# An ultrasound investigation of the Thoracolumbar Fascia of people with and without lower back pain in prone and standing positions.

A thesis submitted for the Master of Science degree in Sport and Exercise Sciences (by Research and Thesis)

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## Abstract

### Introduction

The prevalence of lower back pain is a global issue that is predicted by the World Health Organisation to increase to over 800 million cases in the next 30 years. At any one time, 1 in 5 people in the UK will have lower back pain, and 10% will have chronic lower back pain. Changes to the morphology of the thoracolumbar fascia (TLF) have been identified as a possible cause of lower back pain in adults. In recent years, ultrasound imaging (US) has been shown to be a reliable and valid method to study the TLF. The aim of this study was to measure the TLF in a prone position compared to a standing position, in people with LBP, using US. Outcome measures were thickness and echogenicity.

### Methodology

26 adult participants were recruited, 13 with chronic LBP, 13 without LBP. Mean age was 52.42 (SD 18.59), 38% of participants were male. Age, gender and activity levels were matched between both groups. Pain intensity, frequency and disability were measured with standard questionnaires. US acquisition (Esaote, MyLab25Gold, Rimini, Italy) was made on one visit. US in both prone and standing positions were acquired 2cm medial and 2 cm lateral of the intervertebral disc space between Lumbar vertebrae 2 and 3. Participants laid on a treatment couch for the prone measurements. The standing position was standardised on an isokinetic dynamometer (HUMAC NORM, CSMi, Stoughton, MA, USA). The thickness and echogenicity were analysed in Matlab (version R2020b, The Mathworks, Natick, MA, USA) using a customised greyscale script.

Data was analysed using Pearson's product movement correlation, matched pairs T-tests and non-parametric tests.

Results

There was no significant difference in the thickness of the TLF between the prone and standing position in the whole cohort, nor between the LBP group and control groups. The echogenicity for the whole cohort was significantly brighter in prone compared to standing (p=0.04). There was a strong linear relationship and strong positive correlation between the Oswestry disability score and thickness of the TLF in both the prone (r= 0.92) and standing position (r= 0.62), The thoracolumbar fascia was significantly more disorganised in the standing position (p= 0.04).

Conclusion

To our knowledge, this is the first time a comparison between prone and standing positions of TLF ultrasound images has been conducted. Interestingly, no difference was found in thickness of the TLF in prone or standing. This is significant for future TLF research, particularly for participants who may have been previously excluded because of an inability to lie in a prone position.

The significant decrease in echogenicity in a standing position, may be due to changes in force transmission in the TLF, this warrants further investigation.

The novel nature of using US in a prone and a standing position is a promising finding and contributes to the development of use of US research methodologies into the TLF of people with LBP.

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# Abbreviations

| | |
|---|---|
| ANCOVA | Analysis of Covariance |
| B-Mode | Brightness mode |
| BMI | Body Mass Index |
| cm | centimeter |
| CT | Computed Tomography |
| D | dermis |
| d-value | difference between paired data |
| ECM | Extracellular Matrix |
| ES | erector spinae muscle |
| GPPAQ | General Practice Physical Activity Questionnaire |
| HUMAC®Norm | PC- based isokinetic machine launched in 2003 by Computer Sprots Medicine, inc (CSMi), 101 Tosca Drive, Stourton, MA 02072 |
| L | Lumbar vertebra |
| LBP | Lower Back Pain |
| Matlab | programming and numeric computing platform by Mathworks, inc |
| MHz | megahertz (million cycles per second) unit of frequency |
| MRI | Magnetic resonance imaging |
| N | Newton |
| n | population size |
| NHS | National Health Service |
| NLBP | No lower back pain |

| | |
|---|---|
| NSLBP | Non-specific lower back pain |
| NRS | Numerical rating scale |
| p-value | probability of the data |
| r- value | Pearson's produce moment correlation coefficient |
| REAG | School of sports and exercise sciences Research and Ethics Group |
| ROI | Region of interest |
| S | Sacral vertebra |
| SD | standard deviation |
| SE | standard error |
| SF-MPQ-2 | Short form, McGill questionnaire |
| SZ | subcutaneous zone |
| t- value | Size of the difference relative to the variation in sample data |
| TLF | Thoracolumbar Fascia |
| µ | one millionth |
| µm | one millionth of a meter |
| US | Ultrasound imaging |
| WHO | World Health Organisation |
| z-value | standardised normal deviate. |

## Technical Terminology

| | |
|---|---|
| Anisotropy | Different levels of stretch in different directions in one tissue |
| Aponeurotic Fascia | well defined fibrous sheaths that cover, and keep in place, a group of muscles or serve for the insertion of a broad muscle (Stedman's medical dictionary 1995) |
| Auxetic (negative poison's ratio) | materials that exhibit unusual behaviour when exposed to stress or strain |
| Biopsychosocial | Biological, psychological and social factors and how they combine. |
| Combined zone | Subcutaneous and perimuscular tissue |
| Echogenicity | US measurement of brightness |
| Hyperechoic | Brighter US structures with more Collagen fibers |
| Hypoechoic | Darker US structures with less collagen fibers or more water/gel |
| Hyaluronan | Also known as hyaluronic acid (HA), polysaccharide found in extra cellular matrix. |
| Kinesio-phobia | Fear of pain due to movement |
| Morphology | Study of form and structure of tissues. |
| Perimuscular | Fascial tissue, usually in sheets that lie between the subcutaneous and fascial layer (epimysium) |

| | |
|---|---|
| | around muscle tissue |
| Subcutaneous Fascia | Tissue found just under the skin. Usually filled with adipose cells |

# Chapter 1: Introduction

Lower Back Pain (LBP) is a global issue. The earliest surviving record of lower back pain dates to 1500 BC (Allan and Waddell, 2009). Three and a half thousand years later, in 2020, The World Health Organisation (WHO) estimated that 619 million people worldwide have Lower Back Pain (LBP) and suggests that cases will increase to 843 million by 2050, driven largely by population expansion and ageing (WHO, 2023). Lower Back Pain is the leading single cause of disability worldwide (Hoy et al., 2014; Ferreira et al., 2023). However, the economic cost of LBP disability has only been measured since the 19th century (Allan and Waddell, 2009) when society started to incur the costs of sickness and disability. Globally, LBP is now recognised as the leading cause of activity limitation and work absence in the Western world (Hoy *et al.*, 2014; Hartvigsen *et al.*, 2018; Ferreira *et al.*, 2023). Figure 1.1 shows the global burden of LBP for the years 1990 and 2015 by age group, the greatest increase in disability from LBP is in working age groups (Hartvigsen *et al.*, 2018).

Costs associated with LBP are generally reported as direct medical costs or work absenteeism and/or loss of productivity, often referred to as indirect costs.

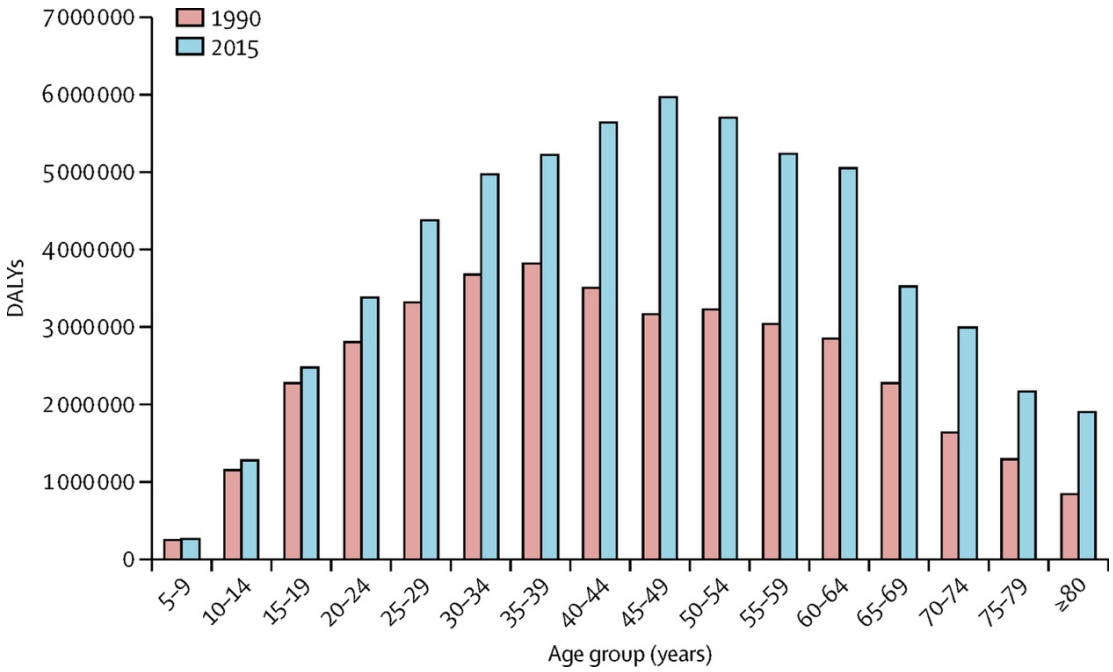



Figure 1.1: Global burden of LBP, in disability-adjusted life years (DALYs), by age group, for 1990 and 2015 (Hartvigsen *et al.*, 2018)

The cost of musculoskeletal treatment (including LBP) in the UK was estimated in 2020 to cost the NHS £4.76 billion per year (Greenhalgh et al., 2020). In 2023, a meta-analysis reported that for high-income countries such as the UK the economic burden for indirect costs, such as loss of output due to LBP, to be up to an additional £10.3 billion per year (Ferreira et al., 2023). In low or developing to middle-income countries such as China, which has the largest number of people with LBP in the world (91.3 million), (Abbafati *et al.*, 2020), the overall cost and burden on social support systems are negatively affected (Xu et al, 2024).

Around 60% of the adult population can expect to experience LBP in their lifetime (Campbell et al., 2013). However, estimates vary between 60% and 90% Andersson, 1999; Knezevic et al., 2021). More specifically, one in five of the UK population will have LBP at any one time. LBP can be experienced at any age

and prevalence increases with age, the highest number of LBP cases occur between the ages of 50-55 and LBP is slightly more common in women (Ferreira *et al.*, 2023). However, looking at the global picture, China has seen the greatest increase in LBP disability in children aged 5-14 (Xu et al, 2024).

LBP is traditionally categorised into two groups: specific LBP; when a specific patho-anatomic diagnosis can be reached, and non-specific LBP (NSLBP), where the cause is unknown (Kongsted *et al.*, 2016). In early studies, it was argued that LBP was self-limiting and resolved itself within 6 weeks (Menezes Costa et al., 2012). However, this categorisation does not address LBP experienced for more than 6 weeks, nor does it recognise intermittent, or recurring LBP episodes. To resolve this, NSLBP was then further categorised: acute (less than 6 weeks), sub-acute (6 to 12 weeks) and chronic (more than 12 weeks) based upon the duration of the episode (Van Tulder *et al.*, 2006). One of the reasons why estimates of NSLBP vary so much in the epidemiology literature is due to the variability in duration and intensity of LBP, from totally debilitating to mild, from a one-off occurrence to intermittent and recurring (Andersson, 1999).

However, categorisation of LBP solely based upon duration of pain is far from optimal. LBP is understood to be multifactorial. The Biopsychosocial model (Waddell, 1987) of pain recognises the physical, as well as key psychological, and socio-economic contributing factors to LBP (Hartvigsen *et al.*, 2018). One of the problems facing clinicians is that they cannot easily see the cause, as it is inside the body. X-rays offered a view but new technologies such as Magnetic resonance imaging (MRI), Computed tomography (CT) and Ultrasound Imaging

(US) offer a way to do this with less danger or invasion to the patient, providing greater clarity without undertaking surgery. This thesis uses US imaging to look at the structures of the tissues of the lower back with the expectation that measurements and observation of these tissues may help with the identification of what may contribute to NSLBP cases.

The field of LBP research has advanced in line with imaging technology. Initially, X-ray imaging focused research on spinal vertebra fractures and alterations in intervertebral discs. In recent years, high-resolution imaging such as Magnetic Resonance Imaging (MRI), Computed Tomography (CT) and Ultrasound Imaging (US), have directed researchers to focus on soft tissues such as muscles and ligaments. A relatively new area of LBP research has emerged in tandem with high-resolution ultrasound imaging, of specialised connective tissues of the lower back, also known as thoracolumbar fascia (TLF) (Adstrum et al., 2019). Figure 1.2 below indicates the location of the connective tissue, known as the TLF on a cadaver. The TLF is a sheet-like connective tissue structure known as an aponeurosis. It is an attachment point for major trunk muscles such as the Latissimus Dorsi and the Gluteus Maximus and is part of a myofascial girdle that surrounds the lower torso. It plays an important role in posture, movement and load transfer.

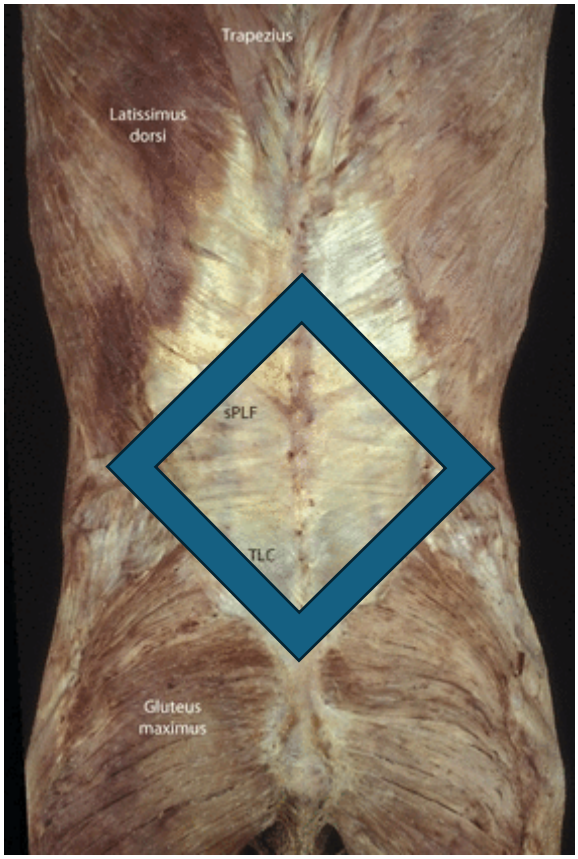



Figure 1.2: The Thoracolumbar fascia, Cadaver (Willard et al., 2012). The figure has been adapted to highlight the location of the TLF within the blue diamond shape.

Fascial layers can be visualised using US. This has allowed for fascial structures, such as the TLF to be studied in detail. Possible changes in TLF morphology may be a causative factor of LBP (Langevin et al., 2009; Whittaker et al., 2013; Gumruk Aslan et al., 2023; Pirri et al., 2023).

The TLF was first suggested as a source of NSLBP in 1939 (Kellgren, 1939 cited in (Casato et al., 2019)), however it is only in the last 30 years that this multi-layered connective tissue of the lower back has been investigated and identified as a cause of LBP (Langevin et al., 2009; Whittaker et al., 2013; Gumruk Aslan et al., 2023; Pirri et al., 2023). Pioneering research in 2009 by Langevin et al. (2009) identified that the thickness and echogenicity of the TLF is associated with LBP,

the TLF of LBP subjects being approximately 25% thicker and brighter compared to a control group. A subsequent TLF LBP study using US found that sheer strain between the layers of the TLF decreased for people with LBP (Langevin *et al.*, 2011). However, all the TLF LBP studies so far have only captured images in the prone position. This thesis aims to extend our understanding of the role of TLF in LBP, by measuring and visually inspecting the TLF in both prone and standing positions in people with and without LBP.

This thesis sets out to explain what fascia is. To highlight the recent discovery of specialised cells found in the fascia called fasciacytes (Stecco et al., 2011; Stecco et al., 2018), and the significance of Hyaluronan, a substance synthesised by fasciacytes (C. Fede *et al.*, 2018). Together with wider issues such as nomenclature, that surrounds this relatively new area of research. This thesis considers theories that the TLF maybe a possible cause of LBP. The structure and function of the Thoracolumbar Fascia (TLF) is explored together with its importance to the movement and stability of the lumbosacral spine (Barker et al., 2014; Bojairami et al., 2022a). The thesis considers the explanations for LBP connected to changes in the morphology of the TLF, such as fascial adhesions and inflammation and how this may restrict glide between the fascial layers of the TLF and cause pain (Langevin *et al.*, 2009). It is not certain if changes in the morphology of the TLF are the cause of LBP or if LBP causes observed and measured changes in the TLF, and there are many theories about what causes a change in morphology. The studies so far can only identify if there is a change in the morphology of the TLF if LBP is present. This thesis hopes to build upon these studies by looking at different positions for US

image acquisition, and the comparison of measurements of TLF thickness, echogenicity, together with a visual analysis in both prone and standing positions.

# Chapter 2: Literature Review

## 2.1 Introduction

Lower back pain (LBP) is a common symptom, it occurs worldwide across all age groups and socio-economic backgrounds (Hoy *et al.*, 2014). For a growing proportion of people, LBP becomes persistent and disabling (Hartvigsen *et al.*, 2018). This literature review provides an overview of current concepts in the LBP literature, with a particular focus on ultrasound imaging of the thoracolumbar fascia (TLF). The number of LBP studies in literature has grown sharply over the last 25 years, increasing from 223 in 2000 to over 900 per annum in the years 2019 to 2021. The focus of LBP research studies has changed over the last 25 years. Disability and management of LBP were predominant in the earlier years, however, since 2012 the determinants of LBP, such as the aetiology of chronic LBP have become the direction of LBP research (Wai Kan Yeung *et al.*, 2022).

## 2.2 Fascia and LBP

Over the last 30 years there has been an expanding interdisciplinary interest in fascial tissue. Fascia is a connective tissue and has a multitude of functions such as force transmission, movement, stability, proprioceptive communication, promoting sliding and reducing friction (Kumka et al., 2012). Interest in fascia as a cause of LBP has evolved in tandem with advances in technologies such as modern imaging systems, new histological and

immunohistochemical staining techniques, hydro dissection, plastination and virtual imaging (Adstrum et al., 2019). This has meant that until relatively recently, fascia has been overlooked as a cause of pain anywhere in the body since it could not be viewed, analysed or measured. Recent fascia research projects have looked at this tissue as a possible cause of pain in the neck and shoulders (Stecco *et al.*, 2013) as well as the lower back (Langevin *et al.*, 2009). Other areas of fascia research include cancer treatments, inflammation and fibrosis (Langevin *et al.*, 2016).

Fascial tissues are found throughout the body, surrounding and penetrating muscle tissue as well as wrapping and connecting organs, tendons and bones. For many years fascia was known by many different names, for example, Superficial fascia is referred to as panicular fascia in some texts. This led to confusion and ambiguities (Kumka et al., 2012).

In the lower back, the thoracolumbar fascia (TLF) is comprised of multi-layered, multidirectional fascial sheaths, connecting the limbs to the torso, and the posterior trunk muscles to the abdominal muscles, like a girdle. This fascia is particularly important for maintaining spinal stability (Schuenke *et al.*, 2012).

### 2.2.1 Fascia Nomenclature

The absence of an internationally agreed nomenclature for fascia has led to disagreement and confusion in the literature (Stecco et al., 2016). Moreover, a lack of clarity in terminology makes comparisons of results across research studies difficult (Stecco *et al.*, 2025). Over the last 2 decades, many attempts have been made to resolve this issue. Historically fascia was defined as a sheath, a sheet, or any other dissectible connective tissue that forms beneath

the skin to attach, enclose and separate muscles and other internal organs. In 2011 the Federative International Programme on Anatomical Terminology, affirmed this definition. However, in 2015 clinicians, researchers and therapists met at the International Fascia Research Conference in Washington to discuss the perceived limitations of this anatomical definition of Fascia, as it did not satisfy both the medical and therapeutic communities. It was suggested that the existing definition did not consider new research on fascia and its functions in the human body, such as force transmission from muscles to the surrounding fascial sheaths (Huijing, 2009) or sensory functions such as proprioception (Langevin, 2021). Additionally, the existing definition did not include soft fascial tissues, such as loose connective tissues that are found between the denser sheaths of fascia to permit glide (Langevin *et al.*, 2011). Moreover, it did not allow clinicians, researchers, scientists and practitioners to communicate with each other (Adstrum *et al.*, 2017) The nomenclature committee therefore proposed an additional and new definition for a new body-wide fascial system (Stecco et al., 2016; Schleip, 2019, Hedley et al., 2019). This longer, more inclusive definition was in turn criticised (Neumann, 2023). A recent paper has suggested that the absence of an inclusive definition is holding back the anatomical teaching of fascia (Stecco *et al.*, 2025). To address this issue the authors of this paper propose that fasciae (Plural) and the fascial interstitia within them, constitute an anatomical system. This anatomical system being defined as a layered body-wide multiscale network of connective tissue that allows tensional loading and sheering mobility along its interfaces (Stecco *et al.*, 2025).

The research questions in this thesis have adopted the inclusive definition of fascia, to enable the inclusion of the loose connective tissues in between the dense connective sheets of the TLF.

## 2.3 Composition of Fascia

All fascial tissue consists of both cellular and extracellular components. Fascia is made up of, an extracellular matrix (ECM) which is fibrous, a fluid component and the Cells that populate, create, and maintain the ECM (Schleip et al., 2021) Fig 2.1 shows the components of fascia, divided into cellular (cells) and extracellular (fibres and ground substance). This is not an exhaustive list, as researchers are constantly discovering new components of fascia.

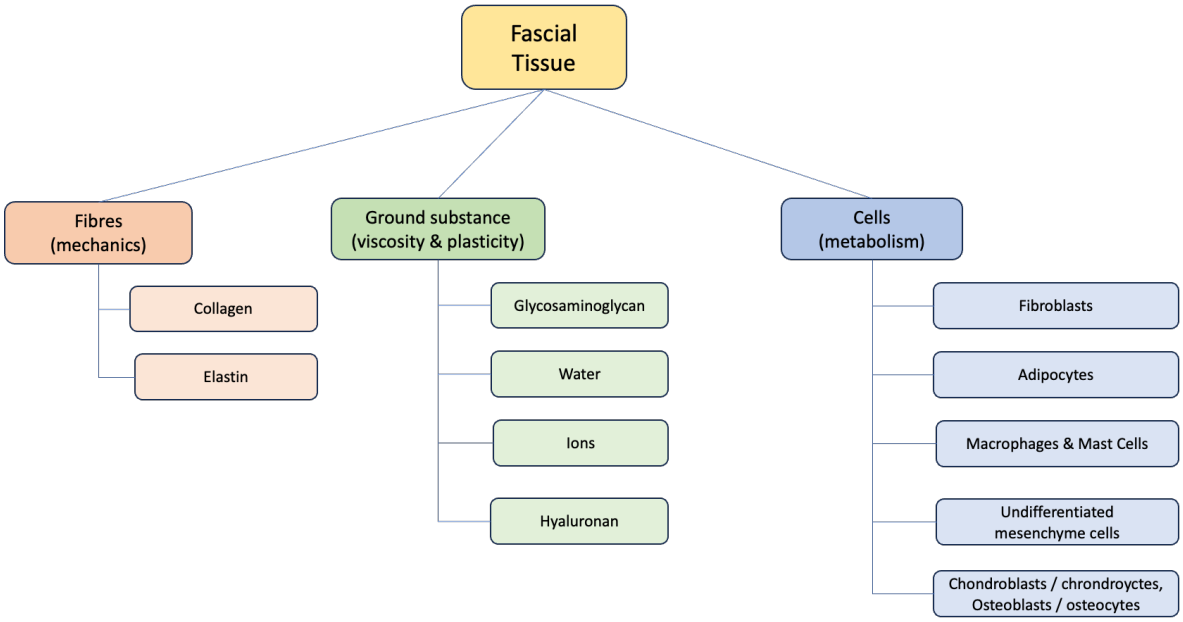



Figure 2.1: Composition of Fascial Tissue. Adapted from (Stecco, 2015)

Cells only make up less than 5% of fascial tissue by volume (Schleip et al., 2021) Most of these cells are fibroblasts, whose function is to produce and

maintain collagen and elastin fibres (Stecco et al., 2018). Very recently, a new specialised fibroblast cell, the fasciacyte was identified. Fasciacyte cells are found in clusters along the surface of each sub-layer and play a major role in permitting glide and autonomy among the various fibrous layers. Fasciacytes biosynthesise hyaluronan, a high molecular weight glycosaminoglycan of the ECM (Cowman *et al.*, 2015), which regulates normal structural integrity as well as responses to injury and repair (Stecco et al., 2018). Hyaluronan (Schleip, 2021) serves several functions, such as, space filling, lubrication of joints, water homeostasis and as a facilitator of cell migration (Cowman *et al.*, 2015). Loose connective tissue is rich in hyaluronan and, importantly, changes in the concentration (amount of Hyaluronan present in specific volume) and molecular weight (mass of a single molecule) of hyaluronan are associated with inflammation and degenerative arthropathies and can affect the sliding movement of fascia (Cowman *et al.*, 2015; Temple-Wong *et al.*, 2016). Depending on the location and purpose of the fascial tissue, the molecular and architectural characteristics vary, and these determine their mechanical properties (Langevin, 2021). For example, some connective tissue is loosely organised and compliant. Rich in Hyaluronan, loose connective tissues allow for glide and are found between sheets of fascial tissue and in places that require a lot of movement such as the subcutaneous layer just beneath the skin. Other fascial tissues are tightly woven and dense, like a fabric, facilitating force transmission and separation such as the aponeurosis of the TLF.

## 2.4 Fascial Layers

Sheets of fascia are found all through the body, surrounding and separating muscles. If two adjacent planes become adhered, due to injury, disease, immobility or habit, gliding capability can be lost (Langevin *et al.*, 2011). The traditional view that muscles worked independently was questioned in Wilke's review of fascia literature (Wilke *et al.*, 2018). For instance, as muscle contracts, muscle fibres get thicker forcing the fascia associated with the muscle (endomysium, perimysium and epimysium) to expand in response (Findley et al., 2015). The fascial tissue arrangement in and around the muscle is shown in Fig. 2.2. Furthermore, these intramuscular fasciae are continuous with other collagen-reinforced structures such as neurovascular tracts, intermuscular septa or interosseous membranes (Huijing, 2009). This means that during exercise, stresses are transmitted to fascia.

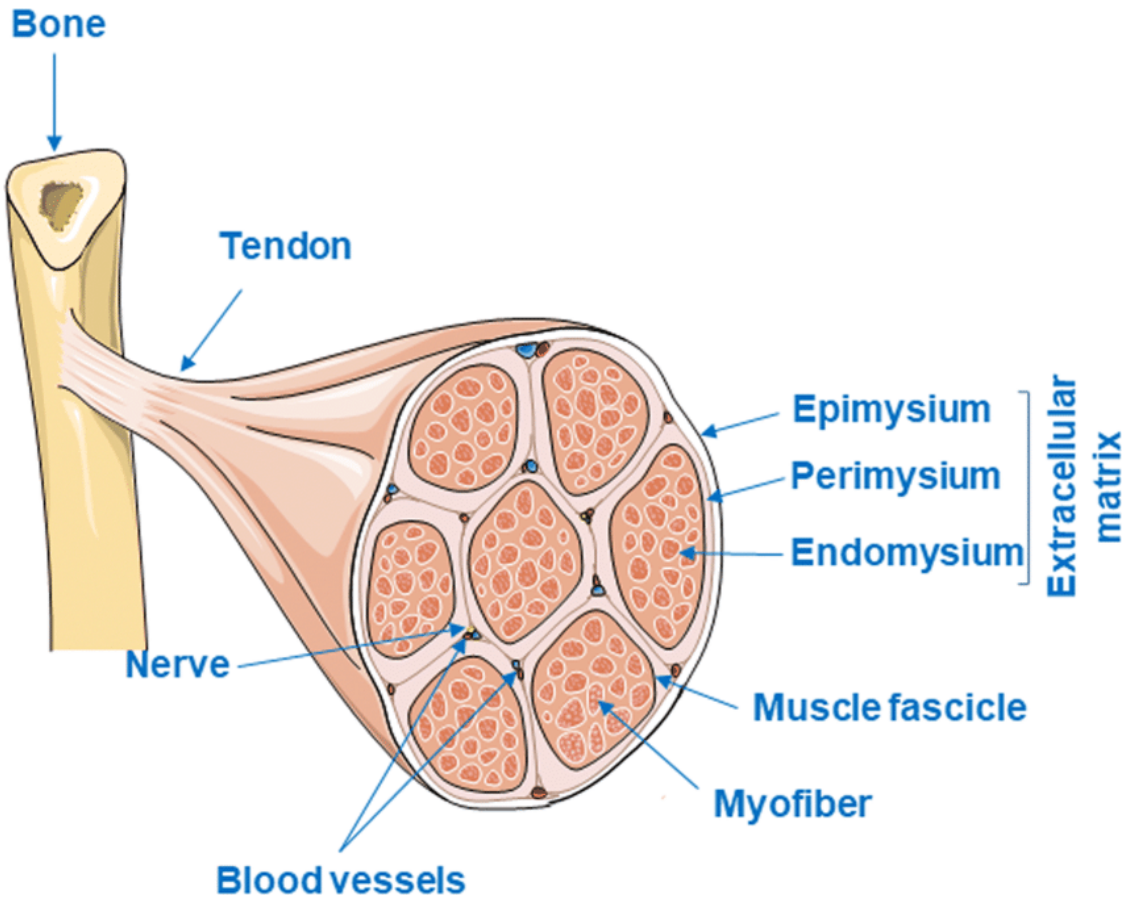



Figure 2.2: A schematic diagram showing the arrangement of fascial tissue in a muscle (Mahdy, 2019).

