age Distribution: The range for male fractures was less than one year old up to 99 years old with the mean age being 29 years of age (SD: +/- 17) The median age for all hand fractures in males was 25 years and the modal age for sustaining a hand fracture in males was 14 years. In females the range was less than one year old up to 106 years old with the mean age for female fractures being 35 years of age(SD: +/- 22). The median age for all hand fractures in females was 32 years and the modal age for sustaining a hand fracture in females was 13 years. (See Table 4-3)

4.7.3 Gender Distribution / Incidence Rates / Relative Risk

Males sustained 67% of all hand fractures with a breakdown of 72%, 64% and 64% for metacarpal, phalangeal and multiple hand fractures respectively. (See Table 4-3 and Figure 4-3) Gender specific incidence rates show that males in BC were at a 2.08 greater relative risk for sustaining any hand fracture than females [4. 85 vs. 2.33 / 1000]. Males were at a 2.58 greater relative risk than females for sustaining a

metacarpal fracture [2.16 vs. 0.84 / 1000], and were at a 1.8 greater relative risk than females for sustaining both phalangeal [2.32 vs. 1.28 / 1000] and multiple [0.37 vs. 0.21 / 1000] hand fractures. (See Table 4-3)

4.7.4 Age and Gender Adjusted Incidence Rates / Relative Risk:

For males, the highest incidence for sustaining a hand fracture was between the ages of 15 to 19 [12.3 / 1000]. In the female group the highest incidence was between the ages of 10 to 14 years [5.3 / 1000 females]. (See Table 4-4 and Figure 4-4) Age and gender adjusted rates showed that males remained at a relatively greater risk for a hand fracture than females up until the age of 60, whereas, females began to show a greater relative risk for a hand fracture after the age of 65. Male peak relative risk was 3.38, occurring between the ages of 20 to 24. Female peak relative risk occurred between the ages of 80 to 84 when they are 1.53 times more likely to sustain a hand fracture than are males of the same age. (See Table 4-4 and Figure 4- 4)

4.7.5 Seasonal Variation

The hand fracture incidence rates were significantly higher in the spring [1.00 / 1000; 95% CI: 0.92 – 1.08] than in the fall or winter at [.84 / 1000; 95% CI: 0.78 – 0.89]. Summer had the second highest seasonal rate at .92 / 1000 [95% CI: 0.86 – 0.97]. (See Figure 4-5) The seasonal variation in hand fractures rates was not influenced by either gender or geographic location. When examined across age category, during adolescence (ages 10 to 20: the age group when hand fractures were the most common), seasonal incidence rates were lower during the summer (1.8 / 1000) when compared to the winter (2.1 / 1000), spring (2.4 / 1000) or fall (2.2 / 1000). (See Figure 4-6)

4.7.6 Geographic Distribution

Compared to overall population incidence rates [3.63 / 1000; 95% CI: 3.28 – 3.99] there were significantly higher incidence rates for hand fractures in the Northern HA [4.57 / 1000; 95% CI: 4.01 – 5.05] and significantly lower rates for hand fractures in the Vancouver Coastal HA [2.76 / 1000; 95% CI: 2.47 – 3.03]. The Fraser, Interior and Vancouver Island HAs had incidence rates very similar to the overall population rate in BC. (See Figure 4-7) Geographic variation was not affected by gender. Age adjusted rates showed that the increased hand fracture incidence seen in the Northern HA relative to the other four health authorities was apparent from the age of 10 and higher. Lower hand fracture incidence in the Vancouver Coastal HA relative to the other four health authorities was most apparent between the ages of 10 to 55. (See Figure 4-8)

4.8 DISCUSSION

This study is unique as it was a true population based epidemiologic study that specifically examined all instances of hand fractures occurring across a whole population, treated in any medical setting, by any medical professional, within a large geographic area of diverse climactic and socio-economic regions. [26] Other related studies are not necessarily reflective of population based rates due to limited access to complete population based data. Most of these studies report epidemiologic data derived from one or more emergency room and / or inpatient hospital settings, usually in geographically restricted areas. [21,22-14,16,17,19,20-22,24.] In addition, the selection criteria were often restricted by age for inclusion to either pediatric (<20), or adults (≥20) fractures, [1,9, 1,22,14-18,23,24] and / or were limited by the type of medical practitioner providing the care. [1,6,11,18,23.] Therefore, it is likely that these studies only present a partial picture of the full spectrum of hand fractures that can occur within a whole population.

Age and gender were both important factors for defining risk for sustaining a hand fracture in BC. In our study the annual incidence rates ranged from 29 / 10,000 for people over 20 years old to 61 / 10,000 for people ≤ 20 years old. Adolescents were most at risk of sustaining a hand fracture and this risk remained elevated into young adulthood (ages 20 to 25). Males sustained 67% of all the hand fractures and were at a 2.1 greater relative risk for sustaining a hand fracture than were females. Male peak relative risk for a hand fracture occurred between the ages of 20 to 25, and remained higher relative to females up until the age of 60. These findings are similar to age and gender hand fracture and hand injury patterns described in other studies. [2,8,9,22,23,27]

Increased hand fracture incidence during adolescence and young adult years, with a noted gender specific increased risk for adolescent and young adult males, was likely due to increased behavioral risk factors, such as participation in higher risk recreational, sport and occupational activities. [5,7,8,21,27] A marked increase in risk for a hand fracture in early adolescence for both genders, with girls peaking at 13, one year earlier than boys, may be explained in part by an additional biologic risk factor. Increased bone fragility in adolescents has been previously described and occurs during the lag time between the most rapid period of growth in length and the subsequent re-modeling and re-mineralization of the long bones following growth. [28-31] An increased risk for fractures in male adolescents may also be explained in part by a biologic gender difference in long bone cortical bone structural (geometric) and material (density / porosity) properties that may leave long bones in adolescent males more susceptible to fracture during this rapid bone development time period. [32]

Findings from our study also suggest that adult males carry an increased occupational risk for a hand fracture throughout adulthood, lasting until the age of 60, around the age of retirement. Again, this is likely due to males working in the heavier or high-risk manual laborer type jobs, especially during their younger and middle adult years (20 to 40 years). An increased relative risk for elderly females (> 65) suggests that, as with the more common fractures in the elderly, age related osteoporotic changes leading to increased bone fragility may also be a contributing biologic risk factor for a hand fracture in elderly women.[2,6,16,19,23]

There was also a notable seasonal variation in hand fracture incidence in BC, where hand fracture rates were highest during the spring and summer seasons when the climate in general favours greater outdoor activities. This was most notable during the prime working years (ages 20 to 45). Throughout adolescence, however, when hand fracture risk is the highest, an interesting finding was a noted decrease in hand fractures rates during the summer season, compared to spring, fall and winter seasons when adolescents are more likely to be involved in outdoor school and sporting activities. There was no difference in hand fracture rates across seasons in people over 60, suggesting that falls associated with icy winter conditions are not a significant risk factor for hand fractures.

In our study there was no marked difference in gender, age, or season specific incidence rates between the Northern half and the South-western corner of the province. However, there was a 1.6 greater relative risk for sustaining a hand fracture in the Northern region. This finding suggests that key socio-economic differences in these two regions such as rural vs. urban living, primary goods vs. secondary service based industry, as well as income, occupation, education and employment status may be contributing risk factors for sustaining a hand fracture.[26] Cooper et al (2004),[1] have also noted a very similar geographic difference in hand fracture incidence rates in children (<18) in which there is up to a 1.6 increased rate for hand fractures in Northern Ireland, Scotland, Wales and England compared to the South Eastern region of England. Stark et al (2002), [33] also demonstrated a significantly higher incidence of hand fractures in economically deprived children in Glasgow, Scotland compared to those from affluent families. Jones S, et al (2004), [34] also noted a 1.6 increased overall fracture risk for socio-economically deprived adults in Wales between the ages of 25 and 54.

Hand fracture annual incidence rates reported in the literature have been quite variable, ranging from a rate of 18 / 10,000 for adults (≥20) in the United Kingdom (van Staa et al; 2001 [23]) compared to a rate of 77 / 10,000 for children (≤ 14) in South Wales (Lyons et al ; 2000 [15]). Much of the difference can be attributed to differences in age for inclusion in the study. Another factor for the variability in incidence rates across

studies could be a selection bias due to restricted data sources and / or limited geographic area for data sampling from within the larger population.

There are also a number of potential limitations of a study based on a retrospective review of administrative health care datasets. In our study, the primary assumption was that all residents in BC with a clinically significant hand metacarpal or phalangeal fracture would seek acute medical attention for treatment of their fracture through the publicly administered universal Canadian health care system. The second premise was that the health care data records retrieved for this study accurately identify all occurrences of treatment for a hand fracture in BC.

There are three issues regarding the potential accuracy of the data utilized in this study. The first is the issue of potential misdiagnosis of a hand fracture by medical professionals in BC. Our premise is that the misdiagnosis of a clinically significant hand fracture is unlikely. X-ray imaging is a definitive tool used to diagnose a clinically significant hand fracture and it is inexpensive and readily accessible by all medical professionals in BC. The second issue relates to potential mislabeling of the diagnostic coding for hand fractures in the datasets. In this study we were able to verify the consistency of ICD-9 coding for hand fractures from multiple health care records, often derived from different health care providers in different health care settings. Finally, there is the potential for missing ICD-9 codes entirely and therefore not retrieved for this study. Fortunately, ICD-9 coding is a mandatory field in both the MSP and Hospital Separation datasets. In addition, if a mandatory field is missing in the MSP record the payment it is not processed; a strong motivating factor for inclusion.

Given the limitations of the database, we were also not able to specifically define which metacarpal or phalangeal bone(s) were fractured, the location of the fracture in the bone, the fracture pattern sustained, whether or not the fracture was open or closed, the mechanism or setting of injury, or any other regional or systemic trauma associated with the hand fracture. Finally, the ability to generalize this study's finding to geographic areas other than British Columbia, Canada is also difficult to define clearly. However, we feel that these data would be applicable to all regions in Canada given the universal health care system and the similarity in population demographics, key socio-economic indicators, geography and climate. Similarly, we feel that the total population, age and gender adjusted rates are also likely to be reflective of hand fracture rates in other countries in the world with similar population demographics, climactic zones and levels of socio-economic development as Canada.

4.9 SUMMARY

Our study provides robust estimates of annual incidence rates for hand fractures, as we were able to review all occurrences of a hand fracture within a population base of approximately 4 million people over a five year time period. Moreover, our study also allowed for the examination of how age, gender, season and geographic location influenced hand fracture incidence rates within a large, diverse population. Hand fractures are the second most common fracture in both children and adults, resulting in a significant societal burden both in terms of health care utilization and lost socio-economic productivity. Population based epidemiologic data can help health care providers plan for the provision of care for hand fractures. Finally, a better understanding of biologic, behavioral and socio-economic risk factors potentially associated with a hand fracture can help identify those individuals most at risk for a hand fracture (eg: adolescent males) and thus define potential preventative measures to help reduce the incidence of hand fractures in BC.

Table 4-1: Seasonally Weighted Annualized Data - Frequency & Incidence Rate / 1000 people for all Hand Fractures (N=86,911).

		Metacarpal		Phalangeal		Multiple		All	
Year	July 1 Pop.	Frequency	Incidence	Frequency	Incidence	Frequency	Incidence	Frequency	Incidence
1996 (annualized)	3,874,276	6,644	1.71	7,268	1.88	1,394	0.36	15,306	3.95
1997	3,948,544	6,321	1.60	7,319	1.85	1,321	0.33	14,961	3.79
1998	3,983,077	6,031	1.51	7,131	1.79	1,225	0.31	14,387	3.61
1999	4,011,342	5,858	1.46	7,245	1.81	1,035	0.26	14,138	3.52
2000	4,039,198	5,804	1.44	7,111	1.76	1,036	0.26	13,951	3.45
2001 (annualized)	4,078,447	5,701	1.40	7,156	1.75	1,313	0.32	14,168	3.47
Total	23,934,884	36,359	n/a	43,230	n/a	7,324	n/a	86,911	n/a
% of All Fractures	n/a	42%	n/a	50%	n/a	8%	n/a	100%	n/a
Mean	3,989,147	6,060	1.52	7,205	1.81	1,221	0.31	14,485	3.63
Upper 95% CI	n/a	6,703	1.73	7,355	1.89	1,495	0.38	15,437	3.99
Lower 95% CI	n/a	5,417	1.31	7,055	1.72	947	0.23	13,533	3.28

Table 4-2: Descriptive Statistics - Age at Fracture (N=72,361).

	ALL	Females	Males
N	72,361	23,715	48,573
Mean	31	35	29
Median	27	32	25
Mode	14	13	14
Std. Deviation	19	22	17
Minimum	<1	<1	<1
Maximum	106	106	99
%	100%	33%	67%

Table 4-2: Gender x Type of Fracture - Annual Frequency, Incidence Rate and Relative Risk M:F (N = 57,345).

		Metacarpal	Phalangeal	Multiple	All
Mean Annual Frequency	**Female**	1689 (1626-1752)	2581 (2505-2657)	413 (311-515)	4682 (4298-5066)
(95% CI)	**Male**	4300 (4177-4423)	4603 (4453-4753)	739 (539-939)	9641 (8888-10,394)
Incidence Rate / 1000	**Female**	0.84	1.28	0.21	2.33
	Male	2.16	2.32	0.37	4.85
Relative Risk	**(M/F)**	2.58	1.8	1.81	2.08

Table 4-4: Annual Incidence Rates and Relative Risk - Age x Gender Adjusted Rates (N= 53,376) [.> / < = > Gender Risk / < Gender Risk]

Age Cat.	Mean Count - Males	Mean Count - Females	Mean Count - Both	Mean Pop. Males	Mean Pop. Females	Mean Pop. Both	Males Rate / 1000	Female Rate / 1000	Both Rate / 1000	Relative Risk (M/F)	Relative Risk (>/<)
0 to 4	82	61	143	118,458	111,840	230,299	0.69	0.54	0.62	1.27	1.27
5 to 9	340	241	580	129,782	123,251	253,033	2.62	1.95	2.29	1.34	1.34
10 to 14	1,532	751	2,284	135,160	127,611	262,770	11.33	**5.89**	**8.69**	1.92	1.92
15 to 19	1,698	508	2,206	137,808	129,315	267,123	**12.32**	3.93	8.26	3.13	3.13
20 to 24	1,047	300	1,347	133,151	128,696	261,847	7.86	2.33	5.14	3.38	**3.38**
25 to 29	907	323	1,230	144,129	141,984	286,113	6.29	2.27	4.3	2.77	2.77
30 to 43	832	341	1,173	157,470	155,800	313,269	5.28	2.19	3.74	2.42	2.42
35 to 39	850	358	1,208	175,308	174,913	350,221	4.85	2.05	3.45	2.37	2.37
40 to 44	666	326	992	167,610	170,309	337,919	3.97	1.91	2.93	2.07	2.07
45 to 49	513	270	782	152,996	152,472	305,468	3.35	1.77	2.56	1.9	1.9
50 to 54	367	227	594	129,131	127,984	257,115	2.84	1.77	2.31	1.61	1.61
55 to 59	242	189	432	97,248	97,062	194,310	2.49	1.95	2.22	1.28	1.28
60 to 64	164	152	318	80,983	81,186	162,170	2.02	1.87	1.96	1.08	1.08
65 to 69	132	142	275	75,224	76,235	151,458	1.75	1.86	1.82	0.94	1.06
70 to 74	116	152	271	61,670	70,927	132,596	1.88	2.15	2.04	0.87	1.14
75 to 79	74	142	217	46,067	61,930	107,997	1.61	2.29	2.01	0.7	1.43
80 to 84	45	109	155	26,658	41,801	68,459	1.7	2.6	2.26	0.65	**1.53**
85+	38	93	133	17,515	35,861	53,376	2.16	2.58	2.48	0.84	1.2
ALL Ages	9641	4682	14336	1986364	2009177	3995540	4.85	2.33	3.59	**2.08**	2.08

CHAPTER 4: FIGURES

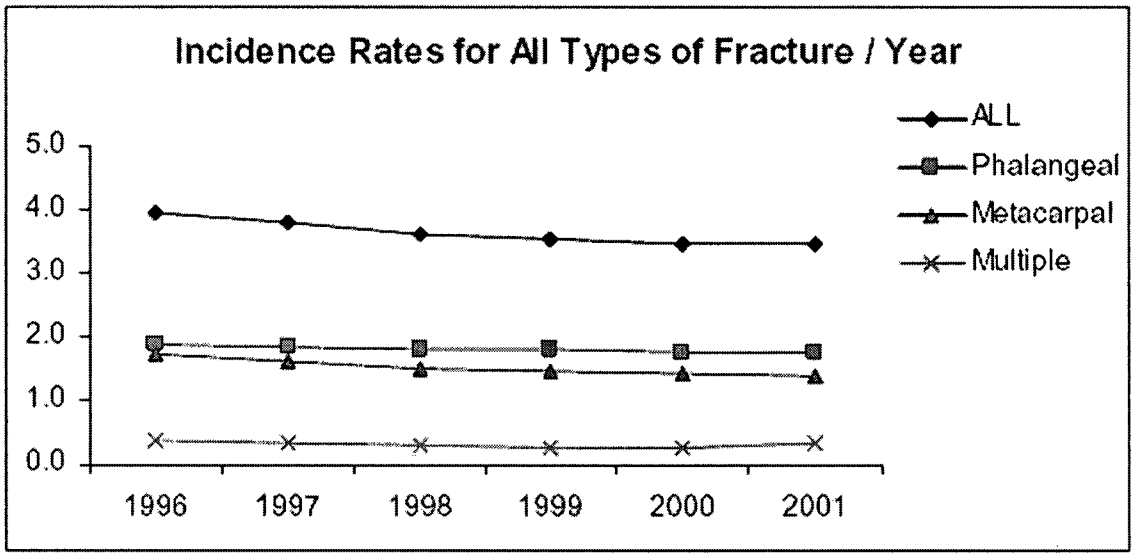

Figure 4-1: Seasonally Weighted Annualized Incidence Rates for Hand Fractures.

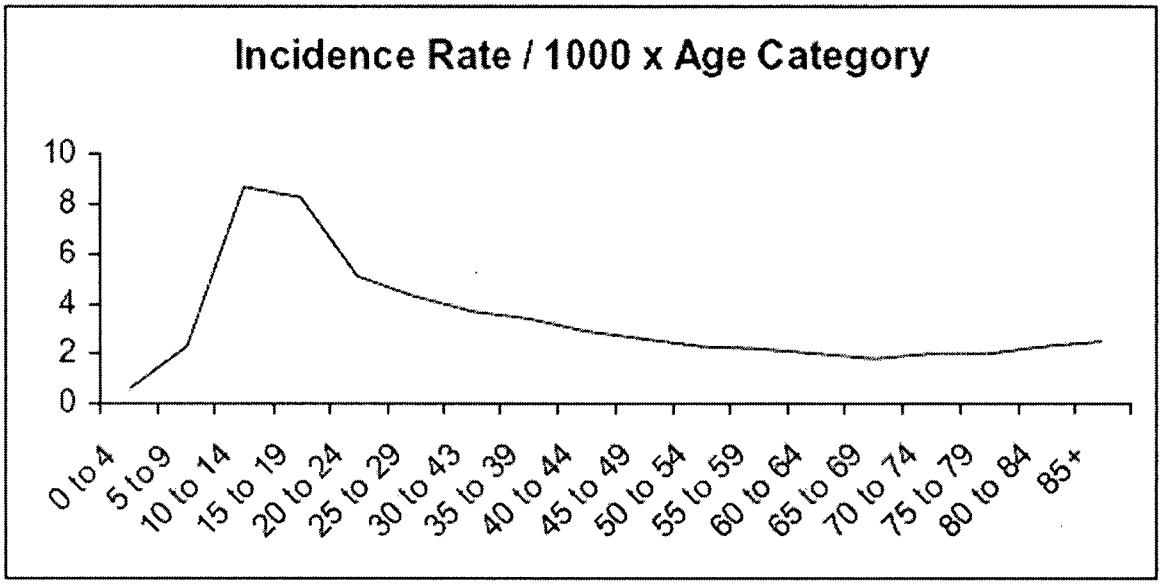

Figure 4-2: Age Distribution for Hand Fractures - Incidence Rates x Age Category.

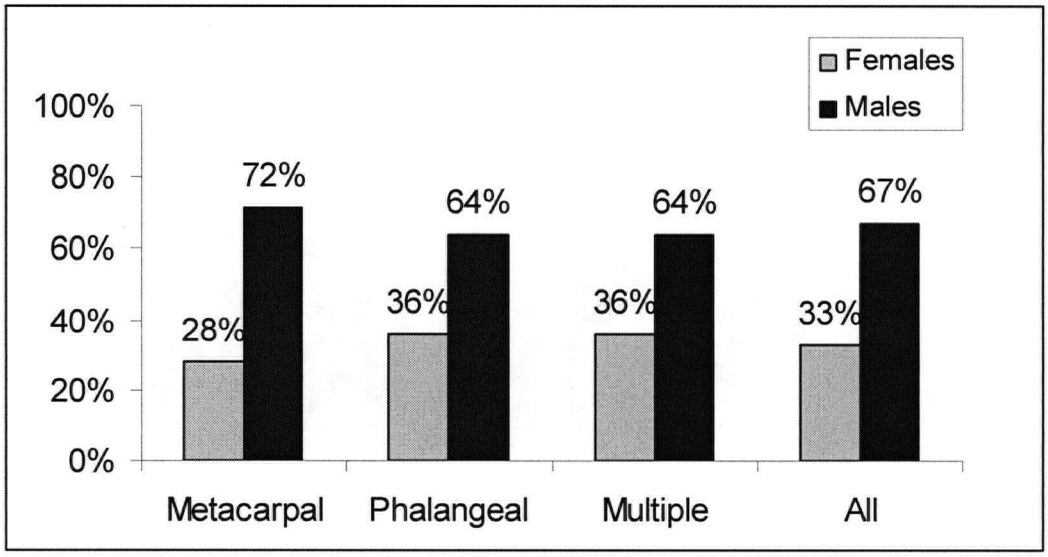

Figure 4-3: Gender Distribution for Hand Fractures – Percent x Type of Fracture.

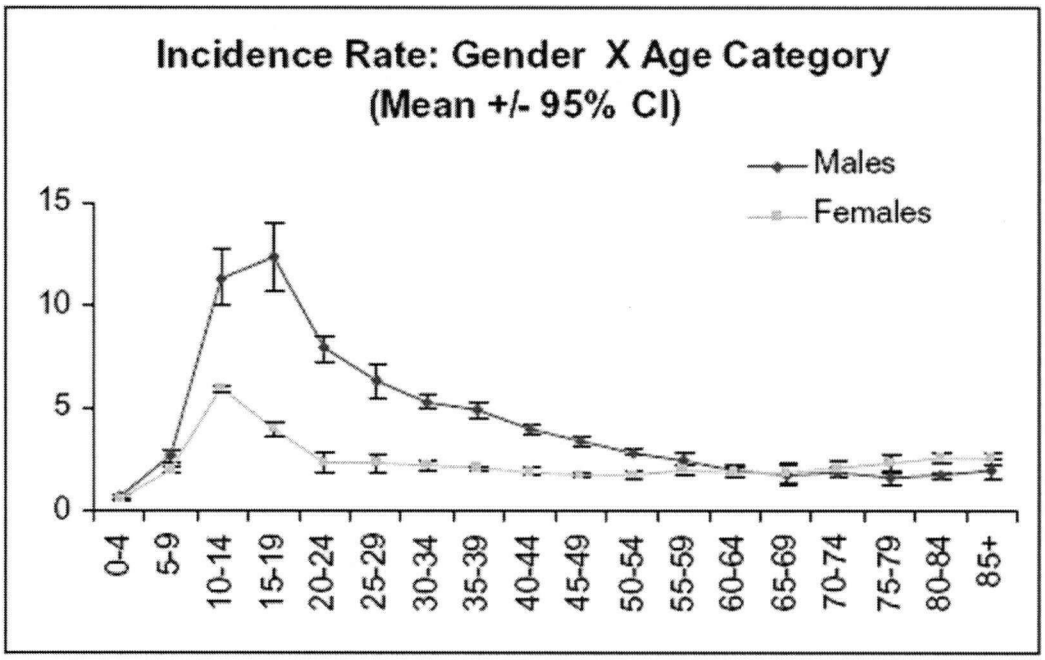

Figure 4-4: Annual Incidence Rates for Hand Fractures - Gender x Age Adjusted Rates [Mean (+/- 95% CI)].

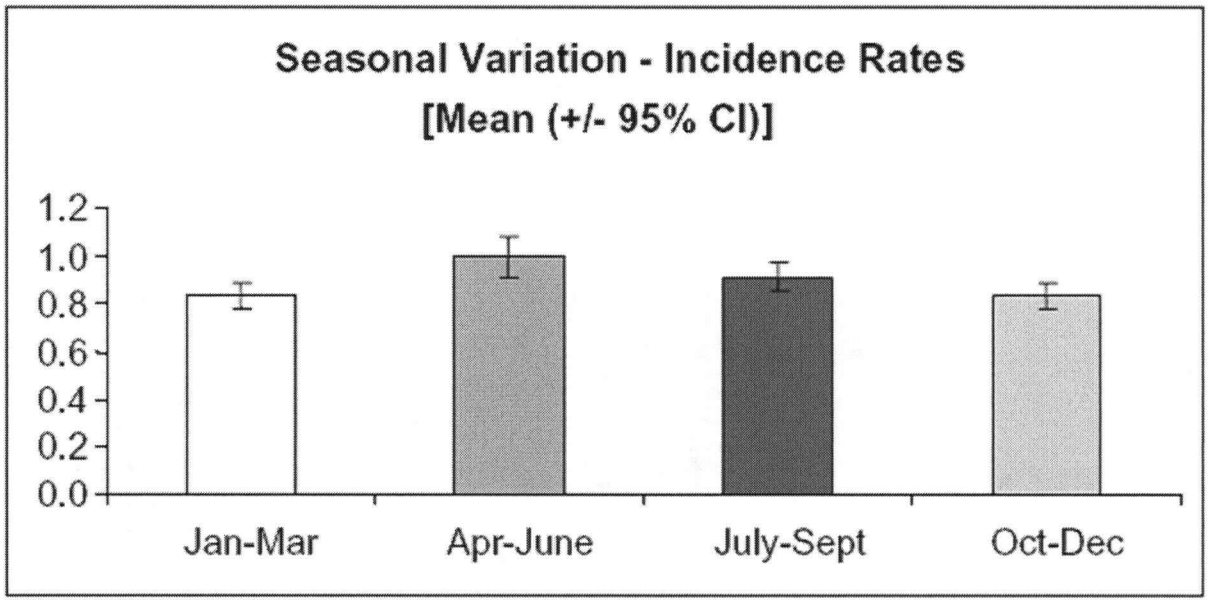

Figure 4-5 : Seasonal Variation in Incidence Rates for Hand Fractures [Mean (+/- 95% CI)].

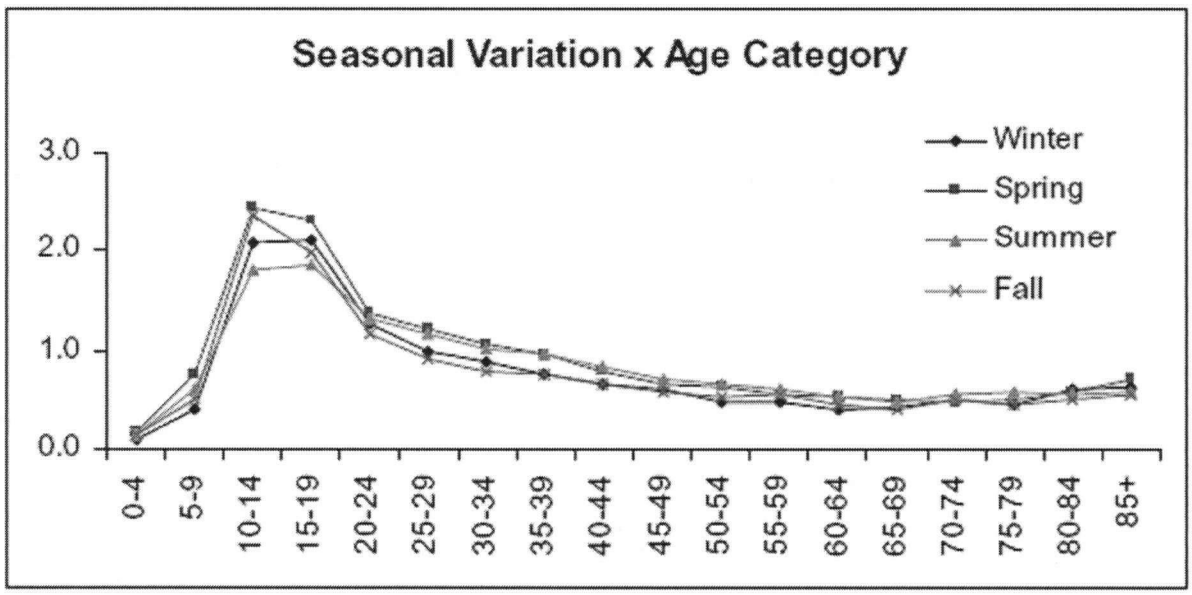

Figure 4-6: Seasonal Variation: Age Adjusted Rates x Season

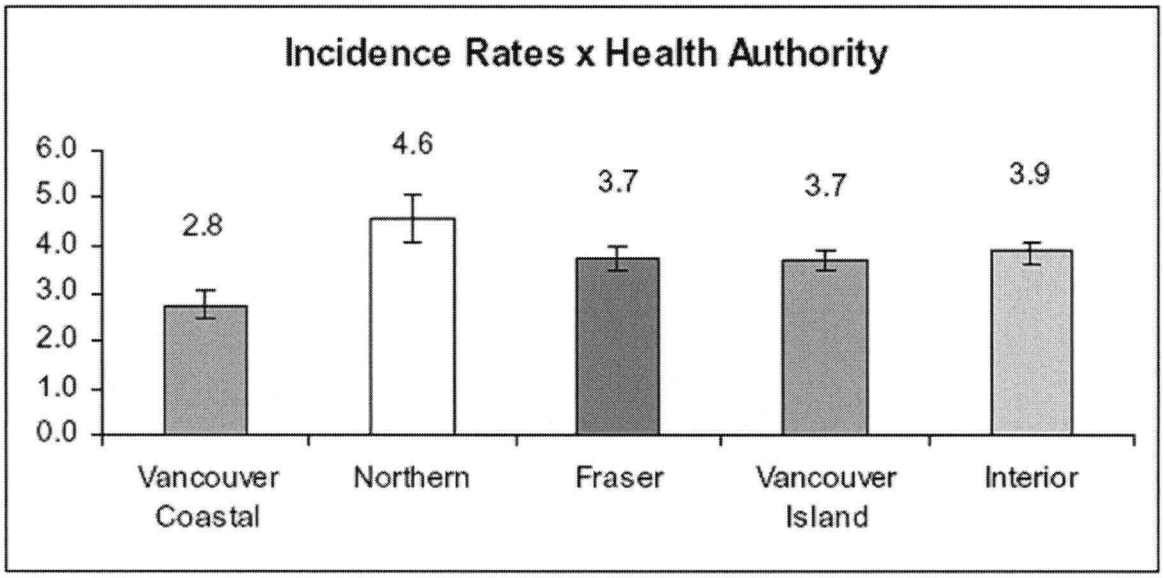

Figure 4-7: Regional Variation (by Health Authority) in Incidence Rates for Hand Fractures [Mean (+/- 95% CI)].

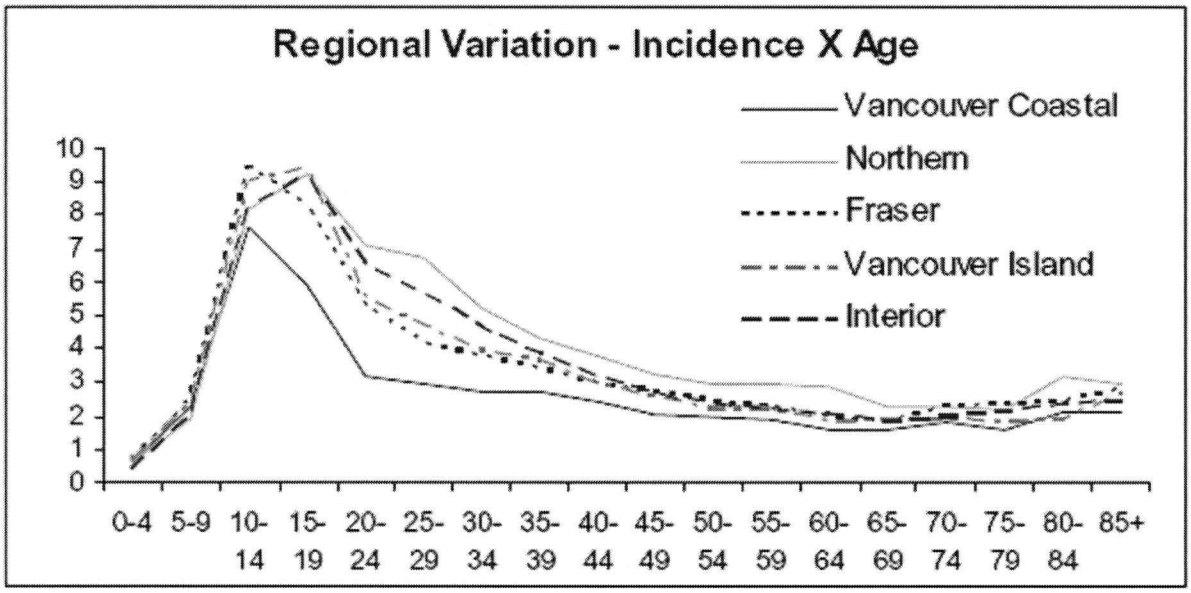

Figure 4-8: Geographic Variation: Age Adjusted Rates by Health Authority

CHAPTER 4: REFERENCES

1. Cooper C, Dennison EM, Leufkens HG, Bishop N, van Staa TP. Epidemiology of childhood fractures in Britain: a study using the general practice research database. J Bone Miner Res. 2004 Dec;19(12):1976-81.
2. Johansen A, Evans RJ, Stone MD, Richmond PW, Lo SV, Woodhouse KW. Fracture incidence in England and Wales: a study based on the population of Cardiff. Injury. 1997 Nov-Dec;28(9-10):655-60.
3. Burke FD, Dias JJ, Lunn PG, Bradley M. Providing care for hand disorders: trauma and elective. The Derby hand unit experience (1989 – 1990). J Hand Surg 16B: 13-18, 1991.
4. Butt WD. Fractures of the hand. Statistical Review. Can Med Ass J 1962;85:775-779.
5. Chung KC, Spilson SV. The frequency and epidemiology of hand and forearm fractures in the United States. J Hand Surg [Am]. 2001 Sep;26(5):908-15
6. Cooley H, Jones G. A population-based study of fracture incidence in southern Tasmania: lifetime fracture risk and evidence for geographic variations within the same country. Osteoporos Int. 2001;12(2):124-30.
7. DeJonge JJ, Kingma J, van der Lei B, Klasen HJ. Phalangeal fractures of the hand. An analysis of gender and age-related incidence and aetiology. J Hand Surg 1994a;19B: 168-170.
8. DeJonge JJ, Kingma J, van der Lei B, Klasen HJ. Fractures of the metacarpals. A retrospective analysis of incidence and aetiology and a review of the English-language literature. Injury 1994b;25:365-369
9. Hastings H, Simmons BP. Hand fractures in children: A statistical review. Clinc Orthop Rel Res. 1984;188:120-130.
10. Hove LM. Fractures of the hand. Distribution and relative incidence. Scand J Plast Reconstru Surg Hand Surg. 1993;27:317-319.
11. Jones G, Cooley HM. Symptomatic fracture incidence in those under 50 years of age in southern Tasmania. J Paediatr Child Health. 2002 Jun;38(3):278-83.
12. Kopjar B, Wickizer TM. Fractures among children: incidence and impact on daily activities. Inj Prev. 1998 Sep;4(3):194-7.
13. Landin, LA. Fracture patterns in children. Analysis of 8,682 fractures with special reference to incidence, etiology and secular changes in a Swedish urban population 1950-1979. Acta Orthop Scand Suppl. 1983; 202:1-109.
14. Lyons RA, Delahunty AM, Kraus D, Heaven M, McCabe M, Allen H, Nash P. Children's fractures: a population based study. Inj Prev. 1999 Jun;5(2):129-32.

