T.C.
ISTANBUL UNIVERSITY-CERRAHPASA
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Ph.D. THESIS

ANALYSIS OF EMG SIGNALS RECORDED FROM QUADRATUS LUMBORUM MUSCLE OF PEOPLE WITH PELVIS ASYMMETRY

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FOREWORD

I would like to thank all the people who were always with me when I needed them the most. I would like to extend to my acknowledgment and my sincere gratitude to you for helping me make this Ph. D. study possible

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June 2019 Sevim ERYIGIT

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	**Explanation**
F	: Female
M	: Male
SD	: Standard Deviation
p	: Significance Level
SEM	: Standard Error Mean
$\boldsymbol{x}(\boldsymbol{n})$	: EMG Signal
$\widetilde{\boldsymbol{p}}_{\boldsymbol{per}}\ (\boldsymbol{\omega})$	: Power Spectral Density (Welch Method)
$\boldsymbol{U}$	: Normalized factor
$\boldsymbol{M}$	: Hamming Window Length
Ag/Agcl	: Silver/Silver Cloride

Abbreviation	**Explanation**
AIIS	: Anterior Inferior Iliac Spine
ASIS	: Anterior superior Iliac Spine
PIIS	: Posterior Inferior Iliac Spine
PSIS	: Posterior Superior Iliac Spine
BMI	: Body Mass Index
CT	: Computerized Tomography
DFT	: Discrete Fourier Transform
DPI	: Digital Pelvic Inclinometer
EMG	: Electromyography
Hz	: Hertz
MLP	: Multilayer Perceptron
QL	: Quadratus Lumborum
LLD	: Leg Length Discrepancy
SIJ	: Sacroiliac Joint
SNR	: Signal-to-Noise Ratio
PSD	: Power Spectral Density

ÖZET

DOKTORA TEZİ

PELVİS ASİMETRİSİ OLAN KİŞİLERDE QUADRATUS LUMBORUM KASINDAN KAYDEDİLEN EMG SİNYALLERİNİN ANALİZİ

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Bu tezin amacı, lumbal omurgada ve alt ekstremitelerde ciddi yaralanmalara neden olabilen bacak uzunluğu eşitsizliği üzerindeki quadratus lumborum kas aktivitesinin etkisini araştırmaktı. Ayrıca, bir dijital pelvik eğimölçerin güvenilirliğini araştırdık. Dikkatli elektromiyografi sinyal kaydı ve analizi derin kasların aktivitesini belirlemede büyük bir role sahip olduğundan klinik bir araç olarak önemli bir değere sahiptir. Bu çalışmaya sağ eli dominant olan toplam 100 sağlıklı birey dahil edildi. Pelvik iliak crista seviyelerini belirlemek için tüm denekler manuel olarak değerlendirildi. Her iki taraftaki pelvik eğim açısını dijital pelvik inklinometre kullanarak ve bacak uzunluğu eşitsizliğini değerlendirmek için ise mezura kullanarak belirlendi. Elektromiyografi sinyalleri quadratus lumborum kası dinlenme pozisyonunda iken ve quadratus lumborum kası maksimal izometrik kasılma halinde iken kaydedildi. Sonuçlara göre (quadratus lumborum kasının istirahat ve maksimal izometrik kontraksiyon pozisyonlarında) sağ taraftaki güç spektral yoğunluğu Sağ iliac Crista Seviyeleri Yukarıda olan grubun / Sağ Kısa Fonksiyonel Bacak Eşitsizliği olan grubun EMG sinyallerinin sol taraf sinyallerinden daha yüksek bulundu.Ayrıca, Sağ İliak Krista Yukarıda olan olan grubun % 100'ü de aynı taraf Kısa Bacak Boyu Eşitsizliği, Sol Krista İliaka Yukarda olan grubun % 98'inde aynı taraf Kısa Bacak Eşitsizliği vardı. Ayrıca, dijital pelvik inklinometre kullanılarak ölçüldü ve sağ taraf > sol taraf açısı ve sol taraf > sağ taraf açısı olmak üzere iki gruba ayrıldı. Dinlenme pozisyonunda quadratus lumborum kas aktivitesinin güç spektral yoğunluk analizi sonucunda her iki grupta da istatistiksel olarak anlamlı olduğu bulundu. Sonuç olarak quadratus lumborum kaslarında artmış aktivite / spazm, alt ekstremitelerde ve lumbal omurgada ciddi yaralanmalara yol açabilecek bacak boyu uyuşmazlığına ve pelvis asimetrisine neden olabilir. Bu çalışma, asemptomatik sağlıklı popülasyonda kuadratus lumborum kas aktivitesinin elektromiyografi sinyal analizi kullanılarak fonksiyonel bacak uzunluğu uyuşmazlığı için bir belirteç belirlemenin mümkün olduğunu göstermektedir.

Haziran 2019, 120 sayfa.

Anahtar kelimeler: Pelvik Asimetri, Bacak Uzunluk Eşitsizliği, Fourier Dönüşümü, Güç Spektral Yoğunluğu, Quadratus Lumborum, İliac Crista, Elektromiyografi, Sinyal Analizi

SUMMARY

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ANALYSIS OF EMG SIGNALS RECORDED FROM QUADRATUS LUMBORUM MUSCLE OF PEOPLE WITH PELVIS ASYMMETRY

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This thesis aimed to investigate the effect of quadratus lumborum muscle activity on leg length discrepancy, which might cause serious injuries in the lumbar spine and lower extremity. Furthermore, we investigated the reliability of a digital pelvic inclinometer. Careful electromyography signal recording and analysis has significant value as a clinical tool because it plays a major role in determining the activity of deeper muscles. A total of 100 healthy right-handed subjects were included in this study. All subjects were assessed manually to determine pelvic iliac levels. The angle of pelvic tilt was measured on both sides using digital pelvic inclinometer and manually using tape measurement to assess leg-length inequality. The activity of quadratus lumborum muscles was recorded at resting and maximal-isometric positions. According to the results (at resting and maximal-isometric contraction positions of the quadratus lumborum muscle), the power spectral density of EMG signals of the right side was higher than the left side for the Up-Right Iliac Crest Level / Short Right Functional Leg Length Discrepancy groups and was higher in the left side than the right side for the Up-Left Iliac Crest Level / Short Left Functional Leg Length Discrepancy groups. Moreover, 100% of participants who had Up-Right Iliac Crest Level also had short functional leg length discrepancy on the same side. 98% of participants who had Up-Left liac Crest level also had short functional leg length discrepancy on the same side. Furthermore, the pelvis angle of the left and right sides was measured using digital inclinometer, and categorized into two groups; left-side> right-side angle and right-side>left-side angle. By the help of power spectral density analysis of quadratus lumborum muscle activity at the resting position, we found that these results were statistically significant in both groups. In conclusion, increased activity or spasm in the quadratus lumborum muscles may be caused by leg length discrepancy and/or pelvic asymmetry, which might lead to serious injuries in the lower extremities and spine. In addition, the present study shows that it is possible to determine a marker for functional leg length discrepancy by using electromyography signal analysis of quadratus lumborum muscle activity on an asymptomatic healthy population.

June 2019, 120 pages.

Keywords: Pelvic Asymmetry, Leg Length Discrepancy, Discrete Fourier Transform, Power Spectral Density, Quadratus Lumborum Muscle, Iliac Crista, Electromyography, Signal Analysing.

1. INTRODUCTION

Assessment of pelvic asymmetry is one of the most prevalent clinical methods used by clinicians for lumbopelvic and lower limb dysfunction [1]. The human body consists of the bony skeleton, and biomechanically all bones of the skeletal system are related to each other. Therefore if there is any alteration in movement or disorder of any position which can lead to body injuries such as fracture, sprain, strain, dislocation, concussion, and sometimes developed into diseases [2]. The pelvis is the fulcrum point of the human body. Its unique position among the upper and lower body makes its essential function and special effects on the bony skeletons and biomechanically subjects. The pelvis is a basin structure of the skeleton composed of hip bones on the sides, pubis in front, sacrum and coccyx from behind. It rests on lower limbs and supports the spinal column [3]. Pelvic functions can simplify how they can have a great effect on these areas. İmportance of the pelvis: It is the main structure for human posture. Moreover, pelvis suspension between the upper trunks and lower limb, as a result, any kinds of pelvic disorders affecting the postural deformities or imbalances [1,3]. Pelvis provide sites for muscles attachment, and nearly 45 muscles are attached to it. The pelvis has another impact on motions of pelvic increased or decreased rotations, which can alter cycles, causing posture deformities [4]. Medically, the pelvis has some close relationship within the gastrointestinal, endocrines, urogenital systems. If we look at the pelvis function, easily we can tell that this region has vital roles in the body because any malalignment of its position can cause not only musculoskeletal problem but also the vascular, endocrines, the peripheral, gastrointestinal tract and the urogenital problems [5,6]. Here in this thesis, we discussed the effects of the quadratus lumborum (QL) activity on functional leg length discrepancy (LLD) and pelvic asymmetry. The objectives of the study were to focus on the QL muscle, LLD and pelvic asymmetry.

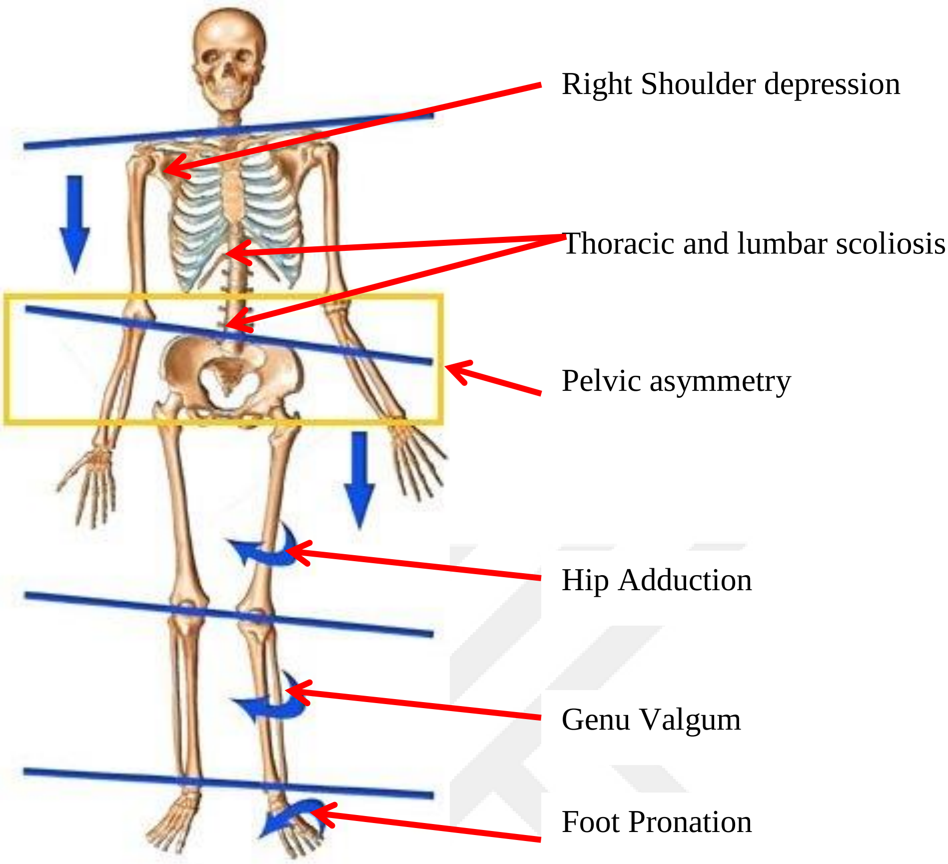


Figure 1.1: Human body pelvic asymmetry.

There are three types of pelvic asymmetry can happen separated or combined, which are: Three types of pelvic asymmetry tilt, shift and up slip could occur together or separated.

- Tilt: Its main functions are the rotations of the hip bones anterior or posterior near the transverses axis's.
- Shift: Its main functions are the rotations of the hip bones anterior or posterior along sagittal axis's.
- Upslip and pelvis: Its main functions are the rotations of the hip bones upward [7-9].

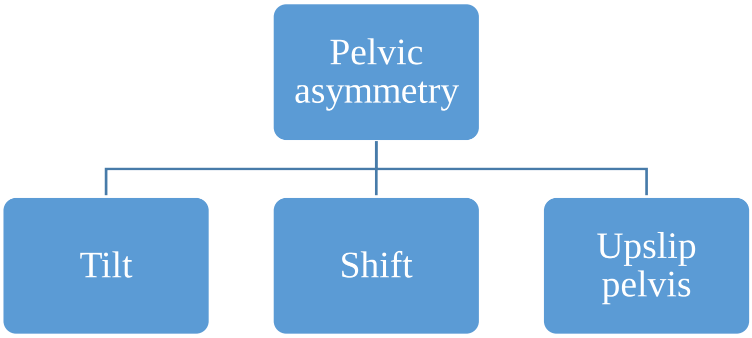


Figure 1.2: Three types of pelvic asymmetry.

All these pelvic asymmetries are the main cause of LLD [10, 11]. LLD is dissimilarity of lower limb lengths inequality between legs is the most commonly split into two groups: anatomical and functional. The first one is structural, and the second one is functional. In structural LLD is inequalities of a limb as of inequalities of the bony structure. But functional LLD is asymmetries of the lower limb without any inequalities of the bony structure. The effects of leg LLD in physiological functions are exploring, which would shade some lights on a promising range of medical impact. LLD are origins of the muscular hypertonicity and changing the strengths and/or coordination's. Expected LLD can be caused more fatigued of trunk muscle[10-13].

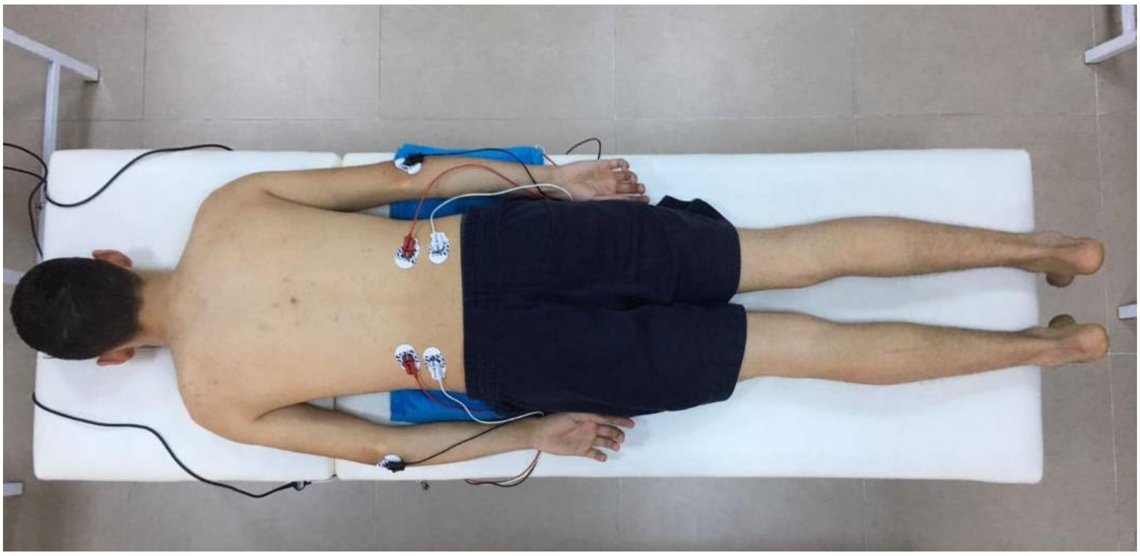


Figure 1.3: Pelvic asymmetry and EMG signal analysis.

Electromyography (EMG) is a common investigational procedure depending on the improvement, signal recording, and evaluating of electrical activity produced by skeletal muscles. In electromyography method, electrical signals are generated by physiological variation in the conditions of muscles fiber membranes. EMG allows to directly observing into the muscle, measurement of muscular performances, also analysis to progress and detect muscles responses in several musculoskeletal conditions [14].

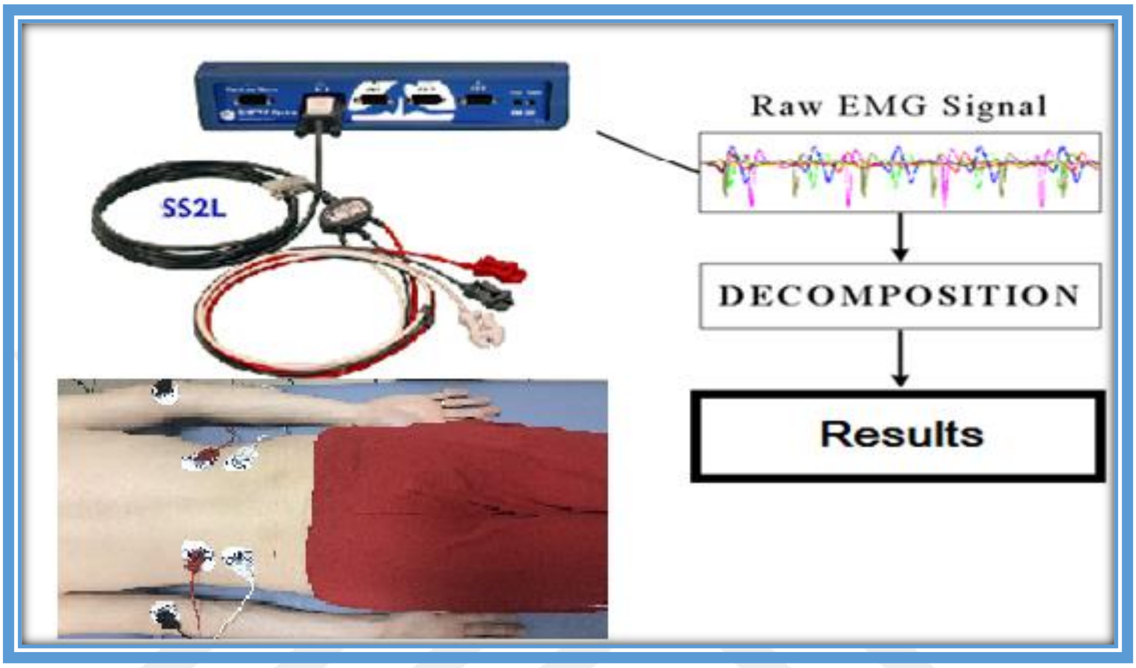


Figure 1.4: EMG signal analysis procedure.

In this study, we tried to find the relationship QL muscle activity between pelvic asymmetry and LLD by EMG signal analysis. In this thesis, we had a detail literature survey about pelvic asymmetry and EMG signal analysis. Where we get information about the pelvic asymmetry main causes and problems its also biomechanical risk factor. Moreover, we tried to measure it by using electromyography method.

1.1. MOTIVATION OF THE THESIS

The thesis aimed to evaluates the EMG signals of QL muscles activities on pelvic asymmetry and LLD as this may cause major damages in the lumbar spine and lower extremity. Although there are lots of studies about the QL muscle in people with pelvis asymmetry analysis, still there is a great necessity for these kinds of studies. Especially the clinical analysis of QL muscle with pelvis asymmetry and EMG has not reached to the desired point and the status of routine clinical usage. Therefore, more effort should be spent on the development of interactive tools. Moreover, there is needed to close collaboration between the academic EMG analysis researches, physiotherapist and physicians. The general purpose of this thesis can be defined below:

- Anatomy of the QL muscle, pelvis and LLD.
- Subjects who fulfilled diagnostic criteria for QL muscle in people with pelvis asymmetry were recruited in the participant group.
- Investigate the effect of QL activity on LLD and pelvic asymmetry. Furthermore, is this might cause severe injuries in the lumbar spine and lower extremity.
- To investigate pathology of the pelvic asymmetry or early detection of the disease that knowing this will be significant data for shedding light on the early diagnosis and therapy of low back pain.
- Describe the experimental set-up of EMG appropriately.
- To create an EMG database with pelvis asymmetry participant group.
- Describe and development of EMG analysis based on signal analysis methods.

To the best of our knowledge there were no other studies which investigate the effect of quadratus lumborum muscle activity on leg length discrepancy and pelvic asymmetry by using electromyography signal analysis.

1.2. LITERATURE SURVEY AND BACKGROUND

1.2.1. Pelvis

The human pelvis is an important structure that contributes to various biological processes, especially in locomotion, childbirth, and thermoregulation. These processes are important for the survival of human beings and the structure is said to have evolved over time to adapt to the constant demands of the human body [15]. When standing in the anatomical position, the pelvis is tilted anteriorly. In this position, ASIS’s and the pubic tubercles lie in the same vertical plane, and the anterior (internal) surface of the sacrum faces forward and downward

[16]. The changes in the pelvic structure over time have also been influenced by the changes in behavior, locomotion, habitat, and climate [17]. The body attempts to compensate due to the imbalance caused by this condition, which affects other parts like the pelvis, the lumbar spine, hips, and knee and also shoulder [18]. The pelvis is made up of various muscles, ligaments, nerves, and bones that work together to ensure it meets its functional properties. The pelvis has several important functions for a number of reasons. It supports a person's upper body weight when seated and it shifts this weight to the lower limbs when a person is standing. It is also great attachment site for the trunk and lower limb muscles and also protects the various internal pelvic organs [15].

In brief, the pelvis is a very important "meeting" place, supporting the spine, the legs, the abdomen, and the lower back so on the whole body, and providing the foundation for good posture. By knowing the importance of pelvis and its vital role in the body we can understand the importance of studying pelvic asymmetry and its effects on the body [19, 20].

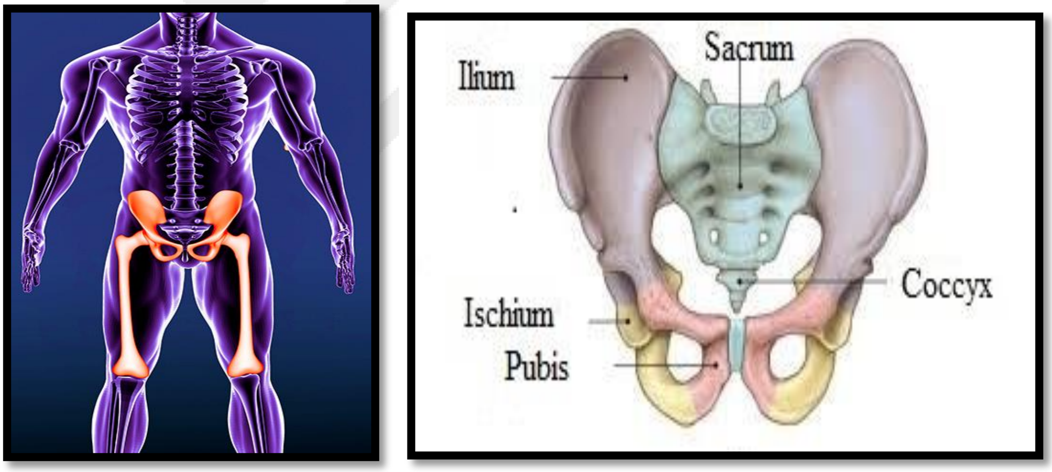


Figure 1.5: Pelvis structure [21].

1.2.2. Anatomy of the Pelvis

The pelvis is a bony structure that is found at the base of the spine. Cranially, the pelvis ' anatomical boundary reaches the 4th and 5th vertebrae of the lumbar. From these, an arc can be drawn to pass through the PSIS, iliac crest, and ASIS. Then the cranial boundary follows to the pubis from the inguinal ligament. The caudal boundary crosses the ischial tuberosities, which can be felt through the gluteal folds [22]. In the body of an adult, the pelvis consists of a ring of bones made up of sacrum, coccyx, and other innominate bones consist of three bones: ilium, ischium, and pubis. After puberty, these three parts fuse. The ilium is found at the uppermost part; the pubis is located at the frontal part while the ischium is at the back-lower, and it also the part we use to sit on [23]. Both hip bones have the pubis, ilium, and ischium that meet to form a cup-shaped space that is also referred to as the acetabulum. The acetabulum sits on the lateral side of the hip bone. The obturator foramen is the opening between the pubis and the ischium on the anteroinferior side [16]. This opening is filled with various connective tissues. The ilium wing forms the lateral projection of the hip, and the smooth inner and outer surface of this wing give attachment to muscles of the limb. The upper free edge of the wing, the iliac crest, is palpable laterally and posteriorly and gives attachment to abdominal muscles. The crest ends anteriorly in the ASIS. On the anterior border of the wing of the ilium below the ASIS is the anterior inferior iliac spine. On the posterior border, below the PSIS and just above the smooth concavity on this border, is the posterior inferior iliac spine. Of the two inferior elements of the hip bone, the ischium is the more posterior. The pubis is the more anterior of the two lower parts of the hip bone. It comprises the body and the superior and inferior pubic rami. Its medial surface is an articular one that enters into the pubic symphysis. The sacrum is roughly triangular shape and is made up of five fused sacral vertebrae that are dorsally convex. The sacrum inserts between the two iliac bones in a wedge-like manner, superiorly articulating with the fifth lumbar vertebra and caudad with the coccyx. The coccyx consists of three to five rudimentary fused vertebrae. Its superior surface is articulated with the lower articular surface of the sacrum [24].

