MRI ANALYSES IN THE LOWER LEG TO ASSESS MECHANICAL EFFECTS OF DROP FOOT TAPING APPLIED OVER M.TIBIALIS ANTERIOR

by

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Submitted to the Institute of Biomedical Engineering
in partial fulfillment of the requirements
for the degree of
Master of Science
in
Biomedical Engineering

Boğaziçi University
2015

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DATE OF APPROVAL: 9 June 2015

ACKNOWLEDGMENTS

At first and specially I would like to thank to my supervisor Can A. Yücesoy for his guidance, insightful comments and endless patience. This patience and tolerance of him has helped me to succeed at my work and tought me to get different perspectives while dealing with a task. I would also like to thank Arda Arpak and Uluç Pamuk for helping me at system analysis, without them I would not be able to complete this thesis.

I am deeply greatful to Alper Yaman and Agah Karakuzu. They tried to explain everything about MRI analysis and Demons algorithm. I wish to express my gratitude to İsmail Devecioğlu, Murat Tümer, Hakan Solmaz, Duygu Şahin, Büşra Kahraman Ağır, Müge Türkaydın, Burçin Acar, Alp Özdemir, Ümit Arabul, Didar Talat, Nermin Topaloğlu, and Ahu N. Türkoğlu for their friendship and support. I would also like to thank Ayşegül Ünal, Çiğdem Günsur and Muhammed Avşar, they were always welcoming in helping with administrative issues.

This thesis is dedicated to my husband, Erdem Çörekçi. I am very grateful to him for his support, patience and encouragement when I am exhausted with work, school, thesis experiment and writings. He made this work possible.

ABSTRACT

MRI ANALYSES IN THE LOWER LEG TO ASSESS MECHANICAL EFFECTS OF DROP FOOT TAPING APPLIED OVER M.TIBIALIS ANTERIOR

Kinesio Taping (KT) is used by physiotherapists e.g., to reduce adhesions in the fascia. Leading to disorganization of connective tissue after trauma, underlying muscle tissue may not function optimally and the circulation in the area gets disrupted. When there is inefficient circulation, the connective tissue network gets denser, creating even more adhesions. To increase the blood circulation and muscle performance, and to decrease pain that may occur after injuries, KT is used during treatment. Numerous studies assessed the effects of KT over pain, range of motion(ROM) and muscle function. However, the mechanical effects of KT applications remain unclear. The present study assesses the mechanical effects of KT in the lower leg of healthy subjects. Drop foot correction is used as a KT application for such testing. The results show that, KT application over the tibialis anterior muscle (TA) causes sizeable and heterogeneous tissue deformations within not only the target but also within all muscles of the lower leg: up to 38.7% lengthening and 26% shortening in the TA, 21% lengthening and 14.2% shortening in mm. peronei, 15.9% lengthening and 16.9% shortening in the deep flexor muscles, 24.7% lengthening and 20.3% shortening in the m. soleus, and 24.9% lengthening and 20.3% shortening in the m. gastrocnemius. It was concluded that, KT plays a major role on the fascia network such that all the tissues starting from the epidermis to individual muscles and intermuscular connective tissue units are utilized to transmit the externally imposed mechanical loading leading to variable local mechanical effects. Although this experiment was conducted in passive conditions, KT application over the TA caused considerably high tissue deformations within the entire lower leg. These findings are very important for physiotherapists to explain the mechanism of effects and limits of such therapeutic mechanical loading applied externally over the epidermis.

Keywords: Kinesiotape, MRI analyses, tissue deformations

ÖZET

M. TİBİALİS ANTERİOR KASINA UYGULANAN DÜŞÜK AYAK BANTLAMA TEKNİĞİNİN ALT BACAKTA OLUŞTURDUĞU MEKANİK ETKİLERİN MRI ANALİZİ İLE DEĞERLENDİRİLMESİ

Kinesio Taping fasyadaki adezyonları rahatlatmak için fizyoterapistler tarafından kullanılan bir yöntemdir. Travma sonucunda konnektif dokunun yapısının bozulması kasın yeterli kasılmasını engelleyebilir ve bölgenin dolaşımı bozulur. Yetersiz dolaşım konnektif doku ağının bozulmasına ve daha fazla adezyon oluşmasına sebep olur. Dolaşımı ve kas performansını arttırmak ve ağrıyı azaltmak için tedaviye destek olarak KT kullanılır. KT'in ağrı, eklem hareket açıklığı ve kas fonksiyonu üzerindeki etkilerini inceleyen birçok sayıda çalışma bulunmaktadır. Ancak, KT uygulamalarının mekanik etkileri hala bilinmemektedir. Mevcut çalışma sağlıklı kişilerde KT'nin alt bacaktaki mekanik etkilerini incelemektedir. Bunun için KT uygulama yöntemlerinden Drop foot korreksiyonu kullanılmıştır. Sağlıklı bireylerde yapılan bu çalışmada TA kasının üzerine uygulanan KT'nin, tüm alt bacak kaslarında, farklı yönlerde ve büyüklüklerde doku deformasyonları oluşturduğu gözlenmiştir: TA'de %38.7 uzama ve %26 kısalma, peroneal kaslarda %21 uzama ve %14.2 kısalma, derin fleksörlerde %15.9 uzama ve %16.9 kısalma, soleus kasında %24.7 uzama ve %20.3 kısalma ve gastrocnemius kasında %24.9 uzama ve %20.3 kısalma. Lokal etkilere bağlı oluşan mekanik yüklemelerin, epidermisten başlayarak tek bir kasa ve kas içi konnektif doku birimlerine kadar iletilmesini sağlayan fasya iletişim ağı üzerinde KT'nin önemli bir rol oynadığı sonucuna varılmıştır. Bu calışma pasif durumda yapılmış olduğu halde, KT uygulaması sadece TA ile sınırlı kalmayıp, tüm alt bacak kaslarında önemli ölçüde boy değişimlerine sebep olmuştur. Bu sonuçlar deri üzerine terapatik amaçlı haricen uygulanan mekanik bir yüklemenin etki ve sınır mekanizmalarının açıklaması açısından önemlidir.
Anahtar Sözcükler: Manyetik Resonans Görüntüleme, Kinesiotape, Doku boy değişimleri

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LIST OF SYMBOLS

cm	centimeter
Kg	Kilogram
T	Tesla
Hz	Hertz
mm	milimeter
mm^2	Square milimeter
s	second
ms	milisecond
$^\circ$	degree
$\bigtriangledown$u	Displacement gradient tensor
u	Displacement vector in x, y and z directions
E	Strain Tensor
I	Identity Matrix
F	Deformation gradient matrix

LIST OF ABBREVIATIONS

m.	musculus
mm.	musculi
TA	Tibialis Anterior
GM	Gastrocnemius Medialis
GL	Gastrocnemius Lateralis
SOL	Soleus
DF	Deep Flexors
PER	Peroneus
AC	Anterior Crural
Max	Maximum
Min	Minumum
MRI	Magnetic Resonance Imaging
EMG	Electromyography
len.	lengthening
short.	shortening
KT	Kinesiotape
SE	Standart Error
RF	Radio Frequency
Turbo Flash	Turbo Fast Low-Angle Shot
IQR	Interquartile Range
2D	two dimensional
3D	three dimensional
SD	Standart deviation
MFT	Myofascial Force Transmission
et al.	and others

1. INTRODUCTION

1.1 Background

1.1.1 Muscle Stucture

Muscle is a viscoelastic tissue that is primarily responsible from movement and force generation of the body and attaches directly or indirectly to bones, cartilages, fascia or a combination of those tissues by tendons and contributes to the postural alignment and locomotion of the body. The attachment of muscles is called the origin (the beginning of the muscle and usually it is the proximal edge of the muscle) and insertion (the ending of the muscle.) The origin and insertion of the muscle and how many joints it crosses affects the direction, quality and quantity of the muscles' contribution to movement. Skeletal muscle is mainly composed of many numbers of cells called muscle fibers elongated within fascicles, which consist of muscle fibers and surrounding connective tissues. Muscle fibers are mainly composed of muscle fibrils (i.e. contractile units of muscle fiber) lying parallel to one another in a matrix called sarcoplasm. Sarcomere (the smallest contractile unit of a muscle fiber) is the repeating unit of the myofibril and it gives the striated pattern to the muscle. Actin (thin) and myosin (thick) filaments are very important elements for the contraction of the muscles. Sliding Filament Theory explains the force generation by the overlap of the thin filament (positioned at the end of the sarcomere) over the thick filament with the help of cross bridges. The thick filament link to the thin filament with cross bridges, which are composed of the globular head of the myosin molecule. The degree of the overlap between actin and myosin filament is directly related with the level of the generated force of the sarcomere (Figure 1.1). Besides, troponin, tropomyosin and titin are the other type of proteins included in intracellular space and have an major role during the contraction of the muscle [3].

The connective tissue of muscle divides the muscle into three compartments:

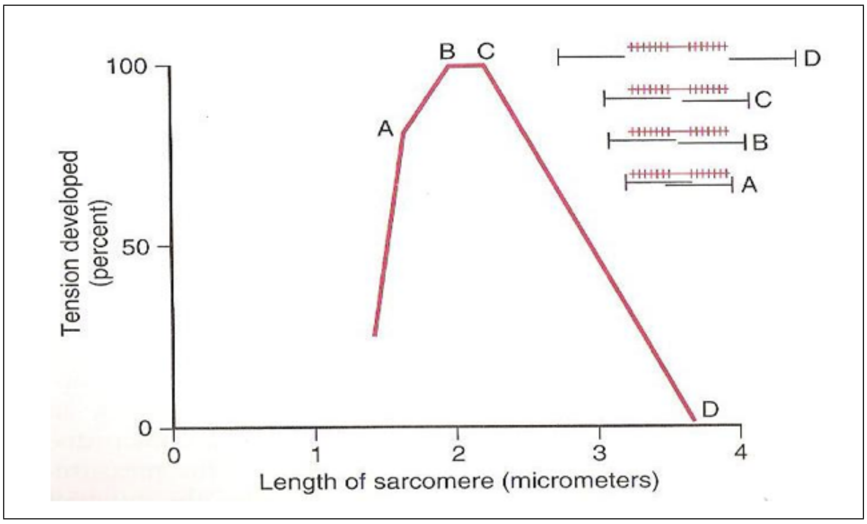

Figure 1.1 Correlation between force generation and sarcomere length [4].