The recent paper by Stecco et al. 2025, addresses and opens up a discussion on the contested idea of layers of fascial tissues that have been referred to in the existing literature on fascia (Stecco et al., 2011; Stecco, 2015; Stecco et al., 2016). Immediately under the skin is the subcutaneous fascial layer. It is connected to both the skin above and the deep fascia below, by retinacula and filled with adipose (fat) cells (see Fig 2.3). Stecco's model (2011) states that the subcutaneous fascia is subdivided by a layer of fascia called the superficial fascia resulting in superficial adipose tissue being most closely connected to the skin, and deep adipose tissue being most closely connected to the muscle. These layers can be identified in US imaging, see Fig 2.3. This arrangement

permits a flexible and yet resistant mechanism of mechanical load transmission from multidirectional forces (Stecco, 2015)

The deep fascia layer (see Fig. 2.3) is denser and more organised in its architecture. It forms fibrous sheaths that interpenetrate and surround muscles, bones, nerves and blood vessels (Willard *et al.*, 2012). It is known by different names depending on its location and purpose. For example, fascia surrounding bones is called periosteum, and fascia surrounding tendons is called paratendon. Around muscles it is called either aponeurosis or epimysium according to its thickness and relationship with the underlying muscles. There is a strong connectivity between muscles and fascia. Muscles are composed of muscle fibres; each fibre is surrounded by a fascia sheath, the endomysium. These fibres are in turn formed into bundles, again surrounded by a fascial sheet, the perimysium. The epimysium surrounds the whole muscle, maintaining its shape (Fig.2.2). The ECM of the epimysium is rich in hyaluronan, allowing frictionless glide (McCombe *et al.*, 2001).

The deep fascia (see Fig:2.4) of the lower back is known as the Thoracolumbar fascia. It is formed of layers of deep fascia and is defined as aponeurosis. Typically, aponeurosis fascia is formed of 2 or 3 layers of sheets of parallel collagen fibres with a thickness of 277μm (±SD 86.1μm) (Stecco *et al.*, 2013). In the TLF, the collagen fibres in each layer are orientated in different directions forming angles of 75°-80°. Each layer is separated by loose connective tissue (mean thickness 43±12μm) (Stecco *et al.*, 2013). This arrangement permits each layer to slide over adjacent layers (Stecco *et al.*, 2013).

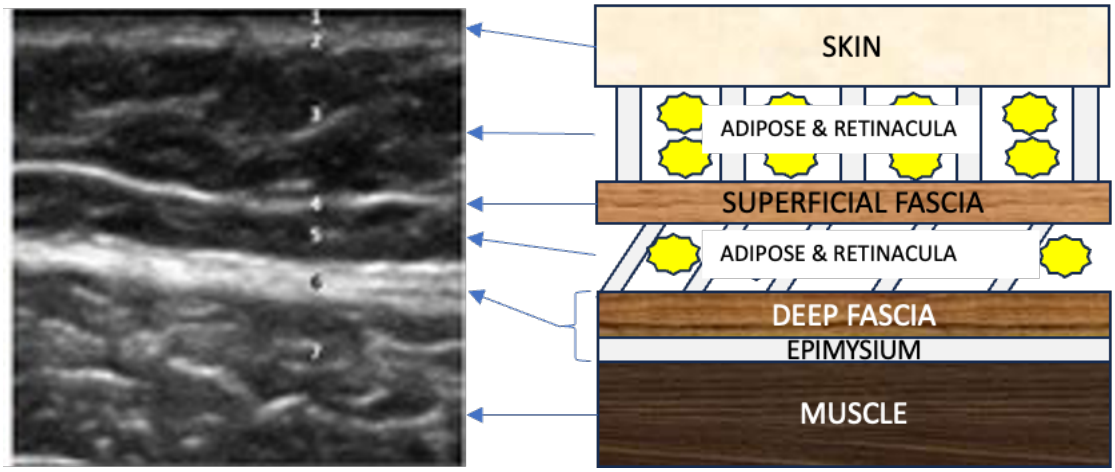



Figure 2.3: Schematic and ultrasound image of the region between the skin and muscle. Ultrasound image (Pirri *et al.*, 2020), schematic based on (Stecco et al., 2011).

The difference between loose and dense connective tissue lies primarily in the density and arrangement of the collagen fibres and the ground substance (see fig. 2.1 for composition). Loose connective tissue has a higher proportion of ground substance and more space around the fibres. Whereas dense connective tissue has a higher proportion of fibres, often arranged in parallel bundles with less ground substance. The difference in structure of the loose connective tissue and the dense connective tissue allows for the different functions of the tissues. Loose connective tissue can be found beneath the skin, around organs and between layers of dense connective tissue. Dense connective tissue is found as tendons and ligaments for example.

All these layers can be identified in US imaging. Fig 2.3 shows all the layers between the skin and the muscle in both schematic form and the corresponding ultrasound image.

## 2.5 Thoracolumbar Fascia Classification and Composition

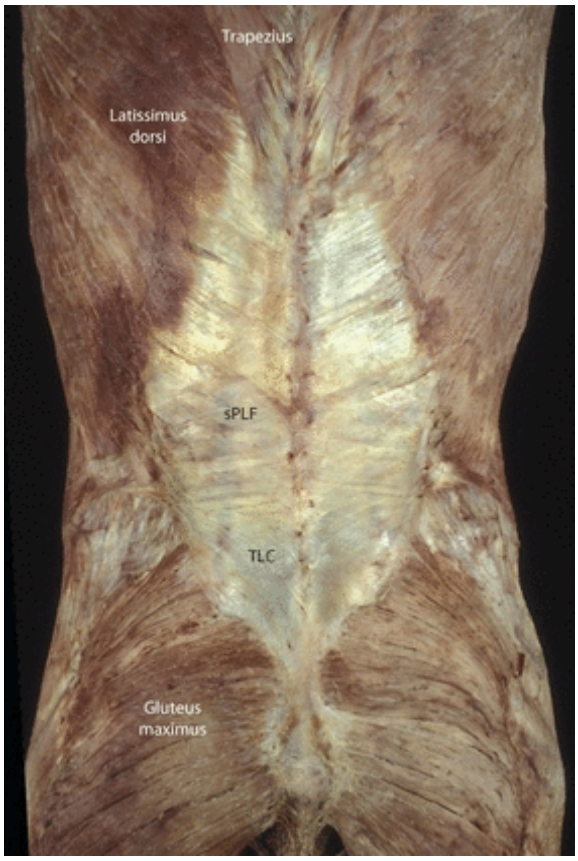



Figure 2.4: The Thoracolumbar fascia, Cadaver (Willard et al., 2012).

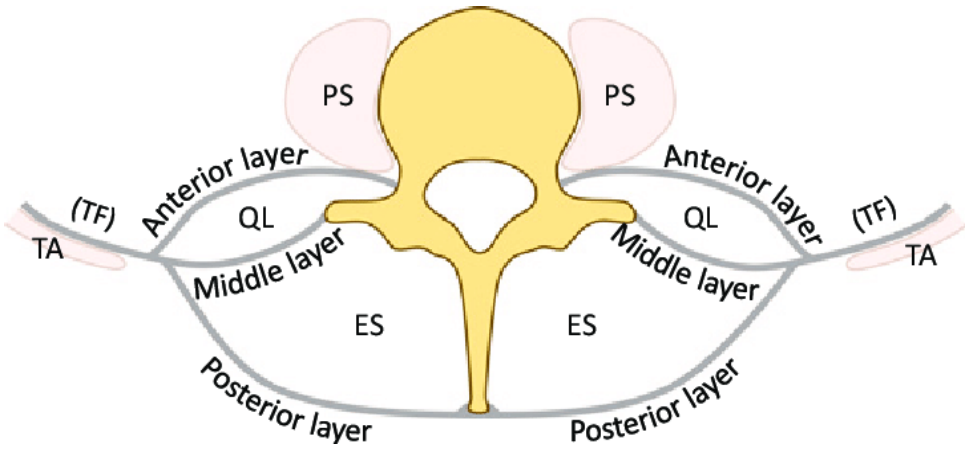
Traditionally the TLF was classified as an irregular dense connective tissue since collagen fibres appeared to be organised irregularly (Langevin et al., 2009). However, cadaver studies discovered that each dense connective tissue sheet is composed of sheets of regularly organised parallel fibres that lay at different angles in a laminar, which gave the impression of irregularity (Langevin et al., 2011; Willard et al., 2012). Each sheet of dense connective tissue slides independently, interspersed by thin layers of loose connective tissue, rich in hyaluronan, aiding the sliding of each sheet. This independent motion of adjacent fascial sheets is particularly relevant to the TLF, as each layer that

makes up the TLF corresponds to the epimysium of muscles with different directions of pull, longitudinal (latissimus dorsi, serratus posterior, erector spinae) vs. transverse (internal/external obliques and latissimus dorsi) (Langevin *et al.*, 2011). To understand the architecture of the TLF it is helpful to consider it as 3-dimensional structure, with height, width and depth. It is also described as a girdling structure connecting fascial architecture with the abdominal muscles of the transversus abdominis (Willard et al., 2012).

The TLF is diamond shaped (Fig 2.4). It covers the back muscles from the sacral region, up through the lumber and thoracic region as far as the fascia nuchae that covers the back of the neck. The lateral borders of the TLF are marked by its junction with the latissimus dorsi muscle and gluteus maximus muscles and connects with the anterior abdominal musculature (Schuenke *et al.*, 2012). The girdling fascial connections can be seen in Fig. 2.5.

The TLF has several functions.  Force transmission through the fascial sheets that make up the TLF is important for movement and stability of the lumbosacral spine (Barker et al., 2014; Bojairami et al., 2022a). TLF also has an important role in force transmission between the lower limbs and trunk (Barker *et al.*, 2014) and among trunk muscles and spine (Gatton *et al.*, 2010).

There are 2 models of the TLF in the literature, a 2-layer model (Stecco, 2015) and a 3-layer model (Willard, 2012), which can confuse. The difference relates to the inclusion of layers of fascia that surround the muscles anterior of the transverse process of the vertebral body (hypaxial) and not the layers that are posterior (epaxial) see Fig. 2.5.




| Three-layer Model | | Two-layer Model |
|---|---|---|
| Posterior layer | 1 | Posterior layer |
| Middle layer | 2 | Anterior layer |
| Anterior layer | 3 | Transversus Fascia |

Figure 2.5: Schematic showing the location of (1) Posterior layer, (2) Middle layer, (3) Anterior layer of the TLF (Kanemura *et al.*, 2017).

Transversus Abdominus (TA), Erectus Spinae (ES), Quadratus Lumborum (QL), Psoas (PS), Transversus Fascia (TF).

The two-layer model only recognises the posterior layer (1) and the Middle layer (renamed anterior layer) (2). The anterior layer of the three-layer model is considered a continuation of the transversus Fascia (TF), see Fig. 2.5.

The posterior layer of the TLF is the same in both models. US studies of the TLF only measure this posterior layer together with the subcutaneous fascia above and the muscles directly below

The posterior layer of TLF is under the skin (dermis) and subcutaneous tissue at the back of the body and over the erectus spinae. It has been noted that there is a definite coupling of gluteus maximus and latissimus dorsi by way of the posterior layer of TLF (Barker et al., 2004; Stecco, 2015). Muscles such as

erectus spinae have easily dissectible epimysium and the posterior layer of TLF can glide over the top (Schuenke et al., 2012).

Fig 2.6 shows an ultrasound image of the posterior layer of the TLF. At the top of the US image is the dermis (D). Below is the loose connective tissue layer of the subcutaneous tissue (SZ). Below that is the posterior layer of the TLF (TFL in image) the white layers of the dense connective tissue, separated by the dark loose connective tissue layers can be seen. The singular horizontal white line below the TLF is the perimuscular fascial tissue around the Erector Spinae muscle (ES), which is at the bottom of the image. In this image the region of interest (ROI) that the researcher was investigating is indicated by the red arrow (De Coninck, 2018) .

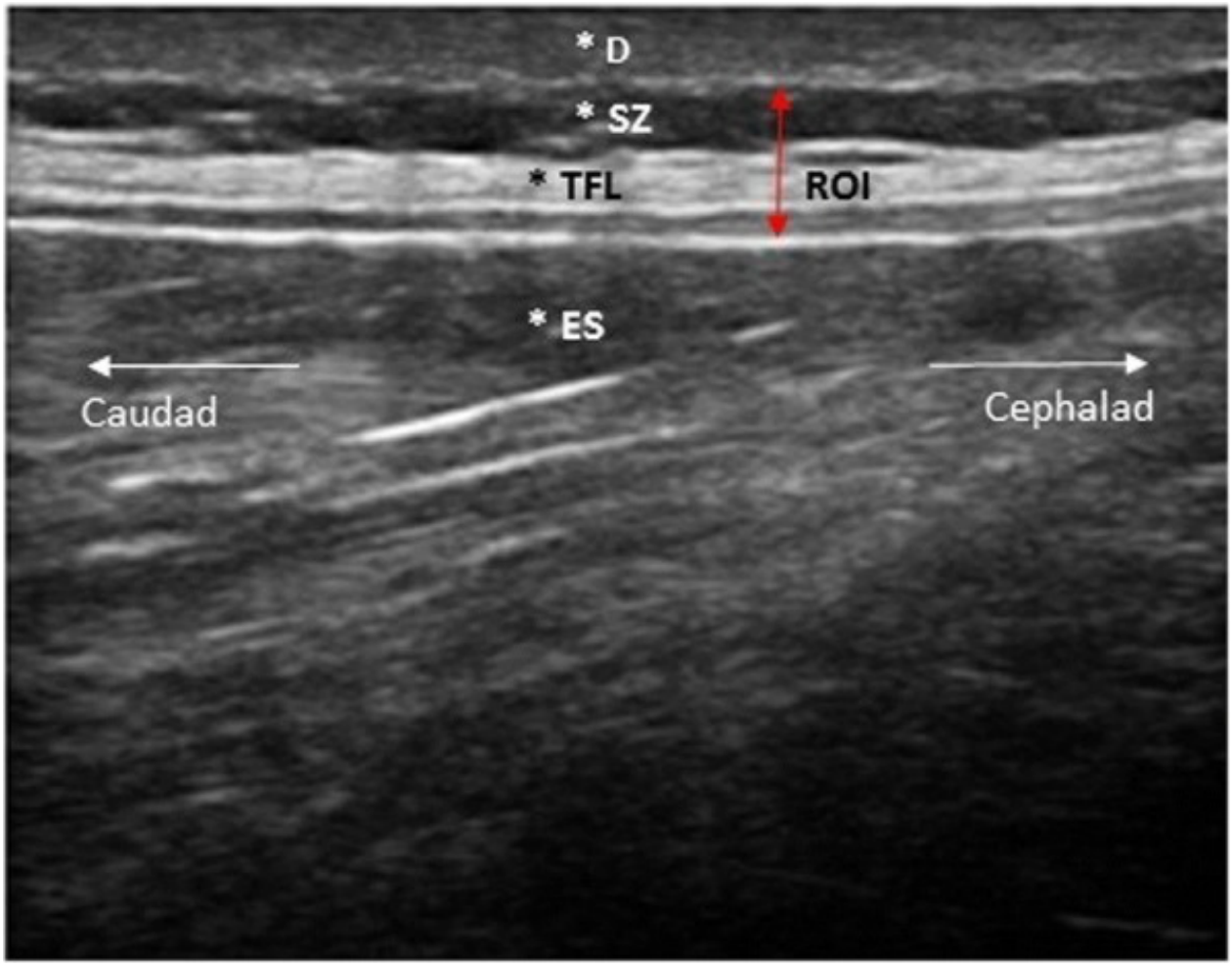



Figure 2.6: Ultrasound image of the posterior layer of TLF (De Coninck et al., 2018).

## 2.6 Innervation of Fascia

The Fascial system is densely innervated (Mense et al., 2016; Mense, 2019) and could be considered a sensory organ (Schleip, 2020). It has been estimated that the human fascial network contains 250 million nerve endings (Schleip, 2020). Analysis of specimens of deep fascia, dissected during planned surgical procedures, has demonstrated that deep fascia is the second most densely innervated tissue, with a mean density of 33.00 ± 2.5/cm $^2$, and skin as the most innervated at 64.0±5.2/cm$^2$ (Fede et al., 2022). The TLF in animal studies (rats)

(Mense et al., 2016) and humans (Hirsch et al., 1963; Bednar et al., 1995) display a dense innervation with nociceptive afferent nerves, which has been linked to lower back pain since nociceptive afferent nerves send pain signals to the brain. Additional hypotheses of the role of the TLF in LBP include irritation of the nerves due to microinjuries and/or inflammation, a loss of proprioceptive signalling due to injury and an increased sensitivity of the nerve endings (Wilke *et al.*, 2017a). Mense et al. (2016) calculated that around 40% of the entire fascia innervation consisted of postganglionic sympathetic fibres. Mense hypothesised that since sympathetic activity was higher when the body is under psychological stress this may explain why many patients find that they have more pain when under stress (Mense, 2019)

## 2.7 The TLF and Force Transmission

The different layers of the TLF illustrated in Fig 2.7, show the direction of collagen fibres. The direction of the fibres indicates the direction of the pull by muscles such as the gluteus maximus (A in Fig 2.7) or latissimus dorsi (D in Fig:2.7). The direction of pull and connection of the TLF is also seen in Fig 2.8 below. The illustration in Fig 2.7 demonstrates the multi-layered structure of the TLF, with for example, the different fibre directions of latissimus dorsi and gluteus maximus giving a crosshatched appearance, which may have been the reason the TLF was thought to be an irregular dense connective tissue (Schuenke *et al.*, 2012). Two cadaveric studies found evidence of force transmission through the posterior layer of the TLF Barket et al (2004) found a contralateral transmission of force between the Latissimus dorsi and gluteus

maximus, where a 10 N force was applied in the direction of the muscle fascicles of the latissimus dorsi or the gluteus maximus and this led to a 4.9 N (0.8 N) displacement of the TLF at L3 (Barker et al., 2004). Whereas Vleeming (1995) found a displacement of the posterior layer of the TLF is caused by traction on the biceps femoris (Vleeming *et al.*, 1995). It is argued that weakness in any muscle associated with the TLF will decrease force transmission and contraction of muscles such as Erectus spinae/Multifidus will increase the tension of the TLF (Macintosh et al., 1987; Vleeming et al., 1995). Alterations to force transmission following soft tissue injury of the TLF have been demonstrated in a porcine study (Nelson-Wong *et al.*, 2018).

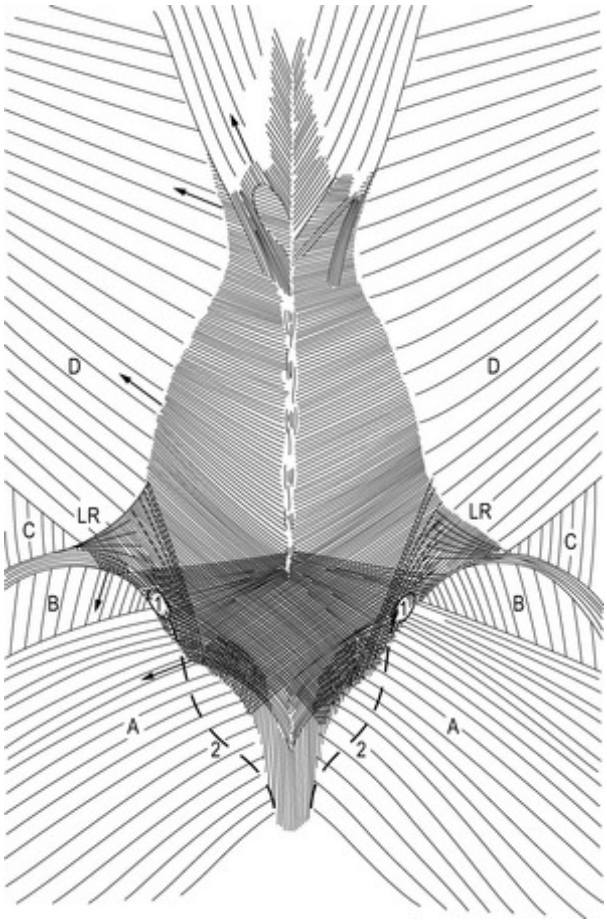



Figure 2.7: Drawing showing the superficial lamina of posterior layer of TLF and direction of collagen fibres (Vleeming et al., 2007).

(A) Fascia of the gluteus maximus. (B) Fascia of the gluteus medius. (C) Fascia of external oblique. (D) Fascia of latissimus dorsi. (E) Cross-hatched appearance of the superficial lamina due to different fiber directions of latissimus dorsi and gluteus maximus. 1. Posterior superior iliac spine. 2. Sacral crest. LR, part of lateral raphe.

A 3D model of the TLF found 3 distinct sub-layers of the posterior layer (Benetazzo *et al.*, 2011). In this study 2 tissue samples were taken from 2 male cadavers,7cm from the spinous process of the 3rd lumbar vertebra, fibre directions of TLF sheets were found to have different angles, thicknesses and organisation. The authors hypothesised the different fibre directions would

enable glide over the deeper muscular structure and provide strength in different directions (Benetazzo *et al.*, 2011).

## 2.8 Lower Back Pain Definitions and Categories

Traditionally, LBP is defined as pain, muscle tension, or stiffness, located in the region of the back that extends from the 12th rib to the iliac crest. More recent definitions include the buttocks and gluteal fold, with and without leg pain often referred to as sciatica (Koes et al., 2006; Knezevic et al., 2021). Historically people with LBP have visited their GP, but increasingly LBP is one of the leading causes of emergency department visits (Edwards *et al.*, 2017).

LBP is usually divided into two main categories, specific LBP and non-specific LBP. Only a small proportion, up to 15% of people, have specific LBP (Kent et al., 2009; Hartvigsen et al., 2018). Specific LBP is diagnosed when caused by a specific pathophysiological mechanism, such as vertebral fractures, malignancy, discogenic pain, muscles strains and infection (Finucane *et al.*, 2020). Whereas approximately 85% of people with LBP are diagnosed with non-specific LBP (O'Sullivan, 2005), idiopathic multifactorial pain, without a specific mechanical cause. The Biopsychosocial model of pain, which considers biological, psychological and social factors and their complex interactions is a common framework for researching the NSLBP experience, which is often categorised by duration (Koes et al., 2006; Kongsted et al., 2016). The key clinical symptoms of non-specific LBP (NSLBP) are pain and disability (Koes et al., 2006). Healthcare has various diagnostic labels for NSLBP, and there is considerable variation of diagnosis and management between countries (Koes

et al., 2006). NSLBP is normally classified into 3 groups, acute, sub-acute and chronic (Koes et al., 2006). Acute NSLBP is defined by the duration of an episode of NSLBP persisting for less than 6 weeks. Whereas sub-acute NSLBP persists between 6-12 weeks and chronic NSLBP is when symptoms persist for more than 12 weeks (Koes et al., 2006). NSLBP is generally perceived as a self-limiting condition, resolving itself in around 6 weeks (Menezes Costa *et al.*, 2012). Menezes goes on to say that the percentage recovering within 6 weeks can be anywhere between 39-90%. When NSLBP is categorised as sub-acute Menezes estimates that 80-90% recover before being categorised as chronic, at a later stage. Beyond this 3-phase categorisation, there is no distinction within the chronic NSLBP sub-group. This means chronic NSLBP can include both people with persistent severe pain and people reporting mild symptoms for more than 3 months (Kongsted *et al.*, 2016). The assumption that NSLBP symptoms remain largely unchanged between the acute phase and chronic phase is increasingly receiving criticism (Hartvigsen *et al.*, 2018). In a pioneering longitudinal study of the trajectory of chronic NSLBP, the authors suggested that the prognosis of NSLBP can no longer be simply described in terms of recovery or chronicity and stressed the need to improve our understanding of the course or trajectory of LBP, which could provide a more meaningful classification of NSLBP (Kongsted *et al.*, 2016). NSLBP is increasingly recognised to be an episodic condition, and that people who experience NSLBP are likely to have further episodes which should be referred to as intermittent or recurrent (Kongsted *et al.*, 2016). Recurring NSLBP is now defined as an episode of NSLBP after a symptom-free period of 6 months (Koes et al., 2006). A slightly different

categorisation of chronic NSLBP, is pain that lasts beyond the expected period of healing, which is closely aligned with the definition of chronic pain (Andersson, 1999). Currently, the search for a conceptual framework for non-specific LBP continues (Kent et al., 2009) and the need remains for a definitive consensus on precise definitions of acute, recurrent, intermittent and chronic NSLBP.

## 2.9 Low Back Pain Aetiology

LBP is multifactorial, the LBP literature can be divided into biological factors (such as pain caused by fractures or soft tissue injuries), lifestyle factors (such as a sedentary lifestyle, obesity and smoking), and psychological factors (such as depression, fear of movement and expectations that pain is caused by injury) (Verbunt et al., 2010; Balagué et al., 2012).

Current LBP literature agrees that only a small proportion of chronic LBP is directly associated with pathologies such as infections, tumours, osteoporosis, fracture, and structural deformity, which are serious aetiologies but much less common (Balagué et al., 2012). Hartvigen (2018) estimates that less than 1 % of people with LBP have a serious spine-related disorder.

The Biopsychosocial model of LBP was developed in response to trying to understand LBP as a multi-factorial condition (Engel, 1978). This model's aim was to broaden a purely biomedical approach to clinical assessment by acknowledging psychological and social impact factors (lifestyle factors) on the development of LBP. Adopting a biopsychological approach to assessment and care planning is becoming increasingly important, with psychological issues,

such as depression, catastrophising and fear avoidance beliefs, affecting the prognosis of this condition (Hartvigsen *et al.*, 2018).

Early LBP studies, prior to 2012, attributed 97% of specific acute LBP pain to mechanical factors such as lifting or carrying (Balagué et al., 2012; Chien, 2008). To some extent, acute mechanical back pain is still thought to be a pathology of the spine, intervertebral discs and the surrounding soft tissues (Campbell et al., 2013; Pirri et al., 2023). Due to the view that the causes of LBP were based primarily on mechanical factors early LBP research mostly focused on treatment methods.

However, more recently, trends in LBP research have changed. Studies focused on the aetiology of NSLBP. This shift in research priorities is mostly due to the introduction of groundbreaking scientific analysis using new high-resolution imaging technologies (Huang *et al.*, 2021). This has enabled research into the pathophysiology of LBP to include the role of connective tissues in LBP, which until that point had been largely ignored.

A pathophysiological component to LBP that has attracted a lot of attention over the last 3 decades is the structure, function and disorders of specialised connective tissues in the lower back, namely, the thoracolumbar fascia (TLF). The TLF has been associated with movement disorders caused by LBP, leading in turn to increased stiffness and decreased flexibility, and consequently further limitation in movement resulting in chronic LBP (Casato et al., 2019). Furthermore, the TLF has been investigated as a possible cause of LBP. Using high resolution technology, a pioneering study linked changes in the morphology of the TLF with chronic LBP (Langevin *et al.*, 2009).

It is evident that LBP is a complex condition and as demonstrated above, its causative factors can be just as complex and multi-factorial.

## 2.10 The Role of TLF in Lower Back Pain

Pioneering studies as early as 1939 recognised the deep fascia as one of the responsible tissues for lower back pain (Casato et al., 2019). Today there is a widespread body of evidence that supports the TLF as of clinical importance for people with chronic LBP (Langevin *et al.*, 2009; Willard *et al.*, 2012; Klingler *et al.*, 2014; Wilke *et al.*, 2017b)

### 2.10.1 Ultrasound Studies

An ultrasound study found that the TLF of subjects with chronic LBP was 25% thicker with a 25% brighter echogenicity than those without LBP (Langevin et al., 2009). A subsequent ultrasound study investigating sheer strain in the TLF suggested that abnormal connective tissue pathology may be a predisposing factor for LBP (Langevin *et al.*, 2011). It has been hypothesised that adaptations to connective tissue structures could be caused by multiple factors such as overuse, repetitive use, habit, trauma, injury, underuse or immobility (Langevin et al., 2007). It has long been accepted that biological soft tissues are capable of functional adaptations and that increasing or decreasing loads can cause a change in soft tissue architecture (Kjær *et al.*, 2009). Fibroblasts are stimulated by everyday strain and loading patterns. Challenges to the tissue's strength, extensibility and ability to shear will stimulate the fibroblasts to respond in a process of constant reconstruction and rearrangement (Schleip et al., 2021).

More recently the thickness of the TLF in individuals with LBP was found to be increased in a US study (Pirri *et al.*, 2023), which compared the TLF thickness of 92 subjects,46 with LBP and 46 without LBP (NLBP). The study observed that TLF was thicker on both sides of the spine for subjects with LBP ($p > 0.05$ on right, $p = 0.03$ on the left). It has been proposed that the increase in thickness may be attributed to remodelling of the TLF over time in response to repetitive stresses caused by pre-existing altered movement patterns, habitual posture or sports-related activities (Langevin et al., 2007; Pirri et al., 2023). It is theorised that micro injuries caused by overuse/underuse may result in an inflammatory response, leading to fibrosis, densification and thickening of the TLF (Wilke *et al.*, 2017a). For many years, several spinal surgeons have reported signs of injury and/or repair, observed during lumbar surgery. It has been suggested that adhesions may have formed following tears in the TLF, causing pain (Dittrich, 1964). Later, microscopic changes in fascial tissues found during lower back surgery suggest the presence of inflammation (Bednar et al., 1995). The fibrosis of the fascial architecture of the TLF, or any injury that causes adhesions between the lamina of the TLF, could lead to the loss of independent motion of adjacent connective tissue layers, further restricting body movement (Langevin *et al.*, 2011). To investigate this further, Langevin tested 121 human subjects, 50 without LBP and 71 with chronic LBP of greater than 12 months duration. The goal of this study was to quantify the shear plane motion within the thoracolumbar fascia. Langevin et al (2011) adopted the same protocol used in a previous study by this group (Langevin *et al.*, 2009) with the addition of taking a cine-recording of a passive trunk flexion using a motorized articulated table.

The results showed that the shear strain for participants with LBP was 20% lower than NLBP. It is interesting to note that male participants had significantly lower shear strain compared to female participants ($p=0.002$). Furthermore, negative correlations were found in men between TLF sheer strain and TLF thickness ($r= -0.45$, $p<0.001$) and echogenicity ($r= -0.28$, $p<0.05$).

Shearing forces or Shear strain, is where two surfaces are pulled or pushed in opposite directions. In healthy normal tissue, using commonly used movement patterns, layers glide past each other in normal movement (Langevin, 2021). The interface or substance between the fascial layers in the lower back is loose connective tissue. Depending upon collagen density, a cross-linking of glycosaminoglycans and water determines the viscosity or state of densification, as well as smooth ease of movement or perceived stiffness. It has been hypothesised that this densification may be reversible with changes in Hyaluronic concentration, P.H. levels and temperature changes (Pavan *et al.*, 2014). As well as the layers of dense and loose connective tissue, the associated muscles often create multiple interfaces where shear strain occurs as tissues are either actively moved by the contraction of muscles or passively moved by an external force. Pathological processes such as inflammation, fibrosis and scarring can cause the layers to adhere to each other and thus reduce shear strain and be a possible cause of LBP. Additionally, it has been suggested that myofascial force transmission through the TLF can be affected by remodelling. Pirri (2023) found that subjects with LBP had less adaptability to move the TLF in different directions.