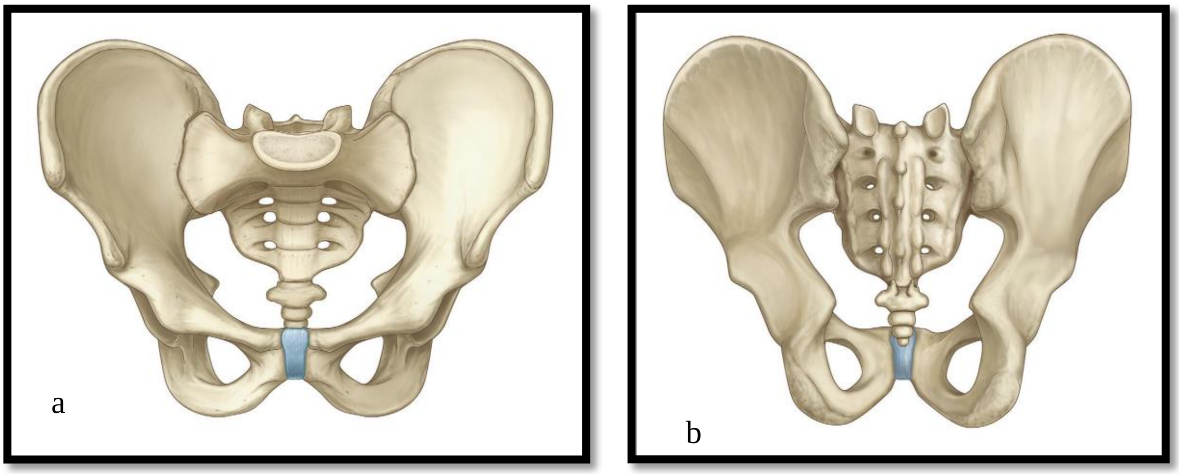


Figure 1.6: a) Front view of the pelvis and b) Posterior view of the pelvis [21].

1.2.3. The Pelvic Joints and Ligaments Connections of the Pelvis

The joints of the pelvis are the symphysis pubis, the sacroiliac joints (SIJ), the sacrococcygeal joint, lumbosacral joint and hip joints. The symphysis pubis is a fibrocartilaginous joint that unites the two pubic bones on the anterior side of the pelvis and is the anterior boundary of the perineum. The joint is surrounded and reinforced by fibrous ligaments that are and superior pubic ligament and inferior pubic ligament. The symphysis pubis is barely movable during most of life, but in women, it becomes much more movable by ligaments around the joint become relaxed during pregnancy [24].

Sacroiliac joints consist of relatively small joints cavity between the sacrum and ilium on each side and are true synovium-lined and cartilage-covered. SIJ is the largest axial joint and has the strongest ligaments connection these joints in the body. The primary purpose of the SIJ is to maintain stability. The SIJ's stability is maintained by the union of the two bones, along with numerous muscles and ligaments. A pair of strong ligaments that are attached between the sacrum and the ilium portions of the hip bone [25]. The anterior sacroiliac ligament on the anterior side of the joint and posterior sacroiliac ligament on the posterior side. The sacrococcygeal joint is another fibrocartilaginous joint that the sacrum and coccyx. The supporting ligaments are the ventral sacrococcygeal ligament, dorsal sacrococcygeal ligament, and the lateral sacrococcygeal ligament. The strong ligament system of the joint makes it more stable for stability and limits the amount of movement available [26, 27].

The sacroiliac joint moves along three main axes. These movements are limited to very small movements. That motions in normal people rarely exceed 3 degrees on each axis [28]. The lumbosacral joint is that between the lumbar vertebrae 5 and the sacral vertebrae of S1. It includes an intervertebral disc and joints between the articular process. The iliolumbar ligament originates from the tip of the 5. lumbar vertebral body to the iliac crest, also two additional ligaments are covering the sacrum and the femur. They are sacrospinous and sacrotuberous ligament. The sacrotuberous and sacroiliac ligaments prevent dorsal shearing movements of the SIJ. All these ligaments help to support and immobilize the sacrum as it carries the body's weight [24].

The hip joints are consist of the articulation between the head of the femur and the acetabulum of the pelvis forming a ball and socket synovial joint. The major function of the hip joint is to provide dynamic support for body weight while facilitating the transmission of force and load from the axial skeleton to the lower limbs, permitting ambulatory and mobility functions. Hip stability is achieved by ligaments that attach the femur to the pelvis and help to keep the ball in the socket and resist specific movements. The ligaments that help to the stabilize the joint include the tibiofemoral, ischiofemoral and pubofemoral ligaments. The hip joint serves as a connection of the lower extremity with the axial skeleton. It enables movement in all three planes: frontal plane (flexion-extension), sagittal plane (abduction-adduction), transverse plane (internal-external rotation) [15-17, 29].

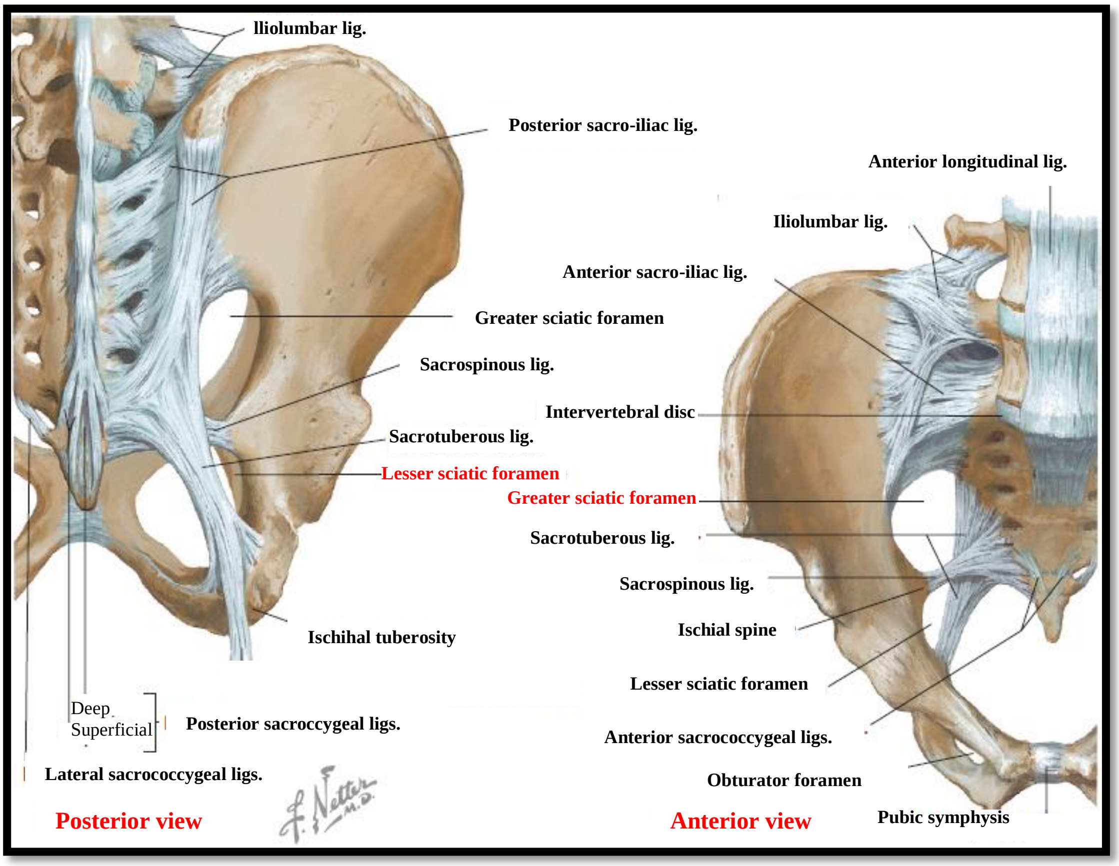


Figure 1.7: Anterior view of the pelvic ligaments and posterior view of the pelvic ligaments [30].

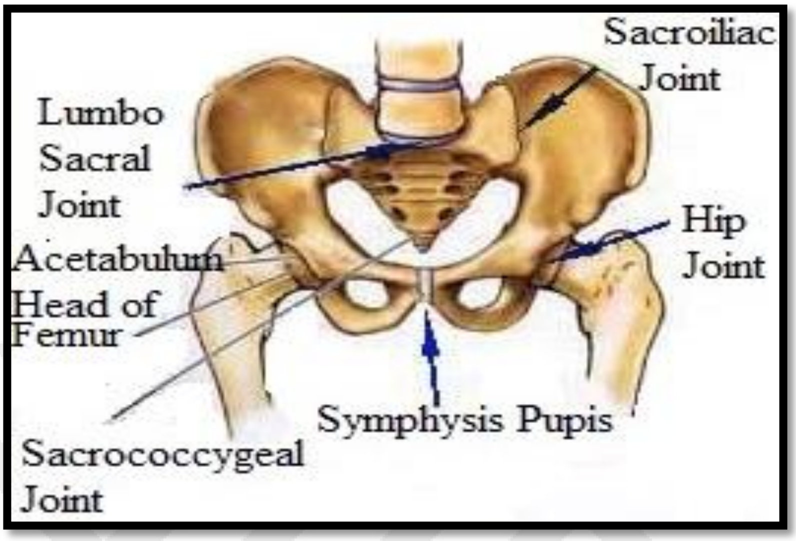


Figure 1.8: Anterior view of the pelvic joints.

1.2.4. The Pelvic Muscles and Motions of Pelvic Joints

Various muscles pass through the pelvis from the spine and hip joint. Pelvis muscles are represented in their three main categories. They are: connected from the trunk to the pelvic, cross the lumbosacral joint from the pelvis to the leg, and cross the hip joint and located wholly within the pelvis as the pelvic floor muscles.

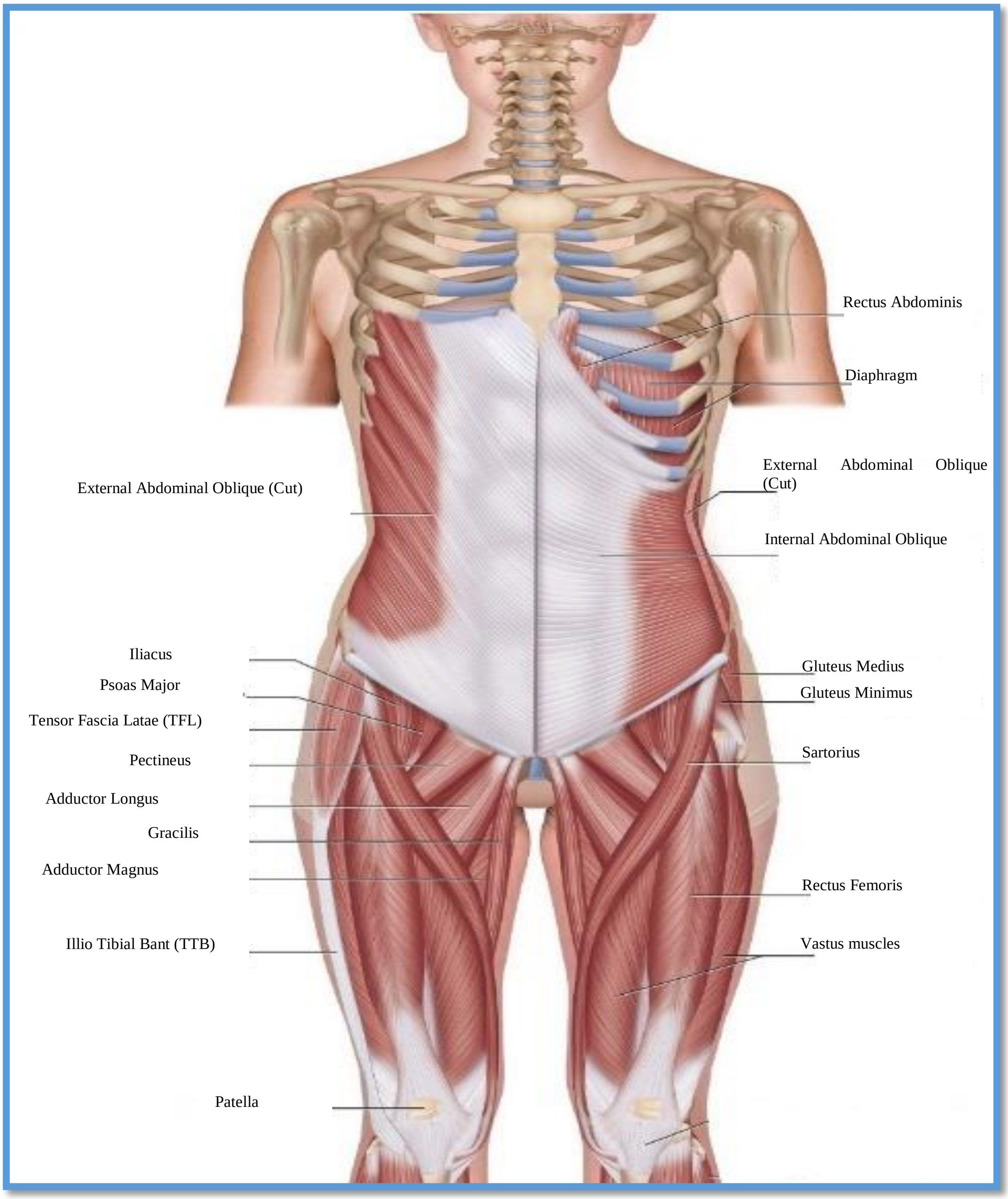


Figure 1.9: Anterior views of the lumbar spine and pelvic region muscles. Superficial layer view on the right side and mid-level layer view on the left side [31].

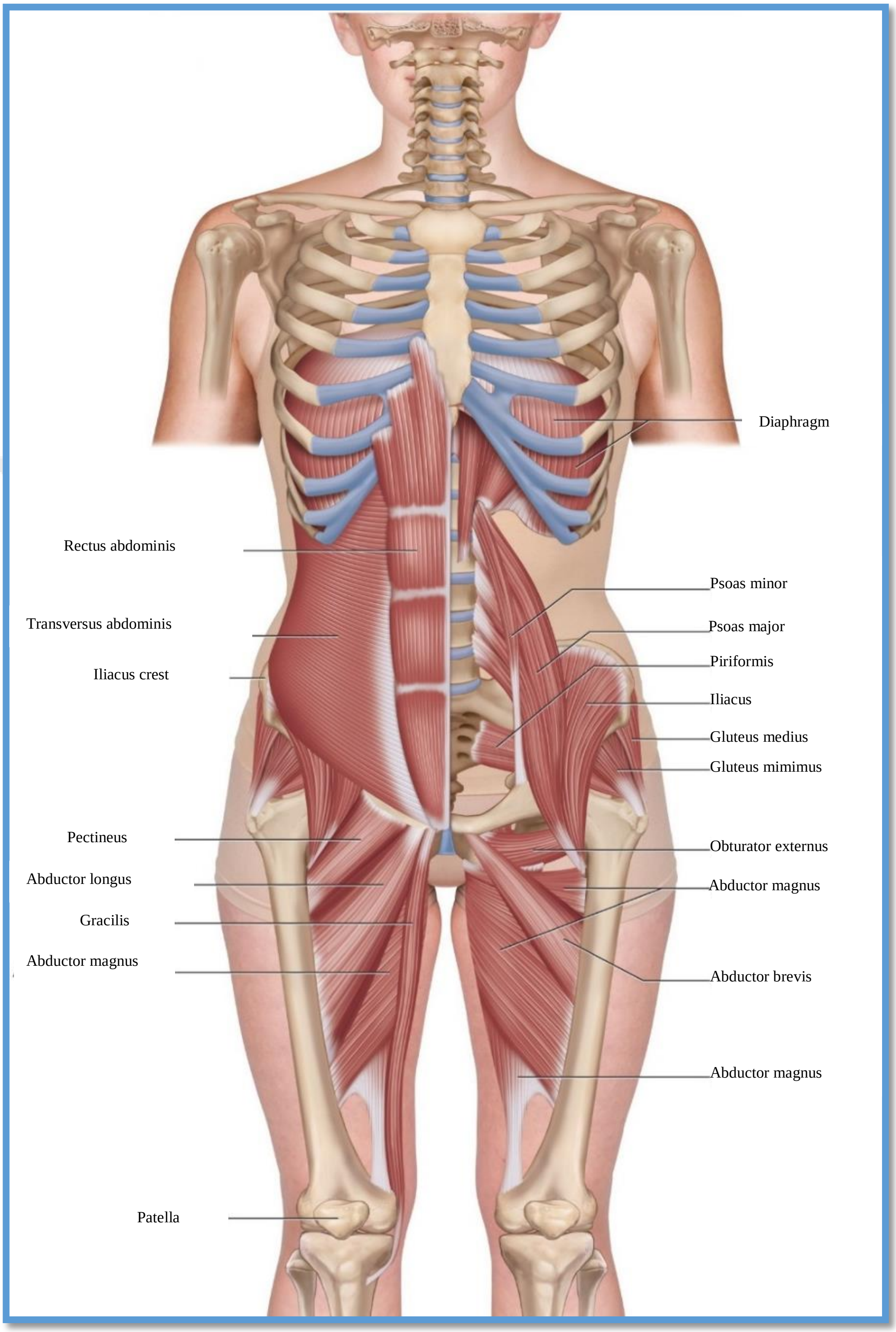


Figure 1.10: Anterior views of the lumbar spine and pelvic region muscles. The deeper layer of views [31].

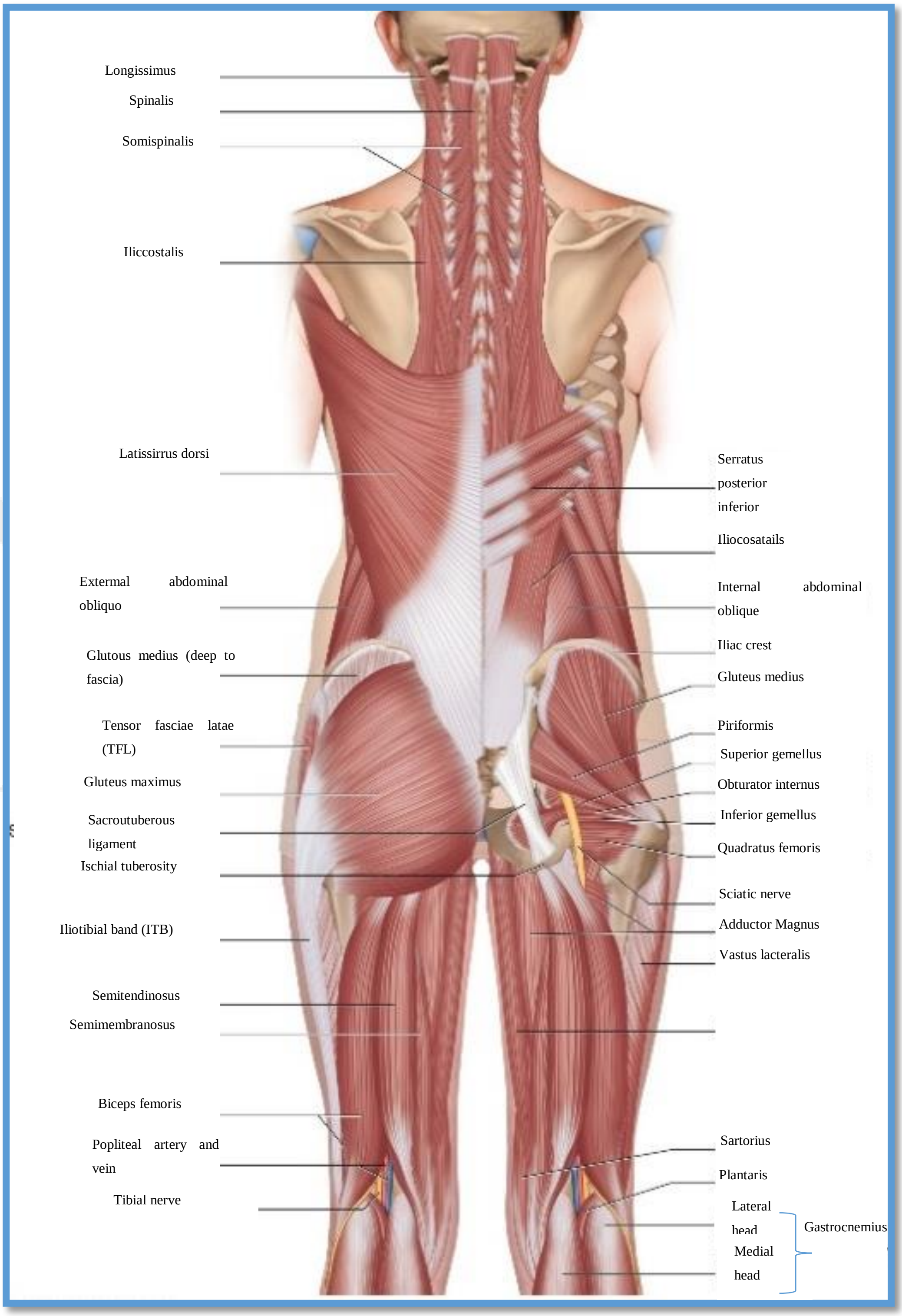


Figure 1.11: Posterior view of the lumbar spine and pelvic region muscles. Superficial layer view on the left and mid-level view on the right [31].

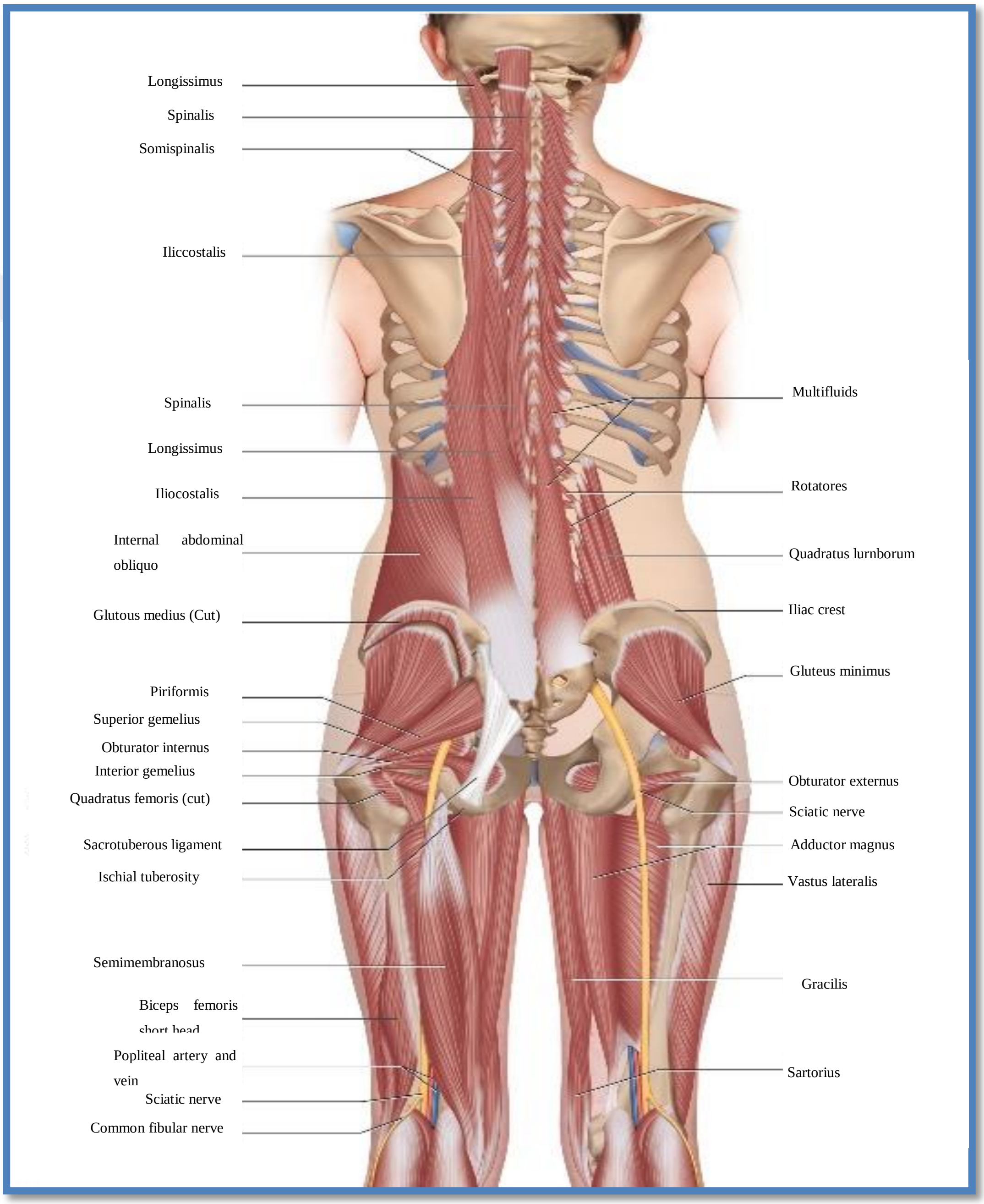


Figure 1.12: Posterior view of the lumbar spine and pelvic region muscles. The deeper layer of views [31].