(1)epimysium, (2)perimysium and (3)endomysium (Figure 1.2). Epimysium surrounds the entire surface of the muscle, which separates it from the other muscles and the skin as an anatomical unit. Perimysium located under the epimysium divides the muscle into fascicles. Between those fascicles neurovascular tract consists of important vessels, nerves and lymphatic pathways are located. Endomysium surrounds individual muscle fibers [5, 6, 7].

1.1.2 Range of motion

The full potential movement of a joint is called the range of motion (ROM). Injuries, length and structural changes within the muscle, pain, scar tissues, rheumathologic and dermatologic diseases; such as rheumathoid atritis, skleroderma, and osteoporosis may affect the ROM. To have ROM, the flexibility of the joint and the surrounding tissues is important. As the body tissues are fully integrated with each other, when the integrity of the dermis and epidermis is damaged (e.g., burn, cut or surgery) it may limit the ROM. Muscles are directly or indirectly attached to the bones and allow joint motion. Neurologic diseases such as cerebral palsy, damage of the cortex, results in an increase or decrease of the muscle contraction related with the injured area of the brain. Thus, it may restrict the ROM although the joint and the muscle

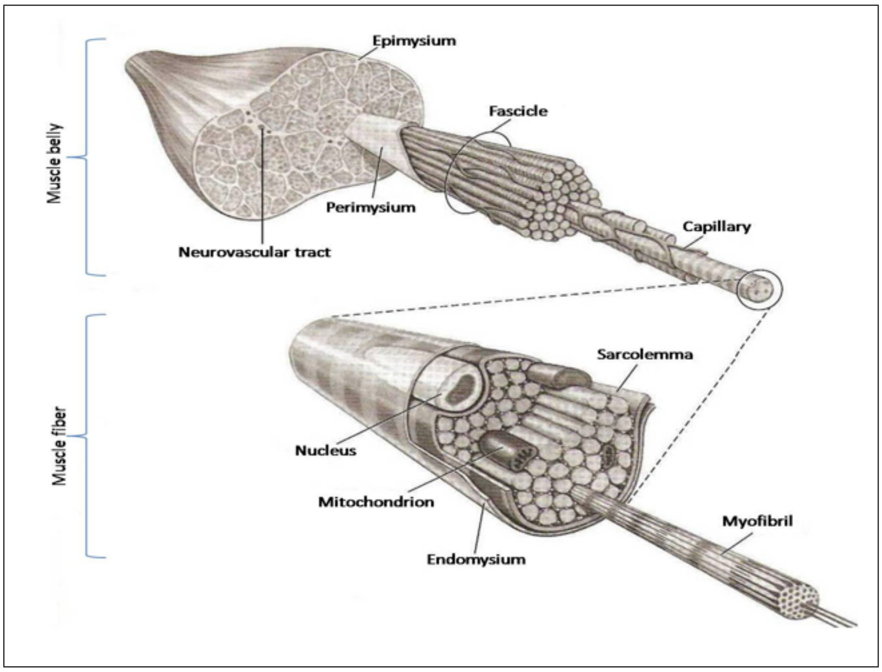

Figure 1.2 Schematic organization of skeletal muscle [8].

itself are healthy. Structural devastation of the muscles also affects the ROM.

1.1.3 Fascia integrity

Fascia which is comprised of connective tissues, provides the unity of the body parts (i.e. muscles, organs, bones, cells, etc.) and seems to be a large network organ of the body. It promotes wrapping for nerves, vessels and lymphatic system, transit movement from muscle to bones and provides the stability of the organs in their proper position. Different connective tissues are considered as fascia according to the terminology of the International Fascia Research Congresses [9]. First layer that gives the shape of a body is called the superficial fascia, which is characterized by a loose connective tissue and adipose and it shows mostly multidirectional or irregular fiber alignment. Intermuscular fascia includes the epimysium, perimysium, and endomysium, and may express different degrees of directionality and density. Visceral fascia including soft tissues like the omentum majus and tougher sheets like the pericardium suspends the organs within their cavities and wraps them in layers of connective tissue membranes. Similar to intermuscular fascia, it reveals varying degrees of directionality and density.(Figure 1.3)

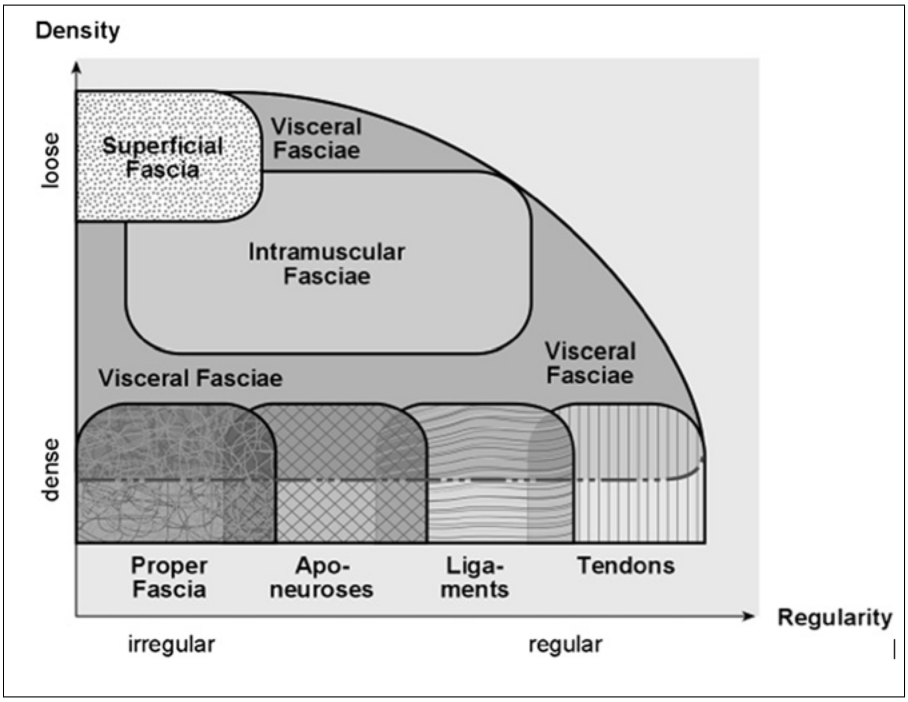

Figure 1.3 Different connective tissues considered as fascial tissues [10].

1.1.4 Proprioception, kinesthesis, nociception and mechanoreceptors

Proprioceptors comprised of many receptors specialized to respond different stimuli are located within the cutaneous, muscles, tendons and joints. These receptors help human beings to be aware of their position in their 3D environment and to enhance a harmonic movement of the body parts. Mechanical, vestibular and visual stimulus are carried by proprioceptors to the three control mechanism of the central nervous system (i.e spinal cord, truncus encephali and cortex) with afferent neurons. After the information processing at the central nervous system, proper motor respond occurs. While standing, walking or lying in our daily lives this system works without our knowledge to adapt human beings to their environment and protect them from the possible threats [11, 12]. Proprioception differs from kinesthesis which is the sense of muscles or tendons and ligaments under a specific movement or condition. Kinesthesis is effective to learn the repetitive movements and positions whereas, proprioception helps the people to accommodate and adapt the whole body during movement in the environment. Mechanoreceptors carry the information with A-beta and A-alfa fibers from such mechanical sense: as touch, muscle strain or joint movement and send it to the central nervous system(CNS). Integration of the visual, vestibular and tissue mechanoceptive stimulus at the cerebral cortex and cerebellum results in proprioceptive sense, which can be described as kinesthetic awareness. Nociception is the process beginning with the awareness of nociceptors about a tissue deformation. After that, it delivers a stimulus to the nociceptive axons (A-delta and C fibers) and finally to the CNS. The potential result of the CNS to the nociceptive stimulus is pain, vasoconstriction, autonomic responses and muscle spasm [13].

1.1.5 Lower leg musculature and the Tibialis Anterior Muscle

Lower leg muscles coordinate the ankle movements, including dorsi flexion, plantar flexion, evertion and invertion. Tibialis anterior(TA) muscle is located at the most medial part of the anterior compartment of the leg. It originates from the lateral condyle and upper half or two-thirds of the lateral surface of the body of the tibia; from the interosseous membrane; from the fascia cruris and inserts on the medial surface of the medial cuneiform and the basis of the first metatarsal of the foot. The TA is innervated by the deep peroneal nerve and it is the dorsi flexor of the ankle. In this study, we are interested in the tissue deformations of not only the TA but also the neighboring muscles such as; mm. Peronei, m. Extansor hallucis longus, deep flexor muscles, m. Gastrocnemius and Solues.

1.1.6 The Sensory-Motor Innervation and Drop Foot

The sensory-motor innervation of the lower leg is conducted by the common peroneal nerve (lateral popliteal nerve) and the tibial nerve (medial popliteal nerve). Until the upper popliteal fossa these two nerves share common sheath within the sciatic nerve and in the upper popliteal fossa they completely seperate from each other.

After giving off the lateral cutaneous nerve of the calf, the peroneal nerve splits into two branches, the deep and superficial peroneal nerve. The deep peroneal nerve is responsible for the innervation of ankle and toe extensors (tibialis anterior, extensor hallucis, extensor digitorum longus and brevis) and peroneus tertius. Related with the intimate contiguity to the caput fibula, the common peroneal nerve may be compressed or damaged due to the trauma of this area. As the common peroneal nerve travels through the surface around the caput fibula, the injury of the nerve is clinically observed very often. When the peroneal nerve is injured, the dorsi flexion and the evertion of the foot will be affected and the patients will be lack of lifting their foot while walking. This functional loss is called drop foot [14, 15] and it may have a severe impact on gait; such as, increasing the hip flexion during the swing phase to avoid bumping the foot to the obstacles, which may lead to an overload and degeneration of knee and hip joints [16, 17]. To prevent or limit such problems, physiotherapists apply different therapeutic modalities including functional electrical stimulation(FES), functional splints as well as Kinesio Taping(KT).

1.1.7 Kinesiotape Technique

Application of KT involves attaching the tape with a range of tension (depending on the expected healing effect) to the skin at certain joint angle and position. KT is a drug free elastic tape that is asserted to stretch to 120-140% of its original length [18]. All the benefits of the tape come from its elasticity. After the application, it would afterward turn back into its original length that is enhancing a proposed pulling force to the skin. According to the size of the affected muscle and the selected treatment effect, KT could be applied in different shapes; such as, 'X', 'Y', 'I', 'Fan', 'Web' and 'Donut' (Figure 1.4.).

