Does a manual treatment on the plantar fascia significantly influence the range of motion of the hip flexion verified by a straight leg raise on healthy subjects compared to the control?

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Karin Mügge

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Abstract

Introduction: The fascia is a continuous sheath of soft tissue that presents itself as a three-dimensional matrix connecting the body front to back and head to toe. The fascia structure provides biomechanical functions whereby the body-wide fascial network plays an important role for the interconnected tensional network and force transmission extending from the cell matrix to the myo-tendinous and myo-fascial systems.

Objective: The intention of this paper is to investigate the question of whether a manual treatment on the plantar fascia significantly influences the range of motion of the hip flexion verified by a straight leg raise on healthy subjects compared to the control on the same subjects.

Method: From the outset the study made a selection of 22 randomly allocated subjects. A dice was rolled to determine what side, either the right or left plantar fascia, was to receive treatment. When the treatment side was selected by this method, the other side was chosen for the control condition. The control condition was performed with the Medical Ultrasound apparatus tuned on, whereas, in order to measure the placebo, the cable leading to the ultra sound head was detached. The straight leg raise and the measurements were performed before and after the treatment and the control condition and a comparison were made.

Results: Results clearly showed a significant difference between the pre-and post-measurements for the group receiving manual treatment on the plantar fascia. The control condition on the other hand, demonstrated no differences.

Conclusion: A manual treatment on the plantar fascia significantly influences the range of motion of hip flexion verified by a Straight Leg Raise (SLR) on healthy subjects compared to the control condition.

Table of Content

1. Introduction ... 1
2. Basics of the anatomy of the fascia ... 4
2.1. The perception and philosophy of Andrew T. Still on the fascia ... 4
2.2. What is fascia? ... 5
2.3. The superficial fascia ... 6
2.4. Deep fascia of the limb ... 6
2.5. Fascial expansions of the lower limb: The Iliotibial tract (It) ... 8
2.6. Further fascial expansion of the lower limb ... 9
2.7. Achilles tendon and heel pad ... 10
2.8. Plantar fascia ... 10
2.9. Heel fat pad ... 11
3. Definitions of the term associated with “transmission” ... 13
4. Biomechanics and response on pathological alteration of the fascia ... 15
5. Further studies on tensile transmission ... 17
6. Osteopathy and other comparative concepts ... 19
6.1. Osteopathy ... 19
6.2. Fascial Manipulation ... 19
6.3. Tom Myers – Anatomy Trains ... 23
7. Approach of the methodology ... 26
7.1. Study design ... 26
7.2. Hypothesis ... 28
7.3. Procedure ... 31
7.3.1. Measurement procedure ... 32
7.3.2. Treatment procedure ... 34
7.3.3. Procedure for the control ... 35
7.3.4. Passive Straight Leg Raise test: Discussion and methodical improvements ... 36
7.4. Material and method ... 38
7.5. Selection of the sample ... 39
7.6. Description of the examined parameter ... 41
7.7. Statistical analyses ... 42
8. Results ... 43
8.1. Description of the sample ... 43
8.2. Overall effect of the treatment vs. control condition ... 45

8.3. **Effect of the selected side** 46
8.4. **Effects of sociodemographic variables** 48
8.4.1. Level of sport activity 48
8.4.2. Age 49
8.4.3. Body Mass Index (BMI) 51
8.4.4. Gender 52
9. **Discussion of results** 54
9.1. **Interpretation of the main findings** 54
9.2. **Analyses of further results** 55
9.2.1. Effects on sides of treatment and control of the limb 57
9.2.2. Age difference 57
9.2.3. Level of athletic activity 58
9.2.4. Body Mass Index (BMI) 58
9.2.5. Gender 58
9.3. **Limitations to the methodological approach** 59
9.4. **Clinical implications and outlook** 60
10. **Conclusion** 63
10.1. **Relevance** 63
10.2. **Further investigation** 65
10.3. **Tensegrity** 66
References 68
Appendix 81
List of Figures 81
List of Tables 82
List of Diagrams 83

1. Introduction

“A knowledge of the universal extent of the fascia is imperative, and is one of the greatest aids to the person who seeks the cause of disease”. (Still, 1902, p.102-103).

These progressive and pertinent words of A.T. Still, founder of osteopathic medicine, stating the essence and the fundamental role of the fascia in the body have proved to be valid over a century. Nevertheless, the study of fascia structure and its function has been largely neglected and overlooked for many years. Only in recent years, research and understanding of this topic have made substantial progress. The fascia structure provides biomechanical functions whereby the body-wide fascial network plays an important role for the interconnected tensional network and force transmission within the cell matrix extending to the myo-tendinous and myo-fascial system (Huijing, 2007; Huijing & Langevin, 1999). Wider perspectives, therefore, arise for further scientific and therapeutic research.

The fascia is a continuous sheath of soft tissue that presents itself as a three-dimensional matrix and connects the body front to back and head to toe. It interpenetrates and surrounds the muscles, bones, organs, nerve fibers and joint capsules and extends to all fibrous connective tissues including the muscular septi, retinacula, ligaments, tendons, aponeuroses, retinaculae, epineurium, dura mater, perimysium, epimysium, endomysium, epineurium, the meninges periosteum, mediastinum, mesentery and the annulus pulposus of the disc (Schleip, Jäger & Klinger, 2012).

Recent research proposes that the body-wide fascial network plays a more vital role in the musculoskeletal system than once commonly assumed.

The primary function of the fascial system is for support and lubrication. According to the latest findings, however, it also has major influence on proprioception (Langevin, 2006; Stecco et al., 2007b), nociception (Stecco et al., 2007b; Yahia, Rhalmi, Newman & Isler, 1992) and on myofascial force transmission (Huijing, 2002).

Tensional force of the function between the tendons and ligaments was never disputed. Now studies reveal that the perimysium and epimysium and the connected deep fascia appear to have a fundamental influence on the transmission of myofascial force. This implies that the muscles should not be seen as an isolated structure but as a complex, interwoven construction with the connective tissue (Turrina, Maritinez-Gonzalez & Stecco, 2013).

A number of authors have discussed their clinical observations (Myers, 2004; Stecco et al., 2006; Stecco et al., 2007a) and numerous studies have explored the epimuscular connective tissue and revealed that there is a functional force transmission of the myofascial system, which has an involvement in the communication in the body as a whole (Huijing, 2012; Huijing & Jasper 2005; Turrina, Maritinez-Gonzalez & Stecco, 2013).

Tom Myers (2004) describes common pathways of myofascial force transmission and its functional relevance for posture and motion. He describes inter alia the superficial back line and the deep front line, which suggests a strong relation between the feet and the lower back.

Luigi Stecco and colleagues (2006, 2007a, 2007b) postulate that the fascia is not just a uniform membrane, but constitutes a specific, structural make-up with a relationship to the underlying muscles. Numerous studies with dissections and histological analyses have confirmed fascia`s role in the tensional force distribution within the fascial system.

The intention of this paper is to demonstrate in a clinical experimental behaviour measurement of how the load transmission of the fascia is distributed to the extended structural segments and the inter-action between the plantar fascia and the hip/pelvic region. Thus, the key issue in this research is investigating the question of whether a manual treatment on the plantar fascia significantly influences the range of motion of the hip flexion verified by a straight leg raise on healthy subjects compared to the control condition on the same subjects.

According to the aim of the study, an experimental design study was carried out to examine the effect of the range of motion of hip flexion performed by a Straight Leg Raise (SLR) by means of a manual treatment on the plantar fascia. From the outset the study made a selection of 22 randomly allocated subjects of which 11 were women and 11 were men. A dice was rolled to determine what side, either the right or the left plantar fascia was to receive treatment. When the treatment side was selected by this method, the other side was chosen for the control condition. The control condition was performed with the Medical Ultrasound apparatus tuned on, nonetheless, in order to measure the placebo, the cable leading to the ultra sound head was detached without the subject's awareness resulting in a non-interventional effect. The straight leg raise and the measurements were performed before and after the treatment and the control condition and the results were compared with each other. The measurement was taken by the iPhone with the help of the application of a measurement tool, "G-Pro", which measures range of motion in the hip joint.

The structure of the connective tissue in the musculoskeletal system is an essential but often overlooked feature in the functional parameter. Knowledge of the existence of the connective signaling network, and its biomechanical effect, can offer new insights and a deeper understanding of treatments directed at fascia and its myofascial system. Fascial extension from the foot to the hip/pelvis helps to understand its fascial integrity and its ability for transmission of the force.

The paper reviews the unifying role of the fascial system as a bodily tensegrity and how the fasciae fibrous membranes are continuous with each other throughout the limbs. Chapter 2 gives an overview about the anatomy of the fascia, beginning with A.T. Still´s perception of the fascia and leading to a detailed description of the superficial fascia and deep fascia and its expressing contractile elements. Furthermore, the fascial expansions of the lower limb with detailed prescriptions of the plantar fascia will be considered. The paper discusses the definition (chapter 3) and biomechanical property (chapter 4) of the myofascial system with the purpose of understanding the fascial force loading and tension transmission. Additionally, recent research concerning the load transmission of fascial integrity is compared in chapter 5, and the latest manual treatments (chapter 6) are reviewed alongside related research concerning the load transmission of the fascial integrity. A descriptive review of the methodology (chapter 7) with the summary of the results (chapter 8) of this study is discussed and analyzed. Further discussions on the comparison of the results of this study compared to other studies, as well as the limitations of the overall study are reviewed in chapter 9.

This study attempts to stress and reiterate the need to see the body not in several separate parts, but in its entirety, with the fascia as a specialized connected entity. Thus, the fascial net system is to be understood as a systemic, integrated element in a holistic treatment approach, and gives valuable insights and explanations in the osteopathic field.

2. Basics of the anatomy of the fascia

2.1. The perception and philosophy of Andrew T. Still on the fascia

Andrew Taylor Still (1828-1917), founder of osteopathy and osteopathic medicine discovered the significance of living anatomy on health and disease. He realized that optimal health is possible only when all tissue and cells of the body function together, and he understood that the human body is composed of many parts, which all intimately form a functional whole. Over a hundred years ago, A.T. Still had already understood the essentiality and the unity of the function of the fascial system. One could here discern the link between the philosophy and concept described by A.T. Still, confirmed by the most recent research.

A.T. Still's (1899) statement that fascia “gives all muscles help to glide over and around all adjacent muscles and ligaments” (p. 164) warrants a closer look.

He describes fascia as covering and surrounding every muscle and organ, thereby assisting in the gliding between all structural layers. Studies show that the fascia binds muscles in bundles and ties them to connective tissue, thereby enabling muscular fibres to insert onto the connective tissue. This creates a complex network of connective tissue able to glide and move over the various layers of structures within the body. The sliding of the muscles occurs in the loose connective tissue located between the deep fascia and underlying muscles (Stecco, 2009).

A.T. Still (1899) furthermore specifies: “Fascia ...sheathes, permeates, divides and sub-divides every portion of all animal bodies; surrounding and penetrating every muscle and all its fibres – artery, and every fibre” (p. 163).

Fascia has its vital functions in separating and organizing muscle groups into compartments. The epimysium provides a continuous network of connective tissue, which permits a mechanical, continuous linkage to form perimysium and endomysium. This arrangement enables a myofascial force transmission between the bordering muscles and even between antagonistic muscles (Huijing, 2007; Huijing & Langevin, 1999).

One of the basic principles of the osteopathic concept, i.e. “Structure and function are reciprocally interrelated” (Chila, 2011, p.3) refers to the interaction of the structure and the function, and the simultaneous interdependence of each. This entails that a defect in one is reflected in the other. Depending on the degree of tensional and straining requirements the tensional network adapts its fiber arrangement, length, and density accordingly. Abnormal structure or function in one part of the body exerts negative influences on the other parts and therefore on the body as a whole (Stecco, 2009).

These quotes of A.T. Still, are just a few examples showing the essence and the fundamental role of the fascia in the body, still true today, and valid since over a century. Years of studies and experiments undertaken by Still are now verified and recognized by recent research.

2.2. What is fascia?

Literature provides a wide diversity of structures regarding the question of what tissue should be included in the term “fascia”. New terms or conventions used at the latest international Fascia Research Congress in 2012 defines fascia as “Fibrous collagenous tissues which are part of a body wide tensional force transmission system” (Schleip, Jäger & Klinger, 2012, p. 502).

Further, Huijing & Langevin (2009) provide a more precise description of the components of the fascia, including:

> “dense connective tissue, areolar connective tissue, superficial fascia, deep fascia, inter muscular septa, interosseal membrane, periost, neurovascular tract, epimysium, intra and extramuscular aponeurosis, perimysium, endomysium.” (p.3)

Moreover, Huijing & Langevin (2009) recommend that the term “fascia” should not include tendons and ligaments since “fascia” in that case would embrace a wide concept with the risk that the connective tissue and associate “fascia” be viewed as connective tissue in general. Nevertheless they recognise the tendons and ligaments to merge within the fascia, especially near their attachment sites where they become more of a fascial structure.

Leading fascia researchers (Stecco & Stecco, 2012) have observed that fasciae fibrous membranes are continuous with each other throughout the limbs where tendons, ligaments and fasciae blend with periosteum, both tendons and fasciae can function as ligaments and tendons can become fascial expansions.

Following this line of thought, this chapter examines the unifying role of connective tissue in the limbs. First, the description of the superficial fascia and deep fascia and its expressing contractile elements is clarified. Further, the fascial expansions of the lower limb with detailed prescriptions of the plantar fascia is explained.

Three fundamental structures form the fascia of the lower limbs: the superficial fascia, the deep fascia and the epimysium.

2.3. The superficial fascia

The superficial fascia, made of dense areolar interwoven connective tissue, is found throughout the body subjacent to the skin layer. It is formed of intertwined collagen fibers, mixed with fat lobes and some elastic fibres (Kawamata, Ozawa, Hashimoto, Kurose & Shinohara, 2003). It connects the skin to the underlying dense, deep fascia and provides a protective cushion for the musculoskeletal framework (Kawamata et al., 2003). The thickness of the superficial fascia is greater in the trunk than in the extremities. On the eminences or frames of the bones and on some ligament folds, the superficial fascia follows to the deeper fascia where an interaction exists between the layers (Stecco et al., 2011a).

The layers of collagen enable mobility for the skin to slide and stretch over the underlying structures, particularly in high mobility parts, i.e. mobile joints and the dorsum of the hand. This mobility, which enables the accommodation of stretching, also is of essence for the blood vessels and the nerves, which run tortuous to adapt themselves in the altered position of the skin elative to the deeper structures (Kawamata et al., 2003). In some regions where movements should be restricted, the underlying tissues are bound to the skin as in the plantar aspect of the feet and hands.

2.4. Deep fascia of the limb

Through its complex network the deep fascia, a fibrous membranous layer, separates, bundles and wraps all muscles together with all the nerves and vessels. Thereby, the deep fascia encloses these structures and forms a firm layer entity (Benjamin, 2009).

The fascial system is rich in proprioceptors. Particularly, the Ruffini’s and Pacini’s corpuscles are frequently seen located at the intersections, either between the fascia and the articulation, or between the fascia and the muscles. Thus the fascia is considered as a sense organ of the human mechanics (Stecco, 2007b) and constitutes a vital apparatus that enables the individual structures to communicate as well as being able to act independently.

The deep fascia consists of layers of connective, highly organized, dense and tougher tissues with specialized features designated to a particular region. These layers can be distinguished from the underlying muscles and the overlying superficial fascia and form connections by some myofascial expansions, primarily in the joint areas (Martini, Timmons & Tallitsch, 2004; Stecco et al., 2008a).

Fibroblast is predominantly present, although in response to mechanical loading a collection of actin stress fibres within these cells have led some authors to regard these cells as myofibroblasts. Hence, fascia is able to contract in a smooth muscle-like manner, thereby influencing myofascial mechanics (Schleip, Klingler & Lehmann-Horn, 2005).

Myofibroblast, with the accumulation of actin stress fibres, displays contractile behaviour. This process is physiological for wound closures (Findley & Schleip, 2007; Gabbiani, 2007), and in normal conditions the myofibroblast cells diminish once the wound closure occurs (Desmouliere, Badid, Bochaton-Piallat & Gabbiani, 1997).

Nevertheless, in a pathological situation myofibroblast, with their smooth muscle cell features, remain and their long-term attendance can be related to a series of fibrotic contractive diseases, i.e. Dupuytren contracture (Gabbiani, 2003), frozen shoulder, plantar fibromatosis (Hinz & Gabbiani, 2007), scars and other fascial diseases (Gabbiani, 2007) (Benjamin, 2009), probably causing an increase in tension in the fascial system.

A continuous gliding plane between the deep fascia and the muscles underneath is created by the surrounding muscle fascia called epimysium. A thin film of loose, connective tissue and hyaluronic acid, a gel-like substance, is found between the deep fascia and the epimysium to facilitate gliding. Under the deep fascia the muscles are free to slide because of their epimysium (McCombe, Brown, Slavin & Morrison, 2001).

Rippled, parallel collagen fibres form the deep fascia and a few elastic fibres are arranged in layers with each adjacent layer of a different orientation. Each layer is separated from the next by a thin layer (mean thickness: 44 μm) of loose, connective tissue which enables separation between the different layers, allowing gliding over the next layers. This multilayer organization of structures has a specific angle of 78° towards each other layer (Benetazzo et al., 2011), and enables the different layers of the fascia to exert a strong resistance to traction for multidirectional forces (Stecco et al., 2009a) (Natali, Pavan & Stecco, 2010).