15. Lyons RA, Sellstrom E, Delahunty AM, Loeb M, Varilo S. Incidence and cause of fractures in European districts. Arch Dis Child. 2000 Jun;82(6):452-5.
16. Melton LJ III, Crowson CS, O'Fallon WM. Fracture incidence in Olmsted County, Minnesota: comparison of urban with rural rates and changes in urban rates over time. Osteoporos Int. 1999; 9(1): 29-37.
17. Mahabir RC, Kazemi AR, Cannon WG, Courtemanche DJ. Pediatric hand fractures: a review. Pediatr Emerg Care. 2001 Jun;17(3):153-6.
18. Packer GJ, Shaheen MA. Patterns of hand fractures and dislocation in a district general hospital. J Hand Surg 18B: 511-514, 1993.
19. Sanders KM, Seeman E, Ugoni AM, Pasco JA, Martin TJ, Skoric B, Nicholson GC, Kotowicz MA. Age- and gender-specific rate of fractures in Australia: a population-based study. Osteoporos Int. 1999;10(3):240-7.
20. Shaheen MAE, Badr AA, Al-Khudairy N, Khan FA, Mosalem A, Sabet N. Patterns of accidental fractures and dislocations in Saudi Arabia. Injury 21:347-350, 1990.
21. Tiderius CJ, Landin L, Duppe H. Decreasing incidence of fractures in children: an epidemiological analysis of 1,673 fractures in Malmo, Sweden, 1993-1994. Acta Orthop Scand. 1999 Dec;70(6):622-6.
22. van Onselen EB, Karim RB, Hage JJ, Ritt MJ. Prevalence and distribution of hand fractures. J Hand Surg [Br]. 2003 Oct;28(5):491-5.
23. van Staa TP, Dennison EM, Leufkens HG, Cooper C. Epidemiology of fractures in England and Wales. Bone. 2001 Dec;29(6):517-22.
24. Worlock P, Stower M. The incidence and pattern of hand fractures in children. J Hand Surg. 1986;11B(2):198-200.
25. Center for Health Services and Policy Research (CHSPR) at the University of British Columbia. (http://www.chspr.ubc.ca/Bclhd)
26. British Columbia Government, BC STATS service BC, Ministry of Labour and Citizens' Services. (http://www.bcstats.gov.bc.ca)
27. Larsen CF, Mulder S, Johansen AM, Stam C. The epidemiology of hand injuries in the Netherlands and Denmark. Eur J Epidemiol. 2004;19(4):323-7.
28. Bailey DA, Wedge JH, McCulloch RG, Martin AD, Bernhardson SC. Epidemiology of fractures of the distal end of the radius in children as associated with growth. J Bone Joint Surg Am. 1989;71:1225-1231.
29. Parfitt AM. The two faces of growth: benefits and risks to bone integrity. Osteoporos Int. 1994;4:382-398.

30. Rauch F, Neu C, Manz F, Schoenau E. The development of metaphyseal cortex, implications for distal radial fractures during growth. J Bone Miner Res. 2001;16(8):1547-55.
31. Jones I E, Williams S, Dow N, Goulding A. How many children remain fracture-free during growth: A longitudinal study of children and adolescents participating in the Dunedin multidisciplinary health and development study. Osteoporos Int. 2002;13:990-995.
32. Schoenau E, Neu CM, Rauch F, Manz F. Gender-specific pubertal changes in volumetric cortical bone mineral density at the proximal radius. Bone 2002;31(1):110-13.
33. Stark AD, Bennet GC, Stone DH, Chishti P. Association between childhood fractures and poverty: A population based study. BMJ 2002;321:457.
34. Jones S, Johansen A, Brennan J, Butler J, Lyons RA. The effect of socioeconomic deprivation on fracture incidence in the United Kingdom. Osteoporosis Int. 2004 Jul;15(7):520-4.

CHAPTER 5: INITIAL HEALTH CARE UTILIZATION TRENDS FOR PEOPLE TREATED FOR A HAND FRACTURE IN BC: A BC LINKED HEALTH DATASET INQUIRY*

5.1 RESEARCH QUESTION ADDRESSED IN THIS CHAPTER

Who is providing the initial care for hand fractures in BC and in what clinical setting?

5.2 INTRODUCTION

Hand fractures are a common injury, accounting for up to 20% of all fractures in adults and children,[1,2] and result in a significant societal burden in terms of the impact on acute health care services and lost socio-economic productivity. British Columbia (BC) is Canada's most western province with very diverse geographic and socio-economic regions.[3] In BC, there are an estimated 14,500 hand fractures occurring each year in a population base of approximately 4 million people, with an annual incidence rate of 36 hand fractures for every 10,000 people.[4] In addition, hand fracture risk in BC is highest in young males between the age of 15 and 40 during their most productive working years.[4]

Studies examining health care and socio-economic costs associated with hand injuries, not necessarily hand fractures specifically, have consistently noted a significant socio-economic burden particularly related to lost work-place productivity.[5-13] The primary limitation of these studies was data derived from restricted data sources, for example only emergency room or trauma registry data,[5,8,9] specialty hand service clinical data, in-patient hospital data [7,10,12] and / or data related to only work-related injuries.[6,11,13] No previous study has specifically examined acute health care utilization trends for all hand fracture injuries occurring in a large, diverse population, across a range of medical settings.

The purpose of this study was to identify the initial health care utilization trends for all people previously identified as having received treatment for a hand fracture during the five year period from May 1, 1996 to April 30, 2001 in BC.[4] Our specific objectives were to clarify who initially provided the medical treatment for these hand fractures and in which health care setting they provided it. Additionally, we wanted to examine the proportion of hand fractures with an associated hospital admission to determine who was admitting hand fractures, what type of admissions were occurring, the wait time and length of stay associated with

* A version of this chapter is to be submitted to the Canadian Medical Association Journal (October 2006). Feehan LM, Sheps S. Initial health care utilization for people treated for a hand fracture in BC: A population based study. This chapter has received Ministry of Health approval.

these hospital admissions, and also to explore if there were any geographic variations in hospital admission rates between the five health authorities in BC. [3]

5.3 MATERIALS AND METHODS

This study was a population based epidemiologic study involving a five year, retrospective review of 72,481 residents previously identified from the British Columbia Linked Health Datasets (BCLHD) as having received treatment for a hand fracture between May 1, 1996 and April 30, 2001. [4] The BCLHD contains comprehensive linked longitudinal population health and social service data for all BC residents. The data are maintained by the Center for Health Services and Policy Research (CHSPR) at the University of British Columbia. [14] These data are available for Ministry of Health (MoH) approved applied health service and population health research projects. This study was approved by the MOH and received institutional clinical research ethics approval. (See Appendix 4-1)

This study utilized data from a research database containing merged information for each hand fracture. These data were retrieved from the BCLHD Medical Service Plan (MSP), Hospital Separation (HS) and the MSP Registration (Registry) data sets. Details of the specific data extraction and syntheses methods have been previously described. [4] (See Chapter 4.3 – Materials and Methods) The MSP dataset contains records of payments made to registered medical practitioners for services provided to BC residents. [14] The HS dataset contains records for every hospital separation (acute, day-surgery, rehab, extended care admission and discharge). [14] The Registry dataset includes individual demographic data, such as date of birth (yyyy, mm), gender (male, female) and regional geographic location (Health Authority). [14] In addition, BC total population and regional demographic data for July 1st for 1996 to 2001 were retrieved.[3] For this study a flow chart was developed from these data to establish the location of the medical setting and physician responsible for the initial fracture treatment, and then to track all fractures with an associated hand fracture hospital admission (See Figure 5-1) The specific data definitions used in this study are outlined in Table 5-1.

This study was conducted in BC in the context of the Canadian Health Care System, which is a federally legislated (Canada Health Act) and a provincially and territorially administered, publicly funded, non-profit, universally accessible primary health care system. [15,16] The Canadian Health Care System is accessible to Canadian residents and covers primary care physician, specialist, and hospital health care services. [15,16] The primary care physician (either a general or family practice physician) is the main first contact health care provider in the Canadian health care system. [15,16] Canadian residents can directly access a primary care physician, for non-specialized preventative and medical health care services. [15,16] Hospital emergency

room services are also directly accessible to Canadian residents and is also a common point of first contact into the health care system. Emergency medical room services include urgent and emergent care, as well as some basic primary care for those without access to primary care physicians. [15,16,17] In British Columbia, specialist medical care is provided on a referral basis. Hospital admissions are the responsibility of a primary care or specialist physician who has admitting privileges at the hospital. [15,16,18] In BC, in 2000/1 there were an estimated 3800 full time equivalent primary care physicians. [17] In addition, there were approximately 1,000 surgical specialists, including approximately 225 General Surgeons, 175 Orthopedic Surgeons and 70 Plastic Surgeons and approximately 3,000 medical specialists (eg: internal medicine, emergency medicine) working in BC in 2001. [19]

5.4 RESULTS

5.4.1 Location of Initial Treatment

Ninety seven percent [97%, n=70,092] of individuals treated for a hand fracture in BC were initially seen as out-patients. Fifty two percent [52%, n=37,842) received their first documented treatment for a hand fracture in a non-hospital based out-patient setting, such as a doctor's office or an out-patient medical care clinic. Forty four percent [44%, n=31,772] were first treated in acute care medical setting, such as, an emergency room, urgent care or ambulatory care setting. Another 1% [n=489] were treated as an out-patient but the location of the treatment was not indicated in the data file. Only three percent [3%, n=2,389] were initially treated for the fracture as a component of a direct in-patient hospital admission. (See Figure 5-2)

5.4.2 Initial Out-patient Treatment Provider

Of those first treated as an out-patient [n=70,092], seventy percent [70%, n=48,762] received their initial documented care for their hand fracture from a primary care practioner. Nineteen percent [19%, n=13,296] received their initial treatment for a hand fracture by either a plastic or orthopedic surgeon, followed by nine percent [9%, n=6,146] initially treated by an emergency medicine physician. Only two percent [2%, n=1,228] were first treated by other medical specialists, and less then one percent [<1%, n=365] were treated initially by a non-medical specialist, such as, a chiropractor, naturopath, osteopath or therapist. (See Figure 5-3)

5.4.3 Associated Hospital Admissions

Ten percent [10%, n= 7,482] of people with a hand fracture had an associated hospital admission for hand fracture treatment of whom (as noted above) three percent [3%, n=2,389] had their initial fracture

management as a component of a direct hospital admission. Thus, seven percent [7%, n=5,093] were seen initially as an out-patient with a subsequent hospital admission. The overall provincial annual incidence rate for a hospital admission for treatment was 37 admissions per 100,000 people in BC. (See Table 5-2) Eighteen percent [18%, 2,442 / 13,800] of people initially treated as an out-patient by a surgeon specialist (Plastic, Orthopedic, or General Surgeon) had a subsequent hospital admission. Whereas, five percent [5%, 2,651 / 56,292] of people initially treated as an out-patient by a non-surgeon specialist had a subsequent hospital admission. (See Figure 5-4)

5.4.4 Type of Admission

Sixty percent [60%, n=4,463] of all hospital admissions [n=7,482] were for day surgery care and forty percent [40%, n=2,996] were an acute hospital admission. Less than one percent [<0.3%, n=23] of people with a hospital admission for hand fracture were treated while staying in an extended care or rehabilitation hospital. (See Figure 5-1) The provincial annual incidence rate for an acute hospital admission for treatment was 15 acute admissions per 100,000 people in BC, whereas, the provincial annual incidence rate for a day surgery admission for treatment was 22 day surgery admissions per 100,000 people in BC. (See Table 5- 2)

5.4.5 Physician Admitting to Hospital

Of the individuals who had an acute hospital admission [n=2,996], sixty-five percent [65%, n=1,937] were admitted to hospital by either an Orthopedic or Plastic surgeon. General or family practice physicians admitted twenty-one percent [21%, n=627] , while general surgeons accounted for five percent [5%, n=134] of physician admissions. The remaining ten percent of hospital admissions were distributed between other medical specialists. (See Table 5-3) Of the people who had a day surgery hospital admission [n=4,463], ninety-five percent [95%, n=4,248] were admitted to hospital by either an Orthopedic or Plastic surgeon. An additional three percent [3%, n=134] were admitted by a general surgeon. The remaining two percent of these hospital admissions were distributed between other medical specialists, including general or family practice physicians. (See Table 5-3)

5.4.6 Wait Time for Hospital Admission

The distribution for the time between initial contact and admission (waiting time) by type of hospital admission is presented in Figure 5-5. Of the 5,093 hospital admissions occurring after an initial out-patient treatment: thirty-nine percent [39%, n=1,993] happened on the same day as the initial out-patient treatment; fifty-eight percent [58%, n=2,934] were admitted within twenty-four (24) hours;and sixty-eight percent

[n=3,431] were admitted within forty-eight (48) hours. Eighty-four [84%,n=4,255] were admitted within a week and ninety-two [92%,n=4,663] were admitted within two weeks of the initial out-patient treatment. Ninety-five [95%, n=4,794] were admitted within thirty days and the remaining five percent [5%, n=299], were admitted after one month.

5.4.7 Length of Stay in Hospital

Six percent [6%, n=4.463] of all individuals with a hand fracture had an associated day surgery admission [LOS=0]. Four percent (4%, n=2,996) of people with a hand fracture had an acute admission (LOS $\geq$ 1 day). Of these, fifty- nine percent [59%, n=1,764] were admitted and discharged within one day. Eighty-six percent [86%, n=2,567] were discharged by the end of the first week, and ninety-one percent [91%, n=2,738] were discharged within two weeks. (See Figure 5-6)

5.4.8 Geographic Breakdown for Hospital Admissions

See Table 5-2 for the geographic breakdown for the annual incidence rates per 100,000 people and the relative rate comparisons for the different types of hospital admissions in the five health authorities in the province. People in the NHA had a much higher relative rate for a hospital admission (RR=2.1), including both a higher relative rate for a day surgery admission (RR=2.4) or an acute care admission (RR=1.7) compared to the overall provincial rates. Whereas, people in the FHA had a much lower relative rate for a hospital admission (RR=0.6), including both a lower relative rate for a day surgery admission (RR=0.6) or an acute care admission (RR=0.7) compared to the provincial rates. People in the VIHA had a greater rate for a day surgery admission (RR=1.5) compared to the rest of the province, with no increase for an acute care admission (RR=0.9). Whereas, people in the IHA showed the opposite finding, having a greater relative rate of an acute admission (RR=1.4) and no increase in a day surgery admissions (RR=1). People in the VCHA had no increase for an acute care admission (RR=1), but did have a much lower rate of day surgery admission (RR=0.6).

5.5 DISCUSSION

In BC almost all people with a hand fracture (97%) received initial treatment for their fracture as an out-patient, with the majority (52%) receiving their care in a non-hospital based setting and most (70%) receiving their initial out-patient care by a primary care physician. This finding suggests that most hand fracture injuries in BC are treated as a non-emergency. In part this may be due to the primary care physician model for health care, where there is likely to be a natural selection bias based on the severity of injury for where / and by whom a person might first seek treatment. It is reasonable to assume that people

with a simple or uncomplicated hand fracture would be more likely to seek their first medical treatment at a non-hospital based setting such as a primary care physician's office. Whereas people with more clinically significant hand fracture injuries, or a multiple trauma injury, would likely choose to go to a hospital emergency room setting for their initial care. Many countries do not have a similar role for, and access to, a family doctor in a universally accessible primary health care system. In these situations one could expect that a greater percentage of people with a simple hand fracture would likely choose to seek their initial treatment in a hospital based setting such as an emergency room.

We also found that nineteen percent (19%) of people with a hand fracture received their initial treatment for the fracture by either a Plastic or Orthopedic surgeon. Given that people in BC generally do not directly access surgeon specialists, it is likely that these patients were first seen by a primary care or emergency room physician but did not receive any definitive care for the hand fracture; rather they were referred to a surgical specialist for definitive diagnosis and initial treatment of the hand fracture.[20,21] This number also likely represents a referral bias, as it is more likely that the more severe hand fracture injuries would be referred on for primary hand fracture diagnosis and treatment by a specialist. This referral bias accounts for much of the difference found in the rates for subsequent hospital admissions for patients first treated by a surgeon specialist (18% admission rate) compared to those initially treated by non-surgeon specialists (5% admission rate).

Ninety percent (90%) of people with an identified hand fracture in BC were managed completely on an out-patient basis, suggesting that the vast majority of the hand fractures were uncomplicated clinical injuries that could be managed conservatively. This hospital admission rate for hand fractures in BC is low compared to the 19% hospital admission rate reported for distal radial fractures in the United Kingdom.[22] However, it is unlikely that any clinically significant surgical procedure for a complicated hand fracture or a surgical repair of other regional hand tissue trauma that may have occurred with the fracture would occur on an out-patient basis.[23,24]

Of the ten percent (10%) of hand fracture injures in BC with an associated hospital admission, six percent (6%) were day-surgery admissions. It is our assumption that these day surgical admissions likely represent the 'more clinically complex' hand fracture injuries as noted above.[22,23] Based on our findings it appears that in BC these more clinically complicated hand fracture injuries will almost always be treated by a surgeon specialist (98%), and that most (83%) will receive their surgery within a week of initial treatment as

an out-patient. The data did not allow for analyses of why there were delays in admissions greater than 100 days post an initial out-patient treatment for a hand fracture for a small percentage of people.

Four percent (4%) of all hand fracture patients had an acute hospital admission for which hand fracture treatment was a component of the admission. It is our assumption that this sub-group of people with an acute hospital admission likely represented the 'most severe' or significant trauma injuries, in which the person was likely to have also sustained other significant local, regional and / or systemic trauma in addition to a hand fracture and / or were more likely to have had other medical complications.[25,26] For this sub-group of more significant trauma injuries with a hand fracture, our findings again suggest that most (70%) will likely be admitted to the hospital by a surgical specialist. As well the vast majority (83%) will be either directly admitted to the hospital or admitted on the same day as their initial out-patient care and they will likely be in the hospital for a short period of time (59% LOS = 1 day; 87% LOS $\leq$ 7 days).

The reasons for the geographic variation in hospital admission rates for hand fractures in BC are not clear. It is plausible that much of the differences in rates are due to actual clinical differences in terms of the severity or complexity of hand facture injury. In a previous study it was determined that people in the NHA were at a 1.3 greatest relative risk for sustaining a hand fracture compared to the rest of the province.[4] If our assumptions are true regarding the relationship between greater fracture or trauma injury severity and the likelihood of either a day surgery or an acute hospital admission, it follows that people in the NHA are seemingly also at a much greater risk for sustaining more significant traumatic hand fracture injuries.

In addition, some of the regional differences in hand fracture admission rates may have been due to differences in physician choices and practice patterns. In some isolated rural communities people have limited access to specialist care and medical follow-up. Subsequently they may have to travel greater distances to receive definitive care for a severe traumatic hand injury. These types of cases may influence the choices physicians or surgeons make as to how or when to admit a person to hospital. However, this is not something we are able to discern from the data we have. Further prospective longitudinal cohort studies are needed to more clearly define how variables like clinical injury presentation, access to primary care and specialist physician care, systemic, and personal factors could affect physician decisions around hospital admissions in different geographic regions.

Finally, our finding of large geographic variations for hospital admission rates for hand fractures is consistent with another study by McGrail et al (2004) [18] examining the relationship between general health

and socio-economic indicators and health care utilization trends in BC. That study also determined that the highest rates for all hospital admissions occurred in the Northern regions and in the more rural, less populous areas of the province. It also noted that there was a moderate relationship between hospital admission rates and health status, with higher hospital admission rates occurring in regions of the province with lower health status indicators.[18]

There are a number of potential limitations associated with conducting a retrospective review of hand fracture data in the BCLHD administrative health services dataset and these have been described previously.[4] (See also Chapter 4.5 – Discussion) In addition, it should also be noted that the data for the location of out-patient treatment in this study should be viewed with some caution as the location for treatment in the MSP dataset is not monitored for accuracy.[14] As well, some of the very isolated and / or socio-economically deprived regions of the province may be under represented in the MSP dataset as most of the primary physician and emergency room health care services in these communities are provided under on an alternate payment program.[17,18] Similarly, emergency room data from two emergency rooms in the Vancouver area may be under represented as they also utilized an alternate payment program during part of this study.[27]

The extent to which our findings can be generalized to other geographic regions within Canada is hard to define. However, given the universal health care system, similar population demographics, diversity in geography, climate and levels of socio-economic development, we believe the health care utilization trends in this study are likely reflective of initial acute health care utilization trends for hand fractures treated throughout the rest of Canada. In addition, these trends are likely similar to other countries such as the United Kingdom, Australia, New Zealand and many Western European and Scandinavian countries. Like Canada they also have a universally accessible primary care model for acute health care service delivery, as well as, similar population demographics and levels of socio-economic development.

5.6 SUMMARY:

This study was a population-based study examining initial health care utilization trends for hand fractures in British Columbia, Canada. Despite the very common nature of this injury,[1,2,3] no previous study has examined the potential impact of initial acute hand fracture management on acute health care resources. This study provides a unique opportunity to examine initial acute health care utilization trends for all hand fracture injuries occurring in a large, diverse population, across a range of medical settings. This study was conducted in the context of the Canadian universally accessible, primary care model for acute health care

service delivery system where the primary care physician is the principle provider of non-specialized medical services.[15,16,17,18] In this health care context, the vast majority of hand fractures were managed conservatively on a non-emergent basis by a primary care physician. The more complicated hand fracture injuries that required a hospital admission were referred to surgical specialists. The majority of these received surgery in a day surgical setting within two days of initial treatment as an out-patient. In addition, the more rural, isolated and socio-economically deprived Northern region of BC had higher rates for hand fracture related hospital admissions. Findings from this study will allow clinicians and health care administrators to plan for provision of acute health care services for hand fracture patients in BC, and likely also across Canada.

CHAPTER 5: TABLES

Table 5-1: Data Definitions

Terms	Data Definition
Initial treatment: • Date • Location • Physician responsible.	Determined for each fracture by which event came first: • The date of service, associated physician code and service location code from the first occurrence of a Medical Service Plan (MSP) payment data record, or • The date of first hospital admission, the associated hospital code, type of admission code and physician responsible code in a Hospital Separation (HS) record.
Length of stay (LOS):	Extracted from the length of stay data field in the HS record.
Wait time:	Determined by the date difference (in days) between the initial out-patient service in the MSP record and the first subsequent hospital admission in the HS record.

Table 5-2: Hand Fracture - Regional Hospital Admission Rates and Relative Rate Comparisons

Health Authority (HA)	Acute: Rate / 100,000	Acute: Relative Rate	Day Surgery: Rate / 100,000	Day Surgery: Relative Rate	All: Rate / 100,000	All: Relative Rate
Fraser	9	0.6	15	0.7	24	0.6
Vancouver Coastal	15	1	14	0.6	29	0.8
Vancouver Island	13	0.9	33	1.5	46	1.2
Interior	21	1.4	22	1	43	1.2
Northern	25	1.7	52	2.4	77	2.1
Whole Province	15	Reference Standard (RR=1)	22	Reference Standard (RR=1)	37	Reference Standard (RR=1)

Table 5-3: Distribution of Physicians Responsible for All Acute and Day Surgery Hospital Admissions for Hand Fractures in BC.

Type of Physician	Acute				Day Surgery			
	Out-patient 1st	In-patient 1st / Only	ALL, Acute	%	Out-patient 1st	In-patient 1st / Only	ALL, Day Surgery	%
Orthopedic Surgery	551	420	971	32.4%	2075	452	2527	56.6%
Plastic Surgery	560	406	966	32.2%	1452	269	1721	38.6%
General Practioner	165	462	627	20.9%	48	15	63	1.4%
General Surgery	35	99	134	4.5%	101	33	134	3.0%
Other Medical	16	54	70	2.3%	2	4	6	0.1%
Neuro Surgery	3	47	50	1.7%	0	0	0	0.0%
Pediatrics	52	36	88	2.9%	9	2	11	0.2%
Psychiatry	9	32	41	1.4%	0	0	0	0.0%
Emergency	11	10	21	0.7%	0	1	1	0.0%
Unknown	5	23	28	0.9%	0	0	0	0.0%
Total	1407	1589	2996	100.0%	3687	776	4463	100.0%
%	47.0%	53.10%	100.0%		82.6%	17.40%	100.0%	

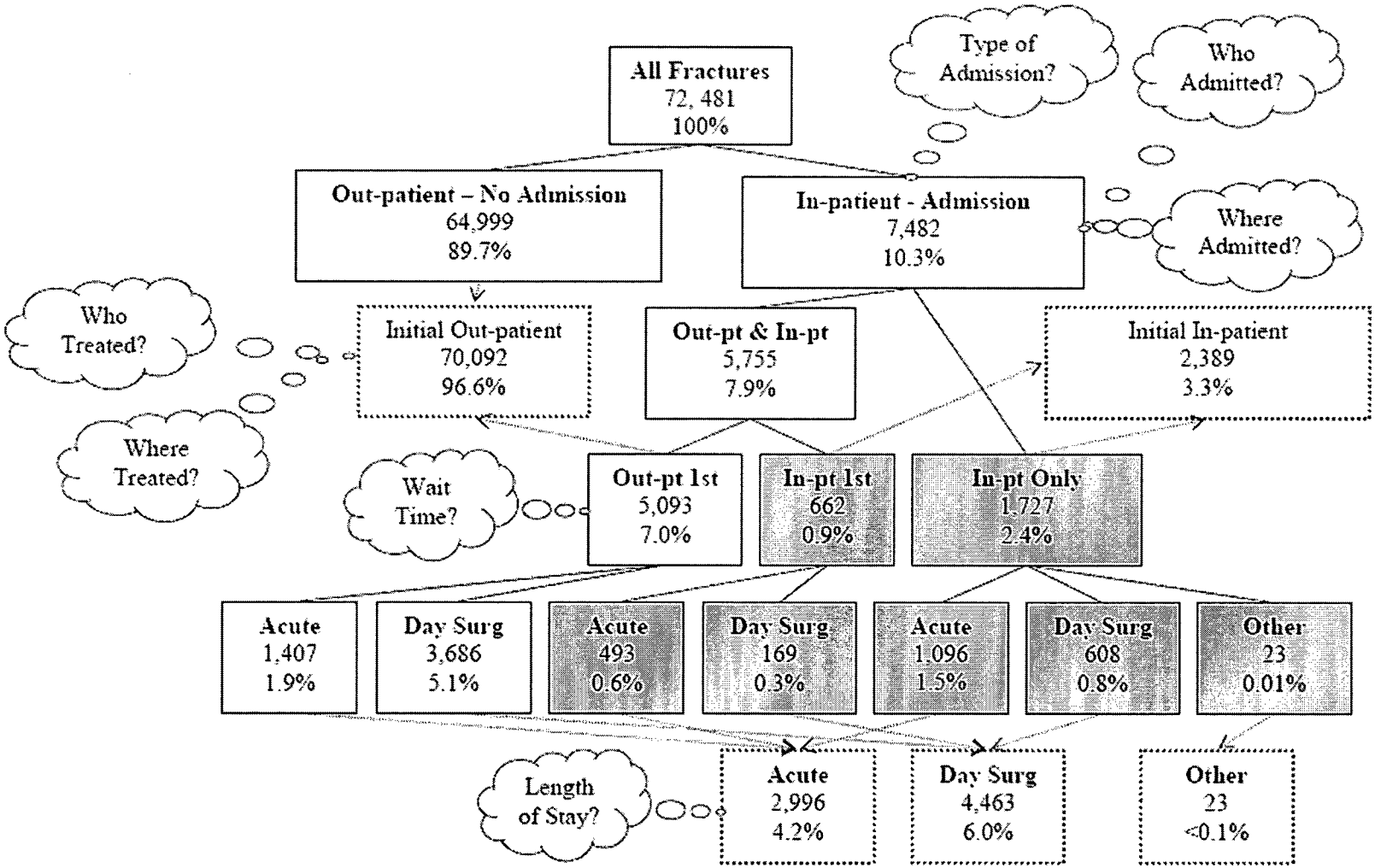

Figure 5-1 Hand fractures in BC - Initial health care utilization flow chart. The "cloud" call-outs highlight the specific health care utilization questions addressed in this study.

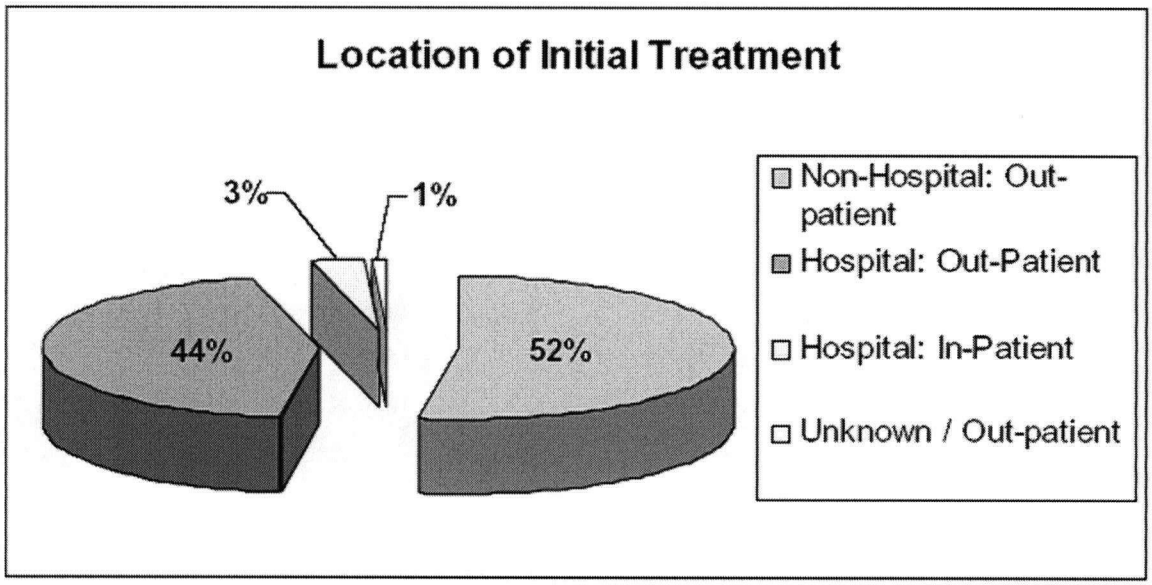

Figure 5-2: Location of initial treatment for a hand fracture presented as percentage of all fractures (N = 72,481).

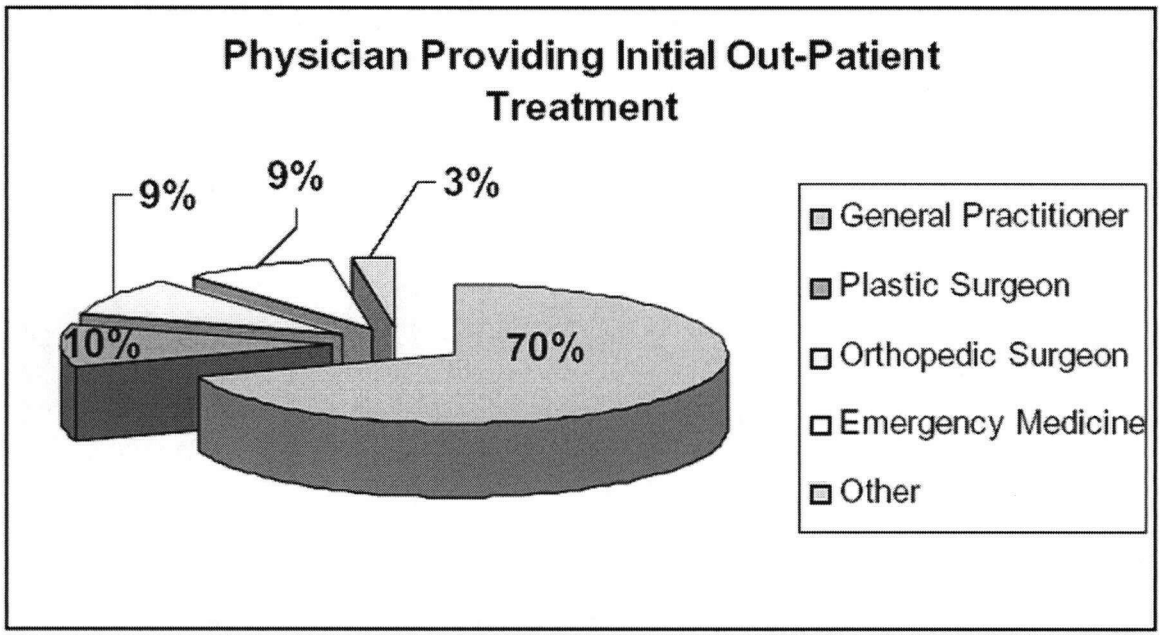

Figure 5-3: Percentage breakdown by type of physician providing the initial out-patient treatment for a hand fracture (N = 70,092).