There are three stretch and recoil applications in KT application, which are intended for facilitation, inhibition and correction. Corrective application techniques involves 1)Mechanical Correction Recoiling; to provide a positional stimuli through the skin, 2)Fascia Correction 'Holding'; to align the tissue in the desired position,

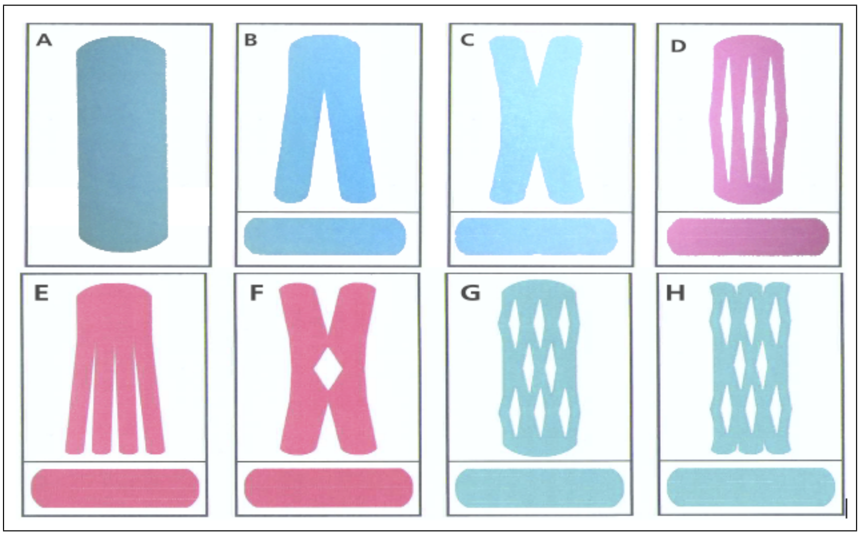

Figure 1.4 Shapes of kinesio tape cuts. A) 'I' shaped tape, B) 'Y' shaped tape, C) 'X' shaped tape, D) 'Web' shaped tape, E) 'Fan' shaped tape, F) 'X' shaped tape with 'Donut' hole, G) 'Basket' cut closed Ending, and H) 'Basket' cut open ending. All of these cutting methods could be used for correctional taping and indurated tissue but A,B, and C are only used for muscle taping [18].

3)Space Correction 'Lifting'; to create more space over the area of pain, eudema or inflamation, 4)Ligament/Tendon Correction 'Pressure'; to increase the stimulation of mechanoreceptors, 5)Functional Correction 'Spring'; to assist or limit the motion and 6) Lymphatic Correction 'Chanelling'; to form areas of decreased pressure which may act like lymphatic channels.(Figure 1.5) To facilitation and inhibition, KT is applied along the targeted muscle. Nevertheless, the facilitation technique starts from the origin of the muscle and ends in the insertion whereas, the inhibition technique direction is insertion to origin (Figure 1.6).

KT was developed by Kenzo Case in the 1970's [19] and it has become very popular, among athletes during the 2008 Olympic games. KT is a taping technique commonly used in sports medicine to improve muscle performance, or in pediatric rehabilitation to correct the posture. Considering that the tape used in KT demonstrates elasticity and thickness resembling that of human skin, it is widely used to enhance the stability of the body or extremities, to support or protect the joint, to correct the alignment of the body or limbs, to modify the biomechanics of movements and to support sensory-motor functions [20].

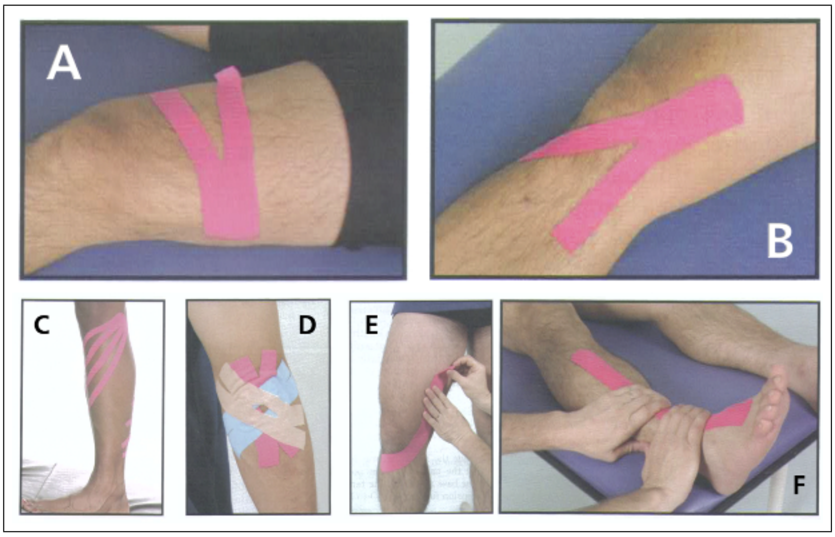

Figure 1.5 Corrective Application Techniques. A) Mechanical correction technique; according to the tension applied to the kinesio strip and the degree of the inward pressure, the depth and perception of the skin movement will alter. B) Fascia correction technique; the application is used for myofascial release.C) Lymphatic correction, D)Space Correction, E)Ligament and Tendon Correction, F) Functional Correction [18].

Physiotherapists usually use their hands to enhance stimulation or relaxation of tissues regarding with the demand of the patient. According to the injury and pain level, myofascial or manipulative therapies can be used for treatment. Manipulative therapy involves high velocity, low amplitude thrust or repetitive joint motion, whereas myofascial therapy is basically a soft tissue technique which may affect the static tissues in between joints [21]. Application of KT could be considered as a myofascial therapy and, due to its adhesive properties, it may hold a long lasting theraupathic influence on soft tissues.

KT approach to treatment is founded along the thought that the body is a mechanism that all parts of which are interconnected to each other. The effectiveness of the approach planned by involving not only the strained muscles or a weak joint, but also those areas associated with the condition. Kase et al. [18] have suggested a number of potential effects, depending on the techniques used and degree of tape stretch. Such effects include giving of a positional stimulus via the skin, aligning of fascial tissues, creating more space by lifting the skin, providing sensory stimulation and assisting in the reduction of eudema. It is considered that KT has major effects

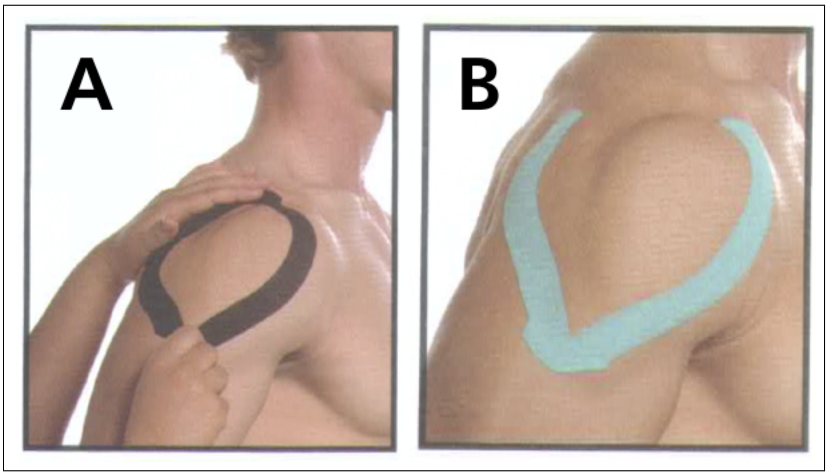

Figure 1.6 Muscle Taping Techniques. A)Fasilitation is used when there is weakness of the muscle and applied from origo to insertio B) Inhibition is used for muscle spazm and reverse to the fascilitation method it is applied from insertio to origo [18].

on reducing pain, increasing range of motion, strength, proprioception and muscle activity. The suggested mechanism for the pain reduction effect of KT arises from the increasing afferent feedback that may occur via the stimulation of sensory pathways of the nervous system. Lifting the skin, thus reducing pressure on subcutaneous nociceptors, could be another theory for the pain relieving effect. Gonzalez-Iglesias et al. [22] conducted a randomized clinical trial and reported short-term effects of cervical kinesiotaping on pain and cervical range of motion after acute whiplash injury. However, although certain improvements were determined in cervical range of motion such findings may clinically not be extensively relevant. The reason for the increase in cervical range of motion could be related with the decrease in the fear of movement. The application of KT may possibly provide a proper sensory feedback to the subjects and it encouraged the patients in the ability of movement.

Hilal K. et. al. [23] carried out a study among children with moderate cerebral palsy to determine the effects of mechanoreceptors to investigate the effects of taping on motor skills of the hand. Taping technique which is devised by the investigators with the purpose of inhibiting the thumb in the palm was applied to 45 children with CP (divided into three groups (1) control group, (2) TG:taping group and (3) PPTG: taping+pressure, (with a piece of polyurethane material). Each group performed nine hole peg test and nine part puzzle test with taping 20 minutes later and 20 minutes after the taping was removed to measure upper extremity function. The results of the study revealed that both TG and PPTG to control the thumb in palm sign were effective in enhancing functional activities. Also the study groups results were different in that 20 minutes after removing pressure and tape in the PPTG the effect of the tape continued whereas in the TG taping effect was vanished. To analyze the therapeutic effects of KT considerable amount of studies have been conducted. The research ElKhatib et al. [24] carried out among 30 children diagnosed with Erb's Palsy revealed that there was not any significant difference between physiotherapy and physiotherapy with KT on the electromyographic activity of deltoid muscle. However, motor function assessments exhibited a remarkable increase in the shoulder flexion and abduction, wrist flexion and radio ulnar supination. Also Chang HY [25] found no significant difference on the grip strength and force sense immediately after the forearm application of KT.

There are many studies in the literature that attempt to demonstrate the effectiveness of KT. A great amount of these studies focuses on the tissue zone immediately in the neighborhood of the tape. A. Luque-Suarez [26] measured the acromio-clavicular distance after the KT application over the shoulder. To exhibit the effects of KT on cervical range of motion Gonzales et. al. [22] applied KT over cervical spine. However, these effects have not been quantified in terms of tissue deformation. Moreover, mechanical effects of KT treatment elsewhere away from such zone remain completely unclear. Despite the widespread use of KT, there appears to be only limited evidence demonstrating its effectiveness.

