

Reliability of crural fascia and Achilles tendon excursion using ultrasound imaging: A pilot study

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Declaration

Name of candidate: Elaine Davies

This Thesis entitled: Reliability of crural fascia and Achilles tendon excursion using ultrasound imaging: A pilot study. Is submitted in partial fulfillment for the requirements for the Unitec degree of Master of Osteopathy.

Candidate's declaration

I confirm that:

- This Thesis/Dissertation/Research Project represents my own work;
- The contribution of supervisors and others to this work was consistent with the Unitec Regulations and Policies.
- Research for this work has been conducted in accordance with the Unitec Research Ethics Committee Policy and Procedures, and has fulfilled any requirements set for this project by the Unitec Research Ethics Committee.

Research Ethics Committee Approval Number: 2012-1089

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Table of Contents

Declaration	2
Acknowledgements	3
Table of Contents	4
Abbreviations	8
Introduction to Thesis	9
SECTION I – Literature Review	11
1. Structure of the literature review	12
2. Literature Search	12
3. Anatomy	12
3.1 Anatomy of the posterior calf and ankle	12
3.2 Overview of fascia, including anatomy and dysfunction	13
3.2.1 Definitions of fascia	13
3.2.2 Anatomy of fascia	13
3.2.3 Crural fascia	14
3.2.4 Fascial restriction	15
3.2.5 Manual therapy to treat fascial restrictions	16
3.3 Achilles tendon	17
3.3.1 Achilles tendon anatomy	17
3.3.2 Paratenon	17
3.3.3 Achilles tendon injuries	18
3.3.4 Achilles tendinopathy	19
3.3.5 Achilles tendon rupture	20
4. Ultrasound imaging	21
4.1 Principles of Ultrasound imaging	21
4.1.1 Principles of ultrasound imaging	21
4.1.2 Ultrasound imaging techniques	21
4.1.3 Ultrasound imaging of the ankle	22
4.1.4 Ultrasound imaging of the Achilles tendon	22
4.2 Tendon and Connective Tissue Excursion	23
4.2.1 Tendon excursion and gliding	23
4.2.2 Measurement techniques for tracking tissue excursion using ultrasound imaging	23
4.2.3 Achilles tendon excursion	24

4.2.4 Triceps surae aponeurosis excursion	30
4.2.5 Fascial sliding.....	30
4.3 Ultrasound imaging and a frame-by-frame cross-correlation algorithm to measure tissue excursion.....	32
4.3.1 Ultrasound imaging and a frame-by-frame cross-correlation algorithm to assess nerve excursion	32
4.3.2 Ultrasound imaging and a frame-by-frame cross-correlation algorithm to assess tendon excursion	36
4.3.3 Ultrasound imaging of fascial excursion and sliding	36
5. Ankle Range of Motion	37
5.1 Ankle range of motion normative values	37
5.1.1 Normal and abnormal dorsiflexion ranges.....	37
5.1.2 Normal and abnormal plantarflexion ranges	38
5.2 Importance of adequate ankle range of motion	38
5.2.1 Functional movements requiring adequate ankle range of motion	38
5.2.2 Health conditions predisposed by limited ankle dorsiflexion	39
5.3 Anatomical structures associated with decreased ankle range of motion	39
5.3.1 Anatomical structures associated with limited ankle dorsiflexion range of motion	39
5.3.2 Anatomical structures associated with decreased ankle plantarflexion range of motion	40
5.4 Measures of ankle dorsiflexion and plantarflexion range of motion	40
5.4.1 Weight-bearing lunge test.....	41
5.4.2 Electrogoniometry to measure ankle range of motion.....	41
5.5 Myofascial interventions effecting ankle joint range of motion	42
6. Rationale for proposed study	43
References	44
SECTION II – Manuscript	60
Abstract	62
Introduction.....	63
Methods.....	66
Experimental approach to the problem	66
Study Design.....	66
Participants.....	67
Measures	67
Ultrasound Parameters and Imaging	67

ROM measures	67
Procedure	68
Identification of scanning point	68
Active and passive movement during USI	68
Ankle ROM measurement protocol	69
Data Analysis.....	71
Selection of videos	71
Cross-correlation algorithm for measurement of tissue excursion	71
Reliability of extracting excursion measurement from cine-loops	72
Statistical analysis.....	73
Results.....	74
Descriptive Statistics.....	74
Extraction Reliability of CF and AT excursion	74
AT excursion	74
Magnitude of AT excursion, SEM and MDC	74
Intra- and Inter-Session Reliability of USI assessment of AT excursion	75
Ankle ROM.....	75
Correlation between AT excursion and ankle ROM	76
Discussion	77
Overview	77
Participants.....	77
Extraction Reliability.....	77
CF and AT extraction reliability	78
Magnitude of AT excursion.....	79
Intra-session versus Inter-session reliability	80
Interpretation of ICC values	80
Identification of the scanning location.....	80
Inherent challenges in imaging active versus passive movement	81
Interpretation of the SEM and MDC.....	82
Correlation between AT excursion and ankle ROM	82
Recommendations.....	82
Clinical Implications	83
Conclusion	84
References	85
Supplementary Data	93

SECTION III - Appendices	94
Appendix A – Participant descriptive statistics	95
Appendix B – Extraction Reliability for the crural fascia and Achilles tendon.....	96
Appendix C – Pooled excursion data for each participant	97
Appendix D – Magnitude of tissue excursion for AT movement, SF movement, and Relative movement of the AT.....	98
Appendix E – SD-pooled, SEM and MDC for AT excursion	99
Appendix F – Ankle range of motion and p-values for paired differences.....	100
Appendix G – Ethics Documentation	101
Appendix H – Journal of Bodywork and Movement Therapies Guide for Authors.....	107

Abbreviations

AT – Achilles tendon

CI – confidence interval

CF – crural fascia

ICC – intraclass correlation coefficients

MDC – minimal detectable change

MG – medial gastrocnemius

ROI – region of interest

ROM – range of motion

SD – standard deviation

SF – subcutaneous fat

SEM – standard error of measurement

TOI – tissue of interest

USI – ultrasound imaging

WBLT – weight-bearing lunge test

Introduction to Thesis

There has been emergent interest in fascia over the past decade, with many studies investigating this tissue (Findley, 2012; Schleip, Jager, & Klingler, 2012; Stecco, Macchi, Porzionato, Duparc, & De Caro, 2011). Recently, interest has begun focusing on investigating the role of connective tissue (eg tendon, fascia) gliding and sliding in accommodating movements and in understanding the potential role this may have in dysfunction (Chaitow, 2014). Although studies have investigated the role of fascial sliding in tendon gliding at the wrist (Guimberteau, Delage, & Wong, 2010), no studies to date have investigated the role of fascial sliding in the crural fascia (CF) of the posterior leg and Achilles tendon (AT) gliding. Furthermore, no studies have quantified the magnitude of excursion that occurs in the CF during ankle movement. Based on clinical anecdotes there may be a relationship between myofascial tissue excursion and ankle range of motion (ROM) (Starrett, 2011). There is extensive literature surrounding AT properties *in vivo* (eg biomechanics, tendon elongation, tendon stiffness, tendon pathology), however, few studies have investigated AT excursion *in vivo* with ultrasound imaging (USI) (Arndt, Bengtsson, Peolsson, Thorstensson, & Movin, 2012; Lee, Lewis, & Piazza, 2008; Pearson, Ritchings, & Mohamed, 2013). In this thesis, high-resolution-ultrasound imaging and frame-by-frame cross-correlation methods were used to investigate the excursion of connective tissues within the posterior leg, the AT and the CF.

Clarification of terminology in this thesis

Within the literature there are several terms used to describe tissue movement, therefore, clarification of terminology used in this thesis to describe tissue movement is required. Tendon excursion refers to the distance the tendon travels when the muscle contracts and the joint rotates (An, 2007). Displacement is also used in the literature to refer to the amount of tissue movement that has occurred. The terms 'excursion' and 'displacement' appear to have been used interchangeably in the literature, with reference to the magnitude of tissue movement. In contrast to 'excursion' and 'displacement', the terms 'gliding' and 'sliding' are generally used to address quality of tissue movement; where authors studying tendon use the term 'gliding', and those studying fascia use 'sliding'. For example, tendons must glide within their synovial sheaths in order to facilitate excursion, and resistance in gliding may negatively impact the magnitude of excursion. This thesis will use 'gliding' in reference to tendons and 'sliding' in reference to fascia. Unless otherwise stated, this thesis will use 'excursion' to refer to magnitude of tissue movement, and 'displacement' if a study has used this term. These terms are used this way throughout the thesis.

Organisation of thesis

This thesis is comprised of three sections. Section I is the Literature Review, which explores and reviews the literature relevant to this thesis, and provides the theoretical basis and rationale for the study reported in the manuscript. Section II is the Manuscript reporting a study that investigated the reliability of measuring CF and AT excursion using high-resolution USI and a cross-correlation method. The manuscript is in the format specified for submission to the *Journal of Bodywork and Movement Therapies* EXCEPTIONS to their guidelines = length and formatting requirements for ease of reading for the purposes of this thesis. Section III contains the Appendices, providing ethics documentation, and other additional information pertaining to reliability and excursion analyses.

SECTION I – Literature Review

1. Structure of the literature review

The purpose of this literature review is to rationalise and justify the methodology chosen for this research. First it will provide a description of the properties and current literature relating to fascia; outline anatomical characteristics of the crural fascia (CF) and Achilles tendon (AT); and discuss AT injuries, in particular, Achilles tendinopathy and AT ruptures. The following section will review the methodologies used to examine tissue excursion with ultrasound imaging (USI); it will discuss nerve, tendon and connective tissue excursion. Finally, it will provide an analysis of the literature around the importance of adequate ankle range of motion (ROM) and discuss measurement of ankle ROM.

2. Literature Search

Searches were conducted through the Scopus and EBSCO health databases, specifically searching within Academic Search Complete, AMED - The Allied and Complementary Medicine Database, CINAHL with Full Text, Health Source: Nursing/Academic Edition, MEDLINE with Full Text, and SPORTDiscus with Full Text. Keywords used in various combinations included: fascia*, myofascia*, "crural fascia", ankle, "Achilles tendon", paraten*, excursion, slid*, glid*, movement, displacement, "sliding surfaces", dysfunction*, tendinopathy, dorsiflexion, plantarflexion, "range of motion," ultrasound, sonography, osteopath*, physio*, "manual therapy," "physical therapy," manipul*, treat*, intervention, therap*. Additionally, relevant articles retrieved from these keyword searches containing useful references were identified and individually retrieved.

3. Anatomy

3.1 Anatomy of the posterior calf and ankle

Drake, Vogyl and Adam (2005) describe the ankle, or talocrural joint, as a synovial, uniaxial joint involving the talus of the foot, and the distal tibia and fibula of the leg, allowing dorsiflexion and plantarflexion ROM. Hertel (2002) lists the talocrural, subtalar and distal tibiofibular syndesmosis as the three joints making up the ankle complex; these work together to create rearfoot motion, occurring in the sagittal plane (dorsiflexion-plantarflexion), frontal plane (eversion-inversion) and transverse plane (internal and external rotation). The gastrocnemius and soleus muscles, or triceps surae group, meet at the musculo-tendinous junction to form the AT and act as the primary plantarflexors of the ankle (Joseph, Lillie, Bergeron, & Denegar, 2012; O'Brien, 2005; Wijesekera, Calder, & Lee, 2011). These muscles are found in the superficial posterior compartment of the leg and have connections with the crural fascia (Stecco et al., 2009).

3.2 Overview of fascia, including anatomy and dysfunction

3.2.1 Definitions of fascia

According to Schleip, Jäger and Klingler (2012) there are many definitions of fascia, and the divergence in terminology has contributed to confusion within the field. Schleip et al. (2012) reviewed the three most common nomenclatures used: the Federative International Committee on Anatomical Terminology; the latest edition of Gray's Anatomy; and the terminology suggested at the last international Fascia Research Congress (FRC) in 2012, which Schleip et al. (2012) view as a more comprehensive definition. The FRC defines fascia as "fibrous collagenous tissues which are part of a body wide tensional force transmission system" and includes the following tissues within the scope of fascia: aponeuroses, ligaments, tendons, retinaculae, joint capsules, septa, intermuscular fibres of the myofascia, endomysium, superficial fascia organ and vessel tunics, dura mater, periosteum, perineurium, and annulus fibrosis of vertebral discs (Schleip et al., 2012). Langevin and Huijing (2009) recommend using twelve specific terms when describing fascial tissues: dense connective tissues, non-dense connective tissues, superficial fascia, deep fascia, intermuscular septa, interosseal membrane, periost, neurovascular tract, epimysium, intramuscular and extramuscular aponeurosis, perimysium, endomysium. Schleip et al. (2012) views this interconnected fascial system as a 'fascial net' or 'tensional network' that may have clinical relevance to musculoskeletal dysfunction.

3.2.2 Anatomy of fascia

Fascia is connective tissue composed primarily of collagen and elastic fibres; it provides continuity and connects anatomical structures within the body (Chaudhry et al., 2008; Schleip, 2003; Schleip, Klingler, & Lehmann-Horn, 2005; Schwind, 2006). The parallel collagen bundles and elastic laminae provide high tensile strength and elasticity to the tissue (McCombe, Brown, Slavin, & Morrison, 2001). Three connective layers make up fascia: the superficial fascia, the deep fascia, and the epi-, peri- and endo-mysium or muscle related layers (Findley, Chaudhry, Stecco, & Roman, 2012; C. Stecco, V. Macchi, et al., 2011). The recommended definitions from Langevin and Huijing (2009) for various fascial structures, defines the superficial fascia as the "enveloping layer directly beneath the skin containing dense and areolar connective tissue and fat" (p.5); while the deep fascia is defined as a "continuous sheet of mostly dense, irregularly arranged connective tissue that limits the changes in shape of underlying tissues. Deep fasciae may be continuous with epimysium and intermuscular septa and may also contain layers of areolar connective tissue" (p.5). In the limbs, the deep fascia is formed by two or three layers of parallel collagen fibre bundles, each separated by a thin layer of loose connective tissue (LCT) which allows the layers to slide over each other (C. Stecco, V. Macchi, et al., 2011).

Drawing on data from a porcine model, McCombe et al. (2001) describe the deep fascia and underlying muscle as forming a gliding interface, allowing the muscle to move freely underneath. Additionally, McCombe et al. (2001) describe the presence of hyaluronic acid concentrated on the inner surface of the deep fascia; this hyaluronic acid is thought to act as a lubricant and facilitate gliding. When the deep fascia is disrupted scar tissue may form spanning the fascial layers and limiting gliding movement between them (McCombe et al., 2001). More recently, Stecco et al. (2011) performed a histochemical (n=3 cadavers) and ultrasonography (n=22 participants) study to examine the LCT of the deep fascia and the presence of hyaluronic acid within these layers. Stecco et al. (2011) demonstrated the LCT layer between the deep fascia and underlying muscle, as well as, the sublayers of the deep fascia are rich in hyaluronic acid, which plays a role in the sliding between fascial layers and muscle.

3.2.3 Crural fascia

The crural fascia (CF) is located in the posterior region of the leg and is often simply described as the superficial and deep fascia of the leg (Drake et al., 2005; Schwind, 2006); and are layers that surround all of the posterior muscles in the calf (Carmont, Highland, Rochester, Paling, & Davies, 2011). A radiologic study of the CF determined that the mean \pm SD thickness of the CF, in healthy participants, was 1.11 ± 0.17 mm (range = 0.75–1.43 mm) (Stecco, Cappellari, et al., 2013). Similarly, anatomical studies of the CF have determined that the mean \pm SD thickness of the CF to be 0.924 ± 0.201 mm (Stecco et al., 2008) and ± 0.220 mm (Stecco et al., 2009). Both studies have identified the CF is composed of two or three layers of parallel collagen fibre bundles, each separated by a thin layer of LCT which provides the capacity for these layers to slide on one another (Stecco et al., 2009; Stecco et al., 2008). Each layer has a mean \pm SD thickness of 0.278 ± 0.087 mm and the LCT has a mean thickness of 0.043 ± 0.012 mm (Stecco et al., 2009). Stecco et al. (2008) discuss the function of the LCT as a cushioning and separating structure, and describe how the biomechanical properties of the tissue can influence how the fascial layers slide on one another. Understanding the role of CF sliding may provide insight into musculoskeletal soft tissue dysfunction in the posterior leg.

Stecco et al. (2009) observed a thin layer of LCT between the epimysium of the gastrocnemius and the CF, which allows the layers to slide on one another. On dissection of the CF, Stecco et al. (2009) claim it is similar to an aponeurosis that can be easily separated from the underlying muscles, and report “there is a virtually uninterrupted plane of sliding between the CF and the gastrocnemius muscle” (p.525). Stecco et al. (2009) infer that the presence of the LCT, and sliding between layers, provides the capacity for fascia to adapt to contractions of the underlying muscles. As an example of

the continuity of tissue structures in the leg, the CF is reinforced by the ankle retinacula and is continuous with the plantar fascia (Stecco, Cappellari, et al., 2013).

To date, the majority of studies on the CF have investigated its anatomical and histological makeup (Benetazzo et al., 2011; Carmont et al., 2011; Stecco et al., 2009). A recent study began a preliminary investigation of the mechanical properties of the CF (Stecco, Pavan, Pachera, De Caro, & Natali, 2014), the study found three main characteristics of the CF: anisotropy, non-linear stress-strain relationship, and viscoelasticity.

3.2.4 Fascial restriction

It has been proposed, that when fascia is unable to slide, stretch or adapt appropriately, musculoskeletal dysfunction occurs (A. Stecco et al., 2011). Stecco et al. (2011) reason that the ability of these fascial layers to slide may be altered in myofascial pathologies, including overuse syndromes, and loss of function following trauma and surgery. Barnes' (1997) clinical opinion outlines how trauma can cause fascia to tighten, lose its pliability, become restricted and thus become an area of tension within the body. Damage to the fascia can create an adhesion point between the layers, forming new lines of force within the fascia and causing the sliding movement of these layers to change (A. Stecco et al., 2011). Langevin et al. (2011) discuss how abnormal connective tissue structure, such as fibrosis and adhesions, can be a consequence of injury, leading to loss of independent motion of adjacent fascial layers, which may restrict body movements.

According to Martínez Rodríguez and Galán del Río (2013), following healing of an acute myofascial tissue injury, fibrotic scar tissue can form in the injured muscle replacing normal tissue. Martínez Rodríguez and Galán del Río (2013) discuss the disordered and nonfunctional nature of this scar tissue: it may hinder muscle regeneration, lead to incomplete recovery and increased risk of re-injury. Development of scar tissue depends on the location and severity of the injury, level of inflammatory response, and treatment protocols such as early mobilisation (Martínez Rodríguez & Galán del Río, 2013).

Franklyn-Miller, Falvey and McCrory (2009) propose inflammation in fascia has the potential to cause adhesions, where these fascial adhesions may develop and adhere to the AT, creating abnormal loading of the tendon, and has been suggested as a precursor state in the aetiology of Achilles tendinopathy. Quantification of tissue mobility within the CF is an important step in investigating the role of fascial restrictions in the pathogenesis and pathophysiology of AT disorders.

3.2.5 Manual therapy to treat fascial restrictions

There are various manual therapies (eg Rolfing, myofascial release, muscle energy, soft-tissue and massage) which aim to alter scar tissue formation, break adhesions points or increase gliding within fascially restricted regions (Simmonds, Miller, & Gemmell, 2012; Tozzi, 2012). Barnes (1997) describes how manual therapy can affect fascia by altering its viscoelastic, shock and energy absorbing properties by changing the ground substance, these changes may be associated with altering the ground substance from a dense to more fluid state. Additionally, Schleip (2003) discusses fascial innervation by mechanoreceptors and the implications manual therapy may have on motor units through stimulating these receptors. Chaudhry et al. (2008) investigated the relationship between mechanical forces and fascial deformation produced during manual therapy techniques by developing a three-dimensional mathematical model. The model was developed with the intention of determining the amount of force required to alter connective tissue properties. Chaudhry et al. (2008) report that for dense fascia such as the fascia lata and plantar fascia, the forces used in manual therapy are insufficient to alter these tissues. It has been proposed that neurophysiological effects also play a large role in producing the benefits observed following manual therapy (Simmonds et al., 2012). For example, Borgini, Stecco, Day and Stecco (2010) investigated the amount of time required to modify a fascially restricted region and decrease pain in patient with low back pain using a 'Fascial Manipulation' technique. Results demonstrated in chronic pain subjects the mean \pm SD time required to halve pain was 3.29 \pm 1.3 min, while in subacute patients the mean \pm SD time was 2.20 \pm 1.1 min. Borgini et al (2010) hypothesize that increasing sliding in the fascial layers generates an increase in temperature that is able to alter the ground substance, and increase the fluidity of the extracellular matrix, thus allowing the nerve endings in the fascia to adapt to the pressure introduced in manual therapy and reduce the perceived pain in that region.