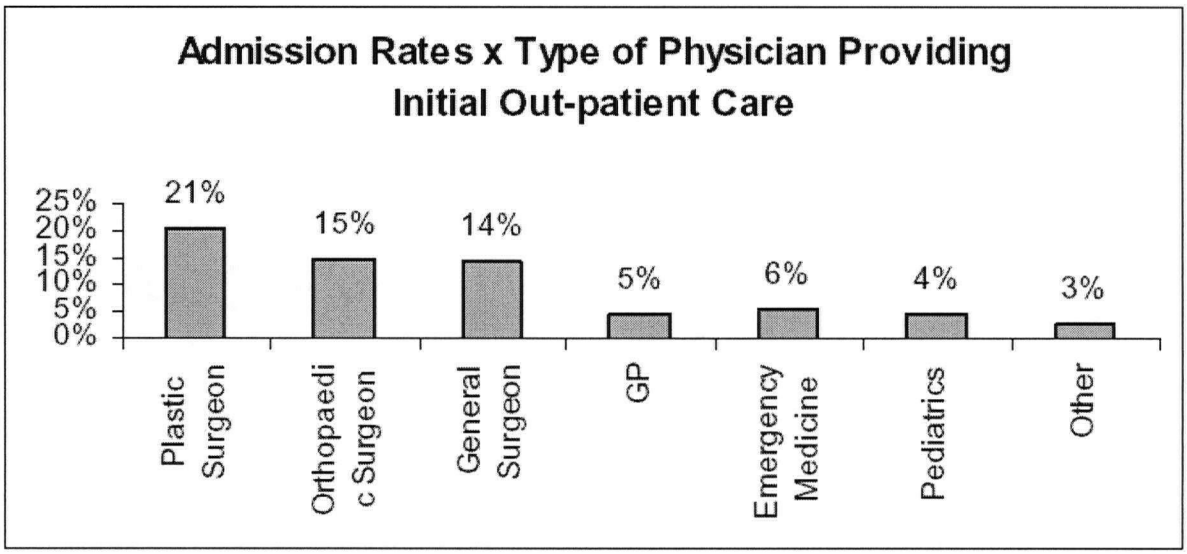

Figure 5-4: Percentage breakdown for subsequent hospital admission rates by type of physician providing the initial out-patient care for the hand fracture (N = 5,093).

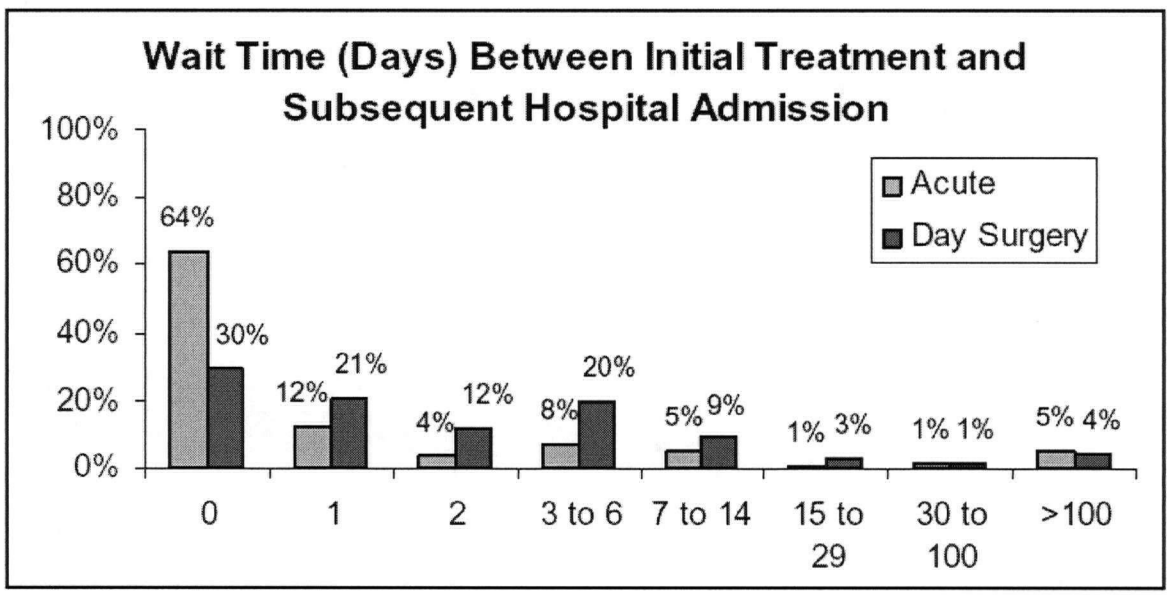

Figure 5-5: Percentage breakdown for waiting time in days between initial out-patient management and first hospital admission for hand fracture treatment. Presented by type of admission (N=5,093).

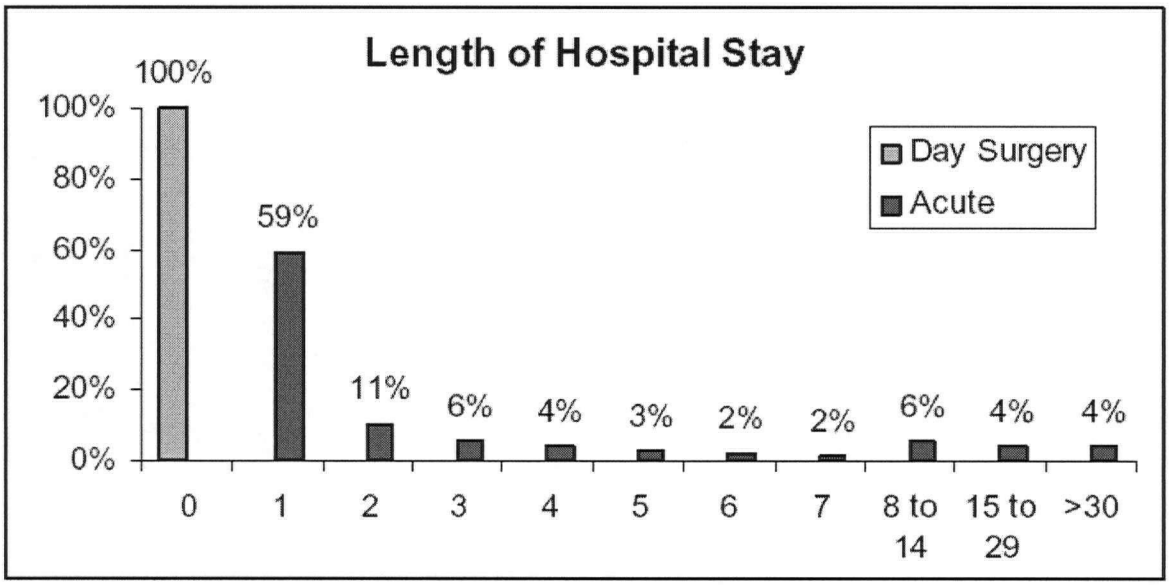

Figure 5-6: Percentage breakdown for length of hospital stay (LOS) for hand fracture treatment for acute or day surgery admissions (N = 7,459)

CHAPTER 5: REFERENCES

1. Cooper C, Dennison EM, Leufkens HG, Bishop N, van Staa TP. Epidemiology of childhood fractures in Britain: a study using the general practice research database. J Bone Miner Res. 2004 Dec;19(12):1976-81.
2. Johansen A, Evans RJ, Stone MD, Richmond PW, Lo SV, Woodhouse KW. Fracture incidence in England and Wales: a study based on the population of Cardiff. Injury. 1997 Nov-Dec;28(9-10):655-60.
3. British Columbia Government, BC STATS service BC, Ministry of Labour and Citizens' Services. (http://www.bcstats.gov.bc.ca)
4. Feehan LM, Sheps S. Incidence and Demographics of Hand Fractures in British Columbia, Canada: A Population Based Study. J Hand Surg 2006; 31A:(Accepted June 7. 2006)
5. Bromback LG, Ekdahl PH, Aschan GW, Grenabo JK. Clinical and socio-economical aspects of hand injuries. Acta Chri Scand. 1978;144:455-61.
6. Mathur N, Sharma KK. Medico-econimic implication of industrial hand injuries in India. J Hand Surg [Br]. 1988;13(3):325-27.
7. Langlais F, Thomazeau H, Bourgin T, Derennes A, Allard G. [Socio-professional evaluation of 184 patients with hand injuries treated in an emergency microsurgery service.] (Article in French) Ann Chir Main Memb Super 1990;9(4):252-60.
8. O'Sullivan ME, Colville J. The economic impact of hand injuries. J Hand Surg [Br]. 1993;18(3):395-98.
9. Grys G, Uszynski H, Sawicki G, Orlowshi J. [Socioeconomic sequelae to hand injuries] (Article in Polish). Chir Narzadow Ruchu Ortop Pol. 1998;63(1):67-71.
10. De Jesus T, Castro C, Garcia LH, Posnett JW. Work-related finger fracture costs: a quality assessment of the Instituto Mexicano del Seguro social medical care services. Rev Med IMSS 2003; 41(4):305-312
11. Trybus M, Guzik P. [The economic impact of hand injury.] (Article in Polish). Chir Narzadow Ruchu Ortop Pol. 2003;68(4):269-73.
12. Raimbeau G. [Costs of hand emergencies] (Article in French). Chir Main. 2004;22(5):258-63.
13. Rosberg HE, Carlsson KS, Dahlin LB. Prospective study of patients with injuries to the hand and forearm: costs, function and general health. Scand J Plast Reconstr Surg Hand Surg. 2005;39(6):360-69.
14. Center for Health Services and Policy Research (CHSPR) at the University of British Columbia. (http://www.chspr.ubc.ca/Bclhd
15. Health Canada. Health Care System. (http://www.hc-sc.gc.ca)
16. Canadian Health Care. (http://canadian-healthcare.org)

17. Watson DE, Brueger H, Mooney D, Black C. Planning for Renewal: Mapping Primary Health Care in British Columbia. Vancouver, BC: Center for Health Services and Policy Research; January 2005. (http://www.primary-care.chspr.ubc)
18. McGrail KM, Schaub P, Black C. The British Columbia Health Atlas. 2nd Edition. Vancouver BC: Center for Health Services and Policy Research; May 2004. (http://www.health-atlas.chspr.ubc.ca)
19. Canadian Medical Association. Statistical Information on Canadian Physicians. (http://www.cma.ca)
20. Maitra A, Burdett-Smith P. The conservative treatment of proximal phalangeal fractures of the hand in an accident and emergency department. J Hand Surg [Br]. 1992;17(3):332-36.
21. Hill C, Riaz M, Mozzam A, Brennen MD. A regional audit of hand and wrist injuries. A study of 4873 injuries. J Hand Surg [Br]. 1998;23(2):196-200.
22. O'Neill TW, Cooper C, Finn JD, Lunt M, Purdie D, Reid DM, Rowe R, Woolf AD, Wallace WA; UK Colle's Fracture Study group. Osteoporos Int 2001;12(7):555-58.
23. Freeland AE, Lund PJ. Metacarpal and phalangeal fractures. In: Russell RC (ed.) Plastic Surgery: Indications, Operations and Outcomes. (Vol. 4 - Hand Surgery). Toronto, Mosby; 2000:1845-1864.
24. Stern PJ. Fractures of the metacarpals and phalanges. In: Green DP, (ed). Operative Hand Surgery (3rd ed). New York: Churchill Livingstone Inc. 1993:695-758.
25. Schaller P, Geldmacher J. [Hand injury in polytrauma. A retrospective study of 782 cases.] (Article in German) Handchir Mikrochir Plast Chir. 1994;26(6):307-12.
26. Aldrian S, Nau T, Weninger P, Vecsei V. [Hand injury in polytrauma] (Article in German) Wien Med Wochenschr 2005;155(9-10):227-32.
27. McKendry R, Reid RJ, McGrail KM, Kerluke KJ. Emergency rooms in British Columbia: A pilot project to validate current data and describe users. Center for Health Services and Policy Research, HPRU 02:16D, December 2002.

CHAPTER 6: EFFECT OF EARLY CONTROLLED PASSIVE MOTION ON 4-POINT BENDING STRUCTURAL PROPERTIES AND FRACTURE ALIGNMENT IN A RABBIT MODEL.*

6.1 RESEARCH QUESTION ADDRESSED IN THIS CHAPTER

How does early controlled passive motion affect the quality and rate of early fracture healing in a rabbit model?

6.2 INTRODUCTION

Early controlled mobilization is commonly used following primary flexor tendon repairs and other equally fragile or potentially "unstable" healing tissues in the hand, but it is not recommended for potentially unstable extra-articular hand fractures.[1-5] Rather, it is recommended that potentially unstable fractures be treated with some form of additional internal or external fracture fixation to facilitate early active regional joint motion or be managed with complete regional hand and wrist joint immobilization for a period of three or more weeks. [1-5] The rationale for this clinical strategy in potentially 'structurally fragile' fractures is that early regional joint motion of any form may cause excessive motion at the fracture site and disrupt early fracture healing and / or fracture alignment. [6, 7]

Interestingly, these were the same concerns expressed in the middle to late 1970s when surgeons and therapists were considering early controlled mobilization of potentially unstable or fragile healing primary flexor tendon repairs. However, despite these initial reservations, related research over the ensuing years demonstrated that early controlled mobilization of healing primary flexor tendon repairs can lead to improved biologic healing, faster strength gains, no increased risk of structural failure (rupture) and better and faster functional recovery of the affected individual. [8-10]

The effect of early controlled fracture motion on early fracture healing has been extensively studied in many different animal models. [11-32] These studies clearly demonstrate the positive effects of early limited or controlled cyclic, usually compressive, micro-strain on influencing the rate and type of early tissue differentiation in secondary fracture healing. However, none of these studies utilized a non-weight bearing limb, closed, diaphyseal fracture that was managed without any additional internal or external fracture

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fixation. Therefore, their theoretical application to the management of a closed, potentially unstable, extra-articular hand fracture is limited.

Early controlled passive motion of one or both joints adjacent to a closed, extra-articular fracture has the potential to generate controlled, cyclic, physiologic loads at the fracture, thereby, having a positive influence on early fracture healing. However, to date, the types of forces generated and / or the amount of fracture motion produced by passive motions of joints adjacent to a healing fracture have not been specifically examined. Therefore, it is also possible that early controlled passive motion of joints adjacent to a potentially unstable, closed, extra-articular hand fracture has the potential to have a negative influence on early fracture healing.

This research project examined the introduction of early controlled passive motion into the management of closed, potentially unstable, extra-articular hand fractures managed without any additional fracture fixation, a possible alternative to acute fracture immobilization.[7] Early controlled passive motion has the potential to enhance early fracture healing, improve hand soft tissue and joint mobility and increase a person's ability to use their hand throughout their recovery. However, clear clinical parameters for the 'safe' introduction of early controlled passive motion interventions have not been defined.[7]

Therefore, the objective of this study was to conduct a pre-clinical efficacy study, investigating in a rabbit model if early controlled passive motion was likely to cause harm with regard to affecting the quality and rate of early fracture healing in a non-weight bearing limb, closed, potentially unstable, diaphyseal fracture. Our null hypothesis was that during the initial twenty eight day healing period, when compared to fractures treated with immobilization (standard care), fractures treated with early controlled passive motion (a novel intervention) would show no significant difference in either fracture callus four-point bending structural properties or fracture callus dorsal angulation.

6.3 MATERIALS AND METHODS

6.3.1 Study Design

A pre-clinical, block-randomized, single blinded (blinded outcome evaluation), efficacy trial examining two treatment conditions [Immobilized (IM: Standard care) vs. Early Controlled Passive Motion (ECPM: Novel Intervention)] at three time periods (Five Days, Fourteen Days, and Twenty Eight Days), with a pooled variable at five days, in which all the rabbits in this time period acted as the baseline for both treatment conditions. (See Table 6-1)

6.3.2 Clinical Parameters

This study examined whether early controlled passive motion could work in an idealized, simulated hand, potentially unstable, closed, diaphyseal fracture in a rabbit model. In addition, we investigated the clinical issue of 'cause no harm' by examining whether early controlled passive motion (a novel intervention) was the same or better than immobilization (standard care). Our primary clinical end-point was day twenty eight, the point when hand fracture immobilization normally ends.[1,5] Our primary clinical outcome was four-point bending 'Initial' stiffness, or the point when the callus initially begins to resist a four-point bending load. The rationale being that initial resistance to a bending load would be similar to a 'clinical stability' test when a healing fracture is gently stressed to determine if there is pain and / or motion at the fracture site. Our secondary clinical outcome was dorsal angulation, the most common pattern of mal-union following a metacarpal fracture.[1,5]

6.3.3 Animal Fracture Healing Model

This study used a non-weight bearing limb, right, rabbit forepaw, closed, three-point bending, third metacarpal shaft fracture healing model. The rabbits used in the study were skeletally mature, female, New Zealand White rabbits. The female New Zealand White rabbit was selected partly due to its size, availability, and ease of handling.[34] In addition, the New Zealand White rabbit muscle, tendon and bone anatomy in the forepaw is very similar to human hand anatomy.[35,36] Finally, the New Zealand White rabbit cortical bone has primary osteon morphology, similar to human cortical bone and is a common animal model in fracture healing studies.[37]

Fifty four rabbits were utilized. There were four withdrawals from the study, only one for a protocol violation (Twenty Eight days – Immobilized) in which the rabbit was found completely out of its metacarpal splint at ten days. The other three withdrawals were for other reasons. (See Table 6-2) The rabbits withdrawn from the study were not replaced. Fifty rabbits completed the study for a ninety three percent completion rate. They ranging in age from five to seven months (mean: twenty eight weeks) and weighed from 3.5 to 5.0 kg (mean: 3.8 kg).

Rabbits were allowed at least one week to acclimatize to the animal care facility, including daily handling and cleaning activities. They were housed communally in groups of two or three in large plastic bins (1.0 x 1.5 x 1.0 m) lined with newspaper and edible alfalfa hay bedding. All rabbits had free access to food pellets and water, as well as, daily treats of carrots and apples. This study received institutional ethical approval and was in compliance with the Canadian Council on Animal Care guidelines.(See Appendix 6-1)

6.3.4 Study Flow

Rabbits were introduced into the study at a rate of three rabbits per week. (See Figure 1) One week prior to creating the fracture, the rabbits were anesthetized and fit with a shoulder spica cast (~45° shoulder girdle forward flexion) and elbow flexion splint (~45° elbow flexion) that eliminated the rabbit's ability to weight bear through the forepaw. (See Figure 6-2-A) They were then pre-fit with a custom molded low temperature thermoplastic metacarpal fracture brace (ORFIT, Classic Soft, 2.0 mm thickness, micro-perforated. Medical Tronix Ltd, Laval, Quebec), (See Figure 6-2-B) followed by an additional "bumper splint" made of remnant splinting materials covered with wire meshing. (See Figure 6-2-C) The bumper splint completely covered and protected the forepaw from ongoing normal daily bumping and chewing activities. The rabbits were allowed one week to adapt to the non-weight bearing bracing system. During this time they were handled daily, carefully checked for any pressure sores and any necessary modifications were made to the splints.

On day zero, a closed, right, third metacarpal, three-point bending fracture was created in anesthetized rabbits using specially adapted three-point bending pliers. (See Figure 6-3-A and B) Fractures were reduced under fluoroscopy (See Figure 6-3-C and D), and the paws were placed back into the custom molded fracture brace. During the next four days rabbits were given twice daily pain medication and were allowed to rest and recover in a quiet environment.

On day five, the rabbits were serially allocated to the fourteen day or twenty eight day time periods and then independently randomly block allocated by sealed envelope to treatment condition within the block. In addition to random allocation to either immobilization or early motion within the blocks, there was also a random distribution of six, five day treatment conditions in each of the fourteen day and twenty eight day time period block randomization envelopes. Rabbits allocated to the five day time period acted as the baseline for both treatment conditions and were immediately euthanized.

The early controlled passive motion protocol used was adapted from early passive motion protocols commonly used following early flexor tendon repairs.[9,10] Where the early passive motion rabbits received two daily sessions [four cycles / minute x fifteen minutes = sixty full motion cycles / session] of full arc passive flexion and extension digital joint motion [3 seconds to full passive digital flexion, 6 second hold, 2 second relax into full extension, 4 second rest] with additional gentle localized 'pinch' fracture stabilization. (See Figure 6-4) All early controlled passive motion was done by two experienced certified hand therapists. Each rabbit received one session a day by each of the therapists. The immobilized group received no further direct intervention to their fractured forepaw but did receive daily handling and holding. At the end of

the allocated time-period the rabbits were euthanized, the forelimbs were disarticulated, coded, labeled, and then fresh frozen and stored at -20° centigrade.

6.3.5 Blind Outcome Evaluation

The third metacarpals were serially dissected out of the frozen forepaws. Peripheral quantitative computed tomography [XCT 2000 scanner, Norland Corp, Fort Atkinson, WI, USA. Scan resolution: 0.1 x 0.1 x 2.2mm] (See Chapter 7.3.2) and lateral digital x-ray [100 mm, 55kv, 200 mA, 1.8 mA/s] images were taken of the frozen metacarpals. (See Figure 6-5) Specimens were then warmed to approximately 37° centigrade in normal saline and tested to structural failure in a quasi-static, four-point bending mode (Dynamight, Instron Corp, Canton, MA). Specimens were first pre-conditioned (stabilized) with an initial 0.1 mm displacement held for one minute, and then tested to failure in the dorsal-volar direction at a rate of 0.1 mm/sec [Span: Lower 14 mm, Upper 9 mm]. (See Figure 6-6-A and Appendix 6-2)

Fracture location and fracture pattern were determined from the lateral digital x-rays using eFILM Workstation 1.9 software (Merge Healthcare, Mississauga, ON). Fracture location was defined as the distance from the distal articular surface to the fracture line on the dorsal cortex, divided by the total length of the third metacarpal and multiplied by one hundred (percentage of total length). Fracture pattern was evaluated based on the direction of the fracture line(s) through the volar cortex (compression side), as all fractures broke with a transverse fracture pattern through the dorsal cortex (tension side). (See Figure 6-7).

Dorsal angulation was measured from the lateral digital x-ray (See Figure 6-5-A). The mean of two independent measures of dorsal angulation was used [Test-retest reliability: Pearson $r = .95$, $p<0.01$]. Peripheral quantitative computed tomography scan analysis was done using the XCT 5.50 analysis software (Norland Corporation, Fort Atkinson, WI, USA). The callus total area was determined using a CALBD analysis, with Contour Mode 1 [Threshold 0] and Peel Mode 2 [Threshold 811] with the filter on. (See Figure 6-5-B) The test-retest reliability for measuring total callus area with pQCT imaging [Pearson $r = .96$, $p<0.01$] was previously determined in four calluses imaged twice on two separate days. The accuracy of peripheral quantitative computed tomography image total callus area (+/- 4 to 6%) was previously determined in three calluses by comparing peripheral quantitative computed tomography total callus area measures to the mean digital photo image measures of total callus area in three consecutive histological slides (50μ, x 100 magnification) of undecalcified, cross-sectional images of the fracture callus corresponding to the 2.2 mm peripheral quantitative computed tomography scan location.

Four-point bending structural properties for failure load, initial stiffness, maximum stiffness, and energy to failure were determined from the load-displacement data. (See Figure 6-6-B) Failure load (N) was defined as the peak load at structural failure (>10% drop in load). Maximum stiffness (N/mm) was taken as the maximum slope of a ten point window in the linear region of the load-displacement curve. Initial stiffness (N/mm) was taken as the slope of a ten point window of the load-displacement curve beginning at the x-intercept of the maximal slope line (Figure 6-6-B). Energy to failure (Nmm) was calculated from the area under the curve between the x-intercept of the maximal slope line and failure displacement. Each of these structural properties was also normalized by dividing by total callus area, to obtain a per unit area measure.[38]

6.3.6 Statistical Methods

Statistical analyses were done using SPSS 11.0 software (SPSS Inc, Chicago, IL). Our primary analysis was a General Linear Model (GLM) two by three u nivariate analyses. The post-hoc analyses for significant main effects were examined with a Sidak multiple pairwise comparison test within timeline and a single Independent T-test comparing early controlled passive motion and immobilized calluses at twenty eight days. Significant interaction effects were explored using simple main effect and Sidak pairwise analyses examining the effect of treatment condition within time period, as well as, time period within treatment condition. In addition, the percentage difference between early controlled passive motion and immobilized calluses at twenty eight days was calculated [ECPM-IM / (average ECPM, IM)].

6.4 RESULTS

All fractures were located in the mid-shaft region of the metacarpal [Mean 50% site, SD: +/- 5 %; range: 40 to 64%]. There was no difference in the distribution of type of fracture pattern across the treatment conditions and time periods. [Chi Square; χ^2 (16, N=50) = 11.25, p = .79] (See Table 6-3)

6.4.1 Initial Stiffness (Primary Clinical Outcome)

(See Tables 6-4 and 6-5 and Figure 6-8-A) Time and treatment condition had significant effects ($p < 0.02$) on the initial stiffness of the healing fracture. There was also a significant interaction effect in which the effect of time was stronger in the early passive motion fractures than it was in the immobilized fractures ($p = 0.03$). Simple main effect and post-hoc pairwise comparison analyses examining the effect of time period within condition determined that time significantly influenced initial stiffness for both treatment conditions ($p < 0.01$) across all three time periods ($p < 0.01$). Simple main effect and post-hoc pairwise comparison analyses examining the effect of condition within time period determined that the two treatment conditions were only significantly different from each other at the twenty eight day time period ($p < 0.01$).A t the twenty

eight day time point, there was a twenty nine percent difference in initial stiffness between the early motion and immobilized calluses, with the early motion calluses having the greater stiffness.

6.4.2 Fracture Dorsal Angulation (Secondary Clinical Outcome)

(See Tables 6-4 and 6-5 and Figure 6-8-B) Time ($p < 0.01$) and treatment ($p < 0.03$) condition also had a significant effect on fracture dorsal angulation. The five day fractures were significantly more dorsally angulated than the twenty eight day fractures ($p < 0.01$), but not significantly different from the fourteen day fractures ($p < 0.08$). Overall, the early controlled passive motion fractures were significantly straighter than the immobilized fractures ($p<0.03$). Across the twenty eight day time period the early controlled passive motion fractures showed a thirteen degree improvement in dorsal fracture alignment. The early motion fractures started at a mean of 29.7 degrees of dorsal angulation at five days and ended with a mean of 16.4 degrees of dorsal angulation at twenty eight days, with most of this change (ten degrees) occurring between the five and fourteen day period. The immobilized fractures only showed a five degree change in dorsal fracture angulation throughout the twenty eight days. At the twenty eight day time point, early controlled passive motion fractures were significantly straighter than the immobilized fractures ($p< 0.05$; 33% difference).

6.4.3 Total Callus Area

(See Tables 6-4 and 6-5 and Figure 6-8-C) Time had a significant effect on total callus area ($p<0.01$), whereas, treatment condition did not ($p = 0.27$). All calluses increased in size significantly from five days to fourteen days and then subsequently significantly decreased in size from fourteen to twenty days. The twenty eight day calluses remained significantly larger than baseline calluses. Overall, the early controlled passive motion and immobilized calluses were not significantly different in size from each other ($p = 0.27$)

6.4.4 Other Structural Properties (Failure Load, Maximum Stiffness and Energy to Failure)

(See Tables 6-4 and 6-5 and Appendix 6-3) Both time and treatment condition had a significant effect on failure load and maximum stiffness ($p < 0.03$), whereas, only time had a significant effect on energy to failure ($p<0.01$). All calluses showed significant gains in both failure load and maximum stiffness across all three time periods. Five day calluses absorbed significantly less energy to failure ($p<0.01$) than did the fourteen and twenty eight days calluses, which did not differ significantly from each other in terms of energy absorbed to failure ($p=.38$) Overall, the early controlled motion calluses showed significantly greater failure load and maximum stiffness than immobilized calluses. At the twenty eight day time point, only maximum stiffness was significantly greater ($p < 0.05$, 21% difference) in the early controlled passive motion calluses compared to the immobilized calluses.

6.4.5 All Structural Properties Normalized by Total Callus Area

(See Tables 6-4 and 6-5) When structural properties were normalized by dividing by total callus area; initial stiffness, maximum stiffness and failure load all remained significantly affected by both time and treatment condition ($p<0.03$). In addition, all three of these parameters demonstrated marked increases in the actual percentage difference between early controlled passive motion and immobilized calluses at the twenty eight day time point, with the early motion calluses being greater in all cases. Initial stiffness increased from a 29% to 37% difference, maximum stiffness increased from a 21% to 29% difference and failure load increased from a 17% to 24% difference.

When energy to failure was normalized per unit area, treatment condition became statistically significant ($p<0.05$). Overall, the early controlled passive motion calluses showed significantly increased gains in energy absorbed per unit area ($p < 0.05$) than did the immobilized calluses throughout the twenty eight day time period. However, at the twenty eight day time point, the early controlled passive motion calluses were not significantly different from the immobilized calluses with regard to energy absorbed per unit area ($p< 0.21$; 21% difference). (See Appendix 6-3)

6.5 DISCUSSION

Early active motion of one or both joints adjacent to a fracture, often introduced in combination with a regional functional fracture brace, has been recommended as a treatment option following a closed, stable, extra-articular hand fractures by a number of authors.[39-56] Sarmiento and Latta (1999)[57] in particular, have been long time advocates for the use of functional fracture bracing in the management of stable, closed, extra-articular fractures. Latta (1980)[58], stated that 'Fracture Bracing' is a philosophy rather than merely the use of orthotic devices, predicated on the belief that immobilization of the joints above and below the fracture is not necessary for secondary fracture healing.[7]

However, the clinical decision for when it might be considered appropriate to allow early active regional joint motion still rests on a mostly subjective determination of a fracture's inherent clinical or structural 'stability'. Ultimately, there are still a number of clinical scenarios for when a closed, extra-articular hand fracture, treated with or without any additional fracture fixation would be perceived to not have enough clinical or structural stability to be able to withstand early active regional joint motion.[2] This study examined another early motion alternative, early controlled passive joint motion, as a potential alternative to acute fracture immobilization in potentially unstable extra-articular hand fractures.[7]

The early controlled passive motion intervention used in this study closely replicated the early controlled passive motion interventions commonly used after a primary flexor tendon repair in the hand.[9] However, in this study early controlled passive motion was applied in the clinical scenario of a potentially unstable, closed, extra-articular, metacarpal fracture in a rabbit healing model. The early physiologic loads at the fracture were generated by twice daily, fifteen minute sessions, of composite passive digital flexion and extension joint motion distal to the fracture, combined with gentle localized 'pinch' stabilization at the fracture site during motion.

In our study we found that early controlled passive motion significantly improved an early fracture callus's ability to resist and bear four-point bending loads, and that these improvements were not due to the fracture laying down a bigger callus. The reason for this is not clear. However, other studies have also shown improvements in the early biomechanical properties of healing fractures following early motion, without demonstrating a marked increase in callus size.[18, 26, 33] It may be that in our study the early controlled passive joint motion intervention provided enough of a mechanical stimulus to have a positive influence on early tissue differentiation within the callus without causing excessive motion at the fracture site; a known stimulus for a fracture to lay down a bigger periosteal callus.[32] In addition, our study also demonstrated that when the four point bending structural properties were normalized by dividing by total callus area to get a per unit area measure for each structural property, that the percentage difference between early controlled passive motion and immobilized calluses at twenty eight days for all the structural properties increased. This finding suggests that the improved early structural properties seen in the early controlled passive motion calluses may be due to differences in early fracture callus mineralization or tissue morphology; either in terms of differences in the geometric distribution of the mineralized and non-mineralized tissue within the callus and / or in terms of differences in overall mineralized tissue content in the callus.

In this study, we did not specifically examine fracture callus mineralization or fracture callus histomorphology so we are unable to speculate how early controlled passive motion may have influenced early fracture callus morphology. However, other studies have reported an increase in early fracture callus mineralization, as well as, regional differences in the distribution of early woven bone in the fracture callus in early motion fractures.[13, 16, 20-28, 31-33] We are currently conducting histomorphologic and peripheral quantitative computed tomography imaging studies to determine if there are any quantitative morphologic differences in the fracture calluses treated with early controlled passive motion compared to immobilization.

Finally, we also found that early controlled passive motion significantly improved the degree of dorsal fracture angulation throughout the twenty eight day time period, with most of this improvement occurring during the initial fourteen days. This improved fracture alignment was likely due to the 'pinch' stabilization of the fracture during early controlled passive motion. The gentle 'pinch' was intended to provide localized fracture stabilization in an effort to counter any potential dynamic deforming forces associated with passive regional joint motion. However, the localized pressure at the fracture seemingly also molded the malleable fractures during this early fracture healing period without adversely affecting the quality and rate of the healing fracture. Although not previously described, the effect of a gentle serial reduction of the fracture during the early stages of healing seen in this study may well be the same desired effects sought by traditional bone setter in many cultures over the centuries. [59]

It is important to note the limitations of this study. The first is the issue of the validity of applying research findings from a fracture healing model in rabbits to humans. However, given there have been no clear clinical parameters for the 'safe' introduction of early controlled passive motion interventions defined, it was appropriate to first test the potential clinical efficacy in an animal model.[7] The rabbit is a common healing model for fracture healing studies. [60] Unlike avian and rodent bone, the rabbit cortical bone has primary osteon morphology in the inner region of the cortex with peripheral lamellar bone in the periosteal and endosteal regions, similar to human cortical bone. [37, 59] As well, the patterns of secondary fracture healing described in rabbit fracture healing studies are very similar to those described in human fracture healing. [61, 62]

In addition, the regional anatomy of the rabbit forepaw is very similar to the human hand. The forepaw has five digits, with smaller rays for the first and fifth digit. The second through fourth digits are very similar to the human hand in terms of relative size of the bones and joint architecture. As well, the rabbit forepaw metacarpal bone is very similar in shape to the human hand metacarpal bone, with markedly similar regional intrinsic muscle and flexor and extensor tendon anatomy in the metacarpal region of the forepaw. [35] Other than using a primate hand fracture healing model, the rabbit forepaw, closed, non-weight bearing diaphyseal fracture healing model utilized in this study was as close as we could come to simulating a potentially unstable, closed, extra-articular human hand fracture in an animal model. Additionally, given the similarity in regional anatomy, we believe the passive digital motion used in this study was likely to have generated similar relative physiologic loads at the fracture site as would be generated using a similar early controlled passive motion treatment intervention in the human hand.

The final issue is with the use of an idealized fracture healing model and treatment intervention scenario, where the characteristics of the fracture and the compliance with the treatment intervention are experimentally controlled; not necessarily representative of the clinical scenario for the implementation of early controlled passive mobilization following an extra-articular hand fracture in a human population.

6.6 CLINICAL RELEVANCE

In our study early controlled passive motion did not cause harm with regard to affecting either the quality or rate of early fracture healing in a potentially unstable, closed, extra-articular, fracture in this rabbit fracture healing model. Rather, early controlled passive motion lead to statistically ($p \leq 0.05$) and clinically (> 25% difference between the groups at 28 days) significant improvements in both our primary and secondary clinical outcomes of interest. In this idealized simulated hand fracture healing model, early controlled passive motion improved an early fracture callus's ability to initially resist a four-point bending load, as well as, early fracture dorsal alignment. Therefore, early controlled passive mobilization passive following a closed, potentially unstable, diaphyseal hand fracture warrants further clinical consideration.