Conclusively, the important role of the deep fascia is to surround muscles and play a vital role within the different muscles found in the limb as it forms a continuous sheath blending with ligaments, retinacula, tendons and the epimysium (Benjamin, 2009).

2.5. Fascial expansions of the lower limb: The Iliotibial tract (It)

Fascia lata is a deep fascia found on the lateral side of the thigh. The denser area of the fascia lata is called the iliotibial tract, which can serve as a tendon for both the tensor fascia latae and the gluteal muscle. Furthermore, the iliotibial band augments the fascia lata. Additional attachments of the iliotibial tract can be found on the lateral intermuscular septum of the thigh where the vastus laterals partly interject (Fairclough et al., 2006; Stecco & Stecco, 2012).

Understanding the anatomical attachments of the iliotibial tract suggests that movements of the leg will cause the lateral intermuscular septum of the thigh to stretch due to tension from the gluteus maximus muscle, in combination with the vastus lateral muscle located further below (Stecco & Stecco, 2012). These observations emphasize the close linkage between the fascial components of the gluteus maximum, iliotibial tract and intermuscular septum.
The iliotibial band finally extends to the Gerdy`s Tubercle of the tibia (Fairclough et al., 2006) and continues to the antero lateral portion of the crural fascia (Stecco & Stecco, 2012). The medial aspect of the crural fascia is also used as a further extension of the pes anserinus, the insertion area for the muscle group of sartorius, gracilis and semitendinousus (Stecco & Stecco, 2012) (see *figure 1* below).

The iliotibial tract spans from the hip, knee and lower leg where Vieira (2007) points out that the iliotibial tract is an essential anterior lateral knee stabilizer as it is providing major support for the stability of the knee (Vieira et al., 2007).

For understanding the transmission of the tension from the fascia’s hip and pelvic region to the knee it is of particular significance to recognise that gluteus maximus performs a major insertion into the fascia lata (Stecco et al., 2013). In fact “most of the fibers of the gluteus maximus muscle (on average 82% of its mass, in some individuals, 100%) insert on the fascia lata” (Huijing & Langevin, 200, p.4).

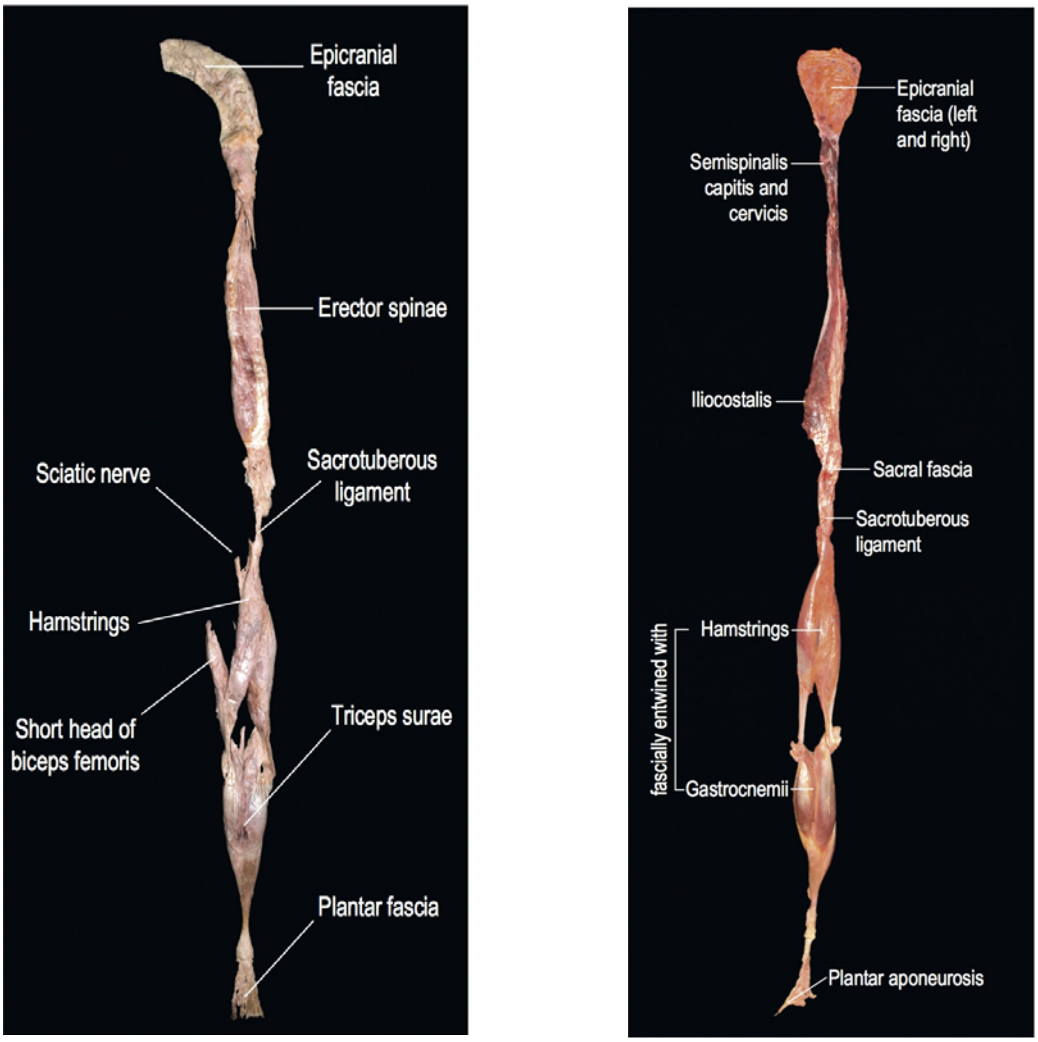

Figure 1: Cranial view from behind (left) and side (right). Fascial expansion from plantar fascia with the continuation of lower limb, sacrotuberous ligament, iliocostalis to the galea aponeurotica (with kind permission of Myers, 2004, n.p)

2.6. Further fascial expansion of the lower limb

Fascial expansion of the quadriceps muscle can be observed to extend over the patella, thereupon fusing onto the fascia lata. The distal tendon of the semimembranosus muscle is directed firstly, to the posterior joint capsule, thereby assisting to reconstruct the popliteal ligament and secondly, towards the popliteal muscle.

The upper part of the gastrocnemius directly attaches to the popliteal fascia, the muscle fibres of which can be attributed to tensing the fascia.

Moving caudally towards the ankle, the interjection of the extensor digitorum brevis and the abductor halluces muscles can be seen to stem from the medial side of the inferior extensor and flexor retinaculum. These strong connective tissues support the deep fascia of the foot (Stecco & Stecco, 2012).

2.7. Achilles tendon and heel pad

The fascial extension continues to extend to the Achilles tendon where it joins the calcaneus and proceeds to and terminates at the plantar fascia and on the fibrous septa of the heel pad (Stecco & Stecco, 2012).

Collective studies (Huijing & Langevin, 2009; Stecco & Stecco, 2012; Vieira, 2007) illustrate the unifying role of the connective tissue within the limb. A sequential continuity can be observed to emerge the myofascial system, namely: the gluteal muscle and its attachment to the iliotibial tract; extending with its insertion on the lateral intermuscular septum of the thigh; continuing with the crural fascia extending to the paratendon of the Achilles through the heel pad; finally extending to the plantar fascia. Thanks to new research on the interaction of the deep fascia of the diverse muscles throughout the limb, it becomes more apparent that load transmission can be assumed.

2.8. Plantar fascia

The plantar fascia, also known by the name of plantar aponeurosis, is a dense connective tissue that forms part of the deep fascia of the sole of the foot. It originates from the medial calcaneal tuberosity region and extends into digits which are divided into five bands, one of which inserts into each toe onto the proximal metatarsal heads. It thereby merges with the volar plates and attaches itself onto the skeleton (Bojsen-Moller & Flagstad, 1976).

Due to its curdled or congealed attachment to the distal part of the metacarpalphalangeas, the plantar fascia is able to work as a “windlass” as Hicks (1954) already noted. This means that during non-weight bearing situations dorsal flexion of the toes marks tension on the plantar fascia and leads to plantar flexion of the corresponding metatarsals. This in turn enables lifting of the medial longitudinal arch and the attainment of stability during weight bearing. During toe-off phase (in the weight bearing position) the fascia starts to tighten again and to elevate the arch which results in supination of the foot and external rotation of the leg due to the “predominantly” medial attachment of the fascia onto the calcaneus (Barthold, 2001).

Further structures to support the foot arch comes from the intrinsic and extrinsic flexor muscles of the foot. The long digital flexors, mostly tibialis posterior muscle (Kura, Luo, Kitaoka & An, 1997) and, not to be forgotten, the intrinsic muscles enable an increase of the arch height and reduction of the internal loading of the plantar fascia (Wearing et al., 2006). This demonstrates how the coupled calf muscles and intrinsic muscles of the foot generate fascial load on the longitudinal arch.

Scott Wearing (2012) argues that rather than viewing the plantar fascia solely as an arch raising structure it should be viewed it as a “dynamic coordinator of movement, effectively synchronizing digital dorsiflexion with supination of the foot and external rotation of the leg” (p. 254)

Benjamin reveals that the Achilles tendon not only attaches to the calcaneus, but also passes the heel and the fibrous septa of the heel fat pad and continues to the plantar aponeurosis (Benjamin, 2009).

The biomechanical relationship between the tensile force on the tendoachilles and plantar fascia is well depicted in the study of Carlson, Fleming & Hutton (2000). This study revealed that an application of tensile force (500N) to the Achilles tendon generated tensile strain onto the plantar fascia. Measurements were repeated at different angles of dorsal flexion of the first metatarsophalangeal joint and this demonstrated an increase of tension force in the plantar fascia proportional to an increase of angle of the metarsophalangeal joint.

Erdemir et al. (2004) concluded during stance phase of the gait that the plantar aponeurosis transmits large forces between the hind foot and forefoot. Thereby, the essential effect of the plantar fascia in transferring force between the Achilles tendon and the forefoot is demonstrated.

These studies reveal that an applied tensile force on either the Achilles tendon, or on the plantar fascia and the resulting tensile strain and force are reciprocated between/on those two structures, thereby emphasizing the close biomechanical relationship between the Achilles tendon and the plantar fascia.

2.9. Heel fat pad

The heel fat pad is situated inside the foot at the rear. Through its highly adipose-based structure the pad protects against the stress generated between the foot and the leg during the heel strike. A three-dimensional morphology in situ study examined the heel fat pad's anatomy, structural behaviour and its material properties (Campanelli et al., 2011). The average thickness of each coronal section of the heel fat pad was calculated for all subjects (excluding the side walls). The shape and structure, including the thickness of the heel pad, impact its functional capability (Miller-Young, Duncan & Baroud, 2002), thereby most likely influencing the biomechanics of the foot. A three-dimensional morphology in situ study examined the heel fat pad's anatomy, structural behaviour and material properties (Campanelli et al., 2011) and revealed that the average thickness of each coronal section (ACST) of the heel fat pad was calculated for all subjects (excluding the side walls). The heel fat pad was found to be thicker in males than in females and the CST values differ between males and females by about 1–3 mm.

The Achilles tendon insertion is situated between the calcaneus and the fat heel pad at the retro calcaneal surface. An observed loss of heel pad shock absorbency capability was observed by (Jorgensen, 1989) and appeared to have caused some cases of achillodynia. When external heel shock absorption was added, patients were cured. Due to the close anatomical insertions it can be argued that the fat heel pad acts as a protection of the Achilles tendon (Campanelli et al., 2011).

It can be concluded that altered properties of the fat heel pad may impact the functioning of the biomechanics of the foot and affect the load transmission between the plantar fascia and the Achilles tendon. Further thoughts can be addressed in particular, if the heel fat pad could act as a lever pivot for the Achilles tendon similar to the patella acting as fulcrum for the knee to increase force of the quadriceps muscles. No studies have so far challenged these thoughts, but they may give rise to new interesting impulses for the observation and understanding of foot biomechanics.

The unifying role of connective tissue and the fascial expansion from the plantar fascia to the continuation of the lower limb was reviewed by this study, the findings of which would appear to correlate with other research concerning the gross and histologic anatomy of the superficial and deep fasciae of the lower limb, which highlights the tensegrity of the body. The biomechanical and close fascial linkage of tendoachilles and plantar fascia gives us a profound understanding of the fascial extension starting from the gluteus maximus and its insertions of fascia latae, the iliotibial tract inserting on the lateral intermuscular septum, gastrocnemius insertion on the popliteal fascia, and finally to the tendoachilles and plantar fascia. This supports the purpose of this study, namely to understand fascial integrity and its ability for transmission of force from the foot to the hip and pelvic regions.

3. Definitions of the term associated with “transmission”

Before examining and reviewing the most recent research on force transmission of the myofascial system, it is important to address the terminology regarding force transmission. Literature shows a wide diversity of definitions for the term “transmission” stating it as, for example, the particular loading acted upon, ex load, stress, force etc. For further clarification, see the following definitions of the terms associated with “transmission”, as listed below.

- “Load” is a non-specific, widespread word for “force” and can also mean “stress”. Any real solid or body will change shape if a load is applied to it. The deformation of the material under load depends on three factors: (1) the original shape and size of the specimen, (2) the load applied; and (3) the mechanical properties of the material itself. The influence of the mechanical properties of the material, or material properties, can be separated from the other factors by defining two parameters; stress and strain (Paul & Barbenel, 1974).

- “Stress” is defined as the force per unit area on which a force acts (Paul & Barbenel, 1974), and for the purpose of this thesis is roughly interchangeable with the term load. If the stress, δ, is uniform across an area, A, where the load or force, F, is transmitted, then $\delta = F/A$.

- “Strain” is defined as the deformation of a body divided by the original dimension. Strain is a measure of deformation representing the displacement between particles in the body relative to a reference length. In other words, when a force (or load) is applied to a connective tissue which causes it to elongate (i.e. change in length), the strain is defined as the ratio of the change in length, ΔL, to the original length, L_0. Technically, strain cannot be transmitted, but rather strain is the response of a tissue to an applied load/force (Paul & Barbenel, 1974).

- “Intermuscular myofascial force transmission” is described as the transmission of force from a muscle to an adjacent muscle. The mechanical interactions between synergistic muscles have been ascribed to changes in the position of one muscle relative to the other and, consequently, changes in the configuration of inter- and extra-muscular connective tissues (Maas & Sandercock, 2010). Whether a mechanism of intermuscular force transmission occurs in humans in vivo and, further, if it has any functional significance, are presently unknown (Herbert, Hoang & Gandevia, 2008).

- "Myofascial load transmission" is a generic term for the transmission of muscle force via extramuscular connective tissues. Huijing (1999) reviews the available literature on myotendinous and myofascial force transmission and describes the muscle force transmission as passing not only through the tendon to the bony skeleton through myofibrils sarcomere to sarcomere, but also sarcomere to the myofascial complex, and then to the muscle tendon and to other structures. Accordingly, his observations point to the force being transmitted from muscle to extramuscular connective tissue, which he terms as "myofascial force transmission", or "extramuscular myofascial force transmission."

Specific applied tension will be referred to as "force transmission" in this work.

Traditionally, force generated within muscle fibers is thought to be transmitted directly via a series of tendons onto the skeleton. In addition to this myotendinous force transmission, it has recently been revealed that transmission of forces occur via alternative pathways; between muscles (intermuscular myofascial force transmission) and between muscle and non-muscular tissues (myofascial load transmission). The relative stiffness of inter- and extra-muscular connective tissues likely determines the fraction of force transmitted via each pathway.

4. Biomechanics and response on pathological alteration of the fascia

To gain a better understanding of how the fascial continuum works on tensile strain and transmission, its biomechanics mechanism and its properties will be clarified in this chapter.

Fascia is a continuous, dense fibrous connective tissue membrane, supporting and enveloping muscles, organs and vessels (Benjamin, 2009). With its complex composition of visco-elastic properties it contributes to distributing and transmitting (mechanical) forces between muscles. Depending on the mechanical loading by which the fascia is confronted, it can change its constitution and can thus vary the properties by shifting its plasticity and elasticity component (Findley et al., 2012).

The fascia is susceptible to viscoelastic deformations such as creep, hysteresis and relaxation. These observed deformations alter fascial stiffness but act temporarily and can take several hours for recovery (Schleip et al., 2010).

The mechanical property of the fascia reveals to be anisotropic, a property that varies with difference in strength depending on direction of load applied. Kirilova et al. (2009) monitored the visco-elastic mechanical properties of human abdominal fascia and observed that the relaxation process was depending on the applied direction of the loading. These observed properties enable the fascia to maintain its volume before and after loading (Findley et al., 2012).

The complex network of connective tissue facilitates sliding, adaptation and mobility of structures within the body. The collagen fibers examined in the crural fascia differ from one layer to the other due to the 3 dimensional collagen orientations. When tension is applied on a single layer in the directions of the collagen alignment, the mechanical reaction assumes anisotropic characteristics and, as mentioned before, the response of the fibers is directionally dependent. The loose connective tissue between the layers enables the local sliding between the layers and thereby the proper reaction to tension and traction (Stecco, 2009). This distinct interlayered sliding is of essence for qualitative sliding and force transmission. In case there is a modification or disruption, either due to trauma or overuse, the myofascial structural adjustment shifts and its function undergoes a non-physiological alteration (Stecco, 2009). Scars can cause defective sliding, thus generating tensional alterations (Bordoni & Zanier, 2013).
Another finding of reduction of fascia's gliding potential and its morphological changes and its

effect is observed by Langevin H. et al. (2011), perhaps influencing lower back pain. Reduction of fascia´s gliding ability in the thoracolumbar region, as Helen Langevin et al. (2011) describes as "reduced thoracolumbar shear strain" is strongly associated with increased thickness of some fascial layers in the thoracolumbar fascia and seems to predetermine lower back pain.