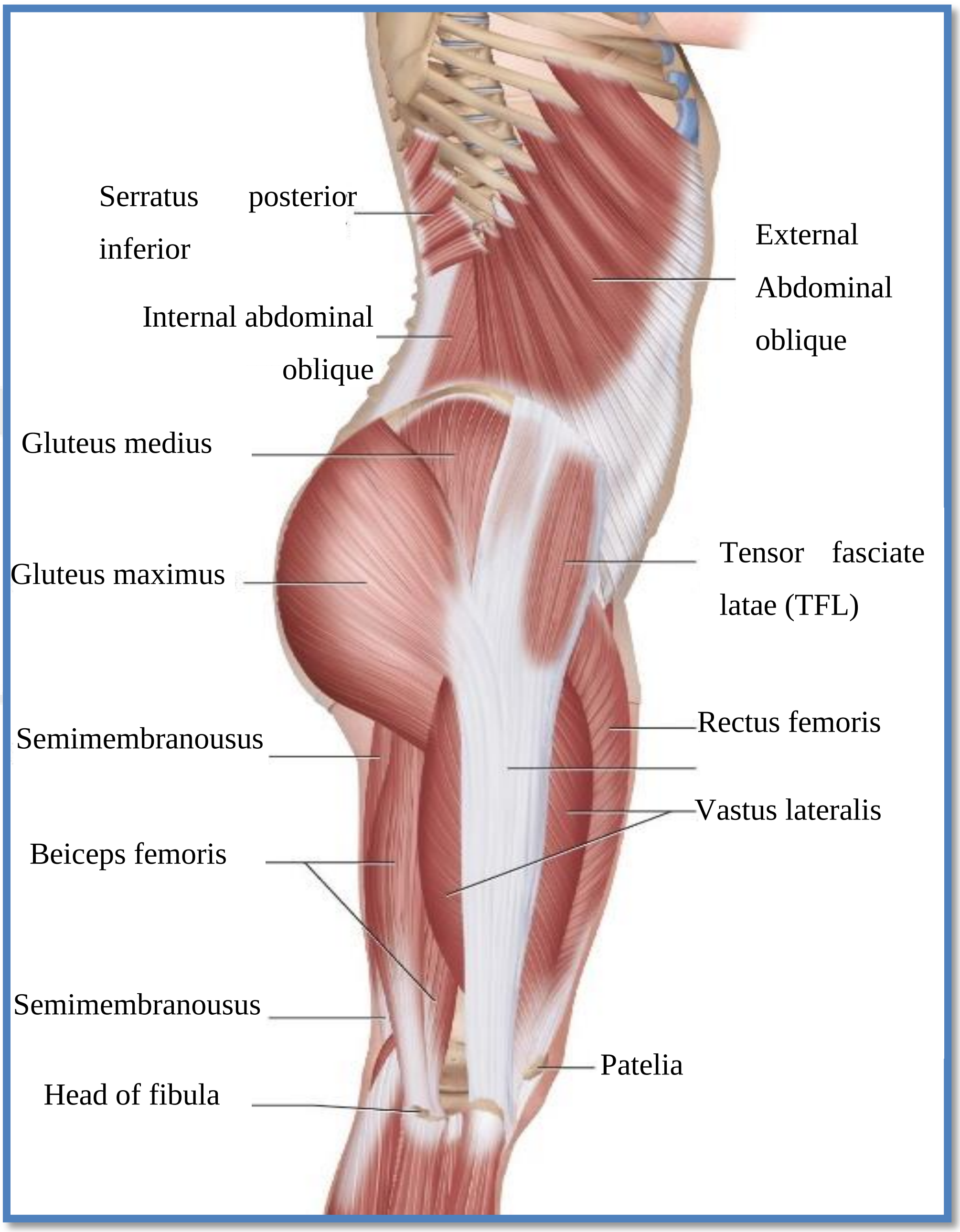


Figure 1.13: Right lateral views of the lumbar spine and pelvis region muscles. View of the lateral side of the superficial layer [31].

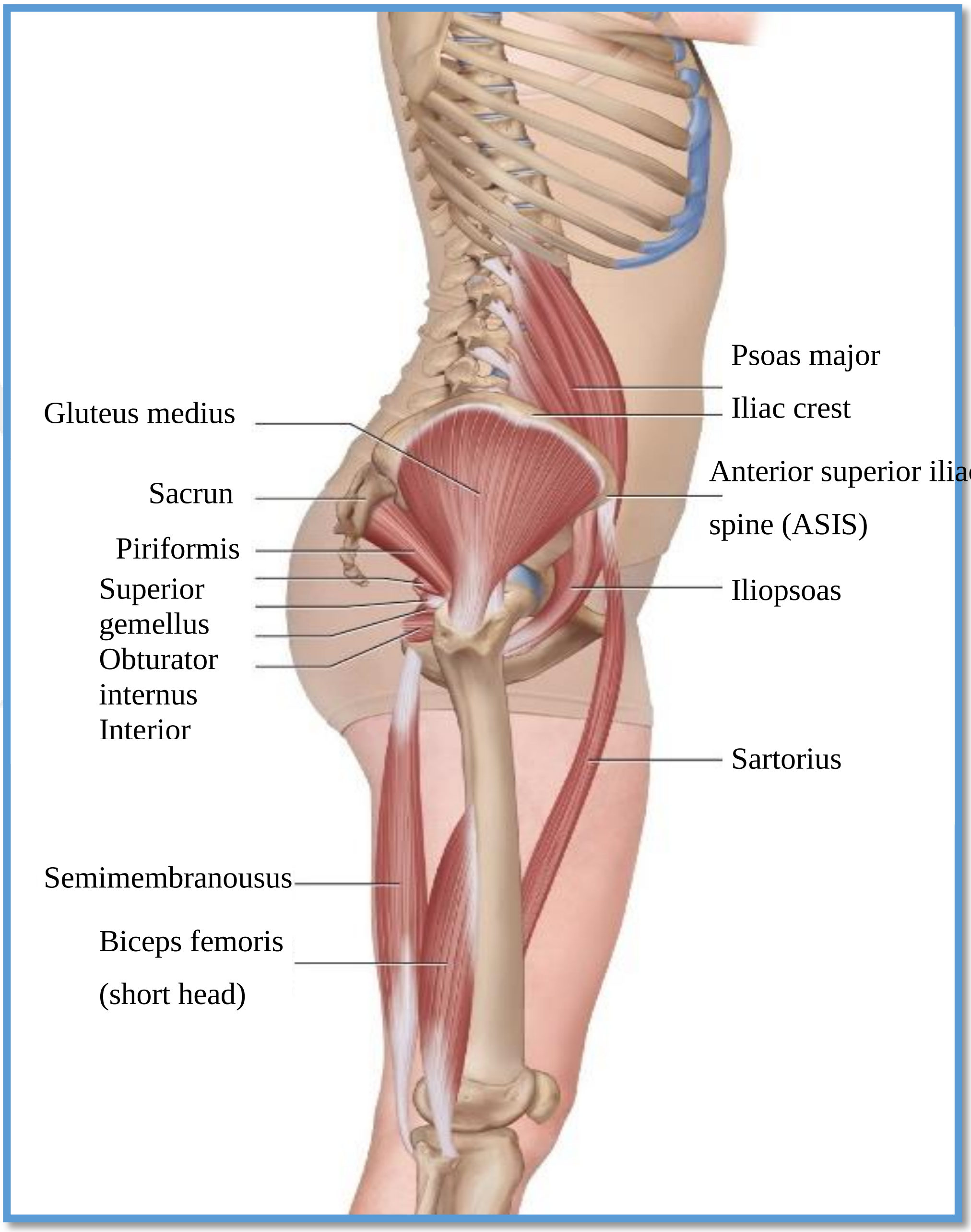


Figure 1.14: Right lateral views of the lumbar spine and pelvic region muscles. View of the deeper layer on the right side [31].

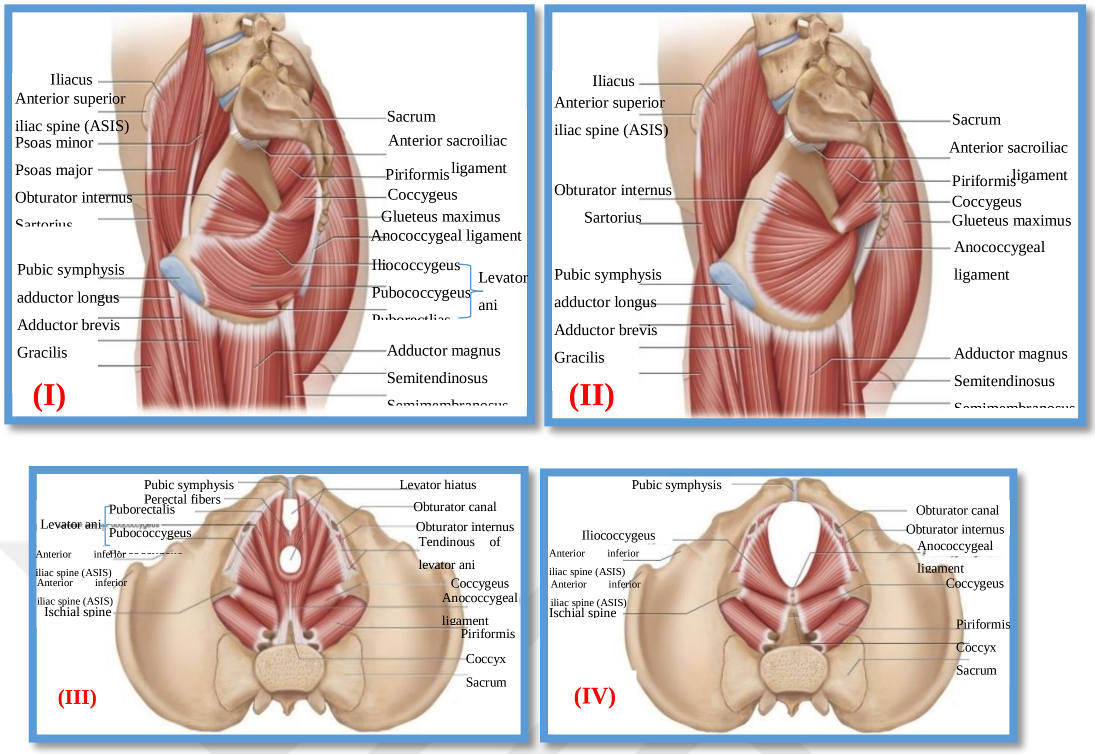


Figure 1.15: The pelvic floor muscle. Medial views of the right side of the pelvis (I, II). Superficial layer (I). Deep layer (II). Superior pelvic floor muscles views (III, IV). Superficial layer (III). Deep layer (IV) [31].

The pelvis can move as a unit relative to adjacent body parts that are to the tight at the hip joint and to the trunk at the lumbosacral joint, and also pelvic motions can occur within the pelvis that intrapelvic motion. The pelvis anterior group muscles that perform posteriorly tilt the pelvis. The pelvis posterior group muscles that perform anteriorly tilt the pelvis. The muscles on the right side elevate the right side of the pelvis (also depress the left side of the pelvis), the muscles on the left side elevate the left side of the pelvis (also depress the right side of the pelvis). Muscles that cross the hip joint that the flexors are located anteriorly, extensors posteriorly, abductors laterally, and adductors medially. Rotation muscles not as easily equated with location; however, as a general rule, lateral rotators are located posteriorly and medial rotators are located anteriorly. Muscles of the pelvic floor do not cross from the pelvis to another body part; for this reason, they do not move the pelvis as a unit relative to the trunk or thighs. Rather, their functions are primarily to stabilize the sacroiliac and symphysis pubis joints as well as to create a stable floor for the visceral contents of the abdominopelvic cavity [31, 33].

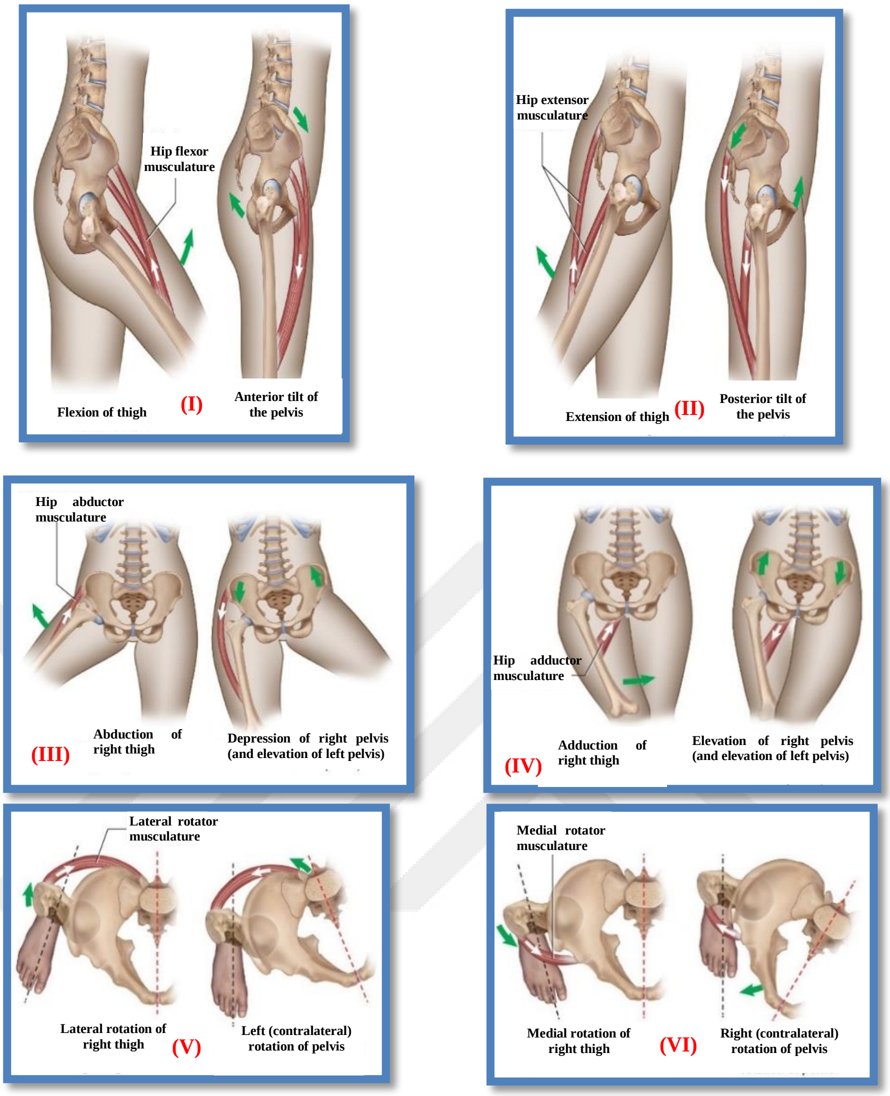


Figure 1.16: The pelvic joint movement at the hip joint is the reverse movement of the tight movement at the hip joint. The anterior pelvic tilt is the reverse movement of the thigh flexion (I) - posterior pelvic tilt is the reverse movement of the thigh extension (II). Pelvic depression is the reverse movement of thigh abduction (III) – pelvic elevation is the reverse movement of thigh adduction (IV). Pelvic contralateral rotation is the reverse movement of the external rotation of the leg (V) – ipsilateral pelvic rotation is the reverse movement of the internal rotation of the leg (VI) [31].

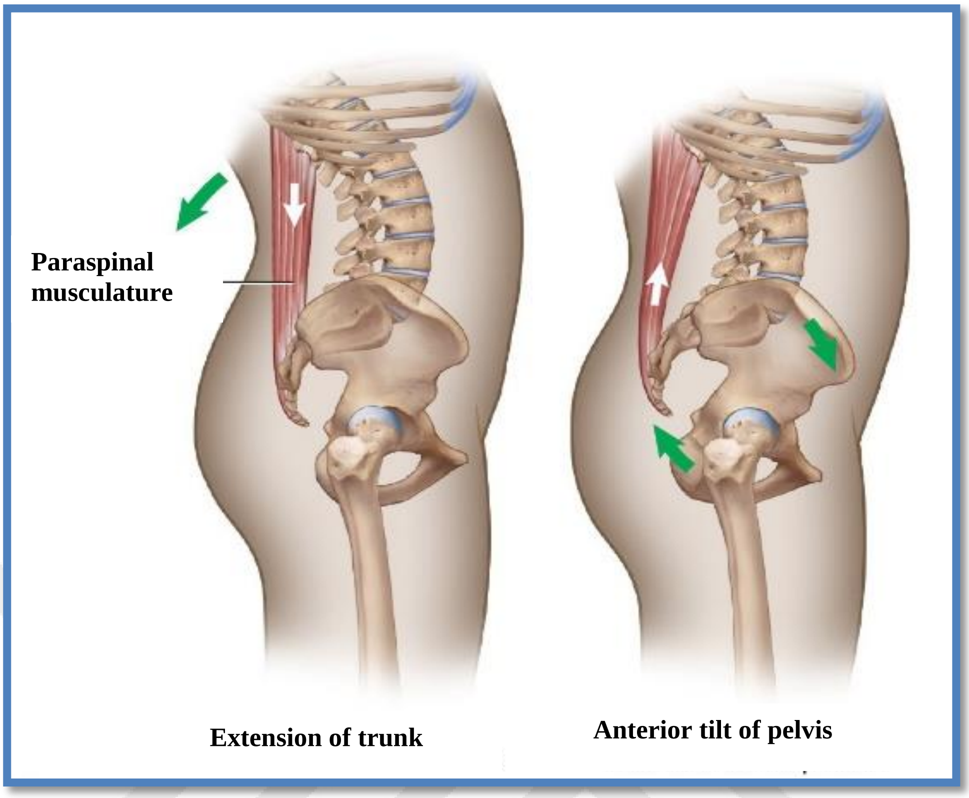


Figure 1.17: Joint movement of the pelvis at the lumbosacral joint is the reverse movement of the trunk moving at the lumbosacral joint. The posterior pelvic tilt is the backward movement of the trunk flexion (I) - the anterior pelvic tilt is the backward movement of the trunk extension (II) [31].

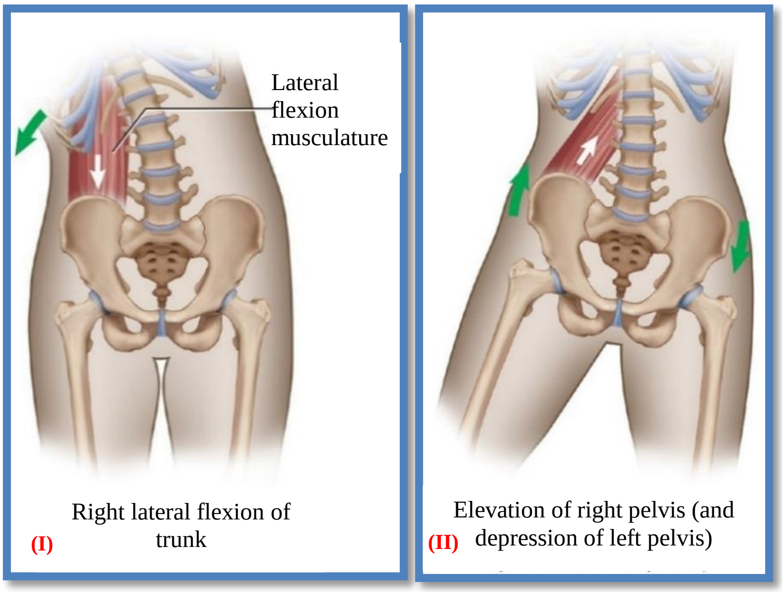


Figure 1.18: Joint movement of the pelvis at the lumbosacral joint is the reverse movement of the trunk moving at the lumbosacral joint. Right side pelvic elevation is the reverse movement of the right lateral flexion of the trunk (I) – left side pelvic elevation is the reverse movement of the left lateral flexion of the trunk (II) [31].

When the sacral motion within the sagittal plane on the coronal axis, the entitles nutation and counternutation are used. When the sacral base drops anteriorly, it is entitled nutation; when the sacral base moves in the posterior direction, it is entitled counternutation. Nutation can also be defined as anterior tilt; counternutation can also be defined as posterior tilt [33].

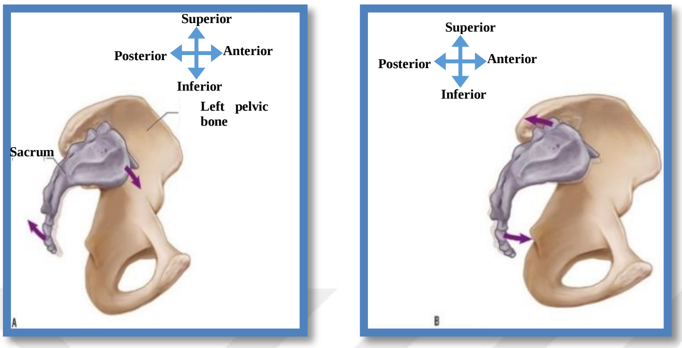


Figure 1.19: Right lateral side view of the motions of the sacrum. Nutation (A). Counternutation (B) [31].

1.2.4.1. Anatomy and Biomechanics of the Quadratus Lumborum Muscle

The quadratus lumborum muscle is found in the posterior abdominal wall that is inside the abdomen, but the back of the iliopsoas [34]. To locate the muscle, one can place their fingers on the upper of the posterior iliac crest around the hip [35].

The quadratus lumborum muscle is quadrilateral in shape, and it arises from the aponeurotic fibers of the iliolumbar ligament and the portion next to the iliac crest for 5cm. It is then inserted into the lower border of the last rib for almost half the length and also by four tendons that are in the apices of the transverse processes that are on the upper four lumbar vertebrae. Sometimes a portion of the muscle is found in front of the preceding [36]. It is originated from the iliac crest and iliolumbar ligament and inserted in the last rib and inserted in transverse processes of last three or four lumbar vertebrae [37].

Quadrtus Lumborum muscle is consist of three layers with muscle fibers that have different directions: The superficial layer is from 12^{th}. rib inferiorly to the iliac crest a thin layer, comprising iliocostal muscle fibers and iliothoracic, from the iliac crest to the lateral area of the vertebral body of T12, which fibers have a tendinous or even muscular termination. The intermediate layer comprises lumbocostal muscle fibers, from the 12^{th}. rib and transverse processes of L1-4 inferiorly and laterally to the iliolumbar ligament and iliac crest. They are muscle fibers, which differ significantly in size, direction and thickness. The posterior layer consists of lateral iliocostal fibers and medially from iliolumbar fibers, from the iliac crest, connecting to the transverse processes of the L1-4 The iliocostal muscle bundles may involve the thoracolumbar fascia, inserting themselves with their tendon endings. In the caudal area, this layer is thicker and more tapered in the rostral portion [38].

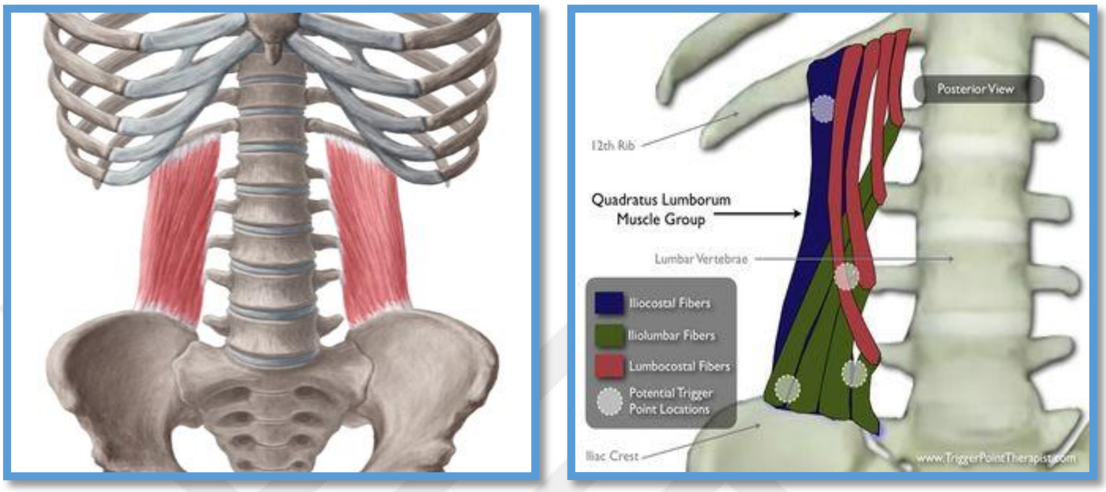


Figure 1.20: a) An anterior view of the quadratus lumborum muscle b) An anterior view of the quadratus lumborum muscle of three layer [39, 40].