As an example of recent research interest, Martínez Rodríguez and Galán del Río (2013) developed a scar modelling technique that involves combined use of torsion, shear, traction, axial and compression vectors on scar tissue to normalise fascial restriction. Currently, further investigations are required to investigate the mechanisms and efficacy of this technique, the use of elastography in conjunction with this technique has been proposed to assess and monitor the technique's effectiveness (Martínez Rodríguez & Galán del Río, 2013). Additionally, hyalonic acid has recently attracted interest for its role in facilitating sliding. A recent study investigated the relationship between manual therapy motions (constant sliding, tangential oscillation, perpendicular vibration) and hyaluronic acid flow within the fascial layers. Results indicated manual therapy is able to increase levels of hyaluronic acid in the fascial layers, this can improve gliding and encourage efficient muscle function (Roman, Chaudhry, Bukiet, Stecco, & Findley, 2013).

3.3 Achilles tendon

3.3.1 Achilles tendon anatomy

The musculotendinous junctions of the medial and lateral gastrocnemius muscle and the soleus muscle, or triceps surae group, merge to form the AT (Doral et al., 2010). The plantaris muscle may also have a small contribution to the tendon (O'Brien, 2005). These muscles are located in the posterior, superficial compartment of the calf (O'Brien, 2005) and converge into aponeuroses (Nandra, Matharu, & Porter, 2012) before conjoining to form the AT in the midcalf region approximately 5-6cm proximal to the AT insertion on the calcaneus (Joseph et al., 2012). The average (range) length of the AT has been reported in the literature, varying from 15.0 cm (11.0-26.0 cm) (Doral et al., 2010) to 18.2 cm (14.0-24.5 cm) (Apaydin et al., 2009). The average thickness of the AT has been described as 6.8 cm (range 4.5-8.6 cm) at its origin (Doral et al., 2010), it narrows to 1.8 cm (range 1.2-2.6 cm) at its midsection and then widens to 3.4 cm (range 2.0-4.8 cm) at its insertion (Apaydin et al., 2009).

The fibres of the AT spiral up to 90° as they descend to the calcaneal insertion (Doral et al., 2010; O'Brien, 2005; Szaro, Witkowski, Śmigielski, Krajewski, & Ciszek, 2009). This orientation allows for elongation and elastic recoil within the tendon, and for the release of energy when required during walking (Maffulli, 1999). In an anatomical study by Szaro et al. (2009) n=20 AT were dissected to describe how the muscle fibres of the triceps surae form the fascicles in the AT. Szaro et al. (2009) discovered: the posterior layer of the AT is composed of the medial fibres of the medial head of the gastrocnemius muscle; the lateral border of the AT is formed by the lateral fibres of the medial head of the gastrocnemius muscle; the anterior layer of the AT is composed of fibres from the lateral head of the gastrocnemius muscle; and the anteromedial part of the AT is made up of fibres from the soleus muscle (Szaro et al., 2009).

3.3.2 Paratenon

The AT is surrounded by a thin paratenon, rather than a synovial sheath, this paratenon permits a gliding movement of the tendon within the surrounding tissues (Carmont et al., 2011; O'Brien, 2005; Paavola & Järvinen, 2005; Soila, Karjalainen, Aronen, Pihlajamaki, & Tirman, 1999; Stecco et al., 2012; Wijesekera et al., 2011). The paratenon also provides the conduit for neural, vascular and lymphatic supply to the tendon (Nandra et al., 2012; Paavola & Järvinen, 2005). The paratenon is partially separated from the AT by LCT rich in hyaluronic acid (Stecco, Cappellari, et al., 2013).

Previously, the paratenon has been described as a structure separate to the CF (Kvist & Kvist, 1980; Paavola & Järvinen, 2005). More recently, anatomical studies (Franklyn-Miller et al., 2009; Stecco, Cappellari, et al., 2013; Stecco et al., 2012) and studies utilizing magnetic-resonance imaging (MRI) (Soila et al., 1999; Stecco, Cappellari, et al., 2013) have determined the CF and paratenon are continuous. In a study using high-resolution MRI on asymptomatic AT in n=81 participants, the paratenon was detected along the posterior, medial and lateral aspects of the AT (Soila et al., 1999). Near the musculotendinous junction the paratenon was viewed as a distinct layer on the posterior aspect of the tendon, but towards its insertion, the paratenon and CF were indistinct from one another and fused with the posterior subcutaneous structures (Soila et al., 1999). According to Franklyn-Miller et al. (2009), who performed an anatomical dissection of the fascia of the lower limb on n=22 embalmed and n=10 fresh cadaveric lower limbs, the paratenon is not a unique structure but is part of the fascia of the lower limb, and is histologically the same as the fascia surrounding the gastrocnemius muscle, implying the paratenon is a layer of the CF. Similarly, an anatomical study of the AT from n=13 cadaver feet concluded the CF is continuous with the paratenon and describe it as enveloping the tendon which permits the sliding movement (Stecco et al., 2012).

The most recent anatomical (n= 10 non-embalmed leg specimens) and radiological (n=60 participants, n=30 with Achilles tendinopathy, n=30 controls) study of the CF and paratenon determined the CF divides posteriorly to envelop the AT and form the paratenon, and in conjunction with the LCT, the paratenon facilitates gliding of the AT (Stecco, Cappellari, et al., 2013). The microscopic study of the paratendinous tissue provides descriptions of the three layers: the paratenon, epitenon, and endotenon. The paratenon is composed of two or three sublayers of collagen fibres arranged in different directions and few elastic fibres. The dense connective tissue of the epitenon is rich in elastic fibres and covers the surface of the tendon. Within the paratenon and epitenon are blood and lymphatic vessels and free nerve endings; and between these two layers is the LCT layer, containing elastic fibres. The endotenon surrounds the tertiary fascicles of the tendon and is composed of collagen fibres and is also rich in elastic fibres. All three layers contain hyaluronan (Stecco, Cappellari, et al., 2013).

3.3.3 Achilles tendon injuries

The AT is one of the most frequently injured (Pierre-Jerome, Moncayo, & Terk, 2010) or ruptured (Szaro et al., 2009) tendons in the body. AT injuries typically occur with increased physical activity where the tendon is unable to withstand the associated mechanical loading (Wren, Yerby, Beaupré, & Carter, 2001) and/or in overuse conditions (Pierre-Jerome et al., 2010). According to Wren et al. (2001) the AT is particularly at risk of injury when loading is suddenly increased by changes in

physical activity due to a failure to adapt to high stresses. The most commonly injured regions of the AT occur at the myotendinous junction with the soleus muscle, and the osteotendinous junction at the calcaneus (Kongsgaard, Nielsen, Hegnsvad, Aagaard, & Magnusson, 2011). There are a variety of AT disorders including: non-insertional Achilles tendinopathy (Paavola et al., 2002; Roche & Calder, 2013), paratendinopathy/paratendonitis (Paavola & Järvinen, 2005), degeneration of the tendon or tendinosis (Paavola et al., 2002), insertional disorders such as bursitis and insertional Achilles tendinopathy (Roche & Calder, 2013); and AT rupture (Nandra et al., 2012).

3.3.4 Achilles tendinopathy

Since the late 1990s there have been attempts to improve clarity of terminology associated with Achilles tendinopathy. According to Maffulli, Khan and Puddu (1998) Achilles tendinopathy is an overuse injury and is characterised by pain, swelling (diffuse or localised) and impaired performance, whereas, tendinosis, paratendinitis, and tendinitis refer to specific histopathological conditions. Maffulli et al. (1998) advocate the umbrella term 'tendinopathy' to include tendinosis (tendon degeneration without inflammation) and paratendinitis (inflammation of the paratendinous tissues). Additionally, paratendinopathy may be used to describe overuse injuries involving the paratendinous tissue (Paavola & Järvinen, 2005).

Achilles tendinopathy is common in physically active people, and is associated with overuse and repetitive tendon loading (Wijesekera et al., 2011). Intrinsic and extrinsic risk factors are both involved in the aetiology of Achilles tendinopathy. Extrinsic risk factors include poor technique, footwear, hard, slippery or uneven surfaces and potentially increased frequency and duration of sports training (Tan & Chan, 2008). Intrinsic risk factors include: alteration in lower limb function, biomechanics, gender, age, genetics (Tan & Chan, 2008), as well as tendon vascularity, triceps surae dysfunction and lateral ankle instability (Maffulli, Sharma, & Luscombe, 2004). A study investigating the effect of foot structure and ROM on overuse injuries determined there was a statistically significant association between Achilles tendinopathy and either decreased dorsiflexion due to a tight gastrocnemius muscle (Risk ratio = 3.57, 95%CI = 1.01 - 12.68; $p < 0.05$) or increased subtalar pronation (Risk ratio = 2.79, 95%CI = 0.91 - 8.55; $p < 0.1$) (Kaufman, Brodine, Shaffer, Johnson, & Cullison, 1999).

In untreated paratendonitis, adhesions form and can bind the AT to its surroundings (Kvist & Kvist, 1980). Kvist and Kvist (1980) describe a surgical technique to trim adhesions linking the AT to the CF, and remove hypertrophied portions of the paratenon, as a treatment for chronic calcaneal paratenonitis. Their findings indicate a thickened paratenon and fibrous adhesions between the

tendon and fascia. According to Järvinen et al. (1997) in chronic Achilles paratendinopathy the paratenon is thickened and friction is increased between the tendon, paratenon, CF and skin. These alterations in the paratendinous tissues result in considerable impaired gliding function of the tendon and lead to painful symptoms (Järvinen et al., 1997).

In chronic Achilles tendinopathy, peritendinous adhesions have been shown by USI through thickening of the paratenon and poorly defined borders (Maffulli et al., 2004). A recent anatomic and radiologic study investigated the role of the paratendinous tissues in Achilles tendinopathy, utilising MRI on n=60 participants (n=30 healthy controls, n=30 patients with Achilles tendinopathy) (Stecco, Cappellari, et al., 2013). The results demonstrated statistically significant differences between patients with tendinopathy and healthy controls in thickness of the CF (tendinopathy mean \pm SD thickness = 1.30 \pm 0.26 mm; healthy controls mean \pm SD thickness = 1.11 \pm 0.17; $p < 0.005$) and the paratenon (tendinopathy mean \pm SD thickness = 1.34 \pm 0.18 mm; healthy controls mean \pm SD thickness = 0.85 \pm 0.24 mm; $p < 0.0001$). Stecco et al. (2013) support the use of the term 'paratendinopathy' and suggest inflammation and pain are due to the paratendinous tissues; when referring to degeneration in the tendon, they support the term 'tendinosis'. Stecco et al. (2013) concluded that paratenon thickness >1.35 mm is associated with AT pathology and that this value may be useful in early diagnosis of Achilles tendinopathy.

3.3.5 Achilles tendon rupture

Achilles tendon ruptures are relatively frequent, this has been attributed to large loads and repetitive forces (eg running and jumping), causing the AT to be susceptible to these injuries (Nandra et al., 2012). AT ruptures most commonly occur in middle-aged males and are typically due to sporting injuries (Nandra et al., 2012; Raikin, Garras, & Krapchev, 2013).

In a study of n=303 patients undergoing surgical repair for AT rupture, Krueger-Franke, Siebert and Scherzer (1995) determined ruptures most commonly occur 3-5 cm proximal to the AT insertion, with the average site of rupture occurring 4.78 cm proximal to the AT insertion. Follow-up examinations were performed on n=122 of these patients, approximately 6 years following surgery. Complications following surgical treatment of AT ruptures included: re-rupture, deep vein thrombosis, pulmonary emboli, infection, dysaesthesias around the surgical scar and secondary wound healing. USI was performed on n=71 of the patients, where n=64 patients revealed scar-like thickening of the AT and n=63 patients had thickening of the paratenon (Krueger-Franke et al., 1995).

The formation of adhesions post trauma is a clinical problem (Sharma & Maffulli, 2005). After an acute AT rupture, a hematoma forms at the site and over time, granulation and eventually scar tissue will replace the hematoma (Hollenberg, Adams, & Weinberg, 1998). The formation of adhesions post-surgery is a common complication (R. Khan & Carey Smith, 2010). Following surgical repair to restore tendon excursion, tendons heal with adhesions to the surrounding paratendinous tissues and limit excursion by impairing gliding (U. Khan, Kakar, Akali, Bentley, & McGrouther, 2000). Furthermore, during tendon healing, scar tissue can result in adhesion formation which may impair tendon gliding (Sharma & Maffulli, 2005).

A study evaluating pathological features of different portions of the AT, harvested from patients with acute AT ruptures, found tendons demonstrated profound histopathologic changes, at the site of rupture, as well as, proximal and distal portions of the intact tendon (Maffulli et al., 2011). Changes were significantly more prominent at the site of rupture and included collagen disorganization and loss of the parallel arrangement of tendon fibres.

4. Ultrasound imaging

4.1 Principles of Ultrasound imaging

4.1.1 Principles of ultrasound imaging

Ultrasound imaging (USI) is an accessible and cost-effective method of medical imaging (Chiou, Chou, Chiou, Liu, & Chang, 2003; Ellis, 2011; Hashimoto, Kramer, & Wiitala, 1999; Jeffery, 2003; Martinoli, Bianchi, & Derchi, 1999; Whittaker et al., 2007). Advantages of USI over other methods of imaging include: ability to measure both in real-time and *in-vivo*; portability as it can easily be moved; and non-invasiveness as it does not use ionizing radiation (Cardinal, Chhem, & Beauregard, 1998; Chiou et al., 2003; Ellis, 2011; Hashimoto et al., 1999; Jeffery, 2003; Martinoli et al., 1999; Walker, Cartwright, Wiesler, & Caress, 2004). Ultrasound imaging is considered to be operator dependent, therefore, its accuracy and validity is dependent on the skill of the operator (Chiou et al., 2003; Ellis, 2011; Martinoli et al., 1999).

4.1.2 Ultrasound imaging techniques

There are several different types of USI techniques including: A-mode, B-mode, M-mode, Doppler and elastography (Anderson & McDicken, 1999; Ellis, 2011; Kossoff, 2000; Wu, Chen, Park, Wang, & Lew, 2012). B-mode ultrasound is widely employed during diagnostic medical imaging (Anderson & McDicken, 1999; Kossoff, 2000; Whittaker et al., 2007). The transducer gathers information as

pixels, in varying degrees of brightness, and the image is represented by shades of grey displaying the location and density of tissue structures (Whittaker et al., 2007); this enables USI to display real-time images allowing tissue motion to be visualised (Anderson & McDicken, 1999; Ellis, 2011; Jeffery, 2003; Kossoff, 2000).

4.1.3 Ultrasound imaging of the ankle

Ultrasound imaging is able to provide imaging of the ankle, including the joint space, retrocalcaneal bursa, ligaments and plantar fascia, and allows diagnosis of a variety of foot pathologies (Fessell et al., 1998). The CF has been investigated using USI and fascial layers can be most easily seen in a para-sagittal plane (Carmont et al., 2011). Carmont et al. (2011) performed a radiological and anatomical study of the AT and determined where the two layers of CF and paratenon merge, termed the 'confluence'. The paratenon covers the posterior, lateral and medial aspects of the AT and is located between the CF and AT (Soila et al., 1999).

4.1.4 Ultrasound imaging of the Achilles tendon

USI is particularly useful in assessing the AT as the superficial location and orientation of the tendon allow easy evaluation (Daftary & Adler, 2009; Hollenberg et al., 1998). The use of B-mode USI is popular for *in vivo* measurements of AT properties (Kongsgaard et al., 2011). According to Wijesekera et al. (2011) a linear high frequency (7 to 12 MHz) transducer should be used to image the AT. USI is useful in imaging the healthy AT, in diagnosing Achilles tendinopathy and is able to view the paratendinous adhesions present in Achilles paratendinopathy (Wijesekera et al., 2011).

There is a substantial literature on the AT *in vivo*, from tendon and muscle biomechanics (Arampatzis, Peper, Bierbaum, & Albracht, 2010; Finni, Hodgson, Lai, Edgerton, & Sinha, 2003; Fukunaga, Kawakami, Kubo, & Kanehisa, 2002; Herbert et al., 2011; Iwanuma et al., 2011; Joseph et al., 2012; Maganaris & Paul, 2002; Park et al., 2011), to AT mechanical properties (Kongsgaard et al., 2011; Magnusson, Aagaard, Dyhre-Poulsen, & Kjaer, 2001), AT moment arms (Fath, Blazevich, Waugh, Miller, & Korff, 2010; Maganaris, Baltzopoulos, & Sargeant, 2000; Manal, Cowder, & Buchanan, 2013), tendon elongation (Arampatzis et al., 2005; Maganaris, 2005), tendon pathology (Arya & Kulig, 2010; Leung & Griffith, 2008; Wijesekera et al., 2011), gender differences (Kubo, Kanehisa, & Fukunaga, 2003), age related differences (Stenroth, Peltonen, Cronin, Sipilä, & Finni, 2012).

4.1.4a Elastography – an emerging technique for measuring connective tissue properties

Ultrasound elastography (or ‘sonoelastography’) is a non-invasive method for assessing tissue mechanical properties, such as tissue stiffness and elasticity (Drakonaki, Allen, & Wilson, 2009; Wu et al., 2012). This imaging technique has been useful in assessing normal healthy AT (De Zordo et al., 2009; Drakonaki et al., 2009) and pathological AT (Wu et al., 2012) including AT rupture (Tan et al., 2012). In addition, sonoelastography has been recommended for objective assessment of connective tissue damage and scar tissue post-injury and to evaluate response to manual therapy (Martínez Rodríguez & Galán del Río, 2013).

4.2 Tendon and Connective Tissue Excursion

4.2.1 Tendon excursion and gliding

According to An (2007) tendon excursion and gliding determine the efficiency with which the tendon is able to transmit muscle forces to the skeletal system. Tendon excursion occurs when the muscle contracts and the joint rotates, the magnitude of excursion is dependent on the amount of rotation at the joint (An, 2007).

Gliding is quantified in terms of a friction coefficient, which is the correlation between the arc of contact of a tendon against its pulley, as the tendon moves tensions proximal and distal to the pulley are related to the angle of the tendon across the pulley and the friction coefficient (An, 2007). An analogy for tendon gliding through the pulley is a belt wrapped around a fixed mechanical pulley (An, 2007). Increased friction, such as from non-ergonomic joint postures, may cause resistance to gliding and provide an explanation for the aetiology of soft tissue disorders such as repetitive strain injuries (An, 2007). Hyaluronate may act as a lubricant and facilitate gliding by reducing resistance between tendon and ‘pulley’ (An, 2007).

Guimberteau, Delage and Wong (2010) reject An’s concept of tendon gliding as they report it is ‘surgically impossible’ to clearly dissect paratenon from tendon due to tissue continuity between these structures. Instead, Guimberteau, Delage and Wong (2010) propose a ‘sliding network’ made up of ‘microvacuoles’ providing tissue continuity facilitating sliding between adjacent tissues. It is clear these concepts of gliding are yet to be resolved and require further investigations.