Another characteristics of the collagen is described to be thixotropic, a feature where fluids change its viscosity depending on the duration of time. The state of the gels and sols becomes less viscous (more fluid) when certain stimulus, i.e. shaking, shear stress or friction is acted upon it and returns to its original state once it is at rest again (Mosby, 2006).

A thin film of loose connective tissue and hyaluronic acid, a gel-like substance, is found at the interface between deep fascia and the epimysium to facilitate gliding over adjacent muscles (Stecco et al., 2011). Both the hyaluronic acid and the viscoelasticity of the fascial structure are influencing the response of the mechanoreceptors. In case of increased viscosity, the lowered lubricating performance of the hyaluronic acid consequently affects the quality of sliding between the fascial layers. Thereby the fascia´s distribution of lines of force becomes altered. Consequently a normal physiological stretch of the fascia could in this case, result in an incitement of the nociceptors (positioned within the fascia) and enforcing myofascial pain.

Systemic disorders or pathologies, where fibro-contractive changes occur may affect also the myofascial system, causing inter alia visceral (Gabbiani, 2003), genetic (e.g.) Dupuytren’s contracture (Nunn & Schreuder, 2014) and vascular (Hinz, 2009) disorders and altering the fasciae function and its capability to withhold its functional property to render the transmission and transition of the tension in an efficient way.

The above examples of altered tension show that the load tensions can produce a non-physiological mechanical stimulus enhancing fibroblast hyperplasia, further densification, conclusively leading to chronic inflammation and nociception stimulus (Buckley et al., 2001; Cao, Hicks, Campbell & Standley, 2013; Deising et al., 2012).

Reviewing the latest research and gaining new insights into this biomechanical model of the human fascial system is valuable for the explanation of the fascial integrity and its ability on transmission of force. It enables us to gain a better understanding of the essence of the qualitative sliding capability of its force transmission and the consequence of a modification or disruption for this system.

5. Further studies on tensile transmission

On the basis of recent studies of the fascia's anatomy, biomechanical, force and load transmission it is suggested that the tension transmitted from the thoracic – lumbar – pelvic/hip to the lower limb is functionally coupled with the fascial-layered continuity to the plantar fascia.

The premise of this chapter is to review the latest research concerning the load transmission of the fascial integrity as a potentially useful comparison with the results of the investigator's experimental application.

In addition to a tensional loading of the myotendinous structures of tendons and ligaments, Huijing (1999) describes in his literature the myofascial force transmission of muscles transmitting a significant portion of their force via their epimysium to laterally positioned tissues. This allows a transmission to the synergistic or antagonistic muscles.

Franklyn-Miller et al. (2009) demonstrated fascial strain transmission in the lower limb fascia by performing a Straight Leg Raise (SLR) test. Microstrains resulting from the SLR were reported in miscellaneous (diverse) areas. Comparison to strain with a 100% outcome of the posterior thigh, 240% tension was monitored on the iliotibial tract, 145% on lumbar fascia (ipsilateral), 100% of the Achilles tendon and with low level but, nonetheless monitored tension of 26% of the plantar fascia (see table 1 below).

Table 1: Strains transmission during Straight Leg Raise - compared to strain of 100% outcome of the posterior thigh (Franklyn-Miller et al., 2009, pp.150-151)

Iiliotibial Tract	240%
Ipsilateral lumbar fascia	145%
Lateral crural compartment	103%
Achilles tendon	100%
Contralateral lumbar fascia	45%
Plantar fascia	**26%**

A further study of Vleeming et al. (1995) verified tensile transmission across the lumbar fascia by applying tension to the posterior layer of the thoracolumbar fascia on cadavers by stimulating traction to various muscles as such gluteus maximus, latissimus dorsi, erector muscle and biceps femoris. In some specimens tension applied on to the fascia thoracic lumbar, mostly below L4 appeared to transmit to the contralateral side. This result coincides with the result of the strain patterns of Franklyn Miller et al. (2009) where 45% (compared to strain of posterior thigh of 100% during SLR) was transmitted on the contralateral lumbar fascia.

Barker et al. (2004) documented tension applied traction onto the transverse abdominal muscles and observed fascial movement of the posterior and middle layers of the lumbar fascia.

These observations demonstrate that tension was evidently effectively transmitted between the attached muscles in the lumbar spine and pelvic region and also other from the foot and to the lumbar spine. This reveals the fascial structures as an integrated system that establishes a basis for the cognition of an efficient load transfer between the spine, pelvis, hip and feet.

6. Osteopathy and other comparative concepts

In recent years manual treatments have increased substantially with the focus on the myofascial system. One of the pioneers of this approach was A.T.Still who introduced numerous concepts in osteopathy.

6.1. Osteopathy

It is now widely accepted within the field of Osteopathic Manipulative Therapies that fascial elements are a primary focus in the visceral and structural manual treatment. Much consideration and attention is given to this approach. Some therapeutic examples that illustrate structural manual osteopathic treatments are “Balanced Ligamentous Tension” (BLT), “Myofascial Release Technique” and “Strain Counter Strain” (SCS). These are just a few techniques mentioned which form a vital part in the osteopathic medicine. These examples of treatments refer to circumstances where fascia is involved and actively engaged and are thus of essence for acknowledging the fascial structure.

In addition, other fascia-oriented therapies can be mentioned which specifically focus on the force strain. The purpose of this chapter is to review the theory with related research concerning the load transmission of the fascial integrity and the latest manual treatments available.

6.2. Fascial Manipulation

Fascial Manipulation (FM) is a manual therapy developed by the Italian Physiotherapist, Luigi Stecco, for treating muscular skeletal pain. It is based on a 3-dimensional biomechanical model for the fascial system. The major concept of this model is that the fascia has a specific organizational sequence and relationship with the underlying muscle and its deep fascia.

Numerous studies on fascial anatomy and dissections of human cadavers have revealed muscular fiber insertions attached onto deep fascia (Stecco et al., 2007a), as well as linkage of adjacent fascial segments through myotendinous expansions (Stecco et al., 2008b; Stecco 2009).

Extensive research on the deep fascia has shown the role of fascia in tensional force distribution within the myofascial system (Stecco et al., 2006).
The orientation of the myotendinous expansions of the deep fascia (Stecco et al., 2008a; Stecco et al., 2009b) is to ensure that the extension of the fascia is synchronized throughout its length so that marginal movements in a particular direction can be achieved.

One example of myofascial sequence that is relevant for this study is the "retromotion sequence" of the lower limb (see *Figure 2* and *Figure 3*) formed by the following myofascial units: a functional unit, composed of unilateral muscular fibres, fascia, nerve structures, joint capsule, and ligaments.

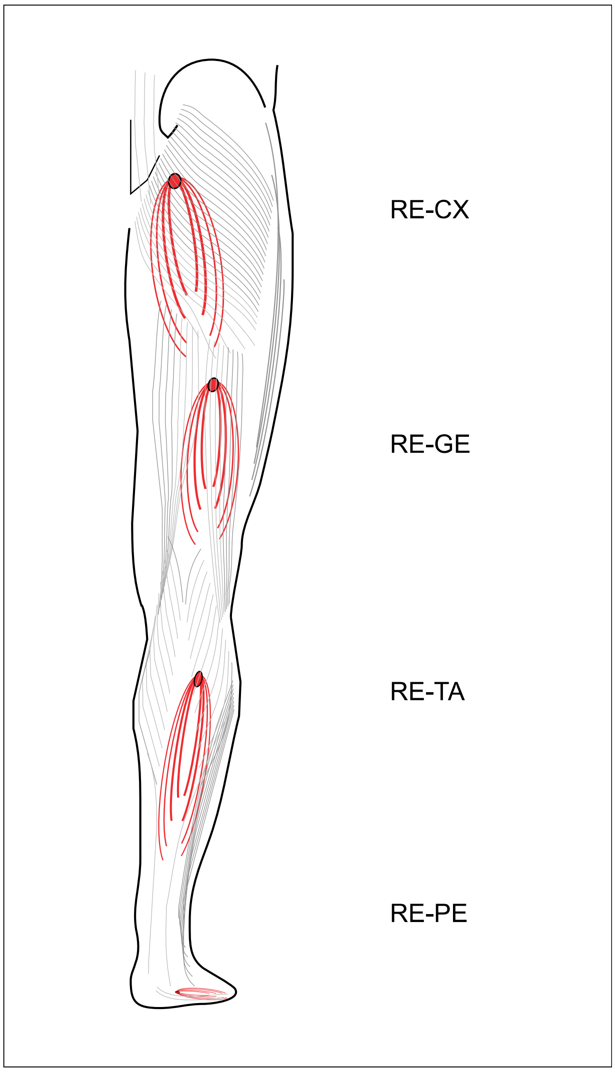

Figure 2: Myofascial unit of retro motion of the lower limb (Stecco, 2004, p. 74)

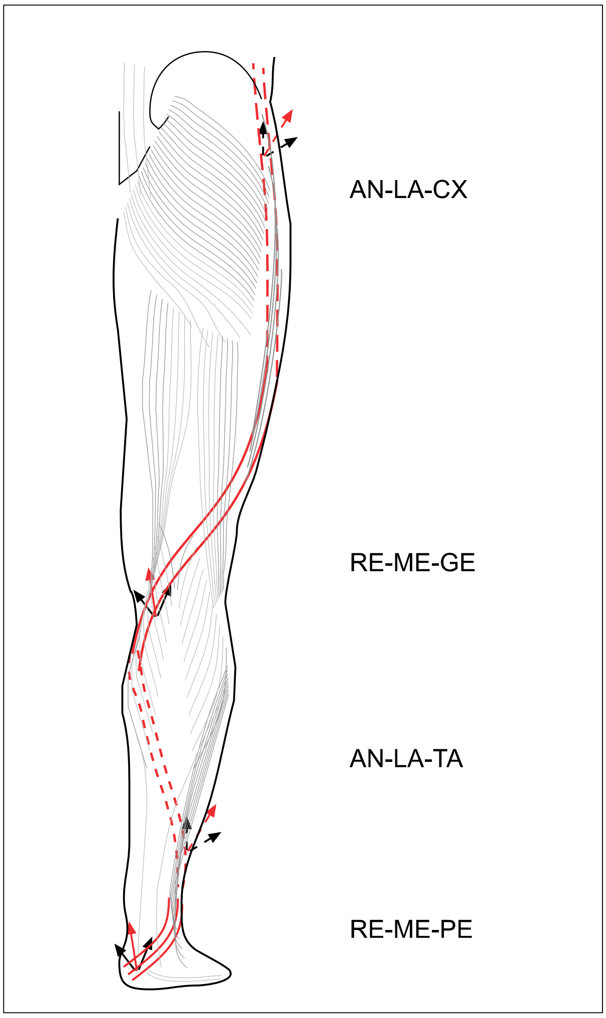

Figure 3: CCs of fusion of the re-me-pe spiral (Stecco, 2004, p. 215)

The portraying of myofascial sequence can confirm the interpretation of the distribution of tensional compensations throughout the fascial system (see *Figure 4*). The types of compensations can be seen as ascending versus descending, or homolateral versus contralateral (Stecco, 2004).

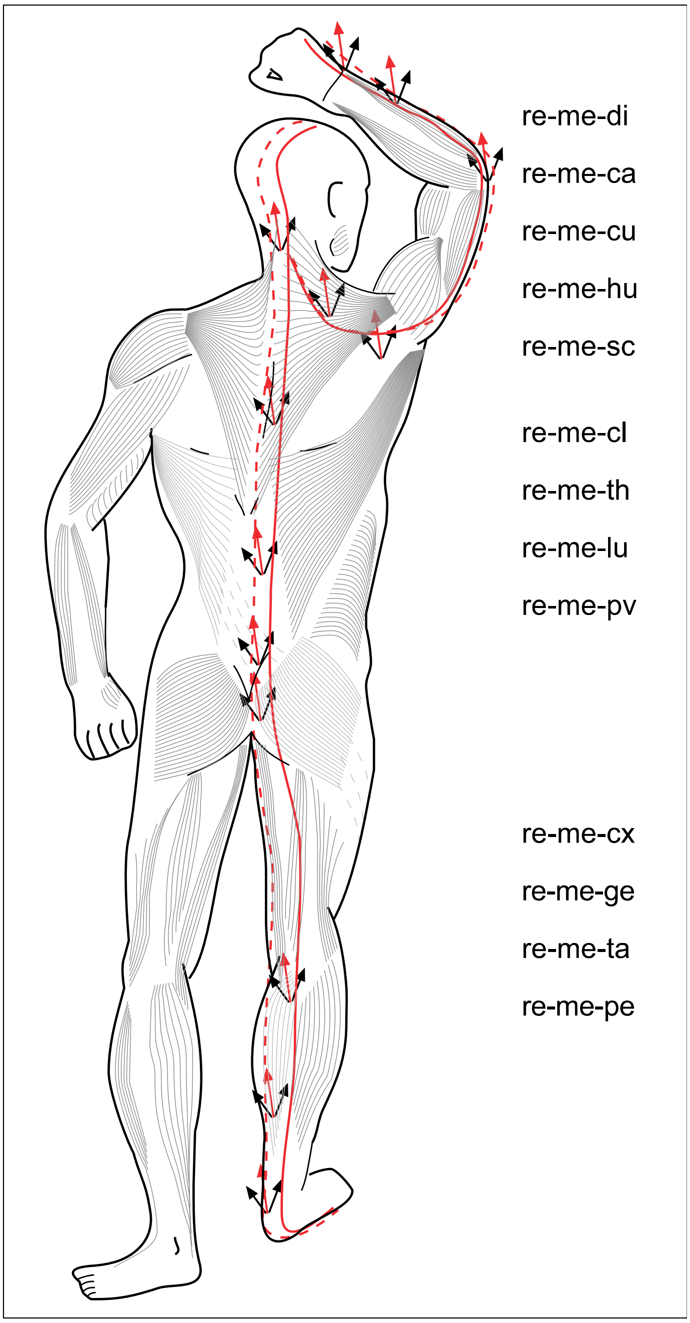

Figure 4: CCs of fusion of the retro-medial diagonal (Stecco, 2004, p. 236)

An essential feature of this method is the differentiation between patients' main complaint of their perception of pain and the required treatment on the fascial point.

Hence FM goes beyond the idea of treating the site of pain, but rather to acknowledge the associated structures, or corresponding treatment points that can point to the fascial origin, or cause of the pain (Stecco, 2004). In addition to pain, poor motor-control and balance problems could be observed.

Alteration of the fascia within the myofascial unit could cause:

- inaccurate muscle recruitment
- non-physiological joint motion
- stimulation of joint nociception and
- joint play.

Any impediments in the gliding of the fascia could alter input, resulting in incoherent movement (Stecco, 2004).

This method points out the significance of “re-establishing equilibrium through the correct interpretation of compensations working appropriated to distant an entire sequence as well as restoring balance between agonist and antagonist muscle fascia unit” (Stecco & Stecco, 2012, p. 339).

6.3. Tom Myers – Anatomy Trains

Tom Myers (2004) describes common pathways of fascial and myofascial linkages and force transmission and their functional relevance for whole body’s system in posture, function and motion. He describes, inter alia, the superficial back line, which suggests a strong relationship between the feet and the lower back (Myers, 2004).

His dissections and observations also established an understanding of fascia as a continuum through many layers, and by the use of these myofascial lines he developed a holistic approach of a so-called training regime whereby the fascial web is involved in whole-body movements.

The superficial backline

The posterior superficial line starts from the superficial layer of the toe flexors and plantar fascia, extends to the calcaneus, Achilles tendon/gastrocnemius muscle, femure condyles, hamstrings, ischial tuberosity, further continuing to sacrotuberous ligament, to the sacrum bone and sacro-lumbar fascia, continuing to the linea nuchae, to the galea aponeurotica, and finally to the arcus superciliaris. This sequence, starting from caudal to cranial, was chosen at random. Tension is observed to start from the center of the body, and then spreading distally to both ends. This force line is predominantly for position and movement in the sagittal layer (see *Figure 5*).

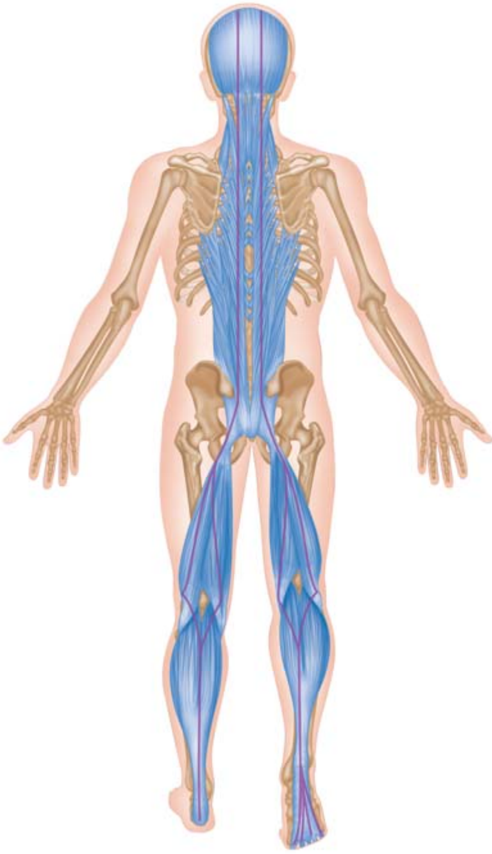

Figure 5: Superficial Backline (Myers, 2004, p.70)

Myers (2004) suggests that the cause of many myofascial distortions starts from the plantar fascia resulting in further tension spreading superiorly. He observed that a decrease in the range of motion in the plantar fascia leads to tighter hamstrings and, furthermore, an extended lumbar lordose.