This muscle takes up lots of space in the abdomen, and it is close to various structures like the colon, kidneys, and diaphragm. It fills up a large amount of space within the abdomen. It continues to the lateral abdominal muscle after it leaves the lumbar plexus when the two iliohypogastric and ilioinguinal nerves travel the lower of the QL muscle. The ventral primary rami of the T12- L1-L4 to QL muscle innervate and the branches of the lumbar artery supply blood to this muscle [37].

1.2.4.2. The Function of the Quadratus Lumborum Muscle

Quadratus lumborum muscle as an extensor of the lumbar spine, a stabilizer of the lumbar area, capable of tilting laterally and capable of acting as an inspiratory accessory muscle. It contributes to the support and flexibility of the pelvis and spine. When a person is bent towards a particular direction, the muscle activates on that side. The muscle supports expiration by holding the 12th rib as the thoracic cage moves. When it contracts bilaterally, it extends the lumbar region and acts as a lateral flexor for the lumbar region when it contracts unilaterally [36, 41].

There are bilateral motions that the QL muscle provides. It allows the lumbar spine extension and the stabilization of the lumbar spine. It also prepares the lumbar spine for transference by participating with the psoas major muscles and the deep erector spinae. It acts as the vertical stabilizer to the diaphragm in the case of a forced inspiration. Inspiration is a function of counternutation, and it is said to be one of the muscle's primary function [36, 42-44].

The quadratus lumborum muscle also performs the unilateral motion. It allows lateral flexion and the rise of the ilium. It also promotes the ipsilateral lumbal rotation though spinal coupling and ipsilateral flexion through counternutation. It raises the ilium while rotating it anteriorly and lowers the rib cage when it turns posteriorly and straightens the lower thoracic spine in the process. Some researchers claim that the QL muscle provides lumbar extension by causing the ilium to move anteriorly. However, this claim does not consider the fact that the sacrum and the ilium move in opposite directions relatively. When observed during the occurrence of nutation and counter-nutation, the anterior movement of the iliac causes the posterior proprioceptive movement of the sacrum to occur which reduces the lordosis. However, an observation can be deceiving since the ilium can shift the entire pelvis forward on the gravitational line and the sacrum moves anteriorly even though this is still a posterior movement relative to the ilium. The lumbar spine moves with the sacrum and the posterior movement cause the reduction of the lordosis. The principles of nutation and counter nutation show that the lumbar curve reverses more with a greater inclination. For example, during pregnancy, the anterior pelvic rotation is exaggerated, and the lumbar spine flattens. The movement pattern shows the natural balance of the counternutation and nutation in the distribution of weight. The movement keeps the body's mass at the center, and it helps in the understanding of the spinal movement in the occurrence of nutation and counternutation [42-45].

The muscle draws down the last rib, and it acts as the inspiration muscle that helps in the fixing of the origin of the diaphragm. When the thorax and the vertebral column are fixed, the muscle acts upon the pelvis, and it is raised towards its side when one muscle is put into action. In cases where both muscles work together from above or below, they cause flexing on the trunk [46].

Quadratus lumborum muscle has the three laminae and these three laminae have different functions. For the first lamina, since the 12th rib is anterior to the iliac crest, the 12th rib is pulled anteriorly and posteriorly, and the ilium is pulled superiorly and anteriorly, and this pulls the L5 and the L4 with it. For the second lamina, the L1-4 and the 12th rib are pulled posteriorly in a way that flattens the lumbar curve while the iliac crest is pulled superiority and anteriorly. For the third lamina, the anterior-posterior pull may be difficult to visualize, but it may require the cooperation of the psoas to provide coupling motion that can flatten the spine on the contraction side [36].

The quadratus lumborum muscle lifts the ilium anteriorly and superiorly, it flexes the spine laterally, and it rotates the spine ipsilateral into counternutation when in coupled motion. The ligaments tie L4 and L5 to the ilium, and they stretch minimally. The stretch pulls the two vertebrae counter to the sacrum and the lumbar spine. The QL muscle has three laminae namely the 12th rib that is inferior to the iliac crest the 12th rib and transverse processes of L1-4 that are inferior and lateral to the iliolumbar ligament and the iliac crest. It also consists of the transverse processes of the L1-4 that are lateral and superior to the 12th rib [36].

The quadratus lumborum muscle also acts as a muscle of inspiration and forced expiration by stabilizing both the 12th rib and the lower attachments of the diaphragm. QL muscle draws the 12th inferiorly and assists with inspiration by fixing the origin of diaphragm. It is also of the abdominal and lower back stabilizers which forms part of the body's core muscles [43].

1.2.5. Pelvic Nerves

The pelvis nerves can be grouped into somatic, musculature, and autonomics. The 4th and 5th lumbar spinal nerves are part of the lumbosacral trunk that joins from the 1st to the 4the sacral nerves and they create the sacral plexus on exit.The sacral plexus runs from the posterior pelvis to the piriformis muscle. There are a number of nerves in the sacral plexus. The sciatic nerve is the largest nerve and it runs from the pelvis to the sciatic foramen and gluteal area. It works with the hamstrings and other organs below the knee. The pudendal nerve is in the 2nd through 4th spinal sacral nerves. It leaves the pelvis through the sciatic foramen and runs to the perineum through the lesser sciatic foramen. The superior gluteal nerve is part of the 4th lumbar and 1st sacral spinal nerves and it runs from the greater sciatic foramen to the innervate gluteal muscles [23].

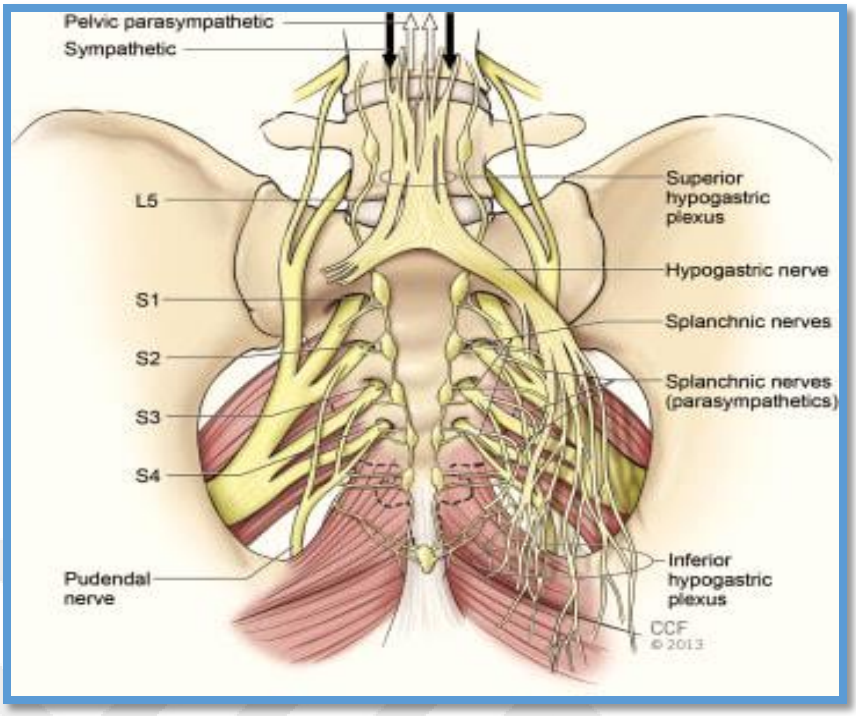


Figure 1.21: Pelvic Nerves [47].

The inferior gluteal nerve is part of the 5th lumbar to the 2nd sacral spinal nerves. It runs from the greater sciatic foramen to innervate gluteal muscles like the superior gluteal nerve. The nerve to the quadratus femoris muscle is part of the 4th to the 1st sacral spinal nerves that run from the sciatic foramen to the innervate hip muscles. The obturator internus muscle nerve is made of the 5th lumbar to 2nd sacral spinal nerves and it also runs from the greater sciatic foramen to innervate hip muscles. The piriformis muscle nerve covers the 1st and 2nd sacral spinal nerves while the perforating cutaneous nerve covers the 2nd and 3rd sacral spinal nerves and it innervates the lower and middle parts of the buttock.The posterior femoral cutaneous nerve is part of the 2nd and 3rd sacral spinal nerve and it serves the perineum and back sections of the thigh and leg. The pelvic splanchnic nerves cover the 2nd to 4th sacral spinal nerves and give the parasympathetic innervation to all pelvic organs. The coccygeal plexus nerve fibers cover the 4th and 5th sacral spinal and coccygeal nerves. They supply the sacrococcygeal joint and the coccygeus and levator ani muscles. The anococcygeal nerves serve the skin in the coccyx and anus. The obturator nerve starts from the lumbar plexus and it does not serve any organ or muscle in the pelvis but it passes through the pelvis up to the medial thigh. It serves the adductors muscles [23].

1.2.6. Pelvis Asymmetries

Most pelvis drawings illustrate it a symmetrical part of the body. However, according to a study, the pelvis is neither equal nor symmetric. Symmetry is the arrangement of an object in a way that it can be divided into two parts and these parts would be mirror images of each other. The asymmetry of the human pelvis is attributed to external factors like biomechanical loading and internal reasons like genetics. Directional asymmetry is said to be a response to loading where the pelvis is subjected to more biomechanical loads than the legs. A study by reports that, due to its locomotor function, the pelvis is expected to show asymmetry characteristics just as it can be found in the lower limbs. It is a way for the pelvis to respond to attempt to continue providing its functional properties like aiding childbirth in women. The study also found that asymmetry is more common in the pelvis canal than in the femur or non-canal pelvis. There are no notable patterns in the occurrence of pelvic asymmetry across different populations or sexes. Pelvic asymmetry is said to cause different kinds of pains in a person's body due to the changes in the body's biomechanics for people with this condition. The human pelvis has evolved over time and has become adapted to the locomotive functions it provides. Scholars continue to pay attention to these changes. For instance, states that pelvic asymmetry causes low back pain [48-52].

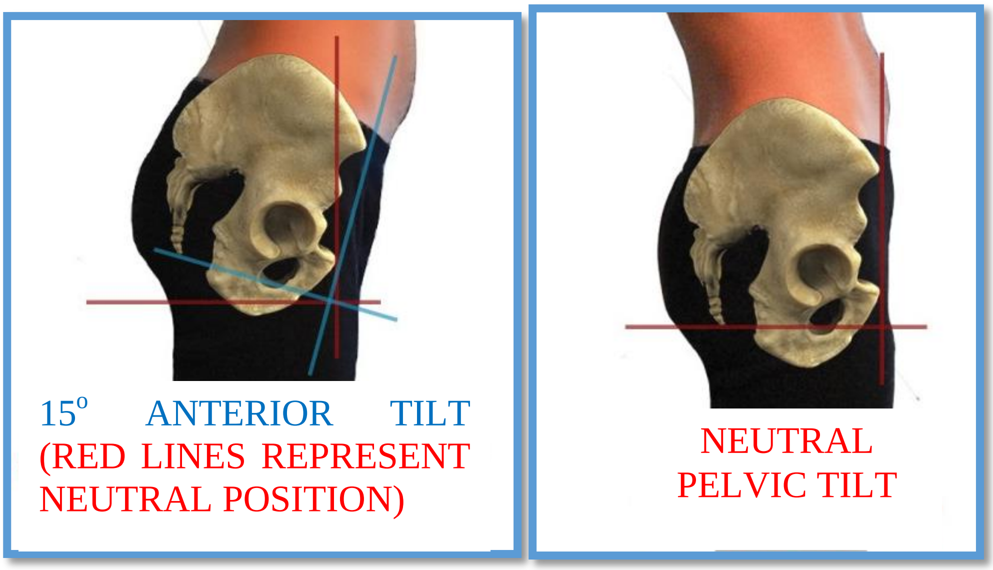


Figure 1.22: Anterior pelvic tilt and neutral pelvic tilt [53].

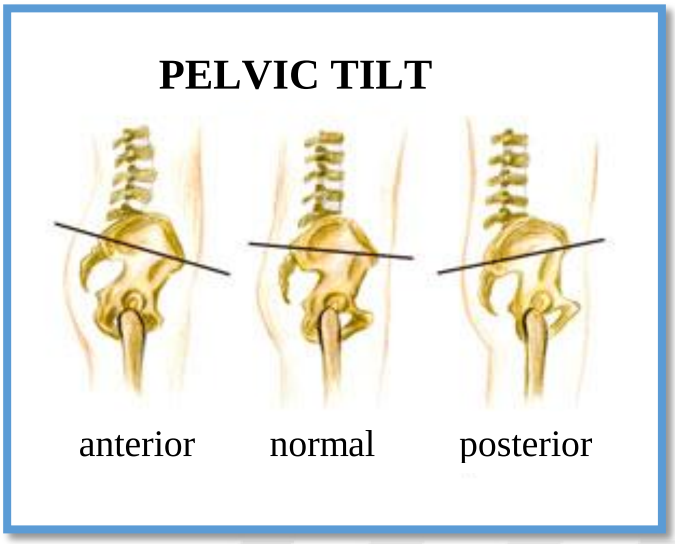


Figure 1.23: Posterior pelvic tilt [54].

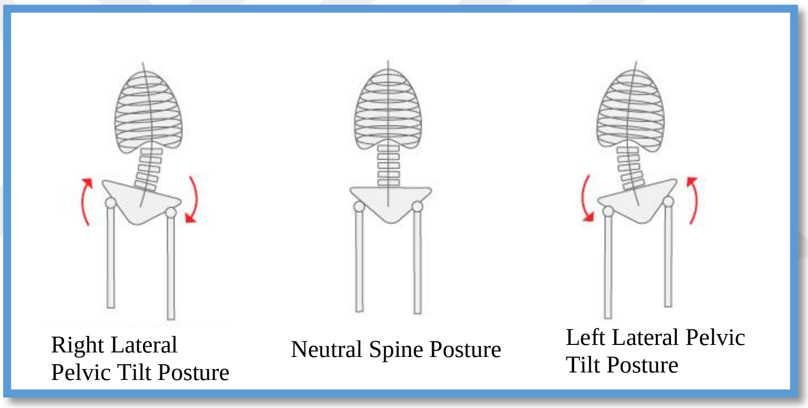


Figure 1.24: Lateral pelvic tilt [55].

1.2.7. Biomechanics and Kinematics of Pelvis and Lumbopelvic Region

Lumbar spine, pelvis, and hip are correlated to each other's so they must be studied biomechanically together for better understanding of this critical region. The motion of the pelvic girdle as a unit can occur in all three body planes: anterior and posterior pelvic tilt in the sagittal plane, lateral tilt in the coronal/frontal plane, and axial rotation in the transverse plane. A combination of all of these motions occurs during the normal gait cycle [56, 57].

The pelvic articulations are situated relatively central to the kinematic chain that stretches from the cranium to the feet. Thus, modifications in ordinary pelvic dynamics such as unilateral sacroiliac fixation can easily generate biomechanical inadequacies above and below the joint concerned. As a general rule, movement deficiency at a link or connections of any kinematic chain forces hypermobility at the closest possible adaptable segments. The body weight and any extrinsic loading of the upper body is transferred from L5 to the sacral base, sacroiliac joints, ilia, and ischia when an person is standing. Impact forces from below emerge from the foot through the tibia and the femur. These axial forces meet at the acetabulum and are spread transversally (mainly) to be absorbed by hip joints cartilages and ligaments, sacroiliac joints, symphysis pubis, and pelvic bone spongiosa. The gross effect is to lock the joints involved by the opposing forces traveling back and forth from the acetabulum around each side of the pelvis. If these counter-directed axial forces are not equalized, according to Newtonian principles, the pelvis cannot be in a state of equilibrium. When the force from below is higher, the femur's head tends to jam within the acetabulum. If the force from above is higher, the L5 and S1 end plates or sacroiliac joints tend to shift from their standard resting place (subluxate). Thus, the sacrum affects and is affected by the trunk and lumbar spine and the impact of the ilium and is affected by the femur's heads. These are significant facts to remember when analyzing postural deviations [58-60].

Terminology:

- **Flexion and Extension**

Flexion/extension occurs when one or more bones move in a sagittal plane about a frontal axis. This terminology is consistent throughout the spinal column and peripheral joints. When the trunk bends forward/backward in a sagittal plane about a coronal axis, this is called forward/backward bending. Within the pelvic girdle, the accepted terms for flexion and extension of the sacrum are nutation and counternutation respectively [59, 60].

- **Rotation**

Rotation motions occur in the transverse plane about a vertical axis. Forward rotation of the innominate in the sagittal plane about a coronal axis is termed anterior rotation; backward rotation is termed posterior rotation. Nutation/counternutation and anterior/posterior rotation of the innominate should be reserved to describe motion between the sacrum and the innominate. When the two innominate and the sacrum rotate as a unit (pelvic girdle) about a coronal axis through the hip joint, this is called an anterior or posterior pelvic tilt [59, 60].

- **Nutation/Counternutation of the Sacrum**

Nutation of the sacrum occurs when the sacral promontory moves forward into the pelvis in the sagittal plane about a coronal axis through the interosseous ligament. Conversely, counternutation of the sacrum occurs when the sacral promontory moves backward in the sagittal plane about this coronal axis [61].

- **Neutral Pelvis**

The position of the pelvis that the line between the ASIS and the PSIS is parallel to the horizontal plane is called a neutral pelvic position [59, 60].

- **Pelvic Tilt**

The pelvic tilt is an anteroposterior motion of the pelvis around an imaginary axis in the frontal plane. The degree to which the position of the pelvis -a line between the ASIS and PSIS-deviates from the horizontal plane when viewed in the sagittal plane, as determined with a pelvic inclinometer [59, 60].

- **Anterior Pelvic Tilt**

In anterior tilt, the front of the innominate acts inferior and anterior while the back acts superior and lateral. The ASIS' acts forward and medial while the ischial tuberosity acts posterior and lateral. An angle of inclination in which the ASIS is inferior to the PSIS in relation to the horizontal plane [62].

- **Posterior Pelvic tilt**

In posterior tilt, the front of the innominate acts upward and lateral while the back acts downward and medial. The ASISs will move backward and lateral while the ischial tuberosity moves forward and medial [59, 60].

- **Lateral Pelvic Tilt**

The lateral pelvic tilt is a frontal plane motion of the entire pelvis around an anteroposterior axis. In the normally aligned pelvis, a line through the ASISs is horizontal. In lateral tilt of the pelvis in unilateral stance, one hip joint is the pivot point or axis for the motion of the opposite side of the pelvis as pelvic hiking or pelvic drops [59, 60].

- **Pelvic Rotation**

Pelvic rotation is the motion of the entire pelvic ring in the transverse plane around a vertical axis [59, 60].

1.2.8. Anatomy of the Leg Length Discrepancies

Leg length discrepancy or inequality is defined as a condition in which (that) the paired lower extremity limbs have a noticeably unequal length. LLD is a condition where there is abnormal loading of the lower extremity and lumbar joints. People with this condition have a femoral head that is lower than their standing side and it can be as a result of functional differences due to abnormal joint functions or anatomical differences in the length of lower extremities bones. Around 59 percent of the population is affected by this condition but most cases are categorized as mild if they are below 20mm. LLD is classified as structural and functional. Structural or anatomical: Difference's in length resulting from inequalities in the bony structure. An actual shortening or lengthening of the skeletal system occurs between the head of the femur and the ankle joint mortise, which may have congenital or acquired cause [63].

Structural LLD is due to side-to-side differences of lower limb length while functional LLD is as a result of abnormal joint functions in the lower limbs. Functional LLD occurs where there is a secondary rotated pelvis brought about by axial malalignments or joint contractures. LLD can be classified into three categories. Mild LLD is for people with a difference of less than 3cm, moderate is for people with a difference between 3 and 6cm and severe LLD is for people with a difference of more than 6cm. There are various causes of LLD. An injury that affects the bone structure like a fracture can cause the bone to grow shorter or faster than normal. Infection on the bone that occurs before a person's bone mature like in the case of juvenile arthritis can affect the growth of the bone. Dislocation of the hip bone can also create an appearance of having the LLD [64].

Effects of Leg Length Discrepancy on Pelvis and Other Body Parts

Leg length discrepancy is said to be the main cause of most issues related to the back, hips, and the sacroiliac [10]. There is contradictory data to show whether LLD cause lower back pains. A study shows that people with LLD of more than 9mm are likely to suffer from low back pains while those with LLD of less than 3mm are unlikely to experience back pains. The successful treatment of back pains using shoe lifts supports the possibility of LLD causing back pains. LLD is also said to affect a person's alignment [11]. An attempt to compensate to get an erect trunk, a person can develop functional scoliosis which enables them to bear weight equally on both legs. However, the degree of the curve may differ with the seriousness of the LLD. According to another study, more than half of the people with LLD of more than 6mm are reported to have developed scoliosis. Additionally, LLD also causes degenerative effects [64]. A study induced LLD by having it subjects wear a heel-raising device and the reported that this caused lateral bending of the lumbar spinal and thoracic parts when walking.

This finding led to the conclusion that the lateral bending can lead to spinal degenerative issues for people with LLD [65].

When a person is in a standing position, their body weight causes the pelvis to induce a force through the hip joints. For a person with LLD, the pelvis is pushed down and it attempts to compensate which can result in postural consequences that can change the pelvic posture on the frontal and sagittal planes. It can also result in rear and anterior rotation of the ilium on the short and long leg respectively. It is common for compensation of LLD to result in pelvic obliquity especially if the LLD is more than 22mm [64].

- **Knees**

Other people can compensate by having a bent knee on the long leg. The pelvic tilt due to LLD alters the center of gravity and cause the body to compensate which can increase the magnitude of the internal joint load and it can place unequal stress on the person's foot, knee, hip, ankle, lumbar spinal joints, and sacroiliac [63].

- **Spine (Low Back Pain)**

Literature is highly ambiguous. LLD appears to affect the lumbar spine, at least partially, by creating lumbar scoliosis. It has been shown that LLD leads to scoliosis induced by pelvic obliquity on the frontal plane. Lumbosacral facet joint angles appear to be smaller on the short side; it is hypothesized that asymmetry of joint angles predisposes patients to osteoarthritic changes in lumbosacral joints.

The data relating to the possibility that LLD causes low back pain in adults are contradictory. Results have been reported no link between the presence of LLD and low back pain, while back pain was prevalent among those with LLD [67]. In [68], a study using 1,309 subjects with chronic low back pain found that 18.3% of chronic low back pain patients had LLD of 10 mm or more compared to 8% of controls a further study done by the same authors reported that subjects who had LLD of greater than 9 mm suffer from altered lumbosacral facet joint angles [69].

The obliquity leads to an unusual alignment of the SIJ which in turn increase the loads on the joint and cause SIJ dysfunction that can contribute to lower back pains [70].

- **Hips**

LLD also contributes towards the development of hip osteoarthritis due to the unequal bearing of weight on the hip joint. The pelvic tilt which occurs in an attempt to compensate for LLD can reduce the contact area for the articular cartilage in the joint due to the abnormal skeletal alignment and the increase of pressure on the underlying bone that can cause the development of osteoarthritis. It is unclear which hip between the short limb and the long limb is under more pressure but study shows that hip osteoarthritis occurs more in the longer limb. LLD is an aid to cause osteoarthritis of the knee which can shorten a person's leg by narrowing the space joint and leading to the loss of cartilage [65].

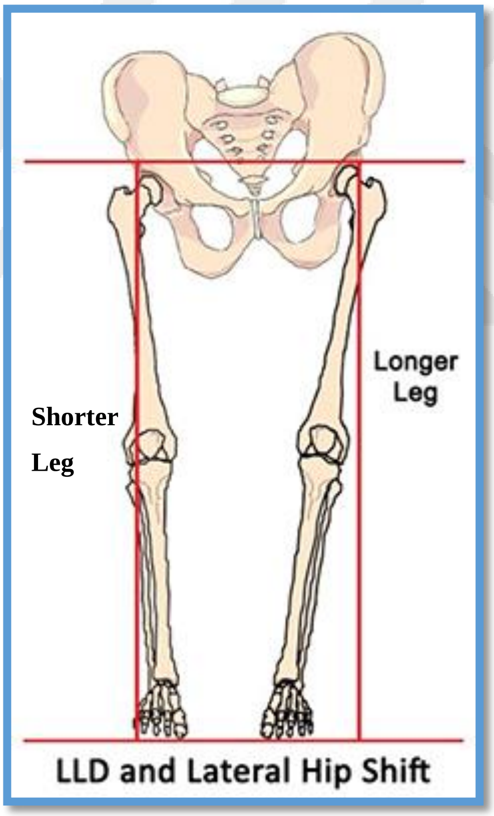


Figure 1.25: LLD and lateral hip shift

Research shows that LLD cause a postural change in people like changing the pelvic posture by causing a posterior rotation on the long leg and an anterior rotation on the short leg. It also makes the pelvis tilt laterally and it can lead to the development lumbar rotatory scoliosis mostly on the short leg. These issues occur for both anatomical and functional LLD. These changes can cause permanent spinal change like disc degeneration, scoliosis, facet joint osteoarthrosis, asymmetrical facet joint angle, and muscle imbalances. Asymmetrical disc degeneration is associated with degenerative lumbar scoliosis [63]. A study researched on effects of simulated LLD on the pelvic position and spinal posture. Osteoarthrosis associated with symptoms like degeneration of articular cartilage and the thickening of the synovial membrane. In the serious stages of this condition, the bone surfaces where the cartilage has reduced in quality become deformed. Secondary osteoarthrosis may develop after an event like fracture or dislocation or the development of conditions such as scoliosis. The pelvic tilt that develops due to LLD can cause unequal stress on a person's foot, limb, knee, lumbar spinal joints or sacroiliac when they are an upright position. This tilting shifts the center of gravity and causes the muscles to compensate and an attempt to do so, the magnitude of the internal joint load may increase. The tilt can also reduce the articular cartilage's contact area and this can disrupt the skeletal alignment. The effect of increased joint load and reduced surface area can lead to increase pressure on the underlying bone or cartilage and this can ultimately cause osteoarthritis [47].