4.2.2 Measurement techniques for tracking tissue excursion using ultrasound imaging

There are various measurement techniques for tracking and measuring tissue excursion (Dilley, Greening, Lynn, Leary, & Morris, 2001; Korstanje, Selles, Stam, Hovius, & Bosch, 2010; Lee et al.,

2008; Loram, Maganaris, & Lakie, 2006; Magnusson et al., 2003). Manual tracking is one method of measuring tendon excursion *in vivo*, using USI. According to Lee et al. (2008) a tissue landmark is chosen (eg musculotendinous junction) and manually digitized on each frame, however, this method is time consuming and prone to operator error. Automated algorithms have been developed to provide an efficient way of tracking tissue excursion and have been used in measuring nerves (Dilley et al., 2001; Korstanje et al., 2010), tendons (Dilley et al., 2001; Korstanje et al., 2010; Lee et al., 2008), connective tissue (Korstanje et al., 2012; van Doesburg et al., 2012; Yoshii et al., 2009), aponeuroses (Magnusson et al., 2003) and tracking changes in muscle contractile length (Loram et al., 2006). All of the automated algorithms use cross-correlation methods and compute optical flow between the successive frames. Optical flow determines the horizontal and vertical pixel velocities between frames, so the displacement of a region of interest (ROI) can be calculated (Lee et al., 2008). Differences in validation methods make it difficult to evaluate and compare algorithms (Lee et al., 2008). A limitation of the algorithm by Dilley and Lee is that a ROI can only be tracked if it is visible throughout the image sequence (Loram et al., 2006).

More recently, Korstanje et al. (2010) developed and validated a tendon-optimized speckle tracking algorithm, using a multikernel block matching USI-based speckle tracking method with a normalized cross-correlation (NCC) algorithm. The advantage of this algorithm over earlier methods is the use of stationary regions of interest to extrapolate movement and allow tracking of tendon excursion beyond the B-mode image size (Korstanje et al., 2010).

A limitation of all the above-mentioned automated algorithms has been measurement of 2-dimensional motion when these tissues (nerve, tendon, connective tissue) exhibit 3-dimensional motion directions (Ellis, Hing, Dilley, & McNair, 2008; van Doesburg et al., 2012).

4.2.3 Achilles tendon excursion

Previously, AT excursion has been calculated to determine moment arms in the lower extremity including the tibialis anterior muscle (Maganaris, 2000) and AT (Fath et al., 2010; Maganaris et al., 2000; Manal et al., 2013). Determining the AT moment arm has direct application to the study of normal and abnormal gait (Manal et al., 2013). The tendon excursion method is one way of calculating AT moment arms to determine tendon excursion (Fath et al., 2010).

4.2.3a In vitro investigation of Achilles tendon excursion

An *in vitro* study of 15 lower leg cadavers (Hintermann, Nigg, & Sommer, 1994) found the average tendon excursion of the triceps surae from flexion to extension (-20° to 30°) was 39.7mm (range

31.3-42.7). In this study, the specimens were mounted on a foot plate, the soft tissues were removed to 3cm above the ankle joint and a wire fixed to the tendon. The wire was attached to a pulley, corresponding to the line of action on the muscle, and a weight suspended from the wire. The weight was "considered heavy enough to overcome possible friction between tendon surface and tendon sheath, and light enough not to induce elastic reaction of tendon tissue" (p.388). The tendon was held for over 10min and markers attached to the wire measured tendon excursion as they moved over a ruler (Hintermann et al., 1994). As most of the soft tissues of the leg were removed, this could significantly increase tendon excursion values. Hintermann et al. (1994) speculate whether their results would be similar *in vivo*, as tension generated on the tendon would be different due to muscle contraction and a closed kinetic chain. Cadaver studies are unable to analyse tendons during functional movements, therefore research on tendon excursion *in vivo* has been recommended (Ito, Akima, & Fukunaga, 2000; Maganaris & Paul, 2002).

4.2.3b *In vivo investigations of Achilles tendon excursion*

There appears to be few studies that have investigated inter and/or intra-AT excursion during active or passive ankle ROM. None of the studies have utilized Dilley et al.'s (2001) frame-by-frame cross-correlation algorithm. Three studies investigated AT excursion during passive ROM (Arndt et al., 2012; Lee et al., 2008; Pearson et al., 2013), while only one study has investigated AT excursion during active ROM (Pearson et al., 2013).

Lee et al (2008)

Lee et al. (2008) developed an automated tracking algorithm for tracking tendon excursion by incorporating a least-squares based method (the Lucas-Kanade algorithm) for calculating optical flow (horizontal and vertical pixel velocities from USI). Lee et al. (2008) tested the accuracy of the algorithm on the AT using a phantom, *in vitro* and *in vivo* experiments. In the phantom experiment, a wire was moved through a known distance relative to the US transducer, the automated tracking measurement was compared to the known distance. For the *in vitro* experiment one cadaveric lower leg specimen was tested, direct AT excursion was measured using an extensometer cable attached to the two heads of the gastrocnemius and foot was moved from 15° dorsiflexion to 35° plantarflexion. This measurement was compared with a manual tracking method, as the automated tracking method was unable to accurately visualize the cadaver tissue due to cadaver tissue properties (dehydration and muscle cell degradation) producing USI that lacked the contrast necessary. For the *in vivo* method the lateral gastrocnemius tendon was imaged in five healthy participants (n=3 females, n=2 males; mean age 24 years). The foot was passively moved by an examiner through the same range as the *in vitro* method. The measurement obtained from manual

tracking was compared with the automated tracking measurement. Tracking estimates were evaluated by calculating root mean squared errors, and analyses demonstrated small errors. Lee et al. (2008) suggest the algorithm is reliable and conclude the method is accurate for automated tracking of tendon excursion. From the *in vivo* experiment, a mean \pm SD AT excursion of 19.5 ± 4.3 mm was measured for dorsiflexion-plantarflexion (Lee et al., 2008).

Arndt et al. (2012)

Arndt et al. (2012) used a block-matching speckle tracking method on the AT to quantify *in vivo* non-uniform displacement within the deep, central and superficial layers of the AT, during controlled passive ankle movement. B-mode USI was conducted on a homogenous sample of $n=9$ healthy active males (mean \pm SD: age 43 ± 12.1 years, height 1.78 ± 0.07 m and weight 77.0 ± 7.4 kg). Bipolar surface electromyography (EMG) electrodes were placed over the tibialis anterior, medial gastrocnemius (MG) and soleus muscle bellies, to verify there was no obvious muscle activation during the passive movements. The transducer was placed longitudinally over the posterior AT with the distal end of the probe 3 cm proximal to the tendon insertion. The foot was fixed to a custom dynamometer plate; the dynamometer controlled passive movement from 20° plantarflexion to 15° dorsiflexion back to 20° plantarflexion at a velocity of $15^\circ/\text{s}$. Data analysis occurred after all scans had been recorded using the block-matching speckle tracking algorithm (Korstanje et al., 2010). Two raters used the algorithm to analyse displacement values twice, the displacement value for each layer was calculated from the mean of these four measurements. Absolute and relative displacement was compared, where absolute displacement referred to displacement of each layer and relative displacement referred to displacement between each layer. Two raters analysed the displacement data for each of the three layers for inter-rater reliability. Each rater also analysed the data twice, with an interval of two weeks for intra-rater reliability.

An average of the 12 mean ICC values was calculated (two observers, two analyses, three layers of the AT) where the average ICC=0.94 (range 0.88 to 0.97). Although the individual ICCs were not reported, the 95%CI for intra-rater reliability was 0.81 to 0.99, and the 95%CI for inter-rater reliability was 0.49 to 0.99. There was no significant difference between the two raters. Analyses revealed maximum displacement was greater in the deep layer of the tendon, mean \pm SD displacement for each layer was: 8.4 ± 1.9 mm in the superficial layer, 9.4 ± 1.9 mm in the central layer and 10.4 ± 2.1 mm in the deep layer. Arndt et al. (2012) speculated why there was different displacement between the layers and related the findings to complex interactions between the tendon insertion and possible differential strains applied to the tendon by the triceps surae aponeuroses. Another speculation related the difference to the spiralling of the AT fibres as they

descend to the calcaneal insertion. Arndt et al. (2012) presume the relative displacement between the tendon layers was due to gliding between the fibre bundles, they related this finding to tendinopathy, where there is loss of gliding between fascicles at regions within the tendon. The results of the study indicated the speckle tracking algorithm was a useful clinical tool for detecting disruption in fascicle gliding and thus intra-tendon excursion and Arndt et al. (2012) suggest treatment protocols should include restoring or 'normalising' intra-tendon displacement. The study had a small homogenous sample, therefore results cannot be generalized to the wider population, although Arndt et al. (2012) did not consider the small sample size to have had an effect on the results of the study.

Pearson et al. (2013)

More recently Pearson et al. (2013) also investigated AT excursion using a normalized correlation coefficient (NCC) automated tracking method during passive movement, and appears to be the first to investigate AT excursion during active movement using maximal force efforts to create high levels of strain in the tendon. The study also compared the automated tracking method to the manual method to establish its validity. While, Pearson et al. (2013) are the first to relate automated tracking with manual methods during active movement, Lee et al. (2008) previously related their automated tracking algorithm to the manual tracking method for passive movement. One healthy male was recruited for the study (age 47 years, weight 91 kg, height 1.81 m). B-mode USI was used to scan the patellar and MG tendons. The MG tendon junction was imaged with the ankle fixed in a 'neutral' position. A marker was placed on the skin as a fixed reference for the manual tracking method. Passive probe movement, where the transducer was moved on the skin within a 20 mm range, was used to examine the validity of the automated method by comparing it to the manual tracking method, using 1- and 2-ROI for comparison. The passive movement used for passive tendon excursion was not explicitly described in the methods, so it is unclear what start and end positions were used. Active movement (applied ramped voluntary contractions) examined the patellar and MG tendons with the transducer fixed to the skin (resulting in tendon stretch). The start of the active movement was defined as where the force was zero, the end was defined as where a force plateau was reached. No ROM values were provided for either the active or passive movements.

The NCC was calculated for the ROI by the automated tracking algorithm. This method was used over other automated methods as it was considered to be more sensitive to speckle tracking in USI. However, Pearson et al. (2013) do not reference the NCC automated tracking algorithm, nor do they describe the software used. The NCC searches for the ROI in the following frame. Another algorithm was used in conjunction to reduce search times required by the NCC. This three steps

searching (TSS) algorithm was developed by Koga and co-workers. It increased the ability of the NCC algorithm to match the ROI in the subsequent frame as the tendon deformed during the active movement.

The study also compared the NCC method with the manual method and determined there were no significant differences ($p > 0.05$) for passive or active movement. The automated tracking method determined that the total displacement of the MG tendon was 11.28 ± 1.36 mm for the passive movement and 16.42 ± 0.85 mm for the active movement. Pearson et al. (2013) noted that active movement was more 'demanding' for automated tracking due to dynamic stretch of the tendon during muscle contraction causing deformation.

Due to incomplete reporting (eg not reporting the tracking algorithm, and clarity on the passive movement), the results of this study are difficult to interpret. In addition, the study included only one participant, so the results are not generalizable and results must be interpreted cautiously. Despite these weaknesses, the study reports the NCC method was valid and useful for tracking *in vivo* tendon displacement in discrete areas of the tendon, when the tendon is under load during active movement.

4.2.3c Age and Achilles tendon excursion

Although it is currently not known if age has an influence on AT excursion, there appears to be an effect of age on AT properties. For instance, Mademli and Arampatzis (2008) found age related changes in the morphological properties at the musculotendinous junction of the MG including shorter fascicles, lower tendon stiffness and tendon forces. Previously, there has been a discrepancy in the literature regarding age-related differences in AT properties and AT stiffness, which has been attributed to sample size or methodological differences (Stenroth et al., 2012). Tendon stiffness refers to the ability of the tendon to transfer muscle forces to the bone, where a stiff tendon transfers force more rapidly than a compliant tendon (Onambélé, Burgess, & Pearson, 2007). Stenroth et al. (2012) investigated AT morphology, mechanical properties and triceps surae muscle architecture *in vivo* in $n=100$ healthy older (70-80 years) and younger (18-30 years) participants ($n=51$ males, $n=49$ females). Stenroth et al. (2012) reported AT stiffness was 17% lower in the older group than the younger group ($p < 0.01$), and 25% lower in women than men ($p < 0.001$); although there was no difference in AT stiffness between the age groups for individuals with similar muscle strength. Another finding demonstrated AT cross-sectional area was 16% larger in the older group ($p < 0.001$). Stenroth et al. (2012) suggest AT properties adapt to match muscle performance, where

older people may increase tendon cross-sectional area as a compensation for decreased tendon material properties.

Sargon, Ozlu and Oken (2005) investigated the aetiology of AT rupture in 30-45 year olds. The authors examined the diameter of collagen fibres in n=28 patients who had undergone AT surgery. Sargon et al. (2005) reported the diameter of collagen fibres decreased significantly in the 30-39 and 40-49 year old groups compared to the 20-29 year old group, and suggest this decrease in diameter has a role in the aetiology of AT ruptures. Information regarding the relationship between age and AT excursion may help to explain epidemiological data regarding age and tendon tears (Hess, 2010; Raikin et al., 2013; Sargon et al., 2005).

4.2.3d Gender and Achilles tendon excursion

Due to the limited research to date on AT excursion, it is currently unknown if gender has an effect on AT excursion. However there appears to be gender differences in the properties of the AT and triceps surae muscle (Joseph et al., 2014; Kubo et al., 2003). Kubo et al. (2003) investigated gender differences in the viscoelastic properties of tendon structures in the medial gastrocnemius muscle and found there is lower stiffness and hysteresis in tendon structures in women. Kubo et al. (2003) speculate men have more stretch resistant tendons than women and thus suggest there are gender differences in the viscoelastic properties of tendons. Similarly, Joseph et al. (2014) compared mechanical characteristics (force, elongation, stiffness) and material properties (stress, strain) in n=17 men and n=14 women (18-30 years) who were at least moderately physically active. The results demonstrated women had greater tendon elongation and strain, and less stiffness indicating a gender difference in AT properties. Joseph et al. (2014) suggest these differences may provide a protective mechanism for women and explain the lower incidence of AT pathology in women. Chow et al. (2000) used USI *in vivo* to establish gender differences in the muscle architecture of the soleus and gastrocnemius muscles and determined males have thicker muscles and larger angles of pennation, whereas, females have longer muscle fibre bundle length. According to Chow et al. (2000) there was no correlation between these parameters and leg length.

Higher percentages of activity-related AT injuries have been reported in men than women (Hootman et al., 2002). A review of AT ruptures reports men are more commonly affected than women, where ratios range from 2:1 to 12:1 (Hess, 2010). Out of n=406 AT ruptures presenting to an orthopaedic clinic, 83% occurred in males, whereas 17% occurred in females (Raikin et al., 2013). Research investigating the relationship between gender and AT excursion may help to explain epidemiological data regarding gender and tendon tears (Raikin et al., 2013).

4.2.4 Triceps surae aponeurosis excursion

Studies have investigated the mechanical properties of the triceps surae aponeurosis *in vivo*, including aponeurosis excursion (Bojsen-Møller et al., 2004; Magnusson et al., 2001; Magnusson et al., 2003). According to Magnusson et al. (2001) tendon and aponeurosis displacement is due to both joint rotation and muscle loading, and suggests small amounts of ankle ROM will contribute to tendon movement.

Magnusson et al. (2003) identified different strain patterns between the MG tendon and aponeurosis by investigating longitudinal displacement of the free AT and deep aponeurosis of the MG, during muscle contraction using USI and an automated tracking method (incorporation of the Lucas-Kanade algorithm). Results demonstrated the mean \pm SD tendon-aponeurosis displacement was 7.97 ± 1.1 mm. Magnusson et al. (2003) reported the strain of the free AT was 5.7 times greater than the aponeurosis ($p < 0.01$) and suggest this indicates a difference between the structures in force transmission.

Bojsen-Møller et al. (2004) investigated the influence of knee joint position on the patterns and magnitude of excursion of the medial MG and soleus aponeuroses during isometric plantarflexion contractions *in vivo*, using USI, with the knee maximally extended and maximally flexed. In the knee extended position, excursion of the MG aponeurosis at maximal force exceeded that of the soleus (12.6 ± 1.7 vs. 8.9 ± 1.5 mm), whereas in the knee flexed position, displacement of the soleus was greater than excursion of the MG (9.6 ± 1.0 vs. 7.9 ± 1.2 mm). Bojsen-Møller et al. (2004) discuss the differences in aponeurosis excursion created a 'shear' effect, where the direction of shear was determined by the knee position. The authors provide explanations for the difference in excursion, such as difference in force output from each of the triceps surae muscles or that aponeurosis behaviour could be due to mechanical properties of the associated connective tissue structures. Bojsen-Møller et al. (2004) suggest the AT is subjected to intra-tendinous shearing during locomotion which may be significant for AT pathologies.

4.2.5 Fascial sliding

A recent editorial discusses the role of gliding between fascial, visceral and muscular tissue layers and the potential importance gliding has on ROM, and if this gliding is reduced or absent, the potential for dysfunction (Chaitow, 2014). Guimberteau, Delage and Wong (2010) describe the role of connective tissue in tendon gliding, and propose a 'sliding system' or 'microvacuolar network' that provides continuity between tissues and enables sliding and mobility of tissues such as tendons, throughout the body. This sliding system encompasses LCT, superficial fascia, paratenon and

subsynovial tissue and acts as a shock absorbing system, permitting gliding without dynamic influence on surrounding tissues (Guimberteau, Delage, McGrouther, & Wong, 2010). USI and elastography have been employed to objectively visualise connective tissue gliding *in vivo* in the carpal tunnel (van Doesburg et al., 2012; Yoshii et al., 2009) and thoracolumbar fascia (Langevin et al., 2011).

The subsynovial connective tissue (SSCT) in the carpal tunnel surrounds the median nerve and flexor tendons and facilitates movement during tendon excursion by allowing individual sliding between each layer to reduce friction (Filius et al., 2014; Guimberteau, Delage, & Wong, 2010). Studies have found that fibrosis within the SSCT is a common finding in patients with carpal tunnel syndrome (CTS) (Ettema, Amadio, Zhao, Wold, & Kai-Nan, 2004; Filius et al., 2014). With increased strain and loading there is limited deformation in viscoelastic tissues, resulting in increased stiffness of that connective tissue and increased risk of injury (Filius et al., 2014).

A pilot study compared Doppler and block-matching speckle tracking for the flexor digitorum superficialis (FDS) tendon and SSCT excursion at the wrist (Yoshii et al., 2009). Results indicated superior detection of tendon excursion in the speckle tracking method but less precision. A maximum velocity ratio (ratio of SSCT velocity to tendon velocity) and shear index (ratio of tendon to SSCT motion) were calculated to represent different aspects of tendon motion. The shear index represents displacement of the SSCT relative to the FDS displacement. Delay in movement or decreases in velocity of the SSCT can lead to an increased shear index. Yoshii et al. (2009) discuss the speckle tracking method may be able to detect presence or risk of SSCT shear injury and improve understanding of its role in CTS. The speckle tracking algorithm was considered to be useful in assessing excursion of the FDS tendon and the SSCT (Yoshii et al., 2009).

More recently, van Doesburg et al. (2012) investigated *in vivo* excursion of FDS tendon and SSCT in healthy controls (n= 22) and patients with CTS (n=18) using speckle tracking. The maximum velocity ratio and shear index were calculated. van Doesburg et al. (2012) used direct measurements during surgery to validate the movement assessed *in vivo*. Results demonstrated no differences between control and patient groups for tendon or SSCT excursion. However, the patient group demonstrated a significantly higher shear index and lower maximum velocity ratio than the control group ($p < 0.05$). This difference was attributed to altered SSCT movement, as fibrotic SSCT can delay its movement or decrease its velocity, and cause higher shearing between the SSCT and tendon. A challenge identified by van Doesburg et al. (2012) was occasional loss of speckle tracking for motion direction of the tendon or SSCT. This was attributed to the 3-dimensional motion directions of these

tissues, but speckle tracking is only able to measure 2-dimensional motion. The study determined speckle tracking was able to measure FDS tendon and SSCT biomechanics and had 'enough' accuracy to distinguish between healthy controls and patients with CTS. van Doesburg et al. (2012) recommended further research, in particular intra- and inter-rater reliability.

