An analysis of Extensor Pollicis Brevis tendon excursion in different wrist positions in normal healthy subjects

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This thesis is in honour and memory of
Imelda, Susan and Vera.

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Attestation of Authorship

“I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgments), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or institute of higher learning.”

Edel Kelly

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Ethical Approval

This research was approved by the Auckland University of Technology Ethics Committee (AUTEC) on the 20th January 2010. Reference: 09/255.

Abstract

Extensor Pollicis Brevis (EPB) is a tendon of the first dorsal wrist compartment and *in vitro* cadaver studies have shown that it moves approximately 14-15mm over the wrist when the thumb is moved through a full range of extension to flexion. Additionally, it has been shown *in vitro* that wrist position has an effect on EPB excursion. To date there are no *in vivo* studies that have examined the excursion of this tendon, or the effect of wrist position. Greater knowledge of excursion of EPB at wrist level could provide valuable baseline information that may be utilised in further studies in relation to pathomechanics, causative factors, assessment and management of forearm conditions, for example deQuervains disorder. Additionally, *in vivo* excursion values may also have relevance for post-operative tendon rehabilitation, as well as tendon transfer and reconstructive surgery. Information gained may assist in further research involving similar methodology.

The objectives of this study were to quantify *in vivo* excursion of EPB at the wrist in different wrist positions and to evaluate the reliability of the methods used. Ultrasound Imaging (USI) and a cross-correlation algorithm were utilised to assess 49 normal EPB tendons (25 subjects, mean age=40.7±12.8yrs), through full thumb extension to full flexion, in three different wrist positions (45° extension, neutral, 45° flexion). Subjects attended on two different occasions. Within-session and between-session intra-rater reliability was analysed for all data, as well as for each of the selected wrist positions.

Results showed that wrist position had a significant effect on EPB tendon excursion ($p \leq 0.05$). EPB excursion in the neutral wrist position was statistically greater from the other two positions ($p < 0.05$). Mean excursions for each position were: Neutral=2.78mm±1.89, Extension=1.67mm±1.15mm, Flexion=1.62±1.4mm. Intraclass Correlation Coefficients (ICC) for all data within-session 1 and within-session 2 were high [ICC=0.88, 95% Confidence Interval (CI) 0.84-0.91 and ICC=0.87, 95% CI 0.92-0.90 respectively]. The neutral wrist position demonstrated excellent reliability for within-session 1 and within-session 2 [ICC=0.93, 95% CI 0.88-0.96 and ICC=0.91, 95% CI 0.84-

0.95]. Between-session analyses was found to be acceptable for all data [ICC=0.76, 95% CI 0.66-0.83] and high for the neutral wrist position [ICC=0.80, 95% CI 0.64-0.89].

In conclusion, *in vivo* EPB tendon excursion measures have, for the first time, been quantified and significant effects of wrist position on EPB tendon excursion have been found. These measures have been found to be significantly less than those found in *in vitro* studies. Reliability analyses demonstrated high to excellent ICC values for both within-session and between-session data. USI and a cross-correlation algorithm are therefore considered to be reliable methods for measuring tendon excursion. Further studies evaluating and comparing EPB tendon excursion in a pathologically affected population are recommended. The methodology could also be utilised in evaluating longitudinal excursion of other tendons.

Keywords: EPB, tendon excursion, deQuervains, wrist position

CHAPTER ONE – INTRODUCTION

There is little known about the mechanics and behaviour of Extensor Pollicis Brevis (EPB). This tendon passes from the distal part of the forearm, across the wrist and thumb, and serves to extend the thumb at the metacarpophalangeal joint. The literature provides information on excursion measures of the tendon through its full composite range, as well as at each of the joint levels. The earliest recorded values of excursion measures of tendons of the hand and forearm, was by Boyes (1970), based on the work of Sterling Bunnell, a founder of Hand Surgery. This excursion data was based on a small population of aged, cadaver subjects, and therefore has limited value.

Since then excursion of EPB has been further investigated in studies relating to tendon anatomy and behaviour in the first dorsal wrist compartment. These studies have explored EPB and its relationship with Abductor Pollicis Longus (APL), with intra-compartmental septal divisions, and most interestingly, with the effect of wrist position (Kutsumi, Amadio, Zhao, Zobitz, Tanaka, et al., 2005; Kutsumi, Amadio, Zhao, Zobitz, & An, 2005). The latter studies also involved aged, disarticulated cadaver subjects and have provided data which is in agreement with the previously established measures by Boyes (1970). They also demonstrated that wrist position had an effect on EPB tendon excursion and concluded that their results supported theories that mechanical changes contribute to the genesis of EPB tendon related pathologies, such as deQuervains disorder.

What is unknown is how much excursion EPB has *in vivo,* whether it differs from original cadaver measures, and if wrist position has a similar effect on excursion. *In vivo* measures of Extensor Pollicis Longus (EPL) excursion across the thumb metacarpal (M. Chen, Tsubota, Aoki, Echigo, & Han, 2009), were found to be significantly less than those published by Boyes (1970), for EPL.

The study on EPL tendon excursion by Chen, M. et al. (2009) utilised a methodology that has been found to be highly reliable in measuring longitudinal nerve movement. The method involves the use of USI and a cross-correlation algorithm to assess tissue motion (Dilley, Greening, Lynn, Leary, & Morris, 2001). It has subsequently been utilised to evaluate nerve excursion in response to different joint positions in the upper limb and during therapeutic techniques (Coppieters, Hough, & Dilley, 2009; Dilley, Lynn, Greening, & DeLeon, 2003). Additionally, it has been utilised to investigate longitudinal motion of the sciatic nerve (Ellis, Hing, Dilley, & McNair, 2008).

This thesis will employ the same USI and cross-correlation methods to investigate longitudinal tendon motion. Its aims are firstly, to establish baseline quantitative measures of EPB tendon excursion at the level of the wrist, in different wrist positions, in normal adult subjects. Secondly, it will evaluate the intra-rater reliability of USI and a cross-correlation algorithm.

This research will potentially provide valuable *in vivo* information on EPB tendon excursion for a normal adult population, which can subsequently be utilised in further studies involving pathological populations. Additionally, data obtained may be applicable in tendon surgery and rehabilitation, and the methodology may be important in further research in the wider arena of tendon analyses and biomechanics.

CHAPTER TWO – REVIEW OF LITERATURE

2.1 Introduction and Background

Measuring tendon excursion in the hand and wrist became of great interest in the 1970's, the years during which important advances in technology were facilitating growth and development of surgical repair of tendons, tendon re-balancing surgery and tendon rehabilitation (Boyes, 1970; Brand, 1974). Data relating to tendon excursion, length-tension relationships, muscle mass and moment arms, were measured from cadavers and this knowledge was adapted and applied to patients in the surgical domain. Conditions such as peripheral nerve palsies, requiring rebalancing surgery, were treated in endeavours to improve hand function. In addition, tendon excursion data was fundamental to the development of rehabilitation protocols (Boyes, 1970; Brand, 1974).

Throughout the literature, limitations have been recognised in relation to the value of information on tendon excursion gained from cadaver studies, and frequently, further research on tendons *in vivo* has been encouraged (Kutsumi, Amadio, Zhao, Zobitz, & An, 2005; Kutsumi, Amadio, Zhao, Zobitz, Tanaka, et al., 2005; Maganaris, 2002). In recent decades a substantial body of research has accumulated in relation to *in vivo* tendon behaviour, which has enriched the field of tendon and muscle biomechanics, more so in relation to tendon pathology (Maganaris & Paul, 2000; Maganaris, 2002; Fukunaga, Kawakami, Kubo & Kaneisha, 2002). Most of this work however, has been performed on the lower limb tendons and the methodologies vary extensively, employing USI, Magnetic Resonance Imaging (MRI), and Computerised Tomography (CT). There are to date no studies that have addressed the *in vivo* characteristics of EPB.

This chapter will outline the anatomical characteristics of EPB and its associated structures. It will examine closely the available cadaver information on EPB excursion and review the methodologies that have been utilised in relation to EPB, as well as other tendons. It will rationalise and justify the methodology chosen for this research and will review the significance of tendon

pathologies, in particular, deQuervains disorder in relation to biomechanical characteristics.

2.2 Anatomy - EPB and Associated Structures

2.2.1 Anatomy

EPB is a small muscle arising from the posterior surface of the lower third of the radius, below the muscle of APL, and from the interosseous membrane (Williams & Warwick, 1980). It becomes tendinous just proximal to the wrist, passing through the same groove on the radius as APL and inserts into the dorsal aspect of the base of the first proximal phalanx (Williams & Warwick, 1980). It is also known to blend into the fibres of the extensor hood of the first metacarpophalangeal (MCP) joint (Gonzalez, Sohlberg, Brown, & Weinzweig, 1995) (Figure 1). It passes over three joints: the wrist, the carpometacarpal (CMC) and the MCP joints, and acts to extend the proximal phalanx of the thumb (Brandsma, Oudenaarde, & Oostendorp, 1996). APL inserts into the region of the base of the first metacarpal and is involved in abduction of the thumb when it works with Abductor Pollicis Brevis; with the extensors, it extends the thumb at CMC joint level (Williams & Warwick, 1980). Both EPB and APL tendons, within the first dorsal compartment, are contained within a single synovial sheath (Williams & Warwick, 1980).

There are several reported anomalies of EPB and APL, both within the first dorsal wrist compartment that they occupy together, as well as at their insertions (Alemohammad, Yazaki, Morris, Buford, & Viegas, 2009; B. Brunelli & Brunelli, 1992; Giovagnorio, Andreoli, & De Cicco, 1997; Gonzalez, et al., 1995; Hazani, Engineer, Cooney, & Wilhelmi, 2008). The most common anomalies reported are the presence of a septum between EPB and APL, as well as multiple slips of APL within the compartment. Additionally, there are insertional variations reported on EPB (Akan, Gideroglu, & Cakir, 2002; Alemohammad, et al., 2009; B. Brunelli & Brunelli, 1992; Hazani, et al., 2008; Kutsumi, Amadio, Zhao, Zobitz, & An, 2005). In order for the moment arms of EPB and APL to be maintained and for it to be able to efficiently power extension of the MCP joint

(Brandsma, et al., 1996), it is controlled proximally by its pulley, the extensor retinaculum (ER) (Figure 1). This is the structure which forms the dorsal extensor compartments of the wrist. This fascial sheath is the region where tendon and pulley pathology presents, as in cases of deQuervains disorder, and results in cicatricial constriction of the tunnel (Mahakkanukrauh & Mahakkanukrauh, 2000). This is the region of interest chosen, in order to investigate excursion of EPB in normal subjects utilising USI.

Figure 1: First Dorsal Compartment Tendons (EPB and APL) and Extensor Retinaculum (ER).
(Modified From: http://www.health-res.com/compartment-tenosynovitis).

2.2.2 Extensor Retinaculum (Zone VII)

The ER at the wrist is said to be a fibrocartilaginous sling that holds the extensor tendons close to the dorsal wrist and prevents bowstringing (Jamadar, et al., 2010). According to the nomenclature adopted by the Congress of the International Federation of the Societies for Surgery of the Hand in 1979, EPB shares Zone VII for the finger extensor tendons and involves all the tendons under the ER (Tubiana, Thomine, & Mackin, 1996). This region, Zone VII, was selected because of the direct relationship between the retinaculum and the tendons of the first dorsal compartment, which is the common site of pain in tendinopathic conditions. The tendons of EPB and APL visibly appear and are easily palpable just distal to the retinaculum and at the radial styloid.

2.2.3 Septum within the Compartment

The literature frequently refers to the relationship between a septum dividing EPB and APL within the first dorsal compartment, and the incidence of deQuervains disorder (Alemohammad, et al., 2009; Giovagnorio, et al., 1997; Kay, 2000; Kutsumi, Amadio, Zhao, Zobitz, & An, 2005; Mahakkanukrauh & Mahakkanukrauh, 2000; Nagaoka, Matsuzaki, & Suzuki, 2000; Witt, Pess, & Gelberman, 1991). Some of these authors consider that the presence of a septum predisposes the wrist to deQuervains disorder. The presence of a septum, or fibrous division, between the two tendons within the common sheath, has been found in many subjects with deQuervains disorder (Leslie, 2006; Leslie, Ericson, & Morehead, 1990; Nagaoka, et al., 2000; Yuasa & Kiyoshige, 1998). Septal divisions have been identified utilising USI and MRI, as well as under operative conditions.

Kutsumi, Amadio, Zhao, Zobitz and An (2005) found that the presence of a septum within the first dorsal compartment produced greater gliding resistance in 60° of wrist flexion, than when a septum was not present. Septum identification was a limitation of this thesis, as a Qualified Sonographer was not involved in the data collection process, and primarily the objective was tendon excursion measurement. Further studies will be recommended to evaluate the effect of divisional septum on EPB tendon behaviour in normal subjects and in a

population with deQuervains disorder. The presence of a septum between the two tendons, as well as biomechanical and clinical implications, may then be further understood.

2.3 Biomechanics

2.3.1 EPB Tendon Excursion

Early research on EPB tendon excursion was published by Boyes (1970), taken from a previous cadaver study by Sterling Bunnell. It was reported that around 30mm of excursion of EPB tendon, from full composite wrist and thumb extension, through to full flexion occurred (14mm at wrist level; 9mm at CMC joint level; 7mm at MCP joint level). Little information was provided detailing the subject population characteristics. A similar excursion range, 7-8mm was found at MCP joint level in another cadaver study (Law, Berglung, Cooney, & An, 1989), which supported data presented by Boyes (1970) for EPB excursion at MCP joint level. The study by Law et al. (1989) did not record EPB excursion at any other level, but did look at variations in excursion at different deviation angles of the MCP joint.

Similarly, a cadaver study which investigated excursion of both EPB and APL tendons at the wrist level through the retinaculum, found consistent measures of excursion of EPB with those of Boyes (1970), averaging 15mm (Kutsumi, Amadio, Zhao, Zobitz, & An, 2005). There were fifteen fresh-frozen cadaver subjects (mean age 76; range 56-97 years), including forearm, wrist and hand specimens, all without pathological evidence of injury or major degenerative change. Specimens were thawed immediately prior to assessment and assessed for absence of tenosynovitis or thickening of the first dorsal compartment. An important consideration when evaluating this *in vitro* data is that the fascial tissue proximally, distally and overlying the tendons and muscles, was removed. This could significantly reduce overall resistance to motion. Saline was used to lubricate the tissues and limitations were acknowledged in relation to the differences in tendon movement between normal interstitial and synovial fluids, and saline assisted tendon movement,

under experimental conditions. Tendon excursion measurement involved a linear potentiometer attached to a tensile load transducer and a movable mechanical pulley. Specimens were mounted on to the testing device and wrist position was maintained using an external fixator that allowed different positions to be set. Only mean values in graphical format were presented in this paper for each of the wrist positions.

The literature therefore provides the information that in a small population of aged, cadaver subjects, in two different studies, that the EPB tendon moves an average of 14-15mm for all wrist positions through the extensor retinaculum, when EPB is passively moved from full thumb extension to full flexion.

2.3.2 Wrist Position

As the wrist possesses large amounts of joint motion, the long extrinsic tendons to the digits on both aspects of the forearm and hand have been reported to be subject to large amounts of excursion. The flexor tendons are thought to move 80-90mm at wrist level through full digital flexion, and the extensor tendons approximately 30mm (Boyes, 1970) through full extension. Wrist position is considered an important variable in finger and thumb function. It is therefore of great significance, firstly, in understanding normal mechanics and secondly, in further understanding the pathogenesis of disorders affecting thumb tendons.

A study by Kutsumi, Amadio, Zhao, Zobitz and An (2005) that looked at EPB tendon excursion at retinacular level, also examined gliding resistance through the retinaculum in different wrist positions. These wrist positions were: 60° flexion, 30° flexion, neutral, 30° extension, 60° extension, as well as 30° of ulnar deviation and 10° of radial deviation. The ulnar and radial deviation wrist positions are not of interest at this time, but should be considered in further studies that utilise similar methodologies in the future. The results of the study by Kutsumi, Amadio, Zhao Zobitz and An (2005) showed that for the two extension positions, as well as the two flexion positions, similar patterns of tendon excursion were found.

Wrist position thus affects both the amount of excursion and gliding resistance of the tendons of EPB and APL. The position of wrist flexion at 60° resulted in the greatest gliding resistance through the compartment for EPB. An extended wrist position at 60° also created high gliding resistance, but less than in wrist flexion. In the wrists where septation of the compartment was present, the values for gliding resistance in wrist flexion at 60° were found to be highest.

With respect to tendon excursion, EPB motion was found to move least in the wrist flexion position of 60° (approximately 12mm), slightly greater in the wrist extension position of 60° (approximately 14mm) and greatest in a neutral wrist position (approximately 17mm). Interpretation of the findings of this cadaver study, suggests that the position of least tendon excursion is associated with greater tendon gliding resistance. Kutsumi, Amadio, Zhao Zobitz and An (2005) propose that their findings support a frictional theory in the pathogenesis of deQuervains disorder: that it is the EPB and/or APL tendons moving against the retinaculum that is the primary aggravating factor. The friction theory has also been presented by An (2007) and states that there is a correlation between the arc of contact of a tendon against its pulley, resulting in a friction coefficient. An (2007) describes the friction theory as analogous to a belt wrapped around a fixed mechanical pulley (Figure 2). As the tendon moves proximally, the tensions in the tendon proximal and distal to the pulley (Fp and Fd) are related to the angle (θ) of the tendon segments across the pulley or arc of contact, and the friction coefficient (μ) (An, 2007):

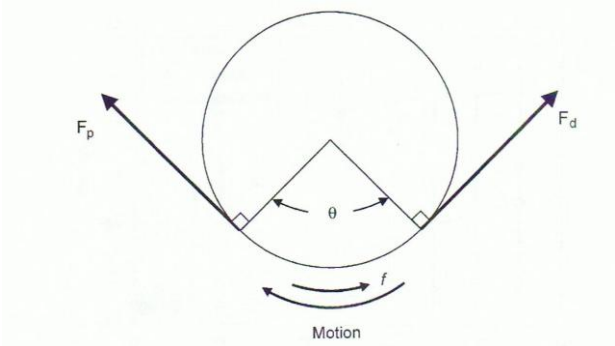

Figure 2: The Friction Theory (F=friction=Fp-Fd)
(Modified From An, (2007). Tendon excursion and gliding: Clinical impacts from humble concepts. *Journal of Biomechanics*, 40, pg 713-718).

2.4 Experimental Methods

Tendon excursion has previously been measured to quantify moment arms. Moment arms have traditionally been calculated as the first derivative of tendon displacement with respect to joint angle measurements (Maganaris, 2000). Much of the work on tendon displacement in the upper limb has involved measurement of moment arms and has historically been done on cadavers. The calculations and therefore the excursion data is not always represented in the literature. It is considered relevant to evaluate experimental methods that have been used in measuring tendon excursion.