1.1.8 Muscle-fascia integrity and myofascial force transmission

The results of many fascia researches have shown that there is a mechanical interaction between muscles and also between muscles and non-muscular tissues (for reviews see [27]). Studies with finite element modelling exhibited that such interactions between muscles may cause highly non-uniform muscle tissue deformations [28], [29]. The study of Huijing et. al. [30] revealed, by changing the knee angle from extension to flexion, a global lengthening and shortening deformations in gastrocnemius and soleus muscles. As a knee flexor, during the knee flexion all the muscle fibrils of gastrocnemius are expected to be shortened. However, the results of this study exhibited both lengthening and shortening within the gastrocnemius. Furthermore, in this study the soleus muscle affected by changing the knee angle. As soleus does not cross the knee joint, it is concluded that there is a mechanical interaction between gastrocnemius and soleus muscles. According to these issues we hypothesized that by applying KT over TA heterogeneous tissue deformations will occur within muscles that are interconnected to each other.

1.2 Objectives

The goal of this study is to assess the mechanical effects of KT with magnetic resonance (MR) imaging analyses. Specifically we expect that the effects of KT quantified as tissue deformations may not be restricted to the immediate neighborhood of the tissues exposed to KT application. Instead we expect that heterogeneous tissue deformations occur both within the targeted and untargeted tissues of the lower leg. Quantification of tissue deformations will allow for an objective assessment of mechanical effects of KT in terms of e.g., tissue stretch as well as release. MR images of the lower leg will be acquired before and after the KT use. Non-rigid image registration analyses will be performed to quantify tissue displacements and hence tissue deformations.

2. METHODS

2.1 Experimental Conditions

2.1.1 Subjects

Five healthy subjects (age=26±2years, height=1.60±5cm and weight=51±8kg) volunteered for this study. In order to reduce the anthropometric differences, only females were involved. Before providing an informed consent, each subject was particularly informed about the experimental procedure and the purpose of the study. Experimental procedures were in strict agreement with guidelines and regulations concerning human welfare and experimentation set forth by Turkish law, and approved by a Committee on Ethics of Human Experimentation at Istanbul University, Istanbul School of Medicine, Istanbul.

2.1.2 Experimental Protocol

Each subject was positioned prone in the MRI scanner. To avoid blurring left lower leg of the subject was fixed in the reference position before the patient table moved in to the MRI bore.
(I) Ankle angle was fixed to 90° by using a MRI compatible fixation device (Figure 2.1). The device consists of two parts: (a) foot part: covers the calcaneus and the whole foot with a joint on the ankle level, which permits to adjust the ankle angle in certain degrees. Velcro on two levels (navicula and head of the metatarsals) was used to stabilize the foot and (b) two panels to fix the device on the table.

(II) To stabilize the orientation of the lower leg, the location of the patella was marked on the patient's table and a piece of velcro is attached both to the patella (with a non-allergic adhesive tape) and the table to keep the knee angle constant between each trial.

(III) The knee angle and hip angle was recorded for both undeformed and deformed condition with a universal goniometer. The knee and hip angle for undeformed state was 158 $\pm$ 5° and 170 $\pm$ 7°, respectively. Knee joint angle was measured by placing the center of the universal goniometer over the lateral epicondyle and the arms of the goniometer with the shaft of the femur and tibia. Hip joint angle was measured by placing the center of the universal goniometer over the greater trochanter of the femur and the arms of the goniometer followed the shaft of the femur and axillar mid-line.

(IV) Chest and hip were supported on the table with MRI compatible positioning belts. After moving the subject into the MRI bore, sets of 3D high resolution MR images were acquired in the undeformed state. Subsequently, the patient table was moved out of the bore. To apply the tape over m.tibialis anterior, the subject was removed from the device, placed supine on the table and correction of drop foot taping technique was applied over m.TA according to the prescription of KT application. While removing from the device, subject's left leg was held to standardize the moving position among all subjects. The subject was secured back into the device and stayed at rest for 30 minutes (no change in position) subsequently. Before moving the patient table into the bore for this deformed condition, the knee and hip angle was corrected to the degree in the undeformed condition and the position of the patella was checked. Being sure that the reference position was enhanced, the patient table was moved back into the bore and sets of images were acquired in deformed condition (Figure 2.1 A-D).

(V) Application of the Kinesiotape for the functional correction of the ankle dorsi flexion: tape was applied by cutting the appropriate length of an I Strip. To determine the length of the I Strip, the distance between the origo and the intertio of the m. Tibialis Anterior was taken for each of the subjects. To assist dorsiflexion and resist plantar flexion the ankle joint is placed in dorsiflexion. At the distal end of the selected area anchor of the tape was attached with no tension. With almost an amount of 50% tension the proximal anchor was attached to the proximal (the origo of the TA) of the application area. With the hands placed on both proximal and distal base the subjects were asked to move their ankles to plantar flexion. With moving both hands towards the middle of the extremity the tape was applied (Figure 2.1 B-C).

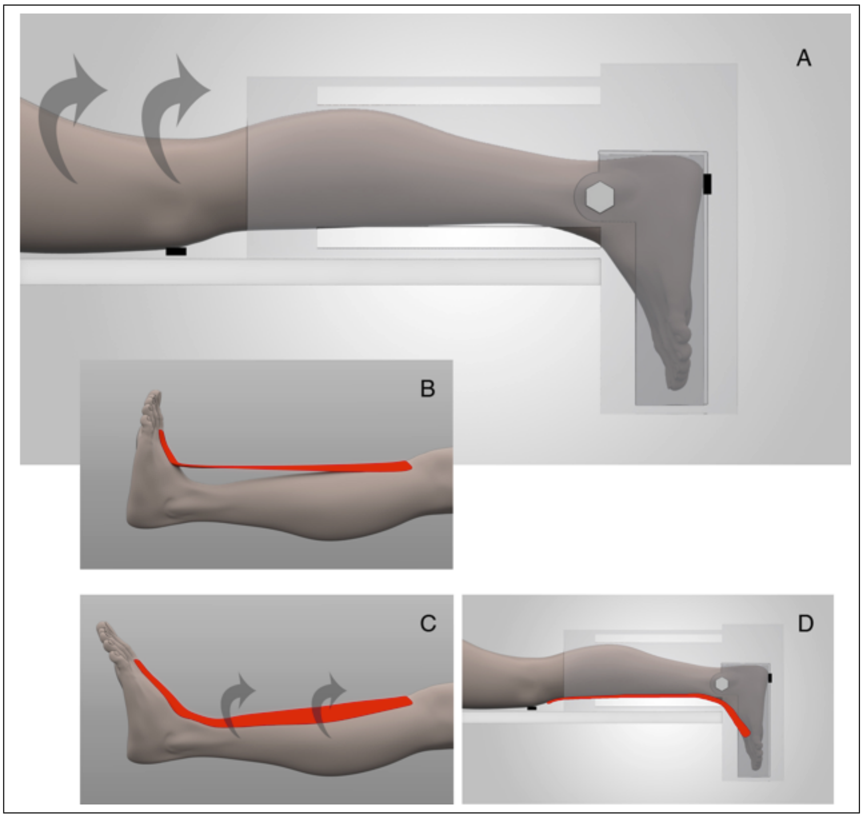

Figure 2.1 Illustrations of subject positioning in the MR scanner and kinesio tape application. MR image sets were acquired before and after tape application. This figure illustrates functional correction method for drop foot and subject positioning for deformed and undeformed states. A) undeformed state image acquisition: ankle angle was fixed at 90 with an MRI compatible fixation device. A piece of Velcro under the heel and strapping over the ankle was used for fixation of the ankle angle B-C) KT application: distal anchor was attached without tension over the dorsum of the foot and the ankle positioned to dorsiflexion. Following the dorsi flexion %50 − 75 tension was given to the KT and the proximal anchor was attached to the origo of the m.TA. After that the subjects were asked to bring their ankle to plantar flexion. With moving both hands towards the middle of the extremity the tape was adhered to the skin. D) deformed state image acquisition: 30 minutes after the KT application MRI image sets of the deformed state were acquired.

2.1.3 Image acquisition

For image acquisition, a 3T Siemens Trio scanner with 6-channel cardiac array coil (matrix size=320*320*144, voxel size = 0.8*0.8*0.8, TR = 2,000 ms, TE = 3.94ms, no fat suppression, flip angle = 12°, bandwidth = 130 Hz per pixel) was used and 3D Turbo Flash based MR coronal image sets were collected. In order to assess tissue effects of KT application, a slice group consisting of 64 consecutive cross-sectional slices was selected manually for each subject (Figure 2.2).

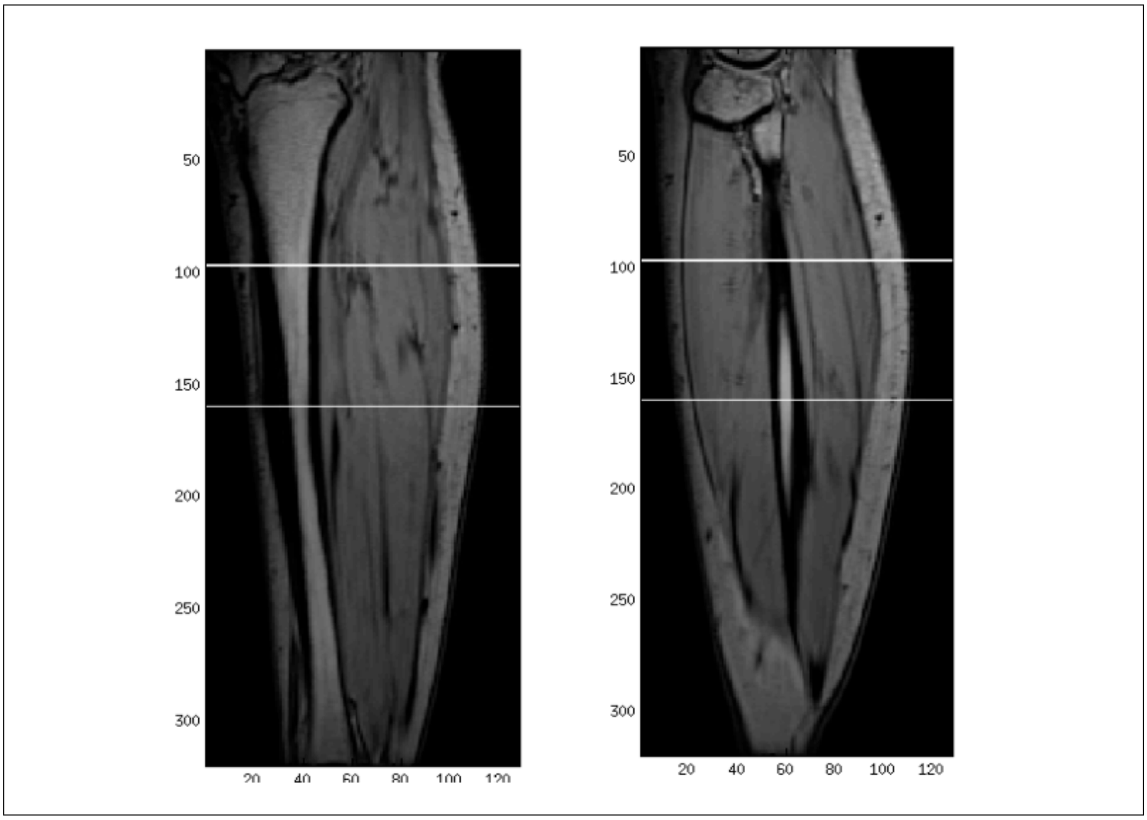

Figure 2.2 The location that the images were taken in the present study.