- **Lumbar Intervertebral Disc**

LLD can also cause degeneration of the lumbar intervertebral disc. The intervertebral disc is an avascular structure that gets nutrients from the end plates. Intervertebral disc generation is said to occur at the beginning of degenerative spinal changes and it can be followed by disc narrowing or the development of osteophytes [71, 72]. A study found that all discs regardless of their location are damaged by unequal pressure [73]. Disc prolapse and degeneration are reported to follow after endplate failure and avulsion especially after an injury that affects the combined flexion or due to torsion forces on the lumbar spine [74].

1.2.9. The Leg Length Discrepancy Measurement

Actual leg length is measured from the umbilicus to the medial malleolus but the right measured is from the anterior superior iliac spine to the medial malleolus. Patients may be come with symptoms or with gait irregularities and abnormalities. Signs of the disorder leading to inconsistency may be present [75, 76].

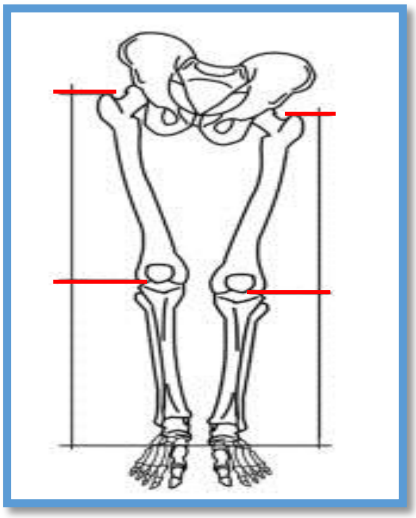


Figure 1.26: Leg length discrepancy

The checkup is done in more detail to recognize the apparent right leg length and associated abnormalities. It is essential to know the position of spine and limb deformities because irregularity may affect the leg length and physically the exact correction is a need for the prevention. The leg length discrepancy measured by two way:

1. Block test
2. With measuring tape.

1.2.9.1. Block Measuring Method

In the block testing method, patients are stand and block are added below the short leg until the pelvis is leveled. The difference is measured from the block. In this way, it takes into account the inequality in the both foot height between the two limbs also aids in showing the functional LLD. This blocking method is a little more dependable and correct according to the tape measurement method. Moreover, it is a primary method as it would not take into the explanation the irregularities that can be affecting the length.

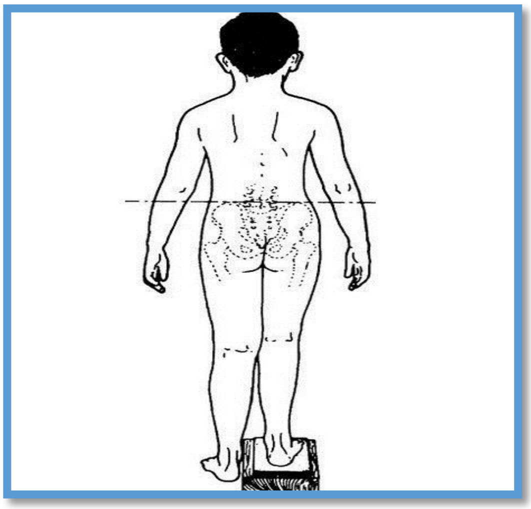


Figure 1.27: Block method [77].

1.2.9.2. Tape Measuring Method

In the tape measurement method, after correction of pelvic tilt and deformities, measure the true limb length from the anterior upper iliac spine to the medial malleolus [10].

Although the tape method is easy, safe and non-invasive it is less reliable when compared to the radiographic methods due to fallacies in determining the bony landmarks, while using the blocks method seems to be more accurate than the tape method. Accuracy of both methods can be increased while using in a clinical situation by measuring twice and averaging the result [10-13, 78, 79].

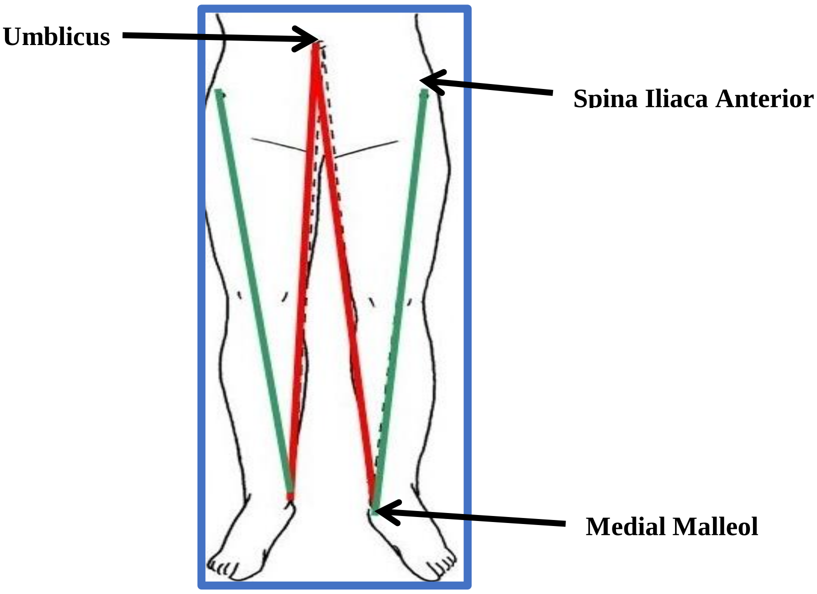


Figure 1.28: Tape measurement method

1.2.10. Imaging Methods of Assessment

1.2.10.1. X-rays

An x-ray image is giving the dense structure, as like as bone. Some times medical doctors need more accurate results for the discrepancy, in that situation they need an x-ray report of your leg [75].

Figure 1.29: Imaging methods of assessment LLD [80].

1.2.10.2. Scanograms

This is a special type of x-ray that uses a series of three images and a ruler to measure the length of the bones in the legs. Medical doctors may order a scanogram in place of, or in addition to, a traditional x-ray [75].

1.2.11. Basic Physiology of Electromyography

Electromyography is a nonstationary clinical method using recording and evaluating of electrical activity produced through muscular contraction. It is a quite complex process; also EMG signals have many artifacts [81]. In the below, an EMG signals recording process are showing (**Figure 1.30**).

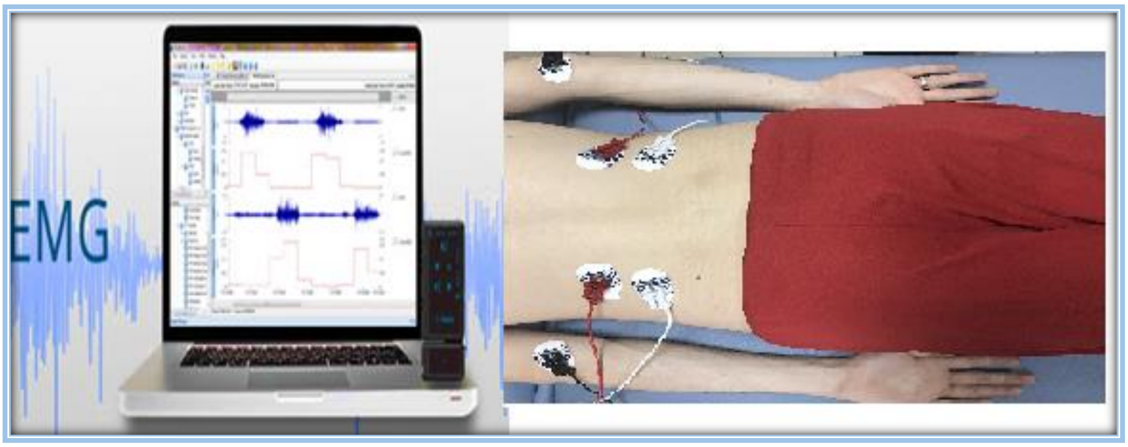


Figure 1.30: A typical EMG signal

Myoelectric signals are produced by physiological variations in the condition of muscle fiber membranes [5]. If it is used correctly, EMG allows to directly looking into the muscle, measurement of muscular performance, analysis to progress sports activities and detects muscle response in ergonomic studies such as; motor control, neuromuscular physiology, and postural control and movement disorders. In the human body, there are two type movements; voluntary movement and involuntary movement. Involuntary movements are generated by smooth and cardiac muscles, which are under the control of the autonomic nervous system. These muscles work without nervous input. In contrast to voluntary movements are initiated by action potentials from motor neurons. Each motor neuron branches and synapses with up to a hundred muscle fibers. These fibers constitute a motor unit. Process of muscle contraction occurs three steps:

1. Excitation (stimulation)
2. Contraction
3. Relaxation

The numbers of fiber contracting will determine the force of the contraction of the whole muscles. The EMG signal is first picked up by electrode and amplified because the signal has extremely small voltage values. Additionally, it should be processed to eliminate high and low-frequency noises causing from the body inside or outside artifacts. This process contains many amplification and filtration stages [14].

EMG quality is described by the signal-to-noise ratio (SNR) which means the ratio between the measured EMG signal and noise contribution from inside or outside of the body. SNR is wanted to be as high as possible. In order to minimize noise contamination, there should be a balance of impedance between electrode sites during the measurement period. At least, they should be close to each other. The stability in impedance over time and the balance in impedance between electrode sites have a profound effect on the SNR of EMG signal. Besides that, properties of electrodes, amplifiers, analog to digital converter, storage element, and electrode-skin interaction are some other parameters to affect the reliability of measured EMG signal [14, 82].

1.3. AIM AND CONTRIBUTION OF THE THESIS

The chapters of this thesis are organized as follows:

Chapter 1 is an introduction to the thesis, this chapter discusses the purpose of this thesis also explains the background about the LLD and pelvic asymmetry. Furthermore, it explains the QL muscle activity on LLD and pelvic asymmetry of different systems disorders and the literature review of EMG.

Chapter 2 this chapter discusses the study subject, leg length measurement method, measurement method of pelvis position and recoding of the EMG signal.

Chapter 3 overall study results are discussed and evaluated also try to find the relationship between pelvic asymmetry and EMG signal analysis in a real clinic.

Chapter 4 presents the discussions of obtained results.

Chapter 5 summarize the conclusion and delivers some recommendation for future research.

2. MATERIALS AND METHODS

2.1. STUDY SUBJECTS

Medical research of ethical report for conducting this study was achieved from the İstanbul Bakirkoy Dr. Sadi Konuk Training and Research Hospital research Ethic Commission, Istanbul, Turkey. All procedures were in agreement with the medical community of the Ethic commission regarding human research developed. Demographic data such as age, height, weight, and gender, etc. were taken after a physical examination, as seen in **Table 2.1**.

Table 2.1: Demographic information and experimental details.

Subject	Mean ± SD
Age	23.5±2.4
Gender	M(50), F(40)
Height	1.72±0.09
Weight	64.8±11.26
BMI	21.9±2.79

BMI: *Body Mass Index,* ***M:*** *Males****, F: F****emales* ***and SD:*** *Standard deviation*

The study was employed in a randomized control study design. A total of 100 right handed healthy subjects were included in this study where 40 subject’s male and 50 subjects female. Their age ranged between 19-24 years. The subjects were students of Gelisim University at College of Health Sciences. All subjects were asked to participate in this study by an announcement in their classroom. All subjects provided written agreement for contribution to this study. The inclusive criteria were: age between 19-30 years must be a student in the university and should be voluntary. All subjects were assessed manually by checking iliac crest level and by tape measurement for LLD then measurement of the pelvic tilt with the digital pelvic inclinometer and then by EMG at two positions to determine the activity of QL muscle. Furthermore, if the subjects had any neurological condition, musculoskeletal pain, chronic and systemic disease, rheumatic and connective tissue disease, any traumatic story, structural LLD, back pain, spinal curvature were excluded from the subject group. **Figure 2.1** below illustrates the organizations of subjects.

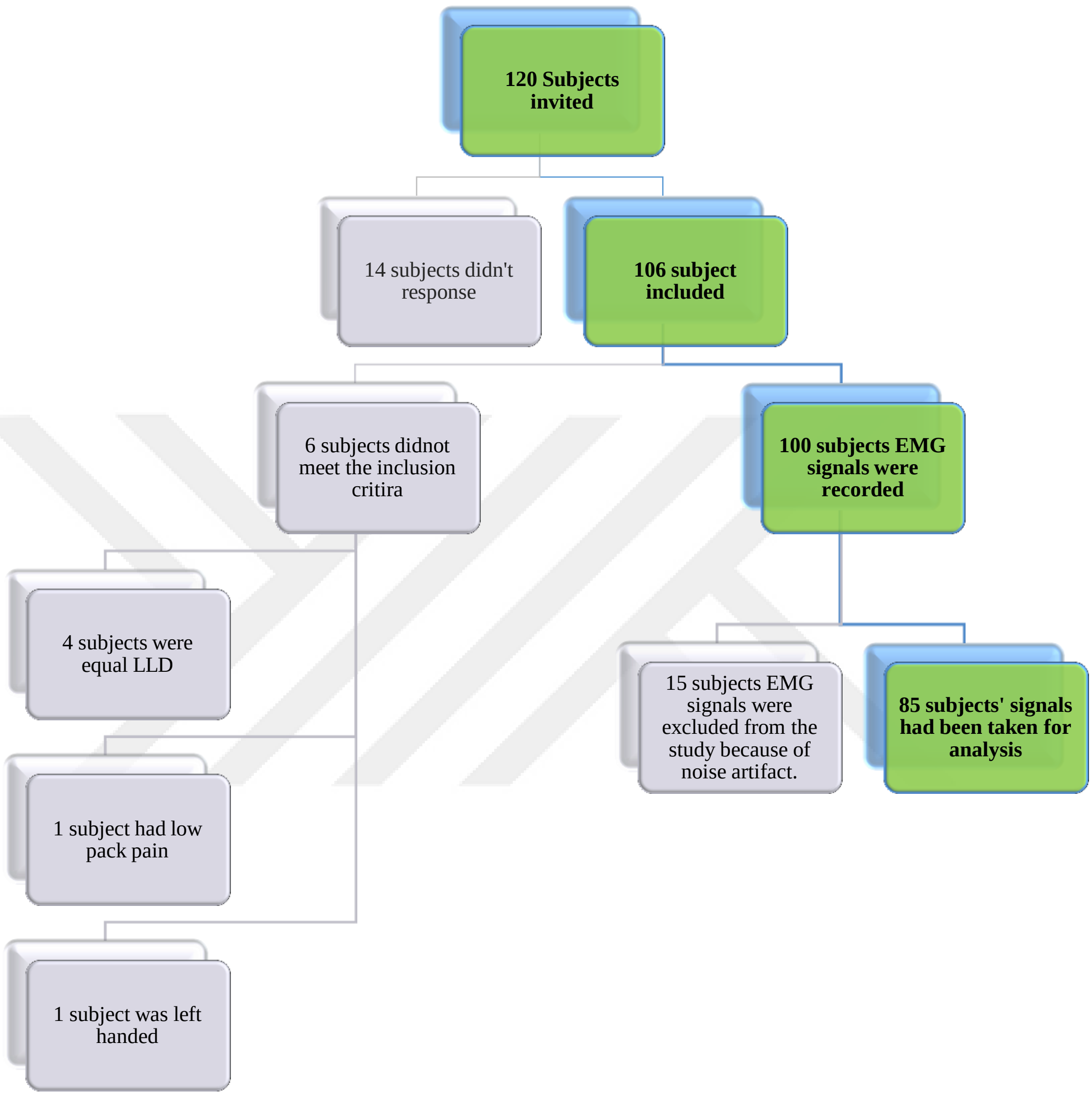


Figure 2.1: Selection of the subjects and proceeding of data.

During the physical examination, some other parameters such as alcohol and smoking are also counted. Therefore we talked to each subject and asked the question of the parameters (see **Figure 2.2**).

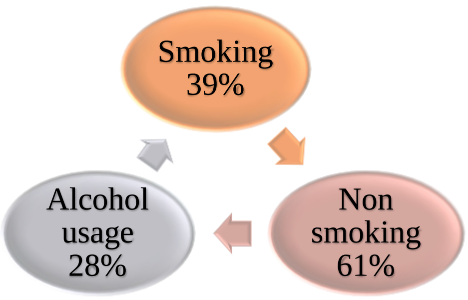


Figure 2.2: Other different parameters.

2.2. CLINICAL TECHNIQUES FOR SUBJECT SELECTION

2.2.1. Tape Measurement

A tape measurement is a clinical method to measure the LLD. This technique is mainly measuring the lengths of both lower extremites by calculating the distance between the medial malleol and ASIS (**Figure 2.3**). Sometimes these tools can make clinical errors because of different the girth of two limbs also hard to recognizing the thin bony prominence moreover angular irregularities. Furthermore, some other reasons are also making errors to measure leg length discrepancy as like as fibular hemimelia and posttraumatic bones losses involve the foot lengths wheres a significant portions of limbs shorts are distal to ankles mortise. But nowadays it is more accurate and easier to measure the lengths of the pelvis because of the reproducibility check and counting system is very simple.

A tape measurement method is measuring between stand positions two selected points. Those two different points are: The first point is between ASIS and the medial malleolus or the second point is between ASIS and lateral malleol.

Still, many researches and debates continue about the clinical validity of tape measurement process. Therefore, some rules and topics are should be followed during tape measurement time given as below:

- Each time using the means value and try to measure at least 3 or 4 times
- Try to measuring the same subject two different clinicians.
- Iliac irregularities maybe mask or accentuate a limb lengths differences
- Using the deviances during the long axises lower limbs
- Irregular umbilicus positions.

2.2.1.1. First Method for Tape Measurement

The first measurement was the distance between the umbilicus and the medial malleol as the right and left sides. For those with equal measurements. As we can see in the (**Figure: 2.3**)

Figure 2.3: Tape measurement from the umbilicus to medial malleol (Middle).

2.2.1.2. Second Method for Tape Measurement

The second measurement was the length between the SIAS and the medial malleol as the right and left side. In the second measure, it was assumed that there were functional leg inequalities whose length measurements were not equal (see **Figure 2.4** and **2.5**).

Figure 2.4: Tape measurement from ASIS to medial malleol (Right side).

Figure 2.5: Measurement from ASIS to medial malleol (Left side).

Generally, the palpations of bone landmarks (ASIS-ASIS or PSIS-PSIS) are assessed in a standing postion as shown in **Figure 2.6**. Those techniques are applied to detect if bony landmark in horizontal positions or else there is any limb length variations found.

Figure 2.6: Palpation of the ASIS on the left side, palpation of the PSIS on the right side.

2.2.2. Manual Iliac Crest Level Measurement

Pelvic crista iliaca levels were assessed manually as posterior both side of the body. The measurement of the crista iliaca position was recorded as below or above each other side. It is true that asymmetric pelvic variations in the plane according to the frontal plane can be connected the limb length dissimilarity. Therefore, during the block corrections techniques are applied, the more trochanter majors and several pelvic landmarks must be palpate and compare between the left side trochanter within the right side trochanter.

The second method involved manual measurement of iliac crest level (see **Figure 2.7**). The participants were divided into two groups:

1. Participants who have up level the right iliac crest and they are right-handed, and
2. Participants who have up level the left iliac crest and they are also right-handed.

Figure 2.7: Manuel measurement of the iliac crest level.

2.2.3. Pelvic Inclinometer Measurement

Usually, pelvic are frequently measured in medical exercise to classify the presence of abnormal postures which can cause dysfunctions also makes the chronic musculoskeletal discomfort, as like as lower back pain. Therefore, anterior pelvic tilt is identified by risk factors especially patient who have lower. Therefore pelvic inclinometer measurements are quite important. In this study for pelvic inclinometer measurement, we used the digital pelvic inclinometer (DPI) application. The DPI permits to practitioner and understanding also measured the part of the pelvis in progress of repetitive damage as well as the lower back. Also, DPI has a quite simple clinical application which is giving the confidence to the physicians (see **Figure 2.8**).

Figure 2.8: Measuring the tilt of the pelvis using digital inclinometer.

Pelvic Inclinometer Process

All subjects reached the university lab and wearing special clothing. After that, all results were calculated. Each subject was measured within the standing position, also wearing loose clothes and without any shoes in a flat level floor in the same lab. There were no specific directions provided to the subjects during the measurement recording time. Each side of the pelvis tilt were measurements to take the correct information by using DPI inclinometer with a digital readout.

Table 2.2: Pelvis inclinometer measurement process.

Pelvis Inclinometer Measurement	
Right and Left (degrees)	Mean ± Standard deviation
ASIS-PSIS Left	11.01±5.107805
ASIS-PSIS Right	10.61778±4.488276

In pelvic inclinometer measurements process, there are two precision arms; each of the arms is attached in the selected body location. In human body contain tri-axial accelerometers that are recorded the angles of pelvic tilt between the two precisions arm. The results of the pelvic tri- axials inclinometer measurement are shown by an angle in degree, with a fluid crystal displays system. For every subject, pelvic inclinometer measurements were done by following standard guidelines which were given by the manufacturer’s company. Manufacturer’s companies’ procedures are as follows: Firstly, the physician placed both index fingers and thumb of both hands on to each fingers griping at the end point of the pelvic inclinometer arm. After that both index fingers slowly prominent set for synchronized palpations of the posterior and anterior superiors iliac spines. The physician selected locations of the pelvic inclinometer in the side of the in nominates bones and takings the liquid crystal reading. The Physicians changes their both index fingers above the maximum prominent points of the iliac crest up to the peak is established for the measurement. Finally, the physicians are reading the degrees of inclination in the DPI liquid crystal display. As you can see in the (**Figure 2.10**)

Figure 2.9: Pelvic inclinometer measurement process.

2.3. ELECTROMYOGAPHY SIGNAL RECORDING AND PROCESSING

Electromyography is an investigational method connected with the advanced techniques; the signal recorded process also evaluated the electrical activity created by muscular contraction. Non-stationary EMG recordings have complex and noisy signals. Moreover, EMG signals are created by physiological variation in the conditions of muscles fibers membrane [5]. Therefore we can say that if EMG techniques are applied accurately, it can allow to observe the muscular performances, muscles response activity especially in the ergonomic field as like as motor controls, neuromuscular systems, the postural controller also physical disorder.

Table 2.3: EMG signal recording device and muscle.

Muscle	Quadratus Lumborum
EMG Device	**Biopac MP36**
Sampling Frequency	**1000 Hz**
High Pass Filter	**10 Hz**
Notch Filter	**50 Hz**

2.3.1. Non-Invasive Method and Surface Electrodes

In EMG method, surface electrodes are used for detecting the original signal which contained the time characteristic. Furthermore, by using the surface electrode, we can easily understand the responses from the muscles to the impulses. In human body, surface electrodes are positioned on the clean skins which cover the target muscles and be able to detect the motion which is gathered from a lot of motor functions. Recently, more accurate surface electrodes are designed for medical research. The most significant of the surface electrodes is its easy application which gives no pain and any discomfort for the patients. Moreover, in the research of simultaneous processes of lots of muscles, it is really useful.

On the other hand, the surface electrodes have some disadvantages like the interference from the close muscle bundels that may interfere with the target EMG signal because of the relative wide electrode surface. This condition makes a lot of questions making about the validation of the recording process.

Figure 2.10: Surface electrode 2-cm diameter Ag-Ag/CL, Kendal Brand.

2.3.2. EMG Setting Procedure

2.3.2.1. The BIOPAC Electromyogaphy Device Program

The BIOPAC application procedure is a widespread technique and supported a broad range of the research study. Additionally, this program is working with a hardware and software simple and complex combinations for particular biomedical researches for different experiments. The BIOPAC program at the same time is making the recording, analysis and can give solutions. Furthermore, physiological measurements studies are approved better human subject are comforted and freedom of program. In BIOPAC student lab program have its own electrode cable, transducer, filtering opportunity, physiological signal recording, signals analysis, and classification systems. Therefore, in this study, we used BIOPAC physiological EMG signals recording program also signals filtering selections included both real-time and post-acquisition filters for the optimal condition of the data.

Figure 2.11: Biopac EMG device.