The most commonly used *in vitro* methodologies found in the literature have methodological set-ups that involve pulleys, lines, weights and rotary potentiometers. These are attached to tissue using nylon or silk suturing and with joints internally stabilised with pins or Kirschner wires (An, Ueba, Chao, Cooney, & Linscheid, 1983). Millimetre slide rules and basic measurement systems have also been used *in vitro,* particularly in measuring relative motion between flexor tendons in the fingers (McGrouther & Ahmed, 1981), thumb and hand (F. Brunelli, DeBellis, Sanguina, Papalia, & Serra, 2001). Variations in methods utilised have been found and there is a considerably greater amount of literature about the finger flexor tendons, than there is about the thumb tendons. Most of this *in vitro* research also appears to involve aged, disarticulated cadaver populations, which has implications in respect of tissue properties, for example, moisture levels. Other important methodological detail that has been considered when evaluating these studies, are the position of the forearm, and particularly the wrist during testing, as well as which joints were stabilised when movement was executed. Such relevant information is often missing.

2.4.1 EPB Measures- *In Vitro*

There is little information in the literature about the characteristics of the EPB tendon, its biomechanics and behaviour. A study by Smutz et al. (1998) examined the moment arms of the four extrinsic thumb muscles in seven fresh cadaver hands (mean age 77 years): Flexor Pollicis Longus, EPL, EPB and APL. The effects of tendon dynamics were assessed at each of the three joints of the thumb, however the authors failed to present the excursion measures that had been determined. Moment arms were computed using the slope of the tendon excursion-joint angle relationship. An electromagnetic tracking device was used to measure joint position. Polynomial regression was used to model the relationship between tendon excursion and joint rotation for each data trial. This was then analytically differentiated to give the instantaneous moment arm, that is, the slope of excursion versus joint angle (Smutz, et al., 1998).

Excursion data on thumb movement at the MCP joint had previously been reported, using very similar methods (Law, et al., 1989). This study analysed the effect of radial and ulnar MCP joint deviation on tendon excursion. Relevant data from this study is that EPB moves 8.2mm+/- 0.7mm through a 60° arc of motion, at the MCP joint, in the neutral position. Wrist position and CMC joint position during testing were not stated in this study. Their results were consistent to those of Boyes (1970) with tendon excursion measures of 7mm at the MCP joint (1.2mm difference).

Brand et al. (1981) have identified limited potential excursion capability of EPB compared with other muscles and particularly compared with APL, its most closely related musculotendinous unit. Although similar in muscle size, both mass fraction and tension fraction percentage calculations were significantly different and thought to indicate that EPB works less than APL, and has therefore less potential excursion (Brand, Beach, & Thompson, 1981). These calculations were reported to have been taken from fifteen cadaver subjects however wrist joint position during assessment was not described. The results do not agree with those of Kutsumi, Amadio, Zhao, Zobitz and An (2005) who have determined that EPB has greater excursion than APL. It is of value and of

interest therefore, to determine if *in vivo* measures of EPB tendon excursion are dependent on wrist position and if they are comparable to available data on *in vitro* EPB excursion measures.

2.4.2 *In Vivo* versus *In Vitro* Tendon Excursion

Significant differences exist between the properties of biological tissue under *in vivo* and *in vitro* experimental conditions and the literature widely acknowledges this (Kutsumi, Amadio, Zhao, Zobitz, & An, 2005; Maganaris, Narici, Almekinders, & Maffulli, 2004). Cadaver studies, although important, do not provide information about tendon behaviour during normal functional movement, and the literature has identified the need for further tendon *in vivo* analyses (Ito, Akima, & Fukunaga, 2000; Maganaris & Paul, 2002; Magnusson, Narici, Maganaris, & Kjaer, 2008). The primary function of tendons is the transmission of muscle forces to the skeletal system and proper excursion of the tendon will determine the efficiency of this function (An, 2007). Fukunaga, Kawakami, Kubo and Kanehisa (2002) have stated that in order to understand the functional characteristics of muscle fibre and tendon during human movement, it is important to measure directly and successively the *in vivo* geometric arrangement of muscle and tendon. Extensive work has been carried out by these authors, amongst others, on muscle and tendon behaviour *in vivo,* primarily however, on the lower limb (Kubo, Kanehisa, & Fukunaga, 2002). Many of these studies have utilised USI methods and some of these will be discussed in more detail.

2.5 Ultrasound Imaging (USI)

USI has traditionally been used for diagnostic purposes in the radiology field of medicine, with the primary function of imaging morphological characteristics and structural integrity of various organs and tissues (Whittaker, et al., 2007). Advancement in technology has served to allow integration of USI into the rehabilitative field of medicine, initially in assessment of lumbar and abdominal muscle morphology in low back pain sufferers (Hides, Richardson, & Jull, 1998). It has since been utilised in rehabilitation by providing biofeedback for muscle facilitation and learning.

The mode of USI most commonly used is B-mode (brightness/brilliance), which displays the ultrasound echo as a cross-sectional grey scale image. Its images provide information gathered from the entire length of the transducer and consist of visible dots, or pixels, of varying degrees of brightness, that represent the location and density of the structures encountered by the ultrasound beam (Whittaker, et al., 2007). Extension of works examining the pelvic floor and bladder relationships have demonstrated acceptable inter-rater and intra-rater reliability for various instruments (Whittaker, et al., 2007). USI is thought to provide a safe, cost-effective and relatively accessible method of examination of various organs and tissues (Hides, et al., 1998).

An integral association exists in the literature between tendon excursion and moment arm measurement, as referred to previously in cadaver studies. Developments in technology have, in recent decades, led to evaluation of moment arms using USI methods as well as MRI. USI has been utilised for tendon analyses, both *in vitro* and *in vivo,* but limitations have been recognised in both.

According to Lee, Lewis and Piazza (2008), the usual method of measuring tendon excursion *in vivo*, utilising USI, is time consuming and manually tracking it is prone to assessment error. A tissue landmark is normally chosen, manually digitised and re-assessed on each frame. Limitations of utilising USI *in vitro* include the dehydration of cadaver tissue and ability to gain good tissue contrast (Lee et al., 2008).

Originally, moment arm measurement using USI was used to calculate tendon excursion in cadavers and was deemed simpler to implement because the method did not require the location of the centre of rotation, or knowledge of the path of the tendon (An et al., 1983). It was calculated as the first derivative of the displacement of the tendon with respect to joint angular displacement (Lee et al., 2008). In other words, tendon excursion, or actual motion, was not actually observed and was the result of a mathematical calculation involving joint angle and tendon displacement measures. The same method has also been applied *in vitro* through visualisation of the tendon displacement using MRI (Lee, et al., 2008).

2.5.1 USI and Tendon Excursion

USI methods for *in vivo* analyses of tendon displacement are continuing to be developed. There are many studies that have examined tendon and muscle behaviour and their interaction during human movement, particularly in the lower limbs. These studies have involved Tibialis Anterior, Gastrocnemius, Soleus and Vastus Medialis (Ito, et al., 2000; Maganaris, 2000; Maganaris & Paul, 2000; Maganaris & Paul, 2002). Other muscle and tendon properties that have been studied include the effect of tendon stretch on maximum force generation (Maganaris & Paul, 2000), the interaction between lower limb muscles and tendons during movement (Fukunaga, Kawakami, Kubo, & Kaneisha, 2002), as well as hysteresis measures (Kubo, Kanehisa, & Fukunaga, 2002). Also examined have been viscoelastic properties and aponeurotic length changes of Achilles tendon (Maganaris, Kawakami, & Fukunaga, 2001). The older USI methodologies involved complex set-ups for measuring forces using dynamometers and potentiometers.

These studies have identified some of the limitations of USI *in vivo*. The first of these is the insufficiency to evaluate three-dimensional motion. The other is the dependency of the tendon movement, or elongation, on the tensile force applied, as well as on the length of the in-series contractile system (sarcomeres) (Magnusson, et al., 2008). It is considered that future studies include loading of the EPB unit in assessment of tendon behaviour *in vivo*.

Further to these, an automated tracking device has been utilised which incorporates a least-squares based method (the Lucas-Kanade algorithm) for horizontal and vertical pixel velocities from ultrasound images for tracking tendon excursion (Lee, et al., 2008; Maganaris, et al., 2001). In the study by Lee et al. (2008), the authors' objective was to move a phantom wire through a known distance, in both *in vitro* and *in vivo* conditions, and to compare the results. Absolute Root Mean Squared analyses demonstrated small errors and limitations were attributed to the ability of USI to accurately visualise dehydrated tissue in the cadaver specimens used.

2.5.1.1 Colour Doppler Methods

Colour Doppler Imaging (CDI), another method of USI, has also been used to examine tendon excursions *in vitro.* Buyruk et al. (1998) do not agree that the original moment arm measurement systems that were determined by tendon excursion, joint rotation angles and diametric measures, are precise. They performed a study on an 87 year old cadaver using CDI and compared the excursions of some of the flexor tendons of the fingers and thumb to those measured by a digital displacement meter. Results showed that there was an irregular range of excursions and that CDI measures were 3% less than displacement meter readings. This difference was attributed once again to the desiccated state of cadaver tissue and the ability of USI to accurately image it.

The literature so far infers that USI is not a highly reliable method for measuring tendon excursion in cadavers. It implies that measuring tendons *in vitro* has limited use and clinical relevance, however methodologically these procedures and studies have advanced the field of biological tissue measurement.

Observation of other tissue properties has become increasingly relevant in the medical and rehabilitation domains, and subsequently CDI has more recently been used to quantify the velocity of FDS and its relationship with the sub-synovial connective tissue (SSCT). Thickness of the tendon and SSCT were measured in the carpal tunnels of 8 fresh cadavers; the methods were thought to be a very precise way of assessing changes in the carpal tunnel, especially in Carpal Tunnel Syndrome (CTS) (Ettema, et al., 2006). Excursion of the FDS tendon was only observed in relation to the other tendons and the SSCT.

The same authors went on to examine the FDS and carpal tunnel relationship *in vivo,* with CTS subjects undergoing surgical decompression (Ettema, An, Zhao, O'Byrne, & Amadio, 2008). They used two cadaver groups as controls, the first were subjects with a pre-mortem history of CTS and the second, a group with no history of CTS. The method in the *in vivo* group was of surgical markers on the tendon with a millimetre rule set-up in the camcorder field, so that motion could be recorded (Ettema, et al., 2008). A similar method was used in recording motion of the mounted, dissected cadaver limbs, except that the attached Dacron cord to the proximal cut tendons was pulled manually by an assessor. It was found that similarities existed in the motion pattern of the cadaver hands with CTS and the live subjects with CTS, and that there were significant differences between these and the cadaver group without CTS. In contrast to the previous studies, this latter study using CDI concluded that cadavers could be used as controls.

From the evidence above, CDI is considered to be a useful means of measuring tendon motion at the level of the wrist and hand, and could be considered for future studies. The study by Ettema et al. (2008) has demonstrated that CDI is useful in assessing both *in vitro* and *in vivo* consistencies in motion patterns, in both normal and pathological tissue states.

2.5.2 Three–Dimensional Tissue Analyses

2.5.2.1 *In Vitro*

Of additional interest in longitudinal excursion analyses, is the three-dimensional motion of tendon and this was addressed by Ugbolue, Hsu, Goitz and Li (2005). These authors investigated the *in vitro* displacement of the median nerve in relation to the finger flexor tendons, proximal to the carpal tunnel, with movement of the MCP joints of the index and middle fingers. Shim markers were placed on the median nerve, FDS and FDP tendons, in the wrist region of seven cadaveric specimens. These specimens had a younger mean age than other studies referred to and were moistened with saline. The MCP joint position was altered for each of the dependent variables. A three-dimensional digitiser was used to obtain the coordinates of the markers attached on the tendons and the nerve. The coordinates were then transformed to provide position data of the markers with respect to the anatomical wrist coordinate frame (Ugbolue, et al., 2005). They found that flexor tendons and the median nerve move transversely through radio-ulnar and dorso-palmar planes to a small and irregular degree, and occurs concurrently with longitudinal motion. The methods were repeatable and reproducible by no greater than 0.3mm. Similar patterns of three-dimensional motion were observed in EPB analyses in this current study.

2.5.2.2 *In Vivo*

One of the earliest studies found in the literature relating to USI methods and measurement of *in vivo* tissue, was that of Nakamichi and Tachibana (1992). These authors attempted to analyse the three-dimensional movement of the median nerve in the carpal tunnels of fifteen asymptomatic volunteers using USI. Active-resistance of the flexor tendons, with minimal finger joint motion, was performed under different wrist positions. The theory was that tensioning of finger flexor tendons in the carpal tunnel could cause pressure on the median nerve, playing a possible role in mechanical deformation that could lead to CTS (Nakamichi & Tachibana, 1992).

More recently, Yoshii et al. (2009b) used fifteen asymptomatic volunteers to examine the relative motion of the FDS of the middle and long fingers and the median nerve at the volar wrist crease, proximal to the carpal tunnel. An active motion of the middle finger was performed from extension to flexion whilst USI images were taken. Both the tendon and the nerve were outlined in each of the recorded images, and the initial and final frames of the motion for each of the extension and flexion positions were chosen. Displacement was defined as the distance of the centroid coordinates between the digital extension and flexion positions. In addition, the distance between the centroids of the median nerve and FDS was measured in the palmar-dorsal and radio-ulnar directions (Yoshii, et al., 2009b).

The last two studies demonstrate that cross-sectional displacement and deformation of tendon and nerve can be made using USI, taking three-dimensional perspectives into account. Statistical analyses showed positive results in the latter study however the methods have not yet been used for longitudinal tendon motion analyses.

Yoshii et al. (2009a) went on to examine the Speckle Tracking measurement of flexor tendon excursion and relative median nerve motion in the carpal tunnel, with the added dimension of velocity. Reliability results for Speckle Tracking analyses were compared with results for CDI analyses: the ICC was higher for joint angle/tissue Speckle Tracking tendon excursion, than for joint angle/tissue Doppler excursion. The Speckle Tracking method could also discriminate differences in maximal velocity ratio and shear index, for the different tube sizes that were used during grip motion of the fingers (Yoshii, et al., 2009a).

These studies are considered to be very important in further defining a methodological process for examining longitudinal and three-dimensional tendon motion, and also in understanding the relationship between structures in the carpal tunnel. Three-dimensional tendon displacement away from the central longitudinal plane was a factor that was considered in this thesis and was observed during assessment of EPB excursion, but not measured. It was noted more often in the positions of wrist flexion and extension, and observed to

move in dorso-ulnar directions. Tendon displacement of EPB in radio-ulnar and dorso-palmar planes, as it moves longitudinally, will be important in fully understanding the biomechanics of moment arm changes, but in the first instance and under *in vivo* conditions, it is of greater priority to firstly establish uni-dimensional motion. Three-dimensional motion may well have significance in the pathogenesis of tendinopathy and will be recommended for further study.

To date, it has been determined from the literature that there have been many developments in tendon excursion analyses *in vivo,* utilising USI. Much of the research is promising and provides sound experimental basis for larger, better defined studies, utilising capable procedures like CDI and Speckle Tracking, with respect to three-dimensional imaging of tissue motion and velocity measures. Of particular interest at this time, is the ability of USI to reliably and quantitatively measure tendon excursion longitudinally.

2.6 USI and a Cross-Correlation Algorithm

This current study proposes that USI and a cross-correlation algorithm can reliably measure the excursion of EPB *in vivo,* with the wrist in various positions. This method has been used to analyse median nerve and sciatic nerve excursion, with altered joint positioning of the respectful limbs (Dilley, et al., 2001; Ellis, et al., 2008). It has also been used to assess excursion of Extensor Pollicis Longus (EPL) at thumb metacarpal level (M. Chen, et al., 2009), and these studies will be discussed.

2.6.1 Studies on Nerve Tissue

Quantitative analyses of both median and ulnar nerve displacement in relation to wrist, elbow and shoulder position, have been previously carried out (Dilley, et al., 2003; Dilley, Summerhayes, & Lynn, 2007). These researchers utilised frame-by-frame cross-correlation analyses of recorded real-time USI to assess relative movement of the median nerve. Sequences of images are captured at a frame rate of 10 images per second, converted into a digital format (Bitmap)

and analysed offline using software developed in the Matlab (Mathworks, USA). The software employs a cross-correlation algorithm to measure the motion of fine speckle features in selected regions of interest (ROI), between adjacent frames of the image sequence (Coppieters, et al., 2009; Dilley, et al., 2001).

Dilley et al. (2001) first used string and avian sciatic nerve in a water bath with the ultrasound transducer mounted on a micromanipulator to test the reliability of USI. The water bath was placed on a chart paper, with a chart recorder attached and the bath moved a known distance. These phantom controls showed consistency of the imaged motion with the known motion, and the cross correlation algorithm was shown to be reliable, particularly for the three higher velocities tested; 1mm/s, 2mm/s and 10mm/s. A number of experiments were then undertaken to examine the ability of the cross correlation algorithm to calculate a precise movement in a control subject. The transducer was placed over the subjects' median nerve with the arm submerged in the water bath, and moved a known distance of 1-3mm within 4 seconds. The algorithm successfully measured each 1-3mm movement with less than 10% error, and regions of different tissue (nerve, tendon, muscle) from the same series of images, producing similar results (Dilley, et al., 2001).

With respect to reliability of the algorithm, studies were subsequently performed on median nerve sliding, during wrist extension and index finger extension, with measures repeated three or four times. Standard deviations were 0.2-0.4mm for wrist extension testing, and 0.2-0.7mm for finger extension, and these figures demonstrated reliability in repeat trials, consistent with anatomical estimations and previous cadaver measures (Dilley, et al., 2001).

Further to this, a study utilised the same methods to examine median nerve excursion in the arm under different upper limb joint positions (Dilley, et al., 2003). Thirty-four asymptomatic adult subjects were examined. Repeated measures of nerve movement with different joint movements were taken in different transducer locations. Joint movements, lasting between two and four seconds, were: wrist extension, shoulder abduction, elbow extension and contra-lateral neck side flexion (Dilley, et al., 2003). Median nerve excursion for

wrist, shoulder and elbow movements in this experiment, were found to be consistent with those found in cadaver studies conducted by Wilgis and Murphy (1986) and Wright et al. (1986) (as cited in Dilley et al., 2003).

The aforementioned cross-correlation method was shown to have high reliability and small measurement error, during analyses of median nerve excursion, in a study examining six different nerve gliding exercises of the upper arm (Coppieters, et al., 2009)**.** This study involved fifteen asymptomatic subjects and was aimed at determining whether different nerve mobilisation techniques were associated with different amounts of longitudinal excursion. Mobilisation techniques involved movement of the elbow and cervical spine, and results showed that different techniques produced differences in nerve excursion. Sliding techniques demonstrated larger excursions than tensioning techniques. The authors evaluated inter-tester reliability, by using three assessors to analyse the USI sequences of the sliding technique of the first ten participants. An ICC was calculated at 0.96. The USI technique proved to be difficult in respect of measuring transverse movement of the nerve, and the importance of finding a transducer position where the transverse movement was minimal, was emphasised.

In a study of sciatic nerve excursion, it was found that USI and cross-correlation analyses was a highly reliable method of measuring longitudinal nerve motion (Ellis, et al., 2008). These authors examined sciatic nerve excursion in twenty-seven normal subjects, in response to a neural mobilisation exercise, consisting of cervical extension and ankle dorsiflexion. Transverse movement of the sciatic nerve was measured and static USI images were taken at the beginning and end of the neural mobilisation exercise. Digital markers were placed at the lateral-medial and anterior-posterior extremities of the visualised nerve. Digital callipers were used to measure the distances between the markers and three successive measurements were taken by the same sonographer. Longitudinal nerve movement was then measured using the cross-correlation algorithm and three successive measures taken.