2.2 Calculation of In Vivo Strains

In order to calculate the deformations caused by the KT application, Demons algorithm, a non-rigid and non-parametric image analysis technique, was applied to MR images acquired in the deformed and undeformed state. In this study an advanced version of Demons algorithm was applied to the MR image sets to align images of the deformed and undeformed states approximately. To precede instabilities for small gradient values by additional constants, to extend the algorithm using optimizer and restricted use of memory, to adapt for large deformations by multi-resolution approach and to accelerate by extending the equation using also the image gradients at the deformed zone Demons algorithm has been advanced. To characterize the displacement values for each voxel, Demons algorithm uses the gradients of images and the differences between images i.e, differences between gray scale values of consecutive voxels within each image and corresponding voxels in deformed and undeformed state. The algorithm tries to fit the deformed and undeformed states simultaneously with the alignment process. Also, by an iterative process, it recalculates the exact cubic shape made up of four original voxels from the undeformed state into a deformed shape of approximately constant volume. Three criteria (1) the varieties of voxel gray scale values, (2) voxels grayscale gradients within the images, and (3) the array of voxel gray scale differences was used to allocate the volume elements of the deformed shapes corresponding to the original undeformed elements. Gaussian Kernel was applied throughout each iteration process to smooth the displacement fields. After the alignment of the deformed and undeformed states the deformation gradient matrix, F was calculated by using the displacement gradient tensor, $\bigtriangledown u$.

$$F = \bigtriangledown u + I \tag{2.1}$$

Green-Lagrange strain tensor, E calculated as;

$$E = \frac{1}{2}(F^T F - I) \tag{2.2}$$

Before calculating the principal strains, to remove shear effects, rotation was applied to the tensor. The first (local lengthening) and third (local shortening) principle strain was used separately in the analyses.

2.3 Response to rigid body motion

Image sets of the undeformed state were transformed by a synthetic rigid body motion imposed on the data for each subject: The rigid body motion imposed on the data consisted of (1) a 5° rotation in the cross-sectional plane corresponding to a knee rotation that may be occurred as any global movement that may occur when changing the subject position as described. (2) a 3° rotation in the coronal plane, (3) a 4° rotation in the sagittal plane and (4) a 4 mm translation in the axial direction. To keep rotations in cross-sectional and sagittal planes and the translation in axial directions infinitesimal, the position of the left leg preserved during the mobilization of the subject on the MRI table to apply KT over the TA. Also the landmarks were important to adjust the subjects on the MRI table as their first position that undeformed images were acquired. Thus, the artifacts that may be the result of turning the patient prone to supine were smaller than rigid body motion imposed on the data and that allowed us to get a clear calculation of strain distribution.

3. RESULTS

3.1 Subject repositioning artifacts

The results of the study revealed that mean strain errors were quite small for all anatomic regions(Table 3.1).

3.2 In vivo strains and interquartile ranges

Figures below are examples of the orientation and the magnitude of the length changes in the deformed state (Figure 3.1). After KT application the tissues show non-uniform length changes and the deformations were not limited to a restricted area under the dermis. From superficial to deeper tissues, a considerable strain distribution were noticed. It was also observed that the direction of deformations subsequent to KT application were not in the same direction of the tape application.

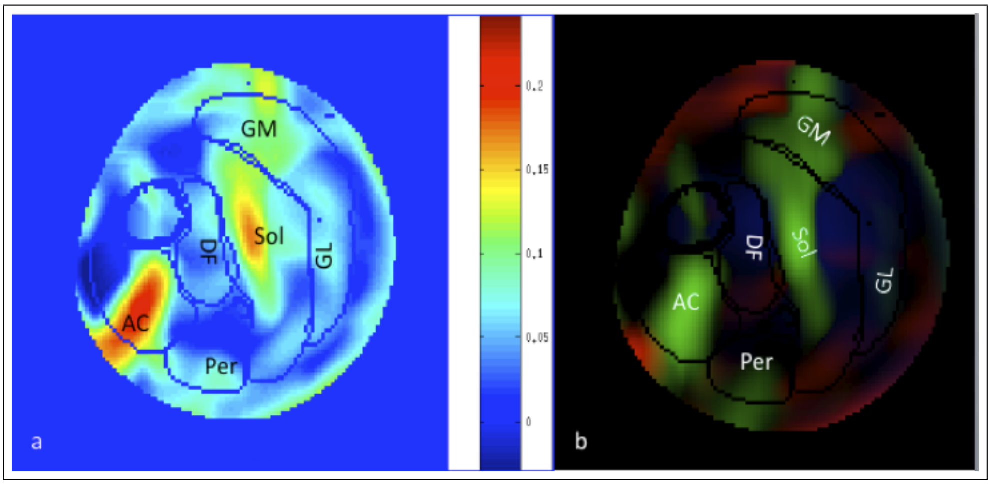

Figure 3.1 a) The representation of length changes occurred after KT application over TA. AC: Anterior crural muscles, DF: Deep flexor muscles, Per: m. Perenoalis, Sol: m. Soleus, GM: Medial head of m. Gastrocnemius, GL: Lateral head of m. Gastrocnemius. b) Orientation of the length changes was illustrated by different colors. Red: Left-Right, Green: Anterior-Posterior, Blue: Superior-Inferior, Magenta: Red + Blue, Cyan: Green + Blue, Yellow: Red + Green. Note that these figures correspond to the 64th cross-section at axial view, hence almost the middle of the muscle belly of the TA.

Table 3.1
Strain errors due to baseline I strains (synthetic rigid body motion) (All subjects)

Mean±SE	AC	m.peronei	DF	m.sol.	m.gastro.
Strain Error(length.)	0.015±0.012	0.013±0.011	0.010±0.008	0.013±0.010	0.011±0.009
Strain Error(short.)	-0.016±0.011	-0.013±0.009	-0.013±0.008	-0.012±0.010	-0.013±0.009
Local principal strains due to KT application(All subjects)					
Lengthening	0.075	0.049	0.031	0.045	0.046
Shortening	-0.073	-0.054	-0.044	-0.047	-0.055

Table 3.2
Interquartile ranges, peak values

	AC	PER	DF	SOL	GM
Max values for lengthening	38.7%	21%	15.9%	24.7%	24.9%
Min values for shortening	26%	14.2%	16.9%	20.3%	20.3%
Interquartile range (iqr) for lengthening	08.2%	04.4%	02.6%	03.6%	03.8%
Interquartile range (iqr) for shortening	06.8%	04.8%	0.34%	04.1%	04.4%

Maximum values for lengthening and shortening of anatomical regions are listed for all subjects (Table 3.2). Interquartile range indicates the heterogeneity of local deformations. Significant tissue deformations were observed in the anterior crural muscle group. Although the tape was applied over the anterior crural, significant length changes were observed also within m. peronei, deep flexors, m.soleus and m. gastrocnemius.

(1) AC muscles' peak local lengthening and shortening equal 39% and 26%,

Table 3.3
The peak lengthening direction of AC based on the eigen vectors

% of Voxels	Superior-Inferior	Anterior-Posterior	Lateral-Medial
Subject 1	06.8%	32.4%	00.1%
Subject 2	08.4%	29.5%	00.3%
Subject 3	06.9%	40.7%	01.0%
Subject 4	07.9%	06.7%	08.1%
Subject 5	09.%3	36.3%	02.0%

respectively. Local deformations were heterogeneous for all subjects, IQR lengthening (E1) and shortening (E3) amounts to 0.082 and 0.068, respectively. When the lengthening direction of eigenvectors were analyzed, except for subject 4, for all subjects, AC muscles' lengthening were greater in anterior-posterior direction (Table 4.3). (2) For m. Peronei muscles, peak local lengthening=21% and shortening=14%, with E1=0.044 and E3=0.048. (3) For the Deep flexor muscles, peak local lengthening=16% and shortening=17%, with E1=0.026 and E3=0.034. Although KT is superficially applied, its effects are apparent also fairly deep among the tissues. (4) For m.soleus, peak local lengthening=25% and shortening=20%, with E1=0.036 and E3=0.041. (5) For m. Gastrocnemius, peak local lengthening=25% and shortening=20%, with E1=0.038 and E3=0.044 (Figure 4.2).

3.3 Eigen vector analyses

Calculated deformations for the anatomical regions studied were significant and heterogeneous among subjects (Table 3.3). Further analyses of eigen vectors revealed that the percentage of voxels contributed to lateral-medial and superior-inferior direction, which is parallel to KT direction, is less than anterior-posterior direction (except subject 4). Thus, it could be said that the KT has a major effect on lifting the skin and aligning the fascia to decrease the pressure on the injured tissue.