2.3.2.2. Micro-Electrode Interface Cable for MP36/36R

Micro-electrode interface cable for MP36/36R is used which are fully-shield very high-impedances and resolutions recording of biopotential signals.This cable joins double ultra-high impedance buffer amplifier to permit the connection within the needle, wire or very small surface electrode. The adapter terminates normal 1.5 mm male touch proof electrodes connector. Usually, these electrodes interface cables are using with indicator, wires, pellets, or small electrodes for use in animals or human organ experiments. In this study, three different colors of micro-electrode interface cables are used. Those are:

- **Vin+** Red
- **Ground** Black
- **Vin-** White

Figure 2.12: Micro-electrode interface cables.

2.3.2.3. EMG Recording Room

In this study, all subjects’ signals were recorded in a calm and quite laboratory room; try to minimize any extracutaneous signals. Moreover, it’s very important to reduce the subject’s movement; therefore, recording room condition and relaxed position were also very vital. To get a good quality signal from the subject’s horizontal position was the best choice. Totally, electrical technologies of the EMG recording setup should be isolated. Also, in the recording room, electronic components individually to ensure there was no current flow from the subjects’ body. EMG BIOPAC device hardware computer and other connections were plugging into a medical rank isolated transformer.

Figure 2.13: EMG signal recording room.

2.3.2.4. Preparing the Skin

To prepare the subject's skin, first try to find out the exact point in the body skin where the electrodes will be placed. In the body selected places should be cleaned to reduce the noises. Moreover, before the place, the electrodes, and shave off skin hair which may reduce the impedance of the skin electrodes interface also we can use the electrode cream or jelly to remove the transmission of the signals. Furthermore, after uses the jelly we have to wait at least one minute to penetrating the jelly into the skin. (**Figure: 2.14**)

Figure 2.14: Electrode placement on the quadratus lumborum muscle.

2.3.3. EMG Signals Recording Process

The electromyography signals of the QL muscle were recorded while participant was lying in the prone position on the table containing a head hole owing to preventing any rotation of the neck rotation as this could affect the reading, the arms were next to the body, the lower limbs were neutral position side by side with the free body. QL muscle signals were recorded in two separate positions using the EMG machine.

2.3.3.1. Recording of the Bilaterally Quadratus Lumborum Muscules Signals at the Resting Position

In the first position, electrodes were placed separately for right QL muscle and left QLmuscle. BIOPAC micro-electrode interface two cables with three electrodes (active, passive and ground electrodes) were used in this study. The active electrode was placed on the 12th rib, the passive electrode was placed under the 12th rib by 2cm and the ground electrode was placed on the olecranon process. When the QL muscle contractions on the resting position we started to record the right and left side EMG signals (see **Figure 2.15**).

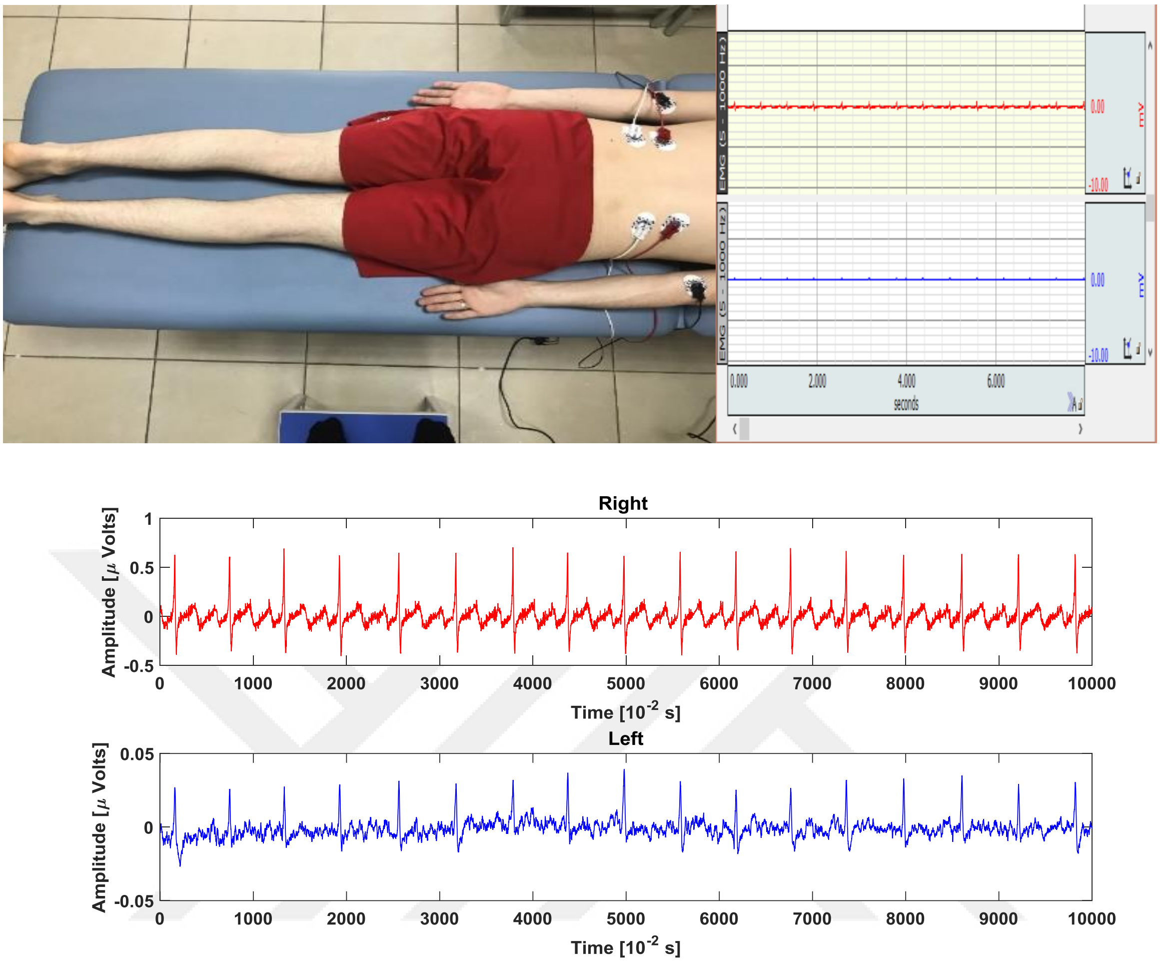


Figure 2.15: Recording of bilaterally quadratus lumborum muscles signals on the resting position and EMG signals.

2.3.3.2. Recording of Right and Left Quadratus Lumborum Muscules Signals While Maximal Isometric Contraction on the Lateral Flexion Position

In the second process, we recorded right side EMG signal during the QL muscles right side maximum isometric contraction time. In this process, electrodes were placed separately for each muscle, right and left. two cables with three electrodes were used each cable on each side, the three electrodes were active, passive and ground electrodes, active electrode was put on the 12^{th} rib, the passive electrode was put under the 12^{th} rib by 2cm and the ground electrode was put on the olecranon process. After that when the QL muscle right side /left side maximum isometric contraction was started we started to record the right side EMG signals (see **Figure 2.16** and **2.17**).

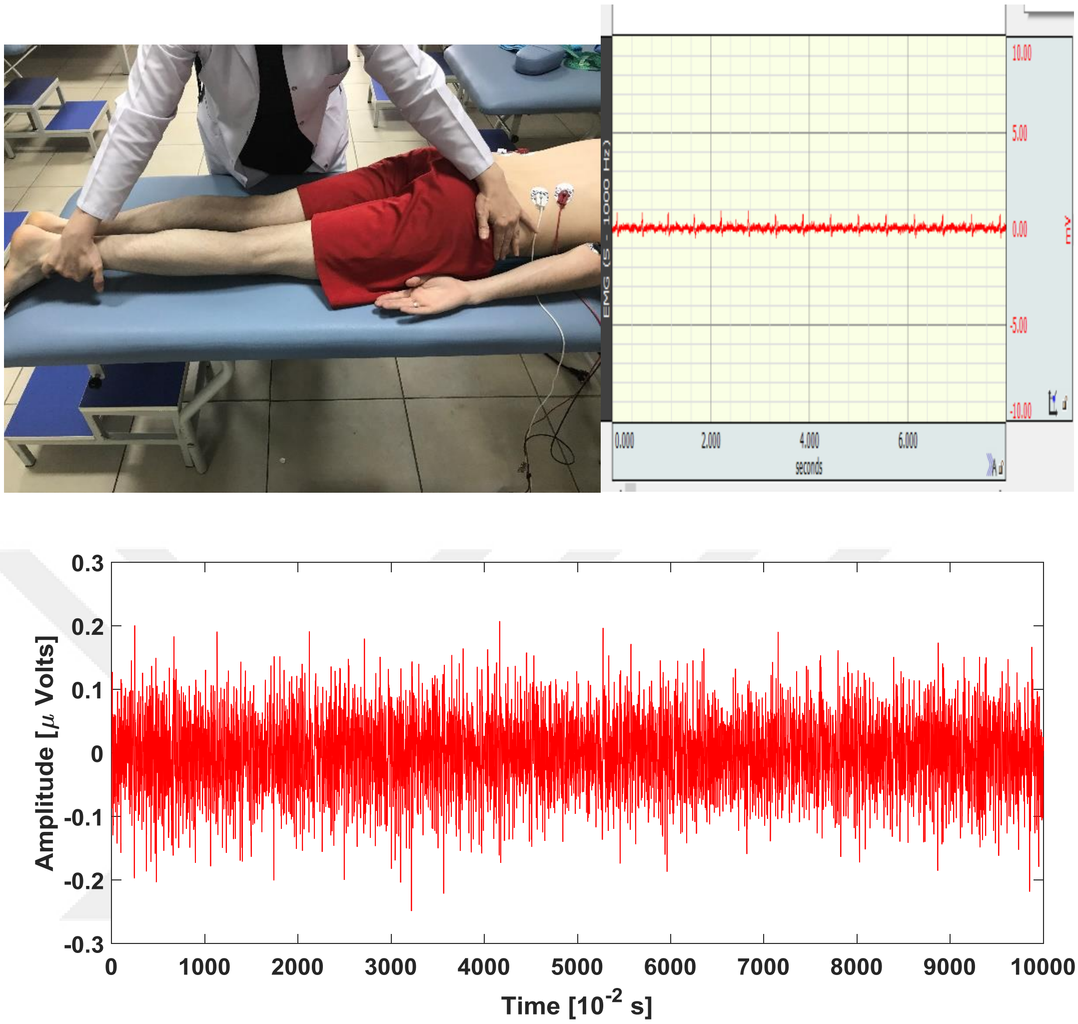


Figure 2.16: At the right side maximum isometric contraction and right side EMG Signal

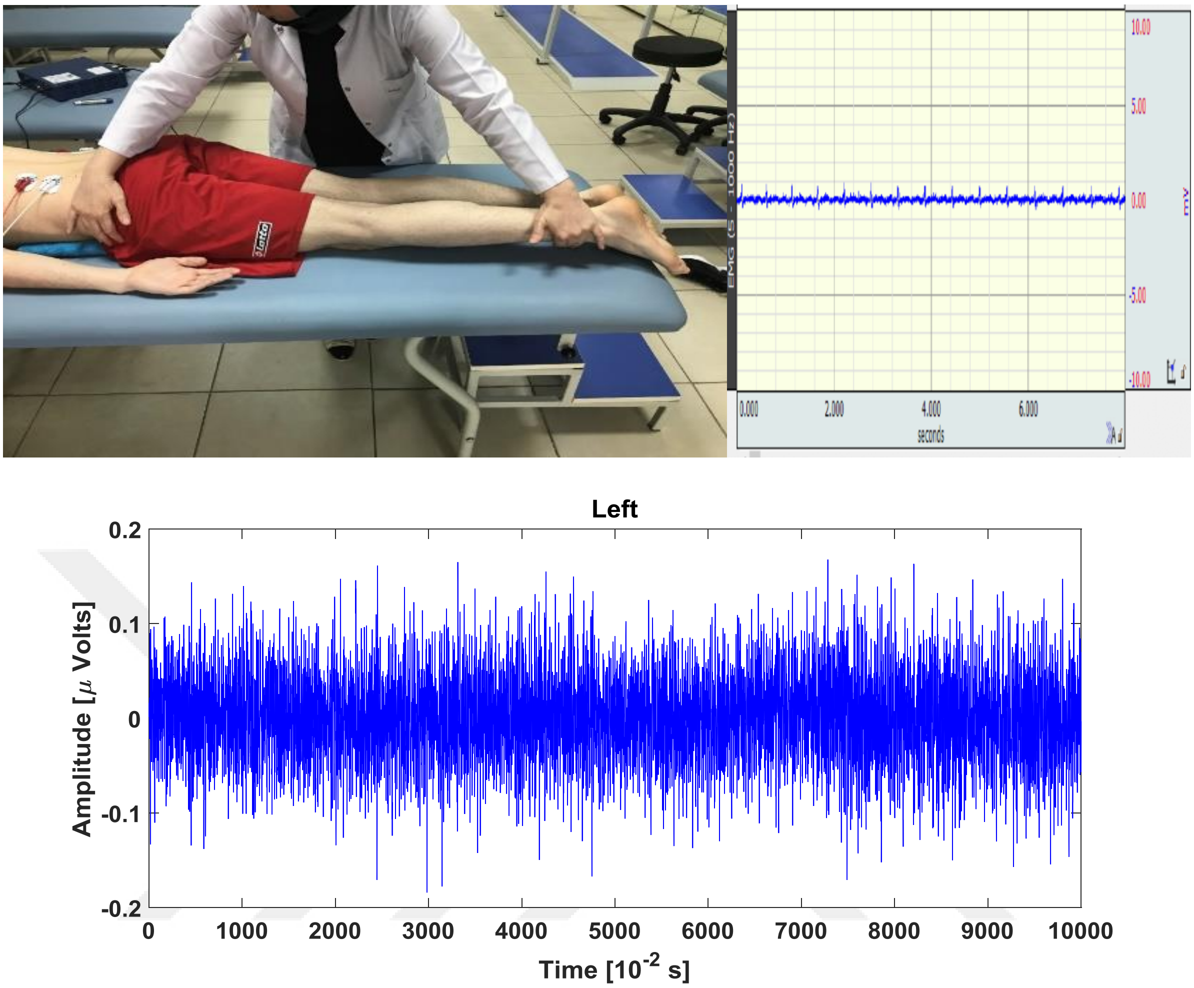


Figure 2.17: At the left side maximum isometric contraction and right side EMG Signal.

2.3.4. Electromyography Signal Processing

The proposed EMG signals analysis relies on the frequency domain where features of healthy EMG signal were analysed and compared. Such that, the relationship between the EMG signals and the contracting properties of QL muscles by analysing its Power Spectral Density (PSD) was described. The Welch estimation method was used to calculate the PSD by taking Hamming Window for the healthy signals. The analysis can provide important clues to design feature extraction methods and the resulting information can be used to determine the origin of the weakness. EMG Signals cannot be described by a well-defined formula. EMG signal is a random process whose value at each time is a random variable. The Fourier transform used in the previous section views non-random signals as weighted integral of sinusoidal functions. Since a sample function of random process can be viewed as being selected from an ensemble of allowable time functions, the weighting function for a random process must refer in some way to the average rate of change of the ensemble of allowable time functions. PSD of a wide sense stationary random process is computed from the Fourier transform of the autocorrelation function.

2.3.4.1. The Discrete Fourier Transform

The Discrete Fourier transform (DFT) method is very helpful tools for physiological signal processing. In this study, we used the DFT method to calculate the signals frequency spectrum. The DFT is a straight examination of information's that determined the frequency, and amplitudes of a component sinusoid. Furthermore, the DFT methods are applied for the system's frequency responses after the method's impulse responses and vice versa. In this process analyses the frequency domain, just as convolution permits systems to be analyses of the time domain. Similarly, the DFT method could be applied as an intermediate stage to more complex signal processing techniques [83-85].

2.3.4.2. Welch Method Based PSD

Welch's method was titled by P. D Welch who used this method in Math and physic first time for approaching the power of signals in numerous frequencies. Welch's method usually established from periodogram spectrum estimations which is work on the estimation of signal power at different frequencies. Moreover, this process is developed to periodical spectrum approximation method and Bartlett's procedure, where it decreases the noise ratio by using power spectra conversation by reducing the frequency resolutions. In this study, we calculated PSD estimation of DFT sets coefficients respectively by using Welch's method. Welch method can be mathematically expressed as follows:

$$\tilde{p}_{per}\ (\omega) = \frac{1}{MUL}\sum_{i=1}^{L} \left| \sum_{n=0}^{M-1} x_N^i\ (n) w(n) e^{-in\omega} \right|^2 \quad (1)$$

$$U = \frac{1}{M}\sum_{n=0}^{M-1} w^2\ (n) \quad (2)$$

Where $\omega = 2\pi f$ is the angular frequency, *U* is the normalization factor for the power, x_N^i is the number *I* section of, signal length,total *L* sections with *M* overlapping w(n) is the hamming window function of length *M* [83-85].

2.3.4.3. The EMG Signal Processing

In this study for the EMG signals processing, we applied a high-pass 10 Hz FIR filter and a 50 Hz notch filter for signal data preprocessing. After that by using Welch method power spectral density is calculated. Welch's method parameters: 50% overlaps the signals and data are divided into total 8 segments after those hamming window formulas are applied for each segment. Separately segments are subjects to a 256 points DFT. The amplitudes are then squared. At last, a singles power spectral density are obtained as the averages of all these parts. All digital signal processing work are done by using the MATLAB program (MathWorks software).

3. RESULTS

The physical characteristics of the 100 healthy university students (age, height, body weight, and BMI) were shown in (**Table 3.1**). Moreover we used statistical analysis especially for t-test subjects age, weight, height also Body Mass Index analysis to distinguish all subject. The student t-test is a statistical test that is extensively used to compare the means of different subjects. The t-test looking like the difference between their means relative to the spread or variability of their scores. However, as we can see in the number of female subjects was significantly higher. Conversely, we found no significant difference in age, weight, height and BMI.

Table 3.1: Demographic characteristics of the cases.

	Total (n=100) **Mean ± SD**	**P value**
Age (year)	21.13 ± 0.14	0.52
Weight (kg)	61.48 ± 5.13	0.54
Height(m)	1.64 ± 0.19	0.07
BMI (kg/m^2)	20.25 ± 2.24	0.69

BMI: Body Mass Index, SD: Standard deviation.*$p<0.05$

3.1. ANALYSIS OF TAPE MEASUREMENT AND EMG SIGNALS CORRELATION

In the tape measurement process: we applied two different methods for EMG signal analysis.

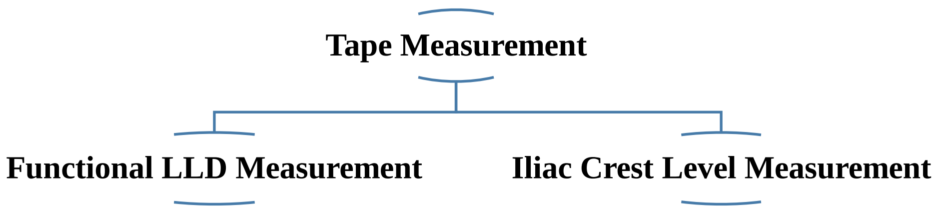


Figure 3.1: Tape measurement process.

3.1.1. Functional Leg Length Discrepancy Measurements

The first method involved the participants were lying supine position and measured between ASIS and prominent parts of medial malleolus of their ankle to obtain a leg length measure. This was done on both limbs and any difference in length was noted. If there were any differences between the two limbs we performed a second measurement. In the second measurement was taken from the umbilicus to the important parts of medial malleolus of their ankle, if the leg lengths were equal in the second measurement but the first measurement was not equal we accepted that the participants have functional LLD.

3.1.1.1. Analysis of Resting Position Functional Leg Length Discrepancy and EMG Signal

For the 100 subjects LLD measurement, in resting position, there were two groups short right functional LLD where we got 45 subjects and another group short left functional LLD 40 subjects. In short right functional LLD subjects, we recorded two different signals those were called right side LLD EMG signals and left side LLD EMG signals. Again for short left functional LLD subjects, we recorded two different signals those were called right LLD EMG signal and left LLD EMG signal. As we can see in the below (**Figure: 3.2**.)

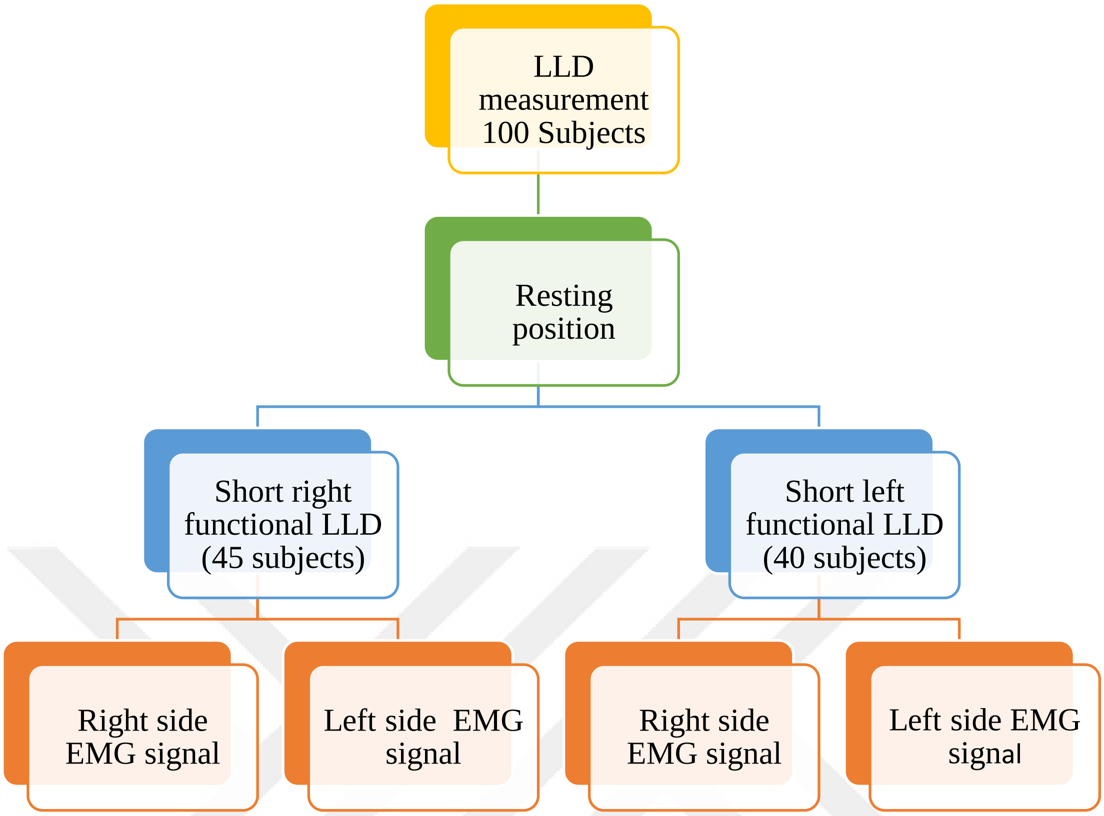
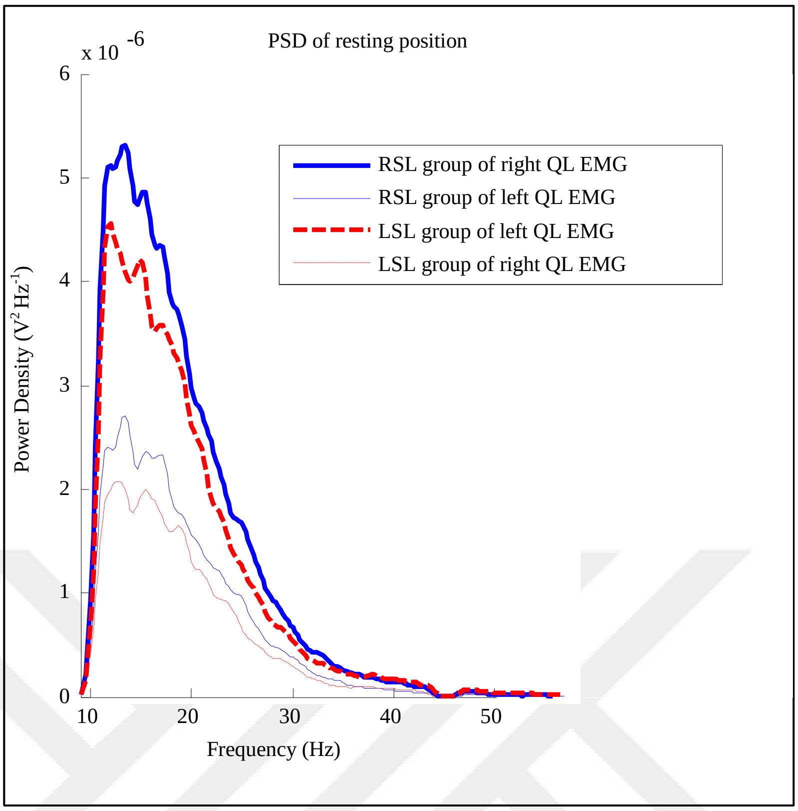


Figure 3.2: Summary of functional LLD at the resting positions EMG signal analysis.