Results showed significant reduction in lateral movement at the posterior mid-thigh (PMT) point, compared to that at the popliteal crease (PC), both laterally and in an anterior-posterior (AP) direction. There was significantly greater longitudinal movement of the sciatic nerve at the level of the PC compared with that at the PMT. Reliability across the three trials at PMT level was high for lateral (ICC=0.76) and longitudinal movement (ICC=0.75) but low for AP movement. At the PC, reliability was found to be high for lateral movement (ICC=0.70) and low for AP movement. It was not possible to measure reliability of the PC longitudinal sciatic nerve movement, due to movement of the nerve beyond the field of the ultrasound image, in all but three subjects (Ellis, et al., 2008). Although the authors recognised the main limitation of USI and cross-correlation methods as being only a two-dimensional measure, their results demonstrated high reliability in longitudinal sciatic nerve measurement.

Dilley et al. (2001) advocated the use of this cross-correlation algorithm with USI in examining other biological tissue, such as tendon. The literature contains sufficient evidence to suggest it is a reliable method of assessing longitudinal nerve motion.

2.6.2 USI and Cross-Correlation Studies on Tendon

The gliding distance of the EPL tendon, at the first metacarpal level, was subsequently imaged with the wrist in four different positions, and analysed using the same USI and cross-correlation algorithm as discussed above (M. Chen, et al., 2009). This was the first, and only, published study of tendon excursion using these methods. The thumbs of twenty-five healthy subjects were supported to MCP joint level, using a splint, and the proximal and distal phalanges were passively flexed, whilst EPL was imaged over three seconds duration.

Chen, M. et al. (2009) reported that their results demonstrated similar measures to that of previous cadaver studies, only that they were slightly less. In fact, the comparison of EPL measures between this *in vivo* study (Table 1) and Boyes

(1970) cadaver measures (Table 2), appear to differ significantly. It is recognised that the anatomical point of measurement differs in these studies. Results can therefore only be loosely compared, of measures around first metacarpal level. Boyes (1970) presents 6mm EPL excursion at the MCP joint; Chen M. et al. (2009) present 2-3mm of excursion along the first metacarpal.

Chen, M. et al. (2009) postulated that reduced motion *in vivo* could be due to a level of active tension in the tendon during passive movement, or to resistance from surrounding tissues. Another reason presented was that the sample population were young females with little fatty tissue, and that clearer imaging could usually be gained over more fatty tissue (M. Chen, et al., 2009). In this thesis however, it was found that the tendons of all males and young females were easier to image than those subjects with more fatty tissue. Radial angulation of the distal radius is greater in females (Kay, 2000) and this is considered to be a possible reason for the smaller mean excursion of EPL, in the all female study by Chen, M. et al. (2009).

The methodology utilised in this current thesis is similar to that utilised by Chen, M. et al. (2009), however it will aim to measure the amount of EPB excursion through a much larger, full composite range of thumb motion.

Table 1: Gliding distance of EPL tendon (mm) over the 1st metacarpal
(Modified From Chen, M., et al. (2009). Gliding distance of the extensor pollicis longus tendon with respect to wrist positioning: observation in the hands of healthy volunteers using high-resolution ultrasonography. *Journal of Hand Therapy: 22*(*1), pgs 44-48).*

Wrist Position	*Mean*	*SD*	*95% CI*
Neutral	1.74	0.79	1.41-2.06
30 degrees extension	2.49	1.02	2.07-2.91
30 degrees flexion	1.08	0.59	0.83-1.32
20 degrees ulnar deviation	1.35	0.50	1.14-1.55

Table 2: Cadaver measures of EPL
(Modified From: Boyes, J. H. (Ed.). (1970). *Bunnell's Surgery of the Hand* (5th Ed.). Oxford and Edinburgh: Blackwell Scientific Publications

Level	*EPL excursion*
Wrist	33mm
CMC	7mm
MCP	***6mm***
IPJ	8mm

In conclusion, USI and a cross-correlation algorithm are considered suitable methods to examine tendon excursion over the wrist, when the wrist is in different positions. Well designed *in vivo* studies on the median, ulnar and sciatic nerves, as well as on the EPL tendon, have demonstrated high reliability.

2.7 deQuervains Disorder

2.7.1 Clinical Presentation

The EPB tendon is of particular interest because of its involvement in the common condition, deQuervains disorder. Although there is no known definitive cause for this disorder, the literature contains some evidence that EPB is the tendon most responsible for the painful condition (Kutsumi, Amadio, Zhao, Zobitz, & An, 2005; Kutsumi, Amadio, Zhao, Zobitz, Tanaka, et al., 2005; Yuasa & Kiyoshige, 1998). Clinically, deQuervains disorder affects the first dorsal wrist compartment which includes the two tendons, EPB and APL (Figure 1).

A previous study suggests it is the change in the retinaculum itself which causes stenosis of the tendons (Bahm, Szabo, & Foucher, 1995). USI studies have demonstrated retinacular thickening and oedema (deMaeseneer, et al., 2009; Giovagnorio, et al., 1997), however some studies have also shown thickening of the tendons themselves (Glajchen & Schweitzer, 1996). Therefore, both retinacular and tendon tissue changes are thought to be consistent with a stenotic condition.

The classification system that Jarvinnen et al. (1997) recommend, is useful in differentiating the tissues involved in a range of tendinopathies, and the description of a 'paratenonitis' is probably the most appropriate for deQuervains disorder. This terminology implies the involvement of surrounding tendon tissue and incorporates disorder status such 'tenosynovitis', 'tenovaginitis' and 'peritendinitis'. Jarvinnen et al. (1997) conclude that it is the morphological alteration in the paratendinous tissues that result in considerable impaired gliding function of the tendon leading to painful symptoms.

Finkelstein's Test (Figure 3) is the most pathognomonic test used in the diagnosis of deQuervains disorder. This test involves compression of the tendons between the ER and the bony radial styloid, as the tendons are stretched. The forearm is in a neutral position and the wrist is taken into ulnar deviation during this test (Kutsumi, Amadio, Zhao, Zobitz, Tanaka, et al., 2005).

These authors found that EPB in the cadaver model was under more stress during Finkelstein's test manoeuvre, than APL.

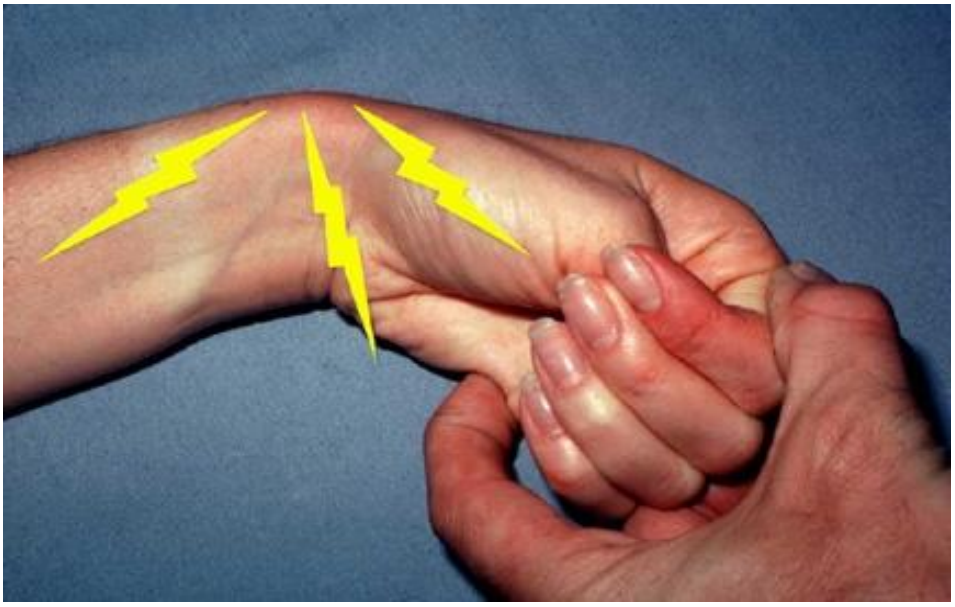

Figure 3: Finkelstein's Test
Draws the tendons of the first dorsal compartment distally and causes sharp, local pain when tendon entrapment has occurred and inflammation is present.
(Modified From http://emedicine.medscape.com/1243387-overview)

Females are affected by deQuervains disorder eight to ten times more often than males, and it occurs more often in the third to fifth decades (Moore, 1997; Read, Hooper, & Davie, 2000). It also occurs in post-partum women in their second and third decades, and relationships regarding hormonal influences have been considered. There appears to be no evidence in the literature to support hormonal factors as being a primary causative factor of deQuervains disorder. There is now, however, some evidence to support a purely mechanical pathogenesis in females (Fredberg & Stengaard-Pederson, 2008).

Mechanical pathogenesis has greater substantiated evidence than a purely metabolic process, although there is evidence to suggest that females are more likely to develop the inability to regenerate tissue, than males (Kjaer, et al., 2009). These authors suggest that a gender difference exists, in that females respond less than males with regard to an increase in collagen formation after exercise. They also suggest that oestrogen may contribute toward the diminished collagen synthesis response in females. Their theories fit with

demographics of deQuervains disorder and much higher incidence of the disorder in females.

2.7.2 Pathogenesis

Correlation between causation and treatment are important considerations in the management of any medical condition, however there is lack of agreement amongst researchers and clinicians, as to the exact aetiology of deQuervains disorder. The frictional theory presented by An (2005, 2007) and Kutsumi, Amadio, Zhao, Zobitz (2005), and the mechanical theories of repetitive wrist and thumb motion, coupled with awkward wrist positions (Kay, 2000; Moore, 1997), are all valid concepts that have yet to be confirmed or discounted. Repetition and overuse, as well as quick cutting motions that involve acceleration and deceleration, are responsible for causing injury to tendons and upset the balance between mobility and stability of joints. This in turn, can lead to other soft tissue damage (Jung, Fisher, & Woo, 2009). Mechanical loading may also be a primary factor in the development of tendinopathy, whether it is a single event or repeat loading that occurs (Kjaer, et al., 2009).

Wrist position is potentially a significant factor in the loading of EPB tendon during activity involving use of the thumb. The mechanical loading theories, which exist mainly for lower limb tendon disorders, propose that there is a threshold where the tendon clinically becomes symptomatic (Fredberg & Stengaard-Pederson, 2008). Biomechanical alterations in tendons, such as change in joint position, influence the moment arm of the tendon as the musculotendinous unit changes in length and tension (Maganaris et al., 2004). Wrist position may indeed have significant effects on EPB tendon excursion, potentially stressing certain sites within the first dorsal compartment, particularly in relation to the radial styloid. Subsequently, tendon stresses may lead to biochemical processes that may precede and/or sustain pathology (Arnoczky, Lavagnino & Egerbacher, 2007). Other factors that may be related to pathogenesis include anatomical anomalies, such as septum within the first dorsal compartment (Kutsumi, Amadio, Zhao, Zobitz & An, 2005).

2.7.3 Histopathology

Recent theories, regarding histology of tendinopathy, outline clearly a typical sequence of cellular events and activity, from acute to chronic episodes. Both acute and chronic paratenonitis result in profound proliferation of all types of blood vessels, and the intensive hypertrophy of the paratendinous tissue increases the friction around the tendon (Jarvinnen, et al., 1997).

There are many good studies in the literature that have demonstrated the benefits of glucocorticoids for the treatment of deQuervains disorder (Goldfarb, et al., 2007; Jirarattanaphochai, et al., 2004; Kay, 2000) as well as for other tendinopathies, and which support the theory of the condition being of an inflammatory nature. Conversely, there are also several studies that have examined the histology and pathology of deQuervains tissue that have shown degenerative characteristics (Clarke, Lyall, Grant, & Matthewson, 1998; Leslie, 2006; Read, et al., 2000). Hand Therapists have previously been encouraged to embrace a paradigm shift to the latter, the degenerative tendon (Ashe, McAuley, & Khan, 2004).

There is now however, evidence from immunohistochemistry and flow cytometry, that the initiators of tendinopathic pathways in general include many pro-inflammatory agents, such as cytokines, prostaglandins, different growth factors and neuropeptides (Fredberg & Stengaard-Pederson, 2008). These authors propose that distinguishing sharply between chemical and neurogenic inflammation is perhaps impossible, and that an inflammatory process may be related not only to the development of tendinopathy but also to chronic tendinopathy. Fredberg and Stengaard-Pederson (2008) suggest that inflammation and degeneration exist co-dependently, but without necessarily a causal relationship.

CHAPTER THREE – STUDY AIMS AND HYPOTHESES

3.1 Study Aims

The aims of this study are firstly, to quantify the *in vivo* excursion of EPB at the wrist, in different wrist positions, in a population of normal adults. Secondly, it aims to determine if the methods of USI and a cross-correlation algorithm utilised are a reliable means of measuring tendon excursion.

3.2 Null Hypotheses

1. There is no difference in EPB tendon excursion at wrist level when the wrist is in the different positions of extension, neutral and flexion.

2. USI and a cross-correlation algorithm are not a reliable means of measuring tendon excursion.

CHAPTER FOUR – METHODS

4.1 Study Design

An observational and reliability study was chosen to examine EPB tendon excursion at wrist level, with the wrist in the pre-determined positions of flexion, neutral and extension.

1. USI and a cross-correlation algorithm were employed to measure tendon excursion. The primary researcher performed the USI assessment, and recorded and analysed the images.

2. Multiple images were recorded for each subject, on each day, in order to investigate within-session reliability.

3. Subjects were tested on two occasions, on different days, in order to obtain data to determine between-session reliability of the methods utilised.

Data collection began in May 2010 and finished in July 2010, and all data was collected at the Health and Rehabilitation Research Institute, AUT-Horizon Scanning Laboratory, AUT Akoranga, Auckland.

4.2 Ethics

Ethical approval was gained from AUTEC (Auckland University of Technology's Ethical Committee) on 20th January 2010 (Appendix D).

4.3 Participants

Healthy volunteers between the ages of 18 and 65 were recruited to participate in the study. Advertisements were placed within the University and volunteers were received from students and colleagues.

Subjects were provided with an information leaflet (Appendix A), and having consented (Appendix B) to participation in this study, they were asked to attend for USI assessment of their wrist, on two separate occasions, within one month of each other. Exclusion criteria were assessed and only those subjects who did not possess these criteria were included in the study. The majority of subjects were able to offer both wrists for assessment, only one subject had one wrist excluded due to a previous distal radius fracture. A total of 49 wrists were therefore examined. The criteria were as follows (Table 3).

Table 3: Inclusion and exclusion criteria

Inclusion Criteria	***Exclusion Criteria***
Normal subjects 18-65 years	Autoimmune disorders such as Rheumatoid Arthritis
	Corticosteroid injections in the wrist or thumb area
	Endocrinological and neurological conditions
	Previous or current fractures of the radial bones of the wrist and hand
	Recent episode of deQuervains disorder
	Pain present in the wrist or thumb

Demographics collected included age, gender, right side, left side, hand dominance and thumb composite range of motion. Dates were recorded for each attendance. Each image taken was labelled with respect to subject identification, right or left side, wrist position and the number in the sequence of images taken.

4.4 Equipment

Table 4 contains a list of equipment utilised in this thesis.

Table 4: Equipment

Diagnostic Ultrasound Machine *Philips iU22* • L15-7io Linear Transducer • Ultrasound transmission gel, paper towels, non-allergenic tape • Elbow strap for supporting transducer cable • Pillow to support assessors elbow
Hinged, thermoplastic wrist and hand splint • Wooden base and mount for gutter arm of splint • Aluminium outrigger device • Wing nut, screws • Velcro • Protractor, pencil, blu-tac, glue
Adjustable table
Adjustable chair Static chair
Expansion drive
Frame-by-frame cross-correlation software (Matlab, USA)
AVI4BMP software (Version 2.4, Bottomap Software) digital conversion software

4.5 Set-up

A 2.4mm thermoplastic hinged wrist splint was constructed and mounted on a wooden block, and secured on a base (Figure 4). The base was secured to an adjustable table during assessments. A wing-nut connected the two outriggers at the level of the wrist, at the distal end of the ulna, to create a hinge. The outriggers and hinge connected the larger gutter component of the splint with the smaller distal hand piece. The adjustable hand piece was fabricated to encase the ulnar border of the hand and could fit both right and left hands. The hand piece could also slide proximally or distally to fit different arm sizes.

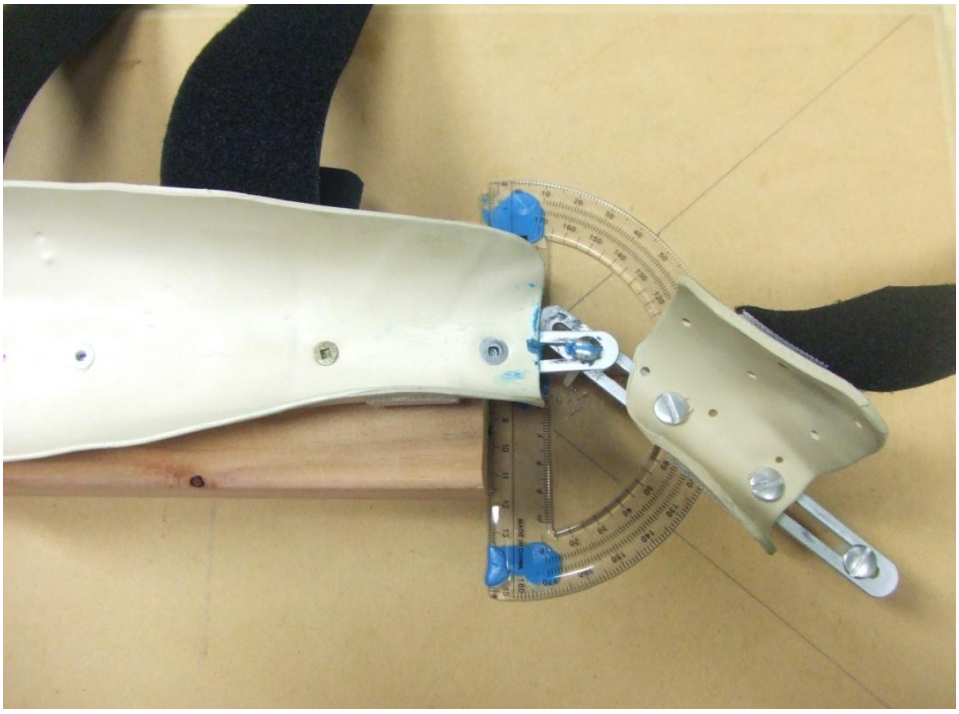

Figure 4: Splint Set-up

4.5.1 Wrist Angles

For the purpose of this research, more moderate positions of wrist flexion and extension were chosen to examine, compared with the angles selected in the study by Kutsumi, Amadio, Zhao, Zobitz and An (2005). Wrist angles of 45° of both flexion and extension were therefore chosen, as well as the neutral position. This decision was based mainly on the desire to achieve representation of tendon behaviour in a more functional range.

A protractor was secured to the board at the base of the wooden mount with the central point aligned directly beneath the hinge of the splint. Manual markings were made along the lines of the protractor angles at 45° on either side from the centre point beneath the hinge. This centre point was accurately measured with a ruler. The protractor was secured with glue, reinforced with blu-tac and monitored closely throughout the study for any transition. The position of the protractor was regularly re-checked against the manual markings drawn on the base. The central line marking indicated a wrist neutral position and was continuous with the distal arm of the splint. The hinge was always fastened securely in each position when measures were being taken.