### 2.10.2 Measurements of back pain, disability and Kinesio phobia in US TLF studies

In previous US studies looking at the TLF and LBP, participants have been asked to complete questionnaires on levels of pain, disability and fear of pain (Langevin *et al.*, 2009, 2011). Pain questionnaires such as the McGill Questionnaire (SF-MPQ-2), are a self-reporting measure of pain. It assesses both quality and intensity of subjective pain. The questionnaire is composed of a list of words, which respondents choose that best describe their experience of pain. The SF-MGQ-2 has 22 words, and the respondent scores each word a 0 (no pain) to 10 (severe pain). It also has a present pain intensity rating scale (0=no pain today to 10 severe pain today) and overall intensity of the pain experience from no pain to excruciating pain. This test is considered reliable and is validated (Melzack, 1987).

The gold standard for assessing disability and quality of life for individuals with LBP is The Oswestry Disability Index. The Oswestry Disability Index uses a 10-item questionnaire with each item assessing different aspects of daily living, such as personal care or social life. It is a self-administered questionnaire, and each item is scored on a 0-5 scale with 0 being no disability to 5 being greatest disability. The score is calculated as a percentage, 0% (no disability) to 100% (highest level of disability). This questionnaire is considered a validated and reliable measure of assessing disability related to LBP (Fairbank et al., 2000).

The Tampa scale of kinesiophobia assesses fear of movement or re-injury in individuals who have LBP. It is a self-reported questionnaire where respondents indicate their level of agreement with statements related to their fear of

movement using a 4-point Likert scale 1 indicating strongly disagree with statement and 4 being strongly agree with statement, the higher the score the greater degree of kinesiophobia. It has acceptable test-retest reliability and internal consistency (Swinkels-Meewisse *et al.*, 2003; Woby *et al.*, 2005). The Langevin (2009) study found no significant correlation between US outcome measures and responses to the McGill pain questionnaire or the Oswestry disability index, however, pain duration was weakly correlated with thickness of the TFL ($p=0.01$ among the LBP participants, this persisted after controlling for the influence of BMI. However, the levels of self-reported pain, disability and anxiety scores in this study were low, making statistical analysis of disability scores difficult (Langevin *et al.*, 2009). In this study, it was observed that subjects with LBP who volunteered were generally active people and most of these subjects had mild (67% of participants) to Moderate (21% of participants) Oswestry disability scores. Many participants with higher disability scores had to be excluded because of prior back surgery for example (Langevin *et al.*, 2009). The Langevin study (2011) asked over 100 participants to complete the McGill pain questionnaire (Melzack, 1987). the Oswestry Disability questionnaire (Fairbank and Pynsent, 2000), and the Tampa scale of Kenesio phobia (Swinkels-Meewisse *et al.*, 2003). In this later study, Langevin (2011) reported no significant correlations with disability, pain levels or measures of anxiety associated with LBP and TLF shear strain, again the majority of the subjects (94%) recorded mild to moderate Oswestry disability scores.

Other measures regularly taken at the time of data collection by US study researchers of the TLF include Body Mass Index (BMI), waist-to-hip ratio and

Physical activity levels (Langevin *et al.*, 2011; Pirri *et al.*, 2023). BMI is a tool used to evaluate and screen for overweight and obesity. BMI is calculated easily using height and weight measurements and expressed in 4 categories, underweight (<18.5), healthy (18.5 to 24.9), overweight (25-29.9) and obese (>30). Obesity and sedentary lifestyles can be associated with LBP (Verbunt et al, 2010). Obesity is also viewed as an important factor in the Pathogenesis of LBP (Roffey *et al.*, 2013; Gasibat *et al.*, 2017) The Langevin study (2009) found that BMI was highly correlated with the thickness and echogenicity of the TFL ($p<0.001$), BMI was used as a co-variant in statistical analysis in this study. The study also found that the thickness of the combined subcutaneous layer and the TFL, was greater in LBP participants ($p<0.01$).

Data from Physical activity questionnaires are evaluated in US studies on the TLF and LBP to assess the types and frequency, and duration of physical activity of the participants. The questionnaires are usually self-administered, but they can be influenced by recall bias and individuals' interpretation of activity levels. It has been suggested that they should be used in conjunction with other questionnaires such as the Oswestry Disability index (Carvalho *et al.*, 2017). Physical activity scores show correlations with LBP. One study, using the Oswestry disability index to qualtify disability caused by LBP, reported significant differences ($p<0.05$) between groups of female desk job workers who were assessed as low, moderate and high for physical activity (Kayihan, 2014).

### 2.10.3 Visual inspection of US images

The visual inspection of US images of the TLF, using a Likert scale is a further development of TLF image analysis (De Coninck, 2018). A visual inspection of US images found a higher level of disorganisation for young athletes with chronic LBP compared to athletes with NLBP (Almazán-Polo *et al.*, 2020). As a promising development, Almazan-Polo et al (2020) suggest using visual inspection of TLF morphology as a criterion for sub-classification of LBP.

## 2.11 Imaging Technology in Low Back Pain Research.

One of the ways of visualising the body's internal structures without surgery is to use imaging technology. Imaging technology is key in the search for causative factors of NSLBP, along with its usefulness as both a diagnostic tool and to evaluate rehabilitation protocols.

Since the 1980s imaging technologies have been constantly under development to meet the diverse needs of researchers and clinicians (Huang *et al.*, 2021). Before technologies such as Computed tomography (CT), Magnetic resonance imaging (MRI) and Ultrasound (US) imaging, non-surgical observation of soft tissue structures of the lower back were limited to palpation.

CT diagnostic imaging method combines the technology of X-rays with that of a computer, these are mainly used in a hospital setting. Its strengths are that it is excellent at looking at bony detail, it is faster than an MRI scan to perform and can be used for patients with metal implants. Its limitations are that it uses

radiation and has less soft tissue contrast than MRI so is not as helpful for visualising fascial tissues as MRI or US.

MRI is based on the principle that certain atomic nuclei can absorb and emit radio frequency energy when placed in an external magnetic field, again, these are commonplace in hospitals. Its strengths are that it has good soft tissue contrast, provides detailed images and can differentiate between normal and abnormal tissues. Its limitations are that it is expensive, has a long scan time and is not suitable for patients with metal implants.

US imaging uses the interaction between the applied probing energy (sound) and the tissues (Zhang and Yao, 2018). Its strengths are that it is non-radiating and can be safely used in vivo. It provides real-time imaging and is cost-effective. Its limitations are limited penetration depth, provides less detail than MRI or CT and is operator dependent, in that it relies upon a skilled operator to use subtle probe management to capture images (Morton *et al.*, 2016). Currently, there are no standard guidelines for US management, patient position, consistency of probe location and position. this is a limitation for comparing US research. (Pirri *et al.*, 2024). However, US scanners are now commonplace in the clinical setting and are increasingly being used by clinicians to investigate soft tissues, such as fascial tissues and fascial structures as possible causes of Low Back Pain (Whittaker *et al.*, 2013).

The following Table summarises some of the benefits and limitations of each imaging modality.

Table 2.1: Summary of benefits and limitations of imaging technologies used in LBP diagnosis

| | **CT** | **MRI** | **US** |
|---|---|---|---|
| Invasive | yes | no | no |
| Cost | medium | high | low |
| Portable | no | no | yes |
| Safety/comfort | Radiation exposure | reasonable | good |
| Real-time /dynamic data | no | no | yes |
| Depiction of fascia | high | medium | high |
| Operator dependent | *no* | *no* | *yes* |

Adapted from (Macchi, 2024)

The use of imaging technologies has not, however, been without controversy. MRI technology has been enthusiastically adopted by clinicians and researchers, as it was thought to provide patients with an earlier diagnosis or as a reassurance to patients. However, research showed a poor causative relationship between MRI findings and LBP, which has led to unnecessary surgery and persistent poor health (Ash et al., 2008). It has also been found that both MRI imaging and physical examination do not correlate well with symptoms or prognosis (Pransky, Buchbinder and Hayden, 2010). For example, an MRI study found observable spinal pathologies in 62 asymptomatic participants (63%), out of a total of 98 asymptomatic participants (Jensen *et al.*, 1994). However, LBP was not reported in the 62 asymptomatic participants even though they had observable spinal pathologies. Latterly, developments in MRI technology have made it more sophisticated. However, even with higher resolution and better

quality of MRI imaging, it is not considered the best imaging modality for evaluating soft tissues such as fascia (Genu *et al.*, 2014)

## 2.12 Ultrasound in Musculoskeletal and Fascia Research

Ultrasound (US) has shown promise in the diagnosis and treatment of LBP and has been used in research studies to see if it can be useful in the diagnosis and treatment of LBP. US is one of the most widely used imaging technologies in musculoskeletal medicine. It offers the clinician an evaluation of tissue and tissue movement. It is radiation-free, can be used in real-time and with good graphical resolution in vivo (Bauermeister et al., 2021). Importantly, US is relatively inexpensive and portable compared to MRI or CT scanning. It also offers a cross-sectional view of the anatomical structure (Chan et al., 2011). Ultrasound uses sound waves and acoustic impedance to create a visual 2-D image of the tissue being examined. To look at muscles, bones and other structural tissues such as fascia, US machines use sound waves at a range of 2-18 MHz. The sound waves are generated by a piezoelectric crystal. When an electric field is applied to the crystal it rings at a resonant frequency determined by the crystal's thickness. The same or similar crystal is used as a receiver to produce an electrical signal when struck by the returning US wave. The speed of US in tissue depends upon the stiffness and density of the tissue being scanned. The stiffer the material the faster the US transmits. US can work at different depths; a high-frequency probe will have better resolution (fine detail) but poor depth penetration.

The Brightness mode (B-mode) is the gold standard scanning mode for soft tissues and is used to view fascial tissues (Whittaker et al., 2011). B-mode scanning produces images consisting of pixels. The intensity of the pixel can be measured using greyscale. Greyscale provides valuable information about tissue characteristics and aids in accurate diagnosis. Greyscale in ultrasound imaging refers to shades of grey used to represent different tissue densities. The darker the shade could indicate fluids and is described as hypoechoic; the brighter the shade indicates denser structures such as bone and is described as hyperechoic. Numeric values are attributed to the greyscale where a minimum of 0 indicates very low echogenicity and is black (hypoechoic), and a maximum of 256, which is white and indicates an extremely high echogenicity (hyperechoic) (Jesuino *et al.*, 2023).

US imaging has been used to investigate changes in morphology of the TLF for subjects with LBP because the TLF comprises layers of dense fascial tissue high in collagen fibres that show as white on an US image interspersed with layers of loose connective tissue that show as black on an Ultrasound image (Langevin *et al.*, 2009; Pirri *et al.*, 2020). Figure 2.8 below shows the different layers of the TLF that US imaging interprets as lines of black and white, an example of US imaging of the TLF is seen in figure 2.9 below.

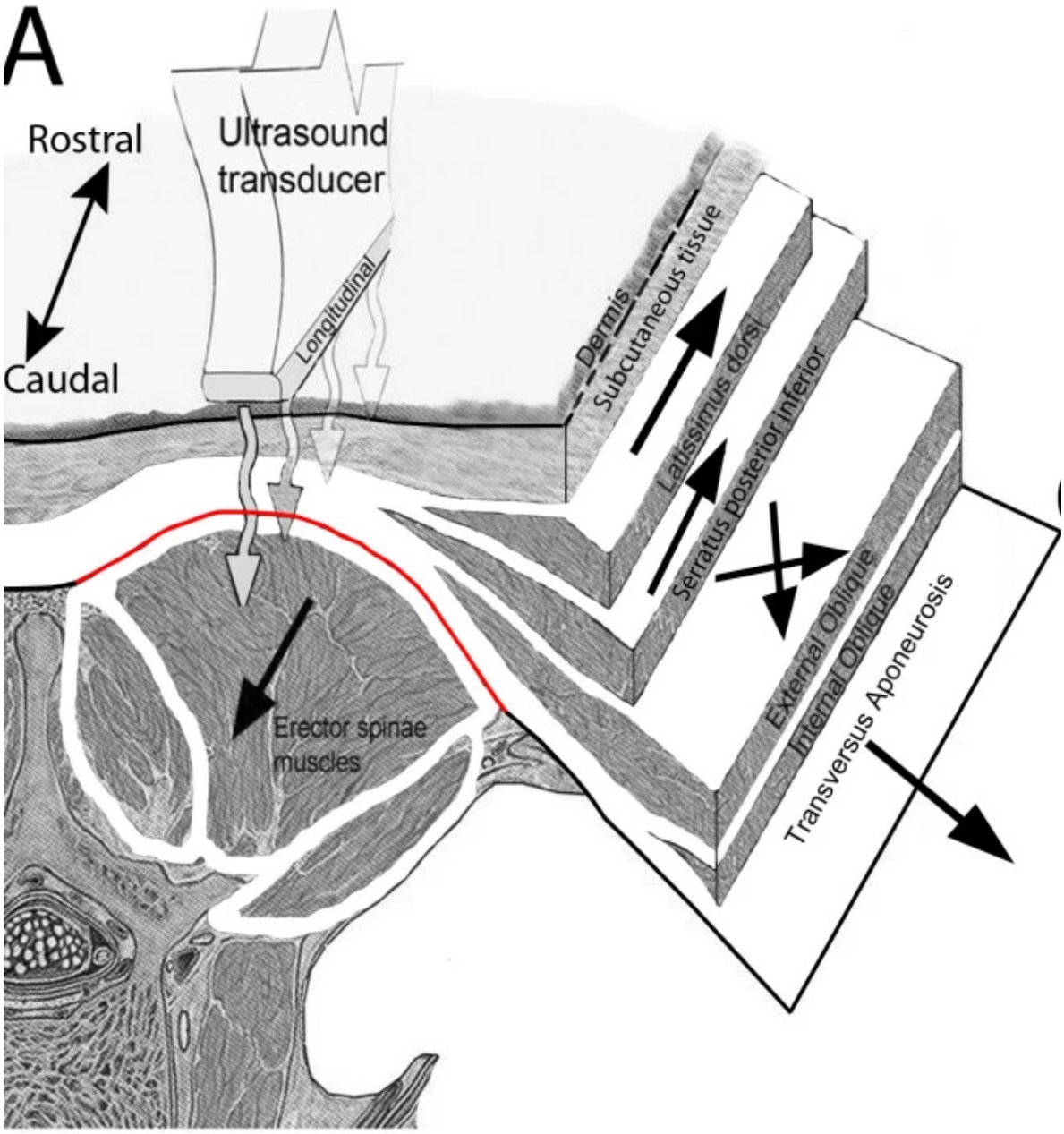



Figure 2.8: Illustration of layers composing the TLF corresponding to the aponeuroses of back and abdominal wall muscles. Arrows indicate directions of pull for individual muscles (Langevin *et al.*, 2011).

Fascial tissues can easily be viewed with Ultrasound. In Figure 2.9 below, image (a) the layers of the TLF's appear white (hyperechoic) on the scans and can be clearly observed. Whereas image (b) shows the loose connective tissue, fat,

and liquids such as water and gels seen as dark areas (hypoechoic) of the subcutaneous tissue between the dermis and the TLF.

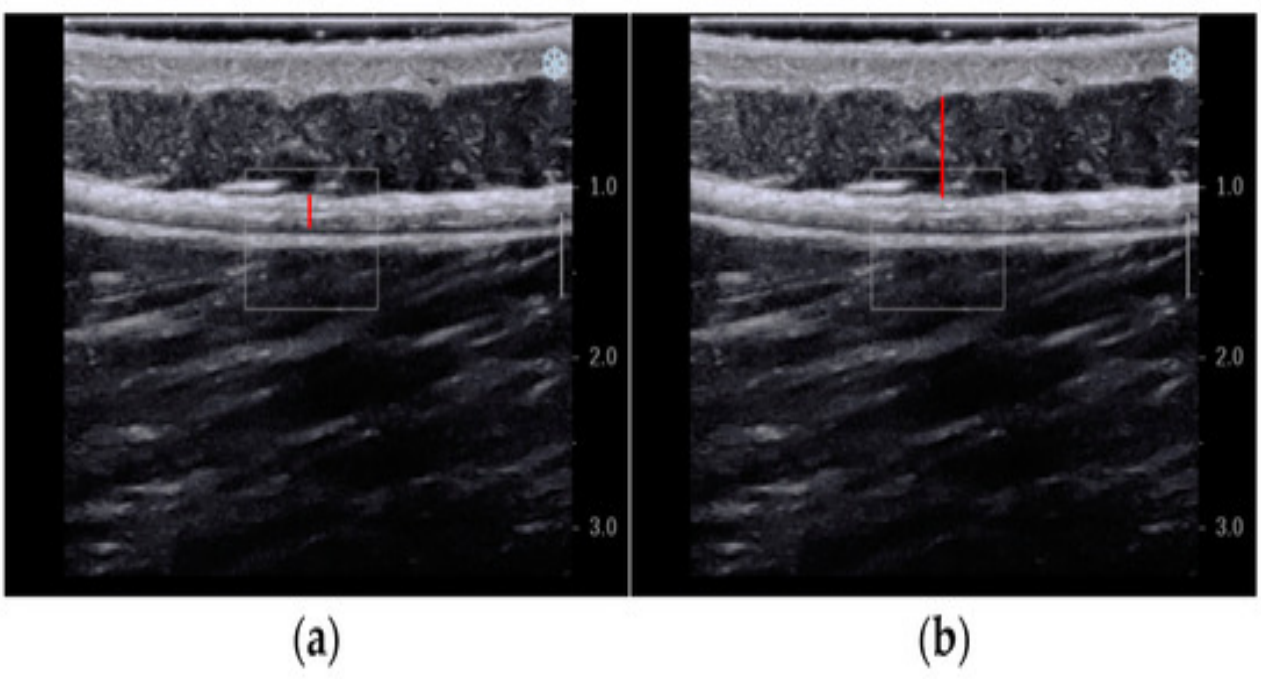



Figure 2.9: Ultrasound image of one participant's lower back. Image a indicates with a red line the layers of the TLF. Image b indicates with a red line the loose connective tissue of the Subcutaneous layer above the TLF. (Devantéry et al., 2023).

The images of fascial tissues captured during a scan can be analysed using different image analysis methods. The thickness of the tissue can be measured off-site either by a mathematical program such as Matlab (The Mathworks, Natwick, MA, USA) (Langevin *et al.*, 2009; De Coninck, 2018) or ImageJ (Pirri *et al.*, 2023), both image analysis platforms are standardised, valid, reliable and repeatable. US has also been used to measure the stiffness of tissues (Chen *et al.*, 2021). Figure 2.10 below shows how Shear wave elastography can assess the thoracolumbar fascia.

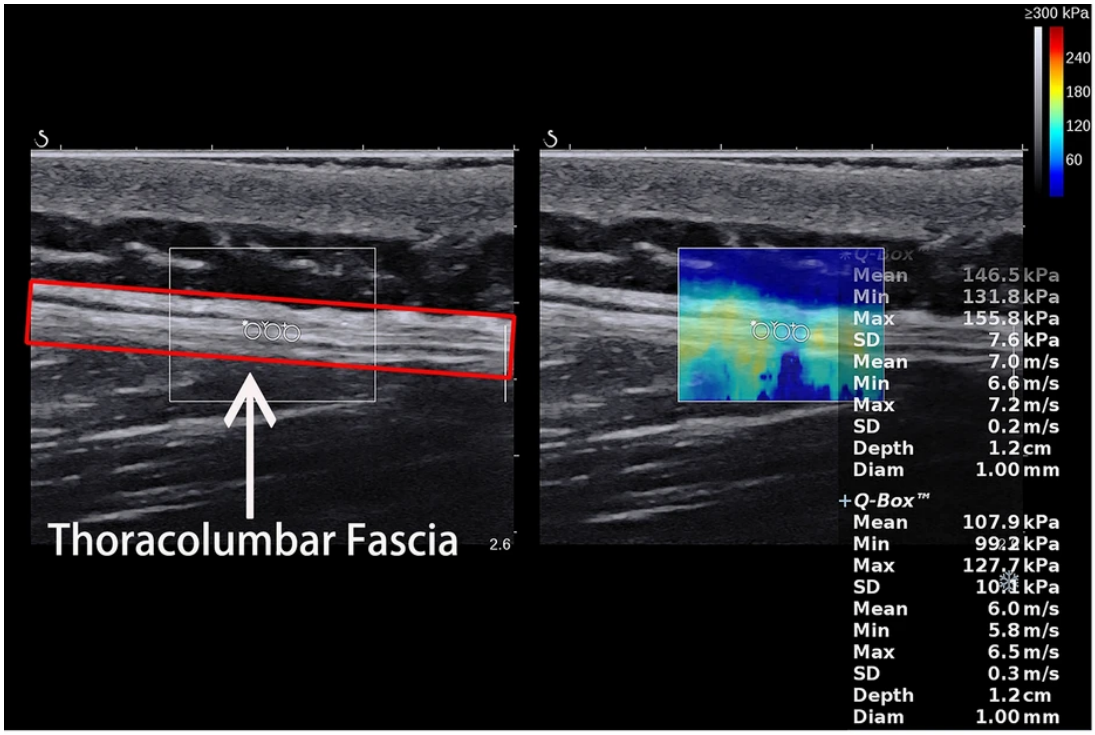



Figure 2.10: Image showing shear-wave elastography assessment of the Thoracolumbar fascia (Chen *et al.,* 2020).

A recent US shear strain study found higher shear strain in the TLF of participants with NSLBP (Tomita *et al.*, 2025).

The dynamic data or real-time nature of US also allows for observation and measurement of how tissues dynamically move relative to each other (Langevin *et al.*, 2011; Brandl *et al.*, 2024). Figure 2.11 below shows how US imaging can be used to changes in morphology due to movement; this image is from a recent paper by Brundl et al. (2025) and pioneers a new method of measuring dynamic data.

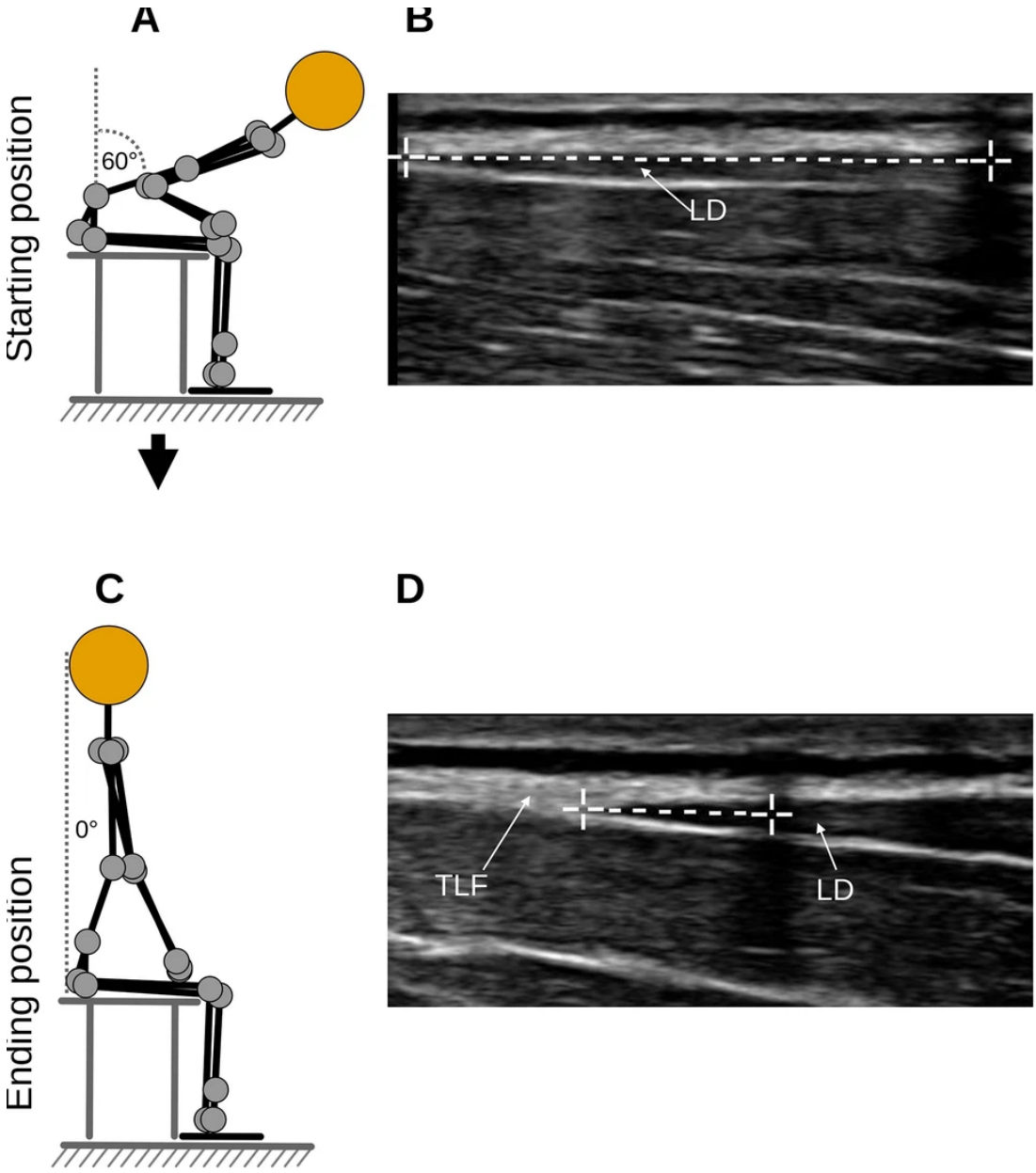



Figure 2.11: Participant positioning and corresponding US image demonstrating how US imaging is being used to evaluate dynamic data (Brandl *et al.*, 2024).

A represents flexion phase, B represents US image of flexion phase, C represents extention phase, D represents US image of extension phase. TLF is Thoracolumbar fascia, LD is Latissimus dorsi.

Disruption or damage to these structures can be easily visually identified (De Coninck *et al.*, 2018) Use of US imaging means that researchers and clinicians can now consider fascial causations for LBP alone or with other soft tissue damage to muscles.

In contrast, Fig.2.12:  below shows an MRI image of fascial layers in the lower back.

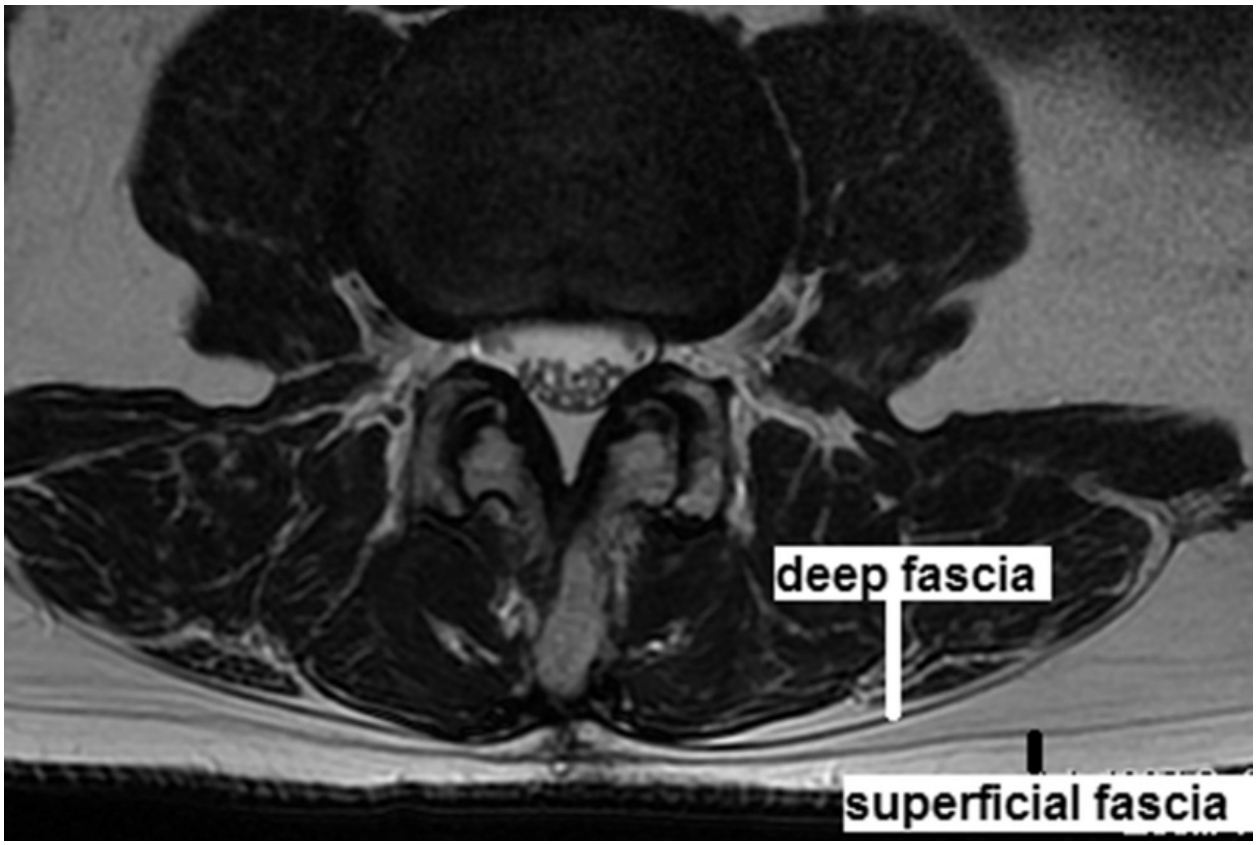



Figure 2.12: M.R.I. image showing deep and superficial fascia (Stecco *et al.*, 2016).

## 2.13 Ultrasound Measurement of Fascial Tissue in Different Body Positions.

Ultrasound-based LBP studies have been conducted almost exclusively with participants positioned in a prone position.  This standardised position ensures image capture is accurate, of good quality and easy to compare with other studies. However, in daily life people switch and alter positions, from standing and walking, to bending forward, sitting, lying supine or side-lying etc. Humans

became bipedal around 6 million years ago (Schilling *et al.*, 2005) and it is commonly thought that the characteristic human S-shaped spine evolved at the same time. It is however interesting that lumbar lordosis develops with the beginning of walking (Wagner *et al.*, 2012) to help absorb forces through the spine during walking and running (Schilling *et al.*, 2005). Notwithstanding this developmental adaptation of the spine, LBP is often attributed to humans being in an upright posture and the evolutionary compromises humans must accept for a bipedal mode of locomotion (Schilling *et al.*, 2005).