When we compare both side EMG signal analysis in the resting position, in the results we found that participant who has short right side functional LLD had higher PSD of EMG signals on the right side functional LLD than the left side functional LLD, however participant who had short left side functional LLD had higher PSD of EMG signals on the left side compared to the right side functional LLD. When we compared both groups (short right LLD and short left LLD) it was showing that short right side functional LLD group had higher PSD of EMG values than the short left side functional LLD group as we can see in the (**Figure: 3.3**).



RLS : Right Short Leg, LSL:Left Short Leg, PSD: Power Spectral Density

Figure 3.3: Resting position functional LLD EMG signal analysis graph

In this study resting position LLD measurements were obtained from the different subjects each group into account, we applied t-test for statistical analysis between the right side and the left side EMG signals in both short right LLD and short left LLD groups. Moreover, a p value of less than 0.05 were measured as statistically significant. For this aim power spectral density (PSD) graphics were obtained using EMG and PSD were calculated. We found both groups features were statistically significant for the short right LLD (**0.046***) and short left LLD (**0.005***) see in the below (**Table: 3.2**.).

Table 3.2: PSD values calculated from EMG signals received resting position LLD measurements in the short right functional LLD and short left functional LLD groups.

LLD measurement Resting position		PSD **Mean±SEM**	P values
Short Right Functional LLD (45 subjects)	The right side EMG signal	0.00198±0.00014	**0.046***
	The left side EMG signal	0.00014±0.00003	
Short Left Functional LLD (40 subjects)	Left side EMG signal	0.00165±0.00348	**0.005***
	The right side EMG signal	0.00084±0.0081	

PSD: Power Spectral Analysis, LLD: Leg Length Discrepancy, SEM: Standard Erorr Mean, *p value<0.05

3.1.1.2. Analysis of Functional Leg Length Discrepancy and EMG Signal Maximal Isometric Contraction Position

Furthermore, in maximal isometric contraction position all subjects were divided into two group's short right functional LLD where we got 45 subjects on the other group short left functional LLD 40 subjects. Each subjects short right functional LLD were recorded into two different signals those are right side LLD EMG signals and left side LLD EMG signals. Again for short left functional LLD subjects, we recorded two different signals those were right LLD EMG signal and left LLD EMG signal. As we can see in the below (**Figure: 3.4**.).

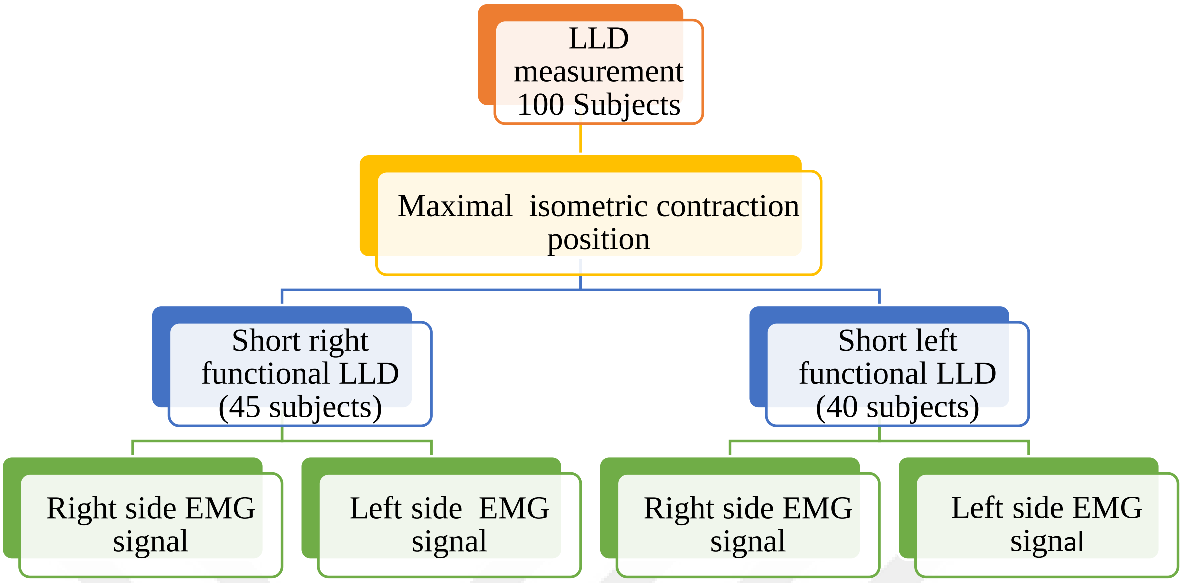
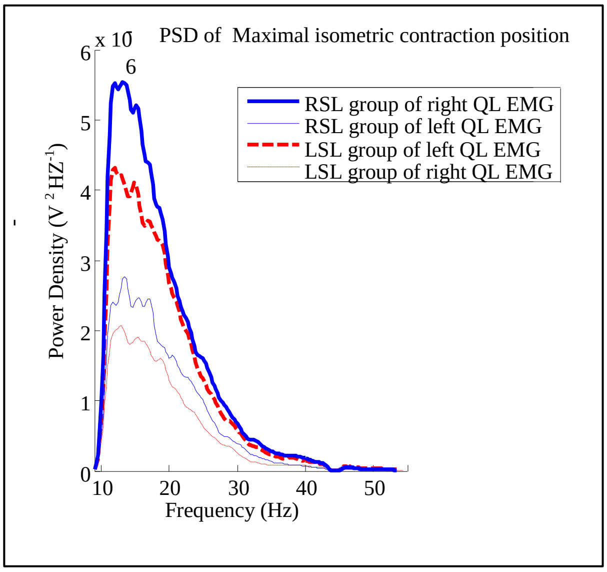


Figure 3.4: Summary of maximal isometric contraction positions EMG signal analysis.

In second position (maximal isometric contraction) participants who had short right LLD had higher right side PSD of EMG signals than left side EMG signals, while participants who had short left LLD had higher left side PSD of EMG signals than right side EMG signal. Comparing the two groups (short right LLD and short left LLD) it was showing that short left LLD group had generally high PSD of EMG values than the short right LLD group. As we can see (**Figure: 3.5**).



RLS: Right Short Leg, LSL:Left Short Leg, PSD: Power Spectral Density

Figure 3.5: Maximal isometric contraction position functional LLD EMG signal analysis graph.

For maximal isometric contraction position LLD measurements were obtained from the different subjects each group into account, we applied t-test for statistical analysis between Right side and left side EMG signals in both short right LLD and short left LLD groups. Moreover, a p value of less than 0.05 were measured as statistically significant. For this aim PSD graphics were obtained using EMG and PSD were calculated. We found both groups features were statistically significant for the short right LLD (**0.009***) and short left LLD (**0.023***) see in the below (**Table: 3.3**.).

Table 3.3: PSD values calculated from EMG signals received maximal isometric contraction position LLD measurements in the short right functional LLD and short left functional LLD groups.

LLD Measurement Maximal Isometric Contraction Position			p values
Short Right Functional LLD (45 subjects)	The right side EMG signal	0.0002±0.000013	**0.009***
	The left side EMG signal	0.000014±0.0008	
Short Left Functional LLD (40 subjects)	The left side EMG signal	0.00056±0.0049	**0.023***
	The right side EMG signal	0.00051±0.0017	

LLD: Leg Length Discrepancy ***p value<0.05***

3.1.2. Manual Iliac Crest Level Measurement

The second method involved manual measurement of iliac crest level. In this section within the same way, all participants were divided into two groups: participants who had up right iliac crest and they were right handed, and participants who had up left iliac crest and they were also right handed. Moreover, in manual iliac crest level measurement procedure out of 100 participants, we found that 48 participants had up right iliac crest and 42 participants had up left iliac crest. The remaining10 participants had equal left and right iliac crest. Subsequently, both groups were analysed in the resting position and isometric contraction positions. After that, both groups EMG signals were compared to each other.

3.1.2.1. Iliac Crest EMG Signal Analysis for Resting Position

In the second method involved manual measurement of iliac crest level 100 subjects. For resting position there were two different groups, first one was Up Right Crista which had 48 subjects and Up Left Crista which had 42 subjects. Each group again divided into two different groups. In the Up Right Crista 48 subjects were divided the right QL muscle EMG signal and the left QL muscle EMG signal. Again for the Up Left Crista 42 subjects were divided right QL muscle EMG signal and left QL muscle EMG signal. As we can see in the below **Figure 3.6:**

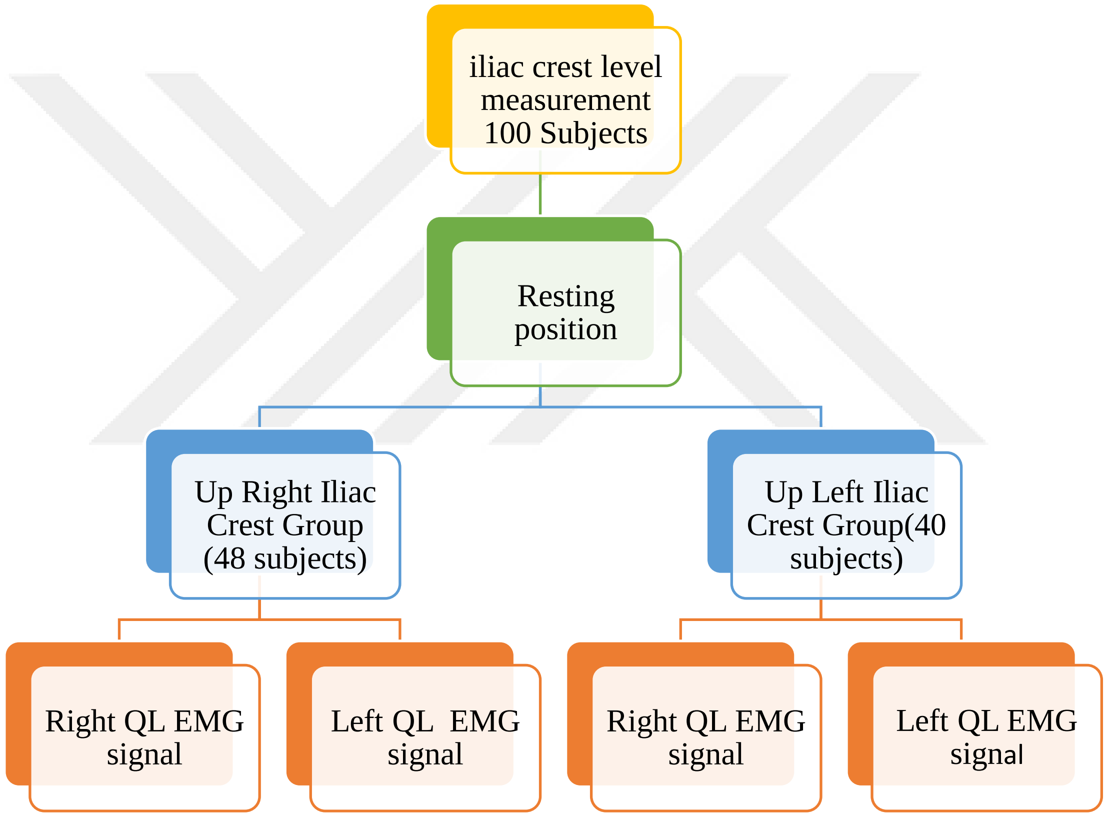
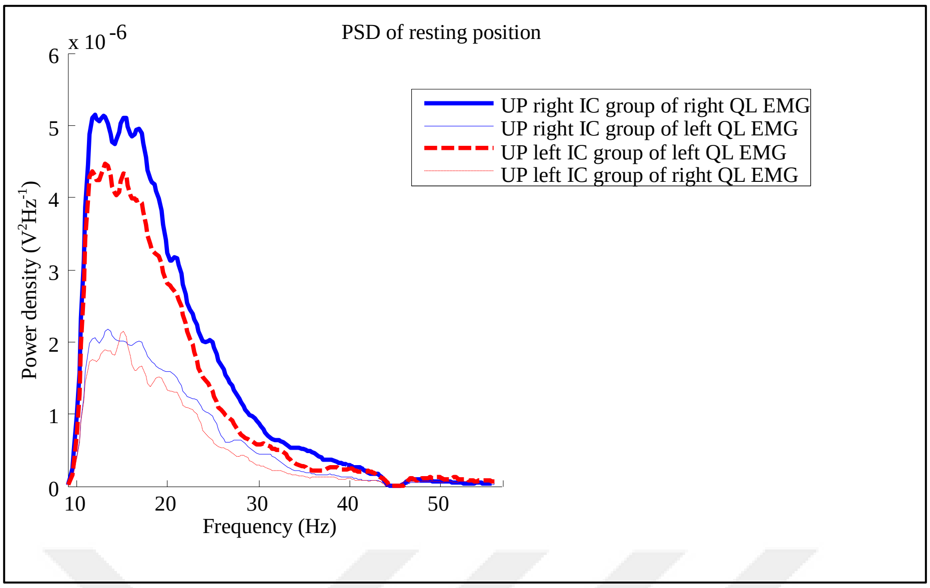


Figure 3.6: Summary of iliac crest resting position EMG signal analysis.

In the resting position participants who had Up Right Crista had higher PSD of EMG signals on the right side QL muscle than the left QL muscle. Moreover, participants who had Up Left Iliac Crest had higher PSD of EMG signals on the left QL muscle than the right QL muscle. Comparing the two groups (Up Right Crista and Up Left Iliac Crest) it was showing that Up Right Crista group generally had higher PSD of EMG values than the Up Left Iliac Crest group. (**Figure: 3.7**).



IC: Iliac crest level, PSD: Power Spectral Density

Figure 3.7: Resting position iliac crest position EMG signal analysis graph.

For resting position iliac crest level measurements were obtained from the different subjects each group into account, we applied t-test for statistical analysis between the right side and the left side QL muscle EMG signals in both Up Right Iliac Crest and Up Left Iliac Crest groups. Moreover, a p value of less than 0.05 were measured as statistically significant. For this aim PSD graphics were obtained using EMG and PSD were calculated. We found both groups features were statistically significant for the Up Right Iliac Crest (0.011*) and Up Left Iliac Crest (0.032*). see in the below (**Table: 3.4**.)

Table 3.4: PSD values calculated from EMG signals received resting position iliac crest level measurements in the up right iliac crest and up left iliac crest groups.

Iliac Crest Level Measurement Resting Position			p values
Up Right Iliac Crest group (48 subjects)	Right QL EMG signal	0.00036±0.0004	**0.011***
	Left QL EMG signal	0.0000174±0.0007	
Up Left Iliac Crest group (40 subjects)	Right QL EMG signal	0.00026±0.0019	**0.032***
	Left QL EMG signal	0.0001±0.0003	

p value<0.05

3.1.2.2. Iliac Crest EMG Signal Analysis for Maximal Isometric Contraction Position

For analysis of maximal isometric contraction positions of iliac crest level were divided within two different groups, first one was Up Right Iliac Crest which had 48 subjects and another one is Up Left Iliac Crest which had 42 subjects. Separately Up Right Iliac Crest and up left iliac crest group again divided within two different groups. In the Up Right Iliac Crest 48 subjects were divided right QL muscle EMG signal and left QL muscle EMG signal group. Again for the Up Left Iliac Crest 42 subjects were divided right QL muscle EMG signal and left QL muscle EMG signal. As we can see in the below **Figure 3.8**:

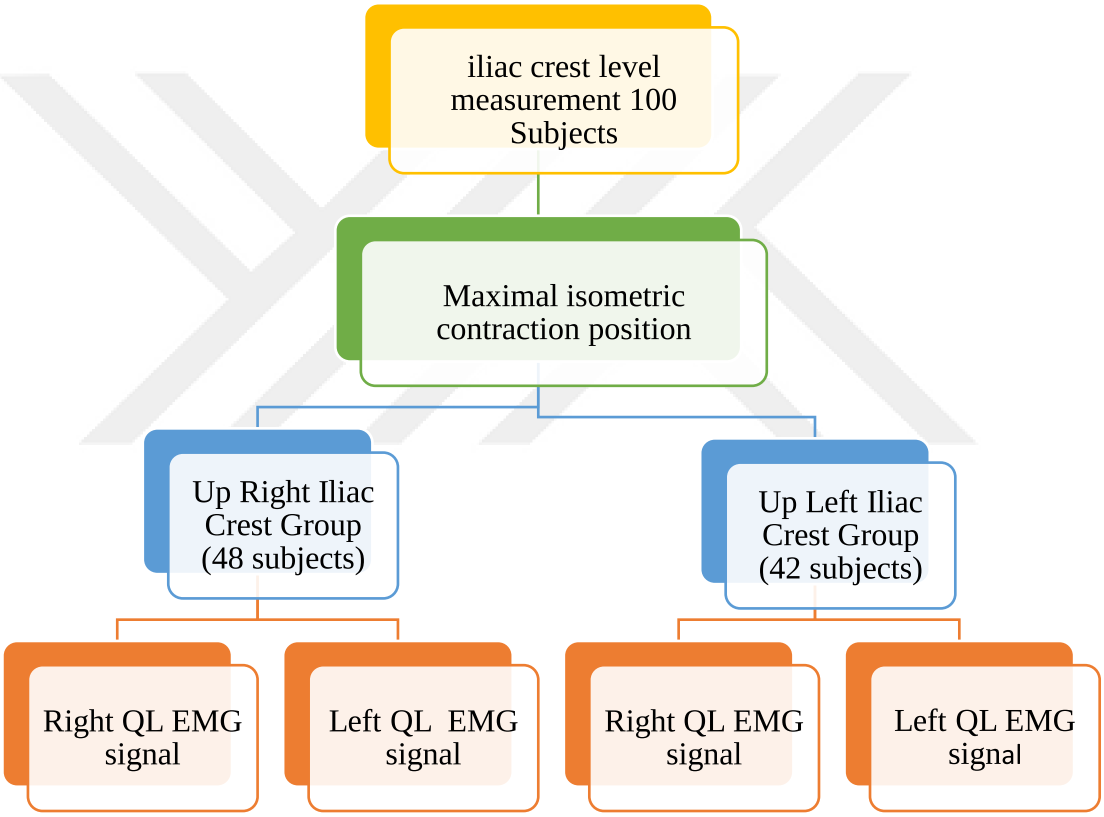
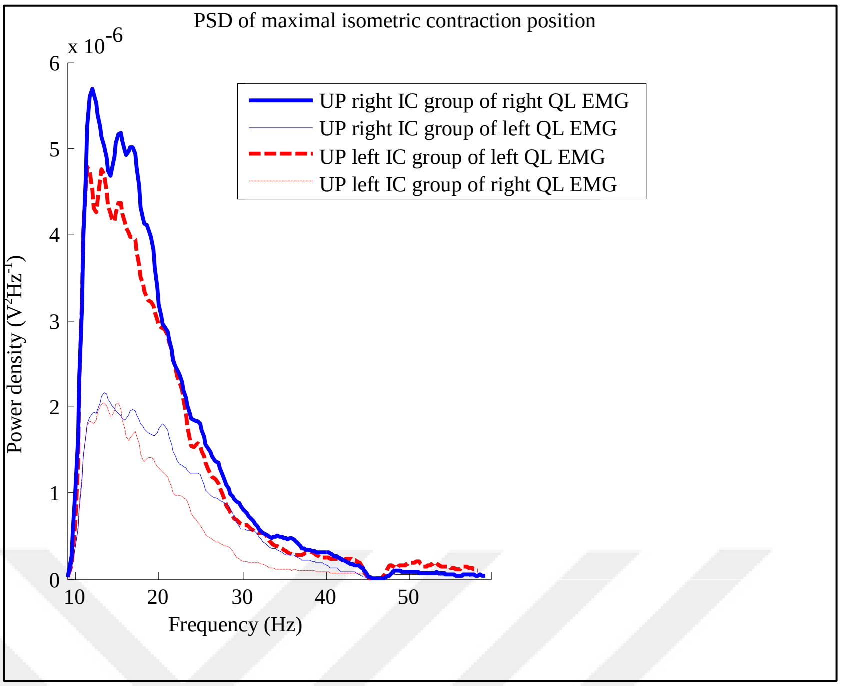


Figure 3.8: Summary of maximal isometric contraction position EMG signal analysis

When we see the maximal isometric contractions position graph analysis we found that those had up right iliac crest had higher PSD of EMG signals on the right QL muscle than the left QL muscle; conversely, participants who had up left iliac crest had higher PSD of EMG signals on the left QL muscle than the right QL muscle. When we compared both side (up right crista and up left crista) we found that the up right crista group had mostly high EMG values than the up left crista. (**Figure: 3.9)**



IC: Iliac crest level, PSD: Power Spectral Density

Figure 3.9: Maximal isometric contraction iliac crest position EMG signal analysis graph.

For maximal isometric contraction position iliac crest level measurements were obtained from the different subjects each group into account, we applied t-test for statistical analysis between the right side and left side QL muscle EMG signals in both the Up Right Iliac Crest and the Up Left Iliac Crest groups. Moreover, a p value of less than 0.05 were measured as statistically significant. For this aim PSD graphics were obtained using EMG and PSD were calculated. We found both groups features were statistically significant for the up right iliac crest (**0.0358***) and up left iliac crest (**0.012***).

Table 3.5: PSD values calculated from EMG signals received maximal isometric contraction position iliac crest level measurements in the up right iliac crest and up left iliac crest groups.

Iliac Crest Level Measurement Maximal Isometric Contraction Position			p values
Right Up Iliac Crest Group (48 subjects)	The right QL EMG signal	0.00061±0.00002	**0.0358***
	The left QL EMG signal	0.000045±0.00011	
Up Left Iliac Crest Group (42 subjects)	The right QL EMG signal	0.00014±0.0009	**0.012***
	The left QL EMG signal	0.0071±0.00023	

p value<0.05

Furthermore, we found that nearly 98% of the cases with lower extremities short on the left, the iliac crest level were to be in the elevation position on the left side. We also found that 94% of the cases with shortened right lower extremity were in the elevation position on the right side of the iliac crest.

3.2. DIGITAL PELVIC INCLINOMETER MEASUREMENT AND EMG SIGNAL ANALYSIS RELIABILITY

3.2.1. Left Side > Right Side Digital Pelvic Inclinometer Rate

The reliability of the DPI measurement and EMG signal analysis in resting position on both right and left side of the pelvis were measured.

Digital pelvic inclinometer measurement: Out of 92 subjects, only ten subjects included who have left side digital pelvic inclinometer more than 8 degrees than the right side digital pelvic inclinometer rate moreover left side degree and right side degree differences were more than 5 degrees.

Table 3.6: Descriptive statistics for pelvic tilt.

Subjects	Right Side Rater 1 (Mean± SD)	Left Side Rater 1 (Mean± SD)
Descriptive statistics for pelvic tilt.	12.88 ± 3.019	19.75 ± 3.4715

SD: Standart Deviasyon

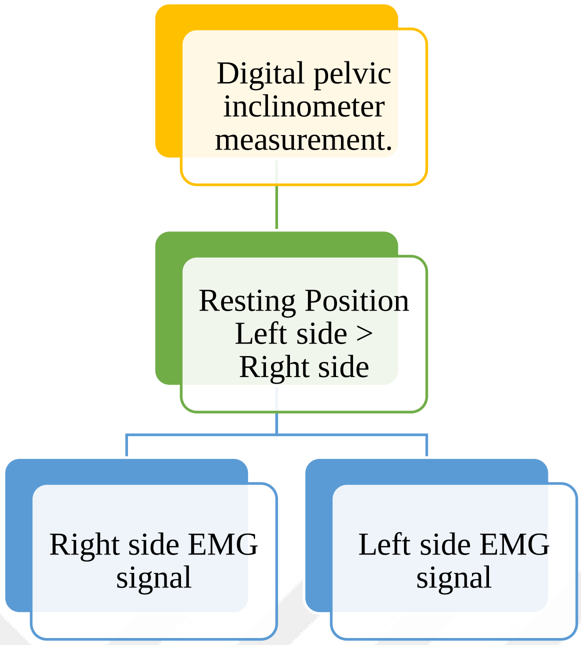
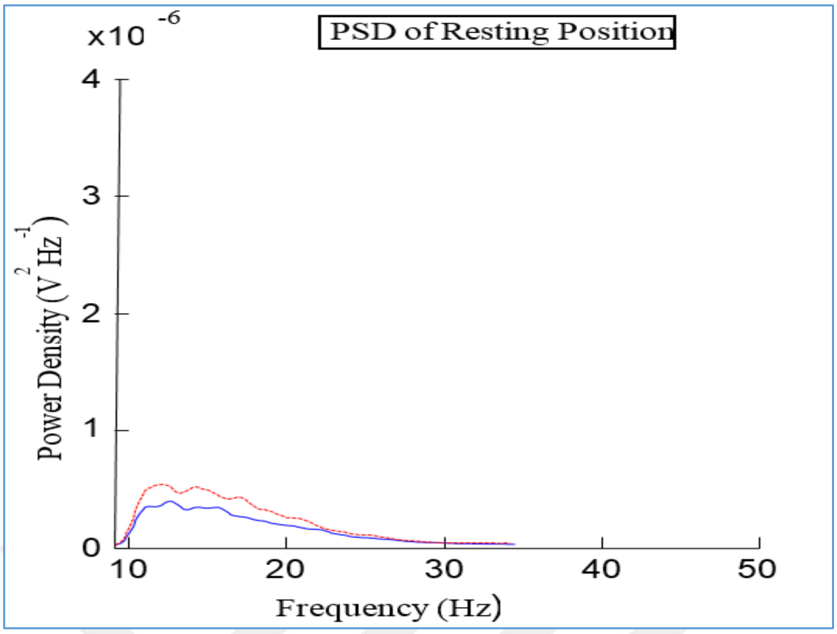


Figure 3.10: Summary of digital pelvic inclinometer resting position (Left side > right side) measurement EMG signal analysis

The reliability of DPI measurement and EMG signal analysis for measuring pelvis angle on both the right and left sides of the pelvis were assessed, in a convenience sample of young, healthy males and females groups.