Langevin et al. (2011) investigated mobility of the fascial layers within the thoracolumbar fascia in a group with chronic low back pain (LBP) (n=71) and a control group with no LBP (n=50) using ultrasound elastography during passive trunk flexion. Langevin et al. (2011) quantified lateral tissue displacement and shear strain deformation within the thoracolumbar fascial layers. Results demonstrated less independent movement of fascial layers, thickening of the deeper layers, and lower shear strain in the LBP group than the control group, the authors provide possible explanations including the presence of connective tissue pathology such as chronic inflammation and fibrosis (Langevin et al., 2011). While Langevin et al. (2011), van Doesburg et al. (2012) and Yoshii et al. (2009) display recent interest in fascial sliding research utilising USI, to date there is no literature investigating excursion or sliding of the CF *in vivo*.

4.3 Ultrasound imaging and a frame-by-frame cross-correlation algorithm to measure tissue excursion

4.3.1 Ultrasound imaging and a frame-by-frame cross-correlation algorithm to assess nerve excursion

USI has been used to visualize the course and branching of peripheral nerves in both the upper (Brochwicz, von Piekartz, & Zalpour, 2013; Coppieters, Hough, & Dilley, 2009; Dilley et al., 2001; Dilley, Summerhayes, & Lynn, 2007) and lower extremity (Carroll, Yau, Rome, & Hing, 2012; Ellis, 2011; Ridehalgh, Moore, & Hough, 2012). Peripheral nerves are able to move and slide independent of the surrounding tissue or 'mechanical interface,' this movement is influenced by and adaptable to limb movements (Dilley, Lynn, Greening, & DeLeon, 2003; Ellis, 2011; Shacklock, 1995). In conjunction with computer assisted data analysis techniques, USI can be used to analyse movement between adjacent tissue interfaces using cross-correlation analysis (Dilley et al., 2001). This method has been found to have excellent reliability when measuring longitudinal nerve movement in the median nerve (Coppieters et al., 2009; Dilley et al., 2001), sciatic nerve (Ellis et al., 2008; Ridehalgh et al., 2012) and tibial nerve (Carroll et al., 2012) and these reliability studies will be discussed.

4.3.1a Development of the frame-by-frame cross-correlation algorithm by Dilley et al. (2001), validity and reliability of the technique in measuring median nerve excursion

Dilley et al. (2001) developed the frame-by-frame cross-correlation algorithm using high-resolution USI to measure longitudinal nerve and muscle movement. The algorithm determines relative movement between successive frames in each sequence of ultrasound images by measuring the movement of fine speckle features in the region of interest (ROI) to be measured (eg nerve, tendon). The algorithm compares the ROI in the adjacent frames and calculates the correlation coefficient for each individual pixel shift.

To test the validity of the algorithm, Dilley et al. (2001) performed a pilot study using “phantom” controls (string and avian sciatic nerve). The phantoms were fixed in a water bath and placed onto chart paper with a chart recorder attached and the US transducer was mounted on a micromanipulator and placed into the bath. The bath was moved a known distance at a constant velocity while the phantom was imaged. The results of the phantom experiment demonstrated the method was accurate and reliable at velocities of 1-10 mm/s.

In vivo experiments examined the accuracy of calculating precise movements in a control participant. The participant’s forearm was placed in the water bath and the transducer positioned over the median nerve for imaging. The transducer was moved a known distance over the forearm, for 1-3 mm. The algorithm successfully measured relative median nerve movement with <10% error. Different regions of tissue (nerve, tendon, muscle) were analysed from the same images and produced similar results.

Repeatability of the algorithm for median nerve sliding was then assessed during 0-30° passive wrist extension (n=3) and index finger extension (n=7). Measures were repeated three or four times, the results demonstrated reliability in the repeat measures. ICCs were not calculated to determine reliability, instead reliability was indicated by low variability within sessions for both 30° passive wrist extension (SD 0.2–0.4 mm) and 30° passive index finger extension (SD 0.2–0.7 mm) (Dilley et al., 2001).

4.3.1b Coppieters et al. (2009) investigation of inter-rater reliability in measuring median nerve excursion

Coppieters et al. (2009) investigated longitudinal median nerve excursion *in vivo* using the cross-correlation algorithm during six nerve gliding exercises in n=15 healthy participants (n=8 females, n=7 males; mean \pm SD age 30 \pm 8 years; height 169 \pm 12 cm; weight 64 \pm 13 kg). The nerve

mobilisation techniques involved elbow and cervical spine movements, the results demonstrated different techniques produced different amounts of nerve excursion ($p < 0.0001$). Coppieters et al. (2009) appear to be the only study that has evaluated inter-rater reliability for the cross-correlation method. Three assessors were used to analyse the USI data for the sliding technique in the first 10 participants. 'Excellent' inter-rater reliability was demonstrated (ICC=0.96, 95%CI = 0.883 - 0.988) with small measurement error (SEM=0.66 mm).

4.3.1c Ellis et al. (2008) investigation of intra-rater reliability in measuring sciatic nerve excursion

Ellis et al. (2008) investigated intra-rater reliability transverse and longitudinal sciatic nerve excursion using the frame-by-frame cross-correlation algorithm during a modified slump test neural mobilisation technique (ankle dorsiflexion/plantar flexion and cervical extension/flexion) in n=27 participants (n=14 females, n=13 males; mean \pm SD age 22.82 \pm 4.61 years, range 18-38 years). The sciatic nerve was imaged at two locations, the posterior midthigh (PMT) and popliteal crease (PC). To measure transverse nerve excursion, static USI images were taken at the start and stop positions of the mobilization exercise. Within each image, digital markers were placed at the lateral-medial and anterior-posterior boundaries of the nerve (AP movement). Digital callipers measured the distance between the markers on each image. The procedure was repeated for the medial-lateral boundaries (lateral movement). Three measurements were taken at 1 min intervals. To measure longitudinal nerve excursion the cross-correlation algorithm was used for three measurements.

The reliability of transverse sciatic nerve excursion was 'fair to excellent' (ICC=0.39–0.76).

Results demonstrated increased nerve movement at the PC over the PMT for both lateral and AP transverse movements. Lateral transverse movements had more excursion than AP movements at both locations. Reliability at the PMT for lateral sciatic movement was 'excellent' (ICC=0.76, 95%CI = 0.60 - 0.87, SEM \pm 1.18 mm), compared with the AP movement which had 'fair' reliability (ICC=0.39, 95%CI = 0.15 - 0.63, SEM \pm 0.78 mm). Reliability at the PC was considered 'fair' for both the lateral sciatic movement (ICC=0.70, 95%CI = 0.51 - 0.84, SEM \pm 1.10 mm), and AP movement (ICC=0.56, 95%CI = 0.34 - 0.75, SEM \pm 0.99 mm).

The results indicated USI and cross-correlation analysis was a highly reliable method for measuring longitudinal nerve excursion, as reliability of longitudinal sciatic nerve movement at the PMT was 'excellent' (ICC = 0.75, 95%CI = 0.59 - 0.87, SEM \pm 0.79 mm). Reliability of longitudinal sciatic nerve movement at the PC was not possible to determine as the nerve moved beyond the image field and data was only recorded for 3 participants. This movement during the mobilisation exercise was

attributed to a region of 'high compliance' behind the knee, where there is more space for the nerve to move freely (Ellis et al., 2008).

4.3.1d Ridehalgh et al. (2012) investigation of repeatability in measuring sciatic nerve excursion

Ridehalgh et al. (2012) established repeatability of the frame-by-frame cross-correlation method for assessing longitudinal sciatic nerve excursion during a modified passive straight leg raise (SLR) test in n=18 participants (n=9 males, n=9 females; mean \pm SD age 28.9 \pm 14.3 years, range 19-68 years). The sciatic nerve was imaged in the posterior thigh, participants lay on their side, a 'purpose made jig' was used to allow the hip to be positioned in 30° and 60° of hip flexion. The knee was passively moved into extension from 90° to 0° in three steps to ensure the nerve stayed within the field of view. The sciatic nerve was imaged in 30° of hip flexion during passive knee extension, where the 'start' position was 90° and the 'stop' position was 0°, the procedure was repeated for 60° hip flexion. The procedure was repeated 48 hr to 1 week later. Longitudinal sciatic nerve excursion was analysed using cross-correlation software.

Results demonstrated 'excellent' repeatability for both 30° (ICC=0.92, 95%CI = 0.79 - 0.97, SEM= 0.69) and 60° (ICC=0.96, 95%CI = 0.89 - 0.99, SEM= 0.87) of hip flexion during the modified SLR. The ICC values determined by Ridehalgh et al. (2012) were higher than those determined by Ellis et al. (2008), with narrower confidence intervals. In addition, the magnitude of sciatic nerve excursion was larger than those found by Ellis et al. (2008), this was attributed to joint movement closer to the region of scanning (knee movement versus cervical and ankle movement). Ridehalgh et al. (2012) determined breaking down large movements into smaller ones allowed for optimal imaging of the nerve, to assist the tracking software in visualising the nerve, although they recognised any validity errors in amount of movement would be tripled.

4.3.1e Carroll et al. (2012) investigation of intra-rater reliability in measuring tibial nerve excursion

Carroll et al. (2012) quantified longitudinal tibial nerve excursion during ankle dorsiflexion in a weight-bearing position and investigated intra-rater reliability of measuring longitudinal tibial nerve excursion using USI and the frame-by-frame cross-correlation algorithm, in n=16 healthy participants (n=10 female, n=6 male; mean \pm SD age 34.7 \pm 9.3 years). Participants were positioned in weight-bearing on a platform that allowed one foot to move from 20° plantarflexion to 10° dorsiflexion while the tibial nerve was imaged, for 3 measurements. There was a 5 min interval between session 1 and 2.

Results demonstrated intra-rater reliability of longitudinal tibial nerve excursion was 'excellent' (ICC =0.93, 95%CI = 0.70 - 0.96). There was low standard error of measurement for both session 1 and 2 (SEM=0.28 and 0.22 mm), but high smallest real difference (SRD) values (SRD= 0.84 and 0.66 mm) and high SRD percentage values (SRD%=27 and 22%) indicating 'relatively large' measurement error.

4.3.2 Ultrasound imaging and a frame-by-frame cross-correlation algorithm to assess tendon excursion

It appears there are only two studies that have investigated tendon excursion using Dilley et al.'s (2001) frame-by-frame cross-correlation algorithm, and both studies involved tendons in the wrist (Chen, Tsubota, Aoki, Echigo, & Han, 2009; Kelly, 2011). Although Chen et al. (2009) were the first to utilise USI with Dilley et al.'s (2001) frame-by-frame cross-correlation algorithm to investigate tendon excursion, no reliability analyses were explored. Kelly (2011) is the first, and only, study to date that has investigated any form of reliability of the technique, for measuring tendon excursion.

4.3.2a Kelly (2011) investigation of extensor pollicis brevis tendon excursion

Kelly (2011) investigated extensor pollicis brevis (EPB) tendon excursion at the wrist and the intra- and inter-session reliability of using USI and a cross-correlation algorithm to measure tendon excursion. EPB excursion was quantified through full thumb extension to full flexion in three wrist position (45° extension, neutral, 45° flexion) in n=49 normal EPB tendons (n=25 participants, mean \pm SD age 40.7 \pm 12.8 years). This was the first study to establish any form of reliability using USI and the frame-by-frame cross-correlation algorithm to assess tendon excursion. Results demonstrated 'high to excellent' reliability for both intra-session data from session 1 and session 2 (ICC=0.88, 95%CI = 0.84 - 0.91 and ICC=0.87, 95%CI = 0.92 - 0.90), and inter-session (ICC=0.76, 95%CI = 0.66 - 0.83) data (Kelly, 2011). Kelly (2011) concluded USI and the cross-correlation algorithm is a reliable method for measuring tendon excursion.

4.3.3 Ultrasound imaging of fascial excursion and sliding

To date, there appears to be no literature utilising this cross-correlation algorithm or any other automated tracking method to quantify fascial excursion.

5. Ankle Range of Motion

5.1 Ankle range of motion normative values

5.1.1 Normal and abnormal dorsiflexion ranges

There is inconsistency in the literature on what constitutes ‘normal’ dorsiflexion ROM, with values ranging from 13° to 30° (Boone & Azen, 1979; Cornwall & McPoil, 1999; Hoppenfeld, 1976; Kapandji, 2010; Kitaoka, Luo, & An, 1997; Magee, 2006; Roaas & Andersson, 1982; Soucie et al., 2011). Hoppenfeld (1976) states normal passive ankle dorsiflexion ROM is 20°. Cornwall and McPoil (1999) also claim approximately 20° is generally accepted as the value for passive ankle dorsiflexion ROM. In contrast, a study by Boone and Azen (1979) measured active dorsiflexion ROM, with a goniometer, in n=109 males aged 18-54 years and found the average ROM was 12.6°± 4.4°. Macedo and Magee (2009) determined passive dorsiflexion ROM, with a goniometer, in n=90 women aged 18-59 years was 13°± 9°. The findings of these two studies conflict with the American Academy of Orthopaedic Surgeons and the American Medical Association whose databases both report 20° as normal dorsiflexion ROM (Macedo & Magee, 2009), although statistical tests were not run to determine if these differences are significant.

A more recent study by Soucie et al. (2011) established normative joint ROM values in the upper and lower limbs using standard goniometry to measure passive ROM in n=674 healthy men and women, aged 2-69 years. Mean passive ankle dorsiflexion ROM measurements were presented for normal ROM; results are summarized in Table 1.

Table 1: Ankle ROM normative values by age and gender (95%CI)

Age (years)	Dorsiflexion		Plantarflexion	
	Females	Males	Females	Males
2-8	24.8° (22.5-27.1)	22.8° (21.3 – 24.3)	67.1 (64.8–69.4)	55.8 (54.4–57.2)
9-19	17.3° (15.6-19)	16.3° (14.9-17.7)	57.3 (54.8–59.8)	52.8 (50.8–54.8)
20-44	13.8° (12.9-14.7)	12.7° (11.6-13.8)	62.1 (60.6–63.6)	54.6 (53.2–56.0)
45-69	11.6° (10.6-12.6)	11.9° (10.9-12.9)	56.5 (55.0–58.0)	49.4 (47.7–51.1)

Adapted from Soucie et al. (2011).

Limited ankle dorsiflexion range, or ‘ankle equinus’, also lacks consensus on a definition, with reviews listing values that range from 0° to <20° (Charles, Scutter, & Buckley, 2010; DiGiovanni et al., 2002; Gatt & Chockalingam, 2011). Where various authors have reported equinus as 0° (Lavery, Armstrong, & Boulton, 2002; Sobel, Caselli, & Velez, 1997), <5° (Johnson & Christensen, 2005; Orendurff, Rohr, Sangeorzan, Weaver, & Czerniecki, 2006), <10° (DiGiovanni et al., 2002; Rome,

1996), and $<20^\circ$ (Brantingham, Lee Gilbert, Shaik, & Globe, 2006) of ankle dorsiflexion ROM. Charles et al. (2010) describe 5° or 10° ankle dorsiflexion as ankle equinus, where 10° represents the cutoff before gait changes occur and 5° represents the cutoff for increased forefoot loading. Charles et al. (2010) propose two stages in a definition of ankle equinus: stage 1 or $<10^\circ$ dorsiflexion indicates minor compensation and minor increased forefoot pressure, stage 2 or $<5^\circ$ dorsiflexion indicates major compensation and major increased forefoot pressure. According to Gatt and Chockalingam (2011), the podiatric medical definition of limited dorsiflexion ROM is $<10^\circ$ when the subtalar joint is in neutral.

5.1.2 Normal and abnormal plantarflexion ranges

The study by Boone and Azen (1979) found the average active plantarflexion ROM in males was $56.2^\circ \pm 6.1^\circ$. As with dorsiflexion ROM, Boone and Azen's findings contrast to the American Academy of Orthopaedic Surgeons, whose standard reference reports an average of 48° as normal plantarflexion ROM (Boone & Azen, 1979). Boone and Azen's findings are comparable to more recent findings by Macedo and Magee (2009) who determined passive plantarflexion in $n=90$ women aged 18-59 years was $60^\circ \pm 13^\circ$, these values are also similar to the normative values determined by Soucie et al. (2011) for passive plantarflexion (see Table 1).

5.2 Importance of adequate ankle range of motion

5.2.1 Functional movements requiring adequate ankle range of motion

Various authors state 10° of ankle dorsiflexion is required for normal gait (Charles et al., 2010; Hughes, 1985; Magee, 2006). If the ankle is prevented from reaching 10° of dorsiflexion, the subtalar joint will pronate to compensate and may provide apparent dorsiflexion up to 10° , this added pronation in the foot during gait is postulated to predispose towards foot pathology (Hughes, 1985). Several studies advocate balance and functional tasks such as walking quickly, going up and down stairs, and standing from a chair require adequate ankle dorsiflexion ranges to safely perform these tasks and reduce the risk of falls (Bohannon, Tiberio, & Waters, 1991; Nitz & Choy, 2004). There appears to be a lack of literature surrounding ankle plantarflexion, while there is a substantial amount of literature focused on ankle dorsiflexion, this is likely due to its functional requirements (eg gait). Whereas, plantarflexion range is more often required for performance enhancement in sports such as rowing (Soper, Reid, & Hume, 2004) and dancing (Dickson, Hollman-Gage, Ojofeitimi, & Bronner, 2012).

5.2.2 Health conditions predisposed by limited ankle dorsiflexion

Limitations in ankle dorsiflexion range have implications across a variety of age groups from children to the elderly and have been associated with a number of health conditions. Decreased dorsiflexion predisposes to compensatory subtalar pronation, which is a common cause of foot pathology such as metatarsal stress fractures (Hughes, 1985). Excessive subtalar pronation has also been identified as a risk factor for the development of patello-femoral pain syndrome (Barton, Bonanno, Levinger, & Menz, 2010; Tiberio, 1987) and Achilles tendinopathy (Nigg, 2001). Tabrizi, McIntyre, Quesnel and Howard (2000) demonstrated reduced dorsiflexion increases risk of ankle fracture and sprains in children. Pope et al. (1998) found limited ankle dorsiflexion ROM is significantly correlated with an increased risk of having an ankle sprain in army recruits. Additionally, limited ankle dorsiflexion has been associated with increased anterior cruciate ligament loading and risk of injury (Fong, Blackburn, Norcross, McGrath, & Padua, 2011).

Limited ankle dorsiflexion has also been linked as a predisposing factor for plantar fasciitis. Riddle et al. (2003) looked at several risk factors for plantar fasciitis in both men and women using a case-control design of n=50 participants with plantar fasciitis with two controls for each. Results demonstrated significant differences ($p < .001$) in limited ankle dorsiflexion for the plantar fasciitis group compared to the control group. Riddle et al. (2003) determined the most important risk factor for developing plantar fasciitis was limited ankle dorsiflexion. A recent study of n=100 participants, n=50 with plantar fasciitis and n=50 controls determined 'tightness' of the posterior lower limb muscles, including the triceps surae, was associated with plantar fasciitis. Where significant differences were demonstrated between the plantar fasciitis and control groups in limited ankle dorsiflexion ROM with the knee extended (ICC=0.99, 95%CI = 0.972 - 0.999) and flexed (ICC=0.95, 95%CI = 0.795 - 0.997) (Bolívar, Munuera, & Padillo, 2013). This result is supported by an anatomical and radiological study of the plantar fascia and its relationship to the AT (Stecco, Corradin, et al., 2013). Results determined a statistically significant correlation ($p < 0.001$) between thickness of the PF and the Achilles paratenon in participants with Achilles tendinopathy, supporting the relationship between triceps surae involvement in plantar fasciitis (Stecco, Corradin, et al., 2013).