The spine changes shape in the standing position, the angles of the primary curves have been found to increase lordosis by 16.6 degrees and kyphosis by 13.4 degrees compared to the prone position (Salem *et al.*, 2015). Studies have shown that LBP can be more debilitating in standing due to poor posture control or impaired motor control (Koch et al., 2019).

It is increasingly recognised that imaging in different positions can reveal spinal conditions missed in standard supine or prone positions. Upright MRI machines and tilting tables have been designed to allow for imaging of the spine when it is loaded (Splendiani *et al.*, 2019). An ultrasound reliability study of muscle thickness (transversus abdominus and lumbar multifidus) in multiple positions (tabletop, sitting, standing and walking) in healthy persons concluded that it was a reliable method of measuring in different positions (Mangum *et al.*, 2016), and has a high-re-test reliability (Thoirs et al., 2009). An US study to measure changes in muscle thickness across positions in patients with and without LBP showed that in different positions, prone, seated, standing and walking the thickness of the muscle Lumbar multifidus (LM) did not change whereas the

muscle thickness of the Transversus Abdominus (TrA) did (Sutherlin *et al.*, 2018). The study was conducted with 54 participants, 25 with LBP, 34 without LBP. This study assessed the reliability of US measures (ICC ranged from 0.641-0.943)

Measuring back muscles in standing is challenging because of muscle contraction in standing. Muscle thickness may vary depending upon the patient's posture for example, which makes it difficult to compare results between different individuals (Ma *et al.*, 2020). In this study, an ultrasound palpation system (TUPS) that can assess muscle stiffness found no significant difference between participants with and without LBP. However, soft tissue thickness was found to be significantly larger ($p=0.001$) in the standing position compared with the prone position.

Recent US studies looking at interactions between abdominal muscle thickness in standing positions compared with supine positions and anxiety in participants with LBP found that in standing muscle thickness was greater in participants with. Pain anxiety (Hedayati *et al.*, 2024).

One recent study used ultrasound shear wave elastography to investigate tissue stiffness in different static positions, sitting, standing and tilting forward (Chen *et al.*, 2021). The study involved 20 young healthy male subjects and found that stiffness of the TLF between different body positions was statistically significant. Stiffness in a neutral standing was 66.98% higher than in a prone position (Chen *et al.*, 2021). The researchers suggested that stiffness in the TLF may be one of the causes of posture-related LBP.

Ultrasound imaging of morphology of the TLF is still mainly performed in a non-weightbearing, prone position.

## 2.14 Conclusion

Despite modern pharmaceutical and medical advances and a greater understanding of social and psychological contributing factors, LBP remains a major global health issue today. It comes with economic and personal emotional costs, even more so because LBP can become a chronic condition. Indeed, it is estimated that LBP is the biggest contributor to the global disability burden (Hoy et al., 2014; Ferreira et al., 2023; Marto et al., 2023).
Improving diagnostic techniques to refine sub-groupings of NSLBP and to help understand the aetiology of NSLBP has been identified as a key research strategy (Kent et al., 2009; Kongsted et al., 2016; Hartvigsen et al., 2018). Fascia is a relatively new area of research, which has grown exponentially in the last 30 years. In the lower back the thoracolumbar fascia has been linked with possible causes of LBP.  This multi-layered connecting fascial tissue structure of the lower back is connected not just to the main muscles and bones of the back, but also to the limbs. It is also a girdling structure connecting the muscles of the back to the muscles around the front of the abdominal cavity. It is known to stabilise the spine and is important for good movement patterns. We know a healthy TLF transmits force from one area to another, and its layers should be able to glide over each other to permit easy movement patterns. One of the ways ultrasound imaging allows researchers to study the architecture of the TLF is to use measurements of thickness, echogenicity and visual imaging to assess

its health. To do this research studies have compared the TLF measurements of LBP subjects and NLBP (control) subjects. Studies suggest that people with LBP do have a thicker TLF than the control subjects and there have been many theories as to what the cause of this difference may be. There is still no ultrasound study of the morphology of the thoracolumbar fascia in lower back pain subjects in different positions, such as standing (existing studies only measure in the prone position). Some of the most recent research has indicated that the thickness of the TLF can be thicker in subjects who have LBP than in subjects with NLBP, measured in the prone position (Langevin *et al.*, 2009; Pirri *et al.*, 2023). Langevin (2011) went on to study movement in the thoracolumbar fascia using ultrasound cine-imaging, but still in a prone position.

Understanding what happens to the TLF structure in different positions and in movement and how this correlates with LBP would be a significant next step. Furthermore, investigating the TLF using US, in different positions, may provide more options for diagnosis as each position offers unique advantages and limitations (Effatparvar et al., 2022).

Many studies in the literature collect data on disability, pain intensity and fear of movement caused by back pain. However, there are gaps in the literature on how changes in the thickness and echogenicity, or organisation of the TLF are correlated with these measures.

## 2.15 Aims of Research for this Thesis

The aim of this thesis is to investigate the morphology of the TLF in people with and without LBP using ultrasound imaging in both prone and standing positions.

Participants were recruited from a community exercise group, which was known to include subjects with LBP, and via opportunistic sampling at The University of Kent. The images acquired will be used to measure and compare differences in thickness, echogenicity and provide a visual assessment of the organisation of the TLF between participants with and without chronic LBP. Additionally, data on disability, pain intensity and fear of movement will be collected.

## 2.16 Research Questions

1. Is there an overall difference in the thickness measurements of the TLF between prone and standing positions?
2. Is there an overall difference in the echogenicity of the TLF between prone and standing positions?
3. Is there a difference in the thickness measurements of the TLF between LBP and NLBP subjects in prone and standing positions?
4. Is there a difference in the echogenicity of the TLF between LBP and NLBP subjects in prone and standing positions?
5. Is there a correlation between disability score and the thickness of the TLF?
6. Is there a correlation between disability score and echogenicity of the TLF?
7. Can visual inspection of TLF US images be used to differentiate between a prone position and a standing position?
8. Can visual inspection of TLF US images be used to differentiate between subjects with and without LBP in prone and standing positions?

# Chapter 3: Methodology

## 3.1 Participants

The sample size was determined using G*Power (Faul *et al.*, 2007). Using means and SD of previous US studies of the TLF of participants with and without LBP at the time of data collection (Langevin *et al.*, 2009; Whittaker *et al.*, 2013). With a 80% power and alpha set at 0.05 resulted in a sample size of 20 participants in both the LBP and NLBP groups. Initially, 60 participants were recruited. Due to co-morbidities, 34 were removed from the initial cohort of 60 participants. There was no capacity to recruit additional participants due to the restricted time frame of a master's Thesis.

Data was collected from 26 adults, 15 with self-reported LBP in the last 12 months as defined by Koes et al (2006) and 15 without LBP in the last 12 months. LBP was defined as pain, muscle tension or stiffness in the lower back region within the last 12 months not attributable to period pain. Exclusion criteria for both groups were participants undertaking cancer treatment, pregnancy or attempting to conceive. Further exclusion criteria were participants with heart conditions/high blood pressure, arthritis or osteoporosis, displaced vertebrae or spondylolisthesis, hip/knee/back/abdominal surgery, corticosteroid injections in lower back, structural spinal condition such as kyphosis or scoliosis. Long-term conditions such as ankylosing spondylitis, rheumatoid arthritis, nerve root compression,

bleeding disorders, and corticosteroid inhaler use. These criteria are in line with previous studies on ultrasound of the TLF of people with LBP (Langevin *et al.*, 2011).

This study was approved by the School of Sport and Exercise Sciences Research and Ethics Group (REAG), at the University of Kent (44_2019_20).

All participants provided informed consent.

Recruitment was primarily via a recruitment poster (Appendix I).

Participants in both groups completed a customised health form (Appendix II), that included the General Practice physical activity questionnaire to assess physical activity, using 4 levels (active, moderately active, moderately inactive and inactive). The questionnaire used was simple and a validated screening tool for use in National Health Service primary care to assess adults (The Department of Health, 2009). Height and weight were recorded to calculate Body Mass Index (BMI), and waist and hip measurements were also recorded to calculate a ratio. BMI is calculated using height and weight measurements (BMI= $kg/m^2$) and is a tool used to screen and sort participants into 4 categories, underweight ( <18.5), healthy (18.5-24.9), overweight (25-29.9) and obese (>30). BMI does have limitations as it does not account for body composition (i.e. relative amounts of fat, muscle and bone in the body). It is therefore important to consider waist circumference as a better way of measuring abdominal fat, a key risk factor for metabolic health problems (NHLBI, 2022). Both sets of measurements were taken, only BMI was used in analysis to be comparable with other US studies on TLF and low back pain (Langevin *et al.*, 2009, 2011).

To assess the pain levels, disability caused by back pain and the fear and anxiety felt by participants with LBP, the self-identified LBP group completed the Oswestry Disability Questionnaire (Fairbank et al., 2000), the Tampa scale of Kinesio phobia questionnaire (Swinkels-Meewisse *et al.*, 2003) and the McGill Questionnaire (SF-MPQ-2) (Appendix III) (Melzack, 1987).

The LBP group were asked to record if the back pain was recurring, and if it had recurred in the last 4 months.

Each participant was required to visit the laboratory for one visit lasting 45 minutes. Data collection for both prone and standing US image capture was undertaken concurrently in the same visit.

Each participant was asked to complete and sign a consent form before measurements were taken.

The protocol list completed for each session is in Appendix IV

## 3.2 Ultrasound Image Acquisition

Training undertaken by the researcher to acquire US images of the TLF was completed over a period of 4 months under the mentorship of a trained and qualified supervisor. The participants completed 1 trial attempt in the standing position before US imaging commenced, no training was required. The competency of the researcher was established by a pilot study assessing the quality of the images acquired by the researcher and comparing these to images taken by the supervisor, through visual inspection and a comparison of image analysis using a Grey-scale script in Matlab, version R2020b(The

Mathworks, Natick, MA). This inter-rater reliability was good ICCs ranging from 0.91-0.99. (Boucher, 2023).

Researcher training to undertake this specific US image capture, along with data collection protocols, such as correct use and disposal of massage couch covers and health and safety around the laboratory, together with an instruction session direct from the manufacturers of the Isokinetic Dynanometer (HUMAC® Norm, Computer sports medicine, USA), was undertaken over several months before data collection visits. Image analysis of the TLF Ultrasound images was acquired using a semi-portable ultrasound Scanner (MylabGold 25; Easote. Rimini, Italy) using a linear- array transducer (40 mm footprint,6-18 MHz; Easote LA435) to generate B-Mode images. A Frequency of 18MHz was set for all images, with a depth of 4 cm and brightness at 100%.

Ultrasound images were taken in 1 visit, with participants in two different positions:

1. Lying prone on a treatment couch.
2. In a standing position, in a specialised trunk module, attached to an Isokinetic Dynamometer (HUMAC® Norm, Computer sports medicine, USA).

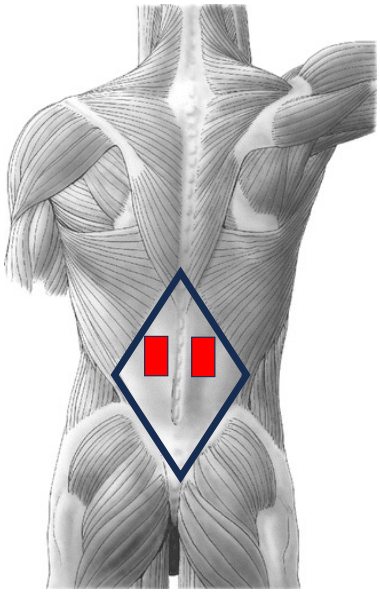


Figure 3.1: schematic of trunk, showing location of TLF (black diamond) and position of US probe on either side of spine. Adapted from [Grim et al., 2001]

The area of image acquisition is shown in Fig 3.1. Key anatomical landmarks were located using standardised protocols (Langevin et al., 2009; Whittaker et al., 2013 De Coninck, 2018).

The researcher followed the same protocols as used by Langevin (2009,2011). A schematic of probe location and position are shown in Figure 3.2 below.

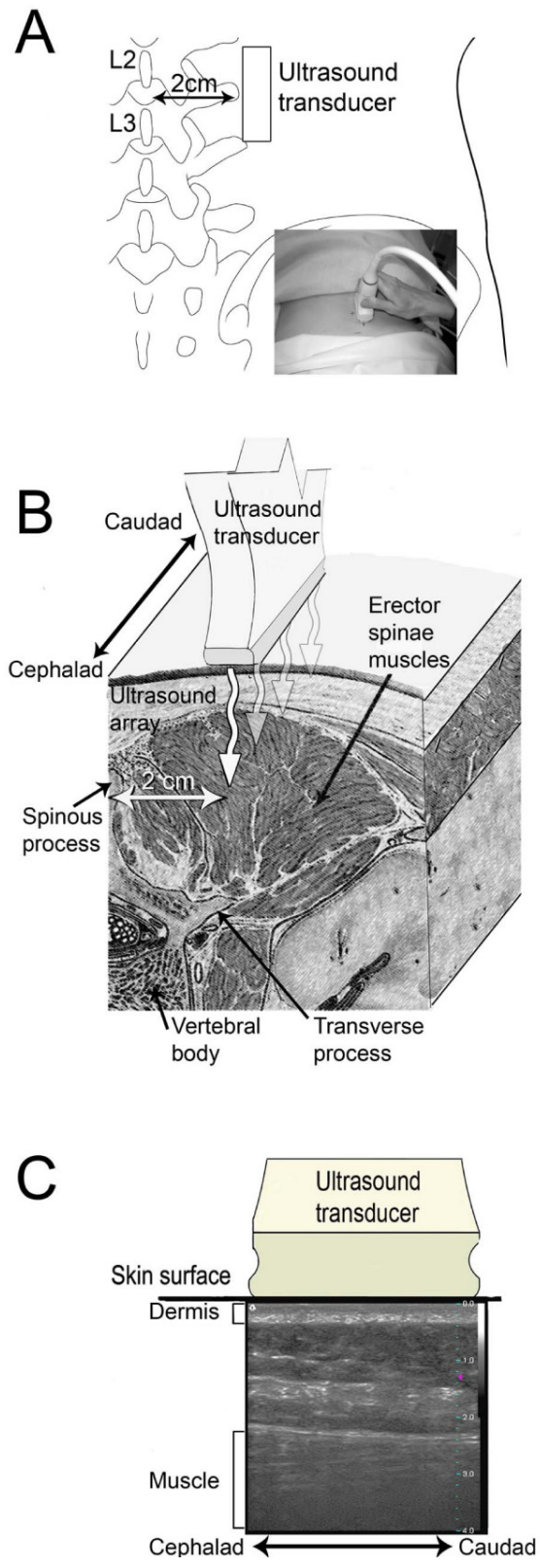



Figure 3.2: Schematic of the ultrasound image acquisition method followed using the Langevin (2009) method.

A: location of US transducer relative to the spine. B: anatomical cross-section showing structures imaged. C: example of US image showing location of dermis and muscle (Langevin *et al.*, 2009).

The inter-vertebral disc space between L2 and L3 was found by locating the sacrum, L5, L4, L3 and L2 using ultrasound imaging. This intervertebral disc space was marked with a skin marker pen, at the midline of the spine. Using a sterile ruler, longitudinal lines (approximately 2 cm long) were made 2 cm lateral to the left and right of the central mark. This specific region of interest was chosen because at this spinal level, the fascial planes are the most parallel to the skin (Langevin *et al.*, 2009). Additional lines at 3cm lateral to the midline mark were made to facilitate easier image collection in the standing position. A mark was made at the level of S1 to help correctly position the participant in the Isokinetic Dynamometer Trunk module for the standing image collection (see Figure 3.3).

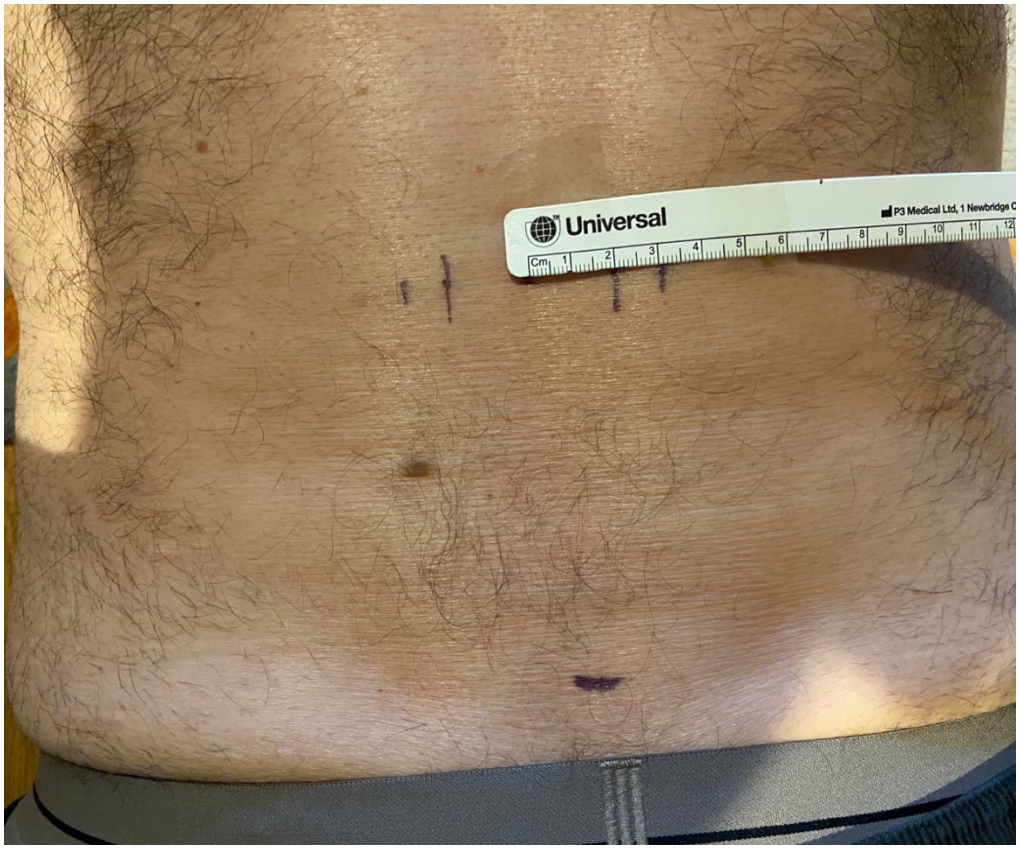



Figure 3.3: Example of skin marks in area of image acquisition.

Fig 3.3 Shows the horizontal positioning mark for standing placement in isokinetic dynamometer trunk module and marks 2cm on either side of the midline for ultrasound image acquisition, plus 3cm mark (back-up mark). The subject is in a prone position.

## 3.3 Prone Position Ultrasound Image Acquisition.

Participants lay prone on a treatment couch, arms placed at the side of the body and participants continued to breathe normally and did not speak during image acquisition. The midline of the probe was aligned with the 2 cm mark. Images were acquired bi-laterally. Care was taken not to apply undue pressure on the skin surface.

## 3.4 Standing Position Ultrasound Image Acquisition

The subjects were invited to step onto The HUMAC Norm Isokinetic Dynamometer Trunk attachment (CSMi, Stoughton, MA). The Trunk attachment was necessary to maintain a constant upright neutral spine position (Fig. 3.4). Training in the Trunk attachment was provided by a HUMAC Norm trainer. The HUMAC Norm Isokinetic Dynamometer is generally considered to be good to excellent in inter-rater reliability studies for strength measurements (Habets *et al.*, 2018). However, this function was not fully used as the trunk attachment was used to standardise the standing position.

A neutral standing position or neutral spine position is when all three normal curves in the spine are present

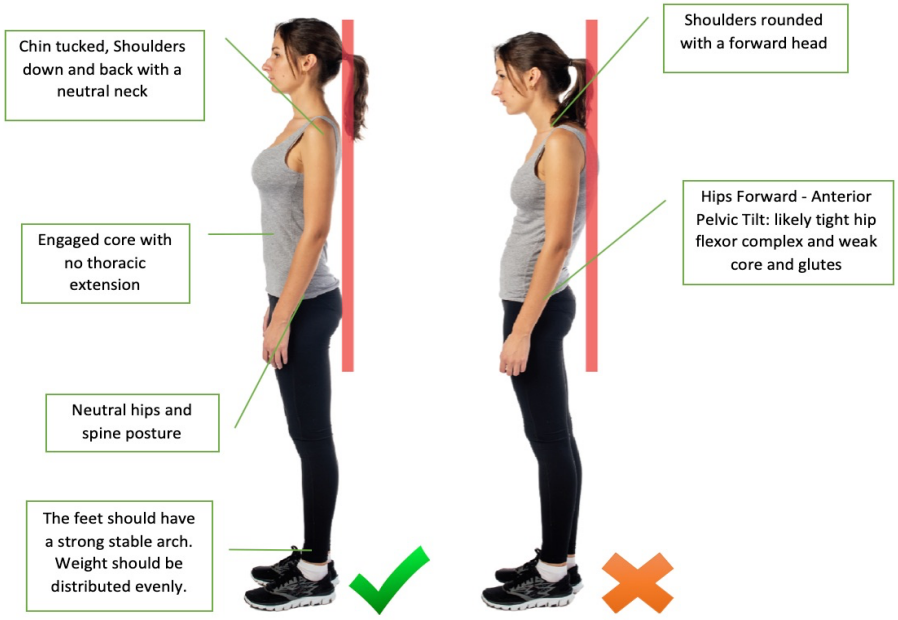



Figure 3.4: Neutral standing position

(Standford University, Environmental Health and Safety)

The participant's safety was paramount, so two operatives were required to take all standing images. The isokinetic dynamometer trunk module has several moving parts so that the trunk module can be calibrated to fit the height and proportions of each participant. The standing platform moved up and down, so the region of interest was accessible for participants, independent of their height. The mark made on the back of each participant at the level of vertebra S1 was used to line up the pelvis with the safety belt around the pelvis. The scapular support pad was placed at scapular level and the shoulder girdle restraint was clipped in place. These adjustments were made to maintain a neutral spine. Movement in the legs was restricted using pads below the knee cap. The participants were secured at points just below the patella, the hips and at scapular level for the shortest possible time.


Figure 3.5: The HUMAC Norm Isokinetic Dynamometer trunk attachment

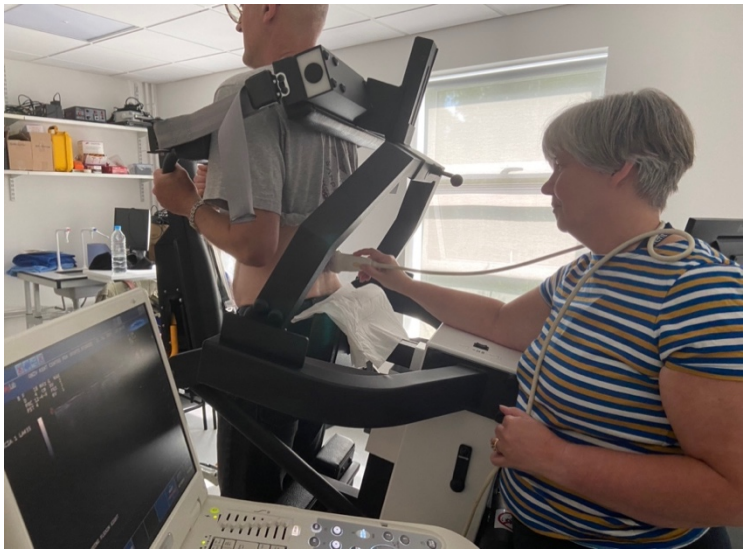


Figure 3.6:  Investigator acquiring images with participant in standing position.

Bi-lateral Images were taken from the left-hand side from the rear of the participant, through the backrest of the trunk connector (Fig: 3.6). Images were acquired with the midline of the probe placed in alignment with the inner 2 cm

skin mark. Probe position and location on the back was In line with the methodology used for prone position set out in Langevin's papers (2009,2011) see Fig. 3.2 above. If it was not possible to maintain flat contact with the back, the probe was placed on the outer (3cm) line. On two occasions, due to the height of the participant, a level just above L3/L2 had to be used (e.g. very short-bodied participant's region of interest did not clear the fixed lumber pad on the module). Two sets of standing data could not be collected using the HUMAC Norm isokinetic dynamometer trunk module due to equipment failure.

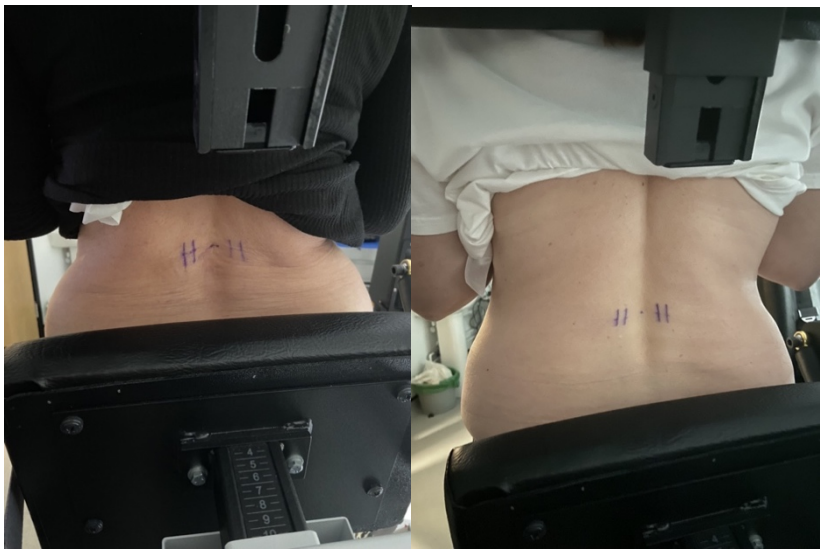


Figure 3.7: Examples of different presentations in standing position. The skin marks made when the participant was in the prone position show the position of the probe either side of the spine.

## 3.5 Ultrasound Image Analysis

The ultrasound images were transferred onto a computer, to be analysed offline using a customised Grey-scale script in Matlab, version R2020b (The Mathworks, Natick, MA). The Matlab script selected a standardised region of interest (ROI), an area 1 cm wide in the center of the scan image. To calculate the thickness of the TLF, the borders of the subcutaneous, perimuscular and

combined layers were manually selected, which produced a graph differentiating 3 layers or zones:

1. The subcutaneous zone. Between dermis (red line in Fig. 3.7) and top of perimuscular zone (TLF) (green line in Fig. 3.7). This is coloured blue on Matlab graph in Fig 3.7
2. The perimuscular zone (TLF) between the top of the muscle (blue line in Fig 3.7) and top of perimuscular zone (green line in Fig. 3.7). This is coloured red on Matlab graph in Fig 3.7.
3. The combined subcutaneous and perimuscular zone (between blue line of base of dermis and top of the muscle green line in Fig. 3.7). This is coloured green in Fig 3.7.

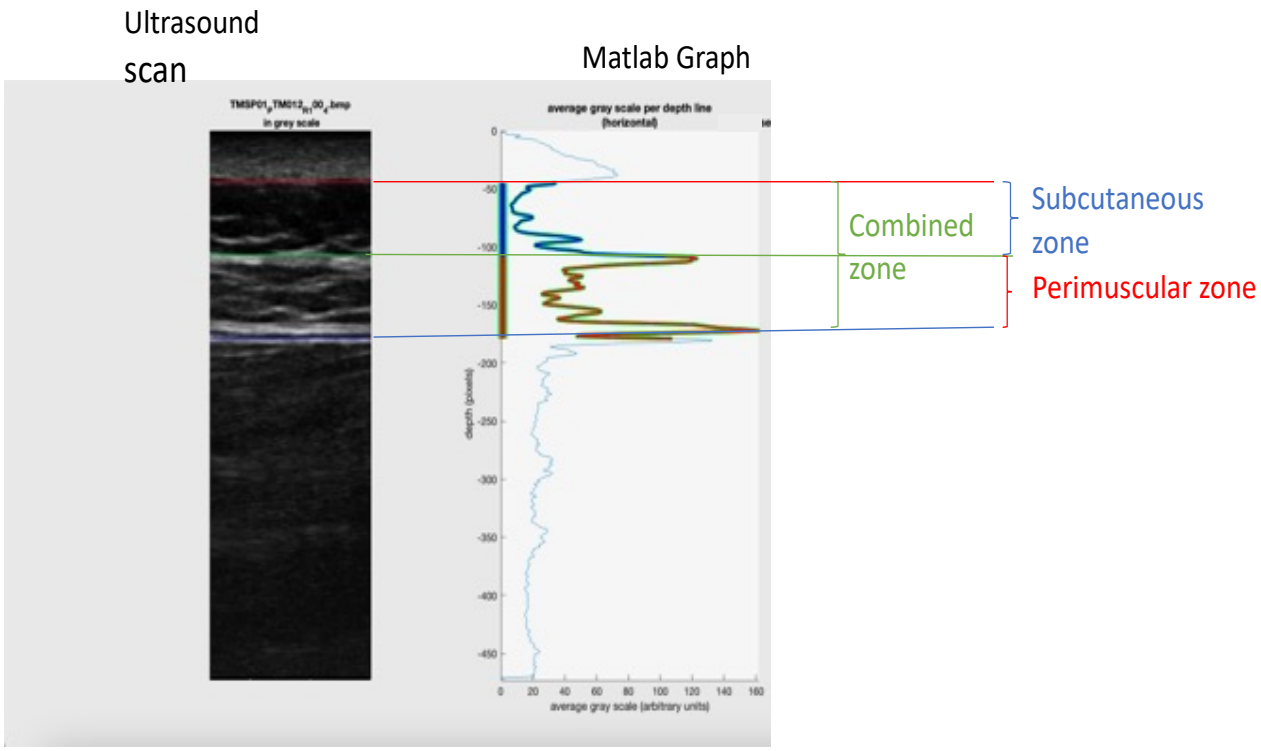



Figure 3.8: Example of Ultrasound image analysis method using Matlab program.

Echogenicity was calculated automatically in Matlab. as the average grey-scale value for each zone (subcutaneous, perimuscular, combined). This calculation was made for both left and right side of each anonymised participant in prone and in standing.