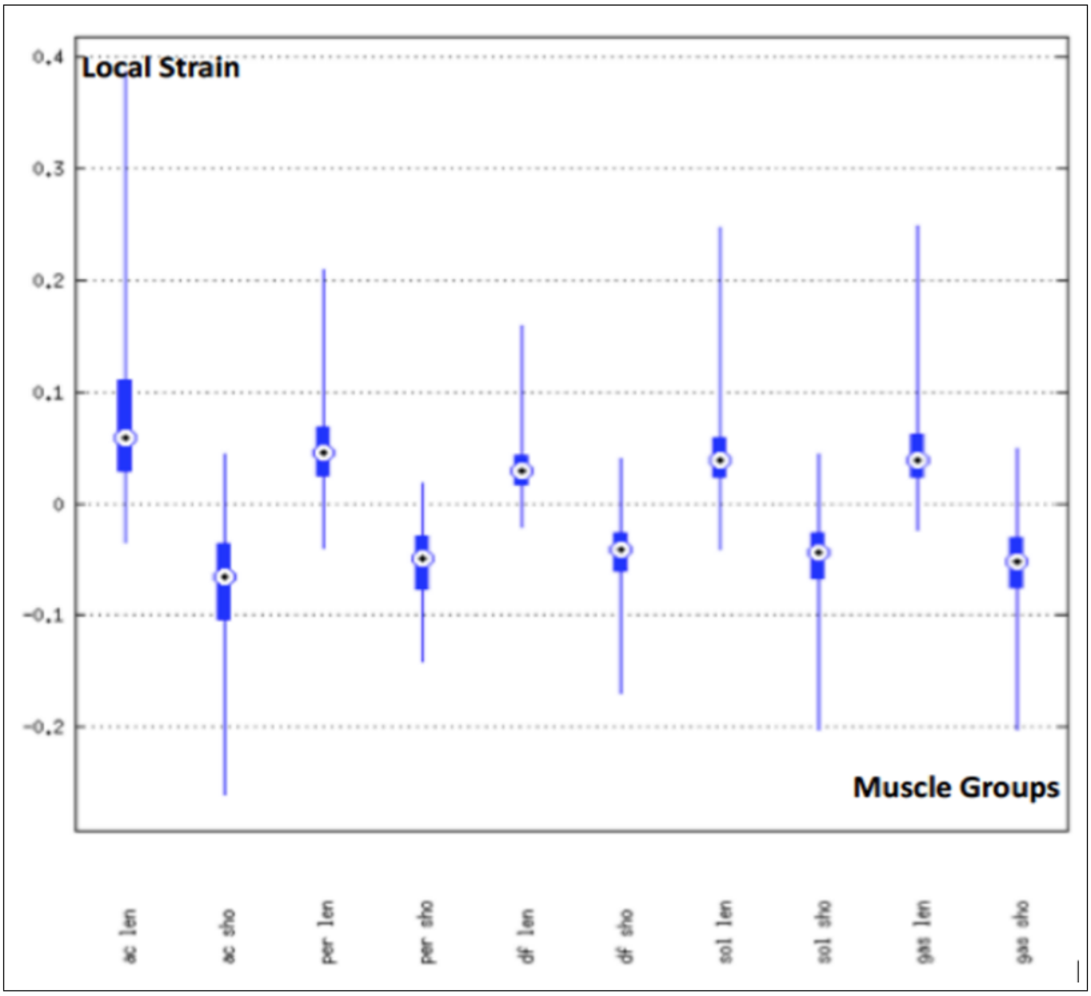

Figure 3.2 Local lengthening and shortening effects of KT application. The horizontal line inside the box represents the median strain value; the upper and lower edges of a box itself represent upper and lower quartiles (i.e., the 75th and 25th percentiles), respectively, and lines extending from the median represent range of values of the principle strain plotted.

4. DISCUSSION

Major findings of the current work show that (1) local strains are much higher than the synthetic rigid body motion strains imposed on the image, (2) kinesiotaping affects a part of the limb which is much larger than the area on which the taping was applied. These effects include heterogeneous local strains observed in anterior to posterior, superior to inferior and lateral to medial directions from the taping area. The results of this study revealed that mechanically lifting the skin with the tape causes heterogeneous tissue deformations, not only within the targeted tissues but also within the untargeted tissues of the lower leg. This means that every part of the body, from epidermis to muscle, is not mechanically independent from each other. The idea is compatible with most of the fascia researches [31, 27, 32] in which the three-d tensional network, fascia, is expressed as a 'soft tissue component of the connective tissue system that permeates the human body'. Cutis, a derivative of the ectoderm, was not considered as a part of this tensional network. However, the present study revealed the importance of the epidermis and dermis in force transmission.

4.1 The Integumentary System and Myofascial force transmission

To understand how applying KT caused heterogenous tissue defromations within the limb that is much larger than the area on which KT was applied, it is necessary to know the myofascial force transmission and the effect of integumentary system upon it. Human beings are composed of systems within a system. Taking a whole muscle into consideration, sarcomeres within muscle fibers are connected to the intracellular cytoskeleton, which is connected via subsarcolemmal actin filaments to trans-sarcolemmal molecules that are connected to the endomysium [33, 34, 35]. Further, sarcomeres are connected with the perymisium and epimysial tubes because the walls of the endomysial tube form a pathway to perymisial tunnels and the epimysium is connected to the shared walls of perymisial tunnels of adjacent fascicles [36]. (Figure 4.1) On the other hand, the synergistic muscles may be considered to share each other's epimysial tissues [36]. Moreoever, non-muscular structures such as neurovascular tract and the interosseal membrane are connected to the aponeuroses or tendon plate within the muscle tendon-complex, which is covered by epimysium. Therefore, muscular structures are connected to each other with stiff pathways that enhance force transmission.

4.1.1 Myofascial Force Transmission

Recent studies have shown that the force produced by an individual muscle is transmitted to connective tissues within and surrounding the muscle (endomysium, perimysium, epimysium) and to non-muscular connective tissues such as fascia, neurovascular pathways in parallel to myotendinous path of force transmission to bone [27, 37, 34]. The force transmission via connective tissue is called myofascial force transmission [i.e., classified as intramuscular (between muscle fibers), intermuscular (between muscles), and extramuscular (between muscle and adjacent non-muscular tissues)] [38].

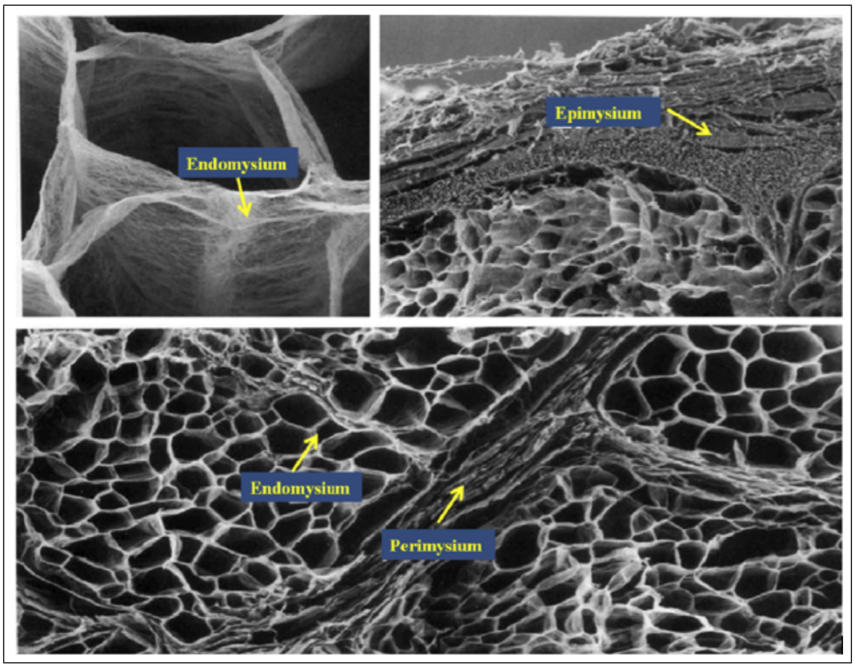

Figure 4.1 The whole intramuscular stroma. The figures are adaptted from [35].

4.1.2 Integumentary System

The integumentary system has expanded from surface ectoderm and the underlying mesenchyme. The skin has two mutually dependent layers; a superficial layer, the epidermis, which developed from ectoderm, and a deep, thick layer, the dermis, which derived from mesoderm and contains collagen, elastic fibers, blood vessels, sensory structures, and fibroblasts [39]. KT application over the epidermis directly affects the dermis because epidermis and dermis are connected to each other with hairs, lymphatic and blood capillaries transmitted through dermis to and from epidermis. On the other hand, hypodermis, also named as superficial fascia, carries blood vessels and nerves to and from the skin and promotes movement between the integument and underlying structures. The superficial fascia contains many numbers of small fibrous bands (Lat. Retinacula cutis) that connects the deep layer of dermis to the muscular structures (deep fascia) [40]. Further, it includes multiple sheets of collagen fibers coupled with the presence of elastin and provide the re-alignment of the collagen fibers within the lamina and protects the underlying nerves and vessels from the damage that may occur due to the skin mobility [41]. Therefore, forces act upon the skin with the application of KT over TA may be transferred via the fibrous bands of the hypodermis to m. tibialis anterior. The transmission of the force to the synergistic (mm. peronei and deep flexors) and the antagonistic muscles (m. soleus and m. gastrocnemius) may be explained by the intermuscular and extramuscular force transmission (for detail explanation see [37]).

4.2 The Tensegrity Model

The term tensegrity, which is developed by R. Buckminster Fuller, is made up of two words “tension" and “integrity" [42]. The explanation of this structural principle is that, certain kinds of stable and adaptable forms could be accomplished through the transmission of elastic tension. This principle was fundamentally used in architecture to define the elastic links between solid components. The human organism is a dynamic combination with solid parts such as bones, and the elastic parts such as myofascial layers and membranes that wrap the bones [43]. Therefore, macrostructure of the human tensegrity model is similar to the architectural construction principle for example rough structure-myofascial skeleton. However, internal structures within the macrostructure of the human body makes the tensegrity of the human organism more complex. Fascial and membrane systems include a certain amount of ground substance which contains a variety of elastic and movable elements and acts like buffers between relatively stiff collagen fibers.

Physiotherapists are often aware of the integrity within body parts and consider this during the treatment. However, previous studies lacked explanations of the effects of the KT applications to the synergistic and the antagonistic muscle groups. Only a few studies such as Lumbroso et. al. [44] investigated the effects of KT in far away zones. These authors showed that two days after its application over the gastrocnemius muscle, KT caused a significant increase in the hamstring muscle peak force. Lumbroso et. al explained these results with the continuum of the fascial structures. The continuum of the fascia, explained in the tensegrity, model allows the body to serve as a mechanosensitive signaling system. The deformations occured due to the KT application may be transferred to the endomysium by inter and extra musclular pathways which is connected to the cytoskeleton through basal lamina. All the cells of the body anchor to the ECM(extracellular matrix, which contains cells such as fibroblasts, tumor cells, immune cells, and adipocytes) through focal adhesions [9]. In biotensegrity mechanical forces applied to the ECM are transferred through these anchors that are termed integrins (transmembrane proteins) to the cytoskeletal tensegrity system (microtubules, microfilaments). Further, fibroblasts respond to mechanical forces by changing the composition and the amount of the ECM [34]. Thus, the overlap between myosin and actin filaments may be altered to the optimum sarcomere length that may increase the muscle force. As within limb effects of KT explained in the present study by the interaction of integumantary system and myofascial force transmission, the increase in the hamstring muscle peak force, in the study of Lumbroso et al. [44], may be discussed by the biotensegrity which means that mechanical forces applied to a part of the body may effect the cytoskeleton of tissues and cause a global and body-wide mechanical changes.