5.3 Anatomical structures associated with decreased ankle range of motion

5.3.1 Anatomical structures associated with limited ankle dorsiflexion range of motion

There are various causative factors implicated in limited ankle dorsiflexion ROM including: muscular, capsular, articular, fascial and neurological disorders. Gastrocnemius and soleus tightness can cause

a reduction in dorsiflexion ROM (Denegar, Hertel, & Fonseca, 2002; Prior, 1999; You et al., 2009), where the stiffness is found within the muscle bellies, rather than the Achilles tendon (DiGiovanni et al., 2002). Magee (2006) also states when the knee is extended, a tight gastrocnemius can limit dorsiflexion, and if the knee is flexed a tight soleus can limit dorsiflexion. Capsular restrictions may be implicated in decreased dorsiflexion (Denegar et al., 2002), however, Magee (2006) claims capsular restrictions in the ankle usually limit plantarflexion rather than dorsiflexion. Ankle adhesive capsulitis can limit dorsiflexion ranges (Lui, Chan, & Chan, 2006). An anteriorly subluxed talus, loss of posterior glide of the talus, or loss of accessory motions in the foot can limit dorsiflexion ROM (Denegar et al., 2002; Hertel, 2002; Hoch & McKeon, 2011). Grieve et al. (2011) discusses myofascial trigger points (MTrPs) have been associated with limited joint ROM, and lists MTrPs in soleus as a cause of ankle dorsiflexion restriction. MTrPs are defined by Travell and Simons (1992) as hyperirritable areas within taut bands of skeletal muscle or fascia, and are usually considered as 'active' trigger points and 'latent' trigger points. Both active and latent MTrPs cause motor dysfunction, with active causing pain and latent causing muscle shortening and increased muscle tension, leading to decreased ROM (Simons, Travell, & Simons, 1999). Neurological disorders, such as cerebral palsy, causing spasticity in the gastrocnemius and soleus muscles, can lead to muscle contracture and decreased dorsiflexion range of motion (Hagglund & Wagner, 2011).

5.3.2 Anatomical structures associated with decreased ankle plantarflexion range of motion

As previously discussed, there appears to be a lack of literature surrounding ankle plantarflexion. Muscular, capsular, articular and fascial structures could all play a role in limiting ankle plantarflexion. For instance tightness in the anterior leg muscles (eg tibialis anterior), restriction in the ankle retinacula or tension of the talofibular ligament could all reasonably impact on available plantarflexion ROM. Additionally, posterior ankle impingement, may result in a loss of plantarflexion ROM due to presence of an os trigonum, loose body, or soft tissue injuries within the posterior aspect of the ankle (Dimmick & Linklater, 2013).

5.4 Measures of ankle dorsiflexion and plantarflexion range of motion

Goniometry is commonly used to measure ankle ROM (Gatt & Chockalingam, 2012; Martin & McPoil, 2005). A review of ankle goniometry by Martin and McPoil (2005) concluded there is poor-acceptable inter-rater reliability for ankle dorsiflexion measurements and limited inter-rater reliability for plantarflexion measurements. A systematic review by Gatt and Chockalingam (2011) reported standard ROM goniometric measurement is unreliable. The study identified 87 articles discussing ankle dorsiflexion measurement techniques, and reviewed them to investigate more reliable alternatives to goniometry; 10 techniques were reviewed and reported to demonstrate

satisfactory reliability, including the weight-bearing lunge test. In addition, electrogoniometry has been demonstrated to be a reliable method for measure ankle ROM (Bronner, Agraharasamakulam, & Ojofeitimi, 2010; Rome & Cowieson, 1996; Soper et al., 2004).

5.4.1 Weight-bearing lunge test

The weight-bearing lunge test (WBLT) is commonly used to assess ankle dorsiflexion ROM (Bennell, Talbot, Wajswelner, Techovanich, & Kelly, 1998; Denegar et al., 2002; Krause, Cloud, Forster, Schrank, & Hollman, 2011; Vicenzino, Branjerdporn, Teys, & Jordan, 2006). The main advantage of this measure is it is performed in a weight-bearing position, which is more likely to replicate function than non-weight-bearing measurements of dorsiflexion (Bennell et al., 1998). Therefore, measurements from the WBLT are more representative of the available range for functional tasks (Bennell et al., 1998) as the WBLT reflects the typical position activities of daily living are performed in (Barton et al., 2010; McPoil & Hunt, 1995). Other benefits include it is cost and time efficient, easy to perform and does not require much equipment (Bennell et al., 1998). Bennell et al. (1998) investigated the inter-rater and intra-rater reliability of the WBLT by measuring the distance from the tip of the great toe to the wall and the angle of the tibial shaft from the vertical, and reported both the distance and angle measurements had 'excellent' intra-rater reliability for the two raters (ICC> 0.97, 95%CI = 0.93 - 0.99; and ICC=0.98, 95%CI = 0.93 - 0.99) and 'excellent' inter-rater reliability (ICC=0.99, 95%CI = 0.97 - 0.99; and ICC=0.97, 95%CI = 0.90 - 0.99) and supported the use of WBLT as an objective measurement of dorsiflexion. Other authors have also found the WBLT to be reliable (Krause et al., 2011), including in a novice rater (Konor, Morton, Eckerson, & Grindstaff, 2012). Krause et al. (2011) investigated intra- and inter-rater reliability of ankle dorsiflexion measurement techniques, including active and passive goniometry and the WBLT. Results demonstrated the WBLT was the most reliable position with 'excellent' intra-reliability for raters 1 and 2 (ICC=0.88, 95%CI = 0.78 - 0.93; and ICC=0.89, 95%CI = 0.80 - 0.94) and 'excellent' inter-rater reliability (ICC=0.82, 95%CI=0.68 - 0.90). Konor et al. (2012) compared measurement of the WBLT using a standard goniometer, digital inclinometer, and a tape measure using the distance-to-wall technique and determined all had 'good' reliability (ICC> 0.85, 95%CI) when measured by a novice rater with no prior experience.

5.4.2 Electrogoniometry to measure ankle range of motion

An electrogoniometer is an electronic version of the standard goniometer used to measure joint ROM, it measures the angular displacement between the two flexible arms (Bronner et al., 2010). Rome and Cowieson (1996) investigated the reliability of the electrogoniometer to measure ankle dorsiflexion. Intra-rater reliability was assessed using n=1 rater and n=8 participants. Inter-rater

reliability was assessed using n=5 raters and n=5 participants. Results demonstrated 'good intra-device reliability' (SD=2.1 to 4.0) when using a standardized procedure. Intra-rater reliability (SD=2.6 and 4.3) was higher than inter-rater reliability (SD=3.8 to 6.5). The authors concluded the electrogoniometer was reliable for assessing ankle dorsiflexion in healthy participants when used by the same rater with the same device. They recognized due to the small sample size their results may not be widely applicable (Rome & Cowieson, 1996).

Soper et al. (2004) determined the reliability of measuring active and passive dorsiflexion and plantarflexion ankle ROM using an electrogoniometer (n=10). For the active measurements, participants were seated in a chair, holding the leg behind the thigh (to take tension off the gastrocnemius muscle), with the hip and knee in flexion. Participants maximally plantarflexed and dorsiflexed their ankle, end-range was determined as the 'maximum tolerable position'. For the passive ankle plantarflexion measurement, the participant stood in a traditional quadriceps stretch (knee flexed, foot held by the same side hand). The knee was moved anteriorly to remove tension from the hip flexors and the participant applied pressure to the dorsal surface of the foot to produce maximum ankle plantarflexion. Passive ankle dorsiflexion was measured using a modified WBLLT. Participants stood with feet parallel, shoulder width apart and flexed their knees 'as much as possible' keeping the knee in line with the first toe and the heel on the ground. Soper et al. (2004) established 'high' reliability for all four measurements between the two sessions using Pearson's correlation coefficient and SEM ($r = 0.90$ to 0.95 ; highest SEM = 2.8° , 95%CI = $1.9 - 5.1^\circ$) where within-subject variation between the two session, expressed as the SEM ranged from 1.5 to 2.8° (Soper et al., 2004).

Bronner et al. (2010) established the reliability, accuracy and concurrent validity of electrogoniometry for measuring extreme lower extremity movements (n=17 dancers). For the ankle, instrument correlations were all 'high' (ICC ≥ 0.998) as were intra-rater reliability (SEM $\leq 3.63^\circ$), and concurrent validity correlations (ICC ≥ 0.954 , SEM $\leq 6.77^\circ$) to motion analysis.

5.5 Myofascial interventions effecting ankle joint range of motion

Myofascial interventions encompass a wide spectrum of techniques including: osteopathic soft-tissue techniques, structural integration (Rolfing), massage, instrument assisted fascial release (eg GrastonTM technique), trigger point release, strain-counterstrain and muscle energy techniques (Simmonds et al., 2012). There are numerous interventions that aim to increase ankle dorsiflexion ROM via myofascial techniques (Grieve et al., 2011; Grieve et al., 2013; Schaefer & Sandrey, 2012; A. Stecco et al., 2011) or triceps surae stretching (Gajdosik, Vander Linden, McNair, Williams, & Riggin,

2005; Johanson et al., 2006; Macklin, Healy, & Chockalingam, 2012). Studies using MTrP release on triceps surae trigger points have demonstrated statistically significant increases in ankle dorsiflexion ROM (Grieve et al., 2011; Grieve et al., 2013) by lengthening sarcomeres and reducing muscle tension (Simons, 2004). Additionally, a study investigating the effect of an 8-week calf stretching program in runners with limited ankle dorsiflexion, determined significant increases ($p \leq 0.05$) in dorsiflexion ROM (Macklin et al., 2012).

A review investigating non-surgical interventions for increasing ankle joint dorsiflexion in healthy individuals concluded there is some evidence to support the efficacy of stretching alone or combined with other therapies (such as ultrasound, heat), however, there was insufficient evidence for MTrP, joint mobilisation or manipulation therapies. The authors note there is a paucity of quality evidence and further research is required (Young, Nix, Wholohan, Bradhurst, & Reed, 2013).

6. Rationale for proposed study

This review of various forms of reliability for measurement techniques, used to examine nerve and tendon excursion, utilising high-resolution-USI and Dilley et al.'s (2001) frame-by-frame cross-correlation method has demonstrated confidence in the reliability of this measurement technique for tissue excursion. Therefore, this thesis proposes there is sufficient reliability to support the use of high-resolution-USI and Dilley et al.'s (2001) frame-by-frame cross-correlation method to measure tissue excursion in the CF and AT.

In conclusion, further research is required to quantify AT excursion *in vivo* during both passive and particularly, active movement. In addition, research is required to investigate CF excursion and the potential role of sliding and fascial restriction in limited ankle dorsiflexion and in the pathogenesis and treatment of AT disorders including Achilles tendinopathy, AT rupture, and plantar fasciitis. Section 2 of this thesis reports a pilot investigation of the reliability of measuring CF and AT excursion, during active and passive ankle movements, using high-resolution-USI and cross-correlation methods.

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SECTION II – Manuscript

Note: The following manuscript was prepared in accordance with the Instructions for Authors for the Journal of Bodywork and Movement Therapies [see Appendix H]. The required word limit and references have been exceeded in order for full evaluation and discussion of the results in this thesis.

Reliability of crural fascia and Achilles tendon excursion using ultrasound imaging: A pilot study

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Abstract

Reliability of crural fascia and Achilles tendon excursion using ultrasound imaging: A pilot study

Background: There has been recent interest in the role of gliding and sliding of connective tissue, such as tendons and fascia, in joint dysfunction. To date there are few studies that have investigated Achilles tendon (AT) excursion *in vivo*, and none that have investigated crural fascia (CF) excursion. Quantifying CF and AT excursion could provide valuable baseline information in relation to aetiology, diagnosis and management of AT disorders such as AT tendinopathy, and AT ruptures. *Aim:* i) to establish the intra- and inter-session reliability of high-resolution-ultrasound imaging (USI) to quantify tissue excursion of the CF and AT; and ii) undertake a preliminary assessment of CF and AT excursion and explore the correlation with ankle dorsiflexion range of motion (ROM). *Methods:* High-resolution, B-mode, USI and a cross-correlation algorithm were utilised to investigate longitudinal CF and AT excursion (n=10 participants, mean \pm SD age=34.7 \pm 18.9 years), through total ankle ROM. Participants attended two data collection sessions. The reliability of extracting excursion measurements from cine-loops was analysed for the CF and AT. Intra-session and inter-session (intra-rater) reliability was analysed for AT excursion. *Results:* Extraction reliability for the CF was 'moderate' (ICC = 0.56 (95%CI = -0.11 – 0.88), while the AT was 'very good' (ICC = 0.86, 95%CI = 0.53 – 0.96). AT excursion was 14.25 \pm 4.86mm during active ROM and 12.26 \pm 5.55 mm during passive ROM. ICCs for all intra-session AT excursion data were 'very large' or 'nearly perfect' (ICC=0.89, 95%CI = 0.57 – 0.97 for active ROM; and ICC=0.96, 95%CI = 0.84 – 0.99 for passive ROM). ICCs for inter-session AT excursion data were 'very large' (ICC=0.80, 95%CI =0.19 – 0.95 for active ROM; and ICC=0.88, 95%CI =0.53 – 0.97 for passive ROM). There was a 'large' statistically significant correlation between passive plantarflexion ROM and passive AT excursion ($r=0.67$, $p=0.04$). *Conclusion:* Frame-by-frame cross correlation analysis of AT excursion during active and passive movement *in vivo* is reliable. Establishing normative data for AT excursion in large samples is recommended, as it would provide a baseline to use in the assessment of AT excursion for post-surgery and post rehabilitation interventions. Future studies evaluating and comparing AT excursion in populations with AT pathology such as tendinopathy are of clinical value and may inform ideas about the aetiology and management of AT disorders.

MeSH Keywords: Fascia; Tendon, Achilles; Ankle Joints; Joint Range of Motion; Ultrasound Imaging

Introduction

Fascia is connective tissue composed primarily of collagen and elastic fibres and provides continuity and connection between anatomical structures (Chaudhry et al., 2008; Schleip, 2003; Schleip, Klingler, & Lehmann-Horn, 2005; Schwind, 2006). The crural fascia (CF) is a layer that surrounds all of the posterior muscles in the calf (Carmont, Highland, Rochester, Paling, & Davies, 2011). The CF is composed of several layers that have the capacity to slide on one another (Stecco et al., 2008), as well as slide on the underlying gastrocnemius muscle (Stecco et al., 2009). Currently, most studies of the CF have investigated its anatomical and histological makeup. A recent study began a preliminary investigation of the mechanical properties of the CF, which discussed three main characteristics of the CF: anisotropy, non-linear stress-strain relationship and viscoelasticity (Stecco, Pavan, Pachera, De Caro, & Natali, 2014). Stecco et al. (2011) propose that the ability of these fascial layers to slide may be altered in myofascial pathologies, including overuse syndromes, trauma and surgery.

The Achilles tendon (AT) is formed at the musculotendinous junction of the gastrocnemius and soleus muscles (triceps surae muscle group) located in the posterior, superficial compartment of the calf (O'Brien, 2005). The AT is surrounded by a thin paratenon, rather than a synovial sheath, and this paratenon permits a gliding movement of the tendon within the surrounding tissues (Carmont et al., 2011; O'Brien, 2005; Paavola & Järvinen, 2005; Soila, Karjalainen, Aronen, Pihlajamaki, & Tirman, 1999; Wijesekera, Calder, & Lee, 2011). According to Franklyn-Miller et al. (2009) the paratenon is histologically similar to the fascia surrounding the gastrocnemius muscle, implying the paratenon is a layer of the CF. Similarly, a more recent anatomical study demonstrated the CF is continuous with the paratenon (Stecco et al., 2012).

Tendon excursion (magnitude of movement) and gliding (quality of movement) determine the efficiency with which the tendon is able to transmit muscle forces to the skeletal system (An, 2007). Quantification of tissue movement within and between the AT and CF is an important step to investigating the role of fascial restrictions and impaired tendon excursion in the pathogenesis of AT disorders. When the deep fascia is disrupted, scar tissue may form between fascial layers and limit gliding movement (McCombe, Brown, Slavin, & Morrison, 2001). Furthermore, during tendon healing, scar tissue can result in adhesion formation which may impair tendon gliding (Sharma & Maffulli, 2005). For instance, due to inflammation in the surrounding fascia, adhesions may develop and adhere to the AT, creating abnormal loading of the tendon, and has been suggested as a precursor to Achilles tendinopathy (Franklyn-Miller et al., 2009). A recent magnetic resonance

imaging study demonstrated a statistically significant difference in thickness of the CF ($p < 0.005$) and the paratenon ($p < 0.0001$) in patients with tendinopathy compared to healthy controls (Stecco, Cappellari, et al., 2013). Additionally, a recent anatomical study reported a statistically significant difference ($p < 0.001$) between the thickness of the plantar fascia in the group with Achilles tendinopathy and the group with no AT pathology (Stecco, Corradin, et al., 2013). Stecco et al.'s (2013) finding supports a study identifying tightness in the triceps surae and hamstring muscles in patients with plantar fasciitis (Bolívar, Munuera, & Padillo, 2013). Bolívar et al. (2013) recommended stretching protocols to target the posterior leg muscles (the triceps surae and hamstrings) to increase ankle dorsiflexion in the treatment of plantar fasciitis. Knowledge of *in vivo* CF and AT excursion could provide valuable baseline information for use in future studies in relation to aetiology, diagnosis and management of AT disorders such as AT tendinopathy, and AT ruptures. Data on *in vivo* AT excursion may also be useful for tendon surgery and post-operative rehabilitation as the formation of adhesions post-surgery is a common complication (Khan & Carey Smith, 2010).

Loss of ankle dorsiflexion range of motion (ROM) has been implicated as a causative factor in Achilles tendinopathy (Kaufman, Brodine, Shaffer, Johnson, & Cullison, 1999). Additionally, limited ankle dorsiflexion ROM may have a number of other health consequences including a predisposition for the development of plantar fasciitis (Bolívar et al., 2013; Riddle, Pulisic, Pidcoe, & Johnson, 2003). Although there is inconsistency in the literature on what is 'normal' and 'limited' dorsiflexion ROM, the podiatric medical definition of limited dorsiflexion ROM is $<10^\circ$ when the subtalar joint is in neutral (Gatt & Chockalingam, 2011). Several causative factors have been implicated in limitation of ankle dorsiflexion including: muscular (Denegar, Hertel, & Fonseca, 2002; Prior, 1999; You et al., 2009), fascial (Grieve et al., 2011; Stecco, Macchi, et al., 2011), capsular (Denegar et al., 2002), articular (Denegar et al., 2002; Hertel, 2002; Hoch & McKeon, 2011), and neurological disorders (Hagglund & Wagner, 2011). Identifying patients with limited ankle dorsiflexion associated with fascial restrictions and decreased AT excursion is important in the diagnosis and treatment of the above mentioned pathologies.

A number of manual therapy techniques have been described that address 'fascial restrictions' within the posterior leg, including: Rolfing, myofascial trigger-point release (MTrP), soft-tissue and muscle energy techniques (Simmonds, Miller, & Gemmell, 2012). For example, studies using MTrP release on triceps surae trigger points have demonstrated statistically significant increases in ankle dorsiflexion ROM (Grieve et al., 2011; Grieve et al., 2013). A plausible mechanism for this increase in ROM is via lengthening sarcomeres and reducing muscle tension (Simons, 2004).

Ultrasound imaging (USI) is useful for examination of the AT and diagnosis of Achilles tendinopathy, and AT rupture (Daftary & Adler, 2009; Nandra, Matharu, & Porter, 2012; Rupp, Tempelhof, & Fritsch, 1995). There is a broad spectrum of literature on the AT *in vivo*. To date, interest has been more on AT mechanical properties (Kongsgaard, Nielsen, Hegnsvad, Aagaard, & Magnusson, 2011; Maganaris & Paul, 2002), and muscle fascicle behaviour, with studies investigating fascicle length and excursion (Joseph, Lillie, Bergeron, & Denegar, 2012; Kwah, Pinto, Diong, & Herbert, 2013; Sakuma, Kanehisa, Yanai, Fukunaga, & Kawakami, 2012).