CHAPTER 6: TABLES

Table 6-1: Study Design. [N=54, 4 Withdrawn (wd), 50 completed] All rabbits at five days were nested, acting as the baseline for both treatment conditions. The remaining rabbits were first serially allocated to either the fourteen or twenty eight time period and then randomly block allocated to either the Early Passive Motion or Immobilization treatment conditions.

Immobilized (Standard Care)	**Early Passive Motion** (Novel Intervention)	
n=11 (1wd)		**5 Days** (Baseline)
n=9 (1wd)	n=9 (1wd)	**14 Days**
n=10 (1wd)	n=11	**28 Days**

Table 6-2: Reasons for Withdrawal from the Study (n=4).

Reason for Withdrawal	Treatment Condition / Timeline
Failed Mechanical Testing	5 Days
Failure to Thrive, Euthanized @ 7 days	Immobilized – 14 Days
Out of Splint @ 10 Days	Immobilized – 28 Days
Unexplained Death @ 10 Days	Early Motion – 14 Days

Table 6-3: Fracture Pattern Distribution by Time Period and Treatment Condition

	5 Days (Baseline)	14 Days, EM	14 Days, IM	28 Days, EM	28 Days, IM	Total
Oblique Proximal	4	3	4	2	2	15
Transverse	2	0	2	2	2	8
Oblique Distal	3	2	2	2	2	11
Butterfly	2	3	0	2	1	8
Butterfly Displaced	0	1	1	3	3	8
Total	11	9	9	11	10	50
[Chi Square; χ^2 (16, N=50) = 11.25, p = .79]						

Table 6-4: Summary Data - All Outcomes [Mean (+/- SD); N=50]

	5 Days	14 Days		28 Days	
	BL (n=11)	**IM (n=9)**	**ECPM (n=9)**	**IM (n=10)**	**ECPM (n=11)**
Initial Stiffness (N/mm) - Primary Clinical Outcome	0.2 (0.1)	38.7 (18.3)	46.2 (17.7)	102.9 (19.3)	137.8 (42.0)
Fracture Dorsal Angulation (Degrees) - Secondary Clinical Outcome	29.7 (5.3)	27.0 (13.8)	20.1 (9.8)	24.4 (8.0)	16.4 (7.4)
Total Callus Area (mm^2)	19.3 (2.5)	28.6 (6.4)	26.6 (2.4)	24.0 (3.6)	23.0 (4.7)
Initial Stiffness / Area (N/mm / mm^2)	0.01 (0.01)	1.4 (0.9)	1.7 (0.7)	4.4 (1.1)	6.3 (2.6)
Maximum Stiffness (N/mm))	0.2 (0.1)	61.5 (22.6)	81.2 (27.0)	138.5 (25.6)	172.5 (44.0)
Maximum Stiffness / Area (N/mm / mm^2)	0.01 (0.01)	2.2 (1.0)	3.1 (1.1)	5.9 (1.5)	7.9 (3.0)
Failure Load (N)	0.6 (0.3)	46.88 (12.40)	58.23 (15.04)	77.3 (16.8)	91.3 (22.3)
Failure Load / Area (N/mm^2)	0.03 (0.01)	1.63 (0.26)	2.21 (0.60)	3.3 (0.9)	4.2 (1.4)
Energy Absorbed (N/mm)	0.3 (0.2)	26.18 (13.3)	29.90 (9.51)	29.7 (9.0)	31.7 (9.7)
Energy Absorbed / Area (N/mm / mm^2))	0.01 (0.01)	0.88 (0.31)	1.13 (0.36)	1.2 (0.4)	1.4 (0.5)

Table 6-5: Statistical Analyses, Summary Data – All Outcomes

	3 x 2 GLM - Univariate			Condition in Time			Time in Condition		% Diff. (@ 28 days)
	Time	Condition	T X C	5	14	28	IM	EM	EM / IM
Initial Stiffness	p< 0.01*	p< 0.02*	p = .03*	p = 1.0	p = 0.49	p = 0.01*	p < 0.01*	p < 0.01*	29%
Initial / Area	p < 0.01*	p < 0.02*	p = .03*	p = 1.0	p = 0.56	p = 0.01*	p < 0.05*	p < 0.01*	37%
				Sidak Pairwise – Time			**T-Test (@ 28 days)**		
Dorsal Angulation	p <0 .01*	p < 0.03*	p = 0.26	5 x 14 p = 0.08	14 x 28 p =0.58	5 x 28 p<0.01*	p < 0.03*		33%
Total Area	p < 0.01*	p =0.27	p = 0.71	p < 0.03*			p = 0.89		- 4%
Max. Stiffness	p < 0.01*	p < 0.01*	p = 0.10	p < 0.01*			p < 0.05*		21%
Max. / Area	p < 0.01*	p < 0.02*	p = 0.10	p < 0.01*			p = 0.07		29%
Failure Load	p < 0.01*	p < 0.03*	p = 0.23	p < 0.01*			p = 0.12		17%
Load / Area	p < 0.01*	p < 0.02*	p = 0.15	p < 0.01*			p = 0.08		24%
Failure Energy	p < 0.01*	p = 0.38	p = 0.78	p < 0.01*	p = 0.68		p = 0.63		7%
Energy / Area	p < 0.01*	p < 0.05*	p = 0.35	p < 0.02*			p =0.21		21%

CHAPTER 6: FIGURES

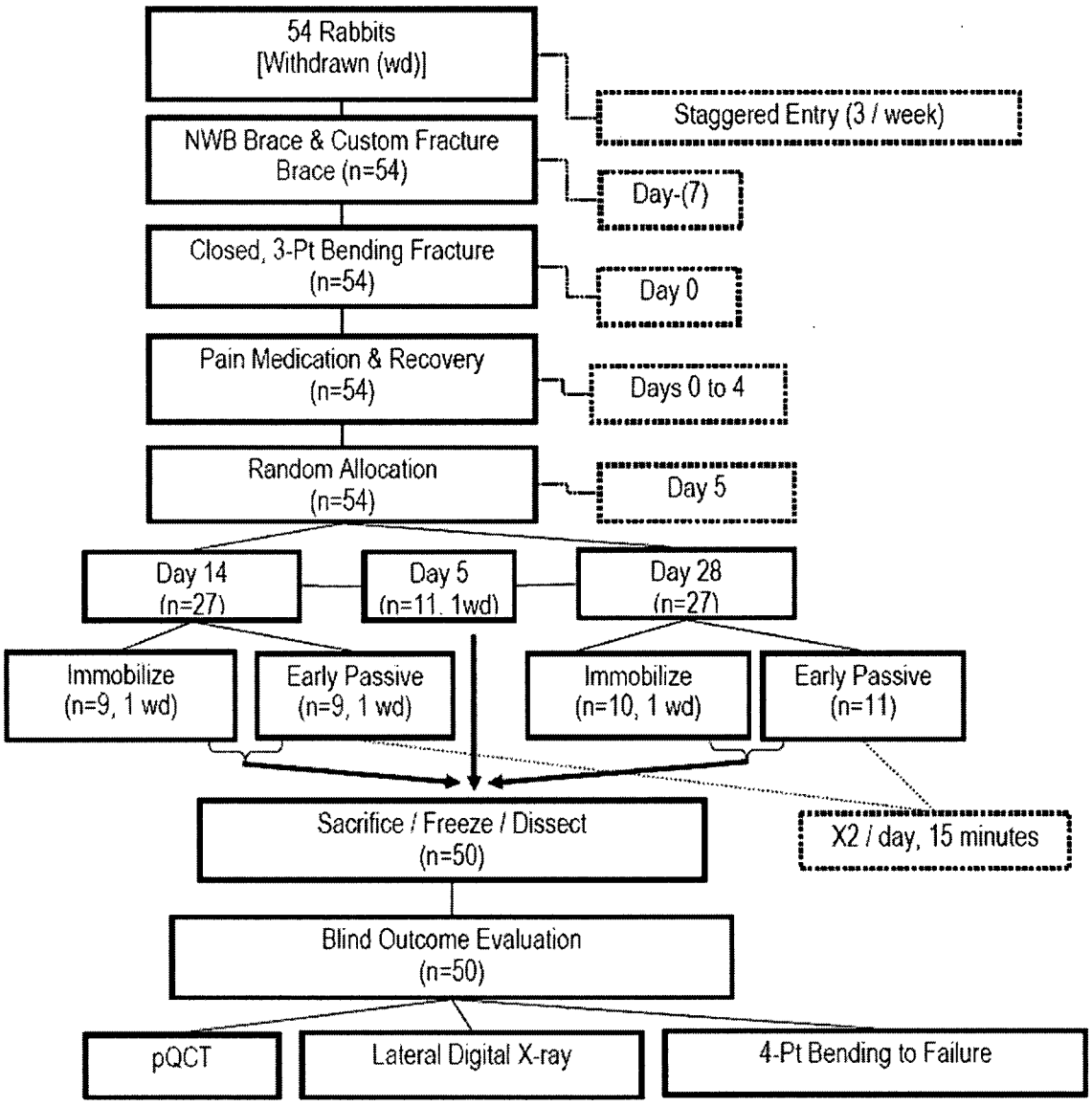


Figure 6-1: Study Flow Chart: Showing the flow of the rabbits through the study, beginning with recruitment into the study to final blinded outcome evaluation

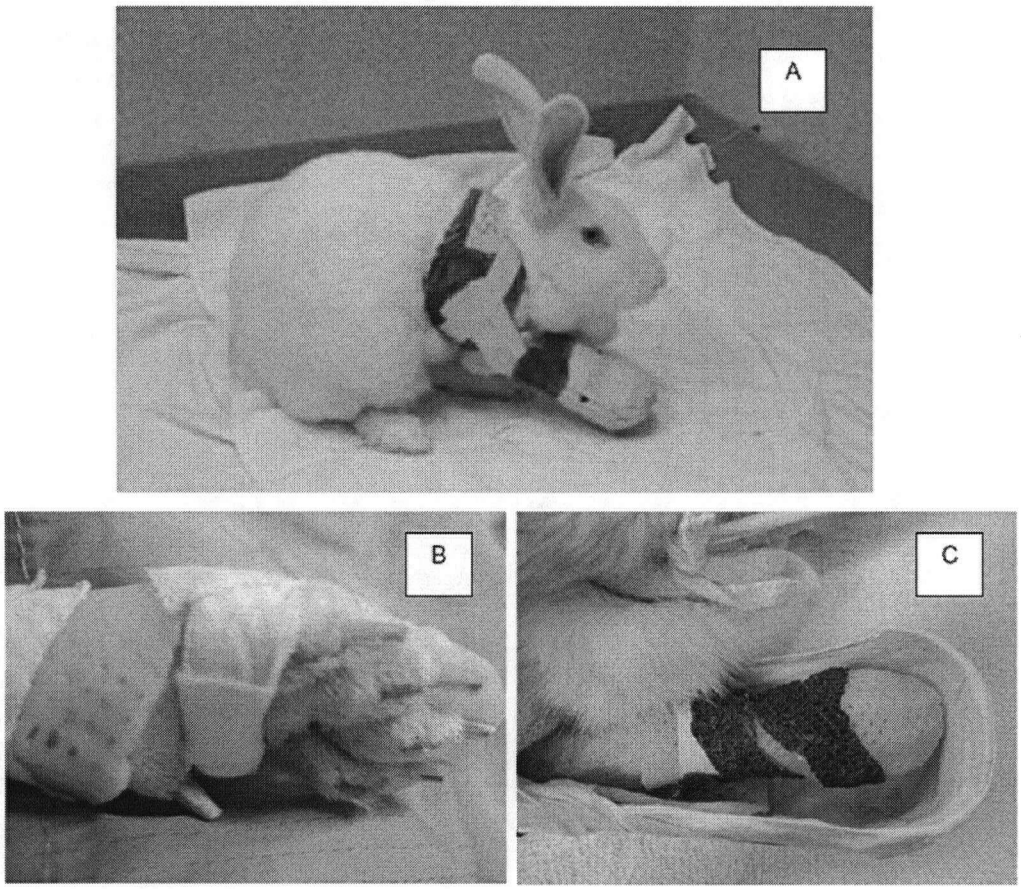


Figure 6-2 : Non-Weight Bearing Bracing System: A) Photograph of a rabbit in the non-weight bearing brace system with the whole protective bumper splint applied. **B)** Close up photograph of an ulnar view of the custom molded metacarpal fracture brace. **C)** Close up photograph of a dorsal view of the "Bumper splint" or protective cap, without the top of the splint applied.

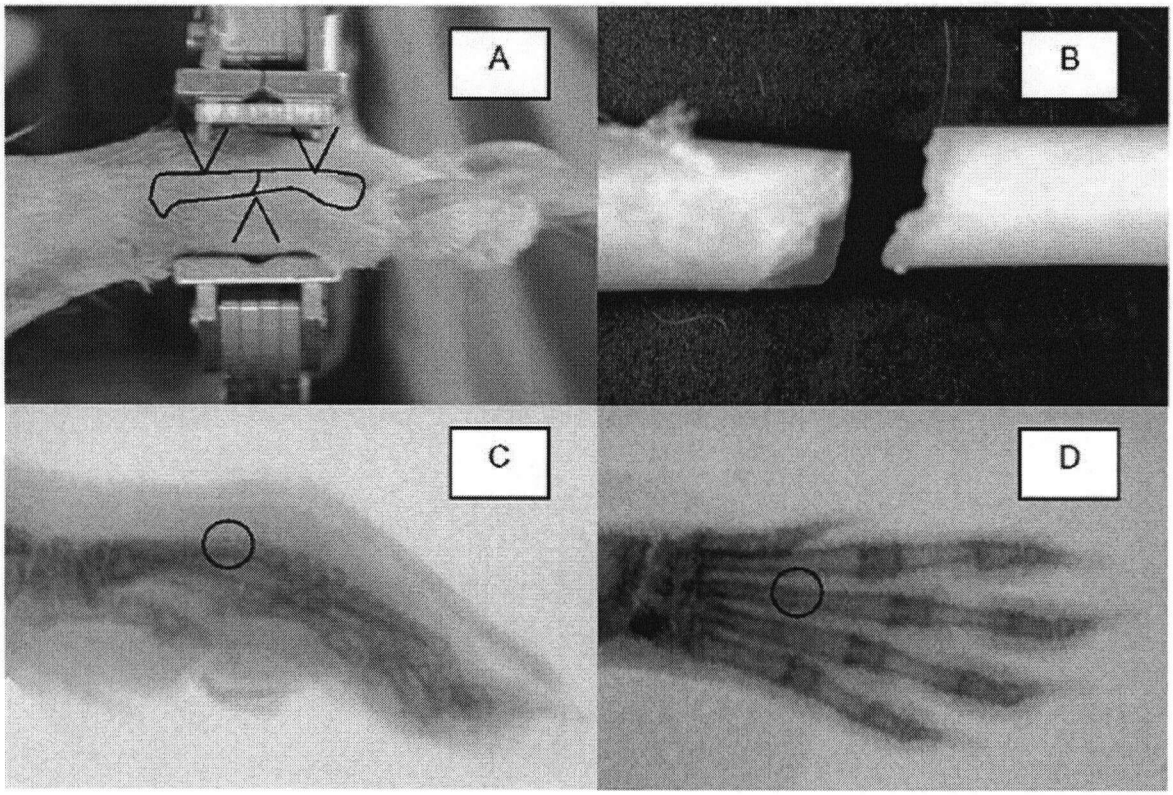


Figure 6-3: Three Point Bending Fracture Creation and Reduction: A) A photograph of the shaved rabbit forepaw in the pliers that created the fractures. Superimposed on the picture is a diagram of the bone with the three-point bending load locations and a typical oblique proximal (OP) fracture pattern. **B)** Digital photograph (x 2 magnification) of a typical oblique proximal (OP) fracture pattern. **C)** A lateral fluoroscopic image of a reduced fracture in a fracture brace (Circle indicates location of the reduced fracture). D) An anterior – posterior fluoroscopic image of a reduced fracture with no fracture brace (Circle indicates the location of the reduced fracture)

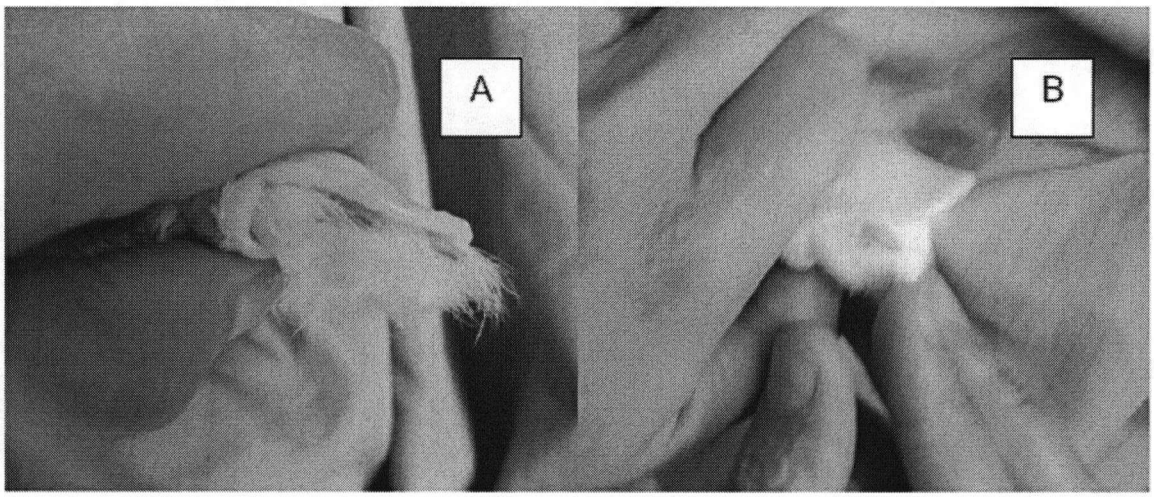


Figure 6-4: Local Pinch Stabilization Combined With Passive Motion Exercise: A) A photograph showing an ulnar view of the gentle local pinch stabilization of fracture. **B)** A photograph showing a dorsal / ulnar view of the full arc passive digital flexion exercise.

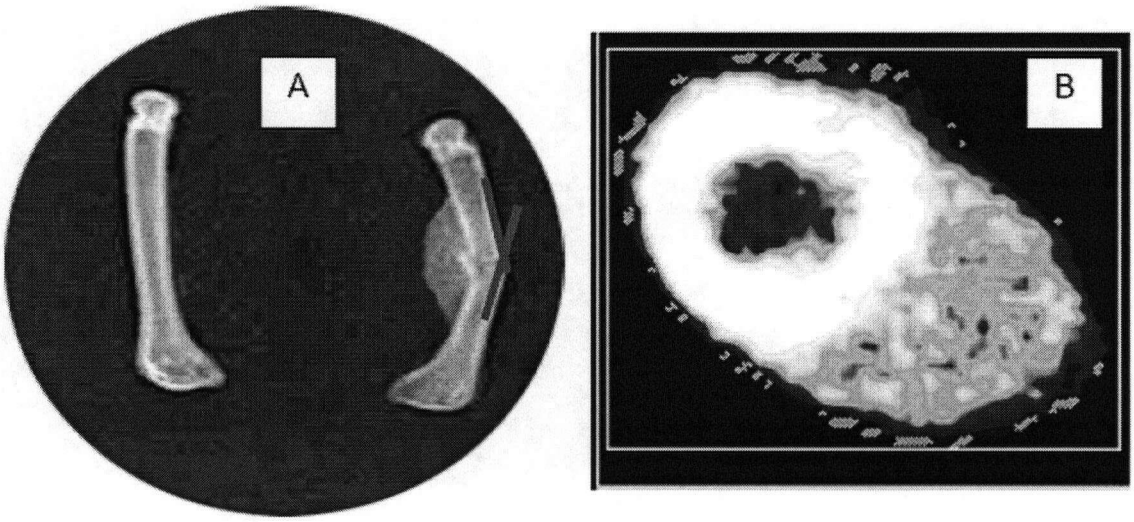
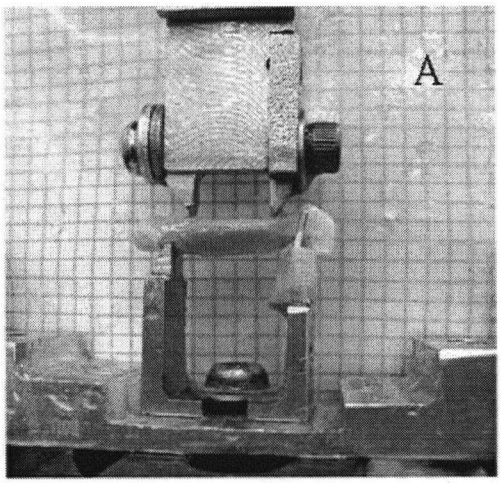


Figure 6-5: Lateral Digital X-ray and pQCT images: A) A typical lateral digital x-ray image of the dissected third metacarpal bones from the intact and fractured side in the same rabbit. The image is from a twenty eight day healing period rabbit. The red lines superimposed on this image represent the degree dorsal angulation in this callus. **B)** A peripheral quantitative computed tomography scan visual image of a typical twenty eight day callus.



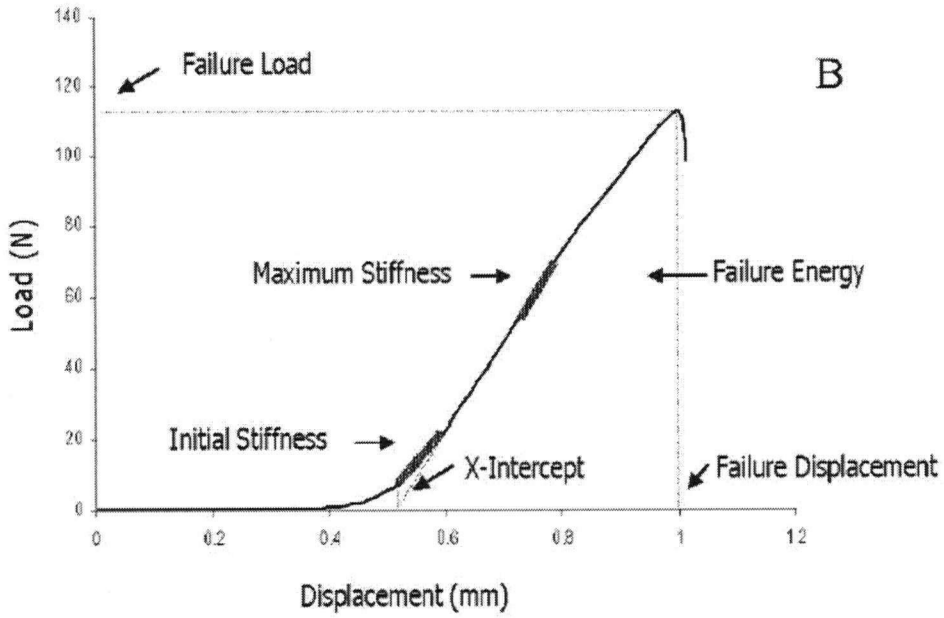


Figure 6-6: Four-point bending set-up and load-displacement curve: A) Close-up photograph showing the 4-Point testing set-up in an intact specimen. **B)** A typical load-displacement curve of a twenty eight day callus showing the four-point structural properties for Failure Load (N), Failure Displacement (mm), Initial Stiffness (N/mm), Maximum Stiffness (N/mm) , and Energy to Failure (Nmm). The x-intercept of the maximum stiffness slope line is also shown.

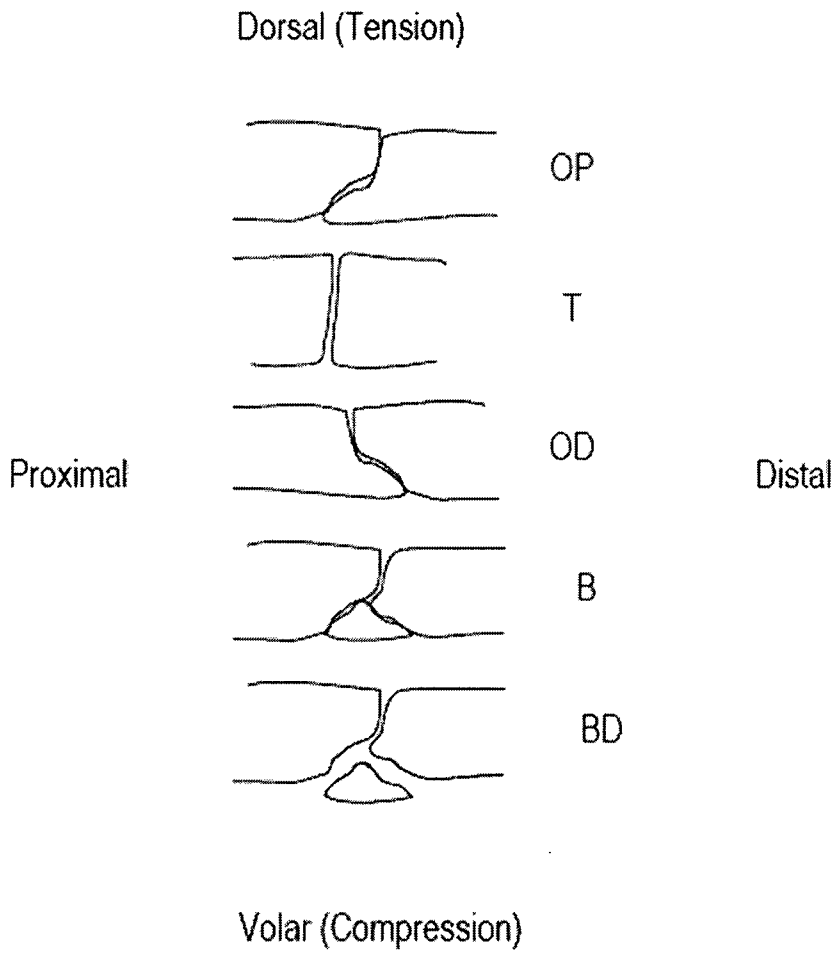


Figure 6-7: Fracture Pattern Classification: OP = Oblique fracture line progressing proximally on compression side; **T** = transverse fracture line on compression side; **OD** = Oblique fracture line progressing distally on compression side; **B** = butterfly fragment, non-displaced on compression side; **BD** = butterfly fragment, minimally displaced on compression side.

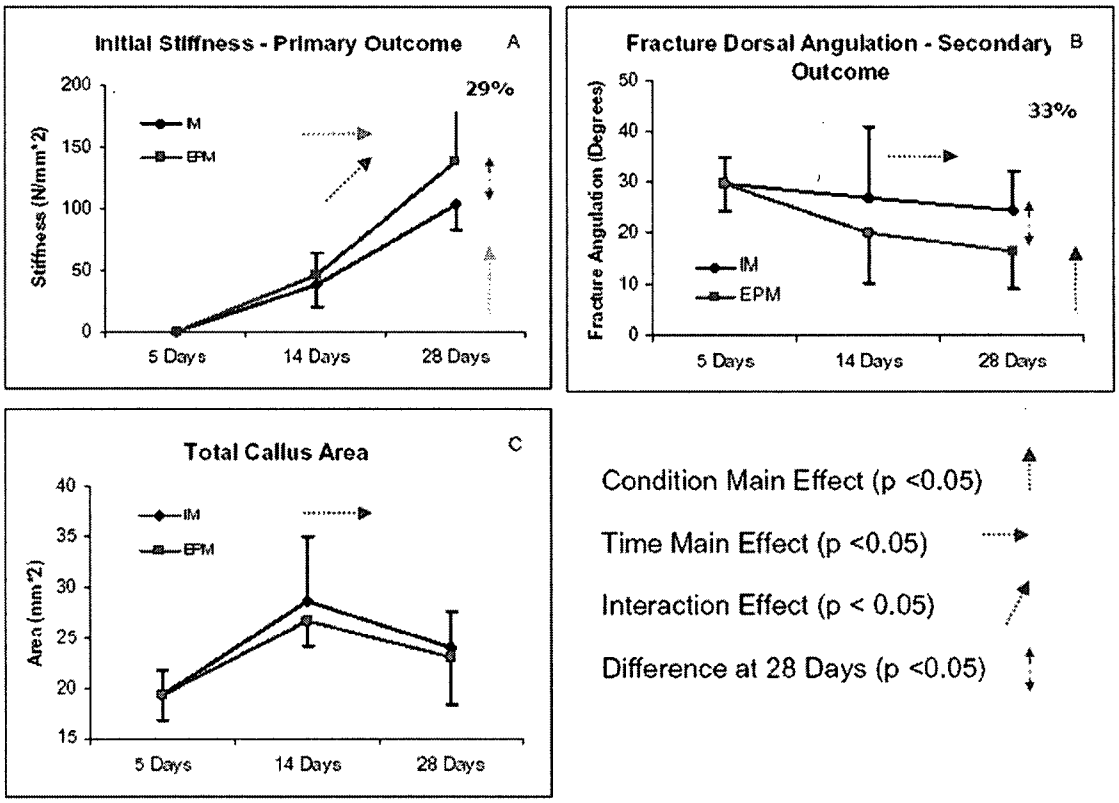


Figure 6-8: Treatment Condition by Time Period Graphs: A) Initial Stiffness – Primary Clinical Outcome; **B)** Dorsal Angulation – Secondary Clinical Outcome; **C)** Total Callus Area. Significant ($p < 0.05$) main and interaction effects, as well as, a significant difference between the treatment conditions at twenty eight days are indicated by the arrows on the graphs and are defined in the figure legend.

CHAPTER 6: REFERENCES

1. Freeland AE, Lund PJ. Metacarpal and phalangeal fractures. In: Russell RC (ed.) Plastic Surgery: Indications, Operations and Outcomes. (Vol. 4 - Hand Surgery). Toronto, Mosby; 2000:1845-1864.
2. Freeland AE, Orbay JL. Extraarticular hand fractures in adults. A review of new developments. Clin Orthop Relat Res. 2006;445:133-145.
3. Harness NG, Meals RA. The history of fracture fixation of the hand and wrist. Clin Orthop Relat Res. 2006;445:19-29.
4. Kozin SH, Thoder JJ, Lieberman G. Operative treatment of metacarpal and phalangeal shaft fractures. J Am Acad Orthop Surg. 2000;8(2):111-121.
5. Purdy BA, Wilson RL. Management of nonarticular fractures of the hand. In: Mackin EJ, Callahan AD, Skirven TM, Schneider LH, Osterman AL (Eds.) Rehabilitation of the Hand and Upper Extremity (5th Edition). St. Louis: C.V. Mosby, 2002:382-395.
6. Buckwalter JA. Effects of early motion on healing of musculoskeletal tissues. Hand Clin. 1996;12(1):13-24.
7. Feehan LM. Early controlled mobilization of potentially unstable extra-articular hand fractures. J Hand Therapy 2003;16(2): 161-170.
8. Lin TW, Cardenas L, Soslowsky LJ. Biomechanics of tendon injury and repair. J Biomech. 2004; 37:865-877.
9. Pettengill KM. The evolution of early mobilization of the repaired flexor tendon. J Hand Ther. 2005; 18(2):157-68.
10. Tang JB. Clinical outcomes associated with flexor tendon repair. Hand Clin. 2005; 21(2):199-210.
11. Ashhurst DE. The influence of mechanical conditions on the healing of experimental fractures in the rabbit: a microscopical study. Phil Trans R Soc Lond 1986; 313(B):271-302.
12. Bailon-Plaza A, van der Meulen M. Beneficial effects of moderate early loading and adverse effects of delayed or excessive loading on bone healing. J Biomech. 2003; 36:1069-1077.
13. Carter DR, Beaupre GS, Giori NJ, Helms JA. Mechanobiology of skeletal regeneration. . Clinical Orthop Related Research 1998; 355S:41-55.
14. Challis MJ, Welsh MK, Jull GA, Crawford R. Effect of cyclic pneumatic soft tissue compression on simulated distal radius fractures. Clin Orthop Relat Res. 2005;433:183-188
15. Chao EYS, Inoue N, Elias JJ, Aro H. Enhancement of fracture healing by mechanical and surgical intervention. Clinical Orthop Related Research 1998; 355S:163-178.

16. .Claes L, Eckert-Hubner K, Augat P The effect of mechanical stability on local vascularization and tissue differentiation in callus healing. J Orthop Res. 2002 ; 20(5):1099-105.
17. Claes LE, Heigele CA. Magnitudes of local stress and strain along bony surfaces predict the course and type of fracture healing. J Biomech 1999; 32(2): 255-266.
18. Egger EL, Gottsauner-Wolf F, Palmer J, Aro HT, Chao EY. Effects of axial dynamization on bone healing. J Trauma. 1993 Feb;34(2):185-92
19. Goodship AE, Cunningham JL, Kenwright J. Strain rate and timing of stimulation in mechanical modulation of fracture healing. Clinical Orthop Related Research 1998; 355S:105-115.
20. Hente R, Fuchtmeier B, Schlegel U, Ernstberger A, Perren S. The influence of cyclic compression and distraction on the healing of experimental tibial fractures. J Orthop Res. 2004; 22:709-715.
21. Hewitt JD, Narrelson JM, Dailiana Z, Guilak F, Fink C. The effect of intermittent pneumatic compression on fracture healing. J Orthop Trauma 2005; 19(6):371-376.
22. Klein P, Schell H, Streitparth F, Heller M, Kassi J, Kandziora F, Bragulla H, Haas N, Duda G. The initial phase of fracture healing is specifically sensitive to mechanical conditions. J Orthop Res. 2003;21:662-669.
23. Larsson S, Kim W, Caja V, Egger E, Inoue N, Chao E. Effect of early axial dynamization on tibial bone healing. A study in dogs. Clin Orthop Rel Res. 2001; 388:240-251.
24. Mark H, Nilsson A, Nannmark U, Rydevik B. Effects of fracture fixation stability of ossification in healing fractures. Clin Orthop 2004; 419:245-250.
25. Mark H, Rydevik B. Torsional stiffness in healing fractures: influence of ossification. An experimental study in rats. Acta Orthopaedica 2005;76(3):428-433.
26. Park SH, O'Conner K, McKellop H, Sarmiento A. The influence of active shear or compressive motion fracture healing. J Bone Jt Surg 1998; 80(6): 868-878.
27. Park SH, Silva M. Effect of intermittent pneumatic soft-tissue compression on fracture-healing in an animal model. J Bone Joint Surg 2003; 85A:1446-1453.
28. Park SH, Silva M. Neuromuscular electrical stimulation enhances fracture healing: results of an animal model. J Orthop Res 2004; 22(2):382-387.
29. Panjabi MM, White AA, Wolf JW. A biomechanical comparison of the effects of constant and cyclic compression on fracture healing in rabbit long bones. Acta Orthp Scand. 1979; 50:653-661.
30. Sarmiento A, Schaeffer JF, Beckerman L, Latta LL, Enis JE. Fracture healing in rat femora as affected by functional weight-bearing. J Bone Joint Surg Am. 1977; 59(3):369-375.
31. Smith-Adaline E, Volkman S, Ignelzi M, Slade J, Platte S, Goldstein S. Mechanical environment alters tissue formation patterns during fracture repair. J Orthop Rel Res. 2004; 22:1079-1085.