The forearm and hand were positioned within the splint construct, and the desired angles were achieved by positioning the hand (specifically the third metacarpal) parallel to the drawn 45° line, viewed from the radial side. The third metacarpal is used in goniometry of wrist angle measurements, and recommended by the American Society of Hand Therapists (ASHT) (Fess & Moran, 1981). The forearm was always static and secured with the straps (see chapter 4.5.3).

During piloting, a Penny & Giles electrogoniometer was used to position the wrist and to validate that the visually estimated manual alignments were accurate. The distal electrode of the electrogoniometer was placed on the radial aspect of the second metacarpal, instead of the third, to gain stability and balance. The proximal electrode was placed along the shaft of the radius, on the radial aspect of the forearm, as recommended by ASHT, and as reliably used in other wrist measurement studies (Rawes, 1996). Electrogoniometry is

generally considered to be a highly reliable measuring tool for wrist range of motion (Rowe, Myles, Hillmann, & Hazelwood, 2001; Shiratsu & Coury, 2003) however, although many variations in measuring tools and protocols exist, intra-rater assessment and reliability is considered to be higher when standard methods are adhered to (Pratt & Burr, 2004). It has been shown that clinical experience and visual estimation of motion in digits have a positive correlation with measurement accuracy (Maury, 2002). During piloting, the electrogoniometer was utilised at intervals to check that the wrist positions were being maintained at the correct angles. It was determined that 'visual estimation' of the wrist positions, parallel with the angle markings, together with the assessors clinical experience, was an accurate means of maintaining correct wrist alignment in this study.

4.5.2 Arm Position

Each subject was seated in a chair with their spine supported by resting against the back of the static chair with their feet flat on the ground. The subjects' arm was supported on an adjustable table so that the humerus was in a relaxed, abducted and stable position. The forearm was then placed in the gutter component of the splint. The elbow was flexed at 90° and the forearm in a neutral rotated position. The hand was placed in the distal part of the splint so that the wrist axis was directly over the hinge of the splint (Figure 5 & 6). For the purpose of this experiment, the axis was taken as the point at the distal end of the ulna, at the ulnotriquetral junction, to ensure consistent positioning between measures. The axes of motion, in the anteroposterior directions of wrist kinematics are understood to function primarily at the radiocarpal articulation, and the mid-carpal articulation in proportions that vary (Tubiana, et al., 1996). The goniometric axis recommended is the capitate bone, through the middle column of the wrist and carpus (Fess & Moran, 1981). For this experiment the wrist was in a neutral position of deviation, although it was found that most subjects had a natural tendency to ulnarly deviate during thumb motion. This was counteracted by instructing the subjects to keep a neutral position, during each procedure.

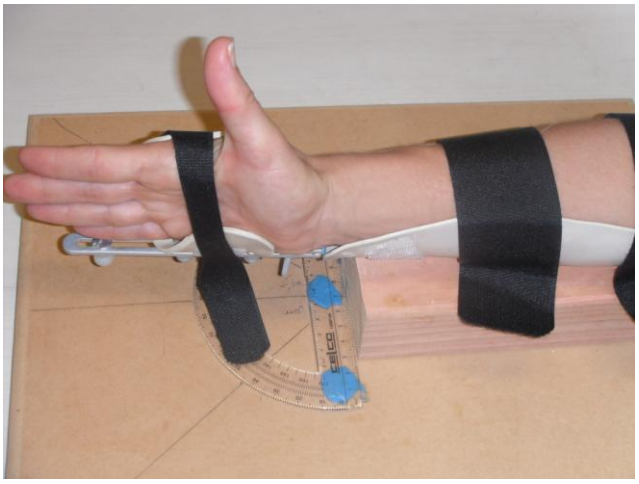

Figure 5: Starting position

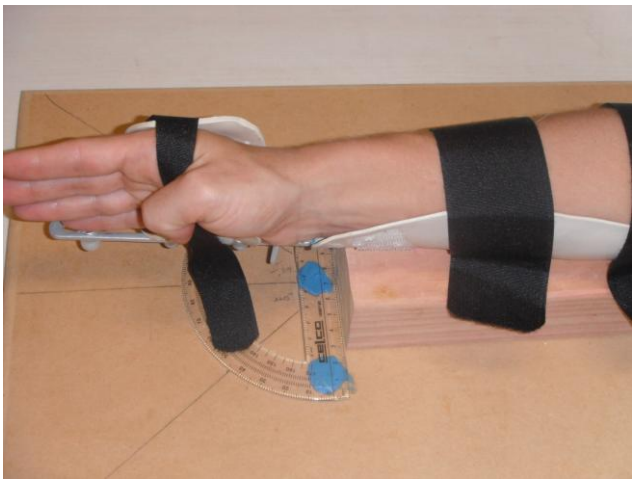

Figure 6: End position

4.5.3 Straps

A proximal, middle and distal strap were placed around the forearm and hand. The middle strap was placed proximal to the area of measurement (distal radius), to avoid interference with the transducer placement, and care was taken to maintain a light tension to minimise interference with EPB muscle activity. The strap around the hand was cut so as to pass through the first web space comfortably and to prevent interference with thumb flexion (Figures 5 & 6).

4.5.4 Thumb ROM

Each of the joints of the thumb was measured individually for extension and flexion (CMC, MCP and IP). Composite flexion range of motion was then recorded for each subject to give the total active range of motion (TAROM) of the thumb. This was calculated using the American Society of Hand Therapists (ASHT) recommended formula for finger joint motion [TAROM = sum of flexion – sum of extension] (Fess & Moran, 1981).

CMC joint extension was measured placing the goniometer laterally, the immovable arm parallel with the radius and the mobile arm parallel with the first metacarpal. The forearm was stabilised in a neutral rotated position and the thumb extended. CMC joint flexion was determined as 0° for all subjects in this study, not at 15° flexion as cited in Hunter, Mackin and Callahan (2002). Flexion of the CMC joint beyond neutral was not observed during piloting. It was found that when measuring with the ulnar forearm and hand supported on the table, wrist ulnar deviation was obstructed and thumb CMC joint flexion only reached a neutral position at 0°.

MCP joint extension was measured with the forearm in the position as above. Hyperextension was recorded as a negative value. Goniometer placement was lateral for extension and dorsal for flexion. Full thumb composite flexion was instructed. Interphalangeal joint measurements were recorded using lateral and dorsal placements. All goniometry placements were in agreement with the ASHT recommended guidelines (Fess & Moran, 1981). The joint motions were recorded to enable EPB tendon excursion to be measured over a mean, composite and total range of joint motion.

4.6 USI Protocol

4.6.1 Transducer

A Philips 17-5io linear transducer was chosen because of its linear property, small size and applicability to a narrow anatomical area. The advantage of a linear array is its wide ‘near field’ which is appropriate for imaging small superficial structures (McKinnis, 2005). The transducer was carefully positioned with the head orientated longitudinally and distally during testing, and this orientation was consistently repeated for each test. This orientation however, produced cross-correlation graphical representation to be in the negative X-Y axis, within the second octant. The orientation was selected because the assessor was right handed and this allowed better stability of the transducer. A coupling gel was applied to the transducer.

4.6.2 USI Parameters

A Phillips IU22 Diagnostic Ultrasound machine was utilised (Figure 7). The depth of USI tendon imaging was taken at 2cm and chosen because of the superficial aspects of the tendons between the distal radius, and the skin and subcutaneous tissue. All structures including the bone, tendons, vessels, and subcutaneous tissue, were easily identifiable at this depth. The frequency of the transducer was 123Hz, and a focal zone in both longitudinal and transverse planes was easily achieved.

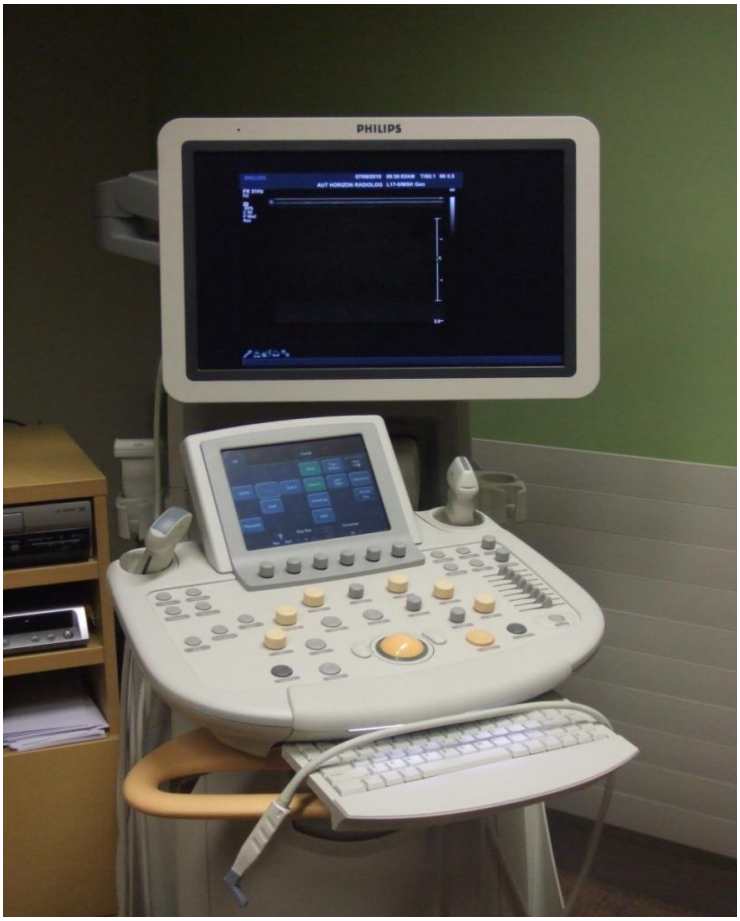

Figure 7: Phillips iU22 Ultrasound Machine

4.6.3 EPB Location and Differentiation

The EPB tendon was found over the distal radius on the radial side by differentiating it from APL. Anatomically, EPB lies dorsal and ulnar to APL within the same compartment. Hazani et al. (2008) have outlined the bony and tendon anatomical landmarks of the radial styloid, Lister's tubercle and the scaphoid, as well as an intersection through these points, identifying APL (ALS juncturae) (Figure 8).

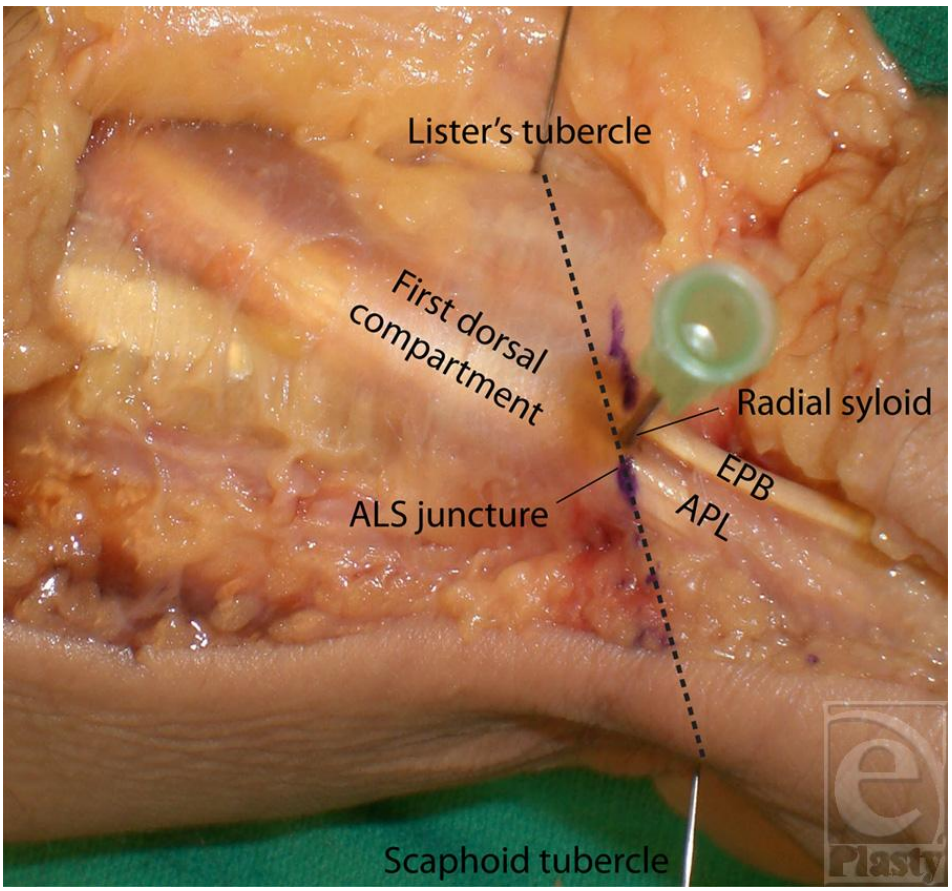

Figure 8: Anatomic landmarks for the first dorsal compartment: APL; ALS juncture (APL-Lister's-Scaphoid); EPB
(Modified From Hazani, et al. (2008). Anatomic landmarks for the first dorsal compartment. *Open Access Journal of Plastic Surgery*, pgs 489-493).

The transducer was placed transversely and then longitudinally (Figures 9-11), following the tendon proximally towards its muscle origin. It was easily differentiated from EPL, which is distinct and more dorsal, winding around and ulnar to Lister's Tubercle (Tubiana, et al., 1996) (Figure 12).

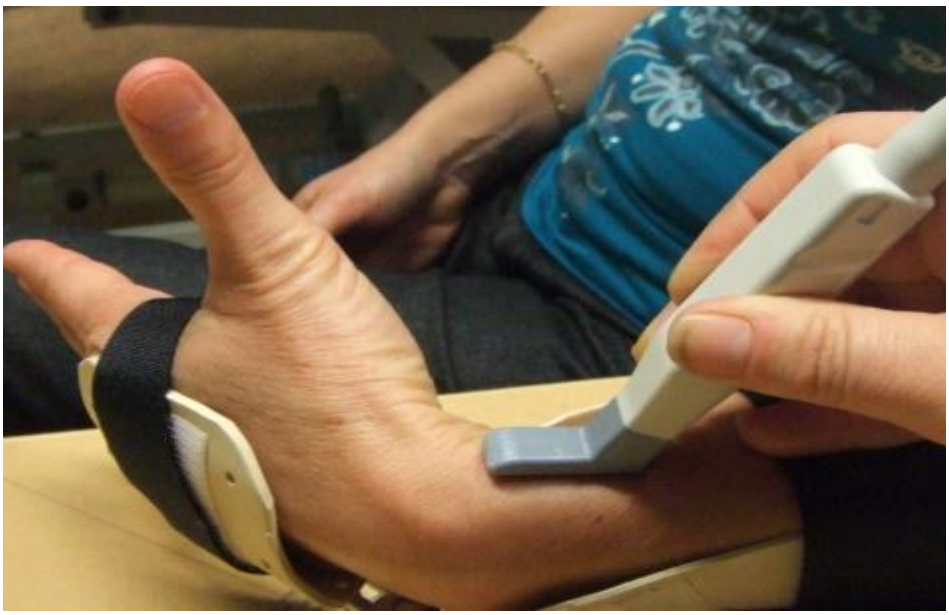

Figure 9: Transducer placement over EPB

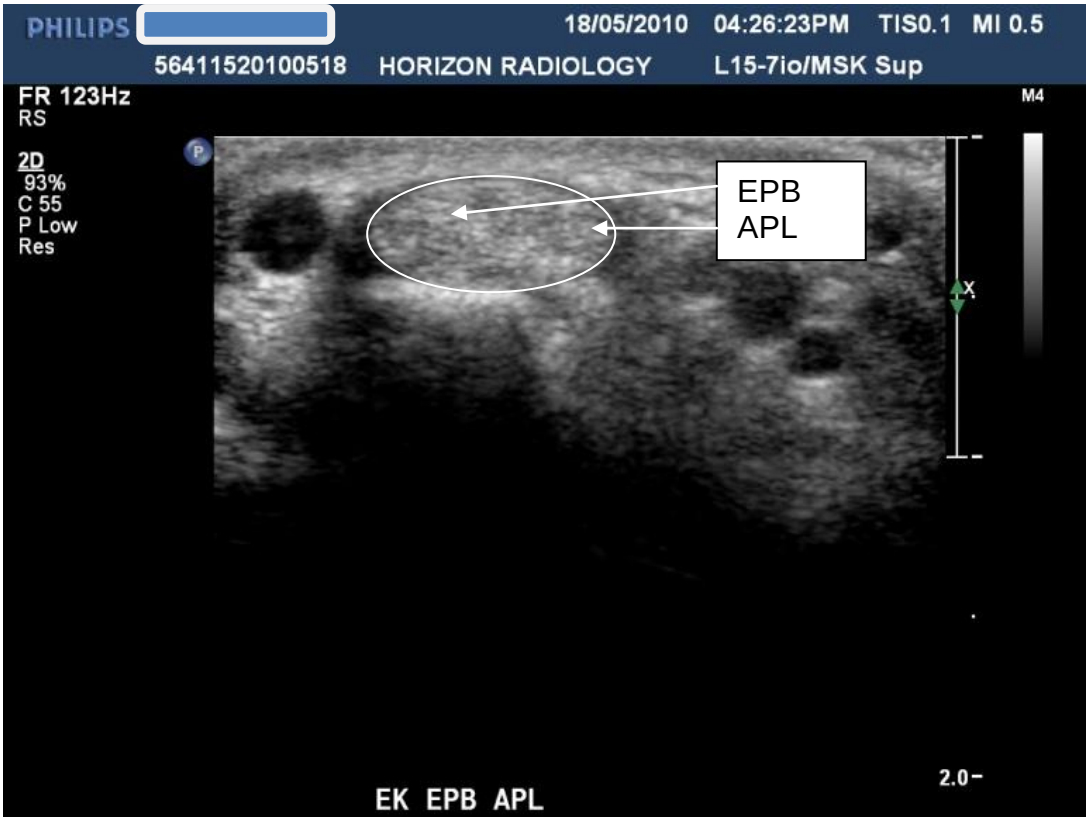

Figure 10: APL and EPB transverse view (1st dorsal compartment)