A closer examination of the superficial back line around the heel illustrates the mechanism of a "bow and arrow", demonstrating a continuation of the plantar fascia and Achilles tendon (as shown in the *Figure 6* and *Figure 7* below).

The implications are that tension in the "bow and arrow" area, often occur due to an anterior shift of the pelvis, thus encouraging the calcaneus forward which creates a 'shorter heel'. Another observation assumes that tension in the bowstring will prevent the calcaneus from moving back as the ankle goes into dorsiflexion.

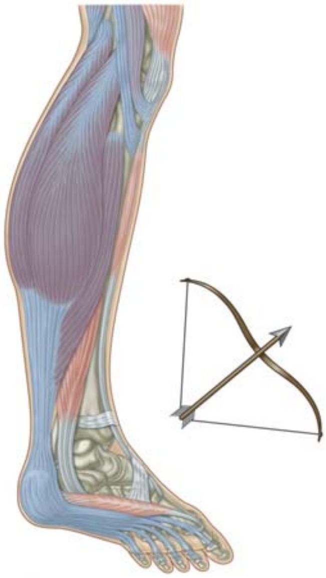

Figure 6: “Bow and arrow” around the heel
(Myers, 2004, p.75, With kind permission of Myers)

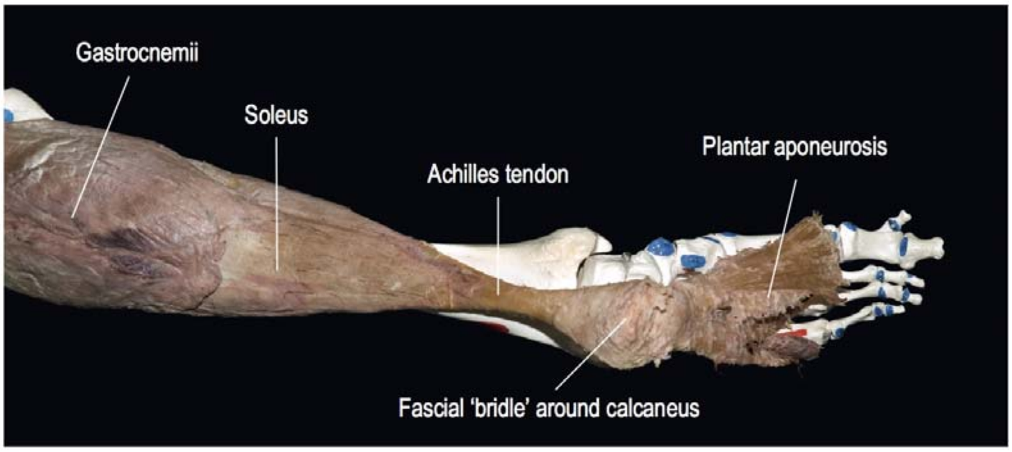

Figure 7: Cadaver of plantar fascia with continuation to the calf muscles
(Myers, 2004, n.p. With kind permission of Myers)

Myers (2001) dissections also established an understanding of fascia as being continuous through many layers, and by the use of identifying these myofascial lines developed a holistic approach of a training regime where the fascial web is encompasses whole body movements.

The general premise is that loading, strains (physiological or pathological), traumas and general movements can lie along this force line.

7. Approach of the methodology

An experimental study was carried out to examine the effect of the range of motion of hip flexion performed by a Straight Leg Raise (SLR) by means of a manual treatment on the plantar fascia. The focus of this chapter will detail the methodological approach followed, as well as discuss the study design, the hypothesis, the study procedure, the material and measurement tools, the criteria for the search of the sample and, finally, dependent and non-dependent variables.

7.1. Study design

This study presents a randomized control trial designed for a treatment and control/placebo measurement carried out on 22 subjects, 11 of whom were women and 11 of whom were men, at the age of 18 and above illustrates its repetitive measurements before/pre-and after/post- intervention of the treatment and control.

A fixed date was assigned for the subjects, the therapist and the investigator. The patient was informed about the procedure verbally, followed by the subject reading and signing a consent form. The inclusion and exclusion criteria of the subjects were evaluated before their visits and excluded subjects if they did not meet the criteria.

Rolling of a dice was used to decide what side, either the right or the left plantar fascia was to receive the treatment, with the opposite leg to receive placebo**.** Once the treatment on the plantar fascia and the measurements (taken before and after the treatment) on the selected side were completed, the other limb of the same subject was chosen for the control/placebo. The control condition was done by formerly applying an ultra sound treatment to the subjects (of 5 minutes) on the plantar fascia while the ultrasound head was detached from the ultrasound machine thus preventing any treatment effect. Evidently the subjects were unaware that the ultrasound head was detached thus assuring the placebo outcome. This structural procedure enabled a control on the same subjects who underwent the treatment, thus allowing a direct comparison between the two results on the same person on the same day.

Furthermore, this allowed for the elimination of the possibility for a diurnal response, which presents a periodic alteration of condition between day and night, thus preventing the risk for alteration of the measurements.

A randomization was achieved in terms of deciding which side, either the right or the left plantar fascia, that was to receive treatment and which side was to receive the placebo. The application of the placebo (using the ultrasound as an official “treatment” with the ultrasound head cable being detached) ensured a control in this study. This set-up enabled the design of this experiment to be a randomized controlled trial. Accordingly, for the research evaluation, this evidence-based medicine approach proved to be a “good” experimental design (Grossman & Mackenzie, 2005).

In addition, this work presents a single-blinding procedure since a second neutral person was present as an investigator was performing the examination and measurements of the passive SLR. To improve methodology and to control confounding factors further methods and aspects were taken into account:

- In order to exclude disturbances of measurements, to maintain the procedure of measurements and to sustain the same performance on treatment and in the control, the following precaution was undertaken, namely that the treatment and control were carried out in the same room. The measurement tool, ultrasound apparatus, treatment bed, and the position of the subjects between pre- and post- measurements were not moved. The sequence of intervention, i.e. first the treatment and then the control, was never switched between the subjects.

- The intervention of treatment and control condition was undertaken on the same day, at the same hour. This allowed for the prevention of any fluctuation of results taking place due to the biorhythm of each subjects.

- To argue the relevance of the placebo group two effects have to be considered. The first effect – “Rosenthal's Pygmalion effect” – is based on the subjects’ unconscious behaviour, which is altered by enhanced expectations of health practitioners /researchers on patients, entailing that the greater the expectations articulated by therapists on the subjects or patients, the better they performed (Rosenthal & Jacobson, 1968; Rosenthal & Jacobson, 1992). The second called “Hawthorne effect” – suggests that subjects improve their performance and change their behaviour due to environmental influences, or by being observed and receiving attention from researchers in experiments (McCarney et al., 2007). In sum, the very fact that subjects are under study, observation or investigation highlights that subjectivity is a factor in analyzing the results.

This aspect of environmental behavior, taking into consideration the response of each individual, should be given due awareness for researchers on how to use their wording, communication and setting while performing their experiments. Of further note, these findings should be taken into account in conducting experiments, especially to ensure that a placebo is in place, to safeguard the validity of the results. Thus, in essence, a careful therapeutic approach and a strict methodological procedure were ensured whereby the request for information from the subjects by the investigator was identical for each subject. This minimized the risk of influencing the performance of the subjects and altering the measurements either by giving them too much attention or verbal interference.

- To allow for standardized measurement procedures and preventing the subjects from performing involuntary, compensationary movements during the performance of the SLR several devices and tools were utilized. Firstly, a belt was placed on the thigh of the unexamined leg, fixed to the table, to prevent a posterior tilt of the pelvic. Secondly, an ankle-foot orthosis brace was positioned on the ankle to maintain a constant angle in the dorsiflexion. The subjects were also instructed not to change position between the pre- and post- measurements.

7.2. Hypothesis

In order to evaluate the effect of the treatment on the plantar fascia and its impact on the range of motion of the hip flexion, 12 hypotheses (A-L) are specified, divided into three complexes.

Treatment versus control condition

The first complex of hypotheses examines the actual subject matter of analyzing the pre-measurement against the post-measurement of the treated side of the limb:

Hypothesis A

$H0_{(a)}$ Manual therapy on the plantar fascia has *no effect* on the range of motion on the hip flexion tested by the SLR.

$H1_{(a)}$ Manual Therapy on the plantar fascia has *an effect* on the range of motion on the hip flexion tested by the SLR.

Hypothesis B

H0 $_{(b)}$ Control condition has *no effect* on the range of motion on the hip flexion tested by the SLR.

H1 $_{(b)}$ Control condition has *an effect* on the range of motion on the hip flexion tested by the SLR.

Effects on the selected segment

The second complex of hypotheses considers effects of the selected side (left or right):

Hypothesis C

H0 $_{(c)}$ Manual Therapy on the plantar fascia has *no effect* on the range of motion of the hip flexion tested by the SLR on samples on the right side.

H1 $_{(c)}$ Manual Therapy on the plantar fascia has *an effect* on the range of motion of the hip flexion tested by the SLR on samples on the right side.

Hypothesis D

H0 $_{(d)}$ Manual Therapy on the plantar fascia has *an effect* on the range of motion of the hip flexion tested by the SLR on samples on the left side. Alternative hypothesis

H1 $_{(d)}$ Manual Therapy on the plantar fascia has *an effect* on the range of motion of the hip flexion tested by the SLR on samples on the left side.

Effects of sociodemographic variables

The third complex of hypotheses examines effects of sports intensity level, age, BMI and gender:

Sport intensity level

Hypotheses E

H0 $_{(e)}$ Manual Therapy on the plantar fascia has *no effect* on the range of motion of the hip flexion tested by the SLR on samples low sports intensity.

H1 $_{(e)}$ Manual Therapy on the plantar fascia has *an effect* on the range of motion of the hip flexion tested by the SLR on samples low sports intensity.

Hypotheses F

$H0_{(f)}$ Manual Therapy on the plantar fascia has *no effect* on the range of motion of the hip flexion tested by the SLR on samples high sports intensity.

$H1_{(f)}$ Manual Therapy on the plantar fascia has *an effect* on the range of motion of the hip flexion tested by the SLR on samples high sport intensity.

Age

Hypothesis G

$H0_{(g)}$ Manual Therapy on the plantar fascia has *no effect* on the range of motion of the hip flexion tested by the SLR on samples with younger age.

$H1_{(g)}$ Manual Therapy on the plantar fascia has *an effect* on the range of motion of the hip flexion tested by the SLR on samples with younger age.

Hypotheses H

$H0_{(h)}$ Manual Therapy on the plantar fascia has *no effect* on the range of motion of the hip flexion tested by the SLR on samples with older age.

$H1_{(h)}$ Manual Therapy on the plantar fascia has *an effect* on the range of motion of the hip flexion tested by the SLR on samples with older age.

BMI

This concerns the value of the Body Mass Index (BMI) which is calculated by height, times mass. Subjects of a BMI below 23.11 were classified lower, and above as higher.

Hypotheses I

$H0_{(i)}$ Manual Therapy on the plantar fascia has *no effect* on the range of motion of the hip flexion tested by the SLR on samples with a high BMI level.

$H1_{(i)}$ Manual Therapy on the plantar fascia has *an effect* on the range of motion of the hip flexion tested by the SLR on samples with a high BMI level.

Hypotheses J

H0 $_{(j)}$ Manual Therapy on the plantar fascia has *no effect* on the range of motion of the hip flexion tested by the SLR on samples with a low BMI level.

H1 $_{(j)}$ Manual Therapy on the plantar fascia has *an effect* on the range of motion of the hip flexion tested by the SLR on samples with a low BMI level.

Gender

The fourth feature evaluates the difference between genders. (Subjects who considered themselves as transgender were not identified in this study).

Hypotheses K

H0 $_{(k)}$ Manual Therapy on the plantar fascia has *no effect* on the range of motion of the hip flexion tested by the SLR on samples with females.

H1 $_{(k)}$ Manual Therapy on the plantar fascia has *an effect* on the range of motion of the hip flexion tested by the SLR on samples with females.

Hypotheses L

H0 $_{(l)}$ Manual Therapy on the plantar fascia has *no effect* on the range of motion of the hip flexion tested by the SLR on samples with males.

H1 $_{(l)}$ Manual Therapy on the plantar fascia has *an effect* on the range of motion of the hip flexion tested by the SLR on samples with males.

7.3. Procedure

This chapter relates to the specific chronicles of procedures for clinical testing and gives detailed information about how the measurements were constructed and which interventions occurred. For both, the treatment and control condition, the measurements were completed in five days for 22 subjects. Since the intervention of treatment and control condition was undertaken on each different leg the subjects only had to come once for the pre- and post-measurements (see figure 8 below). The experiments always took place in the investigator's osteopathic practice.

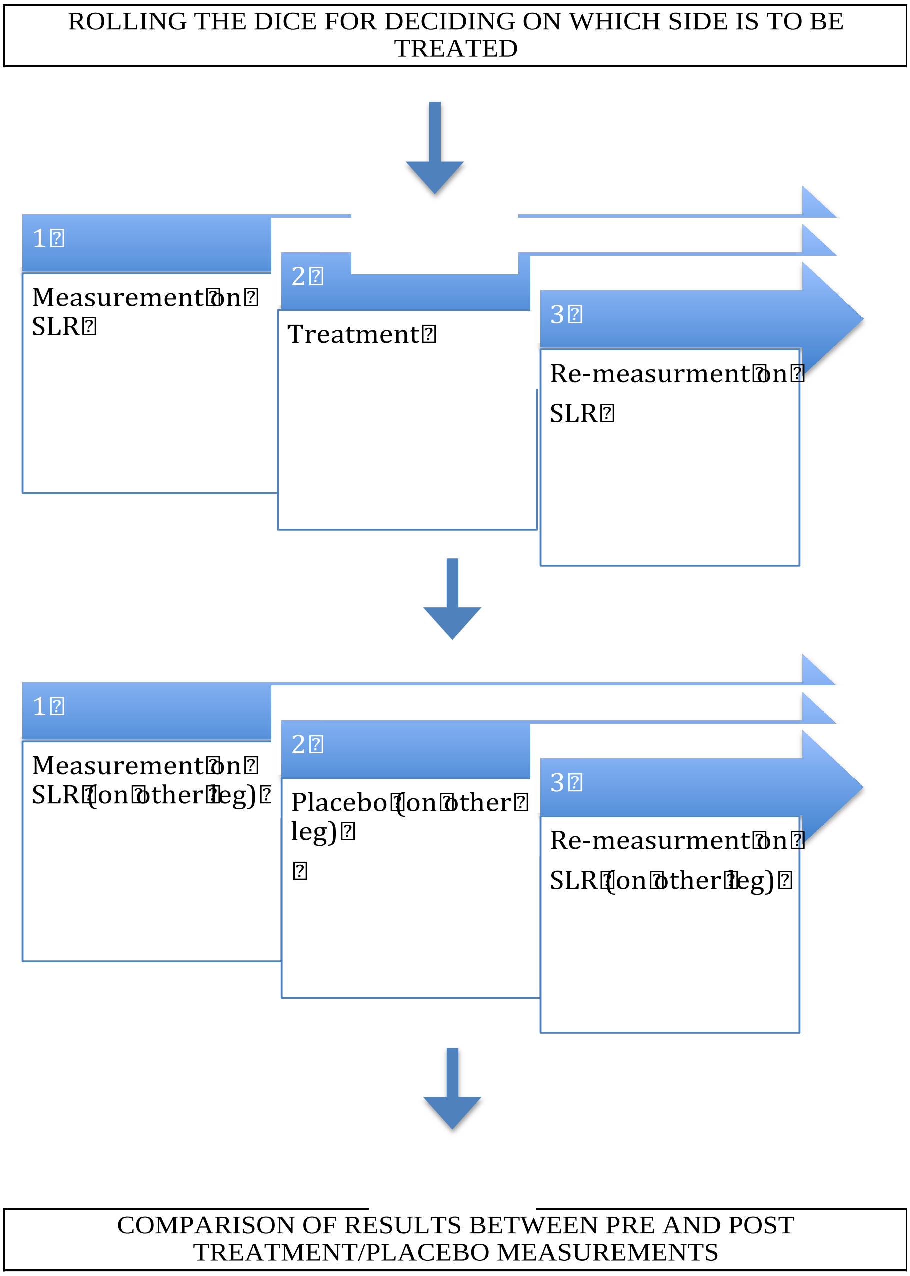

Figure 8: Procedure for the treatment and control condition

7.3.1. Measurement procedure

Procedure for the pre-measurements

A fixed date was assigned for the subjects, therapist and the investigator. Subjects who did not meet the inclusion and exclusion criteria were excluded from the study. The patient was informed about the procedure, followed by the subjects´ reading and signing the consent form.

The rolling of a dice was the deciding factor in determining which side, either the right or the left plantar fascia that was to receive treatment. Accordingly, the other side was chosen for the control condition. This allowed for a randomization of the sequence of application for the treatment and placebo. A number of 22 randomly allocated subjects were selected, of which 11 were women and 11 were men, all above the age of 18.

For the passive SLR, the subject was placed in supine position with the arms at rest on the side of the body (see *Figure 9* below). Intentionally, it was arranged that the subjects could rest their head on a pillow during the intervention. This allowed for additional tension obtained by neck flexion and suggested increased strain extending further to myofascial structures throughout the length on the posterior body structure. Clearly, subjects were instructed not to change the position of the head, nor the pillow during the intervention.