32. Thompson J, Miclau T, Hu D, Helms J. A model for intramembranous ossification during fracture healing. J Orthop Res 2002; 20:1091-1098.
33. Yamaji T, Ando K, Wolf S, Augat P, Claes L. The effect of micromovement on callus formation. J Orthop Sci 2001; 6:571-575.
34. Boers K, Gray G, Love J, Mahmutovic Z, McCormick S, Turcotte N, Zhang Y. (2002). Comfortable quarters for rabbits in research institutions. In: Reinhardt A, Reinhardt V (Eds.). Comfortable quarters for laboratory animals (9th edition). (pp 43-49) Washington DC. Animal Welfare Institute.
35. Popesko P, Rajtova V, Horac J. Color atlas of anatomy of small laboratory animals. Volume 1: Rabbit, Guinea Pig. Wolfe Publishing: London, 1992
36. Rivas R, Shapiro F. Structural stages in the development of the long bone and epiphyses. A study in the New Zealand white rabbit. J Bone Joint Surg 2002;84A:85-100.
37. Martiniakova M, Vondrakova M, Fabis M. Investigation of the microscopic structure of rabbit compact bone tissue. Scripta Medica (brno) 2003;76(4): 215-220.
38. An YH. (2000). Mechanical properties of bone. In: An YH, Draughn RA (eds), Mechanical Testing of Bone and the Bone-Implant Interface. (pp 41-64). New York: CRC Press LLC.
39. Burkhalter WE. Closed treatment of hand fractures. J Hand Surg. 1989; 14A: 390-393.
40. Colditz JC. Functional fracture bracing. In: Mackin EJ, Callahan AD, Skirven TM, Schneider LH, Osterman AL (Eds.) Rehabilitation of the Hand and Upper Extremity (5th Edition). St. Louis: C.V. Mosby, 2002:1875-1886.
41. Ebinger T, Erhard N, Kinzl L, Mentzel M. Dynamic treatment of displaced proximal phalangeal fractures. J Hand Surg 1999; 24A:1254-1262.
42. Feehan LM, Basset K. Is there evidence for early motion following an extra-articular hand fracture? J Hand Ther 2004; 17(2): 300-308.
43. Ferraro MC, Coppola A, Kippman K, Hurst LC. Closed functional bracing of metacarpal fractures. Orthop Rev. 1983; 12(8):49-56.
44. Gonzalez MH, Hall RF. Intramedullary fixation of metacarpal and proximal phalangeal fractures of the hand. Clinical Orthop 1996; 327: 47 – 54.
45. Hansen PB, Hansen TB. The treatment of fractures of the ring and little metacarpal necks: A prospective randomized study of three different types of treatment. J Hand Surg 1998; 23B 2: 245 – 247.
46. Harding IJ, Parry D, Barrington RL. The use of a molded metacarpal brace versus neighbor strapping for fractures of the little finger metacarpal neck. J Hand Surg 2001;26(3):261-263.

47. Jones AR. Reduction of angulated metacarpal fractures with a custom fracture-brace. J South Orthop Assoc 1995;(4): 269-76.
48. Konradsen L, Nielson PT, Albrecht-Beste E. Functional treatment of metacarpal fractures. 100 randomized cases with or without fixation. Act Ortho Scand 1990;61:531-534.
49. Motta P, Mariotti, U, Cettina, R. [Brace for orthopaedic treatment of fifth metacarpal fractures] Ortesi per il trattamento incruento dell fratture del v metacarpo. Minerva Ortop Traumatol 1994;45[5], 179-185.
50. Poolman R, Goslings C, Morton L, Statius Muller M, Steller F. Conservative treatment for closed fifth (small finger) metacarpal neck fractures in adults Cochrane Database Syst Rev. 2005; 20(3):CD003210
51. Reyes FA, Latta LL. Conservative management of difficult phalangeal fractures. Clin Orthop Rel Res 1987; 214:23-30.
52. Sorensen JS, Freund KG, Kejla G. Functional fracture bracing in metacarpal fractures: The Galveston metacarpal brace versus a plaster-of-paris bandage in a prospective study. J Hand Ther 1993;6:263-265.
53. Statius Muller MG, Poolman RW, van Hoogstraten MJ, Steller EP. Immediate mobilization gives good results in boxer's fractures with volar angulation up to 70 degrees: a prospective randomized trial comparing immediate mobilization with cast immobilization. Arch Orthop Trauma Surg. 2003;123(10):534-537.
54. Thomine JM, Gibon Y, Benjjeddou MS, Biga N. Functional brace in the treatment of diaphyseal fractures of the proximal phalanges of the last four fingers. Ann Chir Main 1983; 2:298-306.
55. Trabelsi A, Dusserre F, Asencio G, Bertin R. Traitement orthopedique des fractures du col du cinquieme metacarpien: etude prospective. [Conservative treatment for the fracture of the fifth metacarpal neck: a prospective analysis.] Cirugie de la Main 2001; 20: 226-230.
56. Viegas SF, Tencer A, et al . Functional bracing of fractures of the second through fifth metacarpals. J Hand Surg 1987; 12A: 139-143.
57. Sarmiento A, Latta LL. Functional fracture bracing. J Am Acad Orthop Surg 1999; 7(1): 66-77.
58. Latta LL, Sarmiento A, Tarr RR. The rationale of functional bracing of fractures. Clin Orthop Rel Res 1980; 146:28-36.
59. Green SA. Orthopaedic surgeons. Inheritors of tradition. Clin Orthop Relat Res. 1999; Jun;(363):258-63.
60. Nunamaker DM. Experimental models of fracture repair. Clin Orthop Relat Res. 1998; 355:S56-65
61. Einhorn TA. Enhancement of fracture-healing. J Bone Joint Surg [Am] 1995; 77A:940-956.

62. Park SH, O'Connor K, Sung R, McKellop H, Sarmiento A Comparison of healing process in open osteotomy model and closed fracture model. J Orthop Trauma. 1999; 13(2):114-20.

CHAPTER 7: EFFECT OF EARLY CONTROLLED PASSIVE MOTION ON CLOSED FRACTURE CALLUS REGIONAL TISSUE DISTRIBUTION AT TWENTY-EIGHT DAYS POST-FRACTURE: A pQCT AND HISTOLOGICAL STUDY IN RABBITS*

7.1 RESEARCH QUESTION ADDRESSED IN THIS CHAPTER

How does early controlled passive motion affect the quality and rate of early fracture healing in a rabbit model?

7.2 INTRODUCTION

Early controlled mobilization is commonly used following primary flexor tendon repairs and other equally fragile or potentially "unstable" healing tissues in the hand, but it is not recommended for potentially unstable extra-articular hand fractures.[1-5] Rather, it is recommended that potentially unstable fractures be treated with some form of additional internal or external fracture fixation to facilitate early active regional joint motion or be managed with complete regional hand and wrist joint immobilization for a period of three or more weeks. [1-5] The rationale for this clinical strategy in potentially 'structurally fragile' fractures is that early regional joint motion of any form may cause excessive motion at the fracture site and disrupt early fracture healing and / or alignment. [6, 7]

In a previous study (See Chapter 6) investigating the effect of early controlled passive motion on fracture callus 4-point bending structural properties and fracture alignment in a closed, 3rd metacarpal fracture in rabbits, we concluded that Early Controlled Passive Motion (ECPM) led to clinically (>25% difference) and statistically ($P < 0.05$) significant improvements in the ability of an early fracture callus to resist and bear a 4-point bending load. Furthermore these improvements were not due to the fracture laying down a bigger callus. We propose that these findings suggest that the improved early structural properties seen in the early controlled passive motion calluses may be due to differences in early fracture callus mineralization or tissue morphology. This could be either in terms of differences in the geometric distribution of the mineralized and non-mineralized tissue within the callus and / or in terms of differences in overall mineralized tissue content in the callus. (See 6.5 - Discussion).

* A version of this chapter is a manuscript in preparation and will be submitted for publication to the Journal of Orthopedic Research (December 2006). Feehan LM, Liu D, Oxland T. Effect of early controlled passive motion on closed fracture regional tissue distribution at 28-days post fracture. A pQCT and histological study in rabbits.

Peripheral Quantitative Computed Tomography (pQCT) provides measures of tissue geometry and density and has been used most commonly for the assessment of intact bone quality.[8,9] pQCT imaging provides a three-dimensional evaluation of X-ray attenuation coefficients in the scanned tissues, which have been calibrated against a phantom image with a known density.[8,9] pQCT measurements of callus content and density have been used for the assessment of fracture healing in a number of animal studies,[10-23] and less commonly for the clinical assessment of fracture healing in people.[24,25] pQCT densiometric measurements of callus mineral content and / or density have been shown to correlate positively with fracture callus mechanical strength and stiffness,[26-30] as well as, with the histological evaluation of the degree of mineralized tissue in the callus.[26,27,31] As well, a pQCT geometric measure of polar moment of inertia (i.e. distance away from a defined central point) has also been shown to be positively correlated with callus mechanical strength and stiffness,[29] suggesting that the regional distribution of the mineralized tissue within the callus may also influence early callus structural properties. In contrast, pQCT geometric measurements of mineralized callus area have been shown to correlated with mechanical testing measures of callus strength and stiffness,[27,28,30] which suggests that a larger mineralized callus does not necessarily correlate with better mechanical properties.

The objective of this follow-up study was to investigate if there were any quantitative (pQCT) or qualitative (histological) differences in fracture callus regional tissue distribution for fractures treated with early controlled passive motion, when compared to fractures treated with immobilization at the twenty-eight day time period. The twenty-eight day time period is the time point where the fracture calluses were known to have statistically significant differences in 4-point bending structural properties. Our null hypothesis was that at the twenty-eight day healing period, when compared to fractures treated with immobilization (IM), fractures treated with early controlled passive motion (ECPM) would show no significant differences in the regional distribution of non-mineralized, new-mineralized and residual cortical bone tissues within the callus. A secondary objective was to investigate at the twenty-eight day time period if there were any apparent differences in the degree of residual cortical bone resorption or remodeling at the level of the fracture in fractures treated with ECPM compared to fractures treated with immobilization.

7.3 MATERIALS AND METHODS

7.3.1 Original Study Design, Objectives, and Study Flow

The original study was a pre-clinical, block-randomized, single-blind, efficacy trial examining the effect of two treatment conditions (IM and ECPM) at three time periods (Five Days, Fourteen Days, and Twenty-eight Days) on fracture alignment and 4-point bending structural properties in a rabbit model. The objective

was to investigate if ECPM was likely to cause harm with regard to affecting the quality and rate of early fracture healing in a non-weight bearing limb, closed, potentially unstable, diaphyseal fracture in a rabbit model during the initial twenty-eight days post-fracture.

Fifty, mature, female, New Zealand White rabbits were pre-conditioned for one week to a non-weight bearing limb brace and a custom molded metacarpal fracture brace. Under general anesthesia, closed 3-point bending fractures were produced, reduced under fluoroscopy and placed back into the fracture brace. For four days the rabbits were given twice daily pain medication and were allowed to rest and recover. On the fifth day, the randomly allocated early passive motion rabbits began to receive twice daily, fifteen minute sessions, of a standardized passive digital flexion and extension motion exercise program. Experienced hand therapists did all ECPM. The immobilized rabbits received no further intervention to the affected forepaw. Rabbits were sacrificed at five, fourteen and twenty-eight days post fracture and the healing metacarpals were serially dissected out of the frozen forepaws. Blinded outcome evaluations included lateral x-rays, pQCT imaging and four-point bending to structural failure. Further details of the Materials and Methods are provided in Chapter 6.3.

7.3.2 pQCT Imaging and Analyses

In the original study, prior to mechanical testing the 11-ECPM and 10-IM calluses from the twenty-eight day time period were scanned while frozen, ex-vivo, in air, with an XCT 2000 pQCT scanner (Norland Corporation, Fort Atkinson, WI, USA). (See Figure 7-1-A) The scan diameter was 50 mm with a scan speed of 5 mm / sec. The in-plane voxel resolution was 0.1 x 0.1 mm^2 with a scan thickness of 2.2 (+/-.2) mm. (See Figure 7-1-B) All specimens were scanned with the proximal and distal bone ends set on molded putty that was resting on a low density foam base ensuring the fracture callus was completely surrounded by air. The foam base with the bone specimen was placed within a 40 mm diameter clear plastic tube that was centered and aligned parallel within the gantry. The fracture callus specimens were scanned perpendicular to the fracture line. [See Figure 7-1-A (Inset)].

For this follow-up study fracture callus's raw pQCT imaging data were analyzed using ImageJ software (http://rsb.info.nih.gov/ij), [32] to enable the identification and analysis of each voxel separately. The raw data were imported and re-calibrated using the importing protocol and calibration parameters provided by the pQCT scanner manufacturer [Norland Corp, Fort Atkinson, WI, USA]. ImageJ calibration was verified in two twenty-eight day calluses by comparing measures of Total Callus area (TA) and Residual Cortical Bone area (CA) using a XCT 5.50 [Norland Corp, Fort Atkinson, WI, USA] analyses [CORTBD, Separation Mode

1, Thresholds 0 and 811 mg/cm^3] and ImageJ analyses of TA and CA in non-filtering images using the same threshold parameters. The results for these area measurements were identical (Pearson r = 1.0, $p < 0.01$). In addition, the accuracy (+/- 4 to 9%) of the ImageJ software analyses for defining new-mineralizing tissue (new woven bone) using an apparent density threshold of $\geq$ 200 mg/cm^3 was done in 2 twenty-eight calluses, by comparing ImageJ mineralized tissue area measures to the mean mineralized tissue area in three consecutive digital photo cross-sectional histological images corresponding to the 2.2 mm pQCT scan location. [27]

For each image a region of interest (ROI) was manually defined around the callus. Each voxel within the ROI with a density threshold of zero or higher was identified. In addition, the distance of the center of each voxel away from the center of the voxel corresponding with the "anatomical" center of the fracture callus was determined (See Figure 7-2 and Appendix 7-1). The anatomical center was defined as the center point within the intra-medullary region in the proximal fracture fragment. The anatomical center of the callus was identified by comparing the digital pQCT scan image with the corresponding histological callus slice immediately proximal to the fracture gap. The anatomical centre was then drawn on a digital photo of the pQCT image and this photo was used as a visual cue to identify the corresponding location of the voxel of the anatomical center in the ImageJ image on the computer screen. Intra-rater reliability for two raters, independently identifying the selected anatomical centre in six images on two separate days was very high (Rater 1: Pearson r =.999, $p < 0.01$; Rater 2: Pearson r =.999, $p < 0.01$). Inter-rater reliability for the mean of the two repeated measures for each rater was also very high (Pearson r = .999, $p < 0.01$).

ImageJ data were exported to excel for further analyses using the three validated apparent density thresholds (0, 200 and 811 mg/cm^3) to first quantitatively define the non-mineralized, new-mineralized and residual cortical bone within the callus. (See Figure 7-3) In addition, the non-mineralized (0 to 199 mg/cm^3) and new-mineralized (200 to 811 mg/cm^3) threshold ranges were further divided in half to differentiate between the lower and higher density tissues within each of these threshold ranges (See Table 7-1). Dividing the non-mineralized threshold range into lower and higher density ranges allowed for an analysis of the region of the calluses with a histological morphology corresponding to fibrous tissue (lower non-mineralized tissue density) compared to the region of the callus with a histological morphology corresponding to cartilaginous tissue (higher density non-mineralized tissue density). Similarly, but dividing the new-mineralized tissue threshold range into lower and higher density ranges allowed for an analysis of regions of the calluses with a histological morphology associated with more dense regions of new woven

bone related to more dense mineralization (ie: thicker trabeculae and less porosity) compared to regions of the callus with less dense mineralization. (See Figure 7-4)

The primary outcome variables included area (mm^2), mineral content (mg/mm), mean distance from the anatomic centre (mm) and mean distribution (r^2 x density = mg/mm). Our secondary outcome variables included normalized (% of intact side) residual cortical bone area (an indicator of cortical bone resorption at the level of the fracture) and average residual cortical bone density (an indicator of cortical bone remodeling at the level of the fracture) measures.

7.3.3 Undecalcified Fracture Callus Histological Processing and Analyses

Immediately following mechanical testing to 4-point structural failure the calluses were fixed in formalin (10% buffered) for 24 hours before being re-frozen and stored at -20^0 C. To minimize the degree of tissue disruption with mechanical testing, the 4-point bending testing was stopped immediately after structural failure. In addition, the fracture calluses were manually re-approximated following mechanical testing.

The formalin fixed calluses were thawed and cut to ~ 12 mm length and then processed as undecalcified specimens through serial dehydration in denatured Ethanol and then serial infiltration and block embedding in a methyl methacrylate based resin (Technovit – EXAKT, USA, Oklahoma City, OK). (See Appendix 7-2). Each callus was cut parallel to the fracture line for cross-sectional slides, with each slide initially cut to ~200 µm and then serially ground to ~50 µm using the EXAKT diamond saw and grinding systems (EXAKT systems, USA, Oklahoma City, OK). With each cut with the diamond saw, there was an ~400 µm thickness loss of the fracture callus tissue. Therefore, each slide represented a ~600 µm thickness region within the callus. The specimens were cut in such a way as to try to capture one slide at the level of the fracture, and one slide immediately proximal and distal to the fracture line.

The slides were stained using Toluidine Blue, Methyl Green and Methanil Yellow stains. This staining protocol stained fibrous tissue blue, cartilage tissue purple and mineralized tissue yellow.[33,34] (See Figure 7-4 and Appendix 7-3). The stained slides were digitally photographed at a 100x magnification (5x objective lens and 20x digital camera magnification) [Zeiss AxioPlan2 (CarlZeiss Inc., Thomwood, NY); Northern Eclipse 7.0 Software (Empix Imaging Inc, Mississauga, ON] and then merged into a single digital photo image using Photoshop Elements 3.0 software (Adobe Systems, Inc; San Jose, CA). Outcome evaluation involved a blinded qualitative evaluation by two independent evaluators (one bone pathologist and one

researcher) looking for any apparent differences in the fibrous, cartilaginous, new-mineralized woven and residual cortical tissue distribution at the level of the fracture (Fracture location + / - and one slice).

7.3.4 Statistical Methods

Statistical analyses were done using SPSS 11.0 software (SPSS Inc, Chicago, IL). The primary analyses included a General Linear Model (GLM) univariate analysis of the two treatment conditions (ECPM and IM) by five threshold ranges [0-99; 100-199; 200-499; 500-810; $\geq$ 811 mg/ cm^3] at the twenty-eight day time period; investigating the effect of ECPM on tissue distribution at this time period. Post-hoc analyses included Sidak multiple pairwise comparisons test between the tissue threshold ranges, as well as Independent T-tests (ECPM vs. IM) and percentage difference [ECPM-IM / Average ECPM:IM] at the lower new mineralized tissue (200-499 mg/cm^3) and residual cortical bone tissue ($\geq$ 811 mg/cm^3) threshold ranges. Given the exploratory nature of the post-hoc Independent T-test post-hoc analyses, the alpha values were not adjusted for multiple comparisons.

In addition, a comparison of the percentage of intact cortical bone area and average density between the ECPM and IM calluses was also examined with an Independent T-test and percentage difference calculation, investigating the effect of ECPM on cortical bone tissue resorption (area) and remodeling (average density) at the twenty-eight day time period.

7.4 RESULTS

7.4.1 Fracture location, pattern and original pQCT (XCT 5.5) total callus area measures

All fractures were in the mid-shaft and there was no difference in the distribution of fracture pattern at the 28 day time period [Chi Square; $\chi 2$ (4, N=21) =.286, p=0.9]. (See Table 6-3 details of the fracture pattern distribution at 28 days) Therefore, all calluses in both treatment conditions were pooled for the pQCT and histological analyses.

The original study measures of pQCT total callus area using XCT 5.50 [Norland Corp, Fort Atkinson, WI, USA] analyses software found no significant different between the two groups (p=0.27) throughout the initial 28 day healing period in the original study. In addition, when examined at the 28 day time period specifically, there was again no significant difference in pQCT (XCT 5.5) total callus area (p=0.89) between the two treatment conditions. (See Table 6-5)

7.4.2 pQCT (ImageJ) analyses

See Table 7-1 for the mean (+/- SD) and the results of the primary statistical analyses for each of our primary outcome variables. For all pQCT ImageJ outcomes, there was a significant main effect across threshold range ($p \leq 0.01$) and no significant effect for either treatment condition [ECPM vs IM: area p=0.6; content p=0.8; Distance p=0.6; Distribution p=0.9] or interaction [threshold x condition: area p=0.2; content p=.08; Distance p=0.7; Distribution p=0.8). The post-hoc Sidak pairwise comparison between threshold ranges demons trated a significant difference ($p<0.01$) between both the new mineralized tissue and residual cortical bone tissue threshold ranges for area; between the lower new-mineralized tissue and residual cortical bone tissue threshold range for mean distance from centre; and between the higher new-mineralized tissue and residual cortical bone tissue threshold range for mean distribution. There was no significant difference (p=0.9) between either of the new mineralized tissue or residual cortical bone tissue threshold ranges for mineral content. (See Figure 7-5)

The Independent T-test for ECPM vs. IM at the lower mineralized (200-499 mg/cm*3) threshold range was not significant (p=0.2) for any outcomes. Acknowledging this lack of statistical significance between the treatment conditions, there was a marked percentage difference between the treatment conditions at this lower density new-mineralized tissue threshold range, with the ECPM having a 21% smaller area and 27% less mineral content compared to the IM calluses. (See Table 7-2 and Figure 7-5)

The Independent T-Test for ECPM vs. IM at the residual cortical bone tissue ($\geq$800 mg/cm*3) threshold range was significantly greater in the ECPM group compared to the IM group for area (p=0.03; 14% difference) and approaching significance for mineral content (p=0.08; 27% difference) and mean distribution (p=0.07; 12% difference). There was no significant difference between the conditions for mean distance from centre (p= 0.6; 0% difference) at this threshold range. (See Table 7-2 and Figure 7-5)

The Independent T-test for percentage of intact side cortical bone tissue area and average density for ECPM vs. IM again approached significance (p=.08) for percentage of intact cortical bone tissue area (ECPM 98% vs. IM 79% of the intact side area) and was not significant (p=0.9) for percentage of intact side cortical bone tissue density (both conditions were 75% of the intact side density). (See Table 7- 3)

7.4.3 Histology

Neither of the blinded independent evaluators was able to discern any consistent differences in the distribution of fibrous, cartilaginous, new-mineralized woven or residual cortical bone tissues in the ECPM

and IM calluses at twenty-eight days. There were some variations in the distribution of these types of tissues in all the calluses, but none of these differences occurred in more than 3 of the 21 calluses. One noted difference included the identification of 3 calluses (1-ECPM and 2-IM) with notably larger areas of residual cartilaginous tissue at the level of the fracture (See Figure 7-4). The presence of large areas of cartilaginous tissues in these calluses was in contrast to the rest of the twenty-eight day calluses (n=19) that had very little or much smaller areas of residual cartilage tissue present at the level of the fracture gap, suggesting that these 3 calluses were somewhat delayed in their mineralization across the fracture gap. (See Figure 7-6)

In addition to a consistency of prolific new woven bone formation in the fracture gap in 19 of the 21 calluses, all calluses (n=21) also showed marked periosteal deposition of new woven bone in both slices immediately proximal and distal to the fracture gap (See Figure 7-7), as well as marked endosteal deposition of new woven bone in one or both of the slides immediately proximal to the fracture gap. Two of these 19 calluses (both ECPM calluses) were also noted to have an obviously thinner trabecular pattern with larger spaces in the more peripheral periosteal region of the callus, which is suggestive of ongoing resorption in this region of the callus. (See Figure 7-8)

Also noted was the consistently asymmetrical healing pattern in all calluses, with markedly more periosteal woven bone being deposited on the volar surface of the bone corresponding to the compression side of the 3-point bending fracture, as well as the intrinsic musculature. (See Figures 7-2 through 7-4 and 7-6 through 7-8) Finally, the regional deposition of the new woven bone seemed to be directly related to regional resorption and remodeling of the residual cortical bone at the level of the fracture. There was more endosteal and periosteal cortical bone surface resorption, as well as more internal cortical remodeling (greater porosity) occurring in the regions within the residual cortical bone more closely situated to the new woven bone (See Figures 7-6, through 7-8).

7.5 DISCUSSION

In this study we found no differences in the pQCT measurement of total callus area or mean content at the level of the fracture between the early motion and immobilized calluses at twenty-eight days. As well there was no difference in the mean distance away from the anatomical centre or mean distribution of the mineral content within the calluses. However, when examined across the different density threshold ranges relating to the non-mineralized, new-mineralized and residual cortical bone within the callus, differences between the early motion and immobilized calluses residual cortical bone response at the level of the fracture were

apparent. These findings suggest that ECPM may influence the regional distribution of mineralized tissues within the callus at twenty-eight days post fracture.

Our finding of no overall difference in the total callus area, content and distribution suggests that from a purely biologic perspective there was no apparent difference in the stage of healing at twenty-eight days for the fractures treated with early motion compared to those that were immobilized. This finding was supported by the histology in which all but 3 calluses consistently showed prolific deposition of new woven bone throughout the fracture gap, as well as in the endosteal and periosteal regions of the callus just proximal and distal to the fracture gap. Therefore, in our closed diaphyseal fracture in a rabbit healing model, a 'bony union' as evidenced by bony bridging of new woven bone across the whole fracture gap in all three regions of the callus (periosteal, endosteal / intra-medullary and between the cortical fracture fragments) was evident in all but 3 fractures at the twenty-eight day time period.

Our study findings are consistent with two other histological studies by Ashurst (1986)[35] and Park et al (1999) [36]examining fracture healing at the four-week time point in a rabbit model. Based on these studies, if our fractures had been followed out further in time, the majority would likely have entered into the active remodeling phase of healing within the next week, and begin to show evidence of rapid endosteal and periosteal callus resorption. [35,36] Unlike Ashurst (1986) [35] and Park et al (1999), [36] we did not find consistent evidence of less endosteal bony bridging within the medullary space at the level of the fracture in our closed diaphyseal fracture-healing model. In our study, at the level of the fracture and at either one or both of the slides immediately proximal or distal to the fracture, the endosteal or intra-medullary mineralization was a consistent component of early closed fracture healing at this time point. This finding suggests that intra-medullary mineralization was likely contributing to the mechanical stability of these closed fractures. This may be an important consideration in cases when a closed diaphyseal fracture has been managed with intra-medullary wire fixation, as the loss of contiguous woven bone across the whole fracture gap during the early stages of healing may also delay the development of structural stability in fractures treated with Intra-medullary fixation. [37]

Our study also found pQCT evidence of residual cortical bone resorption and remodeling at the level of the fracture occurring in all calluses. In addition, these apparent changes in residual cortical bone morphology and density were supported by histological evidence of an apparent re-distribution of the mineralized elements from the residual cortical bone tissue to the newly mineralizing woven bone. In all calluses, there was clear histological indication of regional cortical bone endosteal and periosteal surface bone resorption,

as well as regional cortical bone re-modeling as evidenced by greater regional cortical porosity. In addition, the cortical bone remodeling and resorption appeared to have a direct anatomical relationship with the regional deposition of the new woven bone adjacent to the cortex. It has been proposed that there may be a local homeostatic response to a fracture, in which the local mineralized elements may be 're-cycled' from the regional cortical bone and re-deposited locally as mineralizing elements in the new woven bone. [31] However, the exact mechanism(s) for why or how this apparent regional re-distribution of the mineralized elements may occur has not been described.

One possible mechanism for why this cortical remodeling / resorption may occur is the sudden drop in the local load bearing demands in the cortical bone at the level of the fracture, a known mechanical stimulus for a localized increased cortical bone remodeling / resorbing response. [38] In addition the fracture injury may cause local cortical bone and vascular tissue disruption, resulting in regions of non-cellular mineralized bone tissue that may be re-absorbed as a component of early fracture healing. [35,39,40] In either case, it could be that the mineralized elements released due to this early localized cortical tissue remodeling and / or resorption may have provided a direct source of mineralizing elements for new-woven bone deposition . [38] As well these mineralized elements may have been reabsorbed systemically to help replenish the 'net systemic loss' of these mineralized elements in response to the fracture callus mineralization process. [41,42] Our study did not use any dynamic markers for either bone resorption or deposition, nor did we specifically examine the cellular components of the fractures, so we are not able to speculate on the mechanism for how the mineralized tissues may have been re-distributed regionally within the calluses.

Of additional interest is the markedly different residual cortical bone tissue response near the fracture, as well as the marked differences in the regional distribution of the lower mineralized new woven bone in the periosteal region of the callus in the ECPM calluses compared to the IM calluses. When compared to IM calluses, the ECPM calluses had significantly more (14% more) residual cortical bone tissue. As well markedly greater, though not statistically significantly greater, residual cortical bone tissue mineral content (27% greater mineral content) and mean distribution (12% greater distribution) suggestive of less cortical bone tissue resorption at the level of the fracture in the ECPM calluses. (See Figure 7-9) Although again not statistically significant, the IM calluses also had 21% more lower-density new mineralized bone tissue and 27% greater lower-density new mineralized tissue mineral content, distributed 9% further away from the anatomical centre of the callus than did the ECPM calluses. These regional differences in mineralized tissue distribution may explain the structurally superior mechanical differences found in ECPM calluses at twenty-eight days found in our previous study. (See Chapter 6).

The regional differences in residual cortical bone distribution at the fracture suggest that closed, diaphyseal fracture calluses, when subjected to early controlled cyclic physiologic loading may respond to early controlled mechanical stimuli by depositing and / or maintaining more centrally located higher-density / cortical tissue; the location where the early loads are likely occurring.[43,44] Whereas, immobilized calluses may heal with a more diffuse, or non-specific, peripheral mineralizing response. These findings are consistent with other healing connective tissues, such as tendon and ligaments, which have been shown to lay down collagen along the lines of tension when subjected to early controlled tensile loads in contrast to a more randomized deposition in immobilized tissues.[45,46] Again, this is only speculation as this study did not evaluate any specific dynamic markers related to genetic, molecular or cellular expression occurring at the level of the fracture. However, it has been clearly shown in other studies that limited or controlled mechanical stimuli introduced during the initial few days of healing clearly influences the initial genetic and molecular expression in the callus,[47-49] as well as the initial cellular proliferation and differentiation.[50] Which in turn ultimately influence the morphologic presentation of the fracture callus at four weeks post-fracture.[51-53] Therefore, it is reasonable to speculate that these same early controlled mechanical stimuli are not just influencing the specific tissue morphology in the endosteal, periosteal and fracture gap regions of the healing callus, but also the physiologic / metabolic responses in the regional cortical bone tissue adjacent to the fracture.[31,54]

Our pQCT finding of less lower mineralized tissue and mineral content in the periosteal region of the callus, distributed further from the anatomical center in the ECPM calluses may also be an indication of earlier periosteal callus resorption occurring in some of the early motion calluses, as was noted in 2 of the 11 ECPM calluses. (See Figure 7-8). Once again, in this study we did not do any quantitative histomorphometry that may have picked up some quantitative differences in the new woven bone trabecular thickness and / or porosity in the periosteal and endosteal regions of the callus.[35]

The asymmetry in the deposition of the peripheral callus, with more periosteal callus deposited on the volar or compression side of the fracture is likely related to the greater degree of micro / macro damage sustained in the volar cortex when the 3-point bending fracture was created. As described in our previous study (See Chapter 6, Figure 6-7) all the bones failed with a clean, transverse fracture line through the tension side of the cortex. Whereas, the fracture lines in the volar or compression side of the cortex usually progressed longitudinally for some distance proximally and / or distally. In addition, this asymmetrical response may be related to the presence of the intrinsic musculature on the volar surface of the bone. The

presence of muscle tissue adjacent to a healing fracture has been described as an important additional source for cellular and neovascular elements in early fracture healing. [39,40,55]

The primary limitation of this study is the lack of statistical power due to the small numbers of calluses in each of the treatment conditions. An additional limitation relates to the scan thickness (~2.2 mm) relative to the size of the fracture gap (~ 0.4 to 0.8 mm). Each scan voxel within the cortical region of the callus would include the fracture gap (~20 to 25% of total scan thickness), as well as portions of the proximal and distal cortical bone tissue (~ 75 to 80% of total scan thickness). Therefore, the residual cortical pQCT measurements (≥811 threshold mg/cm*3) would reflect not only the degree of mineralization in the fracture gap between the cortical bone ends, but also any ongoing bone turnover associated with cortical bone resorption and remodeling.[56] Given there was no standardization in terms of the size / shape of the fracture gap, this may have increased the variability of the pQCT residual cortical bone measurements in this study.

In summary, this exploratory pQCT and histological study evaluated regional tissue distribution in early controlled passive motion as compared to the immobilized calluses. It reflects strong trends but not statistically significant differences in regional mineralized tissue distribution in fracture calluses treated with early controlled passive motion compared to fractures treated with immobilization. Findings from this study support further investigation in animal models into the effects of early controlled physiologic loading on regional distribution of mineralized tissues in early fracture calluses.

7.6 CLINICAL RELEVANCE

In this idealized, closed extra-articular hand fracture-healing model in a rabbit, early controlled passive mobilization demonstrated some influence on the early regional distribution of mineralized tissue within the callus. It is possible that these differences account for the structural superior mechanical properties of ECPM calluses when compared to calluses managed with immobilization at the twenty-eight day time period. This study provides further support for the consideration of early controlled passive motion as an alternative to acute fracture immobilization in the management of closed, extra-articular hand fractures in humans.

CHAPTER 7: TABLES

Table 7-1: Primary Outcomes: Summary Data [Mean +/- SD] and Primary Statistical Analyses: ECPM (n=11) vs. IM (n=10) by Apparent Density Threshold Ranges at 28 Days.

		Non-Mineralized Tissue (0-199 mg / cm^3)		New-Mineralized Tissue (200-810 mg / cm^3)		Residual Cortical Bone Tissue (≥ 811 mg/ mm^3)
		Lower Density Non-Mineralized (0 – 99 mg / cm^3)	Higher Density Non-Mineralized (100 – 199 mg / cm^3)	Lower Density New-Mineralized (200 – 499 mg / cm^3)	Higher Density New-Mineralized (500 – 810 mg / cm^3)	Cortical Density (≥ 811 mg / cm^3)
Area* (mm^2)	ECPM	3.5 (1.0)	2.9 (1.2)	7.2 (2.7)	5.0 (1.5)	3.0 (0.8)
	IM	3.6 (1.2)	2.9 (0.7)	8.9 (3.6)	4.9 (1.8)	2.6 (0.9)
Mineral Content* (mg/mm)	ECPM	0.08 (0.5)	0.4 (0.2)	2.5 (1.2)	2.8 (1.2)	3.5 (1.0)
	IM	0.08 (0.6)	0.4 (0.1)	3.2 (1.3)	3.1 (1.1)	2.6 (1.1)
Mean Distance from Centre* (mm)	ECPM	3.2 (0.6)	2.9 (0.5)	2.4 (0.8)	1.5 (0.2)	1.1 (0.05)
	IM	3.4 (0.6)	3.1 (0.6)	2.2 (0.4)	1.6 (0.2)	1.1 (0.4)
Mean Distribution* (mg/mm)	ECPM	0.6 (0.3)	1.3 (0.6)	2.0 (0.9)	1.7 (0.5)	1.3 (0.1)
	IM	0.6 (0.2)	1.5 (0.5)	2.0 (0.7)	1.6 (0.5)	1.1 (0.2)

* Significant Main Effect Across Threshold Ranges ($p \leq 0.01$) for all outcomes.
There was NO Significant Main Effect Across Condition (ECPM vs. IM) or NO Significant Interaction (Threshold x Condition) Effect for any outcome.