## 3.6 Ultrasound Image Visual Ranking and Classification

The ultrasound scans analysed through Matlab, were subsequently visually inspected for organisation and ranked into 4 groups (De Coninck *et al.*, 2018; Almazán-Polo *et al.*, 2020) The area inspected is shown in the blue rectangular window in Fig.3.8. below, which shows an US image of a participant with a somewhat organised TLF score 4, the lower layers of the TLF are organised, as shown by continuous parallel hyperechoic (showing white) but the upper layers are not as organised with large areas of hypoechoic (showing black) areas.

- Group 1-very organized (Likert scores 1-3),
- Group 2- somewhat organized (Likert scores 4-5),
- Group 3 – somewhat disorganized (Likert scores 6-7) and
- Group 4- very disorganized (Likert score 8-10).

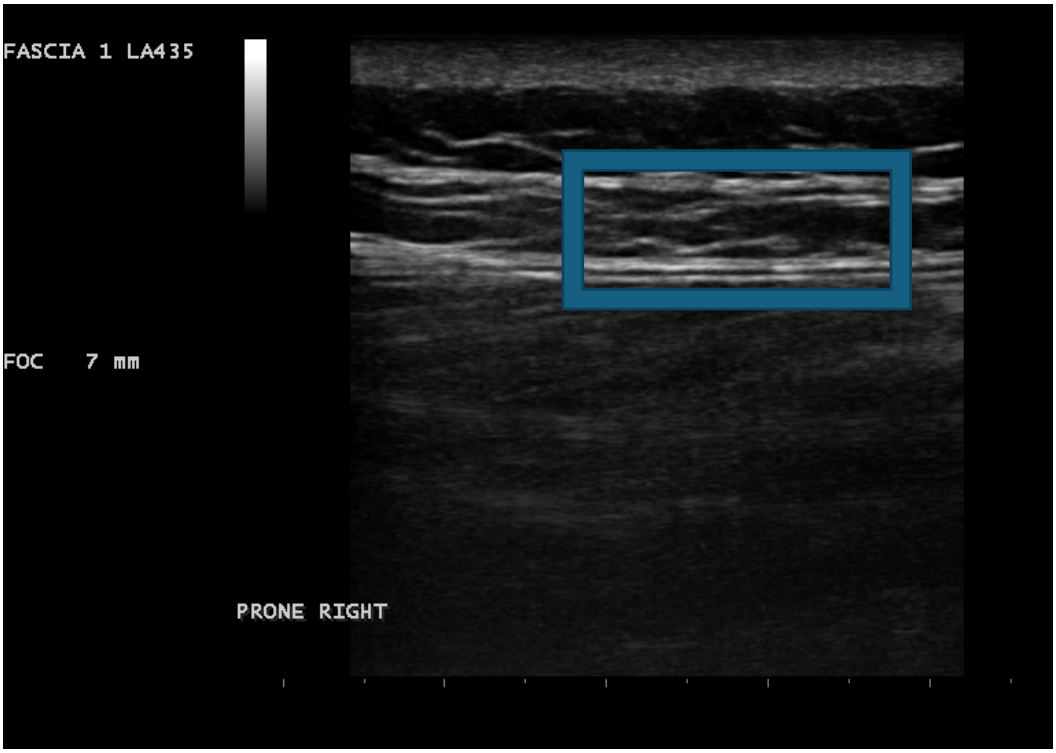



Figure 3.9: Example of US image showing region of interest for visual inspection.

Subsequently, the 4 categories were condensed into 2:

- Organised data (Likert scores 1-5)
- Disorganised data (Likert scores 6-10)

(LaValley and Felson, 2002; De Coninck *et al.*, 2018; Almazán-Polo *et al.*, 2020)

An individual Likert response was produced for each pair of US images and averaged by averaging the left and right image scores. This provided two sets of data for each participant:

How the organization was ranked is shown in Fig 3.9 below

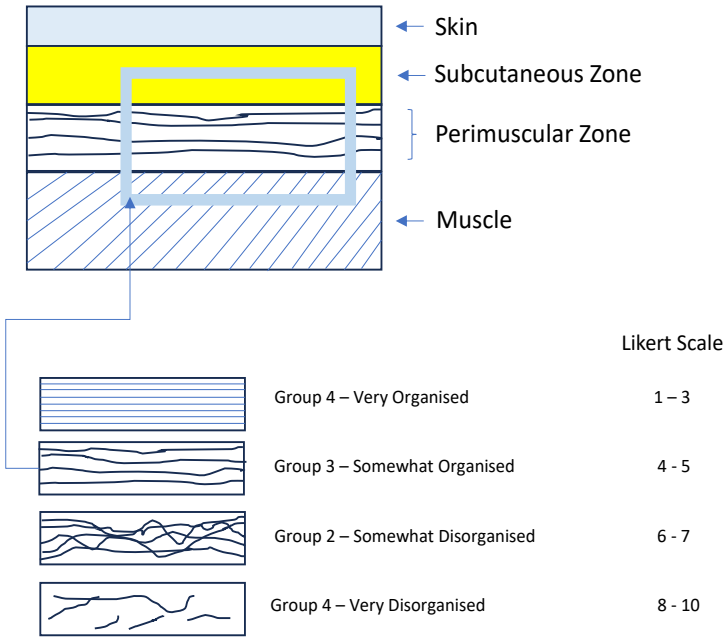



Figure 3.10: Schematic representation of the 4 categories and corresponding Likert scale scores for visual inspection.

## 3.7: Data Analysis

The raw data from all questionnaires, physical measurements, Matlab data for all anonymised participants is shown in Appendix V.

IBM SPSS (version 29.0, Armonk, NY, United States) was used to run statistical tests on the data.

US Image data was analysed from both the left and right in prone and standing positions. However, In line with previous studies (Langevin et al., 2009, 2011).

Independent T-tests indicated no statistically significant difference (p = 0.61) between the thickness measurements of the left and right sides of the dense connective tissue layer of thoracolumbar fascia (TLF). Additionally, T-tests revealed no significant difference (p = 0.92) between the left and right measurements of the combined subcutaneous tissue and TLF. Therefore, the average thickness was used for all subsequent statistical analyses.

For each statistical test performed all assumptions were tested. For this cohort visual inspection of box plots revealed two participants whose data fell outside the parameters so for some tests these outliers were removed and the data retested. For these tests a cohort size of n=24 is reported. An example of one of these box plots is below (Fig: 4.2).

For some statistical analysis, the data has been transformed. The data was observed to be positively skewed, and a logarithmic (Log) transformation was chosen. Data was transformed using log 10. Where transformed data is used it is reported. All results were reported on raw data.

### 3.7.1 Comparison between Prone and Standing Data

US images were acquired for all 26 participants in a prone position and a standardised standing position on one visit. Thickness and echogenicity measurements of the TLF and combined zone were compared for each participant between the prone position and the standing position using paired sample T-Tests. Where the same participant's measurements were compared in prone and standing, a paired sample t-test analysis was selected. This helps to reduce variability between groups.

A flow chart (Fig: 3.11) shows the thought process for the analysis for comparisons. The Right-hand side of the chart shows the process followed for comparisons between prone and standing positions, the Left-hand side of the chart shows the process for comparisons between LBP and NLBP groups.

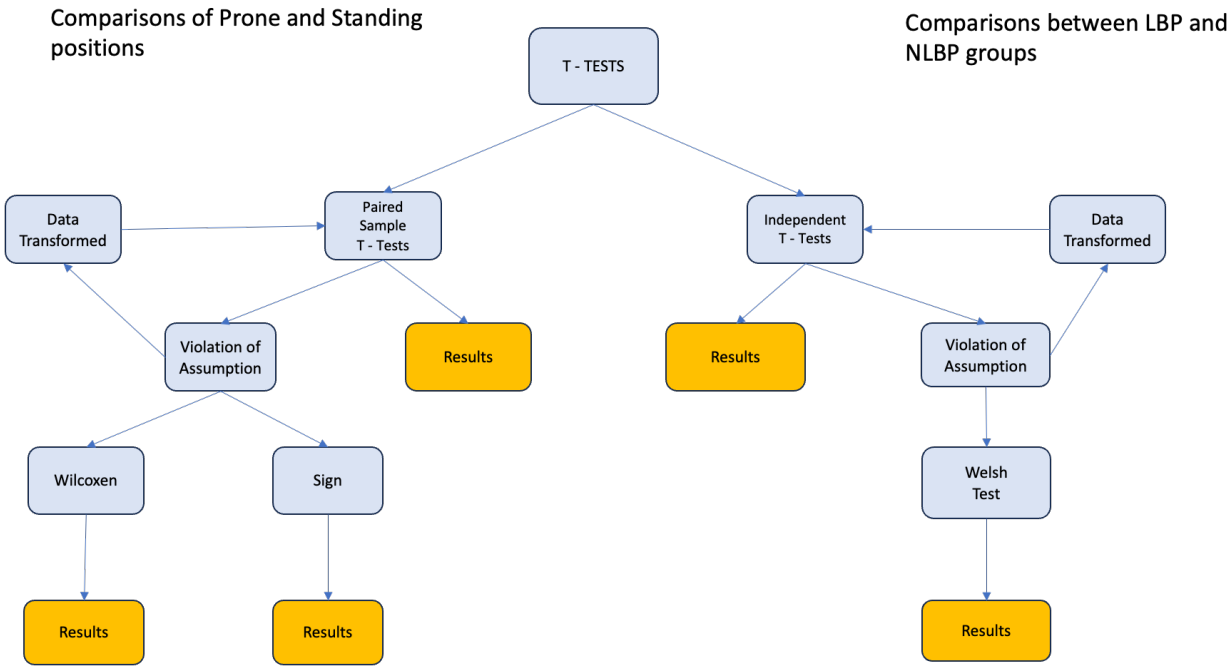



Figure 3.11: Flow chart for comparison of standing and prone data for the whole population (on the left) and LBP v NLBP groups (on the right).

Where assumptions were violated, data was transformed by log10, and T-Tests re-run or another non-parametric test was selected for comparison between prone and standing for the whole cohort, a Sign test or Wilcoxon test was selected. (Fig:3.11)

### 3.7.2 Comparisons between LBP and NLBP groups

Comparisons of thickness and echogenicity of the TLF and the combined zone were also made between participants who self-identified with LBP and NLBP in the last 12 months. Comparisons were made between LBP and NLBP in a prone

position and a standing position. This in line with previous US TLF studies (Langevin et al., 2009, 2011).

Initially, differences between LBP and NLBP groups were assessed using an ANCOVA with BMI as a covariate.

BMI was chosen as a covariate as previous studies identified it as significant in connective tissue outcomes (Langevin *et al.*, 2009). Tests for assumption were made, and where violations were discovered non-parametric tests were substituted.

Fig 3.11 (right-hand side) shows the thought process behind T-Test analysis of the LBP and NLBP groups. Independent sample T-tests were run to determine if there were any differences between LBP and NLBP mean thickness of the perimuscular zone and the combined zone between subjects in a prone and a standing position.

Fig 3.11 shows what occurred if assumptions were violated and the choice of the substitution, non-parametric Welsh test. Where assumptions were violated, other non-parametric tests were substituted, for this comparison a Welsh test was run.

### 3.7.3 Correlations between prone and standing measurements for thickness and echogenicity with Back Pain disability score.

Correlation analyses were used to assess the relationship between the perimuscular zone and back pain demographics. Before each selected test, assumptions were tested and where violations were found outliers were removed and data transformed.

A Pearsons correlation test was used to determine the strength and direction of a linear relationship between the Oswestry disability scores reported by the LBP group and thickness and echogenicity measurements in prone and standing

The Spearman Rank-Order test calculated a measure of the strength or direction of the association/relationship within the LBP group of thickness or echogenicity of the perimuscular zone and combined zones and disability caused by back pain as measured by the Oswestry disability score.

## 3.8 Ultrasound Image Visual Data Analysis.

Likert scale 10-point score was used to rank the morphology of the perimuscular zone. This type of data can be interpreted as ordinal data or continuous data (South *et al.*, 2022). For this analysis, due to the relatively small study size (n=26) the Likert Scale scores were divided into 2 groups, organised and disorganised. Because of the low number of groups, the data in this thesis was treated as ordinal and non-parametric statistical tests were run.

A Wilcoxen test was selected to compare the Likert scale scores in the prone position and the standing position for the whole group and then individually for LBP and NLBP groups.

Graphs were created to show visually the composition of the organized and disorganized Likert scores between LBP and NLBP groups and to show how the Likert scores were affected by BMI and physical activity results.

# Chapter 4: Results

## 4.1 Participant Demographic Characteristics

A total of 26 participants (38% males) took part in this study, with an average age of 52.42 (SD 18.59). 50% (n=13) reported experiencing chronic LBP at least once in the last 12 months. There were no significant differences between the groups in age (p=0.49), gender (p=0.49), Body mass (p=0.54) or BMI (p=0.52). Participant demographics are shown in Table 4.1.

Table 4.1: Participant Demographics

| | **Participants All (n=26)** | **LBP (n=13)** | **NLBP (n=13)** | **p-values** |
|---|---|---|---|---|
| Gender, (%, M/F) | 10 (38.5%) / 16 (61.5%) | 7 (53.8%) / 6 (46.2%) | 3 (23.1%) /10 (76.9%) | 0.49 |
| Age (years | 52.42 ± 18.59 | 49.85 ± 16 | 55 ± 21.20 | 0.49 |
| Body Mass (kg) | 81.85 ± 21.93 | 84.54 ± 18.09 | 79.15 ± 25.66 | 0.54 |
| BMI (units) | 28.81 ± 12.36 | 29.65 ± 7.34 | 27.68 ± 8.13 | 0.52 |
| Activity | | | | 0.19 |
| Inactive (n / %) | 0 (0%) | 0 (0%) | 0 (0%) | |
| Moderately inactive (n/%) | 4 (15.4%) | 3 (23.1%) | 1 (7.7%) | |
| Moderately active (n/%) | 9 (34.6%) | 5 (38.5%) | 4 (30.8%) | |
| Active (n/%) | 13 (50%) | 5 (38.5%) | 8 (61.5%) | |

Each participant was asked to complete the General Practice physical activity questionnaire. Inactive indicates no physical activity, moderately inactive indicates some to 1 hour of physical activity per week (cycling, jogging, swimming etc), whereas moderately active indicates 1-2.9 hours per week of physical activity, and active indicates more than 3 hours of physical activity per week. There was no significant difference between the LBP and NLBP groups (p=0.19). The results are shown in Table 4.1.

Specific LBP occurrence can be seen in Table 4.2, 84.6% of the LBP group had experienced LBP in the last 4 weeks.

Table 4.2: LBP occurrence and re-occurrence

| | **All Participants (n=26)** | **LBP (n=13)** |
|---|---|---|
| Low back pain experienced in last 12 months | | 13(100%) |
| Recent LBP (in last 4 weeks) | | 11 (84.6%) |
| LBP reported as limiting daily activities | | 3 (23.1%) |
| | | |
| **Period of re-occurrence** | | |
| > 3 years | | 3 (23%) |
| 1year- 7months | | 2 (15.4%) |
| 7-3 months | | 3 (23.1%) |
| < 3 months | | 5 (38.5%) |

The LBP participants were invited to complete Oswestry Disability Index , McGill short form and Tampa scale of kinesiophobia. The results are set out in Table 4.4 below.

The Oswestry Disability Index results were calculated by summing the individual question scores for each participant. There were 10 questions scored between 0 (no disability) and 5 (most disability). These scores were then expressed as a percentage and placed into 5 categories, minimal (0-20%), moderate (21-40%), severe (41-60%), crippled (61-80%) and bed-bound (81-100%). None of the participants in this cohort scored more than 60%.

The McGill Short Form Pain Rating questionnaire was completed on the day of the data collection, with ratings based on current intensity of pain (0 = no pain to 10 = worst possible pain) and the number of words selected that described the pain (no words to 22 words). These results were grouped into 3 categories: mild (scored 1-3), moderate (scored 4-7) and severe (scored 8+).

The Tampa Scale questionnaire of Kinesiophobia was scored by summing the individual item scores on a 4-point Likert scale, ranging from 1 (strongly disagree) to 4 (strongly agree). 2 Participants chose not to complete this questionnaire. 4 participants scored 4 for at least one question, but none scored above 37 in total, which would indicate kinesiophobia. The results are shown as numbers of LBP participants and as percentage of all LBP participants, for categories: No- fear (scores of 1), minimal fear (scores of 2), moderate fear (scores of 3), extreme fear (scores of 4).

Table 4.3: Results of Oswestry Disability, McGill Short Form and Tampa Questionnaires.

| **Oswestry Disability** | **Participants (LBP) n=13(%)** |
|---|---|
| Minimal | 11 (84%) |
| Moderate | 1 (8%) |
| Severe | 1 (8%) |
| | |
| McGill Short Form | Participants (LBP) n=13(%) |
| Mild | 3 (23%) |
| Moderate | 7 (54%) |
| Severe | 3 (23%) |
| | |
| Tampa Scale | Participants (LBP) n=13(%) |
| Did not complete | 2(15%) |
| No fear | 4(31%) |
| Minimal fear | 2(15%) |
| Moderate fear | 1(8%) |
| Extreme fear | 4(31%) |

## 4.2. Comparison of Thickness between Prone and Standing Position of the TLF and Combined Zone.

The thickness (mm) of the perimuscular (TLF) and combined zone (subcutaneous tissue and TLF combined) was measured in prone and standing positions in all 26 participants. Fig: 4.1 gives examples of the ultrasound images acquired and illustrates the variance of thickness of combined zone and TLF across the study. In Fig 4.1 the combined zone (between the red lines) represents the combined thickness of the perimuscular zone (TLF) and the

subcutaneous tissue below the dermis. The perimuscular zone (TLF) is delineated by the blue lines. US image A is from a participant with LBP in the prone position. US images B and C are from different participants in the NLBP group.

All bilateral thickness measurements were averaged in line with the protocol in previous Langevin (2009,2011) studies and are shown in Appendix V.

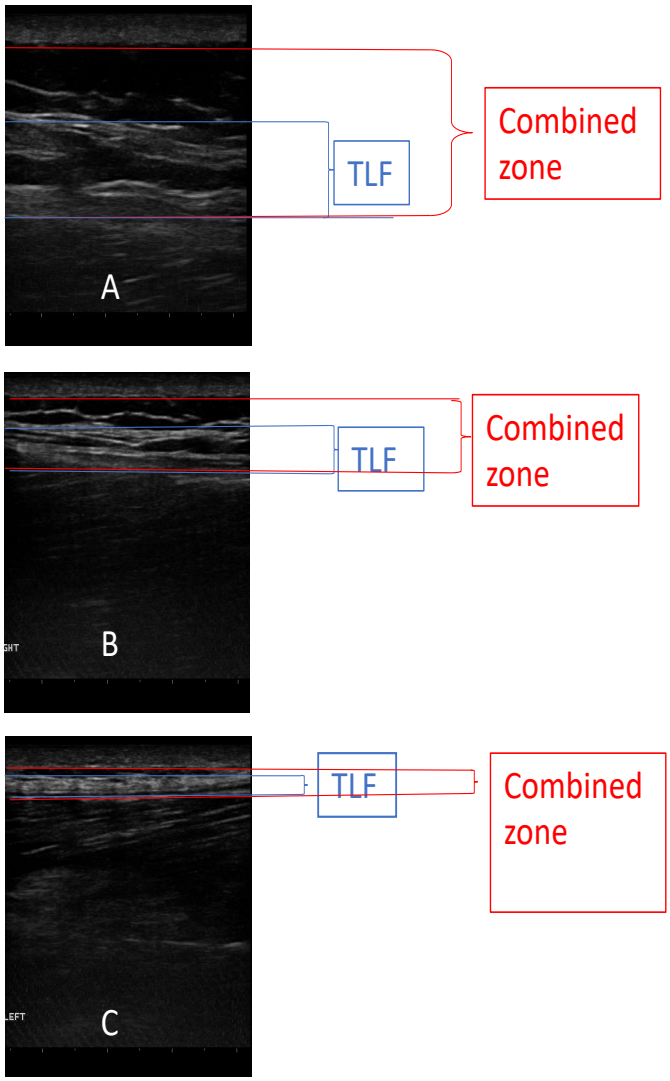


Figure 4.1: 3 US image examples of thickness of TLF and Combined zone .

Although US image capture and subsequent Matlab analysis was made for both left and right sides of the spine, for each participant in both positions. Independent T-tests showed there was no statistically significant difference (p= 0.61) between the left and the right side of the TLF thickness measurements, so the average was adopted in all subsequent statistical analyses. T-tests showed that there was no significant difference (p=0.92) between the left-hand side and the right-hand side measurements of the combined zone (subcutaneous tissue and the TLF) (p=0.92), so an average was adopted for subsequent statistical analysis. The averaged thickness and echogenicity measurements are in shown in Appendix V.

The thickness measurements for both the perimuscular (TLF) zone and the combined zone (subcutaneous tissue and TLF combined) were not normally distributed as assessed by the Shapiro-Wilks test (p = 0.001). In addition, box tests showed that there were outliers for the perimuscular (2 outliers) see fig 4.1below and combined zone (3 outliers) see fig 4.2 below.

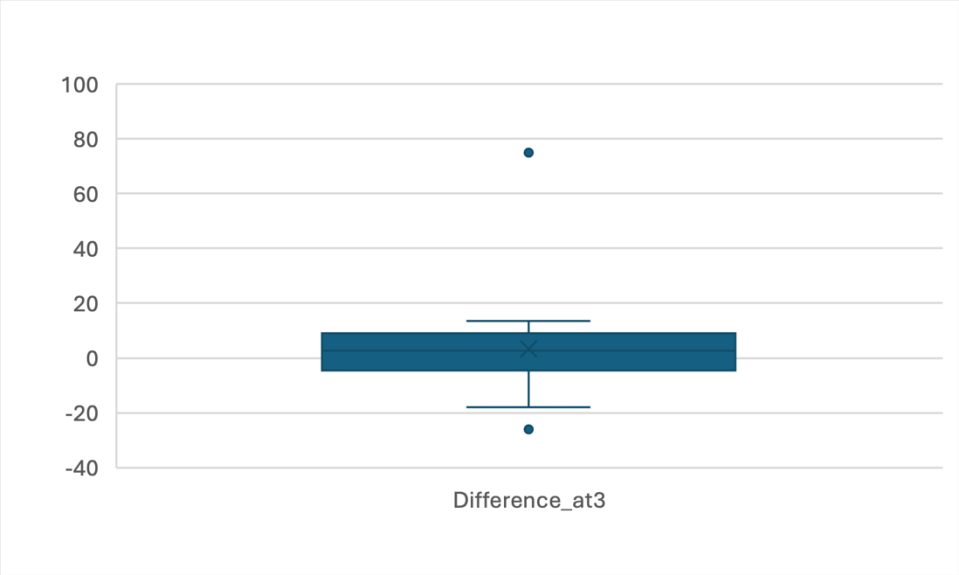



Figure 4.2: Box plot results showing 2 outliers for the TLF thickness measurements for the whole cohort.

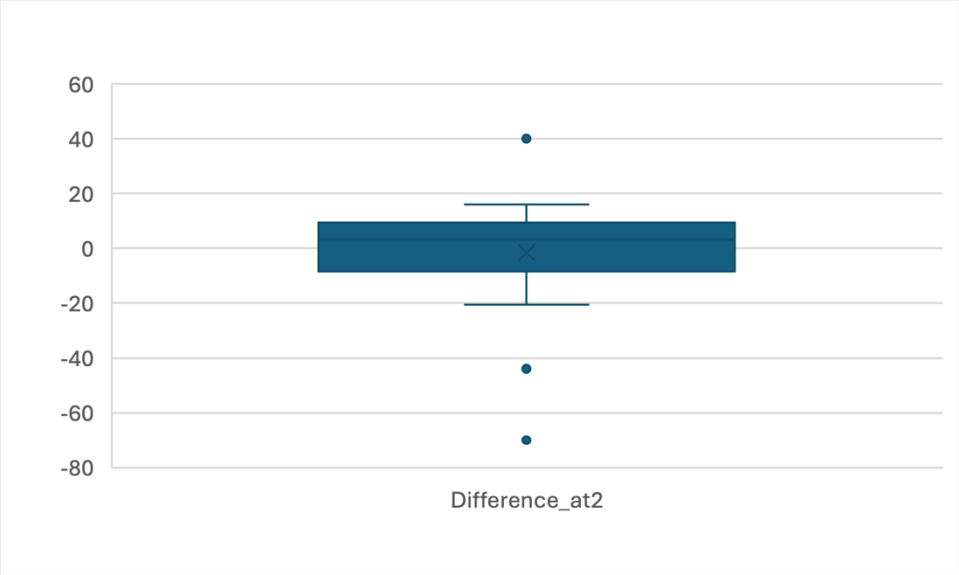



Figure 4.3: Box plot results showing 3 outliers for the combined zone thickness measurements for the whole cohort.

Because of the violation of the normal distribution assumption and the outliers, a non-parametric related samples sign test was selected to see if there was a correlation between the thickness of the TLF in the prone and standing and a correlation between the thickness of the combined zone in the prone and standing positions.

The results of the sign test are shown in table 4.5 below (mean values reported). There was no statistically significant difference between prone and standing positions of the thickness of the perimuscular zone (p=0.42) and the combined zone (p=0.57). Figure 4.3 below shows a graph of the positive differences and negative differences between prone and standing positions in the Related-Samples Sign Test for the TLF. Figure 4.4 below shows the graph of the positive and negative differences between prone and standing positions in the Related-Samples Sign Test for the combined zone.

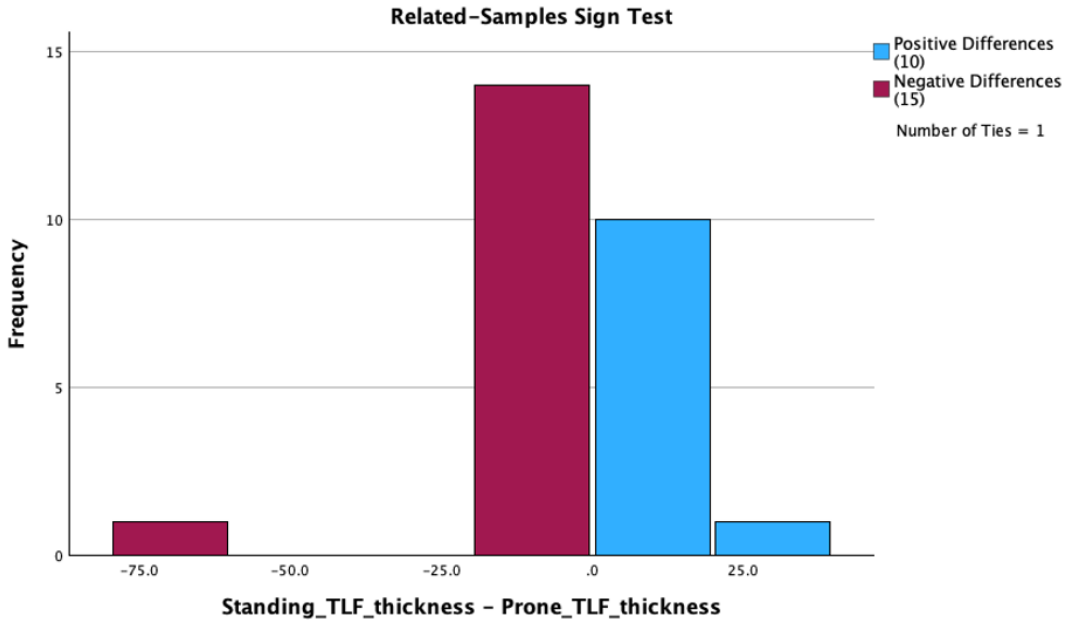



Figure 4.4: Related-Samples Sign test for the thickness of the TLF between prone and standing positions.

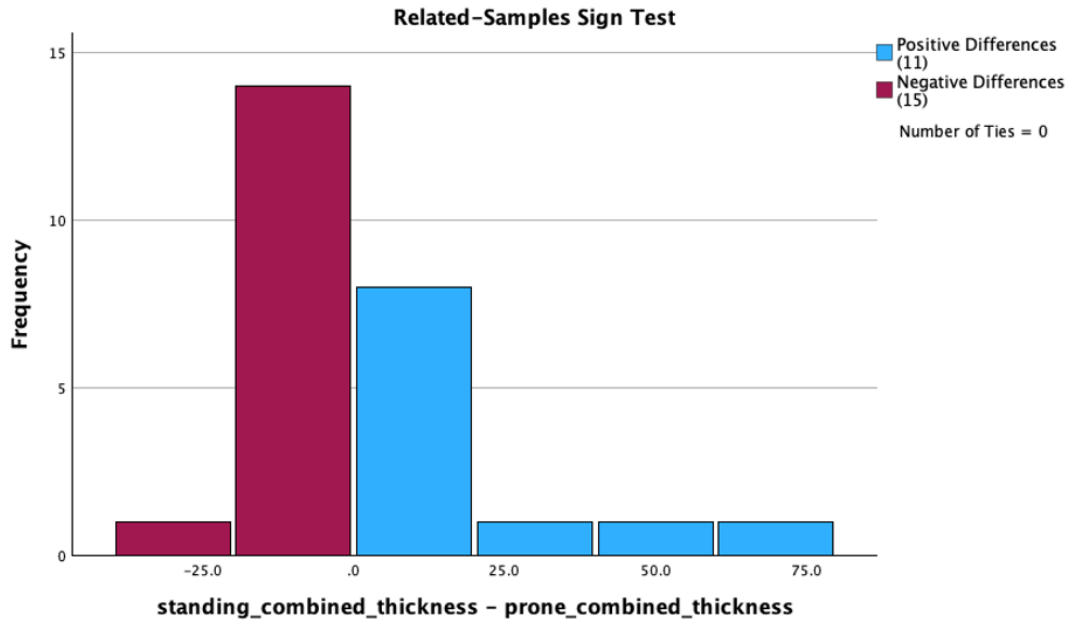



Figure 4.5: Related-Samples Sign test for the thickness of the combined zone between prone and standing positions.

Since data were found to be non-parametric, median values have also been reported (Appendix VI. Table 7.1).

Ultrasound image pixels were converted to millimeters (mm). Each Pixel represents 512th of 30 millimeters. Thickness measured in mm. unless otherwise stated.