USI has been used to visualise the soft tissue structures of the posterior leg (Carmont et al., 2011; Joseph et al., 2012), including the deep fascia (Stecco, Stern, et al., 2011), and may be useful in quantifying the capacity for these layers to slide. Previous studies have analysed USI images using a frame-by-frame cross-correlation algorithm to assess tissue motion (Dilley, Greening, Lynn, Leary, & Morris, 2001). This method has been used to examine peripheral nerve movement in the upper (Brochwicz, von Piekartz, & Zalpour, 2013; Coppieters, Hough, & Dilley, 2009; Dilley et al., 2001; Dilley, Lynn, Greening, & DeLeon, 2003) and lower extremity (Carroll, Yau, Rome, & Hing, 2012; Ellis, Hing, Dilley, & McNair, 2008; Ridehalgh, Moore, & Hough, 2012; Shum, Attenborough, Marsden, & Hough, 2013), as well as, tendon excursion in the upper extremity (Chen, Tsubota, Aoki, Echigo, & Han, 2009; Kelly, 2011). In both tissue types, this method has been found to be reliable for measuring tissue excursion (Carroll et al., 2012; Coppieters et al., 2009; Dilley et al., 2001; Ellis et al., 2008; Kelly, 2011; Ridehalgh et al., 2012). Several studies have investigated AT excursion *in vivo* using USI (Arndt, Bengtsson, Peolsson, Thorstensson, & Movin, 2012; Lee, Lewis, & Piazza, 2008; Pearson, Ritchings, & Mohamed, 2013). Lee et al. (2008) used an automated tracking algorithm to measure passive AT excursion. Arndt et al. (2012) investigated intra-tissue AT excursion, which quantified non-uniform AT excursion within three layers of the AT during passive ankle ROM. Pearson et al. (2013) also investigated AT excursion using an automated tracking method during passive ROM, and appears to be the first study to investigate AT excursion during active ankle ROM. To date, there have been no studies measuring longitudinal AT excursion using the frame-by-frame cross-correlation analysis developed by Dilley et al (2001), and no studies investigating CF excursion with USI using this method or other similar methods.

Therefore, the primary aim of this study was to establish the intra- and inter-session reliability of high-resolution-USI to quantify tissue excursion of the CF and AT. The secondary aim was to undertake a preliminary assessment of CF and AT excursion and explore the correlation with ankle dorsiflexion range.

Methods

Experimental approach to the problem

Due to the exploratory nature of characterising tissue excursion of the CF and AT, the methodological approach was to collect USI data on the posterior leg to visualise and assess both tissue types and determine the reliability of measurement for each. Prior to analysis of all ultrasound videos, the extraction reliability was determined for each tissue to establish the technical limits for analysis. This step was undertaken to ensure the tissue movement recorded was the true value for the video and not dependent on the researcher extracting that data.

Study Design

Intra- and inter-session reliability of tissue excursion measures, calculated using both active and passive ankle movements, were undertaken. See Figure 1 for detailed study design schematic. To explore the relationship between ankle range and tissue excursion in the posterior leg, data on tissue excursion was correlated with active and passive ankle ROM.

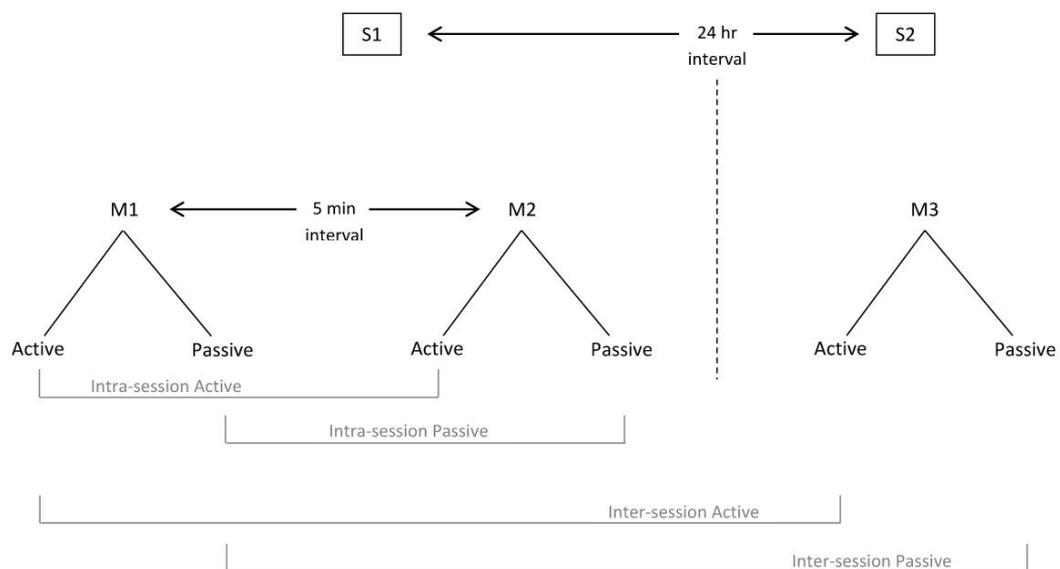


Figure 1. Study design schematic. S1=Session 1; S2=Session 2; M1= Measurement 1; M2=Measurement 2; M3=Measurement 3; Grey bars indicate contrast between measures; Active refers to active movement; Passive refers to passive movement. M1 and M2 were used to calculate intra-session reliability. M1 and M3 were used to calculate inter-session reliability. M1 was selected over M2 for the inter-session reliability calculation to control for the effect M1 could have had on M2, due to the short interval between these measurements.

Participants

Participants were eligible to participate if they were aged ≥ 18 years. Participants were excluded if they had a systemic health condition that might impair joint mobility (eg rheumatoid arthritis), or had a neurological disorder causing muscle spasticity or contracture (eg cerebral palsy). All participants gave written informed consent. The study was approved by the Unitec Research Ethics Committee (UREC Approval 2012-1089).

Previous studies have found ankle dorsiflexion ROM is similar between left and right sides (Backer & Kofoed, 1989; Moseley, Crosbie, & Adams, 2001; Roaas & Andersson, 1982), therefore, the side that was utilised to collect USI data from was randomly selected by a coin toss.

Measures

Ultrasound Parameters and Imaging

To investigate tissue excursion of the CF and AT, high-resolution, B-mode, real-time USI was performed on the posterior leg using a Philips iu22 (Philips Medical Systems Co., Eindhoven, The Netherlands) diagnostic ultrasound machine, with a L15-7io Linear Transducer. The transducer was selected as the upper operating limit of 15MHz is appropriate for examining superficial structures, such as the CF and AT, in fine detail. The linear property is an advantage of this transducer due to its wide 'near field' which is appropriate for imaging small superficial structures (McKinnis, 2005). The transducer was oriented longitudinally to the AT, this orientation was consistently repeated for each measure (see Figure 2B). Ultrasound transmission gel was applied to the transducer. The depth of imaging was taken at 2cm due to the superficial location of the CF and AT. All USI scans were performed by one operator [E.D.]. Cine-loop recordings of 3 s duration were captured at a frequency of 30Hz, commencing from full plantarflexion throughout the total ankle range until maximum dorsiflexion was reached. Recordings of active ankle ROM were followed by passive ROM.

ROM measures

To investigate the correlation between ankle ROM and tissue excursion of the CF and AT, active and passive ankle ROM measurements were collected using an electrogoniometer (Biometrics Ltd, Penny and Giles). The electrogoniometer was positioned on the selected ankle, with one arm in line with the fibular head and lateral malleolus, the other arm was placed in line with the fifth metatarsal (Soper, Reid, & Hume, 2004). The arms were positioned on the skin with doubled sided adhesive tape and secured with sports tape to prevent movement during the session (see Figure 2B). Prior to

all data collection, the electrogoniometer was calibrated to zero with the participant standing in a neutral ankle position.

Procedure

Identification of scanning point

A coin toss was used to select the left or right ankle for imaging. The scanning point was then determined with the following steps: i) participant standing on their toes in full ankle plantarflexion; ii) palpation was used to determine where the two heads of the gastrocnemius muscle meet and was used as the location to place a measuring tape; iii) the participant then stood in a neutral ankle position; iv) the distance was measured from the floor to where the two heads of the gastrocnemius muscle meet with a tape measure, 60% of this distance was calculated and used as the scanning location; v) A point was made on the skin using a marker; two lines were then drawn at the level of this point on the medial and lateral border of the Achilles tendon, the scanning point for the transducer was located between those lines, for all scans during that session; vi) The electrogoniometer was positioned and was not removed from the participant's ankle until all ROM measurements were recorded for that session. Participants performed 6 repetitions of the weight-bearing lunge test (described below) to provide a warm-up for the soft tissues and ankle joint prior to data collection.

Active and passive movement during USI

Participants were positioned on an examination table in prone, with the ankle positioned off the edge of the table, and a foam wedge below the knee to maintain a consistent knee angle in flexion, this position permitted full ankle ROM (see Figure 2A). The electrogoniometer was zeroed in full active plantarflexion, and was used to record the total ankle range available for that participant. The transducer was placed at the scanning site in the longitudinal plane, and a 3 s ultrasound cine-loop was recorded from the *Start* position in full plantarflexion to the *Stop* position in full dorsiflexion. For both active and passive measurements, the procedure was repeated until 4 to 7 clear trials were captured. Active measurements were performed prior to passive measurements.

For the active measurement, each participant was instructed to maximally plantarflex their ankle, then perform the dorsiflexion movement from the *Start* position to the *Stop* position in 3 s, keeping an even rate and smooth movement, then to pause at the *Stop* position until instructed to relax. Two familiarisation trials were performed prior to recording USI videos in order for the participants to learn the correct timing of movement.

For the passive measurement, a research assistant passively plantarflexed the ankle, to the range recorded as zero from the electrogoniometer. Then, while paying attention to maintain the ankle in subtalar neutral, the ankle was passively moved through dorsiflexion from the *Start* position to the *Stop* position, in 3 s. For both active and passive scans, the total ROM achieved from the *Start* to *Stop* position was recorded from the electrogoniometer, for each trial.

Between M1 and M2, the participant was positioned in supine for 5 min and the transducer was removed and repositioned for M2. The procedure was repeated for both active and passive measurements to obtain data for intra-session reliability.

Ankle ROM measurement protocol

Ankle ROM data was collected after USI on each session, as knowledge of ROM prior to USI may introduce bias into the measurement of tissue excursion. After the USI data was collected, the following ankle ROM parameters were recorded: active plantarflexion, active dorsiflexion, passive plantarflexion, and passive dorsiflexion. Active, then passive, ankle ROM measurements were recorded using an electrogoniometer. The electrogoniometer was re-zeroed with the participant standing in 0° of dorsiflexion. For active measurements, the participant was instructed to reach a maximum tolerable range for the movement. Each movement was performed three times and the mean range calculated.

Active plantarflexion and dorsiflexion

For the active measurements, the participant was positioned in supine and instructed to flex the hip and knee, holding the leg behind the thigh, removing tension from the gastrocnemius muscle (Soper et al., 2004). For active plantarflexion the participant was asked to maximally plantarflex the ankle, with the instruction: “point your foot and toes toward the floor as far as you can comfortably” (see Figure 2C for active plantarflexion position). From this same position, the participant was next instructed to maximally dorsiflex the ankle, with the instruction: “bring your foot and toes toward your shin as far as you can comfortably” (see Figure 2D for active dorsiflexion position).

Passive plantarflexion and dorsiflexion

For the passive ankle plantarflexion measurement, the participant was instructed to stand in a quadriceps stretch position, with the knee flexed and held by the same side hand, and the knee moved anteriorly to remove tension from the hip flexors (Soper et al., 2004). The participant then

applied pressure to the dorsal surface of the foot to produce maximum ankle plantarflexion (see Figure 2E for passive plantarflexion position).

The weight-bearing lunge test (WBLT) was used for the passive dorsiflexion measurement, this test is commonly used to assess ankle dorsiflexion ROM (Bennell, Talbot, Wajswelner, Techovanich, & Kelly, 1998; Denegar et al., 2002; Vicenzino, Branjerdporn, Teys, & Jordan, 2006). The participant stood facing the wall, and was instructed to lunge toward the wall so that the knee touched the wall, while staying in the same plane as the first toe, and while keeping the heel in contact with the floor. Maximum dorsiflexion was reached when no additional range could be produced without the heel lifting from the ground. The researcher anchored the participant's calcaneus to monitor and prevent the heel lifting from the floor (see Figure 2F for passive dorsiflexion position). Up to 5 lunging attempts were allowed to find the maximum distance from the wall where the subject could touch the wall with the knee, while maintaining heel contact with the floor. At the maximum lunge point, the range displayed by the electrogoniometer was recorded. The participant extended the knee between each lunge.



Figure 2 – Set up and procedures. (A) USI setup; (B) Transducer positioning; (C) Electrogoniometer placement and active plantarflexion position; (D) Active dorsiflexion position; (E) Passive plantarflexion position; (F) Passive dorsiflexion position.

Data Analysis

All data collection was completed for the three measurement series prior to any data analysis on AT excursion. Therefore the researcher (USI operator) did not have prior knowledge on tissue excursion for any participant. As measures were only extracted from cine-loops once for the intra- and inter-session reliability measurements, blinding was not required.

Selection of videos

During data collection, a minimum of four quality scans were taken for each active and passive measurement. All videos were reviewed and the three videos that satisfied the following criteria were chosen for analysis: clear pixelation of the CF and AT layers visible through the full ankle ROM; smooth motion of the tissues; reasonably constant velocity throughout the range. As there were three measurements, both with active and passive ROM, this resulted in the cross-correlation analysis of 18 cine-loops per participant.

Cross-correlation algorithm for measurement of tissue excursion

A specialised software program (Motion 6, Matlab, USA), utilising a cross-correlation algorithm (Dilley et al., 2001) was used to analyse tissue excursion. Using digital conversion software (Avi4Bmp, version 2.4 Bottomap Software), each video (duration 3 s, capture rate 30Hz) was broken down into 90 separate bitmap images. ImageJ (version 1.46, National Institute of Health, USA) digital image analysis software was used to calculate the number of pixels per millimetres (pixels/mm). The scale for all videos was 23.7 pixels/mm.

A cross-correlation algorithm was used to determine relative movement between the successive frames in each sequence of ultrasound images (Dilley et al., 2001). Each video used in the analysis was viewed to determine the parameters for horizontal and vertical pixel shift. For horizontal pixel shift, a negative value indicated movement to the left and a positive value indicated movement to the right. For the vertical tracking pixel shift, a negative number indicated movement up and a positive number indicated movement down.

Once the parameters for analysis were selected, an initial frame from the video was displayed and regions of interest (ROI) defined. For the initial CF pilot study which analysed CF movement, the CF was selected as the tissue of interest (TOI) and the AT was selected as the background tissue. When analysing AT excursion, the AT was the TOI and the subcutaneous fat (SF) layer was the background tissue. Three ROI were selected in the TOI (see Figure 3), followed by three ROI in the background

tissue. Each ROI was selected, and visually previewed. The preview displays the movement of the three ROI boxes within the TOI, following the movement of those pixels over 90 consecutive frames. An analysis was acceptable if all ROI boxes were confined within the tissue throughout the preview.

Cross-correlation analysis compares the selected ROI from the TOI by subtracting the background tissue (stationary structures i.e. subcutaneous layers and bone) to determine the relative movement of that TOI (Dilley et al., 2001). This step reduces pixel shift variability, and accounts for slight movements of the transducer (Ellis et al., 2008).

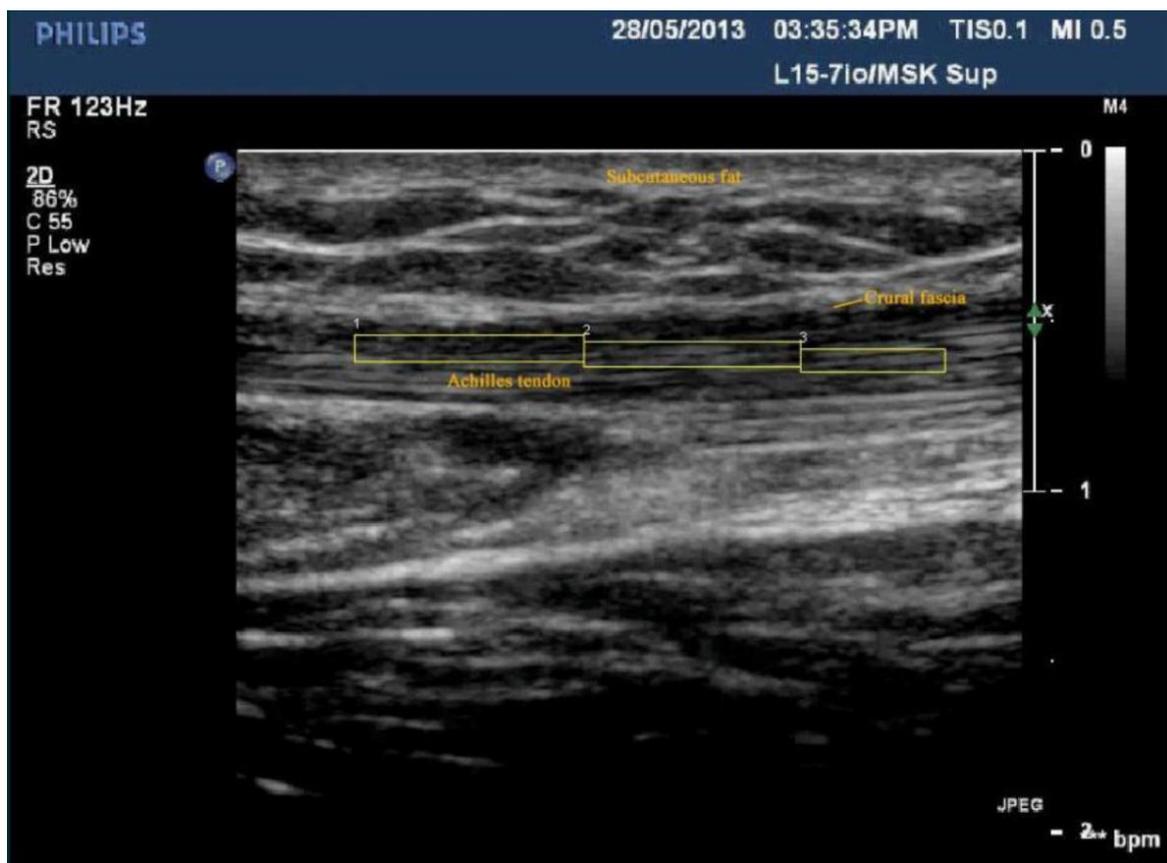


Figure 3 – Image displays a screen capture of the first frame of a typical video and identifies the three tissue types (AT, CF, SF). In this image, yellow boxes indicate selected ROI within the AT for an analysis of AT excursion.

Reliability of extracting excursion measurement from cine-loops

To calculate the extraction reliability for the CF and AT, 10 cine-loops including both active and passive movement were randomly sampled by a research assistant. Each cine-loop file was duplicated and randomly assigned a coded identity number, and all identifying information on each cine-loop was masked. The researcher, who completed all data extraction, was blinded to the paired videos, as prior knowledge of the position of the ROI boxes could inflate extraction reliability. The

researcher initially analysed all videos with the CF as the TOI and calculated the extraction reliability for the CF. Next, all videos were analysed with the AT as the TOI, and extraction reliability calculated for the AT. A table was generated with the coded data and sent to the assistant who unblinded and matched duplicates for statistical analysis. All 10 videos were analysed for AT extraction reliability. One video was excluded from the CF analysis, as it was technically challenging to confine all boxes within the TOI. Therefore, 9 videos were included in the CF extraction reliability.

Statistical analysis

The mean \pm standard deviation (SD) AT excursion for each measurement was obtained by averaging the three selected scans. Reliability coefficients were interpreted using magnitudes of agreement by Hopkins (2002). Intraclass correlation coefficients ($ICC_{3,1}$) based on 2-way mixed ANOVA and 95% confidence intervals (CI) were calculated as an indication of extraction reliability for both the CF and AT excursion. Two-way random average measures, intraclass correlation coefficients ($ICC_{2,3}$), and 95% confidence intervals were calculated as an indication of the reliability of AT excursion during active and passive ankle ROM.