Table 7-2: Primary Outcomes - Percentage Difference and Independent T- test [ECPM vs IM at 28 Days]: Lower New-Mineralized and Residual Cortical Apparent Density Threshold Ranges.

		Lower Density New-Mineralized Tissue (200 – 499 mg / cm*3)	Residual Cortical Bone (≥ 811 mg / cm*3)
Area (mm*2)	% Difference (EM / M)	- 21%	14%
	P Value	p = 0.2	p = 0.03*
Mineral Content (mg/mm)	% Difference (EM / M)	- 27%	27%
	P Value	p = 0.2	p = 0.08 t
Distance (r) from Centre (mm)	% Difference (EM / M)	9%	0%
	P Value	p = 0.6	p = 0.6
Distribution [r^2 x content] (mg/mm)	% Difference (EM / M)	- 1%	12%
	P Value	p = 0.9	p = 0.07 t

* = $p \leq 0.05$; t = $p > 0.05$ & ≤ 0.1

Table 7-3: Secondary Outcomes - Summary Data: Percentage of Intact Side Residual Cortical Area (Resorption) and Residual Cortical Average Density (Remodeling) at 28 days.

		Mean (+/- SD)	% Difference	p = value
Area (mm*2) - % of Intact Side	ECPM	98% (19%)	21%	p = 0.08 [t]
	IM	79% (27%)		
Average Density (mg/cm*3) - % of Intact Side	ECPM	75% (8%)	0%	p = 0.9
	IM	75% (5%)		

t = p > 0.05 & $\leq$ 0.1

CHAPTER 7: FIGURES

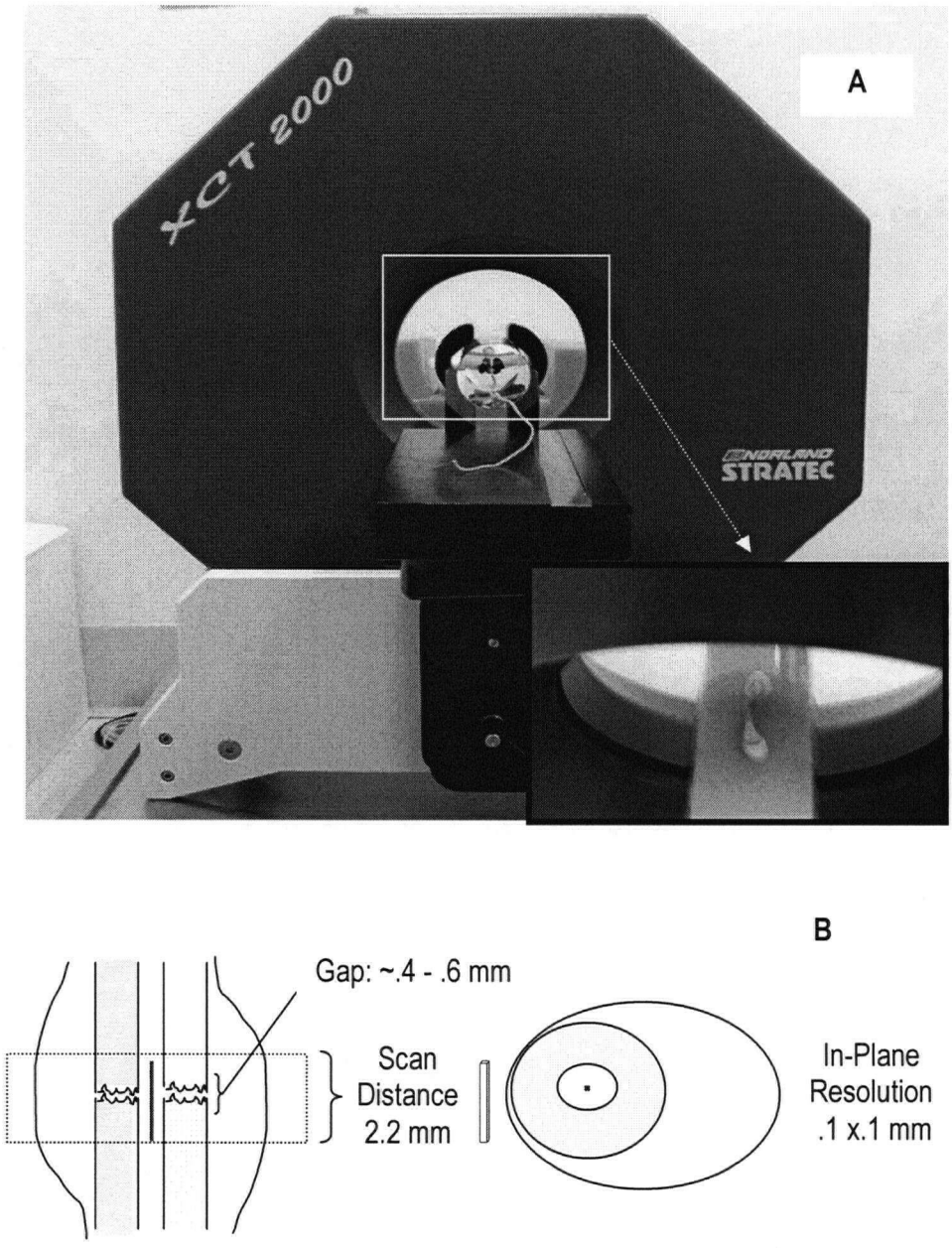


Figure 7-1: A) A photograph of the pQCT scanner set-up. Inset showing the positioning of the scanned specimen. **B)** Schematic of pQCT scanner resolution of the fracture callus / fracture gap. The red line / dot = Anatomical Centre

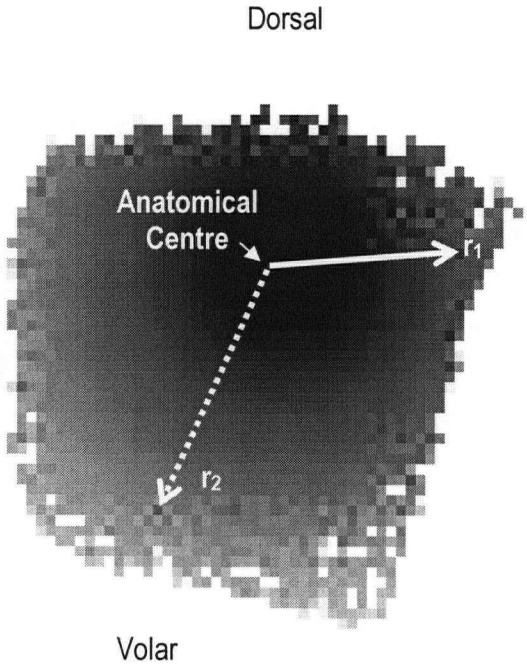


Figure 7-2 : Diagram depicting two distance measurements (r_1 and r_2) away from the anatomical centre. These measurements have been overlaid on a distance map of a 28 day callus. This image is from the same callus shown in Figure 7-3.

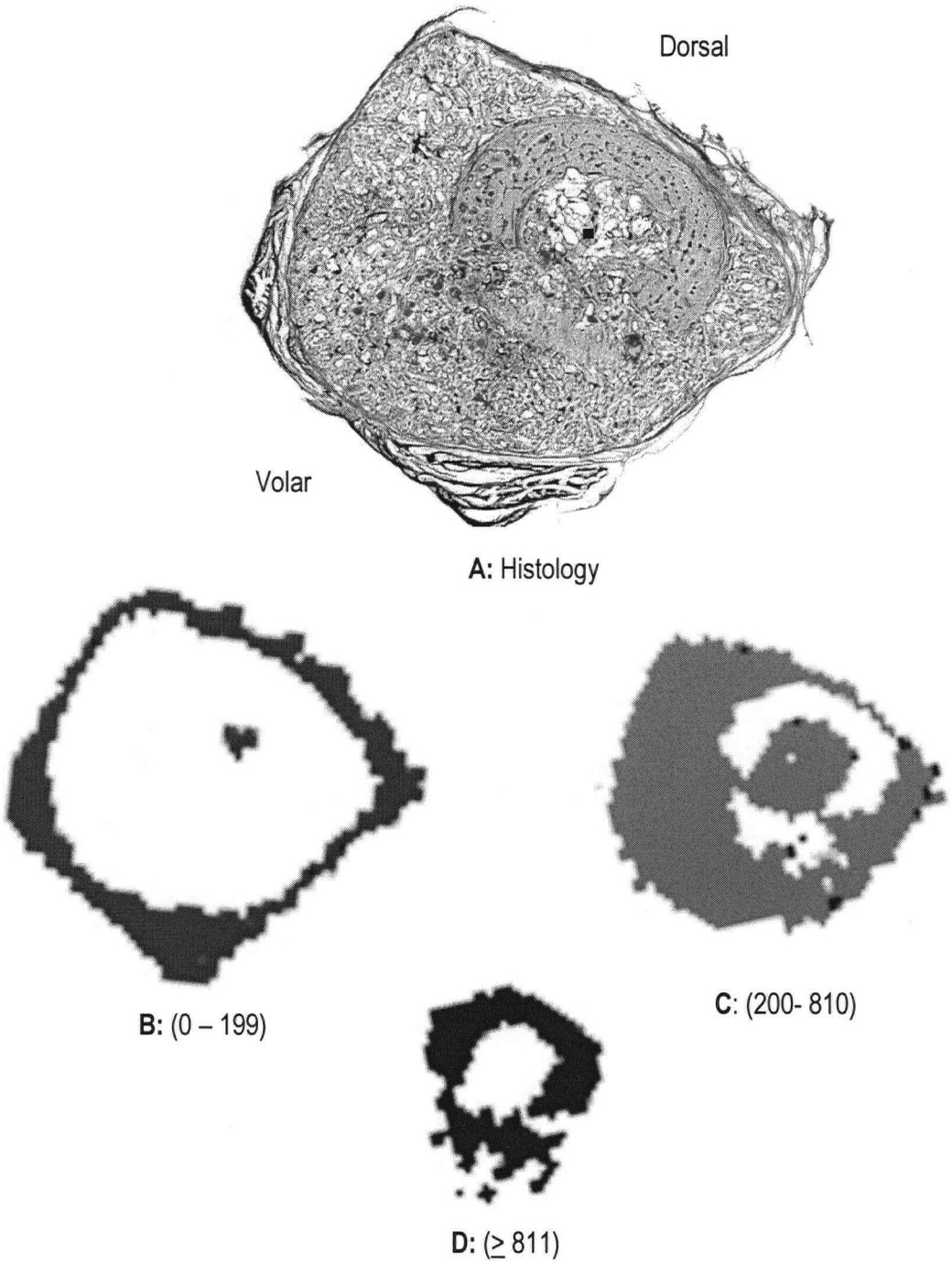
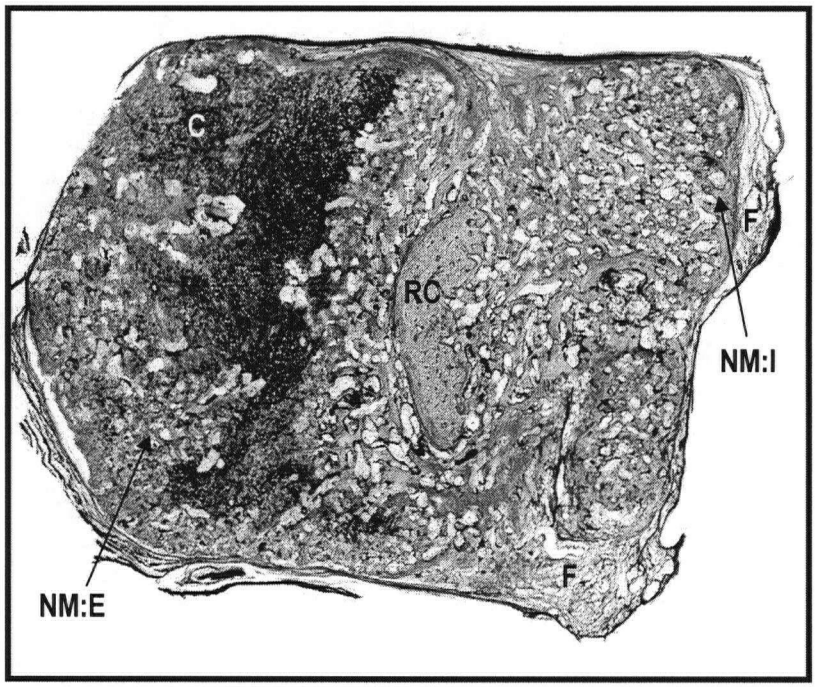


Figure 7-3: A) Histology cross-sectional image of the slice just proximal to the fracture line (undecalcified; 50 µm thickness; x100 magnification; stain = toludine blue, methyl green, methanil yellow; Black dot = anatomical centre) compared to the corresponding pQCT threshold range masks **B)** 0-199; **C)** 200-810 and **D)** ≥ 811 from the same 28 day ECPM callus.

VOLAR



DORSAL

Figure 7-4: An example of a 28 day callus at the level of the fracture gap showing: **Residual Cortical (RC)** bone; **New Mineralized Tissue - Intramembranous Ossification (NM:I)** [higher density new-mineralized tissue]; **New Mineralize Tissue - Enchondral Ossification (NM:E)** [lower density new-mineralized tissue); **Cartilage tissue (C)** [higher density non-mineralized tissue] and **Fibrous Tissue (F)** [lower density non-mineralized tissue]. With this staining protocol all mineralized tissues stain yellow, cartilage tissue stains purple and fibrous tissue stains blue.[33,34] (Undecalcified tissue; 50 µm thickness; x100 magnification; stain = toludine blue, methyl green, methanil yellow)

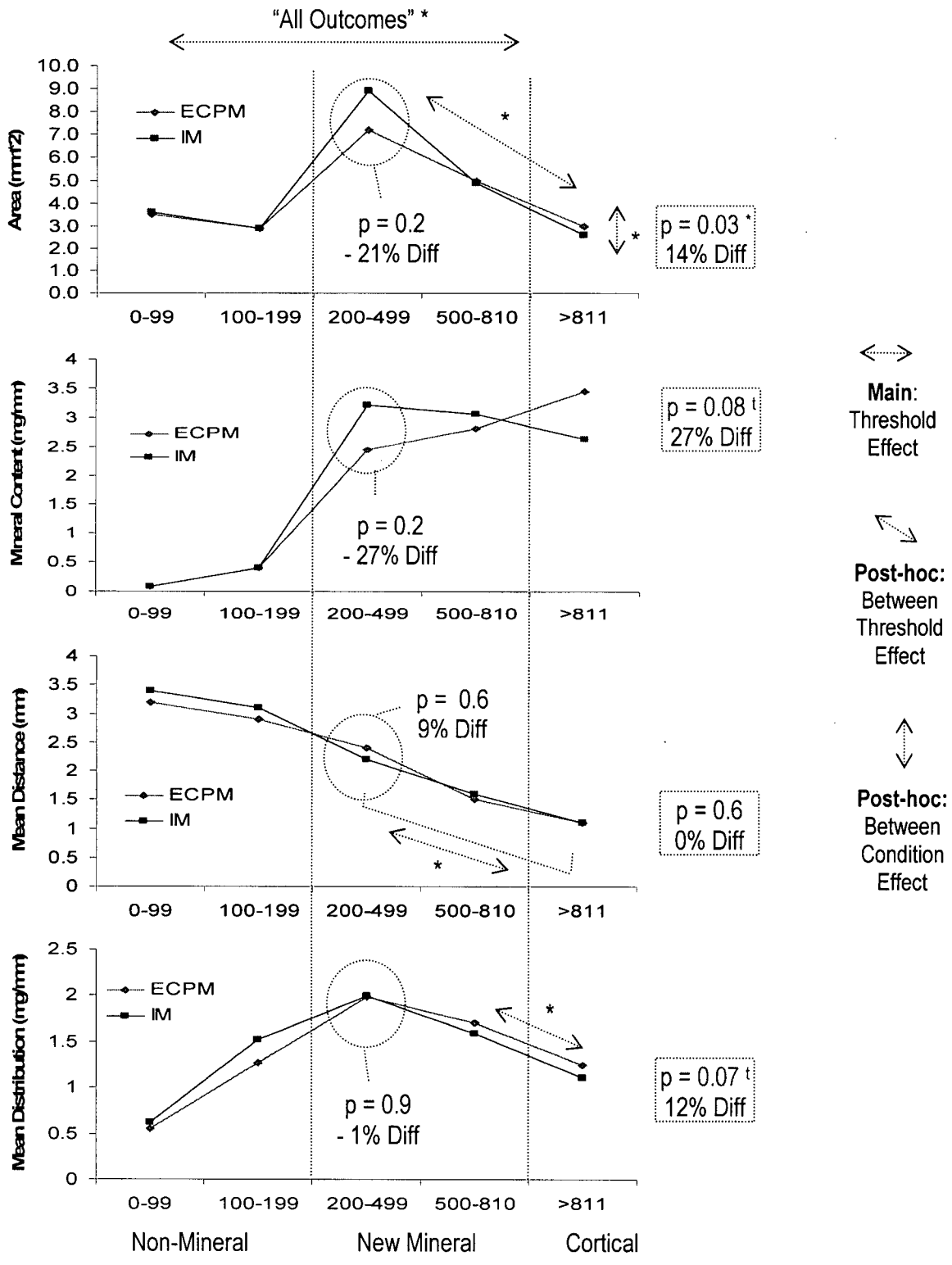
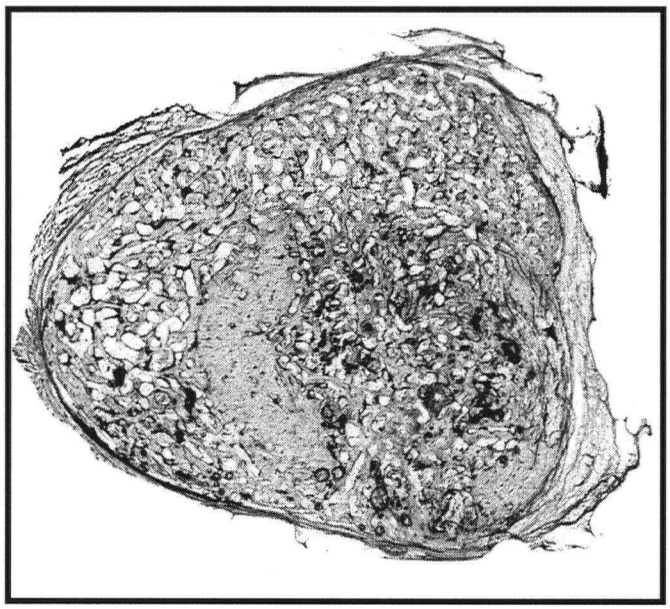


Figure 7-5: ECPM vs. IM across all Threshold Ranges at 28 Days. [* = $p \leq 0.05$; t = $p > 0.05$ & ≤ 0.1]



VOLAR

A: ECPM Callus at 28 Days: Fracture Gap

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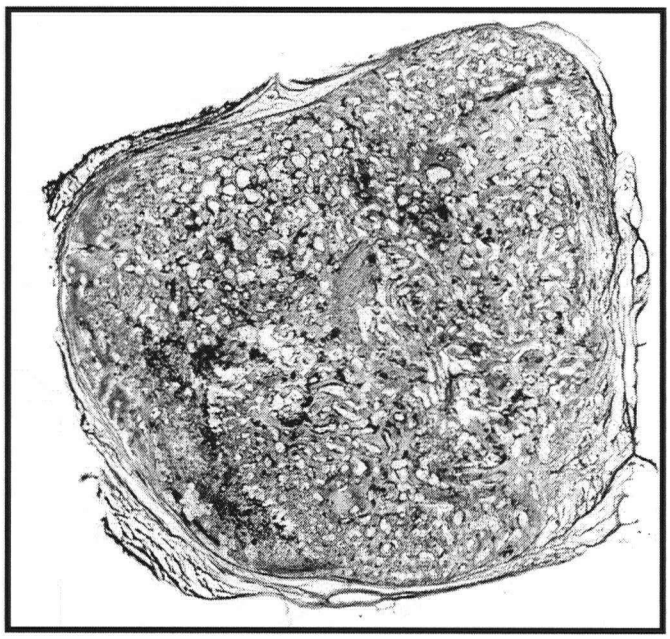
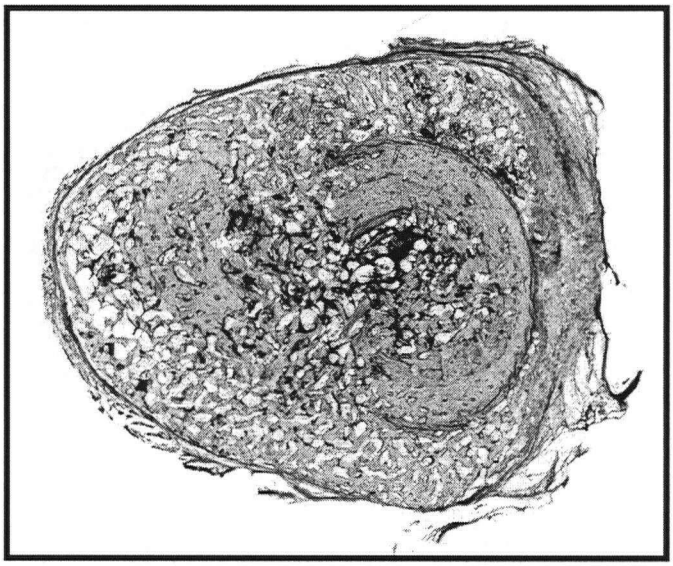
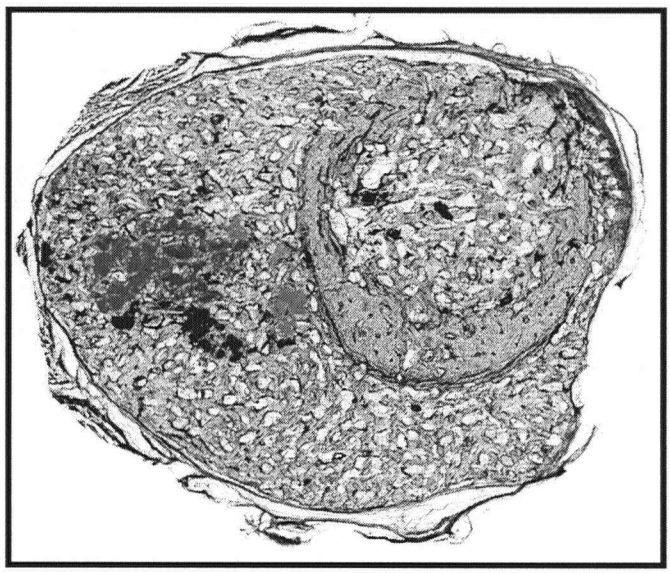


B: IM Callus at 28 Days: Fracture Gap

Figure 7-6: Digital photo cross-sectional image of A) a typical ECPM and B) a typicial IM callus at the level of the fracture gap in two 28 day calluses. In both cases there were still small islands of residual non-mineralized (cartilage and / or fibrous) tissues present. The darker black / gray areas are histological artifact.

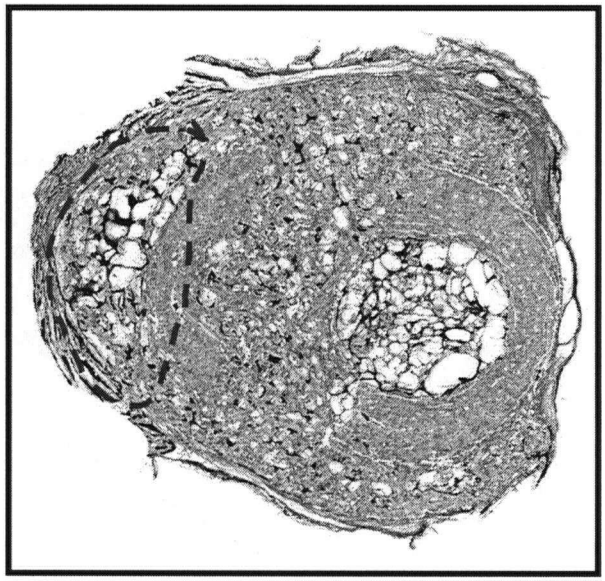


VOLAR **A:** ECPM Callus at 28 Days: Proximal Slide DORSAL



B: IM Callus at 28 Days: Proximal Slide

Figure 7-7: Digital photo cross sectional images of **A)** a typical ECPM and **B)** a typical IM callus just proximal to the fracture gap in two 28 day calluses. In both cases there is prolific endosteal and periosteal new woven bone deposition. In addition, the more peripheral region of the periosteal callus in the ECPM callus shows an example of less dense (thinner trabecular like with much larger spaces between). The darker black / gray areas are histological artifact.



VOLAR

A: ECPM Callus at 28 Days: Proximal Slide

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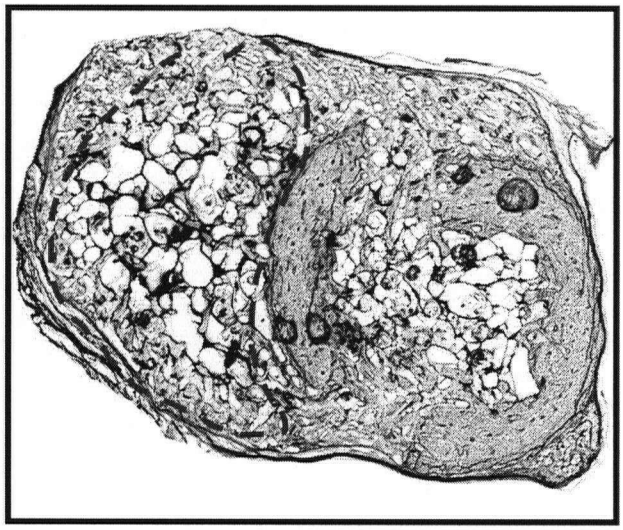
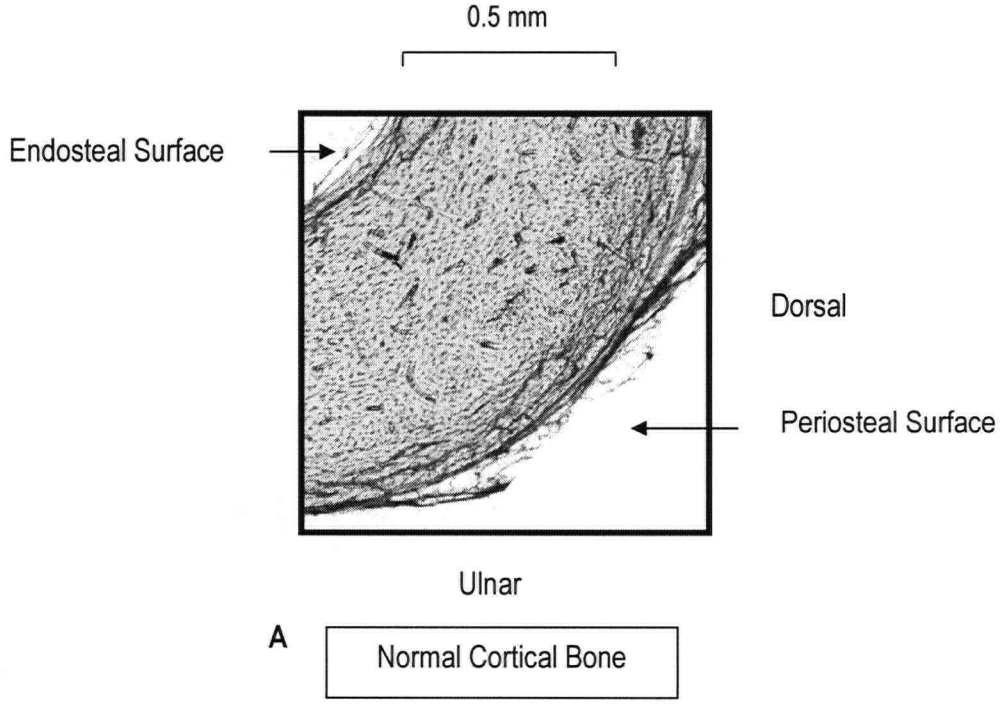


B: Different ECPM Callus at 28 Days: Proximal Slide

Figure 7-8: Digital cross sectional images of two different ECPM calluses at 28 days (**A** and **B**). Both these calluses demonstrate areas of the peripheral periosteal callus with markedly less dense (thinner trabecular lines and large spaces) suggestive of regional periosteal callus resorption. The darker black / gray areas are histological artifact.



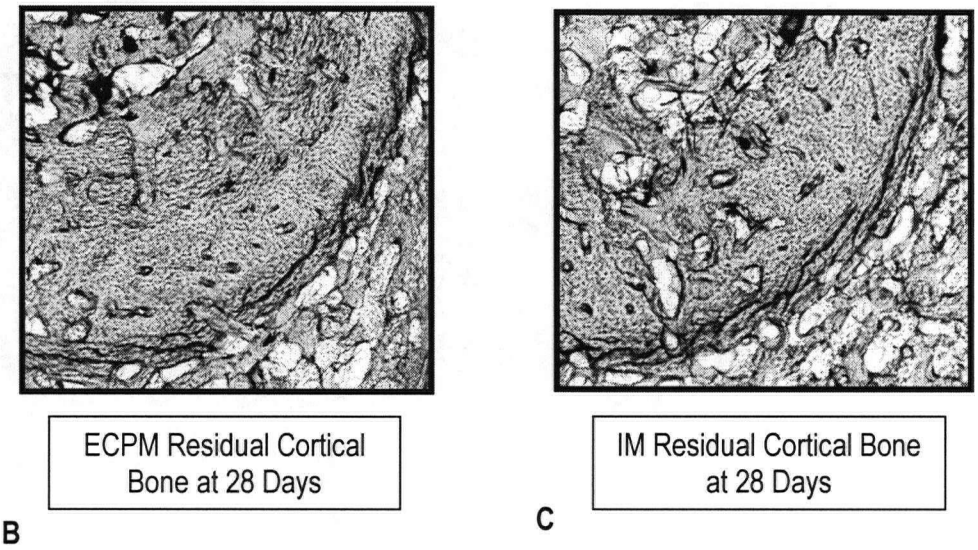


Figure 7-9: Digital Photo Images (Undecalcified; 50 µm thickness; x100 Magnification; Stain = Toluidine Blue, Methyl Green, Methanil Yellow) showing; **A)** normal cortical bone compared to the residual cortical bone just proximal to the fracture gap in; **B)** a typical ECPM and in **C)** a typical IM callus at 28 days. These images show an example of less resorption of the residual cortical bone endosteal and periosteal surfaces in a ECPM callus compared to an IM callus, as well as, similar amounts of residual cortical bone internal remodeling (porosity) in both calluses. Of additional note, is the new woven bone formation directly adjacent and connected to the resorbing cortical bone endosteal and periosteal surfaces in both the ECPM and IM calluses.

CHAPTER 7: REFERENCES

1. Freeland AE, Lund PJ. (2000) Metacarpal and phalangeal fractures. In: Russell RC (ed.) Plastic Surgery: Indications, Operations and Outcomes. (Vol. 4 - Hand Surgery). Toronto, Mosby; pp 1845-1864.
2. Freeland AE, Orbay JL. Extraarticular hand fractures in adults. A review of new developments. Clin Orthop Relat Res. 2006;445:133-145.
3. Harness NG, Meals RA. The history of fracture fixation of the hand and wrist. Clin Orthop Relat Res. 2006;445:19-29.
4. Kozin SH, Thoder JJ, Lieberman G. Operative treatment of metacarpal and phalangeal shaft fractures. J Am Acad Orthop Surg. 2000;8(2):111-121.
5. Purdy BA, Wilson RL. (2002) Management of nonarticular fractures of the hand. In: Mackin EJ, Callahan AD, Skirven TM, Schneider LH, Osterman AL (Eds.) Rehabilitation of the Hand and Upper Extremity (5th Edition). St. Louis: C.V. Mosby, pp 382-395.
6. Buckwalter JA. Effects of early motion on healing of musculoskeletal tissues. Hand Clin. 1996;12(1):13-24.
7. Feehan LM. Early controlled mobilization of potentially unstable extra-articular hand fractures. J Hand Therapy 2003;16(2): 161-170.
8. Schneider P, Reiners C. (1998) Peripheral quantitative compute tomography. In: Genant H, Guglielmi G, Jergas M (eds) Bone densitometry and osteoporosis. Berlin, Springer-Verlat. pp 349-363.
9. Ward KA, Adams JE, Hangartner TN. Recommendations for thresholds for cortical bone geometry and density measurement by peripheral quantitative computed tomography. Calcif Tissue Int. 2005;77:275-280.
10. Augat P, Merk J, Wolf S, Claes L. Mechanical stimulation by external application of cyclic tensile strains does not effectively enhance bone healing. J Orthop Trauma. 2001;15(1):54-60.
11. Bail HJ, Kolbeck S, Krummrey G, Schmidmaier G, Haas NP, Raschke MJ. Systemic application of growth hormone for enhancement of secondary and intramembranous fracture healing. Horm Res. 2002; 58 Suppl 3:39-42.
12. Luppen CA, Blake CA, Ammirati KM, Stevens ML, Seeherman HJ, Wozney JM, Bouxsein ML. Recombinant human bone morphogenetic protein-2 enhances osteotomy healing in glucocorticoid-treated rabbits.J Bone Miner Res. 2002;17(2):301-10
13. Park SH, Silva M, Bahk WJ, McKellop H, Lieberman JR. Effect of repeated irrigation and debridement on fracture healing in an animal model. J Orthop Res. 2002;20(6):1197-204.