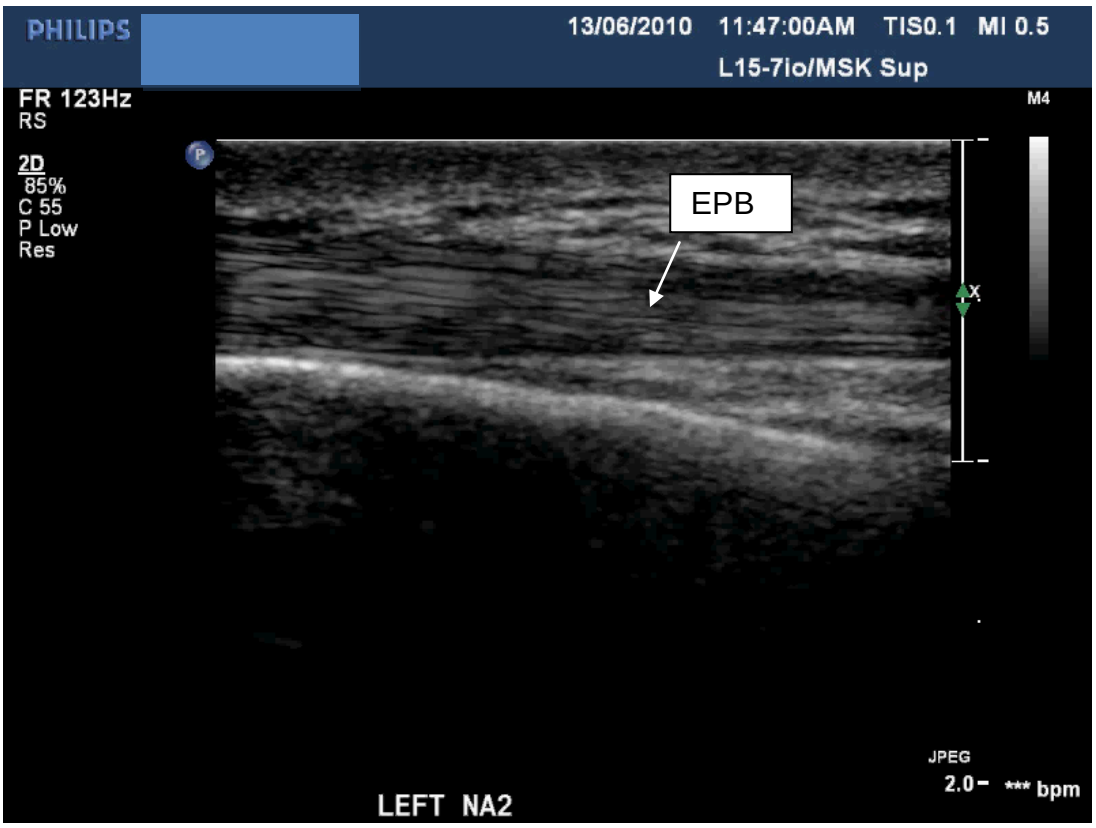

Figure 11: EPB longitudinal view

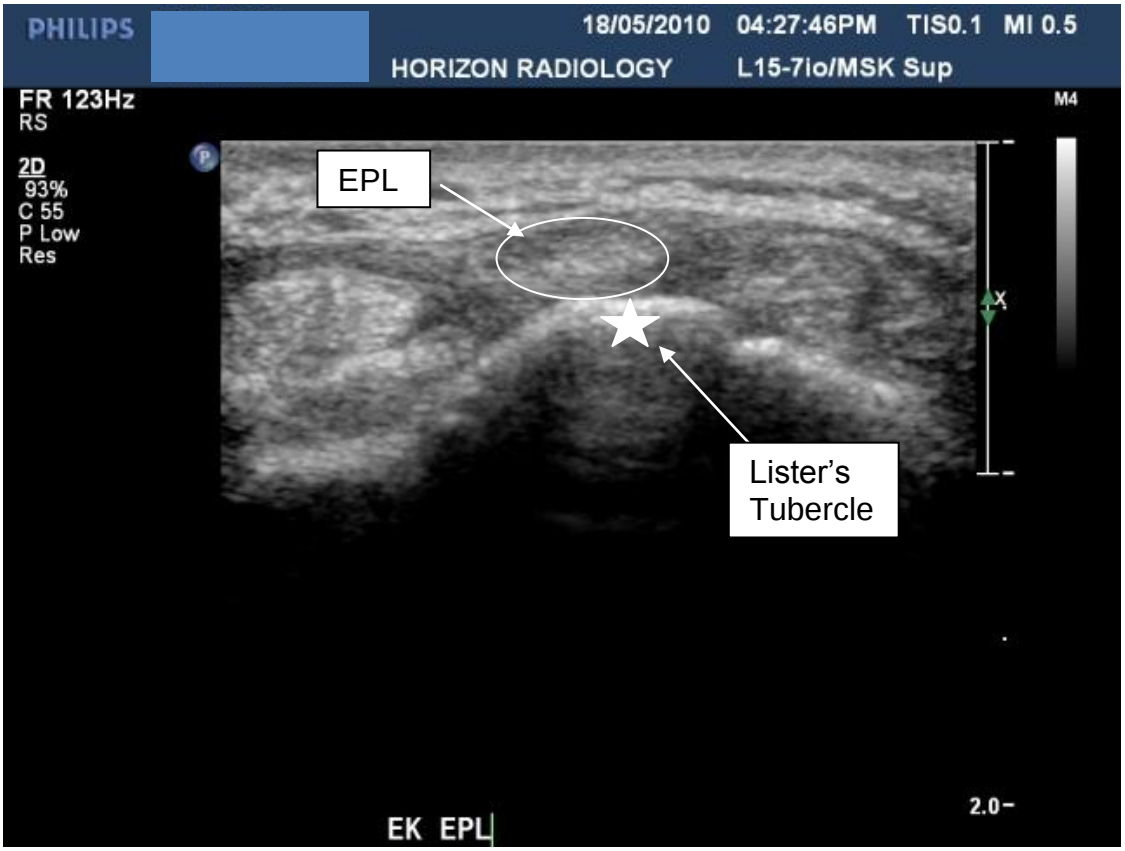

Figure 12: EPL transverse view (3rd dorsal compartment)

The Extensor Digitorum Communis (EDC) and Extensor Indices (EI) were easily distinguished, lying centrally over the dorsal aspect of the wrist (Figure 13).

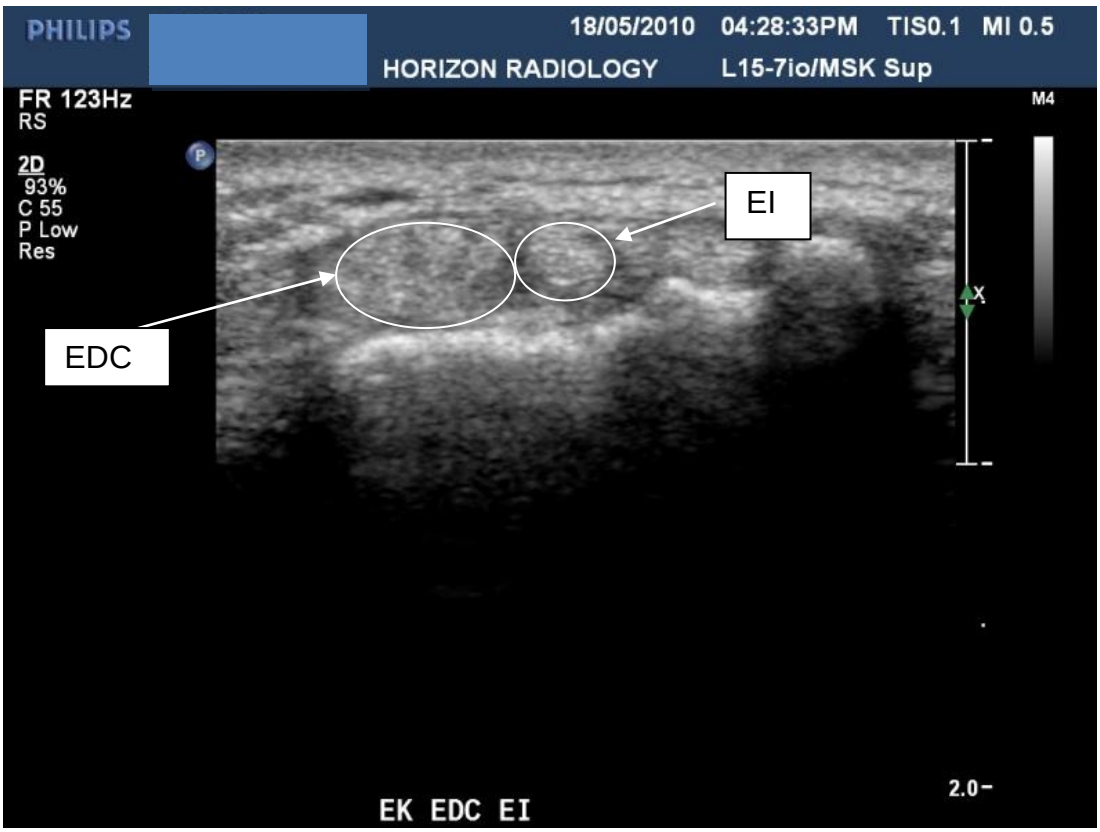

Figure 13: Extensor Digitorum (EDC) and Extensor Indices (EI) (4th dorsal compartment)

The tendons of Extensor Carpi Radialis Longus (ECRL) and Extensor Carpi Radialis Brevis (ECRB) (Figure 14), in the second dorsal wrist compartment are also anatomically positioned ulnar to EPB and APL (Tubiana, et al., 1996), which made it easy to differentiate from the first compartment. Flexor Carpi Radialis (FCR) and Palmaris Longus (PL) were also easily identified. These were found on the volar aspect of the wrist and not in the immediate transducer field during analyses (Figure 15).

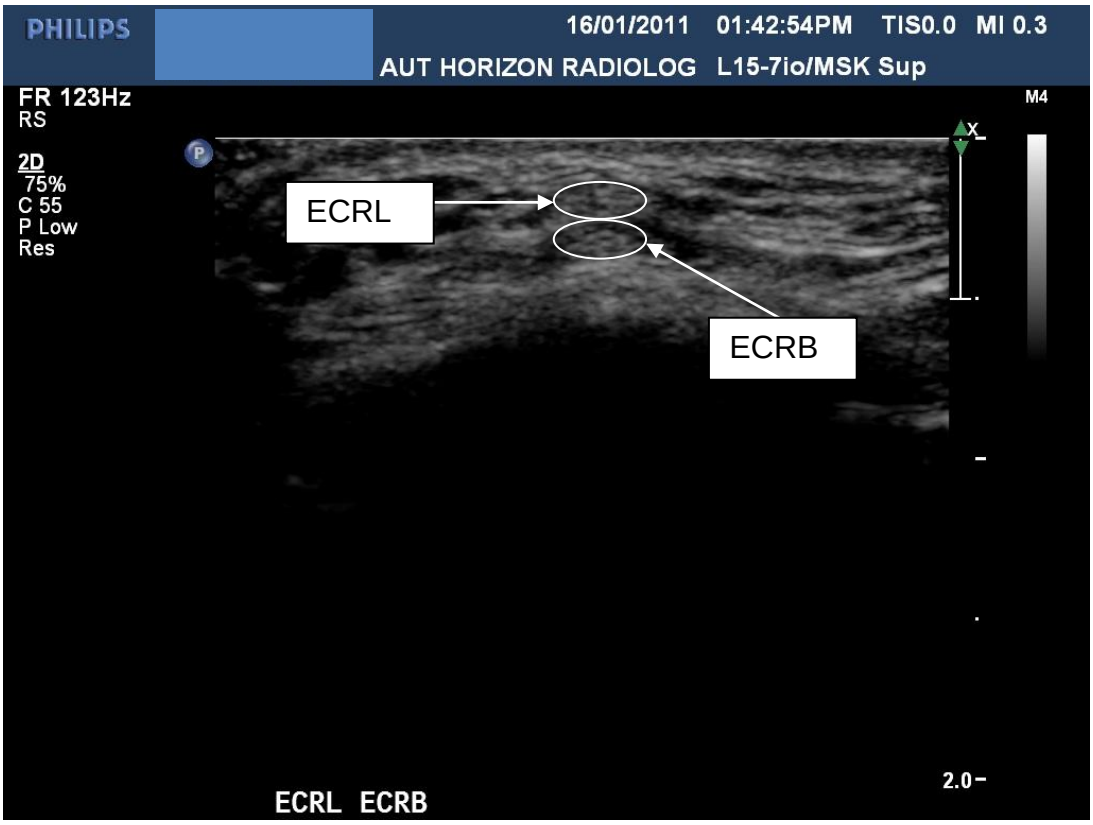

Figure 14: Extensor Carpi Radialis Longus (ECRL) and Extensor Carpi Radialis Brevis (ECRB) (2nd dorsal compartment)

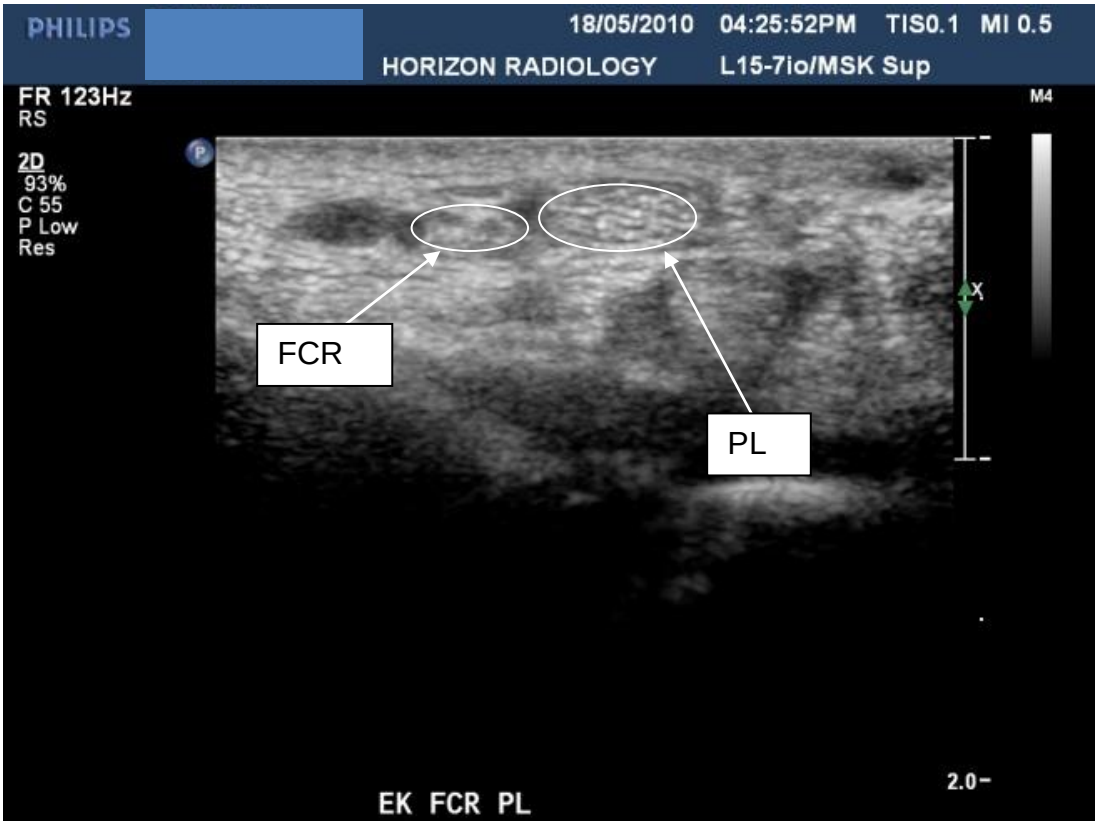

Figure 15: Flexor Carpi Radialis (FCR) and Palmaris Longus (PL)

4.7 Measurement Protocol

4.7.1 Subject Instruction

A source of error observed during piloting, was the significant variation in thumb movement performed between subjects. Variations included the plane of movement, where some subjects abducted the thumb before or during the procedure. Also observed, was the variation in fullness of flexion, where some subjects flexed the IP and MCP joints, and extended the CMC joint. A list of instructions was therefore given to each subject regarding the desired thumb motion from full extension to full flexion (Appendix C). These instructions addressed the following;

- starting position of the thumb (full extension)
- end position of thumb movement (the distal palmar crease at the ulnar border of the hand)
- speed of thumb movement (within 3 seconds)
- completion of movement (within 3 seconds)
- plane of thumb movement (across the palmar plane)

Subjects were then asked to rehearse the movement three times before the measurement procedure was taken. Recording was not initiated until both the assessor and subject were comfortable with the procedure. Caution was observed not to fatigue the musculotendinous unit by over-exerting it prior to recording. Subjects were rested before actual measurement recording began. The instruction and rehearsal helped to standardise the procedure and minimise variation in performance between subjects, therefore reducing the amount of error.

4.7.2 USI Recording

Firstly, EPB was visualised throughout the three second phase. The assessors' left hand controlled the capture button and was pressed after a count of three seconds, as the subject initiated thumb flexion. A minimum number of five recordings were taken, for each of the thumb extension-flexion motions, in each of the three wrist positions. In some cases however, up to eight recordings were taken because of loss of tendon visualisation, or because of subject error caused by such factors, as listed above in section 4.7.1. Assessment then turned to the alternate hand, in all but one subject, whose right hand was excluded, and the same procedure was carried out.

Subjects were analysed on two occasions, the second analyses occurred within four weeks of initial recordings to fit with availability of the USI equipment together with subject convenience, and the same procedure was followed. The assessor was blind to previous measures taken, as the cross-correlation analyses was not performed until completion of all video recordings was obtained. Only two subjects failed to return for second measures. All video data was filed and saved to an external expansion drive for further analyses.

4.7.3 Video Selection Criteria

Each video sequence was reviewed several times. Those videos, where tendon visualisation against other tissue became obscured, were discarded. Only those videos that possessed the following properties were selected to be analysed:

- clear pixilation and identification of all tissue type through full motion
- smooth motion of the tendon through full range
- completed motion at end range flexion
- minimal bone movement
- minimal subcutaneous tissue movement

Of these videos, two sequences were selected for cross-correlation analyses: for each wrist position, on each side, for each subject, giving a total of six videos per wrist.

4.8 Video Analyses

4.8.1 Cross - Correlation Algorithm

Frame-by-frame cross correlation algorithm and calculation software was used to analyse the captured footage (Dilley, et al., 2001). All images selected were converted to digital frames (Bitmaps) prior to analyses using the AVI4BMP (Version 2.4, Bottomap Software) digital conversion software and subsequently analysed in Microsoft Excel. The cross-correlation software employs a cross-correlation algorithm to measure the motion of fine speckle features in selected regions of interest (ROI), between adjacent frames of the image sequence (Dilley, et al., 2001).

From the initial frame of the sequence of Bitmaps (89 or 90 frames) for each image, three rectangular regions-of-interest (ROI) of varied dimensions were selected, within the tendon (Figure 16). During the analyses, the program compares the grey-scale values from the ROIs between adjacent frames of the image sequence. In the compared frame, the ROIs are offset along the horizontal image plane, one pixel at a time, with a predetermined range. A correlation coefficient is calculated for each individual pixel shift. The peak of the quadratic equation, fitted to the maximum three correlation coefficients, is equivalent to the pixel shift/movement between adjacent frames (Dilley, et al., 2001). In order to compensate for vertical shifting of horizontal structures, the ROIs in the compared frame are calculated +/- 2 pixels along the vertical image plane. The relative movement is calculated from the maximum coefficient and its two adjacent values, using the data from each vertical offset (Dilley, et al., 2001).