The standard error of measurement (SEM) was calculated using the formula $SEM = SD_{pooled} \times \sqrt{1 - ICC}$ (Weir, 2005). The SD-pooled used in the intra-session reliability calculations was the SD from the pooled average of M1 and M2 tissue movement. The SD-pooled used in the inter-session reliability calculations was the SD from the pooled average of M1 and M3 tissue movement. The minimal detectable change (MDC) was determined with the following calculation $MDC = 1.96 \times \sqrt{2} \times SEM$ (Weir, 2005).

To explore the relationship between tissue excursion and ankle ROM, Pearson's correlation coefficients and associated significance tests were calculated (Field, 2009). To determine if tissue excursion data from the three measurement series could be pooled, paired *t*-tests were run to explore statistical differences between 1) the pooled average of M1,2 versus M3; and 2) the pooled average of M1,2 versus the pooled average of M1,2,3 for both active and passive movements. Statistical significance was set at $p < 0.05$. Paired *t*-tests were not found to be statistically significant (see Supplementary Data 1), therefore, the 9 trials from the three measurements were pooled into one mean (M1,2,3). To determine if ROM data could be pooled from the two sessions, paired *t*-tests were undertaken to determine statistical differences between S1 and S2 for the four ROM parameters. Paired *t*-tests were not found to be statistically significant for any parameter [see Appendix F]. This result allowed the ROM values from both sessions to be pooled into one average for each of the four ROM parameters.

Results

Descriptive Statistics

Ten participants (n=7 females, n=3 males) were enrolled in the study, providing 10 ankles (n=5 left, n=5 right). The age of participants ranged from 23 – 82 years, with a mean \pm SD age of 34.7 ± 18.9 years, and a median age of 26.5 years. Height ranged from 149 – 188cm, with a mean \pm SD of 167.4 ± 10.6 cm. Body mass ranged from 57 – 87kg, with a mean \pm SD of 68.0 ± 10.9 kg.

Extraction Reliability of CF and AT excursion

Reliability of extracting excursion measurement from cine-loops for the CF resulted in an ICC of 0.56 (95%CI = -0.11 – 0.88). In comparison, reliability of extracting excursion measurement from cine-loops for the AT was ICC = 0.86 (95%CI = 0.53 – 0.96).

AT excursion

Magnitude of AT excursion, SEM and MDC

The average magnitude of AT excursion, from the three measurements, is shown in Table 1. See Supplementary Data 1 for the magnitude of AT excursion for each individual measurement series. The SEM and MDC for AT excursion are also represented in Table 1.

Table 1 – Magnitude of AT excursion, SEM, MDC (mm) during total ankle ROM

	AT excursion (mm)		Intra-Session		Inter-Session	
	Mean \pm SD	Range (min-max)	SEM (mm)	MDC (mm)	SEM (mm)	MDC (mm)
Active	14.25 \pm 4.86	6.89-21.09	1.86	5.15	2.80	7.77
Passive	12.26 \pm 5.55	6.26-24.45	1.14	3.15	2.81	7.79

Notes: Total ankle ROM represents range from full plantarflexion to full dorsiflexion; AT excursion represents M1,2,3pooled (average of all 9 trials from M1,M2,M3); Intra-session (M1 and M2); Inter-session (M1 and M3); SEM = standard error of measurement; MDC = minimal detectable change

Intra- and Inter-Session Reliability of USI assessment of AT excursion

To demonstrate the intra-session reliability of using USI to quantify the excursion of the AT *in vivo* during active and passive ankle ROM, the averages from M1 and M2 were compared. The intra-session reliability for the relative movement of the AT during AROM resulted in a ‘very large’ ICC, and during PROM it resulted in a ‘nearly perfect’ ICC (see Table 2).

To demonstrate the inter-session reliability of using USI to quantify the excursion of the AT *in vivo* during active and passive ankle ROM, the averages from M1 and M3 were compared. The inter-session reliability for the relative movement of the AT during AROM and PROM resulted in ‘very large’ ICCs (see Table 2).

Table 2 – Intra- and Inter-Session ICCs

	Intra-Session			Inter-Session		
	ICC	95%CI (Lower, Upper)	Descriptor	ICC	95%CI (Lower, Upper)	Descriptor
Active	0.89	(0.57, 0.97)	Very large	0.80	(0.19, 0.95)	Very large
Passive	0.96	(0.84, 0.99)	Nearly perfect	0.88	(0.53, 0.97)	Very large

Notes: Intra-session calculated from M1 and M2. Inter-session calculated from M1 and M3.

Ankle ROM

The pooled averages for the ankle ROM parameters are represented in Table 3. [See Appendix F for the individual ankle ROM values from S1 and S2].

Table 3 – Ankle ROM (degrees)

	Active		Passive	
	PF	DF	PF	DF
Mean ±SD	47.12 ±10.96	17.24 ±5.69	60.75 ±11.19	26.87 ±6.90
Range (min – max)	33.50 - 66.50	5.43 - 25.57	49.00 - 79.17	12.67 - 33.17

Notes: Ankle ROM values represent the pooled average of 6 repetitions from S1 and S2; PF= plantarflexion ROM; DF= dorsiflexion ROM.

Correlation between AT excursion and ankle ROM

Based on that no significant differences were calculated from the paired *t* tests, in either the tissue excursion or ROM data, pooling all the sessions for the Pearson's correlation was justified. The average of all three measurements were pooled (9 trials), and the averages of the ROM from the two sessions (6 repetitions) were pooled. With the exception of the passive plantarflexion and passive AT excursion correlation, there were no other significant correlations between ankle ROM and AT excursion (see Table 4 for Pearson's correlation and p-values).

Table 4 – Correlation AT excursion with Ankle ROM

AT excursion	Active PF		Active DF		Passive PF		Passive DF	
	r	p-value	r	p-value	r	p-value	r	p-value
Active	0.29	0.41	0.27	0.45	0.40	0.26	0.24	0.50
Passive	0.52	0.13	0.02	0.96	0.67*	0.04	0.18	0.62

Notes: n=10. AT excursion represents M1,2,3pooled (average of all 9 trials from M1,M2,M3); Ankle ROM represents the pooled average of the two sessions (6 repetitions); PF= plantarflexion ROM; DF= dorsiflexion ROM; r = Pearson correlation coefficient; * = significant at the 0.05 level (2-tailed).

Discussion

Overview

In the present study, AT excursion was measured using USI and a cross-correlation algorithm, a technique that has previously been used to examine nerve excursion in the upper (Brochwicz et al., 2013; Coppieters et al., 2009; Dilley et al., 2001; Dilley et al., 2003) and lower (Carroll et al., 2012; Ellis et al., 2008; Ridehalgh et al., 2012; Shum et al., 2013) extremity, and tendon excursion at the wrist (Chen et al., 2009; Kelly, 2011). The present study aimed to establish the intra- and inter-session reliability of USI to quantify tissue excursion for the CF and AT in the posterior leg. Due to poor precision in extraction reliability of the CF, measures of CF were not further investigated, therefore, the study focused on quantifying excursion of the AT during active and passive ankle ROM.

Participants

To promote generalisability, the recruitment criteria were designed to include a spectrum of participants across age and gender. Although there is some evidence to show age and gender effects on tendon material properties (Kubo, Kanehisa, & Fukunaga, 2003; Stenroth, Peltonen, Cronin, Sipilä, & Finni, 2012), such as tendon elongation and stiffness (Joseph et al., 2014; Kubo et al., 2003; Stenroth et al., 2012), as well as, tendon excursion *in vitro* (Hintermann, Nigg, & Sommer, 1994), these are not relevant to issues of within subject reliability.

Extraction Reliability

Although many studies have used Dilley et al.'s (2001) cross-correlation algorithm, it appears that only a few studies have investigated various forms of reliability for the technique. Dilley et al. (2001) initially used phantom and *in-vivo* controls to demonstrate the validity of the technique, as well as repeatability in the median nerve. 'Excellent' inter-rater reliability (ICC=0.96, 95%CI = 0.88 – 0.99) for median nerve excursion has been established (Coppieters et al., 2009). 'Excellent' intra-rater reliability of the sciatic (ICC = 0.75, 95%CI = 0.59 – 0.87) (Ellis et al., 2008), and tibial nerves (ICC=0.93, 95%CI = 0.70 – 0.96) (Carroll et al., 2012) has been reported. Tracking longitudinal sciatic nerve excursion using the cross-correlation algorithm has been reported to be highly repeatable (Ridehalgh et al., 2012). Only one study (Kelly, 2011) has investigated the intra-rater reliability of the technique for EPB tendon excursion and established 'excellent' reliability for both session 1 and session 2 intra-session measures (ICC=0.88, 95%CI 0.84 – 0.91; and ICC=0.87, 95%CI 0.92 – 0.90), and inter-session measures (ICC=0.76, 95%CI = 0.66 – 0.83). Despite these previous reports of excellent

reliability, it appears there has been no attempt to isolate the contribution of operator error (in data extraction processes) from other sources of error. During the extraction process there are technical challenges where subjective operator decisions can influence the extraction measurement including: positioning of the ROI boxes, size of the ROI boxes, and judging appropriateness of image quality. Determining the extraction reliability of the technique is useful, particularly if reliability is low, as it allows partitioning of error into biological and operator sources. If the extraction reliability is high then operator error can be excluded as the source of error. If the extraction reliability is poor then it may explain why intra- or inter-session reliability is poor. A strength of the present study is the extraction reliability was calculated for each tissue (CF and AT) to establish the technical limits for analysis.

CF and AT extraction reliability

In addition to technical challenges of data extraction, a further issue was the thickness of the CF. A radiologic study of the CF determined the mean \pm SD thickness of the CF, in healthy participants, was 1.11 ± 0.17 mm and a range of 0.75 – 1.43 mm (Stecco, Cappellari, et al., 2013). Similarly, two anatomical studies of the CF have reported the mean \pm SD thickness of the CF to be 0.924 ± 0.201 mm (Stecco et al., 2008) and 0.924 ± 0.220 mm (Stecco et al., 2009). When analysing the CF using the cross-correlation algorithm, it was difficult to confine the ROI because of the thickness of this tissue. Obtaining an acceptable analysis was challenging and contributes to the ‘moderate’ extraction reliability result. Despite using high-resolution USI, the tissues of ~ 1 mm are challenging to visualise. Future technological advances in USI may improve visual resolution which would enhance extraction reliability for low dimension tissues such as the CF. A block-matching speckle tracking algorithm (Korstanje, Selles, Stam, Hovius, & Bosch, 2010) may be an alternate approach to analysis of the CF layer as it does not require anatomical landmarks or a reference tissue and has been used to measure connective tissue of <1 mm thickness at the carpal tunnel (Yoshii et al., 2009). Further attempts at quantifying CF sliding may improve knowledge of the possible role of CF function in Achilles pathologies such as tendinopathy.

In contrast to the CF, the extraction reliability of the AT was ‘very large’. It is likely this result is due to the AT having a substantially larger mean thickness than the CF and therefore easier to confine the ROI within the tissue. AT thickness has been reported as 68 mm (range 45 – 86 mm) at its origin (Doral et al., 2010), 18 mm (range 12 – 26 mm) at its midsection and 34 mm (range 20 – 48 mm) at its insertion (Apaydin et al., 2009). Despite the ‘excellent’ ICC values for AT extraction, the wide confidence interval indicates a lack of precision mostly likely due to the small sample size in the study.

Ultrasound operator

The USI operator who performed all scans, was not a qualified sonographer but was trained in the necessary procedures. USI is operator dependent (Chiou, Chou, Chiou, Liu, & Chang, 2003; Martinoli, Bianchi, & Derchi, 1999) and operator skill can influence reliability (Ellis et al., 2008). However, in the present study, 'excellent' extraction reliability has been demonstrated for the AT, therefore, level of experience did not appear to be a source of measurement error.

Magnitude of AT excursion

There appear to be few other studies that have investigated inter and/or intra-AT excursion during active or passive ankle ROM. None of the studies utilised the frame-by-frame cross-correlation algorithm used in the present study. Three studies investigated AT excursion during passive ROM (Arndt et al., 2012; Lee et al., 2008; Pearson et al., 2013), while only one study has investigated AT excursion during active ROM (Pearson et al., 2013). Lee et al. (2008) used an automated tracking algorithm to measure AT excursion. Five healthy participants had an ankle passively moved by an examiner from 15° dorsiflexion to 35° plantarflexion and a mean AT excursion of 19.5 ±4.3 mm was calculated (Lee et al., 2008).

Arndt et al. (2012) investigated intra-tissue AT displacement during passive ankle ROM *in vivo*. The authors utilised a block-matching speckle tracking algorithm (Korstanje et al., 2010) to analyse intra-tendon displacement in the superficial, central and deep layers of the AT. Results indicated there is non-uniform displacement within the AT layers during passive ROM. The reported mean ±SD displacement value for the superficial layer was 8.4 ±1.9 mm, the central layer was 9.4 ±1.9 mm and the deep layer was 10.4 ±2.1 mm. Although the present study determined inter-tendon (where AT excursion was compared with the SF layer to determine the relative AT excursion) excursion during passive ROM was 12.26 ±5.55 mm, these excursion findings are of a similar magnitude to Arndt et al. (2012).

Pearson et al. (2013) appears to be the only study that has investigated both active and passive AT excursion. The authors investigated AT excursion (n=1), specifically the medial gastrocnemius tendon, using a normalised cross-correlation automated tracking method during passive movement, and appear to be the first to investigate AT excursion during active movement. Medial gastrocnemius tendon excursion was 11.28 ±1.36 mm during passive movement and 16.42 ±0.85 mm during active movement. Although the present study investigated AT excursion for the triceps surae tendon as a whole unit, these excursion findings are of a similar magnitude to Pearson et al.

(2013) for both active and passive movement. However, as only one participant was involved the results must be interpreted with caution.

Intra-session versus Inter-session reliability

Interpretation of ICC values

This study found intra-session passive AT excursion to be the most reliable parameter, while the least reliable was the active inter-session parameter (see Table 2). All intra- and inter-session ICCs had 'very large' to 'nearly perfect' reliability. However, most of the confidence intervals are wide which could be due to either the small sample size, or reflect true variability in the greater population. Intra-session reliability is superior to inter-session reliability, shown by higher ICC values than their inter-session equivalents. The present study obtained intra-session values with a 5 min interval while inter-session values were taken 24 hr apart. Although it is inevitable that extraneous variables influenced the inter-session reliability that did not influence the intra-session reliability, attempts were made to control for the most obvious of these. The same operator conducted all USI scans for all trials, eliminating the possibility of inter-operator variance. The same electrogoniometer was used for both sessions. The method of data collection was consistent between trials, as was the time of day for each session and the instruction to participants not to perform exercise on either day of data collection. Despite these controls, inter-session measures were less reliable than intra-session measures, confirming the presence of extraneous variables such as differences in activity levels between sessions that could not reasonably be controlled for (eg job related activity, amount of walking) were operant. An area of further exploration should be identifying variables that impact tissue excursion stability.

Identification of the scanning location

A source of potential variation was the scanning location, which was identified at the beginning of each session. The same ink mark was used for M1 and M2, but a new mark was found for M3, as participants were instructed to wash off the marking between sessions. There was potential for either slight variation between placement of the marks, which could negatively influence reliability; or for the researcher to be able to detect where the mark had been placed on the first session, which could positively influence reliability.

The method for identifying the scanning point was based on surface anatomy and was informed by preliminary pilot work. Despite standardization of the method, the anatomical scanning point varied between participants due to differences in calf morphology, including gender differences (Chow et al., 2000), length of the AT (Apaydin et al., 2009; O'Brien, 2005) and length of the gastrocnemius

muscle belly (Barber, Barrett, & Lichtwark, 2009). On occasion it was apparent that transducer location was subtly different between measures. Despite this, the tissue of interest was visible on all USI scans and a portion of the AT analysed for excursion, therefore, these subtle differences in transducer location were not more than minimally influential on repeatability.

In this study, an arbitrary point was selected to demonstrate the principle of measuring AT excursion. However, it is not the only point of interest in the AT, and a specific point could be selected on the basis of direct clinical applicability, eg investigating AT excursion following AT rupture, which commonly occurs 3-5 cm proximal to the AT insertion (Krueger-Franke, Siebert, & Scherzer, 1995). In a 6-year follow-up study post-surgical intervention for AT rupture, USI demonstrated 64 out of 71 patients had scar-like thickening of the AT and the paratenon (Krueger-Franke et al., 1995) which may impair normal movement of the AT. More recently, histopathologic changes, such as collagen disorganization and loss of the parallel arrangement of tendon fibres have been demonstrated proximal and distal to the site of AT rupture (Maffulli et al., 2011). These tissue changes could have implications on AT excursion and may negatively impact ankle function.

Inherent challenges in imaging active versus passive movement

Reliability of passive movement was superior to active movement, as shown by higher ICC values and narrower confidence intervals, and this was consistent for both intra- and inter-session reliability. The active movement was more challenging for both the operator to scan and for the participant to perform. One participant experienced a 'cramp' in their gastrocnemius muscle after repeated repetitions, and multiple participants reported mild discomfort while sustaining full plantarflexion during scanning. Active movement was more challenging for the operator, as it was more difficult to obtain good quality images due to tension within the muscle and tendon. It was also more challenging to maintain the transducer in the proper orientation at the scanning site during the muscle contraction. When the scanning point was closer to the calcaneus (due to variation in calf morphology), it was additionally challenging as the surface area for the transducer was narrower. Scanning of passive movement was easier to control and achieve satisfactory image quality. Despite challenges in scanning, it is important to persist with investigating active movement because of the direct relevance to human movement.

Interpretation of the SEM and MDC

As the SEM values are low but the CI's are wide, it is likely that the lack of precision is due to the small sample size rather than due to biological variability. It is important not to over-interpret the MDC values, with this small non-homogenous sample. The MDCs are presented as preliminary calculations and were compromised by the large SD-pooled values [see Appendix E], this was likely due to the non-homogenous sample. The MDC calculation requires further work to clarify the influence of sample homogeneity. This could be achieved with descriptive cross-sectional studies containing a large sample with homogenous subgroup analysis by age and gender.

Correlation between AT excursion and ankle ROM

Anecdotally it is said that myofascial tissue excursion is related to ankle ROM (Starrett, 2011). In addition, an immediate effect of MTrP release on latent MTrPs in the triceps surae has been demonstrated to have significant increases in active ankle dorsiflexion suggesting a relationship between latent triceps surae TrPs and ankle ROM (Grieve et al., 2011; Grieve et al., 2013). The present study conducted a preliminary analysis of the correlation between AT excursion and ankle ROM. There were three 'moderate' or greater correlations between ankle ROM and AT excursion, however, only one was statistically significant. Ankle ROM is modulated by many factors, other than tissue excursion, including: muscular (Denegar et al., 2002; Prior, 1999; You et al., 2009), fascial (Grieve et al., 2011; Stecco, Macchi, et al., 2011), capsular (Denegar et al., 2002), and articular (Denegar et al., 2002; Hertel, 2002; Hoch & McKeon, 2011). Tissue excursion is likely to be one factor but this still requires further exploration.

Recommendations

Due to the exploratory nature of this study, several areas for future research have been identified. If AT excursion reliability is further established, the next step is to establish normative data on AT excursion within a large sample. Normative data on AT excursion would provide a baseline for future studies to use in the assessment of AT excursion for post-surgery and post rehabilitation interventions. In addition, the correlation between AT excursion and ankle ROM should be explored in a large sample. Other correlations of interest are between AT excursion with physical activity levels and AT excursion with history of injury to the lower extremity. An opportunity lies for future research to explore gender differences in AT excursion, due to the nature of reported gender differences in AT properties (Kubo et al., 2003). The influence of age on AT excursion is a further area for exploration. Information regarding the relationship between age and AT excursion may

contribute to explaining epidemiological data regarding age and tendon tears (Hess, 2010; Sargon, Ozlu, & Oken, 2005). Exploration of other techniques *in vivo* to view CF sliding are recommended, such as block-matching speckle tracking (Korstanje et al., 2010) as speckle tracking has been useful in assessing thin fascial layers of the wrist (Yoshii et al., 2009).