Table 4.4: Comparison of TLF thickness between prone and standing of all participants (LBP and NLBP)

| **Thickness (mm)*** | **Prone**<br>**Mean ± SD** | **Standing**<br>**Mean ± SD** | **P value** |
|---|---|---|---|
| TLF<br>N=26 | 2.95 ± 1.4 | 3.14 ± 1.4 | |
| TLF Sign test (1 tie) | 10 | 15 | 0.42 |
| Combined<br>N=26 | 6.61 ± 3.7 | 6.71 ± 3.9 | |
| Combined Sign test | 15 | 11 | 0.57 |

*Mean values

## 4.3. Comparison of Echogenicity between Prone and Standing Position of the TLF and Combined Zone.

The echogenicity of the TLF and the combined zone was measured in prone and standing positions in all 26 participants. All averaged measurements are shown in Appendix V.

No outliers were observed using a box test and all echogenicity scores were normally distributed as assessed with a Shapiro-Wilks test, therefore, averages are reported as the mean, unless otherwise stated. The difference between the prone and standing positions of the TLF echogenicity was analysed with a Paired Samples T-Test.

The echogenicity of the TLF in prone was significantly brighter compared to the standing positions (p=0.046).

There was no statistically significant difference in the combined zone (p=0.063). The results are shown in Table 4.6.

Table 4.5: Comparison of TLF and combined zone echogenicity between prone and standing.

| **Echogenicity**** | **Prone**<br>**Mean ± SD** | **Standing**<br>**Mean ± SD** | **p-value** |
|---|---|---|---|
| TLF<br>N=26 | 56.86 ±16.33 | 51.82 ± 16.54 | 0.04* |
| Combined zone<br>N=26 | 38.24 ±15.59 | 34.95 ± 15.92 | 0.06 |

*Statistically significant

**echogenicity unit of measurement: Greyscale of 0 (100% black)- 255 (100% white)

## 4.4 Comparison of the Thickness of the TLF and Combined Zone between LBP and NLBP groups in Prone and Standing Positions.

Assumptions to see if an ANOVA with BMI as a covariant were violated.
Normality as assessed by Shapiro-Wilks ($p<0.001$) 2 outliers were observed using a visual inspection of Box-plots, and no linear relationship for 3 of the dependent variables. It was decided that a ANCOVA could not be used.
A series of independent sample t-tests were used instead to determine the thickness difference between LBP and NLBP groups in prone and standing of the TLF and combined zone. Two outliers were removed in the NLBP group following visual inspection of box plots.
Figure 4.5 shows examples of the box plot that identifies outlier to be removed in NLBP group (group 2 in box plot) for prone data and figure 4.6 shows example of box plot that identifies outlier to be removed in NLBP group, (group 2 in box plot) for standing data.

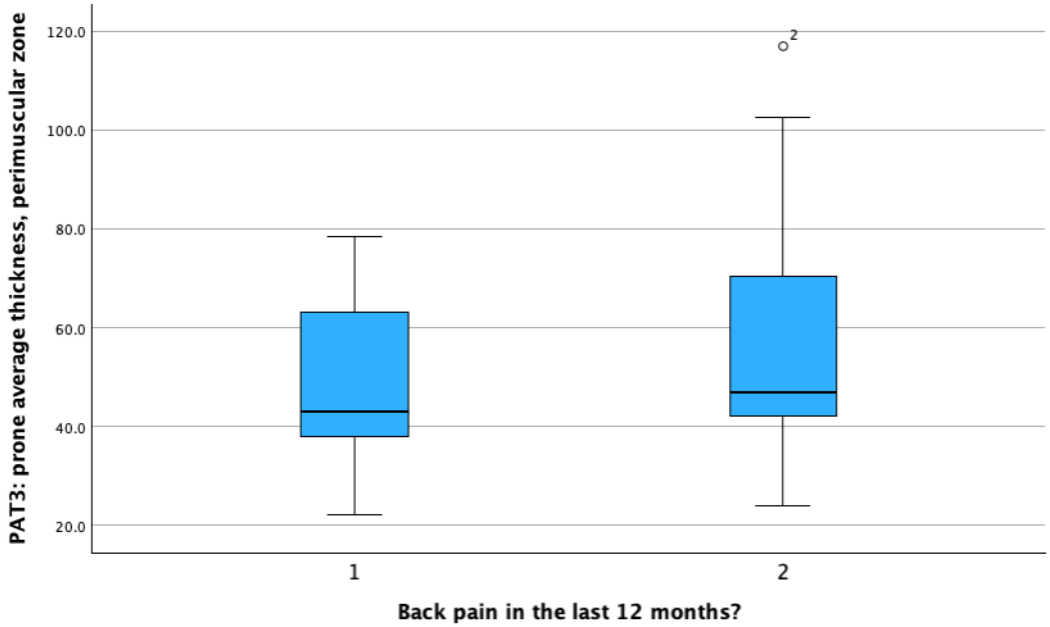



Figure 4.6: Example of box plot that identified outlier to be removed in NLBP in prone position.

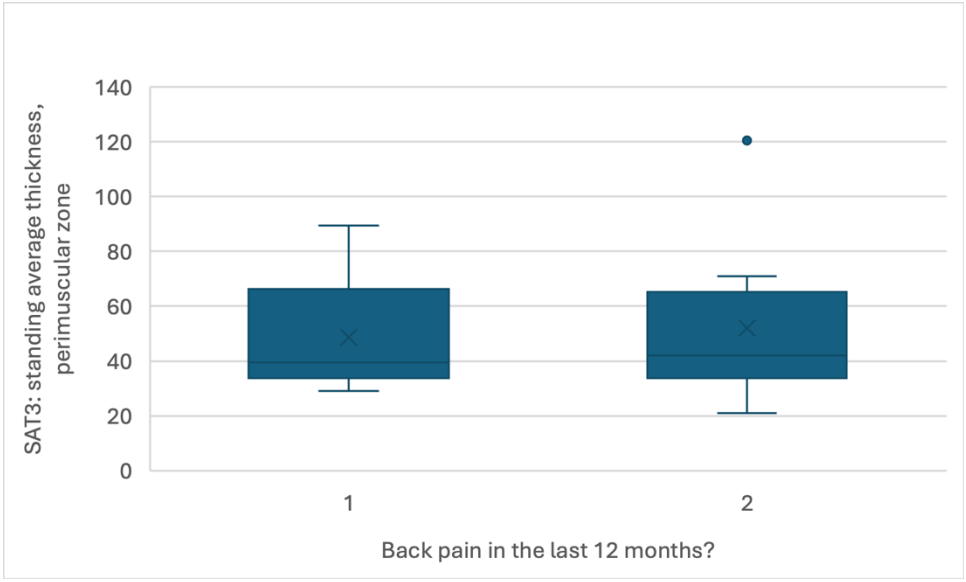



Figure 4.7: Example of box plot that identifies outlier in NLBP group in standing position.

The homogeneity of variances as assessed by Levene's test was not met for the combined zone scores in prone ($p=0.011$) or standing ($p<0.001$), so a Welsh T-test was substituted. Table 4.7 shows the mean difference (mm), t-value and p-

value. Table 4.8 below sets out a comparison of the mean thickness ± SD (mm) of the TLF and combined zone for each position.

Table: 4.6: Comparison of Thickness of TLF and Combined zone between LBP and NLBP groups in prone and standing- Independent sample T-Test and Welsh tests results.

| **Average Thickness (mm)** | **Mean difference ± SE** | **t value** | **p value** |
|---|---|---|---|
| Prone Perimuscular zone | 0.39 ±6.94 | t(22) = 0.56 | p>0.05 |
| Prone Combined Zone (Welsh t-test) | 2.02 ± 1.06 | t(16.28) = 1.9 | p>0.05 |
| Standing Perimuscular Zone | 1.93 ± 7.75 | t(22) = 0.25 | p>0.05 |
| Standing Combined Zone (Welsh t-test) | 2.39 ± 0.99 | t(16.42) = 2.4 | p=0.028* |

*Statistically significant.

LBP n=13, NLBP n=11

Table 4.7: Comparison of Thickness of TLF and Combined Zone between LBP and NLBP groups in Prone and Standing Positions with outliers excluded.

| **Thickness (mm)** | **Prone**<br>**Mean ± SD** | **Standing**<br>**Mean ± SD** |
|---|---|---|
| TLF | | |
| LBP<br>N=13 | 2.88 ± 0.99 | 2.85 ± 1.99 |
| NLBP<br>N=11 | 2.85 ± 0.99 | 2.73 ± 1.00 |
| P value | 0.96 | 0.81 |
| Combined zone * | | |
| LBP<br>N=13 | 6.87 ± 3.51 | 6.98 ± 3.27 |
| NLBP<br>N=11 | 4.85 ± 1.4 | 4.50 ± 1.33 |
| P value | 0.075 | 0.028** |

*Welsh Test used.

**Statistically significant

Table 4.8 shows the comparison of the means and SD thickness in mm of the TLF for participants with LBP and the NLBP group in the prone position (p= 0.96) and the standing position (p= 0.81). Table 4.7 also shows the comparison of the means and SD of the thickness in mm of the combined zone for participants with LBP and the NLBP group in the prone position (p=0.075) and the standing position (p=0.028).

In the standing position, the thickness of the combined zone in the NLBP group compared with the LBP group was found to be significantly thicker (p=0.028).

However, there were no significant differences in thickness of TLF between LBP or NLBP groups in either position nor between the thickness of the combined zone LBP and NLB groups in the prone position.

## 4.5 Comparison of the Echogenicity of the TLF and Combined Zone between LBP and NLBP Groups in Prone and Standing Positions.

Echogenicity scores violated assumptions on linearity and homoscedasticity, so an ANOVA could not be used.

A series of Independent sample t-tests were used instead to determine the difference in echogenicity of the perimuscular zone (TLF) and combined zone between LBP and NLBP groups.

The results are shown in Table 4.9. Table 4.9 shows the means and SD of echogenicity measured using Greyscale, of TLF of participants with LBP and the NLBP group in the prone position ($p=0.77$) and the standing position ($p=0.43$). Also, the means and SD of echogenicity, measured in Greyscale of the combined zone in prone ($p= 0.58$) and standing ($p=0.34$). There was no significant difference in echogenicity in TLF or combined zone between LBP or NLBP groups in either position.

Full results are in Appendix VI Table 7.2

Table 4.8: Comparison of echogenicity measurements of TLF and combined zone between LBP and NLBP groups in prone and standing positions.

| **Echogenicity*** | **Prone**<br>**Mean and SD** | **Standing**<br>**Mean and SD** |
|---|---|---|
| TLF | | |
| LBP (N=13) | 60.17±16.72 | 54.86±17.08 |
| NLBP (N=11) | 55.59±14.91 | 52.03±14.95 |
| P value | 0.77 | 0.43 |
| Combined zone | | |
| LBP (N=13) | 37.79±15.83 | 34.22±15.20 |
| NLBP (N=11) | 41.43±15.58 | 40.19±14.58 |
| P value | 0.58 | 0.34 |

* echogenicity unit of measurement: Greyscale of 0 (100% black)- 255 (100% white)

## 4.6 Correlation Results

### 4.6.1 Thickness of TLF and its Relationship to Oswestry LBP Disability Scores.

The correlation of the thickness of the TLF and the Oswestry LBP disability score was normally distributed as measured by the Shapiro-Wilks test.

Data was transformed (log 10) and 3 outliers were removed. A Pearson's Product-moment correlation was performed.

There was a linear relationship and a strong positive correlation between the Oswestry LBP disability percentage score and the average thickness of the TLF in prone (r=0.92) and standing (r=0.62) using the Pearson's product-moment

correlation (Cohen, 1988). This suggests that for this cohort the thickness of the TLF increased with an increase in disability score in both positions.

### 4.6.2 Echogenicity of the TLF and its Relationship to Oswestry LBP Disability Score.

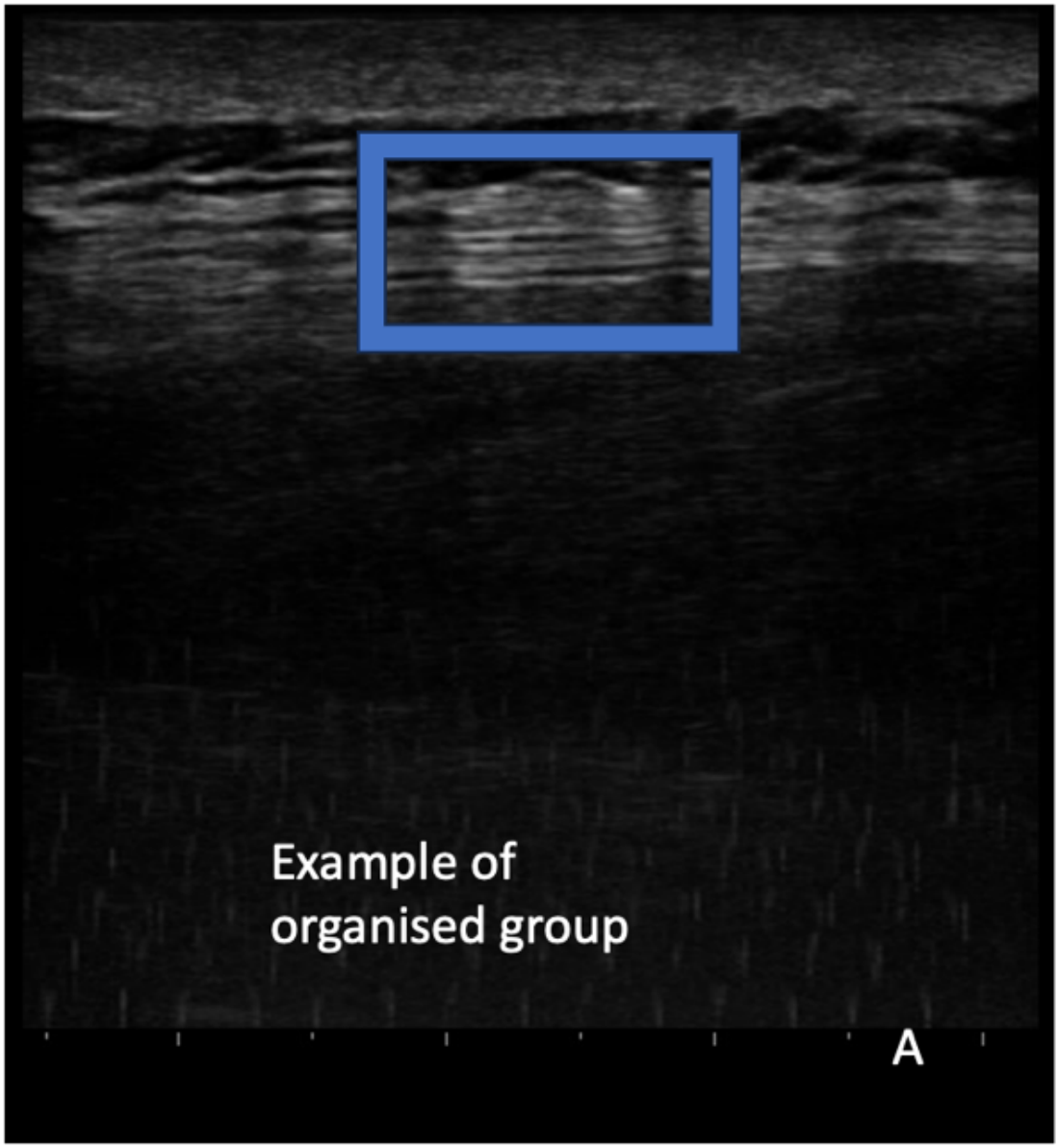
The Correlation of the echogenicity of the TLF and the Oswestry LBP disability score was normally distributed as measured by the Shapiro-Wilks test.
Data was transformed (log 10) and 3 outliers were removed.

A weak correlation was found between the Oswestry LBP disability percentage score and echogenicity of the perimuscular zone in prone (r= -0.28) and standing (r= 0.10), as measured by the Pearson's-moment correlation test (Cohen, 1988). Cohen (1988) described correlations as weak if close to 0 and strong if close to 1. This result indicates that echogenicity has a weak correlation with disability scores for this cohort. No linear relationship was found.

## 4.7 Visual Inspection of TLF Morphology.

Ultrasound images of all 26 participants, were visually inspected. Ultrasound images in both prone and standing positions were included. All images were visually inspected and graded using a Likert scale 1-10. A score of 1 indicating a very organised TLF, and 10 indicating a very disorganised TLF (De Coninck *et al.*, 2018; Almazán-Polo *et al.*, 2020). The average of left and right scores were used for statistical analysis.

The average scores were then placed into 2 groups: organised and disorganised.



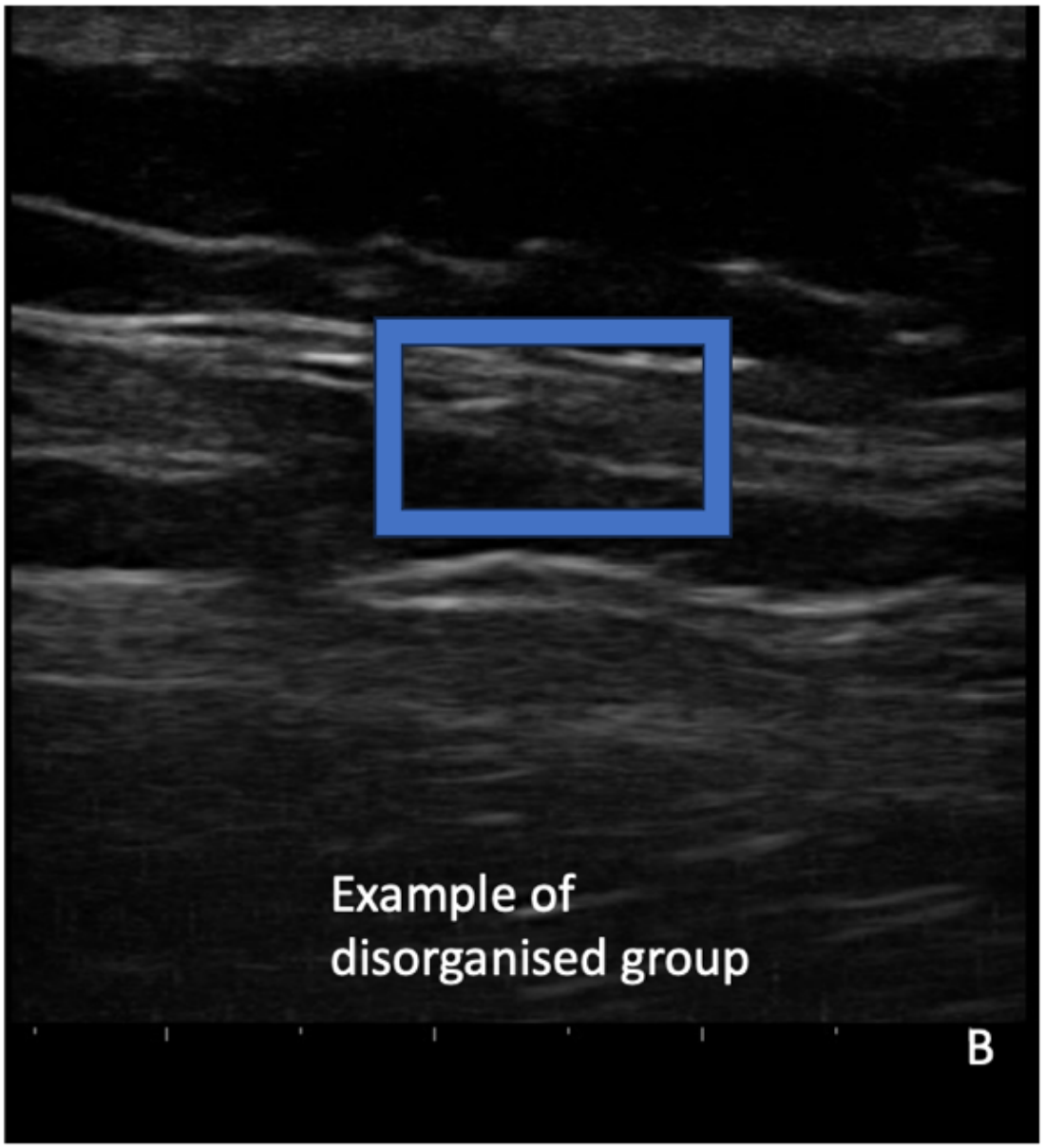



Figure 4.8: US image examples to demonstrate grading of organizational group following visual inspection of images.

Image A: organised group, Image B: disorganised group.

A summary of the averaged scores can be seen in Table 4.10.

Table 4.9: Comparison of organised and disorganised visually inspected groups in prone and standing positions.

| **Prone position** | **Organised** | **Disorganised** |
|---|---|---|
| LBP n=13 | 7 (53.8%) | 6 (46.2%) |
| NLBP n=13 | 9 (69.2%) | 4 (30.8%) |
| Total n=26 | 16 (61.5%) | 10 (38.5%) |
| Standing position | | |
| LBP n=13 | 4 (30.8%) | 9 (69.2%) |
| NLBP. n=13 | 8 (61.5%) | 5 (38.5%) |
| Total. n=26 | 12 (46.2%) | 14 (53.8%) |

To compare visual inspection scores between prone and standing positions, a related samples Wilcoxon signed rank test was run, which returned a statistically significant result (p=0.04) for the whole cohort (Table 4.11). The standing position was significantly more disorganised compared to the prone position in the same participants.

Table 4.10: Comparison of visual inspection scores between prone and standing

| **prone v standing** | **p-value** | |
|---|---|---|
| Whole cohort<br>N=26 | 0.04 | Standing more disorganised |
| LBP<br>N=13 | 0.08 | |
| NLBP<br>N=13 | 0.03 | Standing more disorganised |

Similar results were found in the NLBP group (p=0.03), with the standing position significantly more disorganised compared to the prone. However, there was no significant difference between standing and prone in the LBP group (p=0.08).

A simple comparison of organisational Likert scores for LBP and NLBP groups in prone and standing positions can be seen in Fig 4.9. below. This indicates that the NLBP group had better organisational scores.

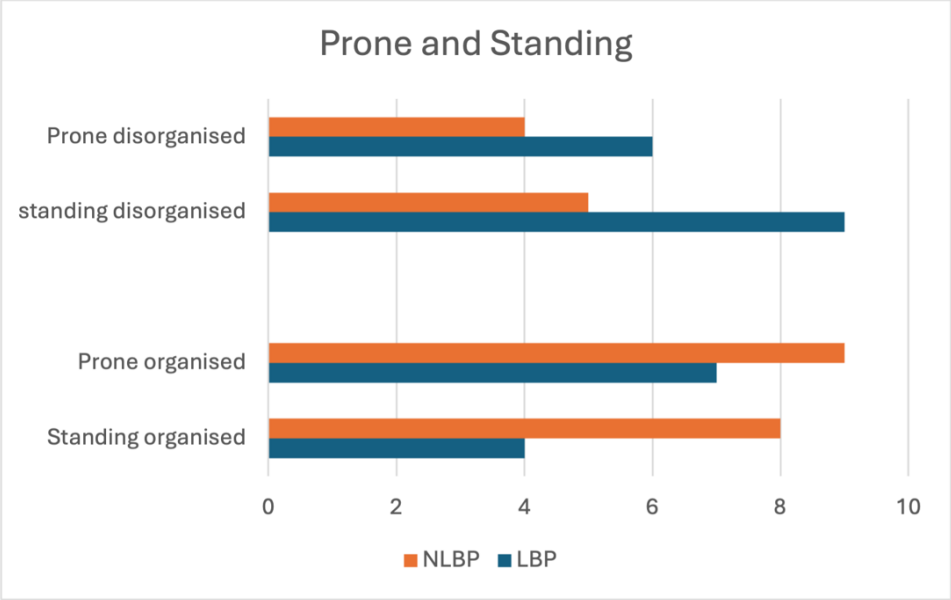



Figure 4.9 Visual inspection of ultrasound images of the TLF of people with and without LBP

Figure: 4.10 below shows the BMI scores by category, underweight, healthy, overweight and obese broken down into 4 raw Likert Scale groups. for both prone and standing positions. This simple bar graph indicates that in the prone position for this cohort, 8 out of 12 participants whose BMI was between 18.5 and 24.9 and described as healthy had organised TLF as measured by the Likert scale. It also indicates that 4 out of 9 participants whose BMI was >30 and described as obese had very disorganised TLF as measured by the Likert scale. In the standing position, the bar chart indicates that there a change in organisation category as measured by the Likert scale. In all BMI categories the organisation Likert scores improve. Because of the small cohort size when split into categories no meaningful statistical test could be run.

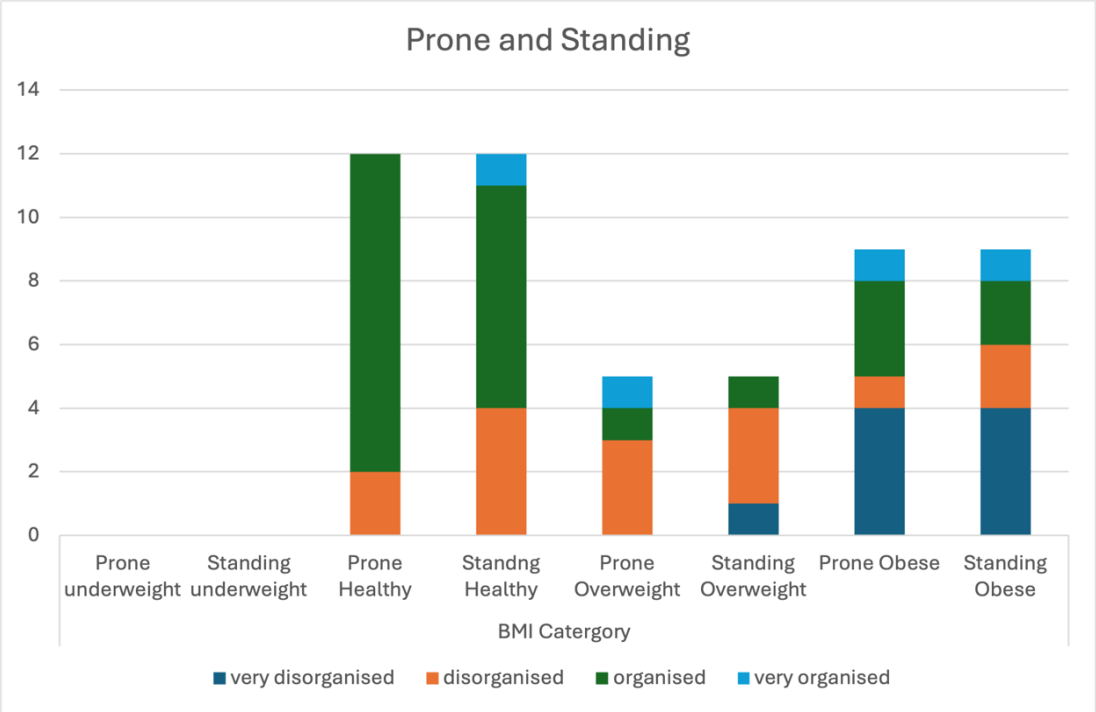



Figure 4.10: Prone and standing Likert bar charts organised by BMI categories.

Figure 4.11 below shows the activity scores by category, inactive, moderately inactive, moderately active and active broken down into 4 raw Likert Scale groups. for both prone and standing positions. Like the bar chart for the BMI categories the subgroups are too small for any meaningful analysis.

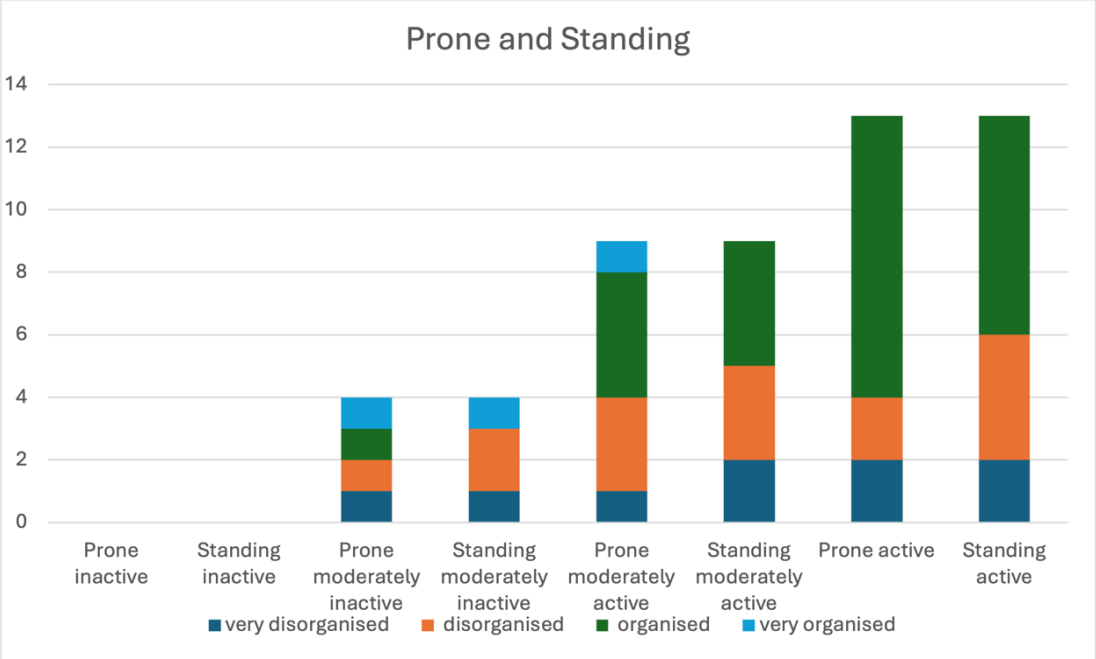



Figure 4.11: Prone and standing Likert bar charts organised by Activity categories.

# Chapter 5: Discussion and Conclusion

## 5.1 Overview of Study Results for TLF

Building upon earlier LBP fascia studies (Langevin et al., 2009; Whittaker et al., 2013; Gumruk Aslan, 2023; Pirri et al., 2023), this study acquired US images of the TLF from 26 people with and without LBP, in the more usual prone position and a novel standardised standing position. To our knowledge, this is the first time that TLF thickness, echogenicity and visual measurements have been acquired in a standing position and a comparison was made with the prone position. This study also compared LBP disability scores with the TLF measurements in each position, which, to our knowledge has not been reported upon before.

Across all 26 subjects, with and without LBP, no significant difference in the thickness of the TLF between the prone and the standing positions was found. Finding no significant difference in the TLF thickness between standing and prone position may have positive implications for clinicians and patients because for some people, such as those in extreme pain, or in the late stages of pregnancy, a prone position may not be accessible or comfortable. This finding may indicate that the TLF thickness of these groups of people could in future be assessed in a standing position.