Figure 9: Procedure for the measurements of the passive SLR with the use of the ankle-foot orthosis brace to stabilize the dorsiflexion of the ankle and the belt to prevent the posterior tilt of the pelvis

The subject's non-tested leg remained at rest with a straightened knee on the table. A belt was wrapped around the thigh (on the non-tested leg) fixed to the table to stabilize the leg in order to prevent a posterior pelvic tilt. On the leg receiving treatment, or placebo, an ankle-foot orthosis brace was placed on the ankle to allow for a constant dorsal flexion and prevention of a fluctuation of the angle of the ankle. Furthermore, measurements made by Carlson et al., (2000) showed that different angles of dorsal flexion of the first metatarsophalangeal joint produced an increase of tensional force in the plantar fascia proportional to the increase of angle by the metarsophalangeal joint. Therefore, the investigator maintained a close observation on the subjects to ensure that they did not move their toes during the performance of the SLR. The investigator raised the testing leg with a straight knee. The other hand was placed above the knee to prevent knee flexion. The pivot of movement was located on the hip joint.

7.3.2. Treatment procedure

Measurement

The range of motion of the angle for the passive SLR was measured with the use of an “iPhone 5” and with the application “G-Pro” (see *Figure 10* below). The investigator lifted the testing leg with the command to the subjects “lift as far as you can go” until the subjects said “stop”. At this point the investigator pressed the stop button on the application “G-Pro” and the result was noted.

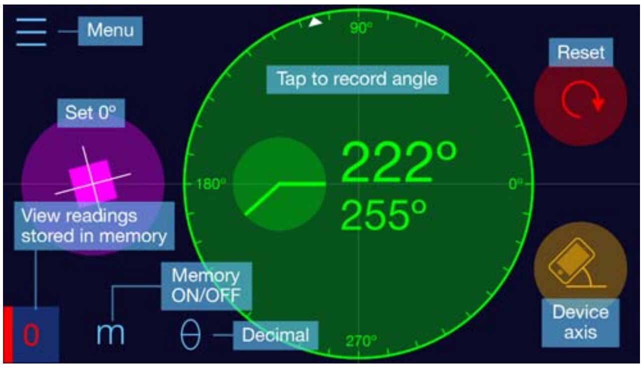

Figure 10: Application “G pro” for the iPhone 5 to measure range of motion in the SLR test

Treatment procedure

The belt and ankle-foot orthosis brace was removed from the subjects. The results of the dice decided which side, right or left, of the plantar fascia that was to be treated.

The manual treatment was applied with the therapists’ thumb on the plantar fascia. The focus of the treatment was applied on the densification, mostly on the medial side of the foot (since the thickest plantar fascia and highest density of innervation are found there). Further research might reveal that the heel pad influences the biomechanics of the foot, as was observed by Miller-Young et al., (2002), indicating that the shape, structure and thickness of the heel pad had an impact on the functional capability of the foot.

Thus, with this new awareness of the profound effect on the biomechanics of the heel fat pad, this study emphasizes the application of manual treatment on the heel fat pad. It thereby addresses the mobility of the heel fat pad by applying a sliding force to the heel pad by the use of a manual device named “Fazer” by Artzt Vitality®. The thumb pressure was applied with about 2-2.5 kg (measured by a luggage scale). Manual treatment was carried out for 10 minutes. By the investigator’s empirical observations, 10 minutes seemed to be the right duration to receive an alteration of the densification on the plantar fascia, as was intended in the study.

Re-measurement

The belt and ankle-foot orthosis brace were again attached to the subjects. The investigator proceeded with a SLR and re-measurement of the range of motion for the angle of the passive SLR with the use of an “iPhone 5”, with the application “G-Pro”. The investigator then lifted the leg as far as it could go i.e. until the subjects indicated a verbal “stop”, whereupon at this point the stop button on the application “G-Pro” was pressed and the result was noted again.

7.3.3. Procedure for the control

Measurements for the control/placebo.

After the treatment and its measurements the control condition was applied on the other leg. The belt and ankle-foot orthosis brace were attached on the subjects. Measurements of the angle of the SLR were taken with the application “G-Pro” by the use of an “iPhone 5”, and the results were noted down.

Control procedure

The belt and ankle-foot orthosis brace were detached from the subjects.

The Medical Ultrasound apparatus was turned on and the ultrasound head with the use of a lubrication gel was applied on the plantar fascia and heel pad. The process took 5 minutes, a standard treatment-time for the ultra sound. Nonetheless, the cable leading to the ultra sound head was detached without the subject’s awareness resulting in a non-interventional effect.

Re-measurement

Once the control procedure, and its measurements, was completed the belt and ankle-foot orthosis brace were attached onto the subject for the last time.

The range of motion for the angle of the SLR was applied by the use of the "iPhone 5", with the application "G-Pro". Again the investigator lifted the leg as far as it would go i.e. when the subject said a verbal "stop", whereupon the stop button on the application "G-Pro" was pressed and the result was noted. The differences of the measurements before and after the placebo were evaluated.

7.3.4. Passive Straight Leg Raise test: Discussion and methodical improvements

The SLR is considered to be an important neurodynamic manual test in diagnosing a herniated lumbar disc disease and to measure the hamstrings muscle length.

Several studies show unsatisfactory results regarding inter-rater reliability (Hunt et al., 2001; Kosteljanetz, Bang & Schmitdt-Olsen, 1988; Scott et al., 2008) on the passive SLR test. Therefore, measurements were taken by the same investigator before and after the interventions to eliminate unwanted measurement variations.

Measurements have demonstrated, with few exceptions (Porter & Trailescu, 1990) a good to excellent intra-rater reliability testing with the use of an inclinometer (Hunt et al., 2001; Scott et al., 2008), and goniometer (Boland & Adams, 2000; Chow et al., 1994).

The measurement of the angle was undertaken by the use of a smartphone, chosen for this study instead of a goniometer, because of its practicality and ease of handling for the investigator during the passive modified SLR test. The smartphone "iphone 5", with the use of a smartphone application "G-Pro", has an analyzing system designed for measuring body positions i.e. hip joint range of motion. Studies have demonstrated that the mobile smartphone and the use of applications for body position measurement have a good to excellent reliability (Charlton, Mentiplay, Plua & Clark, 2014; Jones, Sealey, Crowe & Gordon et al. 2014; Milanese et al., 2014).

As mentioned, the SLR test is mostly used as a diagnostic test for hamstrings flexibility, but also for lower back pain associated with lumbar disc herniation and sciatica. To preserve their function, nerves have the ability to regulate themselves for different length variations of the lower limb and trunk. In the case of non-physiological and restricted sliding between the fascial layers where the nerves (in this case the ischiadic nerve) are situated, neural dynamic malfunction and tension develop. Reduction of intra-neural blood flow and the onset of inflammation could result in neuropathic pain in the case of a high-tension situation, such as in the SLR (Kobayashi, Yoshizawa & Nakai, 2003; Kosteljanetz et al., 1988).

The parameter for the limitation of the range of motion for these subjects is determined by the symptoms provoked i.e. pain or maximum tolerance. In healthy subjects, though, fascial restriction and loading transmission were investigated, and for the purpose of this study, measurements were taken at the point of “hamstrings muscle tightness”, the label of which is acknowledged by therapists as being the limiting factor for the range of motion and movement resistance sensed by the subject.

To detect the end of the range of hip flexion without pain being the limiting factor, is in the view of the investigator both challenging and problematic. Hence, the subject was asked to report when the ultimate stop was reached while performing the SLR.

This study defines the range of motion during the performance of the SLR occurring in the hip joint. As a note, however, the investigator would like to point out that the myofascial structures do not only concern the hip flexion or hamstrings flexibility, as commonly postulated, but also the whole pelvic region. Due to the major insertion of gluteus maximus on the fascia latae and, furthermore, the attachments of the iliotibial tract on the lateral intermuscular septum of the thigh (Stecco & Stecco, 2012), this study supports that these structures form a unifying complex. In this context, the aforementioned structures cannot be seen as being isolated, nor as one independent joint. Pertaining to this fact, the author cautions that in this work the term hip joint is used, rather than naming all unifying structures, for examining the range of motion during the SLR.

For the SLR, a sensitizing maneuver was applied such as passive dorsiflexion of the ankle. Passive dorsiflexion of the ankle is used as a standard neurodynamic test, by which the ankle dorsiflexion places tension on the sciatic nerve and its roots (Troup, 1981). Primarily, however, the key issue is the presumed increase in tension and sensitization on the fascial system, which constitutes the purpose of this study (Boland & Adams, 2000).

The response on asymptomatic subjects on structural differentiation maneuvers i.e. ankle dorsiflexion on the SLR have a significant effect on the test response regarding the range of movement (Herrington, Bendix, Cornwell, Fielden & Hankey, 2008).

High inter-rater reliability with the use of a gravity goniometer was found with passive dorsiflexion investigated on a range of passive SLR movements (Boland & Adams, 2000) and is, therefore, applied frequently in the clinical environment.

The manual treatment is focused on the plantar fascia. Hence, tensional changes will most probably be more visual and prominent if the dorsiflexion is included in examining the SLR.

To prevent fluctuation of the ankle position, while performing the SLR, further methodological improvement was applied by placing an ankle-foot orthosis on the subjects' foot to obtain the ankle in a constant 90° position.

The advantage of the application of the SLR is that the subjects stay in a supine position both during the measurements, and during the treatment/placebo. This prevents the subject having to change position, say, if the examination takes place in a standing position, such as in the forward bending test, but the placebo and treatment are positioned in supine. In such cases, alterations in the measurement may occur due to two factors. First, due to the different mechanical-chemical stimulation, every time the subject has to stand up and move, and secondly, due to the risk that measurement tools and subjects are altered resulting in a different measurement.

Another advantage of the SLR compared to, say, the forward bending test is that an intervention does not need to be performed on both plantar fascia.

It is important to perform the test only once before and after the intervention or placebo group. Too many repetitions, or too prolonged a position on performing the SLR may induce creep on the connective tissue, and thus alter the measurements and results. Creep refers to the advancing ("progressive") deformation of the connective tissue that occurs when the structures are under a constant load (McGill & Brown 1992).

7.4. Material and method

Tools for measurements (see *Figure 11* below):

- Ankle-foot orthosis brace/night splint.
- Stop watch: to record the treatment and control time.
- Smart phone "iPhone 5" iOS-based line, designed and marketed by "Apple In" with the use of an application, an analyzing system designed for measuring body position named "G-Pro".
- Medical ultra sound apparatus "Sonopuls 463".
- Lubrication gel.

- “Fazer” device by Artzt Vitality ®.
- Dice.
- Belt.
- Excel file documentation of the measurements.
- Written consent.

Figure 11: List of tools, from left to right and from top to bottom - Ankle brace orthosis, US apparatus, belt, “Fazer” device by Artzt Vitality®, dice, lubrication, watch, iPhone 5

7.5. Selection of the sample

A number of 22 randomly allocated subjects, of which 11 were women and 11 were men, above the age of 18 were selected. Subjects who were not meeting the following inclusion and exclusion criteria were excluded from the study.

Inclusion criteria

The sample was comprised of asymptomatic subjects of the age of 18, and above.

Exclusion criteria

Participants who have the following conditions, listed below, were excluded from the study due to the possibility of condition-related interference affecting the load transmission of the limb.

- Diabetes mellitus, type 1: The examination on the soft tissue changes in the skin and plantar aponeurosis of young people with Type 1 diabetes mellitus has demonstrated, due hyper glycaemia production, a densification of the collagen tissue resulting in a thickening of the plantar fascia and the Achilles tendon compared to healthy patients, (Duffin, Lam, Kidd, Chan & Donaghue, 2002). In addition, Grant et al. (1997) observed fine structural changes in the Achilles tendons of patients with long-term diabetes mellitus detected by electron microscopic investigation. Several variations were seen which included increased packing density of collagen fibers, decreases in fibrillar diameter, and abnormal fibril morphology. In addition, what was commonly seen in the specimens was that collagen fibers appeared twisted, curved, overlapping and highly disorganized. Grant et al. (1997) states that such structural changes could contribute to the tightening of the Achilles tendon, a phenomenon coherent with his clinical observations of extreme shortening of the Achilles tendon-gastrocnemius-soleus complex.

- Participants who had had operations carried out on their lower back/pelvis and lower extremities 3 months previously were excluded and

- those who possessed deep scarring on the lumbar, pelvic, limb or foot regions.

Langevin et al. (2006b) demonstrated that fibroblasts have the ability to change cell signalling, gene expression and cell-matrix and, thus, adhesion according to mechanical load. A high density of myofibroblast (Schleip et al., 2007) was found in scars, which probably caused the increase in fascial basal tension (Hinz & Gabbiani, 2007). Also, studies have shown that surgical procedures of plantar fascial release may disturb and alter the mechanics of the foot (Anderson, Fallat, Ruth & Savoy-Moore, 2001; Erdemir et al., 2004).

- Therefore participants who were immobilized for over 6 weeks were not suitable for the study due to the associated proliferation of the connective tissue, which can cause erratic and irregularly arranged collagen fibers. This was observed in a study undertaken with healthy and immobilized tissue (Järvinen et al., 2002).

- Participants with plantar fibrosis and Plantar Fibromatosis were also prevented from participating. Pathological fascial contracture seen in fascial diseases can be seen in plantar fibromatosis and plantar fibrosis. These are disorders of the connective tissue where there is a known, increased percentage of fibroblasts turning to myofibroblast. This transition to a myofibroblast showed a four times stronger and denser quality when compared to regular fibroblast. An increased presence of myofibroblasts is a driving factor behind chronic fascial contractures such as those in plantar fibromatosis and plantar fibrosis (Hinz & Gabbiani, 2007), and consequently is presumed to alter the tension of the fascial continuum.

- Because blockage of the spine could interfere with pelvic and hip motion and could thus interfere with the load transmission of the limb, those participants who had fusion surgery/spondylodesis were not included.

- Patients with acute plantar fasciitis and severe pain on the foot sole were also deemed not suitable. The treatment on the plantar fascia involved a rather intense pressure. Application of the thumb pressure measured by a luggage scale demonstrated to be 2-2.5 kg. Thus, an acute plantar fasciitis or any severe pain on the foot sole with such pressure would be very painful and would not be tolerable.

7.6. Description of the examined parameter

For the investigation of the hypothesis (see chapter 7.2.), the following parameters were established.

The central independent variable in this study was treatment with two groups, namely, “intervention” and “control condition”. Additional independent variables such as the age (in years), gender, sports activity level (sports activities in days per week) and BMI (calculated from weight and height) were assessed. This data was deemed to obtain the homogeneity of the group and to evaluate the possibility of different results in the measurements.

The dependent variable in this study was the range of motion performed by the passive SLR which was obtained by measurement in supine position by the smart phone “iPhone 5”, iOS-based line, designed and marketed by “Apple In”, with the use of an application designed for body position measurements named “G-Pro”. The measurements were calculated in angles.

7.7. Statistical analyses

For testing the hypotheses, several Analyses of Variance (ANOVA) with repeated measures were performed. For all of them, there were two sets of repeated measures, one for pre- or post- treatment/placebo measurement, and one for intervention versus treatment as the same persons where included in both treatment variations. When including further independent variables, the respective variable was included into the ANOVA with two factors of repeated measures as an additional independent factor. All statistical analyses were performed with IBM SPSS Statistics 20, wherein the Excel file with the documentation of the measurements was imported. The level of significance was set on 5 per cent.

8. Results

As described in chapter 7, the study included 22 persons (11 female, and 11 male) who were used in both the treatment and control groups. All 22 participants received both treatment and control conditions. Treatment was performed on the left side, 12 times (with pre- and post-measurement), and for the control on the right side 10 times (with pre- and post-measurement), or visa versa. As to which side received the treatment and which side the control/placebo, a dice was rolled for randomization. This chapter presents the results of the study beginning with a description of the sample (8.1) and leading to the evaluation of the hypothesis by examining the overall effect between treatment-control condition (8.2), the effect of the selected side (8.3) and effects of sociodemograhic variables (8.4), regarding the level of sport activity, age, BMI and gender.

8.1. Description of the sample

The age group ranged from 18 years, which was the minimum age due to the inclusion criteria, and up to 67 years, with a mean of 41.73±13.086, and a median of 44 years. Diagram 1 presents the distribution of age (grouped), including a median split.

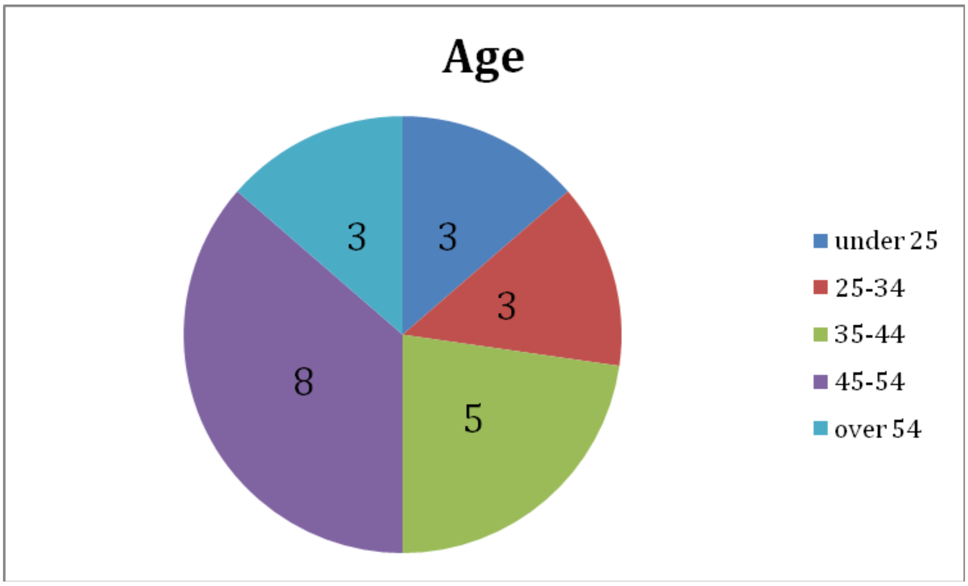

Diagram 1: Age distribution: Absolute frequencies of age groups

Intensity of sports activities was measured as days per week. The range of answers regarding the amount of sport done per week was from 0 to 6 within the group. Diagram 2 presents the distribution of sports activities. It can be seen that more than one quarter of the subjects did no sport at all. Nearly one fifth did sport once or twice a week, so together nearly half of the subjects did sport two times a week, or less. About 55 per cent did sport 3 to 6 times a week.