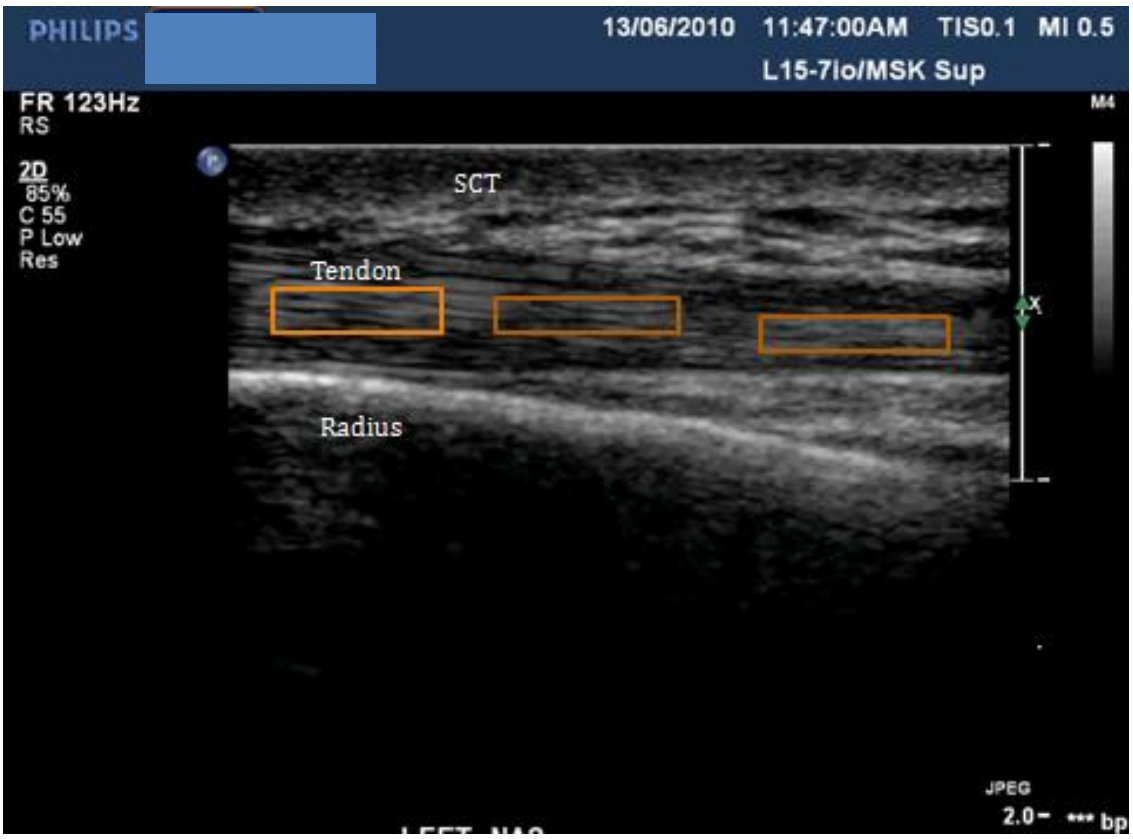

Figure 16: Identification of tissue types and selections of tendon Regions of Interest (ROI). (SCT=subcutaneous tissue)

Pixel shift measurements for the tendon were offset against (subtracted from) pixel shift measurements within the same ultrasound field, from a stationary structure. Piloting determined that subcutaneous tissue movement was minimal and was therefore chosen as the background tissue for measurement (Figure 17). The method allows for any slight movement of the ultrasound transducer to be eliminated from the analyses (Dilley, et al., 2001; Ellis, et al., 2008).

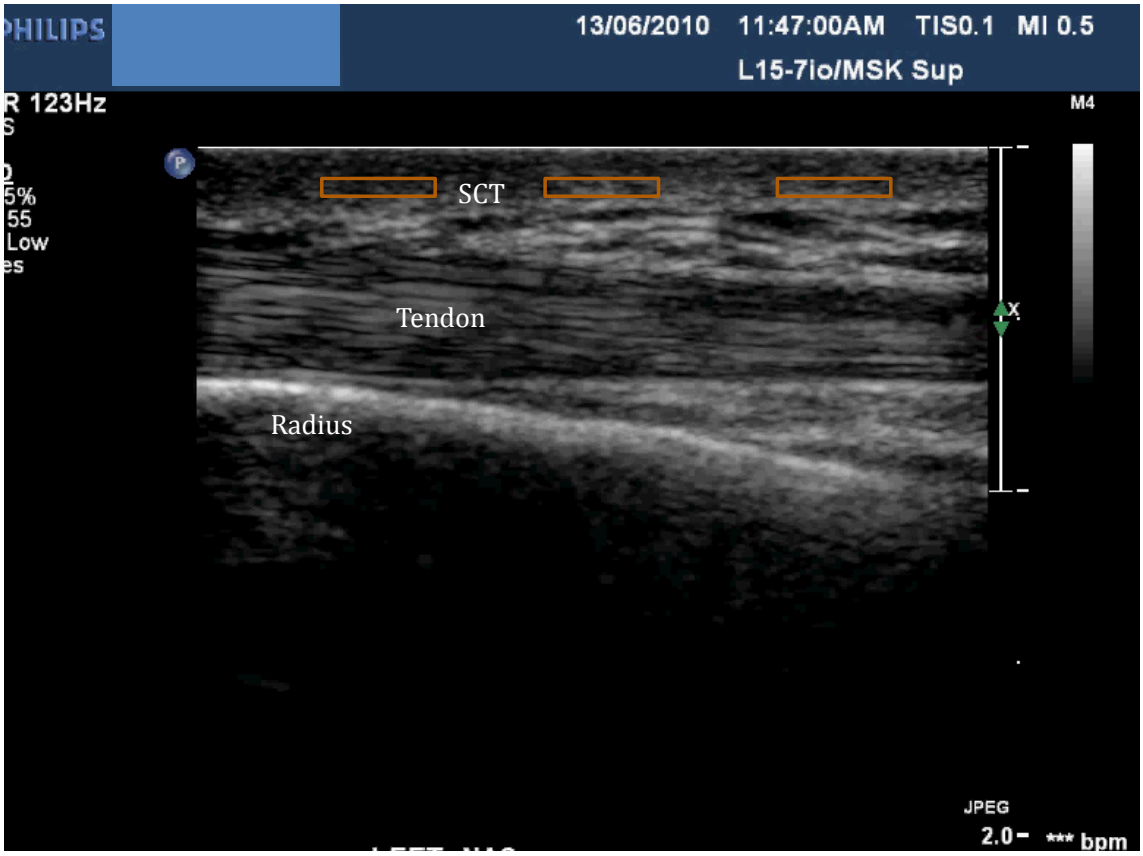

Figure 17: Subcutaneous tissue (SCT): Regions of Interest (ROI)

4.8.2 Graphical Representation

A typical graphical representation of the cross-correlation calculation for each video image is presented in Figure 18. The first and second graphs depict the movement of the tendon and subcutaneous tissue. The graph on the right depicts the resultant tendon motion which is the difference between the tendon and SCT motion, and is depicted in the second octant, due to transducer orientation. These are converted to positive values for analyses and simpler interpretation.

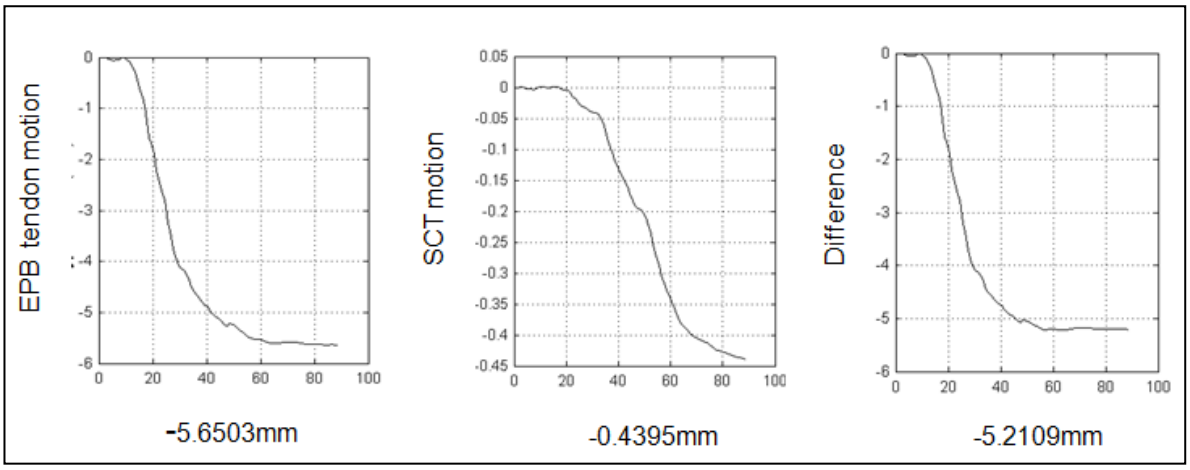

Figure 18: Typical graphical results of the cross-correlation algorithm

4.8.3 Analysis and Interpretation of Graphs

The selection criteria of video footage has been discussed previously and graphs demonstrating resultant tendon motion, as shown above, were produced for each video image. The graphical depiction was used to further assess quality of the image in terms of the tendons behaviour through the motion. It demonstrates smooth unidirectional tendon motion (5.65mm) within the timeframe, through full range, and a very small amount of SCT motion (0.44mm), with a resultant 5.21mm of EPB motion. As mentioned above, the negative values reflect only the direction of tissue movement with respect to the orientation of the transducer. These values are converted to positive figures simply for referencing and for the purposes of statistical analyses.

4.9 Statistical Analyses

Statistical analyses were performed from the baseline descriptive information saved on each subject, using the Statistical Package for the Social Sciences (SPSS), Version 17, software (Chicago, IL). Analyses of statistical comparisons, of within-session reliability (single measures) and between-session reliability (single measures and average measures) was produced from a one-way ANOVA, as only one investigator was involved. The alpha level was set at $P \leq$

0.05, and effects of position, age, gender, and hand dominance on tendon excursion, were analysed.

Repeated measures (test-retest) analyses utilised ICC's to quantify reliability, with 95% CIs determined. A reliability coefficient is determined as the ratio of variance between subjects, to the sum of error variance and subject variance (Bruton, Conway, & Holgate, 2000). The ICC is a pure number without units that is said to be one type of relative reliability index, that can be used to compare reliability between tests (H. Chen, Chen, Hseuh, Huang, & Hsieh, 2009).

Intra-rater reliability involved within-session analyses, comparing measure 1 (M1) and measure 2 (M2) for session 1 (S1), and then measure 1 (M1) and measure 2 (M2) for session 2. Between-sessions analyses compared the means of M1 and M2 from session 1 with the means of M1 and M2 from session 2. In this experiment the wrist position variables were further explored, and filtering of position with the co-variable, was carried out with respect to reliability of measurement.

An ICC ratio of 1 indicates perfect reliability with no measurement error, whilst 0 indicates no reliability (Rankin & Stokes, 1998). Vincent (1999) has reported the following interpretation of ICC values: ICC >0.90 = excellent, 0.80-0.89 = high and 0.70-0.80 = acceptable. An ICC value of >0.60 has been reported to be of useful value (Rankin & Stokes, 1998), although it is recognised that no standard acceptable levels of reliability exist (Bruton, et al., 2000).

Bland-Altman plots have been used to provide graphical representation of key reliability findings. The Bland-Altman method calculates the range within which the difference between the two measures will lie, with a probability of 95% (Bland & Altman, 2003) (Figures 20-23).

Pearson's Correlation Coefficient was used to investigate the relationships between sets of data, in particular age, TAROM and tendon excursion. The

Standard Error of Measurement (SEM) calculation was undertaken, which indicates the extent of measurement error caused by chance variation in measurement (H. Chen, et al., 2009). The Minimal Detectable Change (MDC), or Smallest Real Difference (SRD), was also calculated; estimated from the SEM, and indicating the degree of change that would exceed the expected trial to trial variability (Table 8). The MDC provides a benchmark to determine whether an individual achieves a real improvement beyond measurement error, at a 95% confidence level, and should be low, together with a high ICC when a test is considered to be highly reliable (H. Chen, et al., 2009).

CHAPTER FIVE – RESULTS

5.1 Demographics

Of the 25 subjects included in the study, 10 (40%) were male and 15 (60%) were female. All but one subject met the inclusion criteria for volunteering both wrists, but one wrist was excluded, giving a total of 49 tendons. The mean age of the sample was 40.7 years (age range 18-63). Of the 49 total wrists, 24 right wrists and 25 left wrists were examined. There were 23 right handed and 2 left handed subjects.

All subjects attended the first session for analyses and two failed to attend for second analyses. A large number of video images were collected and six images per wrist for each session were finally analysed. Tendon motion on each video frame was required to be smooth and clearly defined, from full thumb extension and being completed in full thumb flexion. Minimal motion only from subcutaneous tissue and bone was acceptable. Video images were not selected if the quality of the image was not acceptable, such as poor pixilation and clear identification of the tendon. The mean thumb TAROM was 170.4° (SD±26.3°), from the assessment starting position of full extension, to the end position of full flexion (Table 5). All descriptive baseline information was stored for analyses.

5.2 EPB Tendon Excursion

5.2.1 Wrist Position

Wrist position was found to have a significant effect on EPB tendon excursion. Tendon Excursion in the neutral wrist position was statistically significant from tendon excursion in the other positions of flexion and extension ($p<0.05$). The results showed that EPB tendon excursion was greatest in the neutral wrist position (mean=2.78mm, SD±1.89mm), and similar for both wrist extension (mean=1.67mm, SD±1.15mm) and wrist flexion (mean=1.62mm, SD±1.4mm)

(Figure 19). There was no statistically significant difference between tendon excursion in the flexion and extension wrist positions.

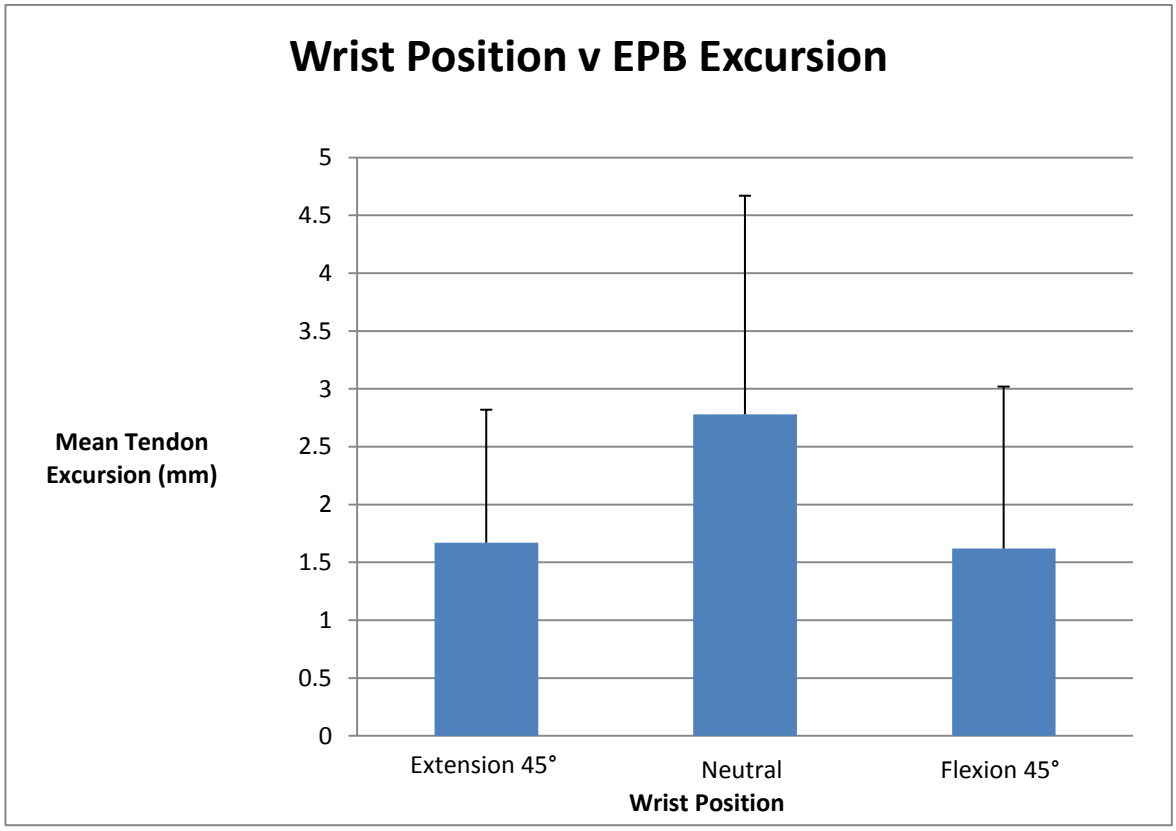

Figure 19: Wrist position and EPB excursion measures

5.2.2 Age

Tendon excursion was found to decrease with age and although the effect was small, it was found to be statistically significant ($p<0.05$). A Pearson's correlation calculation demonstrated an inverse relationship ($r= -0.23$). A small inverse relationship was also found when age and TAROM were investigated ($r= -0.15$).

5.2.3 Thumb Range of Motion

Mean range of motion for each of the thumb joints and their standard deviations, are listed below in Table 5. A correlation between TAROM of the thumb and EPB tendon excursion was investigated in each of the wrist positions using Pearson's statistical analysis in SPSS. Pearson's correlation coefficients

were found to be low in each of the groups (extension r=0.21; neutral r=0.29; flexion r=0.28). There was a low correlation between EPB excursion and TAROM when all measures in all positions were analysed. Therefore, both TAROM and tendon excursion reduce with age.

Table 5: Thumb Total Active Range of Motion (degrees)

Thumb Joint	*Mean Range of Movement (ROM)*	*Standard Deviation (SD)*
CMCJ	46.6°	7.0°
MCPJ	49.7°	14.3°
IPJ	74.1	24.1°
Composite/TAROM	170.4°	26.3°

5.2.4 Gender and Hand dominance

An effect of gender on EPB tendon excursion was investigated; no significant effect was found ($p>0.05$). Hand dominance and excursion were also examined; no effect was found ($p>0.05$).

5.3 Reliability

Within-session analyses are presented in Table 6 and between-session analyses in Table 7. The right hand column represents the categorisation of ICC, determined by Vincent (1999).

Table 6: Within-session Intra-rater analyses

Wrist Position	*Within-session (mean of M1 and mean of M2)*	*ICC*	*95% CI*	*Vincent (1999)*
All Positions	Session 1	0.88	0.84-0.91	High
All Positions	Session 2	0.87	0.82-0.90	High
Neutral	Session 1	0.93	0.88-0.96	Excellent
Neutral	Session 2	0.91	0.84-0.95	Excellent
Flexion	Session 1	0.67	0.41-0.81	Useful
Flexion	Session 2	0.81	0.66-0.89	High
Extension	Session 1	0.85	0.74-0.92	High
Extension	Session 2	0.80	0.65-0.89	High

Table 7: Between-session Intra-rater analyses

Wrist Position	*Between-session (Mean Session 1 and mean Session 2)*	*ICC*	*95% CI*	*Vincent (1999)*
All positions	Session 1 and 2	0.76	0.66-0.83	Acceptable
Neutral	Session 1 and 2	0.80	0.64-0.89	High
Flexion	Session 1 and 2	0.63	0.35-0.79	Useful
Extension	Session 1 and 2	0.66	0.41-0.81	Useful

Figure 20 illustrates the Bland-Altman plot for within-session results for EPB tendon excursion; for all wrist positions, with 95% limits of agreement: a bias of 0.08, with a SD of 0.75 (lower limit -1.39, upper limit 1.55) is illustrated.