## 5.2 Clinical Relevance of TLF

Measuring the thickness of the TLF is useful as it can indicate the general condition and health of this fascial structure. An increase in the thickness of the

TLF can indicate densification or fibrosis in the fascial layers or the loose connective tissue between these layers (Pavan *et al.*, 2014). One study suggested that screening fascia thickness may be a valuable future outcome parameter in the prevention of musculoskeletal disorders (Wilke *et al.*, 2019).

## 5.3 Imaging of TLF: Methodological Considerations

High-resolution technology continues to evolve in response to demands by clinicians and researchers. A relatively new introduction is upright MRI imaging technology, which can account for the mechanics of standing on the lower back. The upright MRI scanner's advantage over the usual MRI is that it visualises spinal morphology in weight-bearing positions, determining causes of LBP that a traditional supine or prone position may alleviate. However, the current drawback is that the upright MRI scanner is expensive and cannot perform all the functions of a conventional MRI scanner (Fiani *et al.*, 2020). Most studies on the upright MRI relate to spinal disorders such as scoliosis or disc pathologies (Hasegawa *et al.*, 2018). To consider fascial tissues US is recognised as a reliable, portable, safe and cost-effective alternative to MRI (Genu *et al.*, 2014). To date, US imaging of the TLF morphology has been performed in a prone position, acquiring images in a standing position may, like the upright MRI spinal investigations provide may new insights into the morphology of the TLF in a weight-bearing position. There are US studies on the stiffness of the TLF in different positions. One has shown that stiffness is 68.98% higher in standing than in prone (Chen *et al.*, 2021). There are also US studies on the muscles of the lower back. One US study on the thickness of

muscles in the low back for participants with and without a history of LBP found no difference in thickness between prone and standing positions (Sutherlin *et al.*, 2018).

Langevin (2009), in a pioneering TLF LBP study reported a 25% increase in thickness for LBP subjects, measured in a prone position. This significant increase was supported in subsequent studies (Whittaker et al., 2013; Gumruk Aslan et al., 2023; Pirri et al., 2023). However, a US study of the TLF by Almazan-Polo et al. (2020) did not find a significant increase in thickness in prone of the TLF. The study presented here did not find a significant increase in the TLF in LBP subjects in either position. A comparison of the wider literature with the study in this thesis is shown in Table 5.1.

Table 5.1: Comparison of TLF thickness studies

| **TLF measurements** | **Langevin, 2009** | **Whittaker, 2013** | **Pirri, 2023 left/right** | **Gumruk.2023 left/right** | **This Study Prone data** | **This Study Standing data** |
|---|---|---|---|---|---|---|
| TLF mean thickness LBP group (mm) | 4.2 *(p<0.001) | 2.9* | 2.27*/2.08* | 2.21*/2.20 | 2.88(± 1.34) | 2.85(± 1.99) |
| TLF mean thickness NLBP group (mm) | 3.5* | 2.3* | 1.96*/1.75* | 1.7*/1.5 | 2.86(± 1.35) | 2.74(± 1.00) |

*Significant difference (p< 0.05) between LBP and NLBP participants

Table 5.1 shows the mean thickness of the TLF in LBP ranged between 4.2mm (Langevin *et al.*, 2009) and 2.08 mm (Pirri *et al.*, 2023). The study in this thesis found a mean thickness of 2.88mm in prone and 2.85mm in standing, in line with the literature. In people without LBP, the mean thickness of the TLF ranges between 3.5mm (Langevin *et al.*, 2009) and 1.5mm (Gumruk Aslan et al., 2023).

Similarly, this study reported a TLF thickness for the control group of 2.86mm in prone and 2.74mm in standing. Even though the actual thickness measurements are within the range found in the literature, this study did not find a significant increase in thickness in the TLF in the LBP group. Earlier studies (Langevin *et al.*, 2009; Whittaker *et al.*, 2013) used US averaged left and right-hand side data following t-tests that showed no significant difference between the sides. The later studies reported on left and right-hand side measurements (Almazan-Polo et al., 2020; Gumruk Aslan et al., 2023; Pirri et al., 2023). Pirri (2023) reported a significant difference for both sides between LBP and NLBP participants, whereas Gumruk Aslan (2023) only reported a significant difference on the left-hand side. Alamazan-Polo (2020) also reported on both left and right-hand sides of the TLF but found no significant difference in thickness between participants with and without LBP. The study in this thesis followed the methodology of the earlier studies by Langevin (2009, 2011).

It is important to comment on the sample size. In previous studies shown in Table 5.1, the number of participants ranged from 107 (Langevin *et al.*, 2009) to 50 (Whittaker et al., 2013; Gumruk Aslan et al, 2023). For the study in this thesis an a-priori power calculation was conducted using G*Power (Faul *et al.*, 2007) with 80% power and alpha set at 0.05. The mean values and standard deviations reported in the literature were used to calculate power. The result was that 20 participants were required for the LBP and NLBP groups, respectively. Initially, a total of 60 participants were recruited for this study. However, due to a high level of co-morbidities in both LBP and NLBP groups, the total cohort was reduced to 26. Since this study is a feasibility study and part of

a Master's thesis with a restricted amount of time available, the decision was taken to move forwards and commence data collection with 26 participants. In future studies, co-morbidities and exclusion criteria ought to be carefully considered to not exclude participants with a complex medical history unnecessarily.

## 5.4 Participant demographics in TLF Research

Comparisons of the demographics of participants in the TLF literature with this study are shown in Table 5.2.

Table 5.2: Comparison of demographics for TLF thickness studies

| **Study** | **Langevin, (2009)** | **Whittaker, (2013)** | **Pirri, (2023) left/right** | **Gumruk Aslan, (2023) left/right** | **This Study Prone data** | **This Study Standing data** |
|---|---|---|---|---|---|---|
| Study size Total (LBP/NLBP) | 107 (60/47) | 50 (25/25) | 92 (46/46) | 50 (30/20) | 26 (13/13) | 26 (13/13) |
| Age - LBP Mean (SD) | 38.3 (13.3) | 46.6(8) | 28.96 ±10.56 | 46.2(10.6) | 49.85 ±16 | 49.85 ±16 |
| Age – NLBP Mean (SD) | 39.4 (14) | 36.3 (9.4) | 27.09 (12.38) | 41.9 (10.5) | 55.0 ±21.2 | 55.0 (21.2) |
| BMI – LBP Means (SD) | 25.7 (0.6) | 24 (3.5) | 23.37 (5.22) | 27.6 (3.9) | 29.65 (7.3) | 29.65 (7.3) |
| BMI- NLBP Mean (SD) | 25.9 (0.7) | 23.5 (2.5) | 24.03 (6.1) | 26.6 (4.8) | 27.68 (8.1) | 27.68 (8.1) |
| Physical activity levels for LBP | High 62% Moderate 29% Sedentary 9% | | | | High 35% Moderate 39% Sedentary 23% | High 35% Moderate 39% Sedentary 23% |

All measurements in Table 5.2 were acquired in a prone position unless stated otherwise.

As seen in Table 5.2 Age and BMI profiles were noticeably different between studies. In LBP groups the mean age ranged from 28 (Pirri *et al.*, 2023) to 46 (Gumruk Aslan et al., 2023), whereas this study reported a mean age of 49. Studies have found that age can influence fascia morphology (Wilke *et al.*, 2019). In Wilke's study, 17 healthy female subjects of 69±4 years and 18 healthy female subjects 22 ±1 years were measured. Right-hand and left-hand side measurements were averaged (thickness of the TLF reported as between 1.45mm and 4.15 mm). An increased thickness of ~ 76% in lumbar fascia thickness was reported for the older group compared with the younger age group. In this thesis, the mean TLF thickness in prone was 2.88mm (±1.34), which is towards the lower end of the range reported in the studies in Table 5.2 above. It should be noted that Wilke's study used a horizontal probe placement and US images acquired at level L2. Wilke et al. (2019) and reported a higher BMI in the older participant group.

The BMI of LBP participants in the TLF literature shown in table 5.2 ranges from a mean of 23 (Pirri *et al.*, 2023) representing a healthy weight, to a mean of 28, representing overweight (Gumruk Aslan et al., 2023). Whereas the study in this thesis, found a much higher mean BMI of 30, representing obesity. Wilke et al.'s (2019) found a systematic positive correlation between BMI and lumbar fascia thickness in both young and old participants. Wilke et al. (2019) went on to argue that connective tissue dynamically adapts to forces acting upon it and that additional weight may require a thicker connective tissue. In this thesis, factors such as age and BMI could not be considered as mediators since the data was not normally distributed and resulted in a violation of assumptions.

BMI is an important consideration for all age groups requiring further investigation.

This study has high SD figures in participant demographics compared with the studies in the literature, particularly for age and BMI. This study had SD's ranging between ±8 and ±21, whereas the maximum reported SD in the literature is Langevin (2009) at ±13.3. A high SD in back pain studies indicate a large degree of variability or heterogeneity in the data or a wide range of experience of back pain within the cohort studied (Choi et al., 2016). A high SD can impact the interpretation of study results as it is harder to detect a significant difference because individual differences may mask the overall change. Back pain studies suggest that an increase the sample size may overcome the impact of a high SD (Wewege *et al.*, 2022).

Difficulties with direct comparison between TLF US studies have been raised (Caterina Fede *et al.*, 2018). For example, the variations in the orientation of the probe. For all the studies in Table 5.1 and 5.2 the probe was orientated in the longitudinal position. However, on closer inspection of the literature, there are differences in the anatomical locations of the probe; For example, Pirri (2023) acquired images at the level of lumbar vertebra (L) 3, and Whittaker (2013) at the lateral Raphe, a few centimetres lateral to the position used in this study. This thesis adopted the validated protocol first reported in Langevin (2009) and later in Gumruk (2023). The probe was positioned 2 cm lateral and medial of the intervertebral space between L2 and L3.

Currently, there are no standard guidelines for US measurements of fascia. The Fascia Research Society have indicated that it is in the process of setting up a

working group to establish practice guidelines for the US imaging of fascial tissue (personal correspondence).

It is interesting to note that through conversations with the participants in the NLBP group, a history of LBP experienced more than one year ago was disclosed, even though participants had been pain-free for more than a year and so met the inclusion criteria for NLBP. Historical back pain may have caused alterations at some point in the past in the TLF of the control group and may explain why this thesis found no difference in thickness between LBP and NLBP. It is also interesting to note that the LBP participants in this study anecdotally disclosed they managed their LBP with regular stretching and Pilates, which may have resulted in lower pain intensity and disability scores. Research has found that Pilates can provide short-term benefits in pain relief and disability scores (Miyamoto *et al.*, 2013). Similarly, stretching has been shown to help reduce pain intensity, disability and fear avoidance (Turci *et al.*, 2023).

## 5.5 Study Results for Combined zone

This thesis found a significant increase ($p=0.03$) in the thickness of the combined zone in LBP subjects compared to NLBP subjects, in the standing position. There was no difference found in the prone position. The combined zone is the combination of the thickness of the TLF and subcutaneous tissue. The later studies (Gumruk Aslan et al., 2023; Pirri et al., 2023) did not report measurements for the combined zone. Langevin (2009) did report an increase in the combined zone thickness for participants with LBP in the prone position.

Langevin (2009) stated this increase was driven by the increased thickness of the TLF. However, in the study reported in this thesis, no increase in TLF thickness in LBP subjects was found. This thesis suggests that for this cohort the increase in combined thickness in standing was driven by the subcutaneous zone. We hypothesise that the subcutaneous zone was thicker in the standing position partly due to an increased lordosis of the lower spine. Standing has been shown to increase lordosis by 16 degrees (Salem *et al.*, 2015). The subcutaneous zone thickness may also be affected by the cohort's high BMI rating. Wilke et al. (2019) found a correlation between high BMI and lumbar fascia thickness.

The profile of the lower back and the effect it has on the thickness of subcutaneous tissues or the TLF has not been considered in ultrasound studies previously because this is not an issue in the prone position. This requires further investigation.

## 5.6 Study Results on Disability Scores Correlation with the TLF

This thesis found a strong positive correlation between the thickness of the TLF and LBP disability scores, as measured by the Oswestry LBP disability questionnaire in prone ($r= 0.97$, $p<0.001$) and standing ($r=0.85$, $p=0.004$). It is interesting to note that previous TLF ultrasound studies have not reported on a relationship between the thickness of the TLF and disability scores, although they all reported that these questionnaires were completed. Functional assessment of ability was not measured in any studies on TLF US literature, this

is an area of study that can be addressed in future research. A reference relating to the data collected from disability, pain intensity or activity levels to thickness or echogenicity was made by Langevin (2009). She stated that pain intensity (8.8 words circled in McGill) and Oswestry disability level scores (67% mild, 21% moderate and 12% severe) were mild compared with NSLBP studies who generally report moderate mean group scores (Sirbu *et al.*, 2023). This is because higher scoring subjects did not meet the study inclusion criteria. Like the Langevin (2009) study, pain intensity scores in this thesis were similarly mild (8.23 (± 6.7) words circled in McGill) and Oswestry disability level scores were 88% mild, 8% moderate and 8% severe. This thesis also found that participants with higher pain intensity and disability scores did not meet the inclusion criteria and were excluded. A recent TLF ultrasound study (Gumruk Aslan et al., 2023) reported a pain intensity of 6 (±1.7) as measured with a numerical rating scale (NRS), whereas Langevin (2009) reported a lower average of 3.2 (±2.2). NRS are usually scored 0 for no pain to 10 for severe pain. Despite these differences in pain intensity, both the Langevin (2009) and Gumruk Aslan (2023) studies found a significant increase in TLF thickness, in prone, for LBP subjects, with significant increases of 25% and 19%, respectively. Whereas this thesis found no significant change in TLF thickness in either prone and standing, in the LBP group, compared to the NLBP group. More investigations into correlations between thickness of the TLF and disability scores, pain intensity scores or Kinesphobia scores are required before any conclusions can be drawn from this result.

## 5.7 Study Results on Echogenicity

The most reported outcome measure in the TLF literature is thickness, whereas few recent studies report on echogenicity. The rationale for this is unclear as echogenicity data can easily be retrieved from ultrasound data using a greyscale analysis. In fascial tissues, echogenicity measurements can indicate greater amounts of collagen fibre (Langevin *et al.*, 2009) or fibrosis, (Pavan *et al.*, 2014). In this thesis, the echogenicity of the TLF was significantly brighter ($p=0.04$) across all 26 subjects in the prone position ($56.86 \pm 16.33$) compared to the standing position ($51.82 \pm 16.54$).

The TLF is a multilayered fascial structure, collagen fibres of the fascial layers are hyperechoic, seen as white lines on the US image. Whereas the loose connective tissue between the dense connective layers of the fascia is hypoechoic (darker areas). Echogenicity values are affected by both hyper- and hypoechoic layers. Langevin (2009) found that echogenicity was 25% brighter in LBP. Whereas this study did not find a difference between LBP and the control group. It was hypothesised by Langevin (2009) that the increase in echogenicity for LBP subjects was due to an increase in collagen fibre content and could indicate remodelling due to repetitive stresses or loads. Pavan (2014) in a study looking at the fascia of the sternocleidomastoid muscle in healthy and chronic pain patients, suggested increased collagen fibre content was due to densification or fibrosis. Interestingly Pavan (2014) reported that chronic densification of loose connective tissues alters the gliding capacity between the fibrous layers, which in turn increases the amount of collagen fibre synthasised. Fibrosis, on the other hand, is like scarring of the fibrous layers, thickening the

collagen fibres and changing the structure and architecture of the fascial tissue. Both densification and fibrosis were considered a source of pain (Pavan *et al.*, 2014). However, in this thesis, the difference occurred between prone and standing positions for the same participants. As it is a comparison between positions using the same participants, the decrease in echogenicity in standing is unlikely to be explained by either remodelling, densification or fibrosis. The change in echogenicity found in this thesis is more likely to be a response caused by the standing position. The literature offers little information on echogenicity changes in different positions. It is not well understood whether the change in echogenicity is solely due to changes in the collagen-rich (hyperechoic) fascial layers or whether the changes are driven by the hypoechoic loose connective tissue between them. In an in vitro animal study, it was suggested that echogenicity is related to mechanical behaviour in a loaded tissue (Duenwald *et al.*, 2011). Duenwald (2011) found that echogenicity in porcine digital flexor tendons was related non-linearly to stress and nearly linearly to strain. Whether stresses and strains through the TLF may alter echogenicity values requires further research.

Therefore, the findings in this thesis are interesting, and further investigations into the effect of force loading and echogenicity of the TLF are warranted.

## 5.8 Study results on Visual Inspection of the TLF

In addition, in this thesis, a visual inspection of the TLF found that the morphology of the TLF is altered in the standing position. Visual inspection of ultrasound images is a relatively new and reliable way to assess the morphology

of the TLF. This an exciting area of research, particularly as it has promising clinical applications. Fig 5.1 below shows two examples of US images that were categorised with a visual inspection, using a Likert Scale. The white layers are the dense fascial layers of the TLF, the dark areas above and between the fascial layers are loose connective tissue. The visual Likert scale used in this thesis was validated to analyse TLF ultrasound images by De Coninck et al (2018) and has subsequently been used in a more recent TLF LBP study (Almazán-Polo *et al.*, 2020). Almazan-Polo et al. (2023) analysed US Images of 30 young semi-professional male athletes with and without LBP in the prone position. The US images were categorised using this Likert scale by grading images into organised and disorganised groups and found significant disorganisation of the TLF for LBP subjects (Almazán-Polo *et al.*, 2020). This thesis similarly adopted De Coninck's (2018) protocol and used a Likert scale to visually inspect and categorise the US scans. The Likert Scale values of prone and standing for all 26 subjects with and without LBP were compared. This thesis found a significant difference between organised and disorganised categorisations for all subjects. For the 26 participants, the standing position was found to be more disorganised than the prone ($p = 0.04$). Fig 5.1 shows two US images for the same participant, Image A in a prone position and Image B in a standing position. This demonstrates the temporary change in morphology that the change in position has caused. More research is required to understand if the temporary change occurs upon standing or if the temporary change occurs when moving into a prone position. Interestingly, this thesis found that the TLF was significantly more disorganised in the NLBP group when standing,

compared with a prone position (p=0.03). Whereas, in the LBP group, there was no significant difference found between prone and standing (p=0.08). However, the NLBP group's higher levels of organisation in prone were in line with the Almazan-Polo (2023) study. It is important to note that higher levels of disorganisation increase the hypoechoic (darker) areas in US images and result in lower echogenicity values. This increase in disorganisation might explain the reduced echogenicity measurements in the standing position found for the same subjects in this study, (see Fig 5.1, inside the blue rectangles)

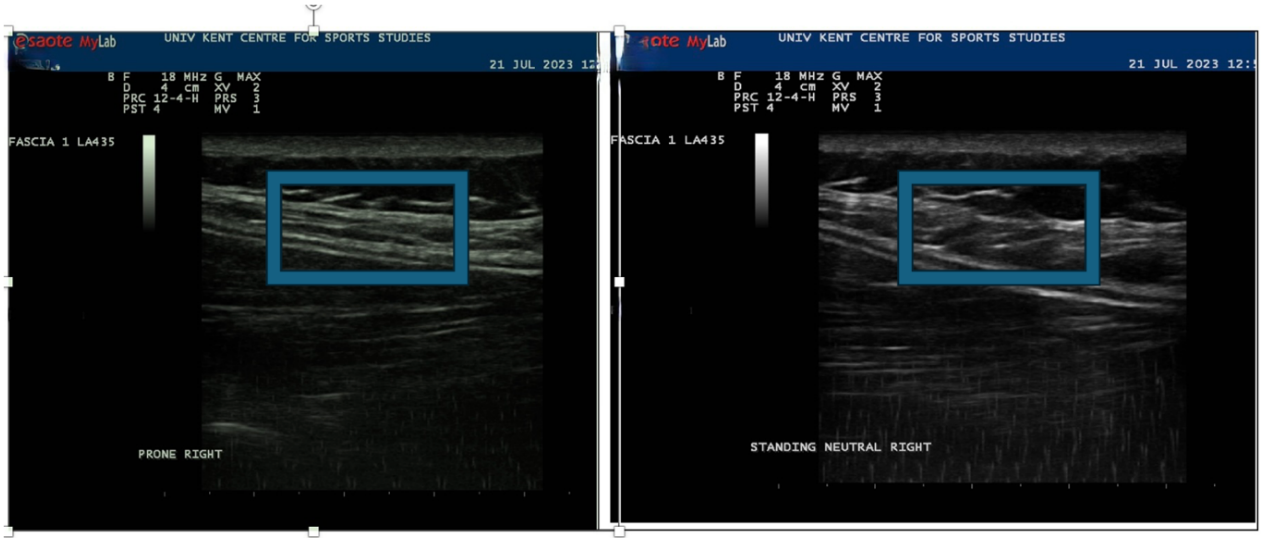



Figure 5.1: US images of the TLF of the same person.

Image A is in a prone position. Image B is in the standing position

The Left image (A) in Fig 5.1 shows the subject in a prone position. The dense fascial layers of the TLF (showing white on the US image) were categorised as organised using the Likert scale. The Right image (B) in Fig 5.1 shows the same subject in a standardised standing position; the dense fascial layers (showing white on the US image) are not as evenly spaced and have more dark tissue between them and were categorised as disorganised using the Likert scale.

The disruption to organisation and the decrease in echogenicity may be associated with the changes in TLF morphology when load is applied. In this thesis force transmission through the fascial system of the TLF has been suggested, as an explanation for the decreased echogenicity and decrease in visual organisation scores in the standing position. The fascial layers of the TLF are associated with muscles in the lower limb, spinal muscles and abdominals, all of which are under more tension in a standing position to provide stability (Tesh et al., 1987; Vleeming et al., 2014). Recently, a three-dimensional finite element spinal model (Bojairami et al., 2022b) suggested that 75% of the stability in the trunk was attributed to the TLF. The TLF is an important part of the tensional network of the body, its laminar structure relies upon loose connective tissue to maintain the independence of the dense fascial layers to glide past each other. In a study of sheer strain in the TLF and chronic LBP (Langevin *et al.*, 2011), a 20% decrease was found in sheer strain in subjects with LBP. The authors suggested this loss of sheer strain might be caused by adhesions, inflammation, and fibrosis of the fascial tissues. Current or historical causes for a restriction in ease of glide between dense layers of fascia in the TLF may cause a decrease in sheer strain (even where pain is not felt). When standing, tension caused by contractions of the stability muscles in the trunk and limbs will necessitate gliding of the dense fascial layers of the TLF as muscles contract and pull in different directions (Barker et al., 2004; Vleeming et al., 2014). If gliding is restricted due to adhesions, inflammation, or fibrosis

then adaptations and changes to the morphology of the TLF may occur when there is a change of position from prone to standing.

More research is required to understand whether there is a sheer strain difference in different body positions. Fede (2018) highlighted the necessity to develop technology to evaluate fascial gliding as a step towards identifying myofascial disorders.

Shear wave elastography (SWE) is used to quantify the stiffness of soft tissue structures such as the TLF. An ultrasound study of 20 healthy young male subjects used SWE to quantify the stiffness of the TLF in 7 static positions to explore the influence of the positions on the stiffness of the TLF (Chen *et al.*, 2021). Chen (2021) found that at the level of L3 TLF stiffness in a neutral standing position was 66.98% higher than in the prone position. Chen (2021) speculated that an increased static load upon the lumbar spine in standing was the reason for the increased TLF stiffness and that the TLF plays an important role in assisting the lumbar spine in load bearing positions.

Another possible explanation for the disruption to organisation and decrease in echogenicity in standing is the morphology of the fascial tissue itself. Connective tissues are known to exhibit unusual changes under mechanical loading. For example, tendons exhibit unusual auxetic properties when placed under strain. This results in a negative Poison's ratio, meaning that when stretched, tendons get fatter rather than thinner (Gatt *et al.*, 2015). It is currently unknown whether the TLF reacts to stretching with a similar auxetic response or why tendons expand when stretched. Gatt (2015) hypothesised that being auxetic gives tendons better functionality such as enhancing their damping

capability, which is the ability to absorb forces in actions such as jumping or running. Gatt (2015) also hypothesised that these properties could potentially be lost when the tendon is damaged. The literature refers to some of the dense fascia layers of the TLF being tendonous in nature (Vleeming and Stoeckart, 2007; Schuenke *et al.*, 2012; Barker *et al.*, 2014). More work is needed to conclude whether the TLF is auxetic.

The TLF has however been found to be anisotropic in an animal study (Nelson-Wong *et al.*, 2018) and a human study (Pirri *et al.*, 2023). Anisotropy is where tissue has different stretch values depending on the different directions the tissue is being stretched. This is best seen in tendons that stretch further along the length of the tendon compared with the width. Pirri (2023) reported that patients with LBP lost anisotropy making the TLF less adaptable and homogeneously thicker. Further research is needed to determine if the loss in anisotropy is reversible and its impact on sheer strain and echogenicity measurements.

These studies demonstrate more research is required to help us understand how the TLF behaves under different loads in different body positions.

## 5.9 Limitations

The cohort size in this study, constrained by the time limits of a Master's thesis, was smaller and more varied in age compared to the TLF ultrasound literature. In line with previous studies, subjects were asked to self-report chronic LBP in the last 12 months, however, this resulted in participants who were pain-free but with a history of LBP (beyond 12 months ago) being included in the NLBP

group. A recent study only included subjects who had never experienced LBP in the NLBP group (Gumruk Aslan et al., 2023). Historic instances of LBP in the control group could potentially have an enduring effect on the morphology of the lumbar fasciae, resulting in a thicker TLF, despite a 12-month absence of pain. Connective tissue remodels slowly over time in response to repetitive stresses, movement patterns, habits, etc (Langevin and Sherman, 2007). Inflammation as well as the influence of nociceptor activation may also cause remodelling (Tamartash et al., 2022). Future studies could address this question by including a longitudinal study to investigate whether disorganised TLF can become organised with a change in repetitive stress, movement patterns, habits, etc. Future studies looking at 3 groups, current chronic LBP, historic chronic LBP, and a control group who have never experienced chronic LBP could also be considered.

## 5.10 Conclusions and Clinical significance of this Study.

This study builds upon previous research by comparing ultrasound images of the TLF in prone and standing, and by visually inspecting the organisation and disorganisation of TLF US images. Lower Back Pain is a global issue and is expected to further increase in the foreseeable future. Adopting validated protocols, the study in this thesis used US imaging to investigate changes in morphology in people with and without LBP. To our knowledge this is the first-time image acquisition in two positions has been reported upon. Increases in thickness and echogenicity of the TLF have both been associated with chronic

LBP in the prone position, but humans stand upright, so stability through the TLF is a high priority. The ultrasound images of the TLF of 26 subjects with and without LBP were compared, and a statistically significant reduction in echogenicity and organisation were found only in the standing position, this cohort included participants with and without LBP. Whether these differences are a result of the mechanics of force transmission, requires further investigations. Interestingly, the thickness of the TLF in the LBP group did not significantly differ from the NLBP group, which is in agreement with A-Polo. However, an increase in thickness of people with LBP is found in the wider literature.

The clinical significance of the findings in this study still requires further investigation. However, they hold promise that the standing position for US imaging may give additional information to clinicians. Further research is needed to evaluate the impact of force transmission on the structure and function of the TLF in people with and without LBP. Additional considerations, such as auxetic tendencies of the TLF show promise for future research. The results of this study may prompt further research into alternative methods for conducting ultrasound measurements to assist patients who have difficulty lying in the prone position.

Visual inspection of US images of the TLF to assess the organisation of the TLF is a promising methodological innovation and requires further studies.

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# Appendices

I Advert created to attract participants

## II Health questionnaire

Determinants of changes of lumbar fascia an ultrasound investigation: Health Questionnaire

Hi,
Thanks for your interest in our research project. It is conducted by the School of Sport and Exercise Sciences at the University of Kent and forms part of a study investigating lower back pain and the thoracolumbar fascia. We are interested in taking ultrasound images of people with and without lower back pain.This study consists of 1 visit of max 2 hours to our laboratory at the University of Kent. Your visit will be scheduled at a mutually convenient time. We will take ultrasound images of your lower back with you lying on a massage couch, and standing upright and slowly bending forward whilst being supported in a frame. Please see the Participant Information Sheet for more detailed information. This Microsoft Form includes the health questionnaires required before you visit our laboratory for your ultrasound imaging.

This study is conducted by Masters by Research student Tracey Mellor: tam46@kent.ac.uk Supervisor: Dr Kyra De Coninck, K.De-Coninck@kent.ac.uk

Your participation is voluntary and you may withdraw at any time without needing to provide a reason.
This study has been approved by the School of Sport and Exercise Sciences Research and Ethics Committee.
We do not anticipate any risks or disadvantages in completing this study, as ultrasound imaging is a pain-free, non- invasive and non-radiating imaging tool. You will be able see images of your lower back, should you wish. You can also opt in to receive a short summary of our findings.

**How we use your information:**

Completion of this questionnaire is anonymous. Your name, IP address and email address are not collected. Your responses will be code-named and stored securely and anonymously in a password protected file and will only be accessed by this study's research team. No one else will be able to see you responses or will know you have taken part in this questionnaire. We will permanently delete your personal information after 12 months.

The anonymised findings of this study may be used in academic journal articles or scientific conference presentations. Your name or personal details will not be used in any dissemination of our findings.

For further information on the University's Data Protection Policies and Procedures, see our website and our Data Protection Notice: https://research.kent.ac.uk/researchservices/wp-content/uploads/sites/51/2020/06/GDPR-Privacy-Notice-Research.pdf You may withdraw from the study at any time, without needing to provide a reason, by emailing the researcher: Tracey Mellor: tam46@kent.ac.uk or Supervisor and researcher Kyra De Coninck: K.De-Coninck@kent.ac.uk

If you have any questions about this study, you may contact Tracey or Kyra on the above email addresses.
If you would like to make a complaint about this study you may contact the Head of the School of Sport and Exercise Sciences, Prof Glen Davison: G.Davison@kent.ac.uk

Please complete all of the following questions, if you are eligible for this study you will receive a follow up email from the researcher to book you in for your ultrasound scans. Thank you.

* Required

## General Information

1

I have read the participant information sheet and signed the consent form to take part in this study.