KT methods often use the fascial connections to support the manual treatments in traumatic conditions, which may cause adhesions within the superficial fascia. The restrictive areas of the superficial fascia may affect the underlying structures and may decrease the sliding of epimysium, perimysium and endomysium, thus the restriction of the superficial fascia may cause adhesions within intramuscular and extramuscular structures and ECM may become stiffer. As the present study was conducted in passive condition, heterogeneous tissue deformations may only be explained by the length changes within fascial structures. If the fascia is considered as a loose knitted sweater, applying KT over the skin may increase the distance between each pattern of the knit, thus the elasticity of the ECM will increase. If there is a soft ECM the activation and the dissociation of the integrins increase because soft matrix has a lower capability to resist forces [45]. Grinell [46] explains the fascial reorganization after a physical manipulation in the following way: "physical manipulation of fascia has the potential to change the cell-matrix tension state and also may influence localized release of cellular growth factors. As demonstrated by our research on fibroblast-collagen matrix interactions, such changes could lead to profound and rapid modulation of structural, functional and mechanical interactions between fibroblasts and the extracellular matrix and, as a result, contribute to the reorganization of fascia that results from bodywork practice". The results of the present study may lead to an increase in the elasticity of ECM. Thus, KT may decrease the focal adhesion, supports the healing process and provides a better environment for myofascial force transmission.

4.3 Drop Foot Technique

Neurological dysfunctions such as stroke or lumbal disc protrusions along with vascular diseases, drop foot may also occur due to the injury of the dorsiflexor muscles or along the nervous pathway of these muscles. The sciatic nerve evolves from the lumbosacral plexus and continues along the posterior aspect of the thigh [40]. It is divided into two branches as common peroneal nerve and tibial nerves above the fossa poplitea. The common peroneal nerve travels superficially and close to the periostum of the fibular neck, covered by only the skin and subcutaneous tissue, thus it is susceptible to direct trauma that may cause drop foot [15, 14]. Also the posterior fibular head dysfunction, which is a diagnosis in osteopathic manipulative medicine meaning the head of the fibula remained in posterior limit of its motion, may cause drop foot as a result of the compression over the common peroneal nerve [14]. To ease the compression over this nerve osteopaths/manual therapists apply HVLA (high velocity low amplitude) manipulations to the fibular head in the anterior directions and they believe that the technique reposition the fibular head to anterior. Thus, the compression over the common peroneal nerve is reduced [47]. In addition to the HVLA techniques, osteopaths use MFR (myofascial release) to release fascial restrictions and to restore the tissues by a low load, long duration stretch along the lines of maximal fascial restrictions [48]. The skin is directly palpated during the treatment and it is moved into the direction of fascial restriction just until the tissue barrier. After finding the collagenous barrier, osteopaths just wait at that point until the fascia complex starts to yield and soften [32].

Osteopaths, physiotherapists and manual therapists do not consider KT as a major therapy method but a supportive technique to their treatments. Thus, drop foot correction technique of KT is applied basically to help the patient to keep the position of the ankle at dorsi flexion and give a positional stimulus to the central nervous system (CNS) by the recoil effect of KT. However, findings of the present research may alter the aim of the application of KT in drop foot treatment and therapists may benefit from its low load and low duration stretch along the fascia similar to the MFR explained above. The results of this study exhibited myofascial effects of KT as the deformations were heterogeneous and the major direction of the eigenvectors within TA was anterior to posterior. If all components of the body are connected to another as described in the Tensegrity Model and even strongly connected components are embedded within an overall elastic context, then the low load and low amplitude effect of the KT may be expected to produce a long lasting result and release the compression over common peroneal nerve. Superior to inferior and medial to lateral deformations within TA may explain the recoil affect of the KT, thus it repositions the ankle at dorsi flexion.

Also in the long term application, KT may enhance sarcomere regeneration as calculated deformations at intramuscular tissue levels may cause a lateral load sharing through the endomysium that makes possible muscle to grow and to repair damaged sarcomere. Purslow (2010), explained the effects of lateral load sharing on the endomysium as following: “Lateral load sharing and coordination of deformations means that a fiber can be interrupted for the addition of new sarcomeres necessary for muscle lengthening during growth, without loss of function of an entire contractile column. By the same mechanism, the contractile capacity of the weakness of a sarcomere in which damaged myofibrils are being broken down and remodelled during muscle repair does not lead to tearing of the fiber at this point, as the endomysial connections between adjacent fibers serve to keep the strains uniform throughout the tissue". To discuss the long term effects of KT, further investigations should be conducted.

4.4 Limitations of the study

4.4.1 Sensory Motor Integration

Muscle fiber is the structural unit of a skeletal muscle and a motor unit consists of a motor neuron and a certain number of muscle fibers innervated by the axonal terminals of that motor neuron. When a motor neuron is activated, all of its muscle fibers contract. In proportion to the muscle size and function, the number of muscle fibers that comprise a motor unit varies, such that motor units of small muscles that are used for fine motor skills are composed of a few muscle fibers. After the activation of a motor neuron, agonist muscles are stimulated to enhance the movement. Antagonistic muscles usually control the movement and the synergistic muscles help the agonist muscles to perform or neutralize [49]. It is welly known that fascia is richly innervated [50] and its receptors will carry the information about the sensory stimulus to the central nerves system(CNS), which may cause a motor result [48]. Therefore, the local length changes shown presently as a result of KT application may not only be ascribable to the resulting mechanical interaction provoked within the entire limb, but they may also be due to the sensory stimulus generated by the initial tissue deformations caused by the KT. In order to isolate the effects of mechanical interactions, the neural pathways should be inactivated. On the other hand, our study does not involve dynamic MRI techniques as well as active muscle contraction. Testing of such conditions is also required to further assess the role of sensory motor integration.

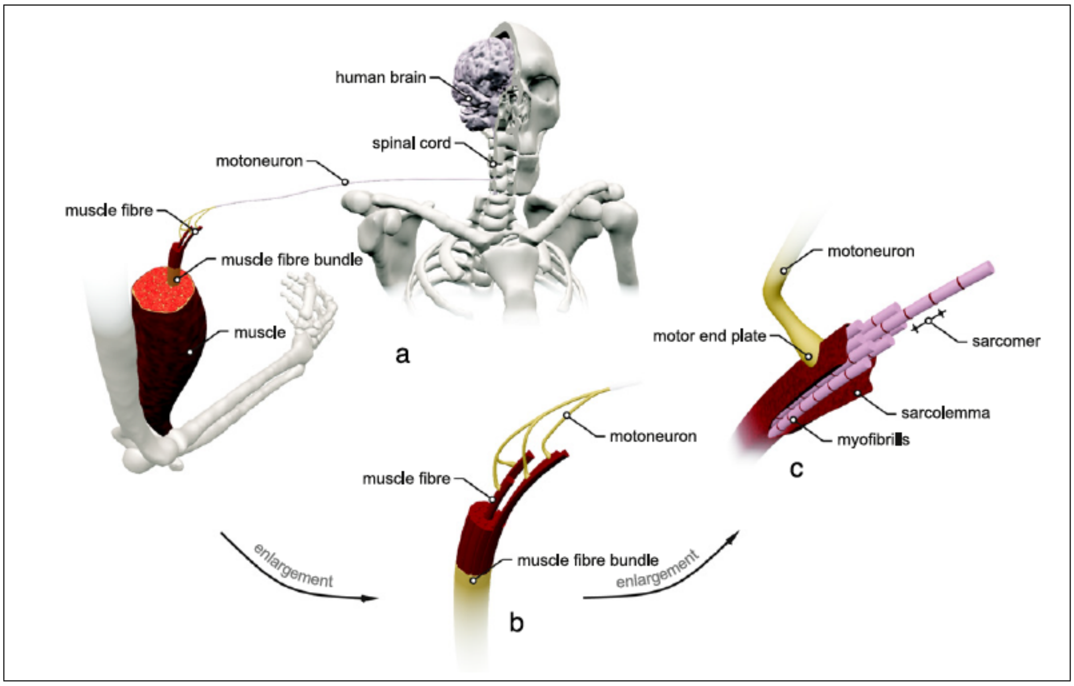

Figure 4.2 Schematic ilustration of the motor stimulus a)The brain sends a signal, b)The motor end plates, c) A muscle fiber comprised of myofibrils [51].

4.4.2 Strain calculations with respect to the global coordinate system

The local muscle strains described in this study were demonstrated in reference to the global coordinate system. However, gastrocnemius and soleus muscles are pennate muscles. Therefore, the muscle fibers of these muscles are in an oblique direction compared to the global coordinates and we do not know if the peak strains are aligned with the muscle fiber directions. Consequently, the local deformations shown presently does not explain the lengthening and shortening along the fiber direction of gastrocnemius and soleus muscle. Therefore, additional MRI methods should be applied to determine the direction of muscle fibers locally within the collected images and convert present strains results to local muscle fiber strain in fiber directions.

In conclusion, the present study revealed the mechanical effects of drop foot method in terms of tissue deformations. However, KT consists of many different applications which are used for the desired treatment. To completely understand the therapeutic effects of KT, further researches including other application techniques of KT should be conducted.

REFERENCES

1. Parreira, P., L. Costa, L. Junior, A. D. Lopes, and L. Costa, "Current evidence does not support the use of kinesio taping in clinical practice: a systematic review," *Journal of physiotherapy*, Vol. 60, no. 1, pp. 31–39, 2014.

2. Basset, K., S. Lingman, and R. Ellis, "The use and treatment efficacy of kinaesthetic taping for musculoskeletal conditions: a systematic review," *NZ Journal of Physiotherapy*, Vol. 38, no. 2, p. 56, 2010.

3. Berthier, C., and S. Blaineau, "Supramolecular organization of the subsarcolemmal cytoskeleton of adult skeletal muscle fibers. a review," *Biology of the Cell*, Vol. 89, pp. 413–434, Dec. 1997.

4. Guyton, A., and J. Hall, "Tıbbi fizyoloji. 10," *Baskı, İstanbul: Nobel Tıp Kitapevleri*, pp. 382–391, 2001.

5. Trotter, J., "Dynamic shape of tapered skeletal muscle fibers," *Journal of morphology*, Vol. 207, no. 2, pp. 211–223, 1991.