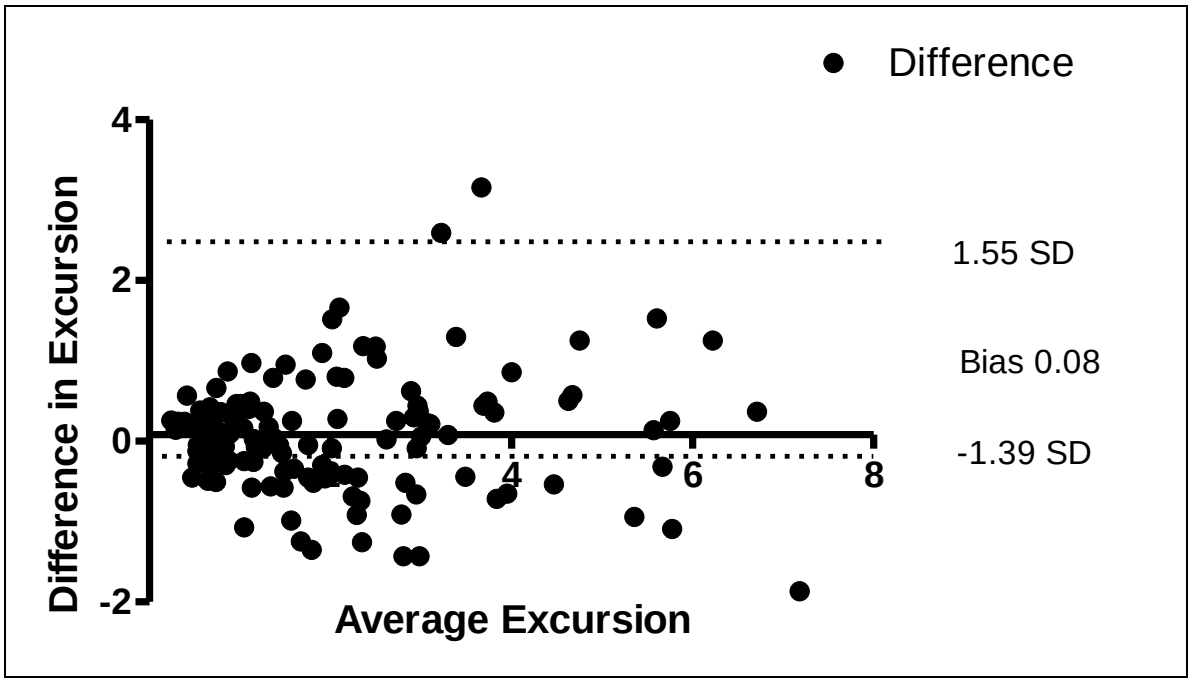

Figure 20: Bland-Altman plots for within-session 1 analyses: all positions

Figure 21 illustrates the Bland-Altman plot for Within-Session 1 analyses, neutral position: with 95% limits of agreement, a bias of 0.17, with a SD of 0.8 (lower limit -1.50, upper limit 1.84) is illustrated.

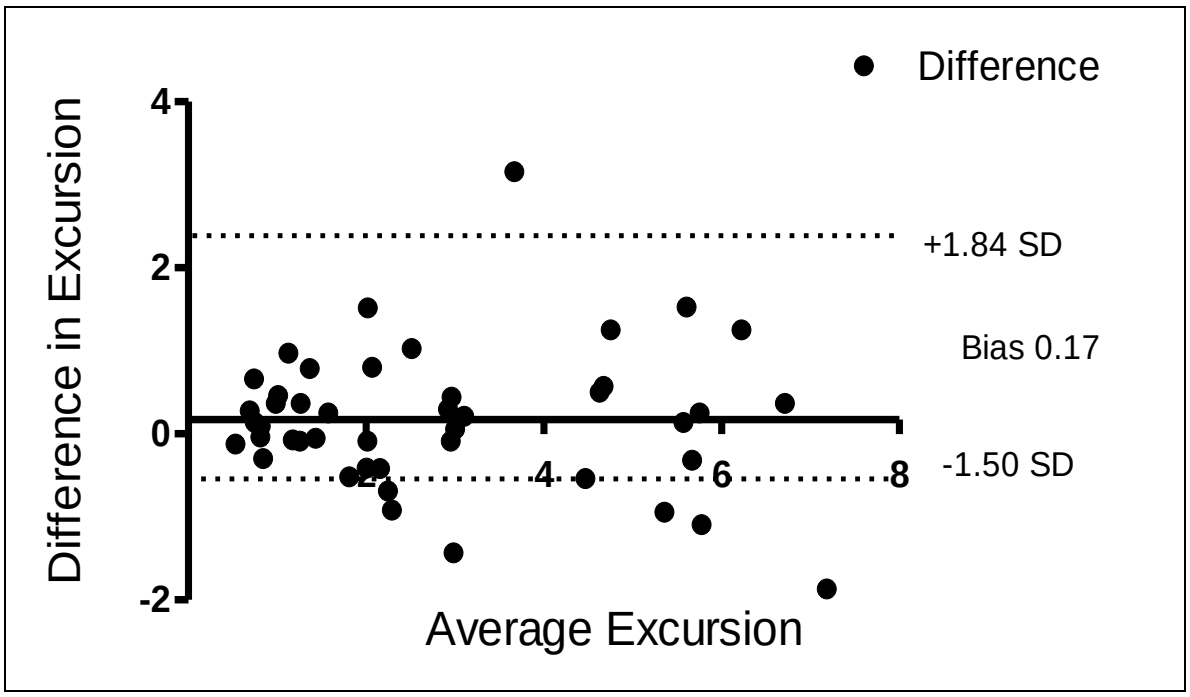

Figure 21: Bland-Altman plot for within-session 1 analyses: neutral position

Figure 22 illustrates the Bland-Altman plot for the between-sessions 1 and 2 analyses for all positions; with 95% limits of agreement: a bias of 0.08 with a SD of 1.20 (lower limit -2.27, upper limit 2.42) is illustrated.

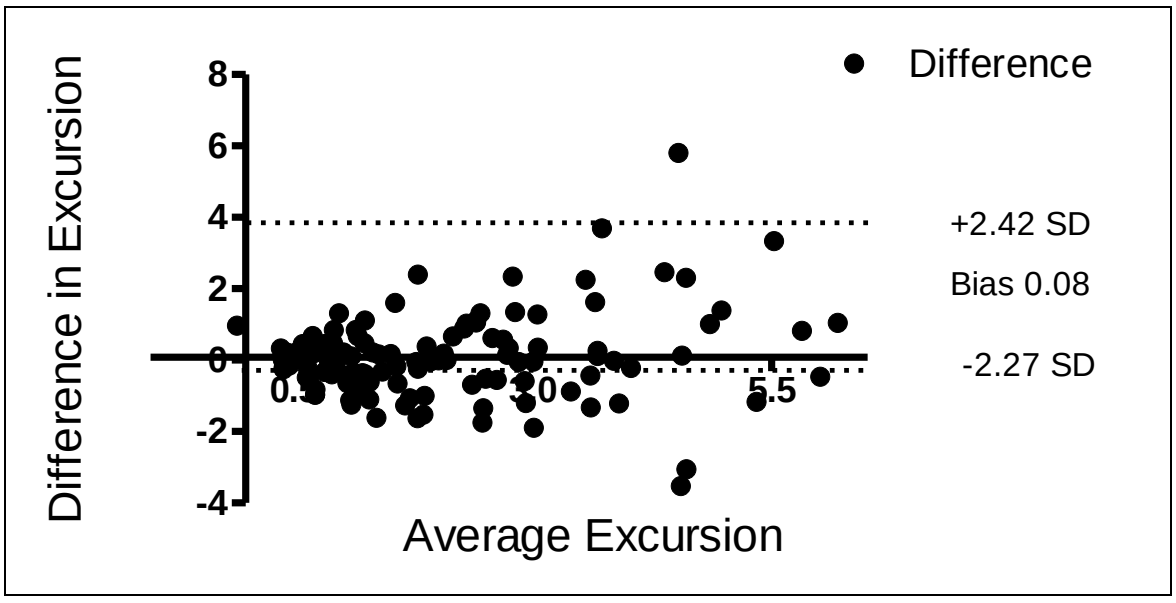

Figure 22: Bland-Altman plot for between-session 1 and 2 analyses: all positions

Figure 23 illustrates the Bland-Altman plot for between-sessions 1 and 2 analyses for the neutral position, with 95% limits of agreement: a bias of 0.33 and a SD of 1.28 (lower limit -2.19, upper limit 2.85) is illustrated.

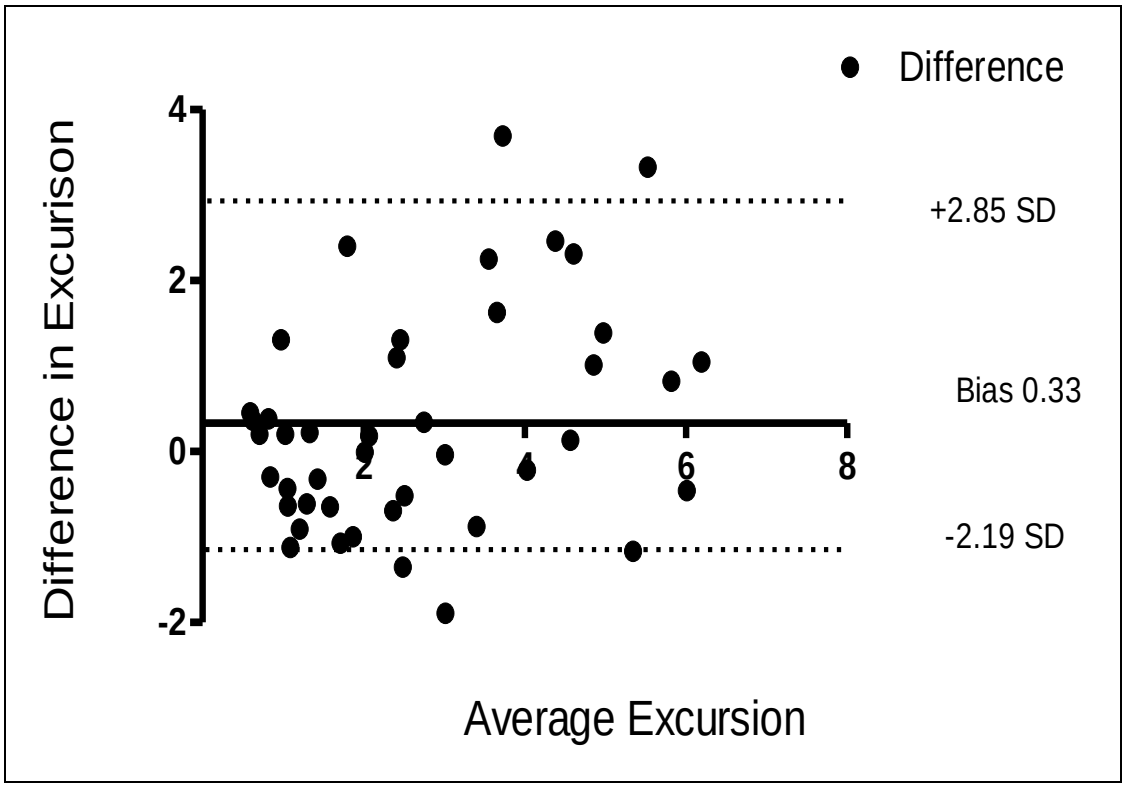

Figure 23: Bland-Altman plot for between-session 1 and 2 analyses: neutral position

Table 8: SEM and MDC: different wrist positions

Wrist Position	*SEM*	*MDC*
Extension	0.181	0.509
Neutral	0.179	0.587
Flexion	0.179	0.587

CHAPTER SIX - DISCUSSION

The results of this study show that tendon excursion of EPB at the wrist is dependent on wrist position. They also indicate that EPB has a significantly greater amount of excursion when the wrist is in the neutral position, compared with the other positions of flexion and extension. Other findings are that age has a significant effect on tendon excursion and that excursion reduces slightly with increasing age. The following discussion will firstly address reliability findings, as the excursion measures are only relevant if methods utilised are found to be reliable tools. It will then go on to discuss the excursion findings, and then address their implications and their application to the domains of therapy, surgery and research. The discussion will conclude by addressing the limitations of this study and will make recommendations for further research.

6.1 Interpretation of Reliability Findings

With respect to within-session intra-rater reliability, the ICC was found to be high for both session 1 (ICC = 0.88; 95% CI 0.84-0.91) and session 2 (ICC= 0.87; 95% CI O.82-0.90), when all wrist positions were evaluated together. When wrist positions were individually analysed, the neutral position produced excellent ICC values for within-session 1 (ICC=0.93; 95% CI 0.88-0.96) and for session 2 (ICC=0.91, 95% CI 0.84-0.95).

The results for wrist extension within both sessions were also found to be highly reliable: session 1, ICC=0.85 (95% CI 0.74-0.918) and session 2, ICC=0.80 (95% CI 0.65-0.89). The wrist flexion position for within-session 1 produced the lowest ICC values of 0.67 (95% CI 0.41-0.81), however for session 2 it was found to be high 0.81 (95% CI 0.66-0.89). This difference may be attributed to methodological factors such as familiarisation of scanning and/or improved subject performance of the motion.

Mean measures of all wrist positions were analysed for between-sessions 1 and 2, and produced an ICC value of 0.76 (95% CI=0.67-0.83). When each of the wrist position groups were analysed separately, for between-session reliability,

it was once again found that the neutral wrist position had the highest ICC (0.80) with wider confidence intervals (95% CI 0.64 – 0.89) than the other two positions. This value is considered to be highly reliable (Vincent, 1999).

Between-session results for wrist flexion (ICC=0.63; 95% CI 0.35-0.79) and wrist extension (ICC=0.66; 95% CI 0.41-0.81) were found to be considerably lower and confidence intervals were wide.

Measurement of EPB tendon excursion utilising USI and a cross-correlation algorithm has, overall, for between-session analyses, been found to be a highly reliable method of *in vivo* tendon analyses. The ICC results ranged from 0.63 with wider CI intervals for wrist flexion positions, to 0.93 with narrower CI intervals for the neutral position. These findings are consistent with the assessors' observations of when the tendon is most visible and easily identifiable. The pattern of difference of excursions found between wrist positions is also consistent with the available cadaver measures. It is acknowledged that overall there were fewer good quality video images collected for the flexion and extension positions. Therefore there was slightly less data for analysis as these did not meet the criteria. Other observations made during testing were that the EPB tendon, when the wrist was flexed, appeared to translate beneath the APL tendon during motion, suggestive of three-dimensional movement in the posterior-anterior direction. In some cases, in each of the wrist positions, EPB was observed to move out of the transducer field completely. In both these aforementioned cases, video recordings were not utilised for data analysis.

Within-session intra-rater reliability was found to be higher than between-sessions intra-rater reliability, when all data was analysed. The within-session ICC results were considered good-excellent, ranging from 0.80 to 0.91, except for the slightly lower value for the wrist flexion position. This ICC value of 0.73 is still considered to be acceptable and explanations for this have been offered. The methods described in this current study can be considered a reliable means of measuring tendon excursion, as they have for EPL measurement (M. Chen, et al., 2009) and longitudinal nerve excursion analyses (Coppieters, et al., 2009; Dilley, et al., 2003; Ellis, et al., 2008). There was no bias as the

assessor was blind to the first session data that was taken, and standard procedures and settings were strictly adhered to. Measurement error was found to be low, indicating that relatively small differences could be detected reliably. This method of measuring tendon excursion could be useful in research and in clinical evaluation. USI equipment is relatively inexpensive and easily accessible, compared to other imaging technologies. A high level of anatomical knowledge of the area under examination, together with examiner experience and practice, would improve reliability and the assessor in our study was considered to have these attributes. Conclusions on the reliability of these test measures are drawn from this experimental, single-assessor design, and for intra-rater testing, however it would be of value to look further at inter-rater reliability. It is important to recognise that a technique is reliable in the hands of a particular investigator over time (Rankin & Stokes, 1998). Inter-rater reliability measures may therefore prove to be quite different and warrant investigation.

USI and a cross-correlation method could be utilised to examine longitudinal tendon motion in diseased or pathological states. A better understanding of tendon behaviour, function and healing, may allow specific treatment strategies to be developed (Sharma & Maffulli, 2005); for example, when positioning joints when splinting to rest structures, or in muscle re-education and training. Greater knowledge of the tendons behaviour gained utilising these assessment methods throughout a pathological episode, may provide more timely and effective treatment strategies. Subsequently, this may reduce the need for further invasive medical techniques, lengthy rehabilitation periods and surgery. Therefore, these methods could offer considerable savings in health costs. They could also be used in a prognostic capacity in professions and sports where the thumb tendons are significantly loaded, as well as in prevention of disorders and pathologies. The visualisation and assessment of three-dimensional tendon movement utilising USI, would be of interest and on the next level of experimental analyses.

6.2 Interpretation of Excursion Findings

To the authors knowledge there has been no other study that has examined EPB behaviour *in vivo*. The results for excursion in this current study were significantly less than expected, based on previous cadaver findings, as well as on tissue motion, observed during scanning. When the wrist was in neutral, there was significantly greater tendon excursion than when the wrist was flexed and extended at 45°.

The amount of excursion in the neutral wrist position (mean 2.78mm±1.89mm) that was found at the distal end of the radius during thumb motion, through full extension–flexion range, is considerably less than *in vitro* results found by Kutsumi, Amadio, Zhao, Zobitz and An (2005), and formerly by Boyes (1970). These authors respectively state that EPB moved 15mm and 14mm at the wrist, through full thumb motion. Boyes (1970) and Law et al. (1989) state that 7mm occurs at metacarpal level. The average total active range of movement for the population in this thesis during composite thumb flexion was 170.4°; the average MCP joint motion was 49.7°. Smutz et al. (1998) examined moment arms of EPB through 60° of MCP joint motion but unfortunately did not publish measures of tendon excursion over the MCP joint. Therefore no comparisons were able to be made.

What has been determined, however, is that wrist position alters the excursion of EPB during thumb motion in normal subjects. Our results found that wrist flexion produced the least amount of EPB excursion (mean=1.62mm±1.4mm), which represented a similar pattern to that found by Kutsumi, Amadio, Zhao, Zobitz and An (2005), who found that wrist flexion at 60° produced both the least amount of excursion and the greatest amount of gliding resistance. In both this current study and that of Kutsumi, Amadio, Zhao, Zobitz and An (2005), the neutral wrist position determined greater EPB excursion than the other positions, and in both studies these findings were statistically significant ($p<0.05$). It is recognised that there were different degrees of flexion and extension under examination in each study; 45° in this current study and 30° and 60° degrees in the study by Kutsumi, Amadio, Zhao, Zobitz and An (2005).

The pattern of results and the large *in vivo* versus *in vitro* differences in excursion measures can be likened to those found by Chen, M. et al. (2009) in their study of EPL excursion using the same methodology. Proportionally, EPB excursion differences were greater than those found for EPL, but both were significant. The large differences between *in vivo* EPB excursion measures found in this thesis, and the *in vitro* data from Boyes (1970) and Kutsumi, Amadio, Zhao, Zobitz and An (2005), could be accounted for by a number of factors. These include: the difference in *in vivo* and *in vitro* tissue properties, the loss of viscoelastic properties in cadavers, the level of tissue dissection to reveal tendons, differences in age of subjects (mean 40.7 yrs) and aged cadavers, the restriction of wrist ulnar deviation during testing, agonist and antagonistic muscle tensions, eccentric EPB muscle action, conscious execution of new/altered motor pattern required for the testing and finally, tendon strain.