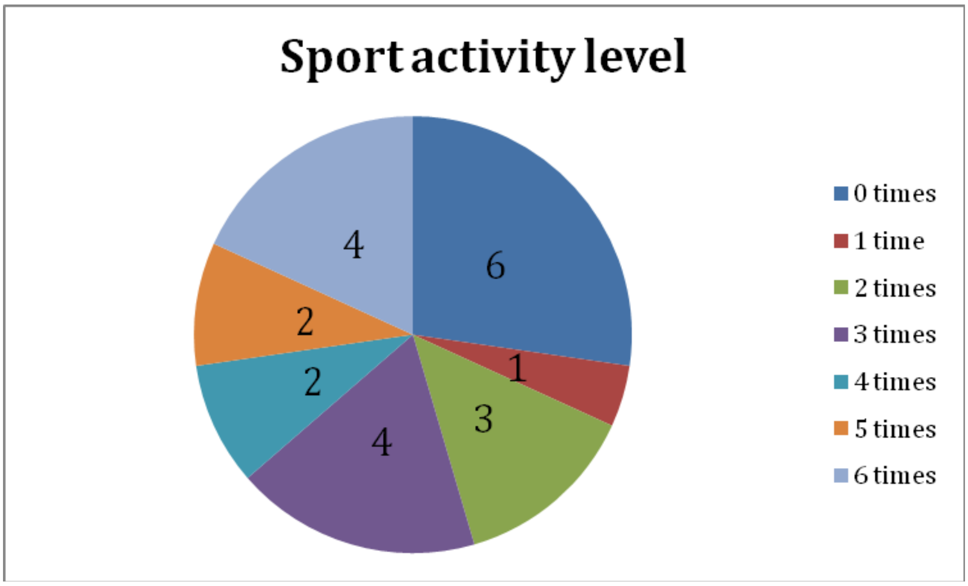

Diagram 2: Distribution of subjects' sporting activities per week (absolute frequencies)

Subjects' weight ranged from 44kg to 115 kg with a mean of 71.82±17.143, and heights ranged from 157cm to 202 cm, with a mean of 174.32±12.276. From these two parameters, the BMI of the subjects was calculated (weight x height). BMI ranged from 17.63 to 28.18, with a mean of 23.30±2.969, and a median of 23.11. Diagram 3 presents the distribution of BMI (grouped) including a median split.

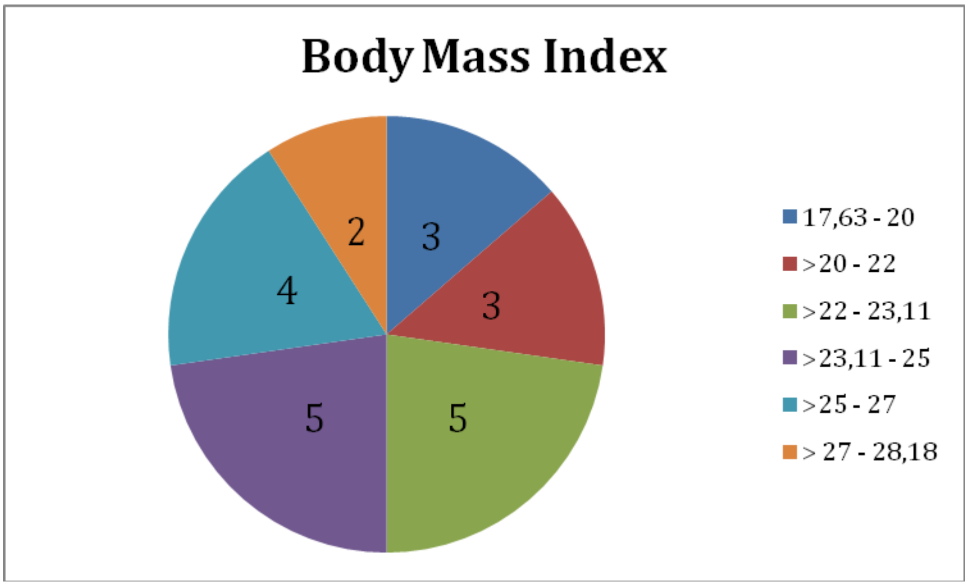

Diagram 3: Distribution of the Body Mass Index (absolute frequencies)

8.2. Overall effect of the treatment vs. control condition

An ANOVA indicates significant main effects for pre-/post- comparison over the treatment groups ($F_{1,21}$=80.102, p<.001), and for the treatment group over the measurement times ($F_{1,21}$=7.897, p=.010). Since there is a significant interaction effect between the treatment groups and measurement time ($F_{1,21}$=32.801, p<.001), the main effect must not be interpreted, and further details should be analysed. This was done by a Bonferroni-adjusted pairwise comparison of the estimated marginal means of the fitted model.

For the condition of performing manual treatment on the plantar fascia these comparisons show a statistically significant increase (p<0.001) in the range of motion on performing the Straight Leg Raise (SLR) in comparison with the range before and after treatment (see Table 2 and Diagram 4). Amongst the subjects in the control condition, no significant difference was observed (p=.079), but a tendency of increased range of motion was depicted (see Table 2 and Diagram 4).

Table 2: Means ± standard deviations of degree of range before (pre) and after (post) the treatment and the control condition

	Pre-	Post-
Treatment	83.55±12.223	95.64±13.910
Control	82.23±13.483	84.05±15.888

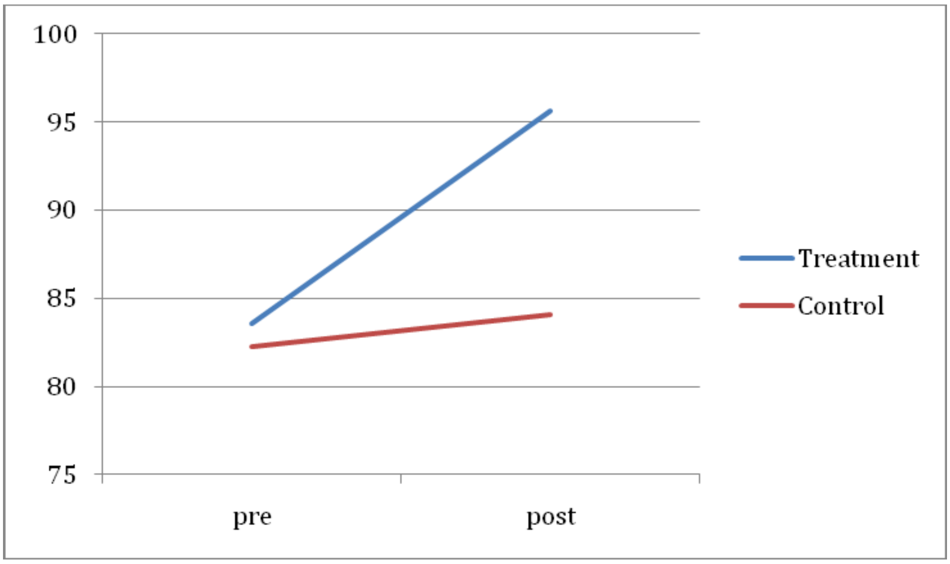

Diagram 4: Treatment vs. Control. The vertical axis shows the degrees of range of motion, and the horizontal axis describes "pre-" (before treatment) and "post-" (after treatment)

Additionally, the pairwise comparisons indicate no difference between the treatment and the control condition in the pre-treatment measurement (p=.513), i.e. the starting conditions were similar for both groups. In the post-treatment measurement, there is significant difference between the two groups (p=.001) indicating a given-effect of treatment.

Inspecting the individual data leads to a further interesting detail. Within the treatment condition, the value of range of motion in the 22 subjects increased between the pre- and post- measurements. In contrast, six of the subjects in the control/placebo condition displayed a lesser range of motion.

Results clearly showed a significant difference between the pre-and post measurements for the treatment group and does not verify the zero hypothesis, or $H0_{(a)}$. The control condition on the other hand, demonstrated no differences and thus confirms the hypothesis $H0_{(b)}$.

8.3. Effect of the selected side

The subject's side (left or right) of the treated and controlled limb was randomly selected by rolling the dice. Out of the 22 samples, 10 subjects received treatments on their left side and control on their right side, and 12 subjects received treatments on their right side and control on their left side.

An ANOVA indicates the same significant main effects for pre-/post- comparison ($F_{1,20}$=75.649, p<.001) and for the treatment group ($F_{1,20}$=8.448, p=.009), as well as a significant interaction effect between the treatment groups and measurement time ($F_{1,20}$=40.197, p<.001), as presented above for the overall analysis.

Neither the interaction between treatment and side, nor the interaction between measurement time and side were significant ($F_{1,20}$=1.156, p=.295; $F_{1,20}$=.000, p=.996). Furthermore, there is no significant main effect for side ($F_{1,20}$=.232, p=.635).

Yet, a threefold interaction between the treatment group and the measurement time and side is just under the level of significance ($F_{1,20}$=4.410, p=.049). The detailed Bonferroni-adjusted pairwise comparisons of the estimated marginal means of the fitted model indicated no differences between the sides in any subgroup of treatment and measurement time (p between .325 and .798). Focusing on the pre-/post-comparison, there are significant differences in both the treatment (p<.001) and control condition (p=.014) for the subjects treated on the right side, but only for the treatment group (p<.001), and not for the control condition (p=.943) for the subjects treated on the left side. Focusing on the treatment, there is a significant difference between the two groups in the post-treatment measurement only for the subjects treated on the left side (p=.001) and a difference only just over the level of significance on the right side (p=.053). In the pre-treatment measurements, there are no differences between the treatment groups on both sides (p=.492 for left and p=.810 for right).

The analysis including the side of treatment mainly confirms the overall finding. (See Table 3 and Diagram 5). The threefold interaction does not point to an impact of the side of the treatment or the effect of the treatment, but only points to variations in the control condition. Further studies would be necessary to investigate this further, but given the p-value of the threefold interaction of .049, as well as the sample size of subgroups, not too much weight should be given to this detail.

Table 3: Side of treatment – means ± standard deviations of degree of range separated by conditions and time of measurement

		Pre-	Post-
Left	Treatment	82.50±7.649	96.50±8.436
	Control	80.40±11.413	80.30±15.195
Right	Treatment	84.42±15.347	94.92±17.604
	Control	83.75±15.327	87.17±16.420

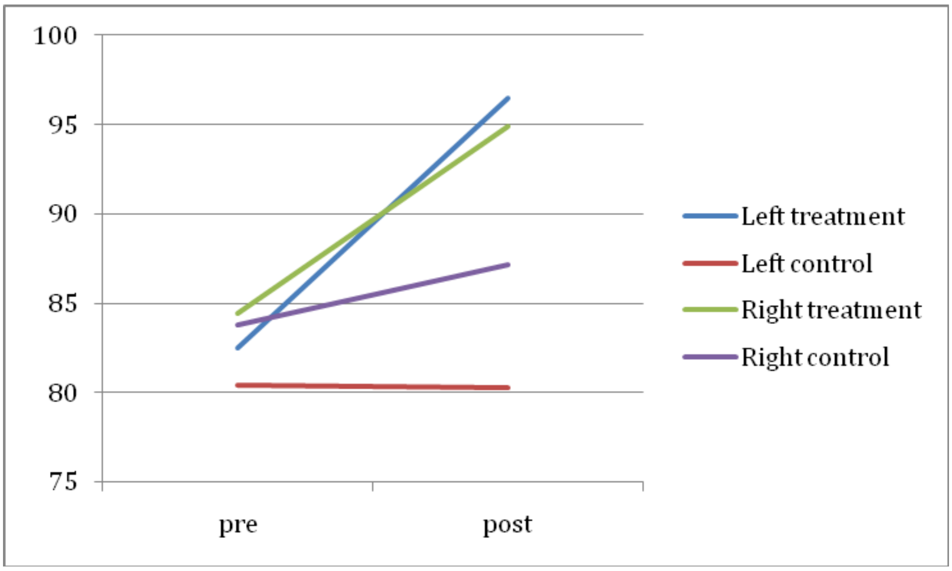

Diagram 5: Comparison of treatments performed either on the left or right foot. The left axis presents the degrees of range of motion and the horizontal axis describes "pre-" (before treatment) and "post-" (after treatment).

Results showed no difference on the treatment between the right or left sides, and thus match the hypotheses $H0_{(c)}$ and $H0_{(d)}$.

8.4. Effects of sociodemographic variables

8.4.1. Level of sport activity

The aim was also to investigate if any changes could be discerned between the measurements with subjects in relation to higher and lower sport activity levels (See Diagram 2). An ANOVA indicates the same significant main effects for pre-/post- comparison ($F_{1,20}$=77.184, p<.001) and for the treatment group ($F_{1,20}$=7.293, p=.014), as well as the significant interaction effect between treatment groups and measurement time ($F_{1,20}$=31.880, p<.001), as presented above for the overall analysis.

Neither the interaction between treatment and athletic activity, nor the interaction between measurement time and athletic activity, or the threefold interaction between these factors were significant ($F_{1,20}$=.474, p=.499; $F_{1,20}$=.777, p=.388; $F_{1,20}$=1.361, p=.257), i.e. there is no variation in the results due to athletic activity. Furthermore, there is no significant main effect for athletic activity ($F_{1,20}$=.918, p=.349), i.e. there is no general difference in degree of range between subjects doing more or less sport.

The analysis, including the level of athletic activity, completely confirms the overall finding and indicates that the effects are independent from this additional factor (See Table 4 and Diagram 6 below).

Table 4: Sport intensity level – means ± standard deviations of degree of range separated by the treatment and control condition and time of measurement

		Pre-	Post-
Low Frequency	Treatment	80.80±6.877	91.00±8.353
	Control	80.10±8.900	82.30±10.220
High	Treatment	85.83±15.296	99.50±16.627

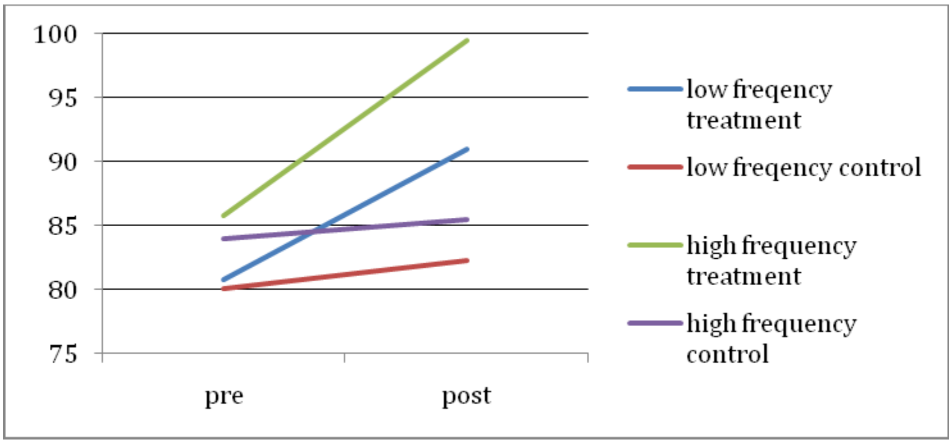

Diagram 6: Comparison between high and low sports' activity in the treatment and control condition. The left axis presents the degree of the range of motion and the horizontal axis describes "pre-" (before treatment) and "post-" (after treatment).

The level of sports' activity, with "low frequency" describes the sports' activity performed twice a week or less and "high frequency" describing 3 times a week, or more. The left axis presents the degree of range of motion, and the horizontal axis describes "pre-" (before treatment) and "post-" (after the treatment).

As indicated, the results verify the hypotheses $H0_{(e)}$ and $H0_{(f)}$.

8.4.2. Age

Even more unexpectedly the data showed no significant difference between subjects in terms of age. Two age groups were determined, under and including 43 years, defined as “young“, and over 43 years of age, defined as “old” (see Table 2) .

An ANOVA indicates the same significant main effects for pre-/post- comparison ($F_{1,20}$=76.338, p<.001) and for the treatment group ($F_{1,20}$=8.894, p=.007), as well as the significant interaction effect between treatment groups and measurement time ($F_{1,20}$=35.712, p<.001), as presented above for the overall analysis.

Neither the interaction between the treatment and age, nor the interaction between measurement time and age, or the threefold interaction between these factors were significant ($F_{1,20}$=3.653, p=.070; $F_{1,20}$=.012, p=.910; $F_{1,20}$=2.864, p=.106), i.e. there is no variation in the results due to age. Furthermore, there is no significant main effect for age ($F_{1,20}$=.105, p=.749), i.e. there is no general difference in the degree of range between older and younger subjects.
The analysis including age completely confirms the overall finding and indicates that the effects are independent from this additional factor (see Table 5 and Diagram 7).