6. Passerieux, E., R. Rossignol, A. Chopard, A. Carnino, J. Marini, T. Letellier, and J. Delage, "Structural organization of the perimysium in bovine skeletal muscle: Junctional plates and associated intracellular subdomains," *Journal of structural biology*, Vol. 154, no. 2, pp. 206–216, 2006.

7. Passerieux, E., R. Rossignol, T. Letellier, and J. Delage, "Physical continuity of the perimysium from myofibers to tendons: involvement in lateral force transmission in skeletal muscle," *Journal of structural biology*, Vol. 159, no. 1, pp. 19–28, 2007.

8. Neumann, D. A., *Kinesiology of the musculoskeletal system: foundations for rehabilitation*, Elsevier Health Sciences, 2013.

9. Findley, T., and M. Shalwala, "Fascia research congress evidence from the 100 year perspective of andrew taylor still," *Journal of bodywork and movement therapies*, Vol. 17, no. 3, pp. 356–364, 2013.

10. Schleip, R., H. Jäger, and W. Klingler, "What is 'fascia'? a review of different nomenclatures," *Journal of bodywork and movement therapies*, Vol. 16, no. 4, pp. 496–502, 2012.

11. Dıraçoğlu, D., R. Aydın, and A. Başkent, "Sağlıklı kişilerde ve diz osteoartritli hastalarda propriosepsiyon duyusunun karşılaştırılması," *Türk Fiz Tıp Rehab Derg*, Vol. 51, pp. 90–93, 2005.

12. Yılmaz, A., and H. Gök, "Propriyosepsiyon ve propriyoseptif egzersizler," *Archives of Rheumatology*, Vol. 21, no. 1, pp. 023–026, 2006.

13. Seaman, D., "Nociception, mechanoreception and proprioception what's the difference and what do they have to do with subluxation? chiral/veb," tech. rep.

14. Pritchett, J. W., and M. Porembski, "Foot drop," *E-Medicine.[Online]*, 2006.

15. Stewart, J. D., "Foot drop: where, why and what to do?," *Practical neurology*, Vol. 8, no. 3, pp. 158–169, 2008.

16. Grauwin, M.-Y., G. Wavreille, and C. Fontaine, "Double tendon transfer for correction of drop-foot," *Orthopaedics Traumatology: Surgery Research*, 2015.

17. Simonsen, E. B., L. M. Moesby, L. D. Hansen, J. Comins, and T. Alkjaer, "Redistribution of joint moments during walking in patients with drop-foot," *Clinical Biomechanics*, Vol. 25, no. 9, pp. 949–952, 2010.

18. Kase, K., J. Wallis, T. Kase, K. T. Association, *et al.*, *Clinical therapeutic applications of the Kinesio taping methods*, Kinesio Taping Assoc., 2003.

19. Mostafavifar, M., J. Wertz, and J. Borchers, "A systematic review of the effectiveness of kinesio taping for musculoskeletal injury.," *The Physician and sportsmedicine*, Vol. 40, no. 4, pp. 33–40, 2012.

20. Firth, B., P. Dingley, E. Davies, J. Lewis, and C. Alexander, "The effect of kinesiotape on function, pain, and motoneuronal excitability in healthy people and people with achilles tendinopathy," *Clinical Journal of Sport Medicine*, Vol. 20, no. 6, pp. 416–421, 2010.

21. Farrell, J. P., and G. M. Jensen, "Manual therapy: a critical assessment of role in the profession of physical therapy," *Physical Therapy*, Vol. 72, no. 12, pp. 843–852, 1992.

22. GonzáLez-Iglesias, J., C. Fernandez-De-Las-Penas, J. Cleland, P. Huijbregts, and M. Gutiérrez-Vega, "Short-term effects of cervical kinesio taping on pain and cervical range of motion in patients with acute whiplash injury: a randomized clinical trial," *Journal of Orthopaedic Sports Physical Therapy*, Vol. 39, no. 7, pp. 515–521, 2009.

23. Keklicek, H., F. Uygur, and Y. Yakut, "Effects of taping the hand in children with cerebral palsy," *Journal of Hand Therapy*, 2014.

24. ElKhatib, R. S., E. H. ElNegmy, A. H. Salem, and A. A. Sherief, "Kinesio arm taping as prophylaxis against the development of erb's engram," *Journal of Advanced Research*, Vol. 4, no. 6, pp. 485–491, 2013.

25. Chang, H., K. Chou, J. Lin, C. Lin, and C. Wang, "Immediate effect of forearm kinesio taping on maximal grip strength and force sense in healthy collegiate athletes," *Physical Therapy in Sport*, Vol. 11, no. 4, pp. 122–127, 2010.

26. Luque-Suarez, A., G. Gijon-Nogueron, F. J. Baron-Lopez, M. Labajos-Manzanares, J. Hush, and M. Hancock, "Effects of kinesiotaping on foot posture in participants with pronated foot: a quasi-randomised, double-blind study," *Physiotherapy*, Vol. 100, no. 1, pp. 36–40, 2014.

27. Huijing, P. A., "Epimuscular myofascial force transmission: a historical review and implications for new research. international society of biomechanics muybridge award lecture, taipei, 2007," *Journal of biomechanics*, Vol. 42, no. 1, pp. 9–21, 2009.

28. Maas, H., G. C. Baan, P. A. Huijing, C. A. Yucesoy, B. H. Koopman, and H. J. Grootenboer, "The relative position of edl muscle affects the length of sarcomeres within muscle fibers: experimental results and finite-element modeling," *Journal of biomechanical engineering*, Vol. 125, no. 5, pp. 745–753, 2003.

29. Yucesoy, C. A., B. H. Koopman, G. C. Baan, H. J. Grootenboer, and P. A. Huijing, "Effects of inter-and extramuscular myofascial force transmission on adjacent synergistic muscles: assessment by experiments and finite-element modeling," *Journal of biomechanics*, Vol. 36, no. 12, pp. 1797–1811, 2003.

30. Huijing, P. A., A. Yaman, C. Ozturk, and C. A. Yucesoy, "Effects of knee joint angle on global and local strains within human triceps surae muscle: Mri analysis indicating in vivo myofascial force transmission between synergistic muscles," *Surgical and radiologic anatomy*, Vol. 33, no. 10, pp. 869–879, 2011.

31. Findley, T., and R. Schleip, *Basic Science and Implications for Conventional and Complementary Health Care*, Elsevier Urban and Fischer, 2007.

32. Tozzi, P., D. Bongiorno, and C. Vitturini, "Fascial release effects on patients with non-specific cervical or lumbar pain," *Journal of bodywork and movement therapies*, Vol. 15, no. 4, pp. 405–416, 2011.

33. Denoth, J., E. STüSSI, G. Csucs, and G. Danuser, "Single muscle fiber contraction is dictated by inter-sarcomere dynamics," *Journal of theoretical biology*, Vol. 216, no. 1, pp. 101–122, 2002.

34. Purslow, P. P., "Muscle fascia and force transmission," *Journal of bodywork and movement therapies*, Vol. 14, no. 4, pp. 411–417, 2010.

35. Nishimura, T., A. Hattori, and K. Takahashi, "Ultrastructure of the intramuscular connective tissue in bovine skeletal muscle," *Cells Tissues Organs*, Vol. 151, no. 4, pp. 250–257, 1994.

36. Huijing, P. A., "Epimuscular myofascial force transmission between antagonistic and synergistic muscles can explain movement limitation in spastic paresis," *Journal of Electromyography and Kinesiology*, Vol. 17, no. 6, pp. 708–724, 2007.

37. Yucesoy, C. A., G. Baan, and P. A. Huijing, "Epimuscular myofascial force transmission occurs in the rat between the deep flexor muscles and their antagonistic muscles," *Journal of Electromyography and Kinesiology*, Vol. 20, no. 1, pp. 118–126, 2010.

38. Huijing, P. A., "Muscle as a collagen fiber reinforced composite: a review of force transmission in muscle and whole limb," *Journal of biomechanics*, Vol. 32, no. 4, pp. 329–345, 1999.

39. Carlson, B., "Integumentary, skeletal, and muscular systems," *Human Embryology and Developmental Biology*, pp. 153–181, 1994.

40. Moore, K. L., A. F. Dalley, and K. Şahinoğlu, *Kliniğe yönelik anatomi*, Nobel Tıp Kitabevleri, 2007.

41. Benjamin, M., "The fascia of the limbs and back–a review," *Journal of anatomy*, Vol. 214, no. 1, pp. 1–18, 2009.

42. Myers, T. W., *Anatomy trains: myofascial meridians for manual and movement therapists*, Elsevier Health Sciences, 2009.

43. Schwind, P., *Fascial and membrane technique: a manual for comprehensive treatment of the connective tissue system*, Elsevier Health Sciences, 2006.

44. Lumbroso, D., E. Ziv, E. Vered, and L. Kalichman, "The effect of kinesio tape application on hamstring and gastrocnemius muscles in healthy young adults," *Journal of bodywork and movement therapies*, Vol. 18, no. 1, pp. 130–138, 2014.

45. Xu, G., C. Yang, J. Du, and X. Feng, "Integrin activation and internalization mediated by extracellular matrix elasticity: a biomechanical model," *Journal of biomechanics*, Vol. 47, no. 6, pp. 1479–1484, 2014.

46. Grinnell, F., "Fibroblast mechanics in three-dimensional collagen matrices," *Journal of bodywork and movement therapies*, Vol. 12, no. 3, pp. 191–193, 2008.

47. Lavelle, J. M., and M. E. McKeigue, "Musculoskeletal dysfunction and drop foot: diagnosis and management using osteopathic manipulative medicine," *JAOA: Journal of the American Osteopathic Association*, Vol. 109, no. 12, pp. 648–650, 2009.

48. M.F., B., "The basic science of myofascial release: Morphologic change of connective tissue," *Journal of Bodywork and movement therapies*, Vol. 1, pp. 231–238, Jan 1997.

49. Haines, D. E., *Neuroanatomy: An atlas of structures, sections, and systems*, Vol. 153, Lippincott Williams Wilkins, 2004.

50. Stecco, C., A. Porzionato, L. Lancerotto, A. Stecco, V. Macchi, J. A. Day, and R. De Caro, "Histological study of the deep fasciae of the limbs," *Journal of bodywork and movement therapies*, Vol. 12, no. 3, pp. 225–230, 2008.

51. Böl, M., R. Weikert, and C. Weichert, "A coupled electromechanical model for the excitation-dependent contraction of skeletal muscle," *Journal of the mechanical behavior of biomedical materials*, Vol. 4, no. 7, pp. 1299–1310, 2011.