*

yes / no

2

Please enter your unique participant code - found at top of invite email. If in doubt, please contact the researcher: Tracey Mellor, tam46@Kent.ac.uk *

Enter your answer

3

Date of birth: *

4

I identify as: *

Female
Male
Intersex Non-Binary Other
Prefer not to say Opt out

5

Are you or could you be pregnant? Are you breastfeeding, or have you given birth in the last year? If you answer yes to any of these questions, then unfortunately, you won't be able to take part in this study. Many thanks for your interest. *

Not applicable

Yes, I'm pregnant

No, I'm not pregnant

Maybe, I could be pregnant

I'm currently breastfeeding

I've given birth in the last 12 months

6

Are you currently receiving treatment for cancer? *

Yes

No

7

Have you been diagnosed with a specific hypermobility condition such as Marfan's or Ehler's Danloss Syndrome? *

Yes

No

8

Have you received any corticosteroid injections in your lower back, trunk or near your spine? *

Yes

No

9

Have you ever had a spinal fracture? *

Yes

No

10

Do you have Rheumatoid Arthritis's? *

Yes

No

11

Have you had any lower back pain in the last 12 months? *

Yes

No

12

Do you have a displaced or injured verterbral disc or vertebrae or spondilolysthesis? *

Yes

No

13

Have you had any spinal, abdominal, hip or knee surgery? *

Yes

No

14

Do you have any structural spinal conditions such as kyphosis or scoliosis? *

Yes

No

15

Do you have ankylosing spondilitis? This is a long-term condition where the spine and other areas of the body become inflamed. *

Yes

No

16

Do you have any nerve root compression or any other neurological condition? *

Yes

No

17

Do you use any asthma inhalers containing steroids? *

Yes

No

Maybe

18

Do you have any bleeding disorders? Or do you take any blood thinning medication? *

yes

no

19

Are you taking a hormone medication, for example contraceptive pill or HRT? *

Yes

No

20

If you answered yes to any of the above questions, please provide more information here:

Enter your answer

21

Do you have any other medical conditions not listed above? * Enter your answer

## Physical Activity Questionnaire

We are interested in finding out about your physical Activity.
This is a simple quick questionnaire used by many National Health Service G.P. practices in the UK and is N.I.C.E. ap- proved.
If you have a smart watch/phone or activity tracker you can refer to this as it gathers information on your physical activity or movement.

22

Please tell us the type and amount of physical activity involved in your work

I am not in employment (e.g. retired, retired for health reasons, unemployed, full-time carer etc) I spend most of my time at work sitting (such as in an office)

I spend most of my time at work standing or walking. However, my work does not require much intense physical effort (e.g. shop assistant, hairdresser, security guard, childminder etc)

My work involves definite physical effort including handling heavy objects and use of tools (e.g. plumber, electrician, carpenter, cleaner, hospital nurse, gardener, postal delivery workers etc.)

My work involves vigorous physical activity including handling very heavy objects (e.g.scaffolder, construction worker, refuse collector, etc.)

23

During the last week (7 days), how many hours did you spend on each of the following activities? Please answer whether you are in employment or not.
a) Physical exercise such as swimming, jogging, aerobics, football, tennis, gym workout etc.

None
some but less than 1 hour
1 hour but less than 3 hours

3 hours or more

24

During the last week (7 days), how many hours did you spend on each of the following activities? Please answer whether you are in employment or not.
b) Cycling, including cycling to work and during leisure time.

None

some but less than 1 hour

1 hour but less than 3 hours

3 hours or more

25

During the last week (7 days), how many hours did you spend on each of the following activities? Please answer whether you are in employment or not.
c) Walking, including walking to work, shopping, for pleasure etc.

None

some but less than 1 hour

1 hour but less than 3 hours

3 hours or more

26

During the last week (7 days), how many hours did you spend on each of the following activities? Please answer whether you are in employment or not.
d) Housework/Childcare

None

some but less than 1 hour

1 hour but less than 3 hours

3 hours or more

27

During the last week (7 days), how many hours did you spend on each of the following activities? Please answer whether you are in employment or not.
e) Gardening/DIY

None
some but less than 1 hour
1 hour but less than 3 hours

3 hours or more

28

How would you describe your usual walking pace?

Slow pace (i.e. less than 3 mph) Steady average pace
Brisk pace
Fast pace (i.e. over 4 mph)

29

Did you use a smart Watch/phone or activity tracker to help provide this information?

Yes / No

## Lower Back Pain Questions

Complete this section if you have experienced lower back pain in the previous 12 months. If you have not experienced lower back pain in the previous 12 months, please select NO, which will take you to the end of this questionnaire where you can submit your answers.

30

Have you experienced any back pain in the last 12 months? *

Yes

No

31

In the **past 4 weeks**, have you had pain in your lower back (in the area shown in the diagram)? Please do not report pain from feverish illness or menstruation) *

yes

no

32

If you answered yes, was this pain bad enough to limit your usual activities or daily routine for more than 1 day?

Yes

No

33

If you had lower back pain in the past 4 weeks, how long was it since you had a whole month without any lower back pain? Please tick only one box. *

Less than 3 months
3 months or more but less than 7 months

7 months or more but less than 3 years
3 years or more

34

Does your back pain recur? *

Yes

No

35

If you had lower back pain in the past 4 weeks, please indicate what was the usual intensity of your pain on a scale of 0 to 10, where 0 means no pain, and 10 means the worst pain imaginable

0 (no pain) 1
2
3

4
5
6
7
8
9
10 (worst pain imaginable)

36

The following questions will give a little more information about your back pain. Please pick one option that best applies to you today

I have no pain at the moment
my pain is very mild at the moment
The pain is moderate at the moment

The pain is fairly severe at the moment

The pain is very severe at the moment

The pain is the worst imaginable at the moment

37

This question relates to personal care, please choose option that relates to you today.

I can look after myself normally without causing extra pain.

I can look after myself normally but it causes extra pain

It is painful to look after myself and I am slow and careful

I need help every day in most aspects of self-care

I did not get dressed, I wash with difficulty and stay in bed

38

This question relates to lifting loads, please choose option that relates to you today.

I can lift heavy weights without extra pain

I can lift heavy weights but it gives me extra pain

Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently placed eg. on a table.

Pain prevents me from lifting heavy weights, but I can manage light to medium weights if they are conveniently placed

I can lift very light weights

I cannot lift or carry anything at all

39

This question relates to walking, please choose option that relates to you today

Pain does not prevent me walking any distance
Pain prevents me from walking more than 2 kilometres

Pain prevents me from walking more than 1 kilometre

Pain prevents me from walking more than 500 metres I can only walk using a stick or crutches
I am in bed most of the time

40

This question relates to sitting, please choose the option that relates to you today

I can sit in any chair as long as I like
I can only sit in my favourite chair as long as I like

Pain prevents me sitting more than an hour
pain prevents me sitting more than 30 minutes

pain prevents me sitting more than 10 minutes

pain prevents me sitting at all

41

The next question relates to standing, please choose the option that relates to you today

I can stand as long as I want without extra pain
I can stand as long as I want but it gives me extra pain

Pain prevents me from standing for more than i hour
Pain prevents me from standing for more than 30 minutes

Pain prevents me from standing more than 10 minutes Pain prevents me from standing at all

42

The next question relates to sleeping, please choose the option that relates to you today

My sleep is never disturbed by pain
My sleep is occasionally disturbed by pain

Because of pain I have less than 6 hours sleep

Because of pain I have less than 4 hours sleep

Because of pain I have less than 2 hours sleep Pain prevents me from sleeping at all

43

This question relates to your sex life, please choose the option that relates to you today

My sex life is normal and causes no extra pain

My sex life is normal but causes some extra pain my sex life is nearly normal but is very painful

My sex life is severely restricted by pain
My sex life is nearly absent because of pain
Pain prevents any sex life at all
I do not want to answer this question

44

This question relates to social life, please choose option that relates to you today

My social life is normal and gives me no extra pain
My social life is normal but increases the degree of pain
Pain has not significant effect on my social life apart from limiting more energetic interests eg. sport

Pain has restricted my social life to my home
I have no social life because of pain

45

This question relates to travelling. please choose the option that relates to you today.

I can travel anywhere without pain
I can travel anywhere but it gives me extra pain
Pain is bad but I manage journeys over 2 hours
Pain restricts me to journeys of less than 1 hour
Pain restricts me to short necessary journeys
Pain prevents me from travelling except to receive treatment

46

This question relates to your own feeling or intuitions about what is happening to your body. please choose the statements (you can choose more than 1 ) that you think relates to you.

I'm afraid that I might injury myself if I exercise.

If I were to try to overcome it, my pain would increase.

My body is telling me I have something dangerously wrong.

My pain would probably be relieved if I were to exercise.

People aren't taking my medical condition seriously enough.

My accident has put my body at risk for the rest of my life

Pain always means I have injured my body.

Just because something aggravates my pain does not mean it is dangerous.

I am afraid that I might injure myself accidentally

Simply being careful that I do not make any unnecessary movements is the safest thing I can do to prevent my pain worsening.

I wouldn't have this much pain if there weren't something potentially dangerous going on in my body.

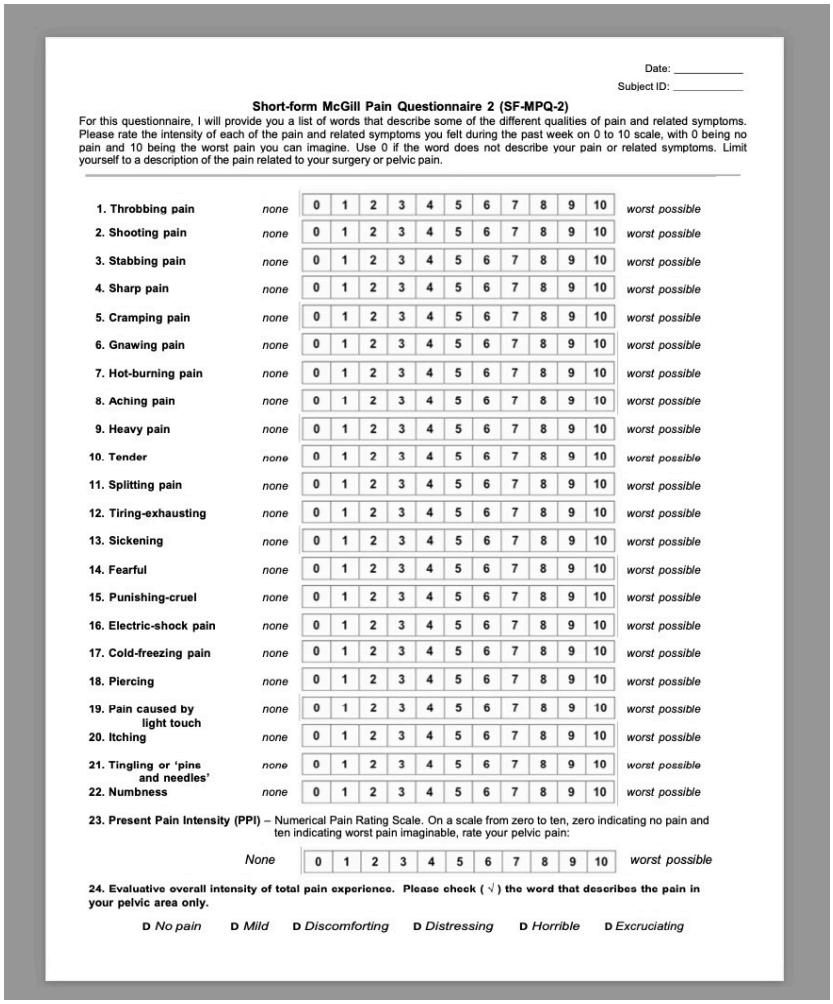
Although my condition is painful, I would be better off if I were physically active.
Pain lets me know when to stop exercising so that I dont injure.
It's really not safe for a person with a condition like mine to be physically active.

I can't do all the things normal people do because its too easy for me to get injured.

Many thanks for completing the form.

Please arrange a suitable time to visit the lab, you will find the link on the participants information form. The visit should take no more than 2 hours.

# III McGill short-form Pelvic pain questionnaire (SF-MPQ-2)



Date: _____

Subject ID: _____

**Short-form McGill Pain Questionnaire 2 (SF-MPQ-2)**

For this questionnaire, I will provide you a list of words that describe some of the different qualities of pain and related symptoms. Please rate the intensity of each of the pain and related symptoms you felt during the past week on 0 to 10 scale, with 0 being no pain and 10 being the worst pain you can imagine. Use 0 if the word does not describe your pain or related symptoms. Limit yourself to a description of the pain related to your surgery or pelvic pain.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1. Throbbing pain** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **2. Shooting pain** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **3. Stabbing pain** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **4. Sharp pain** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **5. Cramping pain** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **6. Gnawing pain** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **7. Hot-burning pain** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **8. Aching pain** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **9. Heavy pain** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **10. Tender** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **11. Splitting pain** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **12. Tiring-exhausting** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **13. Sickening** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **14. Fearful** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **15. Punishing-cruel** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **16. Electric-shock pain** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **17. Cold-freezing pain** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **18. Piercing** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **19. Pain caused by light touch** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **20. Itching** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **21. Tingling or 'pins and needles'** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |
| **22. Numbness** | *none* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |

**23. Present Pain Intensity (PPI)** – Numerical Pain Rating Scale. On a scale from zero to ten, zero indicating no pain and ten indicating worst pain imaginable, rate your pelvic pain:

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *None* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *worst possible* |

**24. Evaluative overall intensity of total pain experience. Please check ( √ ) the word that describes the pain in your pelvic area only.**

D *No pain* D *Mild* D *Discomforting* D *Distressing* D *Horrible* D *Excruciating*

IV Protocol checklist completed by the investigator on the day of data collection.

Protocol check list
Volunteer code PTM_____Date:____/____/2023
Researcher:_____

| Task | completed | measurement |
|---|---|---|
| Consent form completed, counter signed, returned | | |
| New pen, code on packet | | |
| Input code into US ready for recording PTMxxx | | |
| Weight Kg | | |
| Height cm | | |
| Hip measurement (cm) | | |
| Waist measurement (cm) | | |
| Complete McGil questionnaire if required. | | |
| Date of Birth | | |
| Dyno settings, 0 to -20 Input PTMxxx | | |
| Prone Ultrasound image | | |

| | | |
|---|---|---|
| Left | | |
| Prone ultrasound image Right | | |
| Standing ultrasound image left | | |
| Standing Ultrasound image Right | | |
| Wipe down couch, trunk module, probes. | | |
| Thank volunteer | | |

## V All numerical data collected

Participant Data: Demographics

| Participant | AGE: | Gender | activity classification | BMI % | BMI category |
|---|---|---|---|---|---|
| 1 | 24 | 2 | 3 | 26.43 | 3 |
| 2 | 58 | 2 | 4 | 45.36 | 4 |
| 3 | 49 | 1 | 4 | 28.08 | 3 |
| 4 | 63 | 2 | 4 | 23.73 | 2 |
| 5 | 65 | 1 | 2 | 30.1 | 4 |
| 6 | 63 | 2 | 3 | 23.46 | 2 |
| 7 | 59 | 1 | 4 | 25.59 | 3 |
| 8 | 73 | 2 | 3 | 24.59 | 2 |
| 9 | 69 | 1 | 4 | 22.09 | 2 |
| 10 | 78 | 2 | 3 | 24.39 | 2 |
| 11 | 84 | 2 | 2 | 24.84 | 2 |
| 12 | 76 | 2 | 4 | 24.54 | 2 |
| 13 | 61 | 2 | 4 | 23.44 | 2 |
| 14 | 63 | 1 | 2 | 31.35 | 4 |
| 15 | 24 | 2 | 3 | 30.04 | 4 |
| 16 | 63 | 2 | 4 | 22.73 | 2 |
| 17 | 23 | 1 | 3 | 21.45 | 2 |
| 18 | 33 | 2 | 3 | 29.94 | 3 |
| 19 | 45 | 1 | 4 | 24.11 | 2 |
| 20 | 32 | 1 | 4 | 32.87 | 4 |
| 21 | 26 | 2 | 4 | 44.37 | 4 |
| 22 | 33 | 2 | 2 | 43.48 | 4 |
| 23 | 47 | 2 | 4 | 46.17 | 4 |
| 24 | 61 | 2 | 4 | 24.28 | 2 |
| 25 | 59 | 1 | 3 | 21.79 | 4 |
| 26 | 32 | 1 | 3 | 26.17 | 3 |

Participant Data: LBP <12 months, Recent <4 months, Limits activity, Recurring, intensity out of 10.

| Participant | LBP | Recent | limiting | recurring | intensity |
|---|---|---|---|---|---|
| 1 | 2 | 2 | 0 | 0 | 0 |
| 2 | 2 | 2 | 0 | 0 | 0 |
| 3 | 1 | 1 | 2 | 5 | 2 |
| 4 | 2 | 2 | 0 | 0 | 0 |
| 5 | 1 | 1 | 2 | 4 | 3 |
| 6 | 2 | 2 | 0 | 0 | 0 |
| 7 | 1 | 1 | 2 | 1 | 3 |
| 8 | 2 | 2 | 0 | 0 | 0 |
| 9 | 2 | 2 | 0 | 0 | 0 |
| 10 | 1 | 1 | 2 | 3 | 2 |
| 11 | 2 | 2 | 0 | 0 | 0 |
| 12 | 2 | 2 | 0 | 0 | 0 |
| 13 | 2 | 2 | 0 | 0 | 0 |
| 14 | 1 | 1 | 2 | 1 | 4 |
| 15 | 1 | 2 | 2 | 5 | 1 |
| 16 | 2 | 2 | 0 | 0 | 0 |
| 17 | 2 | 2 | 0 | 0 | 0 |
| 18 | 1 | 1 | 1 | 5 | 6 |
| 19 | 1 | 1 | 2 | 3 | 3 |
| 20 | 2 | 2 | 0 | 0 | 0 |
| 21 | 2 | 2 | 0 | 0 | 0 |
| 22 | 1 | 1 | 1 | 4 | 8 |
| 23 | 1 | 1 | 1 | 1 | 4 |
| 24 | 1 | 1 | 2 | 4 | 5 |
| 25 | 1 | 1 | 2 | 5 | 2 |
| 26 | 1 | 2 | 0 | 5 | 0 |

Participant Data: Oswestry Disability %, Oswestry Disability score, McGill word count

| Participant | Oswestry % | Oswestry category | Tampa Scale | McGill number of words |
|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 |
| 3 | 4 | 1 | 1 | 6 |
| 4 | 0 | 0 | 0 | 0 |
| 5 | 24 | 2 | 1 | 8 |
| 6 | 0 | 0 | 0 | 0 |
| 7 | 14 | 1 | 2 | 6 |
| 8 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 |
| 10 | 9 | 1 | 0 | 1 |
| 11 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 |
| 14 | 12 | 1 | 1 | 17 |
| 15 | 0 | 1 | 4 | 7 |
| 16 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 |
| 18 | 2 | 1 | 1 | 9 |
| 19 | 8 | 1 | 4 | 9 |
| 20 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 |
| 22 | 58 | 3 | 4 | 17 |
| 23 | 20 | 1 | 2 | 22 |
| 24 | 18 | 1 | 4 | 1 |
| 25 | 2 | 1 | 3 | 2 |
| 26 | 2 | 1 | 0 | 2 |

Participant Data, Averaged Prone and Standing Thickness (mm)

| Participant | PAT1: | PAT2: | PAT3: | SAT1: | SAT2: | SAT3: |
|---|---|---|---|---|---|---|
| 1 | 40 | 64 | 24 | 40.5 | 61.5 | 21 |
| 2 | 133 | 250 | 117 | 278 | 320 | 42 |
| 3 | 50 | 88 | 38 | 55 | 103 | 48 |
| 4 | 45.5 | 92.5 | 47 | 44 | 108 | 64 |
| 5 | 59.5 | 122.5 | 63 | 64.5 | 130.5 | 66 |
| 6 | 21 | 64.5 | 43.5 | 26.5 | 68.5 | 42 |
| 7 | 34.5 | 77.5 | 43 | 30.5 | 68.5 | 38 |
| 8 | 47 | 96 | 49 | 28 | 80 | 52 |
| 9 | 14 | 52.5 | 38.5 | 16.5 | 46 | 29.5 |
| 10 | 63 | 100.5 | 37.5 | 71.5 | 105 | 33.5 |
| 11 | 35 | 98.5 | 63.5 | 17 | 83.5 | 66.5 |
| 12 | 48 | 118.5 | 70.5 | 49.5 | 112 | 62.5 |
| 13 | 38 | 119.5 | 81.5 | 39 | 110 | 71 |
| 14 | 32 | 74 | 42 | 37 | 76.5 | 39.5 |
| 15 | 127 | 180.5 | 53.5 | 134 | 175 | 41 |
| 16 | 21.5 | 52.5 | 31 | 25.5 | 60.5 | 35 |
| 17 | 33 | 78.5 | 45.5 | 36.5 | 74.5 | 38 |
| 18 | 66 | 140.5 | 74.5 | 80 | 161 | 81 |
| 19 | 18 | 47.5 | 29.5 | 16.5 | 46 | 29.5 |
| 20 | 32 | 74 | 42 | 26.5 | 59 | 32.5 |
| 21 | 149 | 251.5 | 102.5 | 121.5 | 242 | 120.5 |
| 22 | 145.5 | 224 | 78.5 | 142.5 | 209 | 66.5 |
| 23 | 170 | 220.5 | 50.5 | 143.5 | 180.5 | 37 |
| 24 | 14 | 57 | 43 | 15.5 | 49.5 | 34 |
| 25 | 39 | 61 | 22 | 41.5 | 70.5 | 29 |
| 26 | 67.5 | 131 | 63.5 | 85.5 | 175 | 89.5 |

Participant Data: Averaged Echogenicity data expressed in Greyscale in prone and standing

| Participant | PAE1: | PAE2: | PAE3: | SAE1: | SAE2: | SAE3: |
|---|---|---|---|---|---|---|
| 1 | 18.078 | 4.997 | 39.667 | 14.128 | 5.752 | 30.060 |
| 2 | 16.424 | 5.941 | 28.304 | 8.635 | 4.077 | 38.167 |
| 3 | 16.348 | 5.686 | 30.773 | 19.179 | 8.538 | 32.099 |
| 4 | 39.035 | 22.927 | 57.275 | 37.949 | 27.203 | 47.543 |
| 5 | 45.059 | 26.241 | 63.798 | 44.411 | 23.681 | 66.100 |
| 6 | 55.069 | 32.471 | 65.429 | 59.437 | 35.101 | 75.701 |
| 7 | 39.732 | 21.937 | 55.747 | 45.513 | 31.513 | 57.441 |
| 8 | 35.895 | 20.385 | 51.343 | 31.352 | 19.970 | 38.122 |
| 9 | 71.863 | 50.665 | 80.459 | 55.869 | 39.752 | 65.388 |
| 10 | 25.768 | 8.060 | 55.252 | 25.572 | 13.901 | 51.120 |
| 11 | 26.178 | 19.340 | 32.081 | 41.342 | 34.926 | 43.140 |
| 12 | 29.449 | 10.745 | 41.330 | 31.283 | 13.188 | 45.205 |
| 13 | 48.652 | 28.892 | 58.647 | 47.407 | 26.755 | 58.960 |
| 14 | 50.205 | 25.950 | 69.196 | 50.540 | 29.913 | 70.540 |
| 15 | 16.064 | 6.527 | 39.071 | 17.727 | 9.759 | 44.532 |
| 16 | 53.779 | 27.361 | 73.515 | 60.708 | 41.234 | 75.110 |
| 17 | 47.215 | 23.771 | 64.479 | 27.057 | 12.034 | 42.341 |
| 18 | 29.152 | 9.968 | 47.419 | 18.843 | 3.844 | 34.264 |
| 19 | 55.032 | 42.345 | 62.164 | 57.315 | 40.342 | 63.464 |
| 20 | 30.512 | 8.974 | 47.247 | 35.524 | 18.216 | 50.743 |
| 21 | 30.924 | 18.438 | 49.135 | 14.147 | 4.665 | 23.689 |
| 22 | 22.711 | 8.530 | 47.310 | 14.575 | 6.356 | 32.611 |
| 23 | 32.016 | 18.087 | 79.838 | 30.507 | 14.533 | 92.443 |
| 24 | 68.401 | 46.577 | 82.391 | 55.967 | 43.269 | 63.239 |
| 25 | 41.298 | 17.934 | 83.152 | 27.253 | 11.002 | 53.461 |
| 26 | 49.504 | 28.027 | 73.241 | 37.475 | 22.526 | 51.908 |

Participant Data: Organisational data group and Likert scale

| Participant | prone Likert scale | Prone organisational group | Standing Likert scale | Standing organisational group |
|---|---|---|---|---|
| 1 | 2 | 4 | 5 | 3 |
| 2 | 8 | 1 | 8 | 1 |
| 3 | 6.5 | 2 | 6 | 2 |
| 4 | 6 | 2 | 6 | 2 |
| 5 | 5.5 | 3 | 6.5 | 2 |
| 6 | 4 | 3 | 4.5 | 3 |
| 7 | 5 | 3 | 6 | 2 |
| 8 | 4 | 3 | 5 | 3 |
| 9 | 5 | 3 | 4 | 3 |
| 10 | 5.5 | 3 | 6 | 2 |
| 11 | 6 | 2 | 6 | 2 |
| 12 | 4 | 3 | 5 | 3 |
| 13 | 5 | 3 | 6 | 2 |
| 14 | 2 | 4 | 3 | 4 |
| 15 | 9 | 1 | 7.5 | 2 |
| 16 | 4 | 3 | 5.5 | 3 |
| 17 | 5 | 3 | 2.5 | 4 |
| 18 | 7 | 2 | 6.5 | 2 |
| 19 | 5 | 3 | 5 | 3 |
| 20 | 5 | 3 | 5 | 3 |
| 21 | 9 | 1 | 9.5 | 1 |
| 22 | 9 | 1 | 9 | 1 |
| 23 | 5.5 | 3 | 4 | 3 |
| 24 | 4 | 3 | 5.5 | 3 |
| 25 | 7.5 | 2 | 3 | 1 |
| 26 | 7 | 2 | 10 | 1 |

## V.i Codes for each measurement for Table in Appendix V

| Code attributed to each measurement | Type of measurement | Position /condition | Zone |
|---|---|---|---|
| PAT 1 | Average Thickness (mm) | prone | subcutaneous Zone |
| PAT 2 | Average Thickness (mm) | Prone | Combined Zone |
| PAT 3 | Average Thickness (mm) | Prone | Perimuscular Zone |
| PAE 1 | Average Echogenicity (Greyscale) | Prone | Combined Zone |
| PAE 2 | Average Echogenicity (Greyscale) | Prone | Subcutaneous Zone |
| PAE 3 | Average Echogenicity (Greyscale) | Prone | Perimuscular Zone |
| SAT 1 | Average Thickness (mm) | Standing | Subcutaneous Zone |
| SAT 2 | Average Thickness (mm) | Standing | Combined Zone |
| SAT 3 | Average Thickness (mm) | Standing | Perimuscular Zone |
| SAE 1 | Average Echogenicity (Greyscale) | Standing | Combined Zone |
| SAE 2 | Average Echogenicity (Greyscale) | Standing | Subcutaneous Zone |
| SAE 3 | Average Echogenicity (Greyscale) | Standing | Perimuscular Zone |
| | | | |

| | | | |
|---|---|---|---|
| Age | Age of participant | | |
| Gen | Male (1)or Female (2) | | |
| Act | Activity Level<br>1(sedentary)-4(active) | | |
| Body Mass | Body Mass in KG | | |
| BMI % | Body Mass Index as a percentage | | |
| BMI | Category assigned based upon BMI.<br>1 (underweight)<br>2 (healthy)<br>3 (overweight)<br>4 (obese) | | |
| Waist/hip | Hip (cm) to Waist (cm) ratio | | |
| Waist/ catagory | Category<br>1 ( average), 2(above average) | | |
| Back | 1 (LBP in last 12 months)<br>2 (NLBP) | | |
| Recent | LBP in last 4 weeks | | |
| Recurring | Recurring pain<br>5 (> 3months)<br>4 (3-7 months)<br>3 (7-12 months)<br>2 (1-3 years )<br>1 (> 3 years) | | |
| intencity | Intensity levels 0(low), to 10 (severe) | | |
| Oswestry | Oswestry Disability | | |

| | | | |
|---|---|---|---|
| | scores | | |
| Oswestry scores | Oswestry disability score category<br>1 (minimal)<br>2 (moderate)<br>3 (severe) | | |
| Tampa | Tampa scale scores<br>0 (NLBP)<br>1 (LBP- no fear)<br>2 (LBP- minimal fear)<br>3 (LBP moderate fear)<br>4 (LBP- extreme fear) | | |
| McGi | McGill short form scores. Number of words | | |

## VI Additional Tables

Table 7.1: Comparison of median values of TLF Thickness between Prone and Standing positions

| **Thickness (mm)** | **Prone** | **Standing** | **P value** |
|---|---|---|---|
| Perimuscular zone n=26 | 2.71 | 2.43 | |
| Sign test results for increase in thickness 1 tie | 10 | 15 | 0.42 |
| Combined Zone n=26 | 5.52 | 5.46 | |
| Sign test result for increase in thickness | 15 | 11 | 0.56 |

Table 7.2: Comparison of Thickness of TLF and Combined zone between LBP and NLBP groups in prone and standing- Independent sample T-Test results.

| **Average Thickness (mm)** | **Mean difference ± SE** | **t value** | **p value** |
|---|---|---|---|
| Prone Perimuscular zone | 0.39 ±6.94 | t(22) = 0.56 | p>0.05 |
| Prone Combined Zone (Welsh t-test) | 2.02 ± 1.06 | t(16.28) = 1.9 | p>0.05 |
| Standing Perimuscular Zone | 1.93 ± 7.75 | t(22) = 0.25 | p>0.05 |
| Standing Combined Zone (Welsh t-test) | 2.39 ± 0.99 | t(16.42) = 2.4 | p=0.028 |

LBP n=13, NLBP n=11

Table 7.3: Comparison of Echogenicity measurements for LBP and NLBP groups in prone and standing. T-tests.

| **Average Echogenicity (Greyscale)** | **Mean difference ± SE** | **t-value** | **p value** |
|---|---|---|---|
| Prone Perimuscular zone | 5.13±6.52 | t(22) = 0.78 | p>0.05 |
| Prone Combined Zone | 3.61 ± 2.4 | t(22) = 0.57 | p>0.05 |
| Standing Perimuscular Zone | 5.96 ± 6.11 | t(22) = 0.42 | p>0.05 |
| Standing Combined Zone | 3.26 ± 1.67 | t(22) = 1.95 | p=0.063 |

No significant difference was found