Table 5: Age – means ± standard deviations of the degree of range separated by the treatment and control condition, and time of measurement

		Pre-	Post-
Under 43	Treatment	81.27±14.533	92.00±16.383
	Control	82.64±14.821	86.00±17.703
Above 43	Treatment	85.82±9.548	99.27±10-432
	Control	81.82±12.719	82.09±14.432

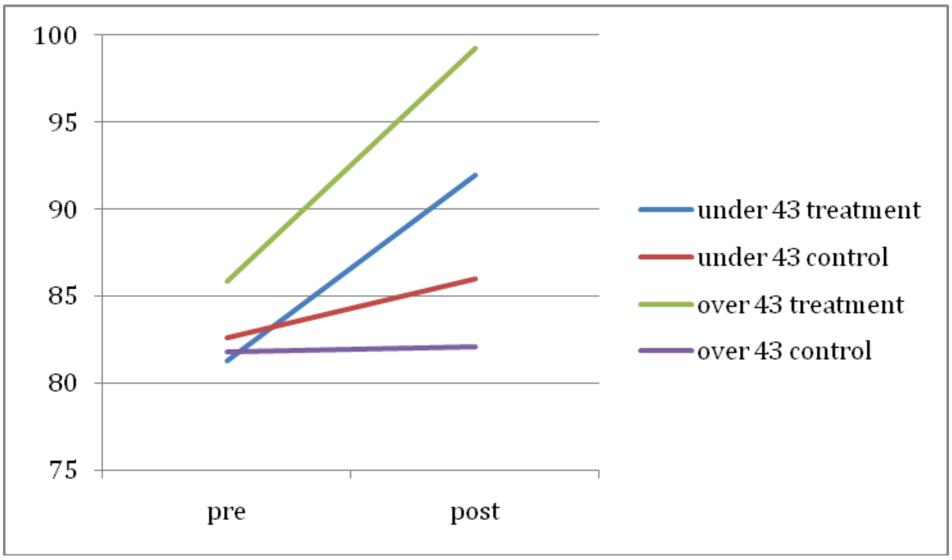

Diagram 7: Comparison of age differences in the treatment and control condition. The left axis presents the degree of the range of motion and the horizontal axis describes “pre-” (before treatment) and “post-” (after treatment).

Ages under and including 43 years was defined as “young”, and over 43 defined as “old”. The left axis presents the degree of range of motion and the horizontal axis describes “pre-” (before treatment) and “post-” (after treatment).

In conclusion, there was no difference between pre- and post- measurements in respect of age. Hence the hypotheses confirms $H0_{(g)}$ in the young group and $H0_{(h)}$ in the older group.

8.4.3. Body Mass Index (BMI)

In this study a marker was set between higher and lower BMI of 23.11 (median-split). A BMI-value of above 23.11 was considered a “high BMI” while a sum below that marker was defined as a low BMI (see Diagram 3).

An ANOVA indicates the same significant main effects for pre-/post- comparison ($F_{1,20}$=78.178, p<.001) and for the treatment group ($F_{1,20}$=9.600, p=.006), as well as the significant interaction effect between the treatment groups and the measurement time ($F_{1,20}$=31.553, p<.001), as presented above for the overall analysis.

Neither the interaction between the treatment and the BMI, nor the interaction between the measurement time and the BMI, or the threefold interaction between these factors were significant ($F_{1,20}$=3.137, p=.092; $F_{1,20}$=.399, p=.535; $F_{1,20}$=.131, p=.721), i.e. there is no variation in the results due to BMI. Furthermore, there is no significant main effect for BMI ($F_{1,20}$=.108, p=.745), i.e. there is no general difference in the degree of range between subjects with a higher or lower BMI.

The analysis including the BMI confirms the overall finding and indicates that the effects are independent from this additional factor (see Table 6 and Diagram 8 below).

Table 6: Body Mass Index (BMI) – means ± standard deviations of the degree of range separated by the treatment and control condition, and the time of measurement

		Pre	Post
Up to 23.11	Treatment	86.20±10.239	99.20±12.726

	Control	81.00±13.540	83.00±15.420
Over 23.11	Treatment	81.33±13.700	92.67±14.687
	Control	83.25±13.949	84.92±16.898

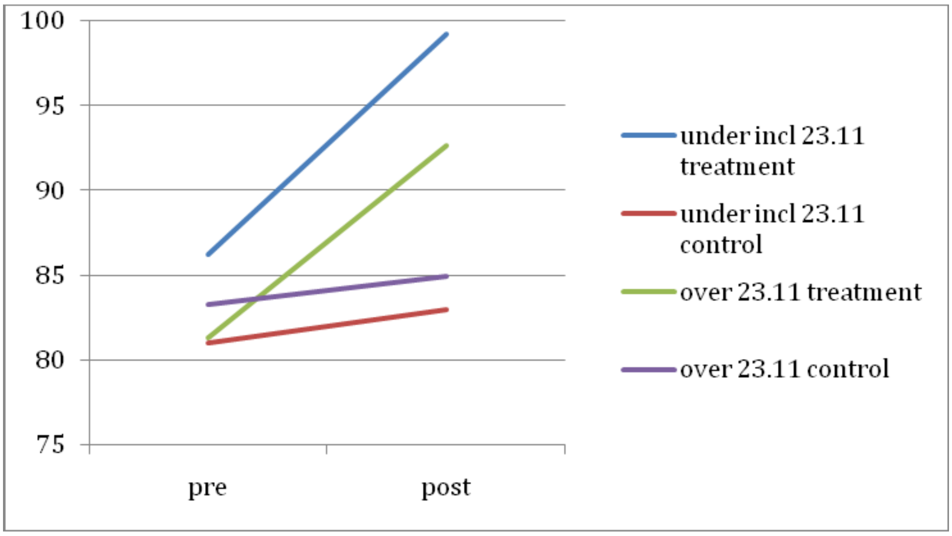

Diagram 8: Comparison between low and high BMI in the treatment and control condition. The left axis presents the degree of the range of motion and the horizontal axis describes “pre-” (before treatment) and “post-” (after treatment).

A number above 23.11 was considered a “high BMI”, while the sum below that marker was valued as a low BMI. The left axis presents the degrees of range of motion and the horizontal axis describes “pre-” (before treatment) and “post-” (after treatment).

Conclusively, no significant difference was measured which supports the hypothesis H0 $_{(i)}$ and H0 $_{(j)}$.

8.4.4. Gender

The sample consisted of 11 female and 11 male subjects. An ANOVA indicates the same significant main effects for pre-/post- comparison ($F_{1,20}$=88.403, p<.001), and for the treatment group ($F_{1,20}$=7.752, p=.011), as well as the significant interaction effect between the treatment groups and the measurement time ($F_{1,20}$=31.428, p<.001), as presented above for the overall analysis.

Neither the interaction between treatment and gender, nor the interaction between measurement time and gender, or the threefold interaction between these factors was significant ($F_{1,20}$=.615, p=.442; $F_{1,20}$=3.176, p=.090; $F_{1,20}$=.121, p=.732), i.e. there is no variation in the results due to gender. Furthermore, there is no significant main effect for athletic activity ($F_{1,20}$=2.632, p=.120), i.e. there is no general difference in degree of range between women and men.

The analysis including gender completely confirms the overall finding and indicates that the effects are independent from this additional factor (see Table 7 and Diagram 9 below).

Table 7: Gender – means ± standard deviations of degree of range separated by the treatment and control condition, and the time of measurement

		Pre	Post
Female	Treatment	81.09±13.134	91.55±16.065
	Control	77.64±14.473	78.45±16.646
Male	Treatment	86.00±11.314	99.73±10.555
	Control	86.82±11.223	89.64±13.574

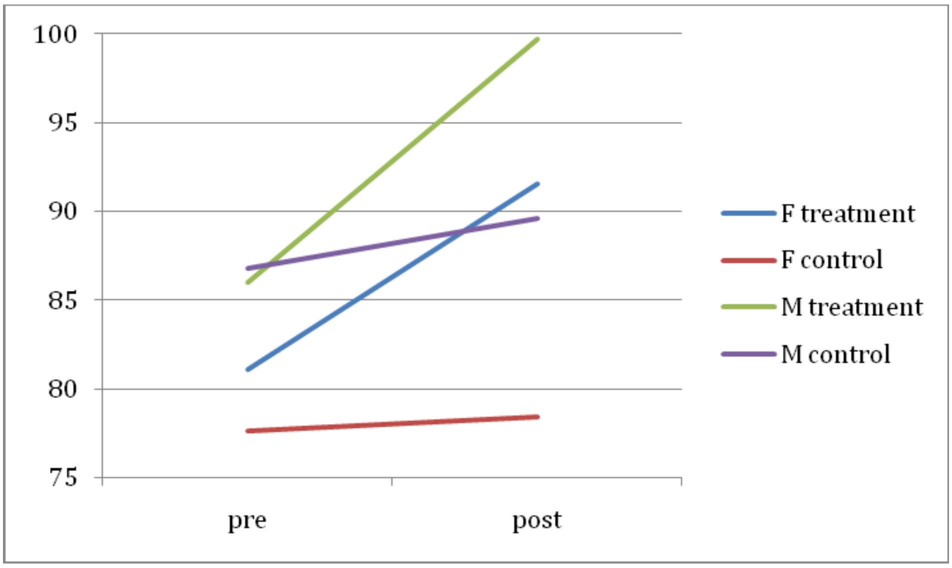

Diagram 9: Comparison between female and male in the treatment and control condition. The left axis presents the degree of the range of motion and the horizontal axis describes “pre-” (before treatment) and “post-” (after treatment).

$H0_{(k)}$ and $H0_{(l)}$ states no significant differences in age, confirmed by these results.

9. Discussion of results

The purpose of the study was to investigate whether a manual treatment on the plantar fascia significantly influences the range of motion of hip flexion verified by a Straight Leg Raise (SLR) on healthy subjects compared to the control condition. The investigator's objective was to explore the prevalence of a pattern of load on the myofascial expansions throughout the length of the posterior backline of the plantar fascia to the hip/pelvic region by performing a movement protocol of the SLR.

9.1. Interpretation of the main findings

The findings support that there is a force transfer between the foot and the hip. When performing manual treatment on the plantar fascia the results of the measurements showed a statistically significant increase ($p < 0.01$) in the range of motion on performing the SLR in comparison with the range before and after treatment.

Amongst the subjects in the control condition, no significant difference was observed, but a tendency of increased range of motion was depicted. The reason may be that there was a repetition of the SLR test. As discussed above (Chapter 4, Biomechanics and Response on Pathological Alteration of the Fascia), fascia is susceptible to viscoelastic deformations such as creep, hysteresis and relaxation. These observed deformations alter fascial stiffness so when the first SLR was performed it could have induced a "creep" on the connective tissue of the posterior region of the limb. Thereby, it may have increased the flexibility and range of motion of the limb and so its fascia during the second SLR test. The difference between the pre- and post-measurement might possibly have been less visible if the subjects were to lie longer on the treatment bed, for instance for the same time it took for the treatment i.e. 10 minutes.

Some of the subjects in the control condition showed a decreased a range of motion in the post measurement. The investigator's understanding for this result is that it could have been caused by resting and lying on the treatment bed (for 5 minutes), followed by stiffness and hence a decreased range of motion. Reasons as to why some subjects under the control condition increased, while others decreased their range of motion during the control condition have so far not been clarified.

As an interesting side observation the objective measurements and subjective sensation of the subjects showed a close correlation. In other words, when the measurements showed a profound increase of range of motion the subjects reported to have the same sensation, or impression. In cases where the measurements depicted just a little or even no increase of range of motion the subjects reported similar impressions. When after the experiments the subjects were asked how they felt, they stated that their treated side was “lighter”, “the leg longer” and “looser” and many verbalised the wish to be treated on the other side too in order to receive their “balance” back again.

In sum, the results of the study suggest that fascial structures form an integrated system that establishes an efficient load transfer between pelvis, hip and foot. Corroborating with these findings, various other studies confirmed the fascial force transmission. The findings of Frankly-Miller et al., (2009) presented similar results by demonstrating the fascial strain transmission in the lower limb fascia by performing a SLR with a monitored tension of 26% of the plantar fascia (in relation to the 100% strain of the hamstring). A further study by Vlemming et al. (1995) verified tensile transmission by applying tension to the posterior layer of the thoracolumbar fascia on cadavers by exciting traction to various muscles, in particular, due its relevance, biceps femoris, resulting in the posterior layer of the thoracolumbar fascia performing a displacement.

The results of the force transmission of the thoracolumbar fascia (Frankly-Miller et al., 2009; Vleeming et al., 1995) and of the limb, as examined in this work, verifies the assumptions of a force transmission of the fascial system.

After performing manual treatment on the plantar fascia the measurements demonstrated a significant increase in the range of motion on the SLR. This suggests that the load transmission expressed, starting from the plantar fascia and continuing to the posterior limb and to the hip/pelvic region, was induced by the fascia, thereby supporting the hypotheses for fascial tensegrity and its fascial continuum. This reveals that the fascial structures are an integrated system that establishes a basis for the understanding of efficient load transfers.

9.2. Analyses of further results

No significant difference between the pre- and post- measurements was observed between the left and right sides and in terms of sports intensity, age, BMI and gender and should be discussed separately.

9.2.1. Effects on sides of treatment and control of the limb

Contrary to the study of Smalls et al., (2006), which showed differences in the results of subjects' dominant and non-dominant sides, this study did not reveal any significant difference between the left and the right sides in the treatment and in the control condition.

Specifically, the investigations that were conducted by Smalls et al., (2006) on physiological changes in tissue structure, composition and function in the dermal and superficial fascia, as termed "subdermal tissue", showed significant differences between the dominant and non-dominant sides. "The dominant side (right for 90% of the subjects) had increased stiffness and decreased energy absorption (tissue softness, compliance) compared with the left side" (Smalls et al., 2006, p.43).

While the findings of Small et al. (2006) are interesting in the context of side differences they are nevertheless an investigation applied on the shoulder where the dominating vs. the non-dominating side assumingly has a bigger impact on the upper limb then on the lower limb. Hence perhaps these observations are not directly compatible with this study.

9.2.2. Age difference

Even more unexpectedly the data showed no significant difference between subjects in terms of age. The two age groups were determined, under 43 – defined as young and over 43 – defined as old.

In contrast, the research of Smalls et al., (2006) show that age has a significant impact on the thickness of the tissue. Also, passive and active examination related to lumbar spine range of motion presented a significantly decreased range of motion as age increased (Dvorak & Vajda, 1995). In addition, sonographic variations of heel fat pad thickness in relation to level of age were investigated (Uzel et al., 2006).

Clearly, the above mentioned studies demonstrate an influence of age on the connective tissue, its biomechanical properties and its response. Assumptions made on the correlation between the measurements of tensile transmissions found in this study and the presented evidence (Smalls, Randall, Wickett & Visscher et al., 2006) of the biomechanical properties of the superficial fascia were not confirmed.

9.2.3. Level of athletic activity

The aim of this study was to investigate if any changes could be discerned between the measurements of subjects in respect to high/low athletic activity levels.

Sonographic changes of heel fat pad thickness and the compressibility index in healthy young adults in relation to their level of athletic activity were investigated (Uzel et al., 2006). The heel pad thickness and heel pad compressibility index (HPCI) was calculated in individuals engaging in athletic activity up to an average of 11 hours/week. The results were equal to those of inactive subjects.

This study supports the findings that no significant difference could be found between the subjects who engaged in high athletic activity levels and those who were sedentary.

9.2.4. Body Mass Index (BMI)

In this study a marker was set between a higher (i.e. than 32.11) and a lower (i.e. than 23.11) BMI. A number above 23.11 was considered a “high BMI”, while the sum below the marker was valued as being a low BMI.

Smalls et al. (2006) observed that the Body Mass Index (BMI) influences the resultant biomechanical properties and physiological changes in tissue structure and function. A higher skin thickness and a higher Body Mass Index (BMI) showed a significantly increased stiffness.

This work revealed no similarities in respect of the observed biomechanical properties in terms of BMI, in the superficial fascia as revealed in the study of Small et al. (2006), compared with the results of this study (in terms of its composition of biomechanical).

9.2.5. Gender

It is interesting to observe that the results did not present any difference between females and males on the range of motion in the SLR.

According to Abu-Hijleh et al. (2006) the arrangement and thickness of the superficial fascia varied according to body region, body surface and gender. His observation showed the superficial fascia to be thicker in females than in males. Also, according to the study of Campanelli et al. (2011) the heel fat pad was found to be thicker in males than in females by 1-3mm, supporting a similar finding to that of Uzel et al. (2006).

On the other hand, passive and active examination related to lumbar spine range of motion in subjects divided into groups demonstrated no significant gender differences (Dvorak & Vajda, 1995).

Differences in biomechanical properties seen on the superficial fascia (Abu-Hijleh et al., 2006) were not confirmed in this study.

9.3. Limitations to the methodological approach

There are several potential limitations of this study that are addressed with additional suggestions for improvement.

- This study was performed a small sample size of 22 subjects. A suggestion for improvement would be to obtain the measurements with a larger sample size.

- Even though the investigators' hand was above the knee to prevent knee flexion during the passive SLR it cannot be ruled out that movement did not occur. To ensure a constant extension of the knee, it would be advisable to attach an orthotic on the subjects' knee to allow certification of correct handling and continuity of performance during the testing.