14. Koivukangas A, Tuukkanen J, Kippo K, Jamsa T, Hannuniemi R, Pasanen I, Vaananen K, Jalovaara P. Long-term administration of clodronate does not prevent fracture healing in rats. Clin Orthop Relat Res. 2003;408:268-78.
15. Lill CA, Hesseln J, Schlegel U, Eckhardt C, Goldhahn J, Schneider E. Biomechanical evaluation of healing in a non-critical defect in a large animal model of osteoporosis. J Orthop Res. 2003;21(5):836-42
16. Park SH, Silva M. Effect of intermittent pneumatic soft-tissue compression on fracture-healing in an animal model. J Bone Joint Surg Am. 2003;85-A(8):1446-53.
17. Park SH, Silva M. Neuromuscular electrical stimulation enhances fracture healing: results of an animal model. J Orthop Res. 2004;22(2):382-7.
18. Perrien DS, Wahl EC, Hogue WR, Feige U, Aronson J, Ronis MJ, Badger TM, Lumpkin CK Jr. 1 and TNF antagonists prevent inhibition of fracture healing by ethanol in rats. Toxicol Sci. 2004; 82(2):656-60.
19. Gorman SC, Kraus KH, Keating JH, Tidwell AS, Rand WM, Parkington JD, Boudrieau RJ. In vivo axial dynamization of canine tibial fractures using the Securos external skeletal fixation system. Vet Comp Orthop Traumatol. 2005;18(4):199-207.
20. Shefelbine SJ, Augat P, Claes L, Beck A.. Intact fibula improves fracture healing in a rat tibia osteotomy model. J Orthop Res. 2005 Mar;23(2):489-93.
21. Uusitalo H, Rantakokko J, Vuorio E, Aro HT. Bone defect repair in immobilization-induced osteopenia: a pQCT, biomechanical, and molecular biologic study in the mouse femur. Bone. 2005; 36(1):142-9.
22. Cao Y, Mori S, Mashiba T, Kaji Y, Manabe T, Iwata K, Miyamoto K, Komatsubara S, Yamamoto T. 1alpha,25-Dihydroxy-2beta(3-hydroxypropoxy)vitamin D(3) (ED-71) suppressed callus remodeling but did not interfere with fracture healing in rat femora. Bone. 2006 Sep 6 [Epub ahead of print]
23. Chan CW, Qin L, Lee KM, Cheung WH, Cheng JC, Leung KS. Dose-dependent effect of low-intensity pulsed ultrasound on callus formation during rapid distraction osteogenesis. J Orthop Res. 2006 Nov;24(11):2072-9.
24. Schnarkowski P, Redei J, Peterfy CG, Weidenmaier W, Mutschler W, Arand M, Reiser MF. Tibial shaft fractures: assessment of fracture healing with computed tomography. J Comput Assist Tomogr. 1995;19(5):777-81.
25. Grigoryan M, Lynch JA, Fierlinger AL, Guermazi A, Fan B, MacLean DB, MacLean A, Genant HK. Quantitative and qualitative assessment of closed fracture healing using computed tomography and conventional radiography. Acad Radiol. 2003;10(11):1267-73

26. Markel MD, Morin RL, Wikenheiser MA, Lewallen DG, Chao EY. Quantitative CT for the evaluation of bone healing. Calcif Tissue Int. 1991;49(6):427-32.
27. Augat P, Merk J, Genant HK, Claes L. Quantitative assessment of experimental fracture repair by peripheral computed tomography. Calcif Tissue Int. 1997;60(2):194-9.
28. den Boer FC, Bramer JA, Patka P, Bakker FC, Barentsen RH, Feilzer AJ, de Lange ES, Haarman HJ. Quantification of fracture healing with three-dimensional computed tomography. Arch Orthop Trauma Surg. 1998;117(6-7):345-50.
29. Bohm AM, Jungkunz B. Bending stiffness of healing fractures can be calculated from quantitative computed tomography. Eur J Radiol. 1999;30(1):28-32.
30. Jamsa T, Koivukangas A, Kippo K, Hannuniemi R, Jalovaara P, Tuukkanen J. Comparison of radiographic and pQCT analyses of healing rat tibial fractures. Calcif Tissue Int. 2000 Apr;66(4):288-91.
31. Korkusuz F, Akin S, Akkus O, Korkusuz P. Assessment of mineral density and atomic content of fracture callus by quantitative computerized tomography. J Orthop Sci. 2000;5(3):248-55.
32. US Department of Health Human Services. National Institutes of Health (NIH). ImageJ. Image processing and analyses in JAVA. (http://rsb.info.nih.gov/ij/)
33. O'Connor KM, Park SH, Bahk WJ, McKellop H. Variation in fracture healing associated with the timing of motion initiation. Trans Orthop Res Soc 23:263, 1998.
34. O'Connor KM, Lin WS, Park SH. Timing of the initiation of interfragmentary axial motion is an important determinant of callus development and fracture strength. Phys Ther 79:S64,1999.
35. Ashhurst DE. The influence of mechanical conditions on the healing of experimental fractures in the rabbit: a microscopical study. Philos Trans R Soc Lond Biol 1986;313:271-302.
36. Park SH, O'Connor K, Sung R, McKellop H, Sarmiento A Comparison of healing process in open osteotomy model and closed fracture model. J Orthop Trauma. 1999; 13(2):114-20.
37. Mark H, Nilsson A, Nannmark U, Rydevik B. Effects of fracture fixation stability of ossification in healing fractures. Clin Orthop 2004; 419:245-250.
38. Frost HM. A 203 update of bone physiology and Wolff's law fro clinicians. Angle Orthodontist. 2004; 74(1):3-15.
39. McKibbin, B., 1978. The biology of fracture healing in long bones. JBJS(BR). 1978; 60:150-62
40. Einhorn TA. The cell and molecular biology of fracture healing. Clin Orthop 1998;46:S7-21.
41. Ingle BM, Hay SM, Bottjer HM, Eastell R. Changes in bone mass and bone turnover following distal forearm fracture. Osteoporos Int. 1999;10(5):399-407.

42. Veitch SW, Findlay SC, Hamer AJ, Blumsohn A, Eastell R, Ingle BM. Changes in bone mass and bone turnover following tibial shaft fracture. Osteoporos Int. 2006;17(3):364-72.
43. Epari, D, Taylor W, Heller M, Duda G. Mechanical conditions in the early phase of bone healing. Clinical Biomechanics, 2006, 21(6):646-55.
44. Klein P, Schell H., Streitparth F, Heller M, Kassi JP, Kandziora F, Bragulla H, Haas NP, Duda GN. The initial phase of fracture healing is specifically sensitive to mechanical conditions. J. Orthop. Res. 2003; 21, 662–669.
45. Buckwalter JA. Effects of early motion on healing of musculoskeletal tissues. Hand Clin. 1996;12(1):13-24.
46. Lin TW, Cardenas L, Soslowsky LJ. Biomechanics of tendon injury and repair. J Biomech. 2004; 37:865-877.
47. Heiner DE, Meyer MH, Frick SL, Kellam JF, Fiechtl J, Meyer RA Jr. Gene expression during fracture healing in rats comparing intramedullary fixation to plate fixation by DNA microarray. J Orthop Trauma. 2006;20(1):27-38.
48. Le AX, Miclau T, Hu D, Helms JA. Molecular aspects of healing in stabilized and non-stabilized fractures. J Orthop Res. 2001;19(1):78-84
49. Dimitriou R, Tsiridis E, Giannoudis PV. Current concepts of molecular aspects of bone healing. Injury. 2005; 36:1392-1404.
50. Hankemeier S, Grassel S, Plenz G, Spiegel HU, Bruckner P, Probst A. Alteration of fracture stability influences chondrogenesis, ostegenesis and immigration of macrophages. J Orthop Res. 2001;19:531-38.
51. Larsson S, Kim W, Caja VL, Egger EL, Inoue N, Chao EY. Effect of early axial dynamization on tibial bone healing: a study in dogs. Clin Orthop Relat Res. 2001; 388:240-51.
52. Thompson Z, Miclau T, Hu D, Helms J. A model for Intramembranous ossification during fracture healing. Journal of Orthopaedic Research. 2002; 20,1091-1098
53. Mark, H., Rydevik B. Torsional stiffness in healing fractures influence of ossification: An experimental study in rats. Acta Orthopaedica 2005; 76(3):428–433.
54. Li J, Ahmed M, Samnegard E, Ahmad T, Stark A, Kreicbergs A. Spontaneous correction of angular fracture deformity in the rat. Acta Orthop. 2005;76(3):434-41.
55. Utvag SE, Grundnes O, Reikeras O. Early muscle-periosteal lesion inhibits fracture healing in rats. Act Orthop Scand. 1998;93:411-22.

56. Ward KA, Adams JE, Hangartner TN. Recommendations for thresholds for cortical bone geometry and density measurement by peripheral quantitative computed tomography. Calcif Tissue Int. 2005;77:275-280.

CHAPTER 8: SHOULD WE BE MOVING TOWARDS EARLY CONTROLLED MOBILIZATION OF EXTRA-ARTICULAR HAND FRACTURES IN BC: A SUMMARY

8.1 RESEARCH QUESTION ADDRESSED IN THIS CHAPTER

Should we be moving towards early controlled mobilization of extra-articular hand fractures in BC?

8.2 INTRODUCTION

Early controlled mobilization of tendon, nerve and other fragile healing hand injuries is a common component of hand therapy practice.[1-3] However, early controlled mobilization (ECM) for most extra-articular hand fractures is still not generally recommended during the first three to four weeks of healing.[4-6] The rationale for this disparity in clinical practice is not clear. However, it may be that early mobilization, even when performed in a protected and controlled manner is still generally considered by clinicians as either 'unsafe' (causing harm) or 'unnecessary' (providing no functional benefit) following an extra-articular hand fracture.[7]

This thesis examined the introduction of early controlled mobilization in the management of extra-articular hand fractures as a possible alternative to acute post-fracture immobilization. In particular it looked at the clinical concern related to the potential negative impact of ECM on early fracture healing and alignment following an extra-articular fracture. As well it examined the clinical issue of whether or not ECM has the potential to improve a person's functional recovery following an extra-articular hand fracture. All of these clinical issues were examined in the context of the application of ECM within the health care system in BC.

The primary objective of this thesis was to investigate the clinical question of: "Should we be moving towards early controlled mobilization of extra-articular hand fractures in BC?" This clinical question was addressed through a series of research investigations related to this primary clinical inquiry. This chapter begins with a brief overview of the key research findings and conclusions from each of the research studies. Followed by a discussion of why, based on these research findings, we should be considering a move towards early controlled mobilization of extra-articular hand fractures in BC. This chapter ends with an overview of some key educational and research initiatives that could be done in an effort to move towards early controlled mobilization of extra-articular hand fractures in BC.

8.3 SUMMARY OF KEY RESEACH FINDINGS

8.3.1 **Question 1:** Can ECM be implemented clinically following an extra-articular hand fracture?

Research Methodology: A clinical overview (See Chapter 2) [7]

Purpose: To review the clinical literature and describe early controlled motion options for potentially unstable hand fractures.

Summary: Early active motion (< 3weeks) following an extra-articular hand fracture has been recommended in two clinical scenarios: following an open reduction and rigid fixation and following a closed, simple, non-displaced fracture. In these instances it is recommended that active motion be introduced in conjunction with some additional external regional fracture brace or splint. [4-6] The rationale is that these fractures have sufficient 'clinical' stability to withstand active motion of the regional joints without interfering with fracture healing and / or the fracture alignment. Early active motion is not recommended when the fracture lacks sufficient stability or strength to withstand early active motion. Examples of such cases are oblique, spiral or comminuted fracture patterns and / or fractures managed with co-aptive or less stable fixation methods. In these instances post-fracture immobilization of the hand, wrist and forearm is generally recommend for a period of up to 4 weeks. [7]

This chapter provided an overview of other ECM options, other than unrestrictive active joint motion, that could be considered when an extra-articular hand fracture is perceived to be potentially unstable. These ECM alternatives are based on the same rehabilitation principles utilized by hand therapists in the management of other fragile healing tissues in the hand. The goal of treatment in the initial 3 to 4 weeks of healing is to protect and maintain the integrity of the fracture reduction, using techniques of protective support and early controlled motion options that allow safe, pain free, progressive mobilization. This overview also noted that the potential benefits of ECM following an extra-articular hand fracture would be negated if motion caused fracture-healing problems of delayed, mal-union or non-union. This chapter also stressed that the planning, design and timing for the 'safe' implementation of an early controlled mobilization program for potentially unstable fractures would require the hand therapist, physician and patient to communicate and work in close interdisciplinary partnership.

Conclusion: Physical and Occupational therapists, with an expertise in hand therapy can apply the principles of ECM for the management of potentially unstable extra-articular hand fractures. Developing clear guidelines for when and how to utilize ECM following an extra-articular hand fracture requires further educational and research collaboration within the hand therapy and hand surgery communities (in BC).

8.3.2 **Question 2:** Is there any scientifically validated clinical evidence to support early motion following an extra-articular hand fracture?

Research Methodology: A systematic review and critical appraisal of the literature (See Chapter 3).[8,9]

Purpose: To examine the level of scientifically validated clinical evidence, defined as at least one good quality randomized clinical trial (RCT), related to early motion following a hand fracture. The research question was: Does the introduction of early (< 21 days) motion of joints adjacent to a fracture affect fracture healing and functional outcomes in people with extra-articular metacarpal or phalangeal fractures when compared with people treated with post-fracture immobilization?

Key Findings: Over 1000 clinical articles were identified as possibly reporting outcomes following a hand fracture, however only six met the inclusion criteria. These studies represented 459 patients with simple, closed, metacarpal fractures in the second through fifth digits, managed with or without a closed reduction. None were managed with any additional fracture fixation. All studies compared fractures treated with regional immobilization to some form of unrestricted active motion of joints adjacent to the fracture, introduced with either a regional fracture brace or a light compressive elastic bandage. No studies were found involving an extra-articular thumb metacarpal, any digital phalangeal or any extra-articular hand fracture managed by an open reduction and / or additional fracture fixation. All included studies were rated as quasi-randomized (i.e poor or unclear randomization strategies) and poor quality (i.e. limited overall quality and internal validity). The heterogeneity of the health outcomes prevented a quantitative synthesis of the data, so a qualitative overview was completed. Two additional studies were subsequently found (n=100, all closed 5th metacarpal neck fractures) that would have met the inclusion criteria. Both were also poor quality, quasi-randomized studies that demonstrated improved functional outcomes with early motion.

Conclusions: There is currently no scientifically valid clinical evidence (i.e. at least one high quality RCT) to either support or refute the use of early regional joint motion following any extra-articular hand fracture. However, six Quasi-Randomized Clinical Trials (Q-RCT) did show a consistent potential for functional benefit with no significant risk of harm when early active motion of regional joints was allowed after a simple, closed, extra-articular, finger metacarpal fracture. This suggests that ECM be considered as a possible option in these fractures.[10] However, it has not been established if early motion interventions would have similar effects following a closed, extra-articular thumb metacarpal or any digital phalangeal fracture. Nor has the effect of early motion interventions on health outcomes been established in any extra-articular hand fracture managed with an open reduction and / or additional fracture hardware fixation. ECM following these types of extra-articular hand fractures requires further clinical investigation.

8.3.3 **Question 3:** Who is most at risk for sustaining a hand fracture in BC?

Research Methodology: A population based epidemiologic study involving a five-year, retrospective review, of all BC residents identified with hand fractures in the British Columbia Linked Health Datasets (BCLHD) (See Chapter 4) [11]

Purpose: To identify population based hand fracture annual incidence rates, demographics, and seasonal and geographic variation from all people seeking treatment for a hand fracture in British Columbia, Canada from May 1, 1996 to April 20, 2001.

Key Findings: This study identified 72,481 hand fractures with an estimated 14,500 hand fractures occurring each year in a population base of approximately 4 million people in BC. In total 50% were phalangeal fractures, 42% were metacarpal fractures and 8% were multiple fractures, with no significant trend for a change over time in number of fractures. The annual incidence rate was 36 / 10,000. Age adjusted annual incidence rates ranged from 29 / 10,000 for people >20 years old to 61 / 10,000 for people $\leq$ 20 years old. Across all ages, males were at a 2.08 relative risk for sustaining a hand fracture. In BC, young adolescents of both genders were most at risk for sustaining a hand fracture, likely due to a period of bone fragility following a rapid growth in height. [12] This risk was sustained throughout adolescence and young adult years (20 to 30 y.o), most notably in young males. This was likely due to increased behavioral risk factors, such as participation in higher risk sport and occupational activities. After the age of 30 until 60 years old, males continued to be at higher risk again likely due to increased participation in higher risk occupational activities. After the age of 65, females began to assume a greater risk for hand fractures, suggesting that bone fragility related to age related changes in bone mineral density was also a risk factor for hand fractures.[13] Rates for hand fractures varied markedly with the season, with the highest rates occurring in the spring and summer when the climate in BC would, in general, favor greater outdoor activities. Finally, a marked increase in hand fracture relative risk in Northern BC also suggests that socio-economic factors may also be a contributing risk factor for a hand fracture.

Conclusion: In BC, males between the ages of 15 to 40 are most at risk for sustaining a hand fracture and therefore, also most likely to potentially benefit from early controlled mobilization following a hand fracture, especially if ECM results in a faster return to normal sport and occupational activities. Young adolescents of both genders are also at high risk for sustaining a hand fracture. Greater public awareness related to increased hand fracture risk following rapid periods of growth, as well as with participation in higher risk sporting and occupation activities could lead to potential preventative measures to help reduce the incidence of hand fractures in BC.

8.3.4 Question 4: Who is providing the initial care for people with hand fractures in BC and in what clinical setting?

Research Methodology: A population based epidemiologic study involving a five year, retrospective review of all BC residents previously identified as having sustained a hand fracture in the British Columbia Linked Health Datasets (BCLHD) (See Chapter 5)

Purpose: To identify who initially provided the medical treatment for these hand fractures and in what health care setting. In addition, to examine hand fractures with an associated hospital admission to identify who was admitting, the type of admission, wait time, length of stay and geographic variation in hospital admission rates.

Key Findings: In BC, the vast majority (90%) of hand fractures were managed with no hospital admission. In addition, just over half were initially treated on a non-emergent out-patient basis with more than 66% treated initially by a primary care physician. Hand fracture injuries requiring a day surgery admission were almost exclusively (98%) admitted by surgical specialists, with the majority (60%) receiving surgery within two days of first being treated as an out-patient. For those requiring an acute hospital admission, the vast majority (83%) were either directly admitted to the hospital or admitted on the same day as their initial out-patient care and were likely to be in the hospital for a short period of time (59% LOS = 1 day; 87% LOS $\leq$ 7 days). There was also a markedly increased rate for both acute and day surgery admissions in Northern BC compared to the rest of the province. This suggests that people in Northern BC may not only be at greater risk for sustaining a hand fracture (Chapter 4), but they also appear to be at a higher risk for sustaining a more complex hand fracture injury. There are also notably higher rates for day surgical admissions on Vancouver Island and acute admission in the Interior compared to the rest of the province. The reasons for the geographic variations in hospital admission rates could not be discerned from the data.

Conclusions: In BC, most hand fractures are initially treated by primary care physicians, with the initial point of contact into the medical care system being either a physician's office or an emergency room setting. Therefore, potential recruitment into a clinical trial and / or education regarding possible alternatives to cast immobilization for simple, closed hand fractures should be directed at primary care and emergency room physicians in the province. In BC, people with more complex hand fracture injuries are being referred to and treated quickly by, Orthopaedic and Plastic surgeons, with only a small percentage admitted to hospital for management of their hand fracture. Education regarding early referrals to hand therapy and / or recruitment into clinical trials related to early controlled mobilization of potentially unstable hand fractures should be targeted at these surgeon specialists in BC.

8.3.5 Question 5: What is the effect of Early Controlled Passive Motion (ECPM) on the quality and rate of early fracture healing in a rabbit model? Part 1: Clinical Outcomes.

Research Methodology: A pre-clinical efficacy study examining the effect of ECPM on fracture alignment and 4-point bending structural properties in a rabbit model (See Chapter 6)

Purpose: To investigate if ECPM was likely to cause harm by affecting the quality and rate of early fracture healing in a non-weight bearing limb, closed, potentially unstable, diaphyseal fracture in a rabbit model.

Methods: Fifty, mature, female, New Zealand White rabbits were pre-conditioned for one week to a non-weight bearing limb brace and a custom molded metacarpal fracture brace. Under general anesthesia, a closed 3-point bending fractures were produced, reduced under fluoroscopy and placed back into the fracture brace. For four days the rabbits were given twice daily pain medication and were allowed to rest and recover. On the fifth day, the randomly allocated early passive motion rabbits began to receive twice daily, fifteen minute sessions, of a standardized passive digital flexion and extension motion exercise program. Experienced hand therapists did all of the ECPM treatment. The immobilized rabbits received no further intervention to the affected forepaw. Rabbits were sacrificed at 5 (n=11), 14 (n=19) and 28 (n=20) days post fracture. Blinded outcome evaluations included lateral x-rays, pQCT imaging and four-point bending to structural failure.

Key Findings: All fractures were in the mid-shaft and there was no difference in the distribution of fracture pattern across the conditions. The early controlled passive motion fractures during the initial 28 days post fracture showed significantly better ($p \leq 0.05$) gains in initial stiffness (29% difference at twenty eight days), maximum stiffness (21% difference at twenty eight days), failure load (17% difference at twenty eight days) and energy absorbed per unit area (21% difference at twenty eight days) when compared to the immobilized fractures. They also showed a significant reduction in dorsal fracture angulation (33% difference at twenty eight days). Throughout the 28 days, total callus area was not significantly different between the two groups.

Conclusion: Early controlled passive motion did not cause harm by affecting either the quality or rate of early fracture healing in a potentially unstable, closed, extra-articular, fracture in this rabbit fracture healing model. Rather, in this idealized simulated hand fracture healing model, early controlled passive motion led to statistically ($p \leq 0.05$) and clinically (> 25% difference) relevant improvements in both fracture initial stiffness (our primary outcome) and fracture alignment (our secondary outcome). Therefore, early controlled passive mobilization passive following a closed, potentially unstable, diaphyseal hand fracture does warrant further clinical investigation in humans.

8.3.6 Question 6: What is the effect of Early Controlled Passive Motion (ECPM) on the quality and rate of early fracture healing in a rabbit model? Part 2: Callus morphology at 28 days.

Research Methodology: A pQCT and histological study examining the effect of ECPM on closed fracture callus regional tissue distribution at 28-days post fracture (See Chapter 7).

Purpose: To investigate if there were any quantitative (pQCT) or qualitative (histological) differences in fracture callus regional tissue distribution at the 28-day time period for fractures treated with early controlled passive motion (ECPM) when compared to fractures treated with immobilization (IM).

Methods: The 28-day callus's pQCT scan data were re-analyzed using apparent density thresholds defining the non-mineralized, new-mineralized and residual cortical bone within the callus. Outcome variables included total area and content and mean distance and distribution away from anatomical centre within for tissue type (threshold range). The formalin fixed calluses were processed as undecalcified specimens through serial dehydration in ethanol and serial infiltration and block embedding in a methyl methacrylate based resin. Serial (fracture line + / - one slice) cross sectional slides were cut, ground (50mμ) and then differentially stained for fibrous, cartilage and mineralized tissues. Two independent evaluators, blinded to treatment condition, evaluated the slides for systematic differences in distribution of different tissue types.

Key Findings pQCT analyses showed ECPM calluses to have significantly more (14% more) residual cortical bone tissue, as well as markedly but not significantly more residual cortical bone tissue mineral content (27% more) and greater distribution (12% more) than did the IM calluses. Although not statistically significant, the IM calluses also had 21% more lower density new mineralized tissue with 27% more lower density new mineralized tissue mineral content distributed 9% further away from the anatomical centre of the callus than did the ECPM calluses. Histological evaluation showed no consistent differences in the distribution of fibrous, cartilaginous, new-mineralized woven or residual cortical bone tissues between the two groups. This indicated that both groups were at the same stage of healing at 28 days, with all but 3 showing a bony union at the level of the fracture. The histology also showed no difference in the amount of residual cortical porosity. However, the IM calluses did show some evidence of increased periosteal and endosteal surface cortical bone resorption which was consistent with the pQCT findings.

Conclusion: Early controlled mobilization appeared to influence the early regional distribution of mineralized tissue within these 28-day calluses. These differences in mineralized tissue distribution possibly accounted for our previous findings of superior mechanical properties of ECPM calluses at the 28-day time period. Further investigations into the effect of ECPM on early regional callus mineralized tissue distribution in animal fracture healing models are warranted. .

8.4 SHOULD WE BE MOVING TOWARDS EARLY CONTROLLED MOBILIZATION OF EXTRA-ARTICULAR HAND FRACTURES IN BC?

Based on the findings of this thesis, there are a number of clinical scenarios where early controlled motion of joints adjacent to a healing extra-articular fracture would be considered appropriate. Therefore, ECM following an extra-articular hand fracture is something we should be moving towards in BC. Unfortunately, the MSP and HS administrative data evaluated in this thesis do not allow for analyses of specific physician practice patterns related to immobilization of extra-articular hand fractures as the data do not identify details of the specific treatments provided. In addition, since payments for out-patient occupational therapy services and / or costs related to splinting are not covered in the MSP administrative data so it is also difficult to predict how many people with an extra-articular hand fracture may already be referred for the provision of fracture brace type splints and early controlled motion exercises. However, despite these limitations in being able to define the current utilization trends for early motion alternatives following an extra-articular hand fracture in BC, it is still reasonable to speculate for whom and under what clinical conditions early motion following an extra-articular hand fracture should be considered.

8.4.1 Early Mobilization of 'Simple, Closed, Undisplaced or Stable' Extra-Articular Hand Fractures in BC.

Given there are currently 65 certified hand therapists working throughout the province, other than in the Northern region, it is reasonable to assume that physicians and surgeons working in collaboration with therapists specializing in hand therapy may well be familiar with the recommendations for functional fracture bracing and early active motion for simple, closed, undisplaced metacarpal fractures. Therefore, they may already be referring some of their patients to hand therapists for regional functional fracture bracing or splinting and early mobilization. Physicians and surgeons not working in collaboration with hand therapists specializing in hand therapy but also familiar with the concept of functional fracture bracing, may also be utilizing limited casting and / or regional taping and elastic compressive bandaging options in the management of these types of fractures. However, it is most likely that the majority of simple, closed, likely clinically stable extra-articular hand fractures in BC are being managed by primary care physicians opting to immobilize the hand, wrist and forearm for periods of up to one month.

Further continuing education directed at the primary care and emergency room physicians regarding early functional fracture bracing options for simple, closed, minimally displaced metacarpal fractures would increase the likelihood that these early motion treatment options would be considered. This education should include the design of modified casting or splinting options for closed metacarpal fractures and

recommendations for how they could be applied in a physician's office or emergency room setting. In addition, details of the patient education and early active motion exercises related to functional fracture bracing treatment should be reviewed, including how they can be implemented by a primary care physician as part of normal post-fracture medical follow-up. Finally, given that further clinical trials are needed to evaluate the efficacy or effectiveness of the use of functional fracture bracing and early active motion following simple, closed, minimally displaced phalangeal fractures, functional fracture bracing for these types of fracture injuries in BC should be implemented by therapists specializing in hand therapy and only in collaboration with a knowledgeable referring physician.

8.4.2 Early Mobilization 'Following an Open Reduction and Rigid Fracture Fixation' of an Extra-Articular Hand Fracture in BC.

In BC, the more complicated hand fracture injuries are being referred to and treated by Orthopaedic and Plastic surgeons. So it is likely that patients admitted to hospital for a more extensive surgical intervention, would be referred post-operatively to hand therapists for splinting and likely some form of early controlled mobilization, especially in areas in the province with access to specialized hand therapy services within the hospital. However, only small percentages (10%) of hand fractures in BC are being treated surgically. In addition, the percentage of those that are likely managed by surgeons with knowledge of, and access to, the specialized surgical implements associated with small hand bone rigid internal or external fixation likely limits the number in patients in BC that are actually treated with these more rigid fixation options.

8.4.3 Early Controlled Mobilization of 'Potentially Unstable' Extra-Articular Hand Fractures in BC.

The results of the research in this thesis related to the effects of ECPM on the quality and rate of early fracture in a rabbit model provide the basic scientific support for moving towards clinical trials in humans. Such trials could examine the efficacy of Early Controlled Motion (ECM) in the management of potentially unstable, closed, extra-articular hand fractures in humans. In addition it is feasible, given the large number and diverse regional distribution of hand therapists in the province of BC, to be moving towards designing and implementing multi-centered, prospective, randomized clinical trials for potentially unstable extra-articular hand fractures. Finally, as with early mobilization following closed, stable phalangeal fractures, the use of ECPM for individual patients in BC with closed, potentially unstable extra-articular fractures should only be implemented by therapists specializing in hand therapy. As well this should be done only in collaboration with a referring physician or surgeon with an expertise in hand fracture injuries.

8.5 RECOMMENDATIONS FOR MOVING TOWARDS EARLY CONTROLLED MOBILIZATION OF EXTRA-ARTICULAR HAND FRACTURES IN BC

8.5.1 Educational Initiatives:

- Include the positive effects of early micro-motion on early fracture healing, as well as the clinical concepts of functional fracture bracing and biologic or flexible fixation in the management of long bone diaphyseal fractures in the curriculum of all students training to become physicians and therapists in the province.
- Offer opportunities for students training to be physical and occupational therapists in the province to learn about the specialization of hand therapy. Provide opportunities for rehabilitation student placements and clinical mentorship opportunities in facilities that offer specialized hand therapy services, including early mobilization of extra-articular hand fractures.
- Provide continuing education opportunities regarding the principles and practical application of early controlled mobilization for potentially unstable extra-articular hand fractures for Orthopaedic and Plastic surgeons and therapists specializing in hand therapy in the province.
- Provide continuing educational opportunities for primary care and emergency medicine physicians in the province regarding limited casting or splinting alternatives, as well as early motion alternatives that could be implemented directly as a component of their management of simple, closed, undisplaced extra-articular metacarpal fractures. Furthermore, review the indications for referral to surgeons and therapists specializing in the management of more complex extra-articular hand fracture injuries. .
- Provide educational opportunities for the medical advisors and case managers at the WCB of BC regarding the management of simple, closed, minimally displaced extra-articular hand fractures with functional fracture bracing and early controlled motion. In addition, educate them on the role of specialized hand therapists in the early management of the more complex hand fracture injuries. Given the hand therapy network that is already in place, pro-active referrals for work related hand fractures for an early hand therapy consultation and / or treatment could be facilitated by the WCB of BC.
- Increase public awareness of the increased risk for a hand fracture in all young adolescents, as well as, a continued heightened risk for males between the ages of 15 to 40. This could lead to potential preventative measures, particularly in high risk sporting and occupational settings, that could reduce hand fracture risk and therefore reduce the incidence of this common injury BC.

8.5.2 Research Initiatives:

- Further basic scientific research examining the effect of early controlled mobilization on closed, extra-articular fracture early regional tissue distribution is warranted. In particular the use of higher resolution micro-CT scans, that examine the regional distribution of all mineralized tissue throughout the healing callus, combined with dynamic fluorescence labeling and histomorphometry could lead to a better understanding of how early physiologic loads may influence the re-distribution of mineralized tissues within the healing callus.
- Prospective, multi-centered, randomized clinical trials in humans are warranted, examining the effect of early controlled motion alternatives on short and long term functional outcomes in individuals with:
  - Simple, closed, minimally displaced, extra-articular phalangeal fractures managed with or without reduction and / or percutaneous pin fixation.
  - Simple, closed, minimally displaced, extra-articular thumb metacarpal fractures managed with or without reduction and / or percutaneous pin fixation.
  - Simple, closed, potentially unstable, extra-articular metacarpal or phalangeal fractures managed with or without reduction and / or additional fracture fixation.

CHAPTER 8: REFERENCES:

1. Muenzen PM, Kasch MC, Greenberg S, Fullenwider L, Taylor PA, Dimick MP. A new practice analysis of hand therapy. J Hand Ther. 2002 Jul-Sep;15(3):215-25.
2. Kasch MC, Greenberg S, Muenzen PM. Competencies in hand therapy. J Hand Ther. 2003 Jan-Mar;16(1):49-58.
3. Pettengill KM. The evolution of early mobilization of the repaired flexor tendon. J Hand Ther. 2005; 18(2):157-68.
4. Freeland AE, Lund PJ. Metacarpal and phalangeal fractures. In: Russell RC (ed.) Plastic Surgery: Indications, Operations and Outcomes. (Vol. 4 - Hand Surgery). Toronto, Mosby; 2000:1845-1864.
5. Purdy BA, Wilson RL. Management of nonarticular fractures of the hand. In: Mackin EJ, Callahan AD, Skirven TM, Schneider LH, Osterman AL (Eds.) Rehabilitation of the Hand and Upper Extremity (5th Edition). St. Louis: C.V. Mosby, 2002:382-395.
6. Stern PJ. Fractures of the metacarpals and phalanges. In: Green DP, (ed). Operative Hand Surgery (3rd ed). New York: Churchill Livingstone Inc. 1993:695-758.
7. Feehan LM. Early controlled mobilization of potentially unstable extra-articular hand fractures. J Hand Therapy 2003;16(2): 161-170.
8. Feehan LM, Bassett K. Is there evidence for early motion following an extra-articular hand fracture? J Hand Ther 2004; 17(2): 300-308.
9. Feehan LM, Basset K. Is There Evidence for Early Mobilization Following an Extra-Articular Hand Fracture? (DARE Structured Abstract) (http://nhscrd.york.ac.uk/online/dare/20049807.htm)
10. Freeland AE, Orbay JL. Extraarticular hand fractures in adults. A review of new developments. Clin Orthop Relat Res. 2006;445:133-145.
11. Feehan LM, Sheps S. Incidence and Demographics of Hand Fractures in British Columbia, Canada: A Population Based Study. J Hand Surg 2006; 31A:(Accepted June 7. 2006)
12. Parfitt AM. The two faces of growth: benefits and risks to bone integrity. Osteoporos Int. 1994;4:382-398.
13. Johansen A, Evans RJ, Stone MD, Richmond PW, Lo SV, Woodhouse KW. Fracture incidence in England and Wales: a study based on the population of Cardiff. Injury. 1997 Nov-Dec;28(9-10):655-60.

Appendix 3-1: DARE Structured Abstract

DARE abstract 20049807

Is there evidence for early mobilization following an extraarticular hand fracture?

Feehan L M, Bassett K. Is there evidence for early mobilization following an extraarticular hand fracture?. Journal of Hand Therapy, 2004;17(2):300-308.

This record is a structured abstract written by CRD reviewers. The original has met a set of quality criteria. Since September 1996 abstracts have been sent to authors for comment. Additional factual information is incorporated into the record. Noted as (A:....).

CRD summary

This review assessed the effectiveness of early mobilisation on fracture healing and function after an extraarticular hand fracture. The authors concluded that there was insufficient evidence to support or refute the use of early mobilisation after an extraarticular hand fracture, and that further research is required. This was a well-conducted review and the authors' conclusions are likely to be reliable.

Author's objective

The authors' objective was to assess the effectiveness of early mobilisation on fracture healing and function after an extraarticular hand fracture.