Clinical Implications

Once normative data on AT excursion is established, investigating AT excursion in participants with tendon pathology such as Achilles tendinopathy or AT rupture has the potential to be of clinical value and may inform ideas about the aetiology of these AT disorders. Understanding the relationship between AT excursion in tendinopathy and clinical severity may provide a better understanding of this injury and directly inform treatment approaches. If the reliability of measuring AT excursion is further established, the method may enable assessment of changes in AT mechanical properties following surgery and rehabilitation of AT ruptures. Understanding the role of compromised CF sliding in Achilles tendinopathy and AT rupture may provide further insight into these pathologies.

Conclusion

The results of the study indicate that using a frame-by-frame cross correlation algorithm to assess AT excursion during active and passive movement *in vivo* is a reliable method. Measures of CF excursion were not further investigated, due to poor precision in the reliability of extracting the excursion measurement. Technological advances in USI may improve visual resolution, which would improve extraction reliability of the CF. Establishing normative data for AT excursion in large samples is recommended.

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Supplementary Data

Supplementary Data 1 – Magnitude of AT excursion (mm) for each measurement and p-values for paired differences between measurements

	Magnitude of AT excursion (mm) during total ankle ROM								Paired Differences			
	M1		M2		M3		M123		M1 vs M2	M1 vs M3	M1,2 vs M3	M1,2 vs M1,2,3
	Mean ±SD	Range (min – max)	Mean ±SD	Range (min – max)	Mean ±SD	Range (min – max)	Mean ±SD	Range (min – max)	p-value	p-value	p-value	p-value
Active	13.74 ±5.69	7.01-22.36	14.86 ±5.92	7.67-26.41	14.15 ±4.60	5.97-20.94	14.25 ±4.86	6.89-21.09	0.35	0.77	0.91	0.91
Passive	12.94 ±5.84	8.81-27.15	11.98 ±5.94	5.63-23.73	11.86 ±5.97	4.33-22.48	12.26 ±5.55	6.26-24.45	0.21	0.40	0.64	0.64

Notes: The mean values are calculated from three trials and represent the magnitude of AT excursion during total ankle ROM (from full plantarflexion to full dorsiflexion); M1=Measurement 1; M2= Measurement2; M3= Measurement3; M1,2=pooled average of 6 trials from M1 and M2; M1,2,3 = pooled average of 9 trials from M1,M2,M3

SECTION III - Appendices

Appendix A – Participant descriptive statistics

Participant ID	Gender	Age	Height (cm)	Weight (kg)
1	F	29	149	59.7
2	F	32	177	63
3	F	25	159	58
4	F	25	163.2	85.6
5	F	26	162.5	61
6	F	24	170	67.3
7	F	27	165	57
8	M	54	173	68
9	M	23	188	87
10	M	82	167	73
Mean		34.7	167.4	68.0
SD		18.9	10.6	10.9
Median		26.5	166	65.15
Range		23 - 82	149 - 188	57 - 87

Appendix B – Extraction Reliability for the crural fascia and Achilles tendon

Extraction Reliability ICCs for the crural fascia and Achilles tendon

	Crural Fascia (CF) n=9		Achilles Tendon (AT) n=10	
	ICC	95% CI	ICC	95% CI
Tissue of Interest (TOI)	0.68	0.09 – 0.92	0.87	0.56 – 0.97
Background Tissue (BT)	0.76	0.24 – 0.94	1.00	0.99 – 1.00
Relative Movement (RM)	0.56	-0.11 – 0.88	0.86	0.53 - 0.96

Notes: Background Tissue for the CF was the AT; Background Tissue for the AT was the SF; RM=Relative movement of tissue of interest; *n* = number of videos randomly selected and analysed from four participants

Appendix C – Pooled excursion data for each participant

Pooled M1,2,3 excursion data for AT movement, SF movement, and Relative movement of the AT

Participant	AT movement (mm)		SF movement (mm)		RM of AT (mm)	
	Active	Passive	Active	Passive	Active	Passive
HLSERAWB	15.01	12.04	3.77	3.36	11.24	8.68
FDJHGLKM	23.76	17.93	4.54	1.53	19.21	16.40
RTUIWERH	11.82	10.17	2.46	1.36	9.35	8.82
JUENAL2	15.45	17.41	1.98	2.08	13.47	15.33
RHADJEL	9.51	7.19	2.62	0.93	6.89	6.26
LBNWYAB	23.63	26.69	2.54	2.31	21.09	24.45
YUEBATH	15.84	12.42	0.83	0.89	15.01	11.53
PWQJFUWN	20.81	14.68	0.25	0.11	20.56	14.57
IUEHMAW	15.57	10.45	0.65	0.84	14.92	9.61
MUQIAQHV	10.73	6.97	-0.02	0.02	10.74	6.95

Notes: AT= Achilles tendon; SF = subcutaneous fat; RM = relative movement of the AT; Pooled M1,2,3 represents the average of all 9 trials from M1,2,3 for AT movement, SF movement, and Relative movement of the AT; AT movement represent absolute AT movement; SF movement represents the background tissue; RM of the AT represents the relative movement between the SF and AT

Appendix D – Magnitude of tissue excursion for AT movement, SF movement, and Relative movement of the AT

Magnitude of tissue excursion during total ankle ROM data for AT movement, SF movement, and Relative movement of the AT

		M1		M2		M3		M1,2,3 pooled	
		Mean (\pm SD)	Range	Mean (\pm SD)	Range	Mean (\pm SD)	Range	Mean (\pm SD)	Range
Active	AT	15.65 (\pm 5.62)	8.04-24.85	16.84 (\pm 5.99)	10.31-28.95	16.14 (\pm 5.42)	7.71-25.55	16.21 (\pm 5.05)	9.51-23.76
	SF	1.92 (\pm 1.15)	0.11-3.48	1.98 (\pm 1.61)	-0.18-4.37	1.99 (\pm 2.21)	-0.37-6.79	1.96 (\pm 1.52)	-0.02-4.54
	RM	13.74 (\pm 5.69)	7.01-22.36	14.86 (\pm 5.92)	7.67-26.41	14.15 (\pm 4.60)	5.97-20.94	14.25 (\pm 4.86)	6.89-21.09
Passive	AT	14.11 (\pm 6.30)	8.84-29.31	13.12 (\pm 6.46)	5.80-26.51	13.57 (\pm 5.91)	5.62-24.26	13.60 (\pm 5.93)	6.97-26.69
	SF	1.17 (\pm 0.89)	-0.02-2.38	1.14 (\pm 1.10)	0.08-2.78	1.73 (\pm 1.92)	-0.41-5.98	1.34 (\pm 1.03)	0.02-3.36
	RM	12.94 (\pm 5.84)	8.81-27.15	11.98 (\pm 5.94)	5.63-23.73	11.86 (\pm 5.97)	4.33-22.48	12.26 (\pm 5.55)	6.26-24.45

Notes: AT = Achilles tendon; SF = subcutaneous fat; RM = relative movement of the AT; ROM=range of motion; M1=Measurement 1, M2= Measurement2; M3= Measurement3; M1,2,3pooled = pooled average of all 9 trials from M1,M2,M3

Appendix E – SD-pooled, SEM and MDC for AT excursion

SD-pooled, SEM and MDC for AT excursion

	Intra-Session		Inter-Session	
	Active	Passive	Active	Passive
SD-pooled	5.68	5.75	6.26	8.22
ICC	0.89	0.96	0.80	0.88
SEM (mm)	1.86	1.14	2.80	2.81
MDC (mm)	5.15	3.15	7.77	7.79

Notes: AT=Achilles tendon; SD pooled = the pooled standard deviation from M1 and M2 (intra-session) and from M1 and M3 (inter-session); SEM = standard error of measurement; MDC = minimal detectable change

Appendix F – Ankle range of motion and p-values for paired differences

Ankle ROM (°) for each session and p-values for paired differences between sessions

		S1		S2		S1,2 pooled		Paired Differences
		Mean (± SD)	Range	Mean (± SD)	Range	Mean (± SD)	Range	p-values
Active	PF	47.73 (± 13.35)	21.33 - 66.67	46.50 (± 10.91)	34.00 - 66.33	47.12 (± 10.96)	33.50 - 66.50	0.72
	DF	16.90 (± 6.67)	6.00 - 27.33	17.50 (± 6.96)	5.00 - 27.33	17.24 (± 5.69)	5.43 - 25.57	0.81
Passive	PF	60.87 (± 15.06)	37.00 - 86.67	60.63 (± 10.71)	47.67 - 78.67	60.75 (± 11.19)	49.00 - 79.17	0.96
	DF	27.33 (± 6.96)	15.67 - 37.67	26.40 (± 8.92)	9.67 - 41.67	26.87 (± 6.90)	12.67 - 33.17	0.72

Notes: ROM=range of motion; PF= plantarflexion ROM; DF= dorsiflexion ROM; S1= Session 1; S2= Session 2; S1,2pooled = average of all 6 repetitions from S1 and S2; p-values for paired differences compare S1 and S2

Appendix G – Ethics Documentation



13 September 2012

Elaine Davies
5/2 Upper Queen St
Auckland 1010

Dear Elaine

Thank you for submitting your research proposal 'A pilot investigation of the sliding surface movement of the crural fascia using ultrasound imaging'.

The proposals committee of the Social and Health Sciences has considered and approved your proposal.

Your principal supervisor is Rob Moran and your associate supervisor is Richard Ellis.

Please be aware that ethical approval may be required for your research once you have finalised your proposal. To determine the need for ethics application and approval, we recommend that you read the Guidelines for Ethical Approval in the *Research* folder on the Moodle site *Postgraduate Students Resources*, to identify any ethical issues that may arise. Discussion with your supervisor or the ethics committee (email: ethics@unitec.ac.nz) may also assist in this decision process. This will help determine the need, or otherwise, for a full application for ethical approval. Ethics applications and accompanying documents should be submitted as email attachments to the above address.

Please contact us if you have any questions, or if we can assist you in your research, by contacting us on extension number 8647 or email address hauyeung@unitec.ac.nz

We wish you every success in completing your research project.

Yours sincerely,

A handwritten signature in black ink, appearing to read 'Craig Hilton'.

Craig Hilton
Chair

Proposals Committee
cc: Principal Supervisor: Rob Moran
Associate Supervisor: Richard Ellis
Committee Administrator: Helen Au Yeung
Research Office: Kath Bridges
Postgraduate Office: Cynthia Almeida



Elaine Davies
5/2 Upper Queen St
Auckland City
Auckland 1010

21.11.12

Dear Elaine,

Your file number for this application: **2012-1089**

Title: **A pilot investigation of the sliding surface movement of the crural fascia using ultrasound imaging.**

Your application for ethics approval has been reviewed by the Unitec Research Ethics Committee (UREC) and has been approved for the following period:

Start date: 27.10.12

Finish date: 27.10.13

Please note that:

- 1. The above dates must be referred to on the information AND consent forms given to all participants.**
- 2. You must inform UREC, in advance, of any ethically-relevant deviation in the project. This may require additional approval.**
- 3. Organisational consent/s must be cited and approved by your primary reader prior to any organisations or corporations participating in your research. You may only conduct research with organisations for which you have consent.**

You may now commence your research according to the protocols approved by UREC. We wish you every success with your project.

Yours sincerely,

Gillian Whalley
Deputy Chair, UREC

Cc: Rob Moran
Cynthia Almeida

study@unitec.ac.nz Tel +64 9 849 4180 Fax +64 9 815 2901 www.unitec.ac.nz	Postal address Private Bag 92025 Victoria St West Auckland 1142 New Zealand	Mt Albert campus 139 Carrington Rd Mt Albert Auckland 1025 New Zealand	Newmarket campus 277 Broadway Newmarket Auckland 1023 New Zealand	Northern campus 10 Rothwell Ave North Harbour Auckland 0632 New Zealand	Waitakere campus 5-7 Ratanui St Henderson Auckland 0612 New Zealand
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A pilot investigation of the sliding surface movement of the crural fascia using ultrasound imaging

Information Sheet for Participants – Part I

About this research

You are invited to take part in a research project that is using ultrasound imaging to investigate the relationship between sliding surface movement in the ankle and ankle range of motion, with a few case studies to explore a technique to increase ankle range of motion.

There are three parts to this study. Part I of this study aims to establish the intra- and inter-session reliability of ultrasound imaging to quantify the sliding surface movement in the ankle. Part II of this study investigates whether there is a correlation between sliding surface movement and ankle range of motion (ROM). Part III will explore, the efficacy of a technique, to the ankle, on ankle ROM in individuals with restricted ROM through a series of case studies.

Recruitment for Part II and III of this study will occur at a later date. If you choose to participate in Part I of this study you will not be required to participate in Part II or III.

The following information sheet is in reference to Part I of this study.

If you choose to participate you will need to undertake the following:

1. Meeting with the researcher for a brief initial screening to ensure eligibility for the project. (10min)
2. Signing the consent form once all information has been received.
3. Attend two data collection sessions taking approximately 20 minutes each, one week apart.
4. Avoid any treatment, exercise or any exercise related activity (running etc) on the day of testing, which could stress the ankle joint.

The 1st data collection session involves:

1. Completion of the Foot and Ankle Ability Measure.
2. Ultrasound imaging will be performed on each ankle, at two sites, through full active ankle ROM (you will move your ankle) and passive ankle ROM (we will move your ankle for you). You will be positioned in prone, with your knee flexed.
3. After 5 minutes, step 2 will be repeated.

The 2nd data collection session involves:

1. Steps 2 and 3 as outlined for the 1st data collection session.

The ultrasound scans obtained from this study are for research purposes only and will not be used for diagnosis.

You have the right to not participate, or to withdraw from this research project at any time until three days following the 2nd data collection session. This can be done by phoning us or by telling us when we contact you that you do not want to participate.

Confidentiality

The researcher will ensure that the information you have given is kept confidential. Raw data collected during the study will be anonymised and will be stored securely so that only the researcher and her supervisors can access. Raw copies of the data will be stored for five years following the study and will then be destroyed.

Consent

This information will be repeated to you before the commencement of the study with an opportunity for you to clear any doubts or concerns. Both verbal and written consent will be gained from you and it is taken as an indication that you consent to participate in this study.

Thank you very much for your participation. If you have any questions at any time during the course of the study or following the completion of the study, please don't hesitate to contact me Elaine Davies or my supervisors.

Primary researcher:

Elaine Davies
Tel: 021 052 3734
Email: elainedavies29@hotmail.com

Research Supervisor:

Rob Moran
Tel: 021 073 9984 or 09 815 4321 ext 8197
Email: rmoran@unitec.ac.nz

Richard Ellis
Tel: 09 921 9999 ext 7612
Email: richard.ellis@aut.ac.nz

UREC REGISTRATION NUMBER: 2012-1089

This study has been approved by the UNITEC Research Ethics Committee from 27 October 2012 to 27 October 2013. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (ph: 09 815-4321 ext 7248). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.



A pilot investigation of the sliding surface movement of the crural fascia using ultrasound imaging

Consent Form – Part I

This research project is an investigation into the correlation between sliding surface movement in the ankle and ankle range of motion, with a few case studies to explore a technique to increase ankle range of motion. This research is being undertaken by Elaine Davies from Unitec New Zealand, and will be supervised by Robert Moran and Richard Ellis. Findings from this research will be used to complete the Master of Osteopathy degree and may be used within a published journal article.

Name of Participant: _____

I have seen the Information Sheet dated _____ for people taking part in Part I of the study, 'A pilot investigation of the sliding surface movement of the crural fascia using ultrasound imaging'.

I have had the opportunity to read the contents of the information sheet and to discuss the project with the researcher and I am satisfied with the explanations I have been given. I understand that taking part in this project is voluntary and that I may withdraw up until three days after the 2nd data collection session, and this will in no way affect my access to the services provided by Unitec New Zealand or any other support service.

I understand there are three parts to this study. I understand recruitment for Part II and III of this study will occur at a later date and I will not be required to participate.

I understand that I can withdraw from this research project at any time until three days following the 2nd data collection session, if for any reason I want to do this.

I understand that my participation in this study is confidential and that no data or information gained could breach this confidentiality.

I have had enough time to consider whether I want to take part.

I know whom to contact if I have any questions or concerns about the project.

The principal researcher for this project is Elaine Davies.
Tel: 0210523734 Email: elainedavies29@hotmail.com

Participant Signature _____ Date: _____

Project explained by: _____

Signature _____ Date: _____

Appendix H – Journal of Bodywork and Movement Therapies Guide for Authors

Guide for Authors

The journal Editor, Leon Chaitow, welcomes articles for publication in the journal. The manuscript should be sent as an email attachment to jbmteditor@mac.com. In order to speed up the refereeing process internet transmission of submissions with illustrations included are encouraged. For ease of downloading these should not be of high resolution at the submission stage. For ease of editing, these should not be embedded as email: they should be sent as attached document files. Full details of electronic submission and formats can be obtained from <http://www.elsevier.com/author> or from Author Services at Elsevier. It is imperative that these guidelines to authors be followed, including referencing style and type and resolution of suggested illustrations. (See below).

DISK SUBMISSION

If unable to submit your manuscript via email then the submission of a disk along with your typescript is accepted. The Editor will accept a 3.5 inch disk in any IBM or Macintosh word processing format (Microsoft Word 2001 is preferred). Please indicate on the label attached to your disk, your name, address, typescript title and the name of the word processing package used.

WORD COUNT

We can accept full articles of between 2000 and 4000 words in length. Shorter reports and items will comprise fewer words. Please check your ideal length with the journal Editor.

PRESENTATION OF TYPESCRIPTS

Your article should be typed on one side of the paper, double spaced with a margin of at least 3cm. Rejected articles, and disks, will not be returned to the author unless an SAE is enclosed. Papers should be set out as follows, with each section beginning on a separate sheet: title page, abstract, text, acknowledgements, references, tables, and captions to illustrations.

Title Page

The title page should give the following information:

- title of the article
- full name of each author
- you should give a maximum of four degrees/qualifications for each author and the current relevant appointment
- name and address of the department or institution to which the work should be attributed
- name, address, telephone and fax numbers of the author responsible for correspondence and to whom requests for reprints should be sent.

Abstract

This should consist of 100-150 words summarising the content of the article.

Text

Headings should be appropriate to the nature of the paper. The use of headings enhances readability. Three categories of headings should be used:

- major ones should be typed in capital letters in the centre of the page and underlined

- secondary ones should be typed in lower case (with an initial capital letter) in the left hand margin and underlined
- minor ones typed in lower case and italicised

Do not use 'he', 'his', etc. where the sex of the person is unknown; say 'the patient', etc. Avoid inelegant alternatives such as 'he/she'. Avoid sexist language.

Avoid the use of first person ('I' statements) and second person ('you' statements). Third person, objective reporting is appropriate. In the case of reporting an opinion statement or one that cannot be referenced, the rare use of 'In the author's opinion?' or 'In the author's experience?.' might be appropriate. If in doubt, ask the editor or associate editor for assistance.

Acronyms used within the text are spelled out at the first location of usage and used as the acronym thereafter. For example, 'The location of a central trigger point (CTrP) is central to a taut fiber. The CTrP is palpated by.....'

Single quotation are used to express a quote marks (Matthews (1989) suggests, 'The best type of?') while double quotation marks are used for a quote within a quote or to emphasise a word within a quote.

Promotion of self, seminars or products is inappropriate. Reference to a particular product as it applies to the discussion, particularly where valid research of the product or comparison of products is concerned, can be included as long as a non-promotional manner is used.

References

The accuracy of references is the responsibility of the author. This includes not only the correct contextual use of the material, but also the citation itself. In the text your reference should state the author's surname and the year of publication (Smith 1989); if there are two authors you should give both surnames (Smith & Black 1989). When a source has more than two authors, give the name of the first author followed by 'et al'. (Smith et al 1989). No commas are used between the name and date. It is important to verify the correct and full title, the full authorship, and all other reference details with the original source (book, journal, etc.,) or through a service, such as Medline or ScienceDirect.

A list of all references in your manuscript should be typed in alphabetical order, double spaced on a separate sheet of paper. Each reference to a paper needs to include the author's surname and initials, year of publication, full title of the paper, full name of the journal, volume number and first and last page numbers. The names of multiple authors are separated by a comma with each appearing as surname followed by initials. The date is placed after the author's name(s), not at the end of the citation.

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