- At the passive SLR, focus was directed on the speed and straight raising of the leg. If the SLR was undertaken too rapidly the reported stop from the subjects could occur earlier (presuming because of less time for adapting "creep" and "hysteresis" deformation). If the test would have been carried out at a slower speed it could be presumed that the fascia's plasticity allowed more time to adjust to the strain thus allowing an increase in range of motion. As discussed previously, examining the viscos-elastic mechanical properties of the fascia revealed it to be orthotropic and it was observed that the relaxation process depended on the direction of the loading (Kirilova et al., 2009).

- Depending on the mechanical loading which the fascia is subjected to, it can change its constitution and can thus vary its properties by shifting its plasticity and elasticity component (Findley et al., 2012). The second investigator was instructed to perform the test with a consistent speed and straight course. Nevertheless, due to a small variation of each of the subject's limbs (with different levers, lengths and weight) the question arises if the speed (which influences creep and hysteresis deformation) and trace (where the anisotropic properties of fascia reports the relaxation process to be depending on direction of load applied - as reviewed in chapter 4) were kept constant. It cannot be confirmed that this was always the case.

- The measurements were only processed once. This paper thus only represents the short-term effect of the manual treatments on the plantar fascia on the increased range of motion verified by the straight leg raise. The long terms effects are therefore not portrayed.

- The sequence of the study was set to first start with the treatment followed by the control condition. The reversed sequence was not examined in this study. In addition, the treatment (constituting 10 min) and the control condition (duration of 5 minutes) did not have the same time span. Due to the different time duration of the interventions, with less time to recover from a "creep deformation" (tissue deformation under the influence of mechanical stresses) (Schleip et al., 2010), occurring after the SLR, there may have been a different result if the study would have been carried out in a reversed sequence, and by performing the treatment and control condition in an ongoing timeframe.

With respect to the limitations of the methodological approach and recommendations for aspects of improvements, especially for further investigations, the results nevertheless suggest that the tension load evidently was effectively transmitted between the suspected myofascial system supporting the hypotheses for fascial continuum. This reveals the fascial structure as an integrated system that establishes a basis for the cognition of an efficient load transfer between the pelvis, hip and foot.

9.4. Clinical implications and outlook

As discussed in chapter 2 (Basics of the Anatomy of the Fascia), the deep fascia is separated by layers adjacent to each other bound by loose connective tissue, thereby allowing a gliding of the layers. This permits the load and force in multiple directions, generated by different muscular orientations, to be transmitted smoothly (Stecco et al.,

2009a) (Natali, Pavan & Stecco, 2010).
Stecco et al (2011) observed increased viscosity of the hyaluronic acid at the interface between deep fascia and the epimysium, lowering the quality of sliding between the fascial layers. When the efficiency of the sliding is reduced the fascia´s distribution of lines of force alters. This could withhold fascial functional property to render the transmission and transition of the tension in an efficient way. This could occur in case of trauma, overuse, inflammation and misuse (Stecco, 2009).

According to Stecco (2007b) the superficial fascia contains a dense presence of sensory mechanoreceptors (Pacini receptors and Ruffini endings) and both the hyaluronic acid and the viscoelasticity of the fascial structure are influencing the response of the mechanoreceptors (Stecco et al., 2011). Altered tension also shows that the load tensions can produce a non-physiological mechanical stimulus, enhancing nociception stimulus (Buckley et al., 2001; Cao, Hicks, Campbell & Standley, 2013; Deising et al., 2012).

Furthermore, the observation of selected myofibroblasts found in the fascia shows that the fascia is able to contract in a smooth muscle-like manner, thereby also influencing myofascial biomechanics (Schleip, Klingler & Lehmann-Horn, 2005).

In conclusion, in case of interruption of the transmission of force between the myofascial layers, the incitement of the varied sensory, nociception and the myofibroblasts can cause a variety of symptoms to emerge, ranging from back pain as "reduced thoracolumbar shear strain" (Helene Langevin et al., 2011) to poor motor-control and balance problems (Stecco et al., 2011) as discussed above on the Stecco's Fascial Manipulation approach (Chapter 6.2).

Awareness of these fascial links help osteopaths to comprehend the multiple structural connections, hence to focus on and be more effective in the appropriate application of techniques. Stecco's et al (2014) observation of the major insertion of the gluteus maximus major into the fascia lata may entail that lateral knee pain, (also termed as "iliotibial band friction syndrome", ITBS), might be provoked by a hypertonic gluteal maximus major muscle. In this situation osteopathic diagnosis and treatment should therefore emphasize not only the knee and the iliotibial band but also the examination of the gluteal maximus muscle.

The observation of Vleemming et al. (1995) verified the direct mechanical force transmission from pelvic to upper extremity by stimulated traction on cadavers on *inter alia* bicebs femoris muscle, gluteus muscle and contralateral lattisimus dorsi muscle, causing tensile transmission further on the thoracolumbar fascia. Consequently, the assumption could be made that force transmission could proceed from gluteus maximus muscles, continuing via sacro-tuberous ligament and further, thanks to the thoracolumbal fascia, to the lower lumbar spine proceeding to the lattismus. Combining these findings with the findings of this paper the myofascial distribution of load can be identified from foot to the shoulder.

Myers' (2004), observations on myofascial distortions such as stiffness of the plantar fascia resulting in further tension spreading upwards through the superficial back line, leading to tighter hamstrings and, furthermore to an extended lumbar lordosis (chapter 6.3) can confirm this assumption.

To reiterate, the fascia is functionally designed to envelop and surround every muscle, every blood vessel, all nerves, and every organ (Schleip, Jäger & Klinger, 2012) as it extends from head to toe, front to back. Throughout history anatomists and clinicians have tended to view the body in its separate parts and not in its complete entirety. This can give a false impression and risks to treat the body partially and not in its complex, whole system. A case in point is the fascial continuity, which cannot be understood as an isolated structure as it forms a complex interwoven construction, in line with the fundamental osteopathic principle of the unity of function (Chila, 2011). The aim of this study was to underline the unity principle by demonstrating the fascial unity from foot to pelvis region and it thereby emphasizing the essential holistic approach for the osteopathic medicine.

10. Conclusion

While it is too early to support the claim of fascia *singularly* performing the load transmission in the lower limb, it is important to acknowledge the findings of this study, which clearly observed an effective force transmission during a Straight Leg Raise (SLR). Growing proposals for holistic or whole body approaches to treatment should be acknowledged and pursued, especially in that they support the underlying philosophy of osteopathy within the human body, which is seen as both a unit and integrated organism, in which no part functions independently.

Literature on experimental investigations of the force transmission during the Straight Leg Raise (SLR) is limited. The central focus of this paper was to investigate whether a manual treatment on the plantar fascia in healthy subjects, verified by a SLR, significantly influenced the range of motion of the hip flexion region compared to the control condition.

During the past 10 years, research on fascia anatomy, function and biomechanics has made substantial progress. Preliminary studies such as, Huijing (2012), Franklyn-Miller et al. (2009), and Vleemings et al. (1995) have shown evidence of force transmission within the fascial system. However, there has been little research reported on the effectiveness of force transmission between the foot and hip/pelvic areas except for a few researchers, for example Franklyn-Miller et al. (2009), and no investigation has been made on the treatment of the plantar fascia and its effect on the range of motion on the hip/pelvis or even on the higher located lumbar spine, and further distal cervical spine.

The findings of this study clearly suggest that there is an effective force transmission of the fascia, which extends to the prolonged structural segments, interacting between the plantar fascia and the hip. Further research is needed, however, to clarify whether it is the fascia acting alone, or whether other structures are also involved in transmitting the load transmission.

10.1. Relevance

These observations provide us with a new understanding for investigating myofascial pathways, force transmission and their functional significance for the whole body pattern.

This work provides convincing evidence that the transmission of the load is facilitated by fascial tensegrity. Thereby, it offers new insights into, and a deeper understanding of, treatments directed at the fascia such as manual myofascial techniques.

Studies have demonstrated that the fascia system has a vital role in the proprioception (Langevin, 2006; Stecco et al., 2007b) and in nociception (Yahia et al., 1992). The findings in this study justify the observation that treatment on the plantar fascia may have an impact on the release of tensional force, thereby relieving stress on the pelvic/hip region. If evidence is proved correct that myofascial force transmission is present, treatment can be applied at a distance from the actual site of the painful area. This allows for fewer contraindications and a safer procedure for treating highly sensitized, painful dysfunctions particularly in the acute phase.

Understanding the fascial force alignment and strain, as in the context of this example, namely the lower limb, effective treatment could address the underlying cause of illness rather than the symptoms, since perception of pain does not necessarily take place in the same region as the origin of disease/condition. This suggests that influences at a distance need to be considered in the osteopathic assessment when seeking the causes and maintaining elements of any pain or restriction.

The principles and treatment methods within the osteopathic field, as were previously mentioned, for instance Fascial Manipulation Musculoskeletal Pain (Stecco, 2004), are based on the understanding that a patients' perception of pain is often localized in a different part of the body than that requiring treatment.

In the medical field there is a tendency to focus on selected specific structures of the body instead of perceiving it in its entirety. This partial approach could give false impressions and misleading insights within the clinical environment and also perhaps inhibit an enhanced understanding of the presented ailments/symptoms. A described complaint, for instance, a "pulling" sensation running down the leg would be labeled as the "sciatica", "piriformis syndrome", or a "pulled muscle". These attempts, however, imply only a perception of standardized scientific terminology based on assumptions. Instead, one can change the perspective and viewpoint in considering fascia's role within the body, which interconnects the vessels, nerves and muscles, thus forming a complex network as whole, which is a key concept of the osteopathy.

10.2. Further investigation

The studies of Vlemmings et al. (1995) and Franklyn-Miller et al. (2009) show that on the contralateral lumbar fascia during the SLR that the force transmission can extend even further to the fascia thoracic lumbar region.

It would be of great benefit to the study of osteopathy to have further investigations carried out on fascial force transmission to observe the effect of the range of motion in the lumbar spine when performing a treatment on the plantar fascia. Tension loading on the lumbar region could for instance be examined with the performance of the forward bending test.

As discussed above, the distinct interlayered structure of the connective tissue is of essence for qualitative sliding explicitly for force transmission. As was also pointed out, a modification or disruption of such sliding, either due to trauma or overuse, causes the myofascial structure to undergo adjustment shifts and thereby altering the biomechanical properties of the fascia alter when confronted with tension (Stecco, 2009). In this case, pathological fibro-contractive changes enhance fibroblast hyperplasia, chronic inflammation and sensitized nociceptors stimulus (Buckley et al., 2001; Cao et al., 2013; Deising, 2012).

Hence the assumption can be made that in the case of systemic disorders or pathologies, where fibro-contractive changes occur, an alteration of the transmission and a transition of tension could follow. Consequently, an uninterrupted healthy myofascial system with qualitative gliding is of essence for effective force transmission, and in the case of disruption, the transmission force could be interrupted, enforcing nociceptive stimulation (Stecco et al., 2009a).

As for the SLR test, clinicians investigating the quality of force transmission of the lower limb, the passive SLR test, used in this study could be a useful diagnostic method in the clinic. These insights into force transmission also indicate interesting implications for the understanding of musculoskeletal pathologies and offer new perceptions and a deeper understanding of, treatments directed at fascia, such as manual myofascial techniques. Its systemic approach provides new avenues for future concepts and new therapeutic perspectives for a wide range of conditions.

The mechanical behaviour of investigated fascia of the lower limb leads to the assumption, though not yet conclusive, that strain transmission between the plantar fascia and the hamstrings flexibility shown in the SLR could exist. Further research is needed to clarify if explicitly the fascia, in addition to this myotendinous force transmission, is *a* structure or *the only* structure that transmits the load transmission, since the fascia was not isolated from other structures in this experiment.

Therefore, specific measurement of the connective tissue and its resistance with the use of specific devises such as the Myotonometer® is recommended. The Myotonometer® measures the amount of resistance and force-displacement characteristics of muscles and other tissues located beneath the measuring probe (Kerins et al., 2013). The probe is applied in a direction perpendicular to the muscle fibers.

Researchers are momentarily examining this device to ensure that it meets high reliability standards in terms of quantifying the compliance of soft tissue and its effectiveness in detecting increased tissue tightness in the shoulder of posterior shoulder tightness (Kerins et al., 2013). If it meets the standard quality criteria it would be justified then to assume this to be a valuable tool in the future for measuring increased tissue tension and strain transmission under strain performed on the myofascial system, for example, as is seen in the SLR test. If this were to be the case, it may be seen as the gold standard for investigating force transmission of the fascial system in the future.

Further investigation is recommended on this hypothesis on subjects with musculoskeletal injury conditions and a change of mechanical properties e.g. muscle tears, plantar fasciitis etc. Questions arise then if the load transmission still performs in a similar way, or whether it is interrupted. Accordingly, the observations detailed in this study can be seen as a first step, but would need to be verified by further investigations through additional research. Preliminary studies such as Vleemings et al. (1995), Franklyn-Miller et al. (2009) and Huijing (2012), also confirm that further investigations are necessary for clarifying key issues on the force transmission of the fascial system.

10.3. Tensegrity

The results of this study may encourage to view the human body as an entire functional unit, one of the main principles of osteopathy by enhancing the understanding that through the fascial continuum it is possible, for a continuous, tensional network to support the whole body system, subsequently forming complete and ideal tensegrity equilibrium.

An equal distribution of force enables the fascia to function throughout the entire body, i.e. enveloping, interacting and permeating every organ, muscle and even every cell creating continuity, thus giving form and function to all of these. This interactive connective tissue constitutes an organ that can affect an individual person's health and may thus influence and circumvent disease. Awareness of the fascia's continuing structure to support and communicate between the body`s tissues becomes significant within a more general perspective concerning a patient's health.

The understanding of the integrated myofascial system and its load transmission clearly shows its complexity. This study constitutes only an initial endeavor to examine this complex system and calls for more scientific and clinical work to reveal the entire principles of its complexity.

With these insights and associated discussions of fascial integration, the study closes with a few words from the father of osteopathy, A.T. Still:

> "I know of no part of the body that equals the fascia as a hunting ground. I believe that more rich golden thoughts will appear to the mind's eye as the study of the fascia is pursued than of any other division of the body." (Still, 1902, p. 48).

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Appendix

List of Figures

Figure 1: Cranial view from behind (left) and side (right). Fascial expansion from plantar fascia with the continuation of lower limb, sacrotuberous ligament, iliocostalis to the galea aponeurotica (with kind permission of Myers, 2004, n.p) 9

Figure 2: Myofascial unit of retro motion of the lower limb (Stecco, 2004, p. 74)...................20

Figure 3: CCs of fusion of the re-me-pe spiral (Stecco, 2004, p. 215) 21

Figure 4: CCs of fusion of the retro-medial diagonal (Stecco, 2004, p. 236) 22

Figure 5: Superficial Backline (Myers, 2004, p.70)..24

Figure 6: “Bow and arrow” around the heel 25

Figure 7: Cadaver of plantar fascia with continuation to the calf muscles..............................25

Figure 8: Procedure for the treatment and control condition 32

Figure 9: Procedure for the measurements of the passive SLR with the use of the ankle-foot orthosis brace to stabilize the dorsiflexion of the ankle and the belt to prevent the posterior tilt of the pelvis 33

Figure 10: Application “G pro” for the iPhone 5 to measure range of motion in the SLR test 34

Figure 11: List of tools, from left to right and from top to bottom - Ankle brace orthosis, US apparatus, belt, “Fazer” device by Artzt Vitality®, dice, lubrication, watch, iPhone 5............39

List of Tables

Table 1: Strains transmission during Straight Leg Raise - compared to strain of 100% outcome of the posterior thigh (Franklyn-Miller et al., 2009, pp.150-151) 17
Table 2: Means ± standard deviations of degree of range before (pre) and after (post) the treatment and the control condition 45
Table 3: Side of treatment – means ± standard deviations of degree of range separated by conditions and time of measurement 47
Table 4: Sport intensity level – means ± standard deviations of degree of range separated by the treatment and control condition and time of measurement 49
Table 5: Age – means ± standard deviations of the degree of range separated by the treatment and control condition, and time of measurement 50
Table 6: Body Mass Index (BMI) – means ± standard deviations of the degree of range separated by the treatment and control condition, and the time of measurement 51
Table 7: Gender – means ± standard deviations of degree of range separated by the treatment and control condition, and the time of measurement 53

List of Diagrams

Diagram 1: Age distribution: Absolute frequencies of age groups 43
Diagram 2: Distribution of subjects' sporting activities per week (absolute frequencies) 44
Diagram 3: Distribution of the Body Mass Index (absolute frequencies)................................45
Diagram 4: Treatment vs. Control. The vertical axis shows the degrees of range of motion, and the horizontal axis describes "pre-" (before treatment) and "post-" (after treatment) 46
Diagram 5: Comparison of treatments performed either on the left or right foot. The left axis presents the degrees of range of motion and the horizontal axis describes "pre-" (before treatment) and "post-" (after treatment)..48
Diagram 6: Comparison between high and low sports' activity in the treatment and control condition. The left axis presents the degree of the range of motion and the horizontal axis describes "pre-" (before treatment) and "post-" (after treatment). 49
Diagram 7: Comparison of age differences in the treatment and control condition. The left axis presents the degree of the range of motion and the horizontal axis describes "pre-" (before treatment) and "post-" (after treatment). 51
Diagram 8: Comparison between low and high BMI in the treatment and control condition. The left axis presents the degree of the range of motion and the horizontal axis describes "pre-" (before treatment) and "post-" (after treatment)...52
Diagram 9: Comparison between female and male in the treatment and control condition. The left axis presents the degree of the range of motion and the horizontal axis describes "pre-" (before treatment) and "post-" (after treatment)...53