Specific interventions included in the review

Studies that compared complete fracture immobilisation of both joints proximal and distal to the fracture with early mobilisation (less than 21 days) of one or both joints adjacent to the fracture were eligible for inclusion. Studies could use additional interventions only if the same interventions were used in both treatment groups. Studies in which fractures were reduced, or in which any type of hardware fracture fixation was used, were included. All of the included studies compared traditional plaster cast immobilisation (for 2 to 4 weeks) with some form of early unrestricted active motion. The studies used different forms of external support: this varied from unrestricted motion in all joints, e.g. taping, to supports that potentially restricted movement in the affected digit but allowed full unrestricted motion of the affected digit metacarpal phalangeal joint

Participants included in the review

Studies of participants of either sex and any age, with an open or closed extraarticular hand fracture (or fractures) in any digit, were eligible for inclusion. Participants with intraarticular metacarpal or phalangeal fractures were excluded, as were those with associated soft tissue trauma. The participants had simple closed fractures of the second

to fifth digits. The mean age of the participants (reported in 4 studies) ranged from 22 to 31 years.

Outcomes assessed in the review

Studies that assessed 'healing status' or 'functional status' were eligible for inclusion. The primary outcomes were the time to union for healing outcomes, and the test score on Standardised Hand Function Test or Health-Related Quality of Life Test Instrument for function. Studies in the review assessed fracture angulation, adverse skin reactions, mobility, grip strength and the time to return to work. The outcomes were assessed up to 6 months.

Study designs of evaluations included in the reviews

Prospective controlled clinical trials, quasi-randomised and randomised controlled trials (RCTs) were eligible for inclusion. In the review, quasi-RCTs were defined as studies reported as RCTs, but with unclear or inadequate description of the method of randomisation and with inadequate concealment of treatment allocation.

What sources were searched to identify primary studies

MEDLINE, EMBASE, BIOSIS Previews, SciSearch and OSHROM (for occupational medicine databases) were searched. Searches for unpublished studies were conducted using in-house databases and directories, commercial databases, web library catalogues, contact with trialists, peer-reviewed internet sites, internet search engines and handsearches of reference lists (specific sources were stated in the paper). No date or language limits were applied to the searches.

Criteria on which the validity (or quality) of studies was assessed

Studies were assessed using 18 items modified from published criteria (see Other Publications of Related Interest nos.1-2). The items assessed were patient selection, interventions, protocol violations, outcome evaluation and analysis. An 'overall quality assessment score' (maximum score 18) and an 'internal validity' percentage score (maximum score 11) were calculated. Studies scoring over 70% were considered to be of a high quality.

How were decisions on the relevance of primary studies made?

Two reviewers independently selected studies and resolved any disagreements by consensus.

How were judgements on the validity (or quality) made?

Two reviewers independently assessed validity using a standardised and pre-tested form. Any disagreements were resolved by consensus.

How were the data extracted from primary studies?

One reviewer extracted the data using a standardised form and a second reviewer checked the accuracy.

Number of studies included in the review

Six quasi-RCTs (n=459) were included.

How were the studies combined?

The studies were grouped by outcome and a narrative synthesis was undertaken.

How were differences between studies investigated?

Differences between the studies were discussed in the review.

Results of the review

All 6 studies were considered to be of a low quality. No studies assessed the primary review outcomes. Three studies that assessed the change in fracture alignment or malunion found no statistically significant change from baseline fracture angulation in any treatment group. These 3 studies, which used functional fracture braces, found different results for adverse skin reactions. One study found considerably more adverse skin reactions in the early mobilisation group provided with a commercially available three-point pressure metacarpal fracture brace (17 of 65 patients versus 0 of 68 patients with an immobilisation cast). Two studies using custom-moulded braces found no pressure sores or skin necrosis in any treatment group. All 6 studies found that early mobilisation statistically significantly improved mobility immediately after the end of the immobilisation period, compared with immobilisation, but found no difference in mobility between treatments at the final follow-up. Three studies found that early mobilisation statistically significantly improved strength immediately after the end of the immobilisation period in comparison with immobilisation. One study found that early mobilisation statistically significantly reduced time to return to work in comparison with immobilisation.

Was any cost information reported?

No.

Authors' conclusions

There was insufficient evidence to support or refute the use of early mobilisation after an extraarticular hand fracture. Further research is required.

CRD commentary

The review question was clear in terms of the study design, intervention, participants and outcomes. The search for relevant studies was extensive and attempts were made to minimise language and publication bias. Two reviewers independently selected studies and assessed validity, and methods were used to minimise bias in the data extraction process. Validity was formally assessed, but the criteria used were not explicitly stated. A narrative synthesis was appropriate given the small number of diverse studies. This was a well-conducted review and the authors' conclusions are likely to be reliable.

What are the implications of the review?

Practice: The authors did not state any implications for practice. Research: The authors stated that well-conducted RCTs are required to evaluate the efficacy and effectiveness of early mobilisation after extraarticular hand fractures.

Other publications of related interest

1. Verhagen AR, de Vet HC, de Bie RA, Kessels AG, Boers M, Bouter LM, et al. The Delphi list: a criteria list for quality assessment of randomized clinical trials for conducting systematic reviews developed by the Delphi consensus. J Clin Epidemiol 1998;51:1235-41. 2. van Tulder MW, Assfendelft WJ, Koes BW, Bouter LM. Method guidelines for systematic reviews in the Cochrane Collaboration Back Review Group for spinal disorders. Spine 1997;22:2322-30.

Subject index terms

Subject indexing assigned by NLM: Early-Ambulation; Finger-Joint/pp [physiopathology]; Fractures,-Bone/co [complications]; Fractures,-Bone/pp [physiopathology]; Fractures,-Bone/th [therapy]; Hand-Injuries/co [complications]; Hand-Injuries/pp [physiopathology]; Hand-Injuries/th [therapy]; Joint-Instability/et [etiology]; Joint-Instability/pp [physiopathology]; Joint-Instability/th [therapy]; Outcome-Assessment-(Health-Care)

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The Centre for Reviews and Dissemination, University of York, has produced this abstract as part of the Database of Abstracts of Reviews of Effects.

Appendix 3-2: Study Quality Assessment Form

STUDY METHODOLOGY - QUALITY EVALUATION FORM

STUDY TITLE: Assessed by: LF KB

PROTOCOL:

- Refer to 'Operationalization' Criteria clarification for each question.
- If disagreement occurs, then discuss and come to consensus / agreement. If no consensus, then a 3rd person will decide.
- When variable is still considered 'unclear' after reviewer discussion. If item considered 'likely yes' then it will be scored positively if item considered 'likely no' it will be scored negatively.

Patient Selection:	(circle most appropriate)
1. Were the inclusion and exclusion criteria for entry into the trial clearly defined?	Yes / No / Unclear
2. * Were patients randomly allocated to treatment condition?	Yes / No / Unclear
3. * Was the treatment allocation adequately concealed?	Yes / No / Unclear
4. Were important baseline characteristics reported and comparable? Principle confounders are: age, gender, # location, # angulation, # duration, method of reduction, method of hardware fixation and timing of ECM.	Yes / No / Unclear
Intervention / Care Program:	
5. Were the experimental and control interventions / care programs explicitly described?	Yes / No / Unclear
6. * *Was the care provider blinded to the care program?*	N/A
7. * *Was the patient blinded to the care program?*	N/A
Protocol Violations:	
8. * Were co-interventions avoided or comparable between groups?	Yes / No / Unclear
9. * Did at least 80% of each group complete the study?	Yes / No / Unclear
10. * Was compliance with the prescribed care program acceptable in all groups?	Yes / No / Unclear
Outcome Evaluation:	
11. * Was the outcome evaluator blinded to the care program?	Yes / No / Unclear
12. Were the outcome measures clearly defined, measured objectively and clinically relevant?	Yes / No / Unclear
13. * Were adverse effects / complications described for all groups?	Yes / No / Unclear
14. * Was the timing of outcome evaluation comparable between all groups?	Yes / No / Unclear
15. Was the duration of follow-up clinically appropriate?	Yes / No / Unclear
Analysis:	
16. * Were the outcomes of patients who did not complete the trial or who did not comply with the care programs clearly described and included in the analysis (intention to treat)?	Yes / No / Unclear
17. Were point estimates and measures of variability presented for the primary outcome measures?	Yes / No / Unclear
18. Was the sample size for all groups described?	Yes / No / Unclear
Additional Reviewer Comments:	

*** Internal Validity Items**

'OPERATIONALIZATION' CRITERIA

SECTION ONE: PATIENT SELECTION

1. Were the inclusion and exclusion criteria for entry into the trial clearly defined?

   Yes, clearly defined.
   Unclear, or inadequately defined.
   No, not defined.

2. Were patients randomly allocated to treatment condition?

   Yes, method of assignment was (unpredictable) or truly random.
   Note: Use of DOB, Date, days of week should not be considered as 'truly random'.
   Unclear, or inadequate attempts to randomize treatment allocation (quasi-random assignment).
   No, there was no attempt to randomly allocate to treatment condition.

3. Was the treatment allocation adequately concealed?

   Yes, the method of allocation did not allow for disclosure of the treatment allocation to the 'care team' prior to completion of the initial medical / surgical management.
   Unclear, inadequate, small but possible chance for disclosure of the treatment allocation to the 'care team' prior to completion of the initial medical / surgical management.
   No, there was no attempt to conceal allocation (eg: open list / tables) to the 'care team'.

4. Were important baseline characteristics reported and comparable? Principle confounders were considered to be age, gender, fracture location, fracture angulation, fracture duration, method of reduction, method of fixation and timing of initiation of ECM.

   Yes, good comparability of groups for key confounding variables, or confounding adjusted for in the analysis.
   Unclear, confounding small, mentioned but not adjusted for, or comparability reported in text without confirmatory data.
   No, a large potential for confounding or poor comparability, or not discussed.

SECTION TWO: INTERVENTION / CARE PROGRAMS

5. Were the experimental and control interventions / care programs explicitly described?

   Yes, the care program / interventions for all groups are clearly described and in enough detail to be able to replicate the study.
   Unclear, or inadequate description of the specific details of the care programs / interventions, making it difficult to replicate the study.
   No, the specific details of the care programs / interventions were not described.

6. *Was the care provider blinded to the care program provided? (Impossible)*

7. *Was the patient blinded to the care program provided? (Impossible)*

SECTION THREE: PROTOCAL VIOLATIONS

8. Were co-interventions avoided or comparable between groups?

   Yes, care programs clearly identical other that intervention of interest.
   Unclear, or inadequate description, but likely trivial differences, or some evidence of comparability.
   No, not mentioned or clear and important differences in care programs other than intervention of

interest. (Note: Describe specific concerns in comment section of evaluation form)

9. Did at least 80% of each group complete the study?

   Yes, withdrawal / drop out rates well described with all groups having at least 80% of sample complete the study.
   Unclear, or inadequate description of withdrawal / drop out rates. Small or moderate chance of less than an 80% completion rate for all groups.
   No, mention or one or more of the study groups did have less than an 80% completion rate.

10. Was compliance with the prescribed care program acceptable in all groups?

    Yes, reasonable attempts were made to monitor / measure compliance and it is unlikely that significant numbers in any group varied significantly from the prescribed care program.
    Unclear, or inadequate description of care program compliance making it difficult to determine if significant numbers in any group varied significantly from the prescribed care program.
    No, mention or no attempt to measure or monitor compliance with prescribed care program, therefore unable to determine if significant numbers in any group varied significantly from the prescribed care program.

SECTION FOUR: OUTCOME EVALUATION

11. Was the outcome evaluator blinded to the care program?

    Yes, effective action taken to blind outcome evaluator to care program.
    Unclear, or inadequate attempts (eg: small or moderate chance of unblinding) to blind outcome evaluator to care program
    No, mentioned or large chance for 'unblinding' of outcome evaluator to care program.

12. Were the outcome measures clearly defined, measured objectively and clinically relevant?

    Yes, the outcome measures were clearly defined, measured objectively and clinically relevant.
    Unclear, or inadequate description of outcome measures, primary outcomes appear to be objective and clinically relevant.
    No, the outcome measures were not clearly described, or were 'soft' / subjective outcomes or were not clinically relevant. (Note: Describe specific concerns in comment section of evaluation form)

13. Were adverse effects / complications described for all groups?

    Yes, adverse effects / complication were clearly described for all groups.
    Unclear, or inadequate descriptions of the adverse effects / complications, making it difficult to determine if there were differences between the groups.
    No, the adverse effects / complications were NOT clearly described, impossible to determine if there were differences between groups.

14. Was the timing of outcome evaluation comparable between all groups?

    Yes, the timing of outcome evaluation for all primary outcomes was comparable between groups.
    Unclear, or inadequate description of the timing of outcome evaluation, making it difficult to determine if comparable between groups.
    No, the timing of outcome evaluation for all primary outcomes was NOT comparable between groups.

15. Was the duration of follow-up clinically appropriate? NOTE: Healing should be 3 mths, Function can be less than 3 mths.

    Yes, all primary outcomes had 'clinically appropriate' follow-up duration in all groups.
    Unclear, inadequate or incomplete descriptions of follow-up duration for all primary outcomes,

making it difficult to determine if all groups were followed for a clinically appropriate duration.
No, the duration of follow-up for all primary outcomes was NOT clinically appropriate.
(Note: Describe specific concerns in comment section of evaluation form)

SECTION FIVE: ANALYSIS

16. Were the outcomes of patients who did not complete the trial or who did not comply with the care programs clearly described and included in the analysis (intention to treat)?

Yes, withdrawals and poor compliance were well described and accounted for in analysis (intention to treat analysis was done).
Unclear, no mention, unclear or inadequate mention, or obvious differences and no adjustment.
No, withdrawals and poor compliance were described and NOT accounted for in analysis (NO intention to treat analysis)

17. Were point estimates and measures of variability presented for the primary outcome measures?

Yes, there were appropriate point estimates (eg: mean, median) and measures of variability (eg: SD, 95% CI) presented for all the primary outcome measures.
Unclear, incomplete or inadequate presentations of appropriate point estimates and measure of variability, however, these could be separately determined given the data presented.
No, there were NO point estimates (eg: mean, median) and measures of variability (eg: SD, 95% CI) presented for the primary outcome measures and there was not way to separately determine this information given the data presented.

18. Was the sample size for all groups described?

Yes, sample size / group was reported.
Unclear, specific numbers not reported directly, but could be calculated given data presented.
No, sample size / group was NOT reported and could not be separately determined.

APPENDIX 4.1: Clinical Study Ethics Approval Form

Appendix 6-1: A Priori Power Calculation. Used in AO Foundation Grant Application

Estimation of Sample Size and Power:

Primary outcome comparison:	Mean Failure Torque (n-m) @ 28 days, IM x EA
Statistical Test:	Independent, Two-tailed, T-test, normal distribution, equal variance and sample sizes.
Sample Size:	10 / condition
Alpha:	.05
mu_1 [estimated population mean (IM)]:	*.3 n-m**
sigma (estimated standard deviation):	*.1 n-m**

Effect Size:	*Power:*
.1 (±33%)	.61
.125 (±40%)	.80
.15 (±50%)	.92

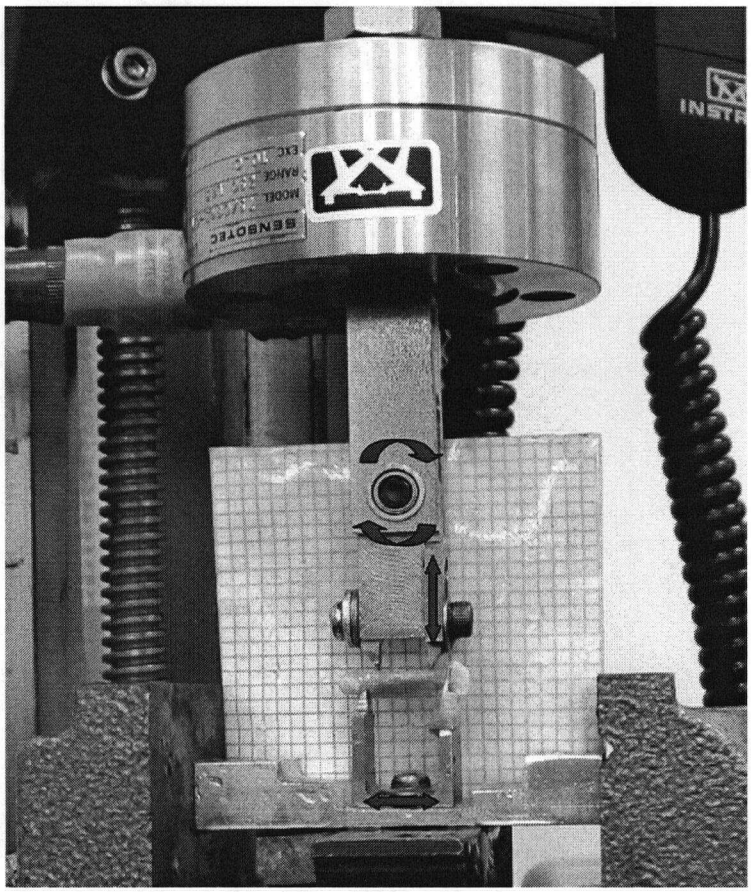
* Bouxsein ML et al. Recombinant Human Bone Morphogenetic Protein-2 accelerates healing in a rabbit ulnar Osteotomy model. JBJBS 2001;83A:1219-30.

Clinical significance: Clinical significance has been defined as a 40% improvement in ultimate failure torque in the EA group as compared to the IM group at 28 days. Based on these power calculations, with a sample size of 10 rabbits / condition, we will have an 80% probability of accurately detecting a population mean difference in ultimate failure torque of ≥40% between the immobilized (IM) and early active (EA) groups at the 28-day healing period.

APPENDIX 6.2: Ethics Approval Form, Animal Care Committee

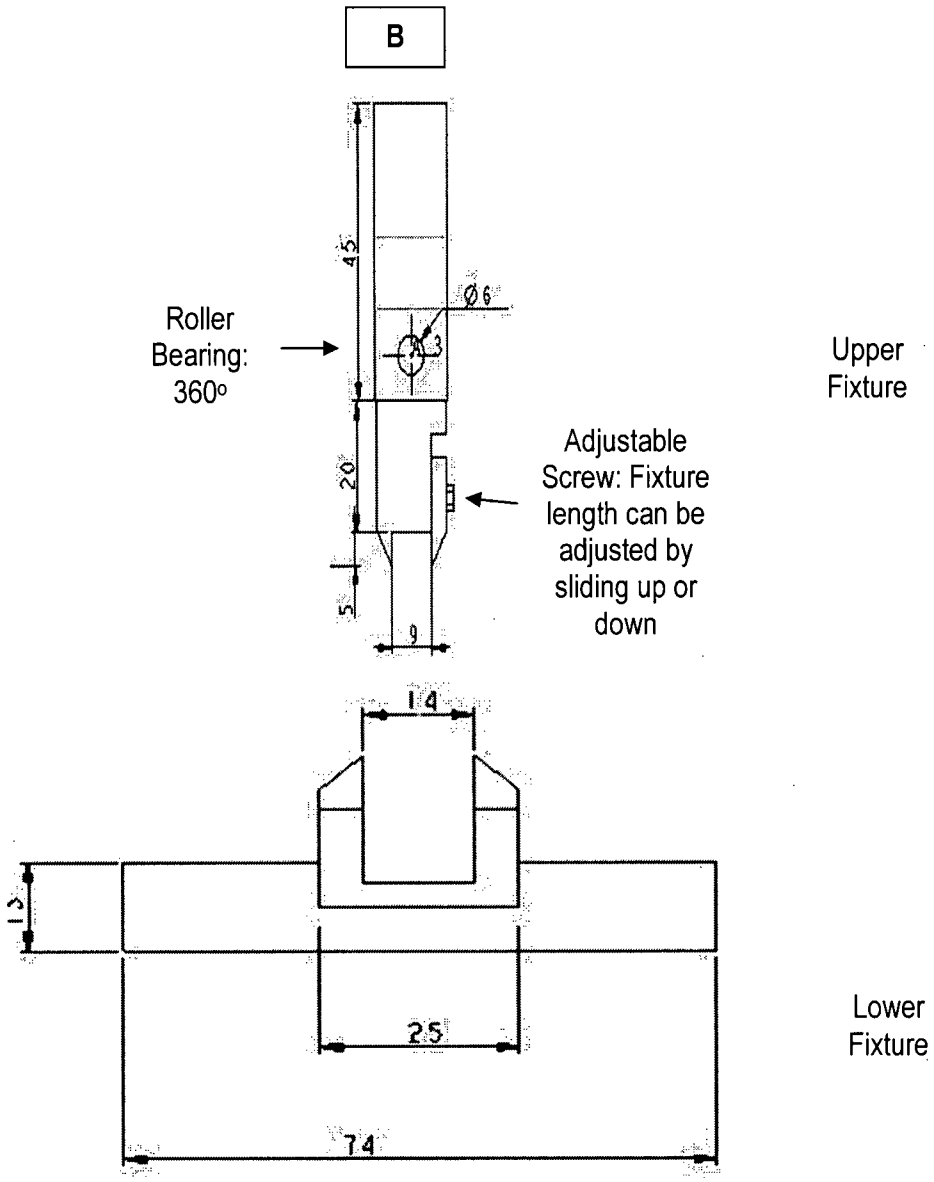
Appendix 6-3: 4-Point Bending Fixture Set-Up and Drawings

A



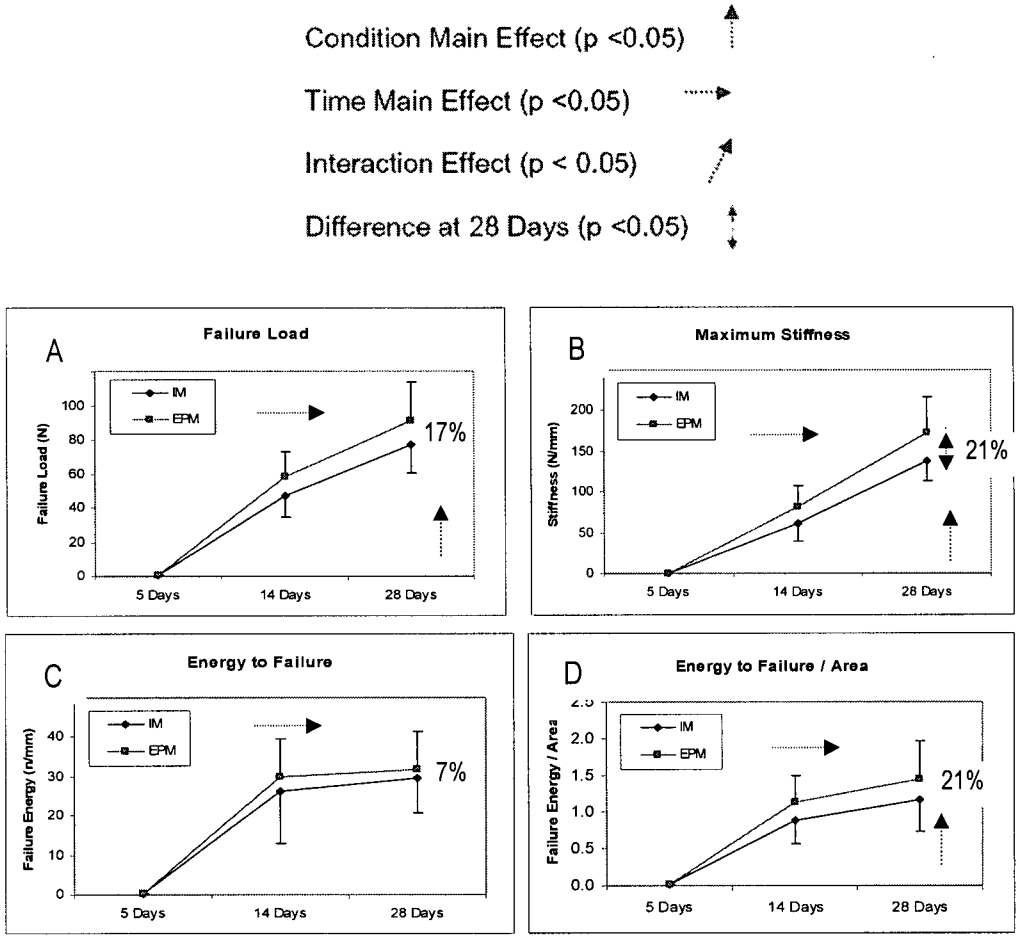
A) Digital Picture of the 4-Point Bending Set-up with an Intact 3rd Metacarpal Specimen– Shown from a Distance. The red arrows indicate dynamic or adjustable components.

Appendix 6-2: 4-Point Bending Fixture Set-Up and Drawings (con't)



B) 4-Point Bending Fixture Design Drawings (Upper and Lower Components - Side view). Values are in mm.

Appendix 6-4: Treatment Condition x Time Period Graphs – Other Key Outcome Variables:



A) Failure Load, **B)** Maximum Stiffness, **C)** Energy to Failure, **D)** Energy to Failure / Area.

Appendix 7-1: ImageJ Distance Measurement Macros

Acknowledgement: These macros were written for ImageJ by David Cooper, PhD. Post-Doctoral Fellow. Bone Health Research Group, Centre for Hip Health, University of British Columbia, Vancouver, Canada. June 26, 2006

//This macro measures the densities of pixels under the threshold mask

```
//
macro "PixelDensities"
{thresh = getNumber("Bone from Background Threshold:", thresh);
x=getWidth();
y=getHeight();
run("Clear Results");
run("32-bit");
run("Set Measurements...", "  mean centroid invert redirect=None decimal=3");
for (z=0; z<y; z++) {
for (i=0; i<x; i++) {
        test=getPixel(i,z);
        if (test>thresh) {
        makeRectangle(i,z,1,1);
        run("Measure");}
```

//This macro calculates distance from a user defined landmark

```
//
macro "DistanceFromLandmark"
{setTool(7);
beep();
print("Anatomical Landmark Needed");
    leftButton=16;
    x2=-1; y2=-1; z2=-1; flags2=-1;
    logOpened = false;
    click = 0;
    while (click< 1) {
      getCursorLoc(x, y, z, flags);
      if (x!=x2 || y!=y2 || z!=z2 || flags!=flags2) {
        s = " ";
        if (flags&leftButton!=0){
                    s = s + "<left>";
                    click = 1;
                    beep();}
        print(x+" "+y+" "+z+" "+flags + "" + s);
        logOpened = true;
        startTime = getTime();}
      x2=x; y2=y; z2=z; flags2=flags;
      wait(10);}
yinvert=getHeight();
```

```
anatx = x + 0.5;
anaty = yinvert - (y + 0.5);
n = nResults;
for (i =0; i < n; i++){
        xraw = getResult("X", i);
        yraw =  getResult("Y", i);
        xdistance = xraw - anatx;
        ydistance = yraw - anaty;
        Distance = sqrt(xdistance * xdistance + ydistance * ydistance);
        setResult("Dist.From.Landmark", i, Distance); }
updateResults();}
```

//This macro maps the distance values onto an image*

```
//
macro "DistanceMap"
{run("Set Measurements...", "  mean centroid invert redirect=None decimal=3");
run("Duplicate...", "DistanceMap.tif");
run("Select All");
run("Clear");
run("8-bit");
n = nResults;
for (i =0; i < n; i++){
        distance= getResult("Dist.From.Landmark", i);
        x = getResult("X", i);
        y = getResult("Y", i);
        yinvert = getHeight()-y-1;
        setPixel(x, yinvert, distance);}
updateDisplay();}
```

Appendix 7-2: Undecalcified Callus, Histology Tissue Preparation Protocol

Procedure	Solution &	# Days in	In	Out	Comments
Fixation	Formalin & 10% Buffer	1 day			Rinse x5 DH2O, Freeze @ -20C until dehydration
Dehydration	10% ETOH	2 hours			Thaw, Ends cut off with diamond saw – specimens ~ 12mm.
	30% ETOH	1 day			
	50% ETOH	3-4 days			
	75% ETOH	3-4 days			
	90% ETOH	3-4 days			
	95% ETOH	3-4 days			
	100% ETOH	3-4 days			
	100% ETOH	3-4 days			
Infiltration	30 / 70 Technovit / ETOH (T/E)	3-4 days			
	50/50 T/E	3-4 days			
	70/30 T/E	3-4 days			
	100% T	3-4 days			
	100% T	3-4 days			
Embedding	100 % T	24 hours			Embed perpendicular to long axis of the bone, parallel to the fracture line

Rabbit Metacarpal Fixation, Dehydration, Infiltration & Embedding Schedule

Feehan / Oxland - Fracture Healing Study

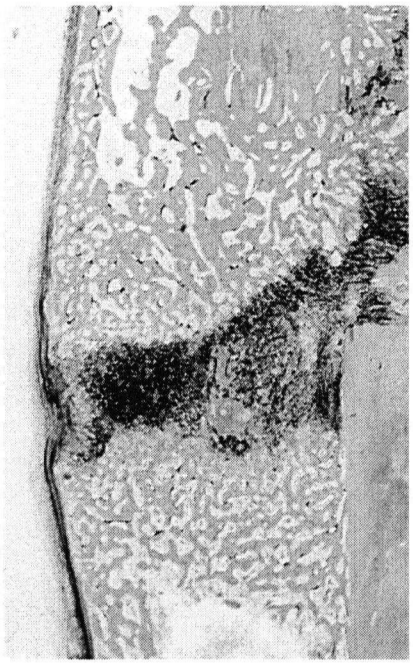
Note: All Fixation, Dehydration and Infiltration Steps Store in Vacuum Jar at 25 mm hg on slow oscillation tray.

APPENDIX 7-3: Undecalcified Bone Trichrome Staining Protocol

Source: Personal Communication and Adapted From: Park SH. Tissue Healing Laboratory at the J. Vernon Luck Orthopaedic Research Center at Orthopaedic Hospital
E-mail: SANG HYUN PARK [SPARK@laoh.ucla.edu]

This protocol used in the following Studies:

- O'Connor KM, Park SH, Bahk WJ, McKellop H. Variation in fracture healing associated with the timing of motion initiation. *Trans Orthop Res Soc* 23:263, 1998.
- O'Connor KM, Lin WS, Park SH. Timing of the initiation of interfragmentary axial motion is an important determinant of callus development and fracture strength. *Phys Ther* 79:S64,1999.



From: (http://pt.usc.edu/labs/BJHL/images/opcallus.jpg)

TOLUIDINE BLUE, METHYL GREEN, METANIL YELLOW.

SAFETY: Wear gloves and protective clothing. Procedures involving chloroform, or concentrated acids must be done in the hood.

Results:
Undecalcified Cartilage- Purple
Calcified Cartilage- Light Green
Bone- Yellow; new bone is darker
Osteoid- Blue Violet
Fibrous Tissue- Blue Violet
Cell nuclei- Blue Violet

Note: Methyl Green washes out with subsequent acid steps. Also seems to fade over time.

Stain Solutions:

1. Toluidine Blue O 1:3 Stain:
   - Mix Stock Toluidine Blue: 1 gm Toluidine Blue O (CI 52040)
     1 gm Sodium Borate Decahydrate
     100 ml Deionized Water (DH20)
     Stir Approx. 30 min.
   - 1:3 Stain: 1 part Stock TB + 3 parts DH20
     - Shake well
     - Store in tightly closed jar; Stable for at least one year.
2. Methyl Green (chloroform washed)
   - Mix primary 2% Methyl Green Solution: 2 gm Methyl Green (Sigma M-8884)
     100 ml DH20
     Stir 1 hour
     Filter
     *Note: There is no CI: FW 653.2; C27H35N2BrCl.ZnCl2
     (Not the same as CI 42585)
   - Wash Primary Methyl Green Solution to remove Methyl Violet
     - Perform in Hood
     - Set up separation flash
     - Mix Primary Methyl Green with Chloroform
       - Approximately 1.5-2 parts Methyl Green to 1 part Chloroform
       - Shake to mix well

- Let settle until purple bottom layer is translucent (use flashlight for back light)
- Drain purple layer
- Add Chloroform as above and wash again. This time the translucent layer should be turquoise rather than purple; if still purple repeat again.
- Pour top 'sludge like' layer into a beaker or Erlenmeyer flask and let sit in hood, open overnight to let residual chloroform evaporate.
- Waste chloroform with methyl violet can be evaporated in the hood or disposed of according to laboratory policy.

- Dilute washed Methyl Green to a 1% solution
  - Add equal parts of Methyl Green and DH20
  - Mix well
  - Filter again
  - Store in tightly closed jar; Stable for at least 1 year.

3. 1% Metanil Yellow
   - Mix: 1 gm Metanil Yellow (CI 13065)
     100 ml DH20
     Stir 30-60 minutes to dissolve crystals well
   - Store in tightly closed jar; Stable for 3 months +; can filter if crystals appear.

Prepare other Agents:

1. Deionized water (in squirt jar)
2. 100% ETOH (absolute)(in squirt jar)
3. 0.5% Formic Acid: 1 ml concentrated Formic Acid*
   199 ml DH20
   Stir well
4. 0.5% Glacial Acetic Acid: 1 ml concentrated Acetic Acid*
   199 ml DH20
   Stir well

*Note: Open and handle concentrated acids ONLY IN HOOD and when wearing protective gloves.

Ready Supplies and Equipment:

1. Oven at 20-32 C
2. Staining tray; pipettes;
3. Tooth Picks
4. Staining dishes with racks for number of sections to be stained in Tol Blue simultaneously
5. Staining dishes equal to 4 for rinsing
6. Mounted MMA sections

Staining Procedure:

1. Warm Toluidine Blue O 1:3 Stain in staining dishes for 30-60 minutes in oven
2. Stain sections in Toluidine Blue in oven for 2 hours
3. Rinse with DH20 (flush in rack under running water in sink until clear)
   Note: Toluidine Blue Stain may be kept in staining dishes and re-used 3-4 times
4. Store sections in DH20 in clean staining dishes

The next steps should be done on the staining rack 3-5 sections at a time:

5. Shake excel water from section
6. Etch with 0.5% Formic Acid for 20 seconds; swirl acid over surface with toothpick
7. Rinse **Immediately** with DH20 to remove all acid
8. Stain with Methyl Green for 5 minutes
9. Rinse well with DH20
   Note: Sections may be dried at this point and store for a week before completing the final stain with Metanil Yellow.
10. Stain with Metanil Yellow for 2 minutes, then add one drop of 0.5% Acetic acid to the Metanil Yellow on the slide; it will turn brown. Swirl and mix acid and Metanil Yellow for 10 seconds with toothpick.
11. Rinse with 0.5% Acetic acid; until no brown remains
    Note: do this **quickly**; do not let section sit in acid as it will remove plastic and create artifacts in the section.
12. Rinse immediately with 100% ETOH until it runs clear (no yellow)
13. To lighten cortical bone rinse with DH20 quickly (1-2 pipettes)
14. Rinse with 100% ETOH again to remove DH20
15. Blot surface dry with paper towel; Store in closed tray to prevent dust accumulation on surface that is not cover slipped.