In live tissue, fluids are present interstitially within the extracellular matrix to differing degrees in different connective tissue. Hyaluronan is a type of proteoglycan and is particularly important because it readily entrains large amounts of water and is present in hydrated soft, loose tissues where repeated movement is required, for example in tendons, sheaths and bursae (Culav, Clarke, & Merrilees, 1999). It allows fibres to move past each other and this gliding is vital for tissue extensibility (Cyr & Ross, 1998). The mechanical ability of tissues to resist tensions, torsions, compressions and extensibility depends on the matrix composition, and according to Culav et al. (1999), there is now good evidence to show that the maintenance of normal tissue architecture actually requires normal physiological mechanical loading. In other words connective tissue responds to change and applied stresses by altering the proteoglycan content, and this phenomenon cannot occur in cadaver tissue. It has previously been identified that one of the primary limitations in tissue motion studies in cadavers is the level of desiccation of the tissue. Other factors that may contribute to the degree of desiccation are: the age of the cadavers, the amount the specimens have been utilised and the amount of fibre damage (Kutsumi, Amadio, Zhao, Zobitz, & An, 2005; Maganaris et al., 2004). In addition, the level of dissection that occurs in the laboratory needs to be

considered as well as the types and amount of moisturising fluids applied during test procedures. Boyes (1970) and Kutsumi, Amadio, Zhao, Zobitz and An (2005) all report utilisation of aged cadavers.

Subjects in this current study were required to actively flex their thumb through to end range and it was emphasised that the there should be no discomfort experienced throughout the procedure. The author is confident that no excessive forces were applied, that the tendons were not over-stretched, and is satisfied that full thumb flexion was still obtained. Brand (1995) discusses the ability of living cells to respond to forces and stresses, and addresses not only viscous properties of tissues, but also their elastic properties (Brand, 1995). He describes the ability to maximise elasticity in cadavers that is, fully stretching a tissue to its limits, and compares this with normal responses in living tissue. Excessive force will produce responses such as tissue trauma, redness, inflammation and pain (Brand, 1995). It is recognised that different tissues possess different viscoelastic properties such as force-relaxation, hysteresis and creep, and that the point of tissue failure, or deformation of tendons, as well as being time-dependent, differs in live and cadaver tissue (Maganaris et al., (2004). Viscoelastic differences and tendon stiffness are therefore possible explanations for the large discrepancies in EPB excursion measures under review.

It is acknowledged however, that by restricting wrist ulnar deviation in this methodological set-up, that full, active excursion of EPB may not have been reached. This is another possible reason for the reduced excursion values observed, compared with the cadaver values. Wrist ulnar deviation is a natural movement involved in grip and grasp functions and is physiologically present even at rest (Tubiana, et al., 1996). Methodological problems, with respect to the restriction of ulnar deviation of the wrist, were first encountered during piloting. The primary problem was that the subjects' wrists often had a tendency to deviate out of the splint construct, hence the need to maintain stability of the ulnar styloid. It will be recommended that further *in vivo* studies be carried out that will include wrist ulnar deviation in the assessment of EPB tendon movement.

Thumb motion requested of the subjects was simple, from full extension to full flexion. It was noted that subjects in the main, executed a purposeful intent to perform the movement correctly, as instructed. The conscious control and relatively slow speed of motion involved, could have led to abnormal balance of agonist versus antagonistic tensions. It is well-known that reciprocal innervation of agonist and antagonist muscle groups occurs during movement. The triphasic EMG pattern is well documented in representing a basic neuromotor control strategy for rapid limb movements (Wickham, Brown, Green, & McAndrew, 2004). It is characterised by two bursts from the agonist muscle/s that are separated by a silent period, and a one burst pattern at some point in between these two bursts from the antagonist. Experimenters are now finding varying patterns of tensions using more EMG points within the antagonist muscle groups and temporal factors play a significant role in these resultant patterns (Wickham, et al., 2004). Speed of motion could therefore have affected normal muscle tensions and normal viscoelastic properties. EPB tensions were not measured in this current study, but were considered to be kept minimal. Interference of normal full thumb and wrist motion, and a subsequent change in tensions, are therefore also considered to be possible reasons for the smaller *in vivo* measures recorded.

The integration of higher motor control centres and peripheral mechanisms in the execution of motion are also considered in explaining the differences in motion *in vivo*. Hierarchically, organised pattern generation and motor control are features of neural networks and viscoelastic properties of the neuromuscular systems (Tresilian, 1999). In other words, the higher cortical control of normal thumb movement is integrated with lower control mechanisms, and in this experiment a new, abnormal movement pattern was acquired, potentially rendering abnormal muscle tensions to be developed.

The findings by Kutsumi, Amadio, Zhao, Zobitz and An (2005) *in vitro,* of least excursion and greatest gliding resistance of EPB in wrist flexion, are important to consider for *in vivo* tissue. If there is an inverse correlation between excursion and gliding resistance *in vivo*, then wrist movement away from the neutral position, together with thumb motion, could have negative biomechanical effects on the tendon and its surrounding structures. These

changes in effect, with or without repetition and loading, could be responsible for pathological changes in the tendon, its surrounding tissue and/or the muscle, such as in deQuervains disorder. The theory would support the mechanical influence of joint position change and force/frictions, as possible aetiogenesis in this pathology.

This current study only examined the movement of the EPB in one plane of motion and under minimal stress conditions of simple active movement, that is, under no additional loading. The knowledge gained however, is important in the therapeutic treatment and management of disorders such as deQuervains disorder. The effect of wrist position on EPB tendon excursion could influence the selection of splint postures and joint angle positioning. If treatment goals are to encourage tendon excursion, then a neutral wrist would be the position of choice when moving the thumb. On the other hand, if the desired treatment objective is to restrict EPB motion, then an extended or flexed wrist position might be the position of choice.

The information gained so far with respect to wrist angles and EPB excursion, could also be applied to the management of surgically repaired EPB tendons in the post-operative period, such as during an active motion protocol. In the early post-operative period, when a small amount of excursion is desired, then a flexed or extended wrist position would be selected for thumb motion. Theoretically, as tendon healing advances and greater gliding warranted, then a neutral wrist position allowing greater excursion would be advocated. No conclusion can be drawn from this study about the influence of wrist position on strain or gliding resistance of the tendon, and further studies are recommended to investigate these properties.

The quantitative values gained could be relevant to hand surgeons considering utilising EPB as a donor in tendon transfer and reconstructive surgery. The *in vivo* measures of EPB excursion differ significantly from the *in vitro* measures published by Boyes (1970), and although EPB is not commonly used for tendon transfer, this new data may be important with regards to the extent to which it can be re-routed and utilised.

Consideration of ‘strain’ of the tendons in the wrist positions of flexion and extension, and the three-dimensional variations on USI observation, could support a hypothesis that the EPB tendon is pulling dorsally or volarly, against the retinaculum during wrist and thumb motion. The greater amount of EPB excursion found when the wrist is in neutral suggests a smoother, freer execution of motion. The theory of EPB compression over the distal end of the radius, reproducing pain during the Finkelstein’s test, is valid, and it has been suggested that the motion of wrist ulnar deviation and thumb flexion combined, are precipitating motions in the aetiopathogenesis of deQuervains disorder (Kutsumi, Amadio, Zhao, Zobitz, Tanaka, et al., 2005). The results of this current study do not directly support the theory that the mechanics of EPB motion in any of the wrist positions contribute to deQuervains disorder, but allow us to consider some biomechanical possibilities such as the proposed increased friction theory presented by An (2007) and Kutsumi, Amadio, Zhao, Zobitz and An. (2005). Clinical reports of pain during the motion of wrist ulnar deviation and thumb flexion are consistent with Finkelstein’s testing. Patients with deQuervains disorder report pain with activities such as peeling vegetables and putting on a bra, which involve wrist flexion and thumb activity. This current study has demonstrated that less excursion occurs *in vivo* in wrist flexion, than in neutral. An association between excursion and strain should be sought in the future.

6.3.2 Age and Tendon Excursion

The significant relationship between aging and loss of tendon excursion, found in this current study, is consistent with previous findings regarding changes in tendon properties with aging (Narici, Maffulli, & Maganaris, 2008). Narici et al. (2008) state that with aging there is progressive loss of mobility and muscle weakness, and although the molecular and cellular changes are not fully understood, alterations in tendon properties such as collagenous structures and loss of glide, contribute to muscle weakness. A higher incidence of tendinopathies in older age-groups is well documented and consistent with the deQuervains disorder and its prevalence in the fourth and fifth decades (Moore, 1997). There are reported inconsistencies in the literature amongst studies that have tried to characterise the effect of age on the mechanical properties of

tendons, and these inconsistencies are thought to be due mainly to the population age-groups considered (Narici, et al., 2008). Kjaer, et al. (2009) suggested that a correlation between gender and tendon regeneration existed and that females have less ability to regenerate after injury.

Our findings found an inverse correlation between age and EPB excursion and identified an associated correlation between excursion and TAROM. Consideration is therefore warranted as to whether it is reduced range of joint motion, or tendon stiffness that leads to reduced tendon excursion.

6.4 Limitations and Recommendations

The primary limitation of this study is that the results, although relevant and informative, are specific to a normal population and provide us with baseline data on the EPB tendon. Further study involving a pathological population is required to determine the tendon behaviour in a pathological state and to compare values of normal versus a symptomatic cohort. In addition, tendon motion analyses, throughout the stages of a disease process in affected wrists, may provide valuable information about tendon changes and even predict or predetermine the course of the disease.

It would be of value to further examine *in vivo* 'strain' of the EPB and APL tendons through the retinaculum; similar to the measure of *in vitro* 'gliding resistance' investigated by Kutsumi, Amadio, Zhao, Zobitz and An (2005). This may be the next level of assessment of tendon behaviour using USI and cross-correlation methods, before examining a study population with deQuervains disorder.

Furthermore, a study of strain involving tendons of the first dorsal compartment, with different wrist positions would be a significant step in understanding forces that may precipitate disease state. Studies that involve tendon motion with strain analyses, in loaded and unloaded states are recommended. Consideration of utilising EMG, as well as assessing heat in the tissues, may

supplement USI methods. Elastography may be a useful imaging tool in providing additional information on tendon characteristics during motion.

Another limitation of this study is the lack of information available about the compartmental anatomical arrangement. It would be of interest to investigate the *in vivo* behaviour of APL in isolation, as well as its dynamic relationship with EPB, particularly during thumb and wrist activity. Further study involving observation and assessment of septal divisions in relation to tendon movement, is recommended using USI.

Limitation of joint movement in this study, not only include the lack of wrist ulnar deviation, but also the restriction of forearm rotation to a neutral position only. These variables warrant inclusion in further studies of tendon excursion. Exploring tendon excursions during normal, composite, wrist and thumb motions, that resemble normal functional patterns, would be valuable.

This study looked at active tendon motion *in vivo* and demonstrated a significant difference than in the *in vitro* works. Recommendations would be to further study the amount of *in vivo* passive tendon motion, and compare directly with *in vitro* results.

It is understood that muscle and tendon interaction is much more complex than this current study encompasses. Further study involving EPB muscle properties and behaviour may further define and enhance understanding about tendon disorders, particularly in relation to age and disease status.

The potential for greater use of EPB as a tendon donor in reconstructive surgery may be supplemented by the *in vivo* data now produced. Since USI and a cross-correlation algorithm have been shown to be reliable methods in measuring tendon excursion, then there is potential for utilisation in any tendon analysis. Published results listed in relevant texts of *in vivo* tendon excursion, as well as the *in vitro* data, would be of value to surgeons faced with rebalancing techniques following peripheral nerve palsies, as well as multi-trauma events and salvage procedures. Additionally, it would also be of value in the development of tendon rehabilitation principles and protocols.

CHAPTER SEVEN – CONCLUSION

This study has provided reliable, baseline, quantitative data on EPB tendon excursion *in vivo*. It is the first study known to analyse EPB tendon behaviour *in vivo,* and the second study to utilise the cross-correlation algorithm for tendon analyses. It rejects the null hypotheses that there is no difference in EPB tendon excursion at the wrist, in different wrist positions, and that the methods of USI and a cross-correlation algorithm are not a reliable means of measuring longitudinal motion. The results are for a normal adult population, but provide information for further comparative studies involving EPB, both in normal and diseased states. The methodology will be useful for tendon excursion and motion analyses in general, as well as in relation to EPB. Limitations of this study have been discussed and reference made to further study. Clinically the study is relevant for surgeons and therapists who work with the hand and upper limb, as well as for researchers in the medical and rehabilitation domains.

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GLOSSARY

- ALS juncture- APL-Lister's-Scaphoid juncture
- AP- Anteroposterior
- APL- Abductor Pollicis Longus
- ASHT- American Society of Hand Therapists
- CI - Confidence Intervals
- CMC - Carpometacarpal
- CT- Computerized Topography
- CTS - Carpal Tunnel Syndrome
- ECRB - Extensor Carpi Radialis Brevis
- ECRL - Extensor Carpi Radialis Longus
- EI - Extensor Indices
- EMG - Electromyography
- EPB - Extensor Pollicis Brevis
- EPL - Extensor Pollicis Longus
- ER - Extensor Retinaculum
- FCR - Flexor Carpi Radialis
- ICC - Intraclass Correlation Coefficient
- IP - Interphalangeal
- MCP - Metacarpophalangeal
- MDC - Minimal Detectable Change
- MRI - Magnetic Resonance Imaging
- PC - Popliteal Crease
- PL - Palmaris Longus
- PMT - Posterior Mid-Thigh
- SCT- Subcutaneous Tissue
- SEM - Standard Error of Measurement
- SRD - Smallest Real Difference
- USI - Ultrasound Imaging

APPENDICES

Appendix A: Information Sheet

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Participant Information Sheet

Project Title:

An analysis of Extensor Pollicis Brevis (EPB) tendon excursion (movement) in different wrist positions in normal healthy subjects.

Date Information Sheet Produced: 24th Sept 2009

Invitation

My name is Edel Kelly and I am a practising Physiotherapist who specializes in Hand Therapy. I am very interested in study and research involving the hand and wrist, to gain a better understanding of certain clinical problems. You are invited to take part in a research study for attainment of my Masters Degree in Health Science. Information from this research will be published as a research paper and may also be presented within academic publications or verbal presentations.

Participation is completely voluntary and you may withdraw from the study at anytime without giving a reason or being disadvantaged.

What is the purpose of this research?

The aim of the research is

1. To assess the reliability of measuring tendon motion of the forearm using Diagnostic Ultrasound Imaging.
2. To assess the effect of wrist position on Extensor Pollicis Brevis tendon movement at the wrist.

How are people chosen to be asked to be part of this research?

If you have normal wrists you are invited to volunteer to take part in the study. Note that if you have experienced any of the following conditions, you will be excluded from the study: previous fractures of the radius, scaphoid or thumb bones, inflammatory and degenerative arthritic conditions, endocrinological and neurological conditions, surgery to the wrist or thumb, previous deQuervains tenosynovitis.

What happens in this research?

You will be asked to sit on the chair whilst Ultrasound images of the tendon at your wrist are taken with your wrist in 3 different positions. A water based gel will be applied to your skin and the Ultrasound probe then positioned over the tendon being examined. Some motion of the probe on your skin is required until a clear image of the tendon is seen on the screen.

Firstly you will be asked to move your thumb from a fully extended position to a fully flexed position in each of the wrist positions. You will be asked to repeat this 4-5 times. Each movement only lasts 3 seconds. The images recorded on the monitor can then be analysed and calculations made.

What are the discomforts and risks?

There are no risks or discomfort from the ultrasound scanning. The transmission gel is water-based thus precluding an allergic reaction. I will endeavour to perform the procedure without eliciting pain or discomfort.

What are the benefits?

The benefit of performing this research is to identify the characteristics of the tendons behaviour at the wrist and ultimately the results would provide unique and important information regarding the causes and treatment of certain pathologies of the tendons.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

Your privacy will be protected by identifying you only by a number. Access to the data is restricted to myself and my supervisor.

What are the costs of participating in this research?

There is no monetary cost. It will however cost approximately 1 hour of your time in total.

What opportunity do I have to consider this invitation?

Before volunteering, please consider carefully whether you are prepared to be part of the study. Any students with whom I have or have had a supervisory relationship will be excluded from this study. There will be some flexibility around the appointment times for the data collection. Please communicate clearly with me so convenience is optimised for all concerned, and appointments run smoothly and are on time.

How do I agree to participate in this research?

You will need to read the Consent Form and sign this in order to consent to and participate in this study. A consent form can be obtained from myself (see contact details below).

Please contact me if you wish to join this study. You will be contacted prior to the start of data collection which is scheduled for May2010. This may be subject to some change.

Will I receive feedback on the results of this research?

Results will be made available to you at the completion of the study, and will be in the form of a written summary. If you wish to receive this, please indicate on the relevant section of the consent form. Any papers that may be published arising from the research can be accessed on request.

What do I do if I have concerns about this research?

If you have any concerns regarding the nature of this project then you should contact me,

Edel Kelly 921-9999 ext 6624.

Any concerns regarding the conduct of the research should be made to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz , 921 9999 ext 8044.

Who do I contact for further information about this research?

Researcher Contact Details: Edel Kelly: 921-9999 ext 6624 or 0211458279

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEC Reference number *type the reference number*.

Appendix B: Consent Form

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Consent to Participation in Research

Title of Project:

An analysis of Extensor Pollicis Brevis (EPB) tendon excursion in different wrist positions in normal healthy subjects.

Researcher: Edel Kelly

- I have read and understood the information provided about this research project (Information Sheet dated September 2009)
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- If I withdraw, I understand that all relevant data, or parts thereof, will be destroyed.
- I agree to take part in this research.
- I wish to receive a copy of the report from the research: tick one: Yes O No O

Participant signature: .....……..

Participant name: …….

Participant Contact Details (if appropriate):

……..

Date:

Approved by the Auckland University of Technology Ethics Committee on 20th January 2010 AUTEC Reference number 09/255 Note: The Participant should retain a copy of this form.

Appendix C: Subject Instruction

Subject Instructions

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

1. Hold your thumb in a fully extended position

2. After a count of 3, bend your thumb slowly across you palm towards the base of your little finger.

3. This movement should be smooth, taking 3 seconds to complete.

4. Do not try and overstrain your thumb at the limits of the movement

5. Try to keep your wrist stable and in contact with the blu-tac attached to the device

6. The movement will be repeated 5 times in each of the 3 wrist positions

7. Please let me know if you experience any discomfort.

Appendix D: Ethics Approval

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To:	Wayne Hing
From:	**Madeline Banda** Executive Secretary, AUTEC
Date:	20 January 2010
Subject:	Ethics Application Number 09/255 **An analysis of Extensor Pollicis Brevis (EPB) tendon excursions in different wrist positions in normal healthy subjects.**

Dear Wayne

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 9 November 2009 and that I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 8 February 2010.

Your ethics application is approved for a period of three years until 20 January 2013.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/research/research-ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 20 January 2013;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/research/research-ethics. This report is to be submitted either when the approval expires on 20 January 2013 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.
When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.
On behalf of the AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.
Yours sincerely

Madeline Banda
Executive Secretary
Auckland University of Technology Ethics Committee
Cc: Edel Kelly edkelly@aut.ac.nz, Richard Ellis