In this step DPI measurements, we found a total of ten subjects had left side pelvic angle was higher than the right side pelvic angle. Those ten subjects of EMG signals were compared.



PSD: Power Spectral Density

Figure 3.11: Resting position digital pelvic inclinometer measurement left side pelvic (red color) and right side pelvic angle (blue color) graph.

In the total results, we found that the EMG activity in the resting position, participants who had left side pelvis angle had higher, those subjects PSD of EMG signals were also higher than the right side PSD of EMG signals. As we can see (**Figure 3.11**).

Table 3.7: PSD values calculated from EMG signals received resting position (Digital pelvic inclinometer measurement in the Left side > Right side group).

Digital Pelvic Inclinometer Measurement Resting Position			p values
The left side > The right side group	The left side EMG signal	0.00527±0.0002	**0.047***
	The right side EMG signal	0.00038±0.00021	

****p value<0.05***

For resting position, DPI measurements were obtained from the different subjects each group into account, we applied t-test for statistical analysis between the right side and left side EMG signals in Left side > Right side group. Moreover, a p value of less than 0.05 were measured as statistically significant. For this aim PSD graphics were obtained using EMG and PSD were calculated. We found group features were statistically significant for the left side > The right side group (**0.047*).** see in the above (**Table: 3.7**.)

3.2.2. The Right Side > the Left Side Digital Pelvic Inclinometer Rate

The reliability of the digital pelvic inclinometer measurement and EMG signal analysis in resting position on both sides pelvis were measured. DPI measurement: Out of 92 subjects only seven subjects included who have right side DPI rate more than 8 degrees than left side DPI rate moreover difference also left side degree and right side degree were more than 5 degrees. As we can see (**Figure 3.12** and **Table 3.8).**

Table 3.8: Pelvic tilt for left side and right side measurements.

Subjects	Right side Rater 1 (mean± SD)	Left side Rater 1 (mean± SD)
Descriptive statistics for pelvic	16.34 ± 2.947	10.914 ± 3.163

SD: Standard Deviation

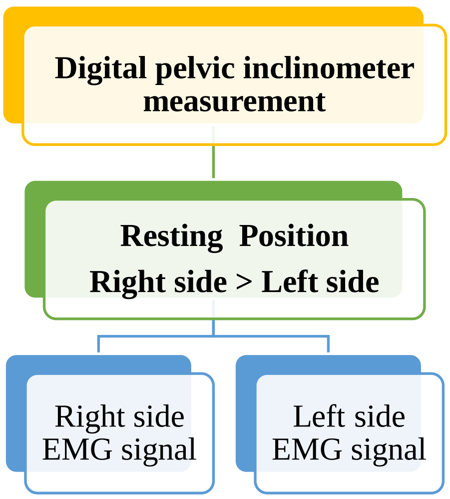
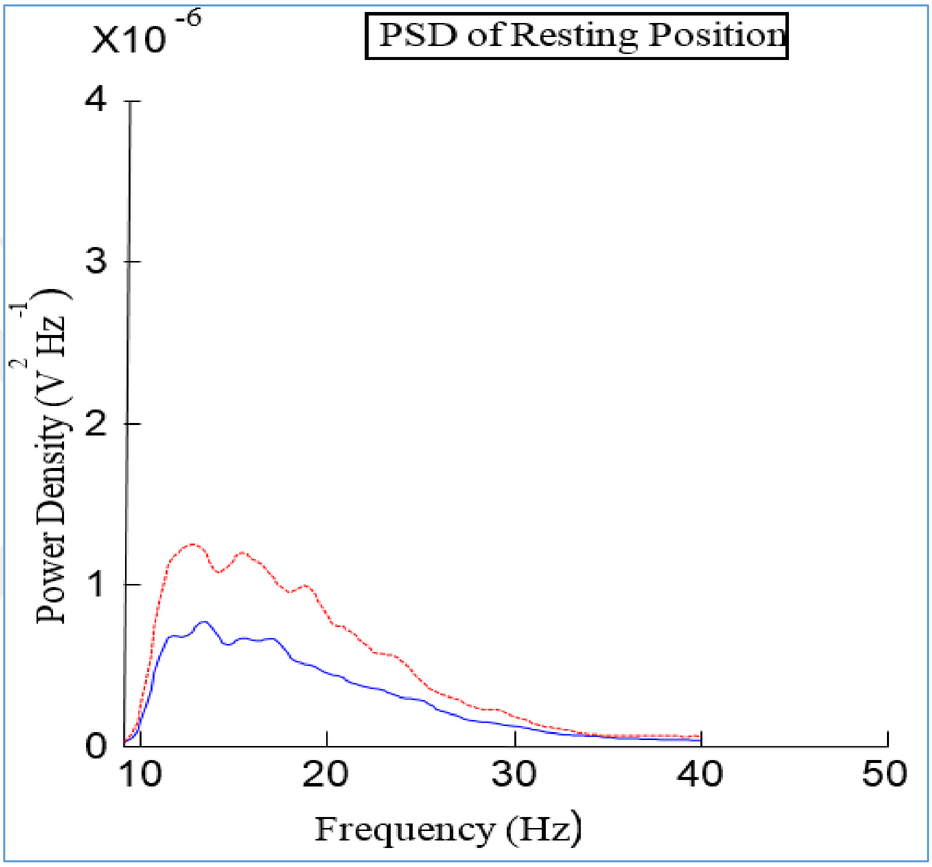


Figure 3.12: Summary of digital pelvic inclinometer resting position (Right side > Left side) measurement EMG signal analysis.

The reliability of DPI measurement and EMG signal analysis for measuring pelvis angles on both sides of the pelvis were measured in both groups. In the DPI measurements, we found total of 7 subjects have right side pelvic angle is higher than the left side pelvic angle. After that those 7 subjects left side pelvic angle and right side pelvic angle EMG signals were compared.



PSD: Power Spectral Density

Figure 3.13: Resting position digital pelvic inclinometer measurement right side pelvic (red color) and left side pelvic angle (blue color) graph.

In the results we found that the EMG activity in the resting position, participants who had right side pelvis angle had higher, those subjects PSD of EMG signals were higher than the left side PSD of EMG signals. As we can see above (**Figure 3.13**).

Table 3.9: PSD values calculated from EMG signals received resting position (Digital pelvic inclinometer measurement in the Right side > Left side group).

Digital Pelvic Inclinometer Measurement Resting Position			pvalues
Right side > Left side	Right side EMG signal	0.00066±0.00042	**0.003***
	Left side EMG signal	0.00005±0.00021	

****p value<0.05***

For resting position, DPI measurements were obtained from the different subjects each group into account, we applied t-test for statistical analysis between the right side and left side EMG signals in Right side > left side group. Moreover, a p value of less than 0.05 were measured as statistically significant. For this aim PSD graphics were obtained using EMG and PSD were calculated. We found group features were statistically significant for the right side > left side group (**0.003*)** As we can see above (**Table 3.9**).

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4. DISCUSSION

The quadratus lumborum muscles are the deepest abdominal muscles which run along both sides of the lower back. The QL muscle starts in the lowest rib and the nearby vertebra also connected to hip crest [1, 86]. This muscles also have responsibilities to stabilize the lower back during the upright condition also play an important role in side of bending. It contributes to the support and flexibility of the pelvis and spine[15, 33, 87]. The QL muscle attempts to compensate for the weak muscles, and this can cause the muscle to stiffen, which is painful. Conditions that cause imbalances in the pelvis or spine, such as leg length discrepancy, can cause the QL muscle to attempt to stabilize the imbalance [88]. Some researchers have found that the maximal activity of the QL muscle, as indicated by EMG measurements, on the same side reached the level of the body when performing lateral flexion and supported the posture by contracting isometrically [6, 88]. In another study, the QL muscle was found to be the most important stabilizer muscle of the lumbar vertebrae [24, 89-91]. Allowing these, it can be said that when QL muscle is hypertonic, it may cause lumbar vertebrae and posture problems. According to the literature, the QL muscle has been found to have a great effect on pelvic asymmetry and LLD.

4.1. RELATIONSHIP BETWEEN FUNCTIONAL LEG LENGTH DISCREPANCY AND QUADRATUS LUMBORUM MUSCLE ACTIVITY

This study investigated the relationship between functional LLD and QL muscle activity. EMG signals were measured in two different positions (resting position and maximal isometric contraction). Subjects were divided into two groups of respect to iliac crista position and LLD. The iliac crista group was then divided again into two groups: Right side iliac crista level up and left side iliac crista level up. Also, the LLD group was divided into two groups: short right LLD and short left LLD. After measuring their iliac crest level manually, we found 45 up right iliac crista and 40 up left iliac crista. Moreover, 100% of participants who had up right iliac crista also had short LLD. 98% of participants who had up left iliac crista also had short LLD.

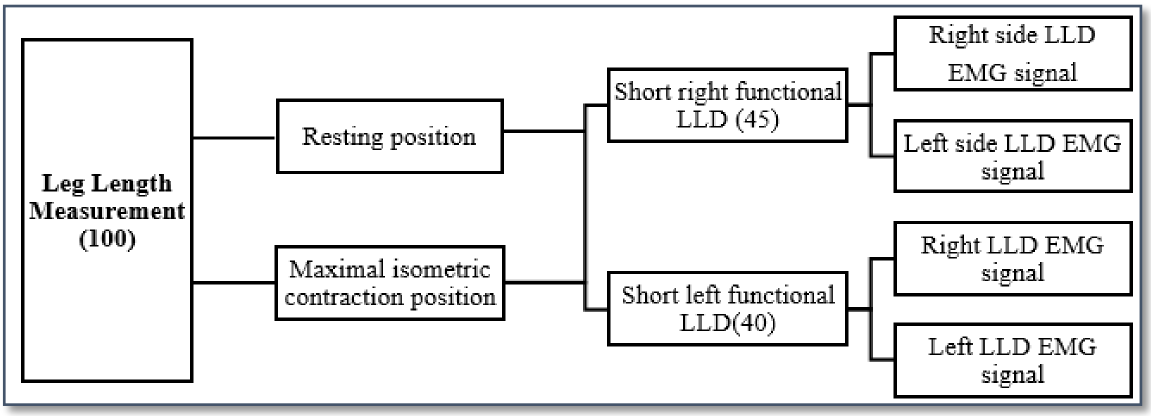

Figure 4.1: Leg length inequality resting and maximal isometric contraction positions EMG signal analysis

When we analyzed the EMG signals of the QL muscle, we found that those at the iliac crest up were higher in both positions than the other side. When we analyzed the EMG signals of the QL muscle according to LLD, we found that the EMG signals of the QL muscle on the short side were higher than on the other side. When we look at all results together, we can say that there is a strong relationship between QL muscle pelvis position, and LLD [2,81,89, 91]. When LLD is found in asymptomatic patients, it is important to inform them that the shorter leg can lead to symptoms in the future which need to be corrected [13].

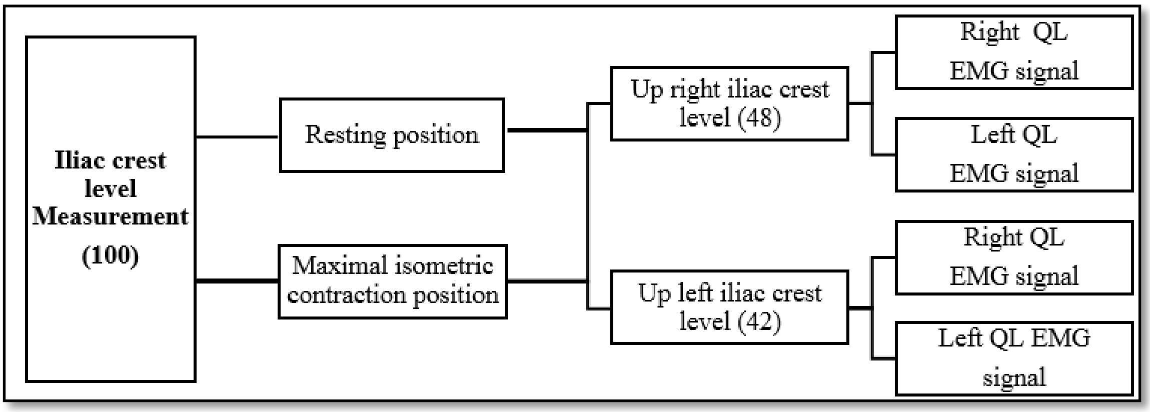

Figure 4.2: Iliac crest level resting and maximal isometric contraction positions EMG signal analysis.

In two different positions, as we can see when comparing the two groups (up right crest and up left crest), it was found that QL muscle activity when the right crest is higher than when the left crest is higher. All participants were right-handed, so according to our results, we can say that right-handed dominancy makes same side QL muscles more active. In right-handed people QL muscles caused an imbalance in the lumbar region, this imbalance causes some people to develop functional scoliosis. In a study in which QL muscle endurance was assessed, it was found that the QL muscles in the side of the short leg had less endurance than the muscle on the other side [92]. According to this result, short muscle spasms are caused by decreasing the muscle contraction ability of the same side muscle: it causes intestinal fatigue and reduces muscle endurance. Previous studies found that cricket fast bowler proved that asymmetric QL muscle progress, that has relation to trunk position adopted in fast bowler technics. This provides support for the idea that a certain sustained trunk position can cause QL muscle asymmetry causing injuries in the lumbar spine [93, 94].

Other studies have investigated the effects of QL muscle hyperactivity and the effects of LLD. Foot rotation, pelvic crest leveling, and supine leg length alignment asymmetry, and their relationship to self-reported back pain were found to be related to supine leg length discrepancy and back pain or recurrent back pain [81, 95, 96]. The pain intensity of those who demonstrated supine LLD was significantly higher than those without such asymmetry. The supine leg length alignment check for recurrent back pain demonstrates acceptable validity indices for sensitivity (87%), specificity (84%), and positive predictive value (73%) [95]. A new study found that QL muscle ipsilateral to the supine short leg had significantly decreased endurance times over the same-side QLmuscle fatigue [96]. A study investigated QL muscle asymmetry and injuries in cricket fast bowlers and results were that: QL muscle asymmetry can cause symptomatic L4 pars injury in cricket fast bowlers and the bowlers with excess QL muscle asymmetry greater than 10 % can experience larger lumbar lateral flexion which may increase the risk for spondylosis development [94].

The long term solution for dealing with lower back pain can be to correct the postural distortion that results in functional LLD. Once the form of LLD is identified, the medical expert may use their visual and palpatory skill to assess the LLD by evaluating the patient’s ASISs levels. By doing so, they may find that the LLD is due to a tight QL muscle. When the patients are in a supine condition, the LLD may be due to the contraction of the lumbar muscle or rotation of the iliosacral muscle [97].

4.2. IMPACT OF DIGITAL PELVIC INCLINOMETER AND PELVIC POSITION

The relationship of DPI measurement and EMG signal analysis for measuring pelvis angles on both sides of the pelvis were measured in all groups. In the pelvic inclinometer measurement, we found out of 92 subjects, only ten subjects included who had left side DPI more than 8 degrees than the right side and seven subjects who have right side DPI more than 8 degrees than the left side. Moreover left side and right side degree differences were more than 5 degrees. After that when we see those participants EMG signals condition, we found that the EMG activity in the resting position, participants who had left side pelvis angle had higher, those subjects PSD of EMG signals are also higher than the right side PSD of EMG signals. Same results we found for the other groups.

Research shows that digital pelvic inclinometer measurement had also been finding to displays good validity by reference [97-99]. Additionally, this devices also had numerous practical benefits to the physiotherapist, being speedily and simply applied, also small in size, transportable, comparatively safe according to radiography and absolutely low-cost in evaluation with low quantity digital stereo radiography and MRI scanning device. DPI also measurement to take both sides of the pelvis that could be significantly specified the changes among sides that had previously been detected [100, 101].

The pelvic tilt that develops due to LLD can cause unequal stress on a person’s foot, limb, knee, lumbar spinal joints or sacroiliac when they are in an upright position. This tilting shifts the center of gravity and causes the muscles to compensate, and in an attempt to do so, the magnitude of the internal joint load may increase. The tilt can also reduce the articular cartilage’s contact area, and this can disrupt the skeletal alignment. The effect of increased joint load and reduced surface area can lead to increase pressure on the underlying bone or cartilage, and this can ultimately cause osteoarthrosis [63].

Leg length discrepancy can also cause degeneration of the lumbar intervertebral disc. The intervertebral disc is avascular structure that get nutrients from the end plates. Intervertebral disc generation is said to occur at the beginning of degenerative spinal changes, and it can be followed by disc narrowing or the development of osteophytes [102]. A study found that all discs, regardless of their location are damaged by unequal pressure. Disc prolapse and degeneration are reported to follow after endplate failure and avulsion, especially after an injury that affects the combined flexion or due to torsion forces on the lumbar spine [103].

Moreover, leg length discrepancy has an impact on a person's walking since it can cause gait abnormalities and spinal imbalance. A standard body can maintain the left and right balance in the spine and pelvis, but for people with LLD, the pelvis and the spine is in the state of imbalance. According to another study, LLD can develop from exposure to a bad posture which affects the alignment of the body, and this can induce deformity is some body parts, and it can also cause the body to compensate for the misalignment [104].

LLD leads to gait imbalance since it reduces the stance phase time for the short leg and increases the pressure on the sole of the longer leg. As such, the time the heel take to leave the ground reduces and this causes gait disabilities. When walking, the lower limb supports the load and the lower limb joints including the ankle, knees, and hips [105,106]. The natural movement of these joints is critical in ensuring the body remain stable, and that one can perform their day-to-day functions. LLD also lead to the development of pain in the lateral patellofemoral region, and this can fasten the development of degenerative arthritis in the hip and knee joints.

No particular treatment program can help all patients. Physical therapists tend to employ different approaches to the rehabilitation of the muscles of a patient's Leg length discrepancy since there is no adequate evidence that one method is superior to others [108]. Many studies are done for the following treatments of patients with LLD and electromyography can be used to analyze the activation of muscles.

4.3. IMPACT OF PELVIC ASYMMETRY

The pelvic asymmetry that occurs in the sagittal plane is referred to as iliac rotation asymmetry, and it is associated with sacroiliac joint dysfunction which is the malalignment of the right and left innominate bones. The failure of the pelvis to perfectly lie in a horizontal position on the frontal plane is referred to as the lateral pelvic tilt. Pelvic symmetry is said to change body mechanics by staining some body segments, and this contributes to the development of musculoskeletal pain [109]. Also, the compensation that happens in the musculoskeletal system can change the lumbar spine's mechanics [109]. It is unclear whether the impact of pelvic asymmetry on trunk mobility occurs when a person is standing and sitting. Understanding the compensatory motions resulting from pelvic asymmetry is important. This understanding is necessary to administer the right treatment. Compensatory functions in the trunk as a result of pelvic asymmetry cannot be corrected by similar treatments like leveling the pelvis when seated. It is important to investigate other issues apart from pelvic asymmetry that could contribute towards the development of chronic back pains and other related conditions [110].

Some issues contribute towards the development of low back pain such as sitting, pelvic asymmetry, and conditions like LLD. It is unclear about the extent to which the psoas major and the QL muscle contribute to spinal curvature in activities like upright sitting. It is also unclear whether their contribution changes for people with low back pain. It is common for people with low back pain to experience difficulties when sitting or when attempting to adopt certain lordosis postures. Some people may adopt the kyphotic or lordotic posture depending on the posture that causes them less pain. Each posture induces a different level of muscle activity, which can be evaluated using EMG signals. Studies that have researched on the adoption of the various postures for people with low back pain have focused on the paraspinal and superficial muscles. However, it is likely that activity in the psoas major and the QL muscle also changes [111-113].

Other studies have proposed the use of other spine and pelvic assessment methods. The bony anatomical landmark is very popular method of assessing positional asymmetry. This is a common assessment method in manual medicine and manipulative therapies like chiropractic, and physiotherapy. There are other evaluation methods apart from bony anatomical landmark positional asymmetry which includes pain provocation, motion testing, point tenderness, and palpation of taut bands. Such methods are used together with the patient's history to determine the existence of a structural asymmetry. Some studies question the reliability of some pain provocation tests. The use of palpation to identify tender points can be adequate in determining asymmetry, but the interpretation of the test should be done with cautions. Positional asymmetries are generally used to determine the dysfunctions of the sacroiliac joints. However, the experimental evidence and poor reliability regarding the amount of motion at the sacroiliac joint leads to people questioning the validity of this assessment method.

4.4. IMPACT OF EMG SIGNAL ANALYSIS TO DETECT PELVIC ASYMMETRY

Various researchers have evaluated the impact of asymmetry on the different muscles by using EMG signals aimed to find out this by evaluating the presence of lower limb asymmetries for people with scoliosis in an attempt to understand the implication of such a condition. The study used kinematic, kinetic and electromyographic analysis to the effect of scoliosis on people's gait. The study aimed to evaluate the right and left lower limb asymmetries in EMG values, the vertical ground reaction force and other parameters concerning the spinal curvature side with scoliosis. The study focused on finding out the extent of the symmetry difference for the study and control group. The study uses 62 subjects, 31 that have a symmetry condition and 31 who do not have the condition and make up the control group. The EMG signals in this study did not differ with the sitting postures, but they found that participants with low erector spinae EMG amplitude had a higher signal amplitude of their psoas major. In this study have identified the use of electromyographic assessment methods to detect pelvic asymmetry, but despite the results, it is still unclear what causes low back pain and which are the best ways to manage the condition. Healthcare professionals may evaluate the electromyographic activity of the trunk muscle for patients who complain about their lumbar region. This assessment method checks the lumbar spine's function [81].

In this study, difference between the EMG signals for healthy subjects were established through the measuring of muscle activity in dynamic, static, and isometric tasks. However, most studies have focused on examining the EMG activity on the back muscle of patients with chronic low back pains who experience significant pain and discomfort during functional movements. However, some people only experience single or recurrent nonspecific low back pains, which may end after a short period. The study aims to evaluate the electromyography activity of erector spinae for the nonspecific low spine pains patients that do not experience pain regularly. The study group for this research was made up of individuals who had experienced any form of low spinal pain while the control group consisted of people who never experienced low back pains. The study used a 2 channels portable microcomputer muscles tester ME 3000 can recorded the EMG from the erector spine muscle. The participants' skins were shaped by alcohol and electrode pairs positioned on the L3 and L4 levels of the erector spinae musculature both right and the left side. The muscle tester used in this study was able to record, amplify, and store the electrical EMG signals, which were later converted to digital signals. The results confirmed what other previous studies. It confirmed that the erector spinae muscle was activated more in patients with low back pains in comparison to healthy people. The hyperactivity is associated with the need to provide more muscular stabilization for back pain individuals in an attempt to control the spine. Evidence shows that hyperactive muscular behavior protects and stiffens the spine. However, if this adaptive mode is maintained for a long time, it could be problematic by causing the superficial trunk muscle to stiffen the spine through increase compression [6].

It is also proposed that people who have more muscular stability of the spine due to the decrease of the back muscle force and the inability to correct perturbations. The unique need is countered by the increase of activity pattern on the superficial lumbar muscles. The findings show that the patients with low back pains are unable to develop trunk muscle force and this impairs their capacity to correct perturbations As a response, the erector spinae muscle becomes hyperactive to overcome the weakness and prevent spinal instability. The results also showed that people with low back pains had a greater level of right and left asymmetry of the erector spinae in comparison to the healthy control group [6].

Sitting can cause the development of low back pain due to the control of the trunk muscles when performing this act. The psoas major muscle and QL muscle enable a person to sit upright by controlling the spinal curvature. Sitting contributes to experiencing low back pain, and individuals with these pins are likely to have a difficult time attempting to adopt neutral lordosis postures. Such people may choose to sit in a lordotic or kyphotic lumbar position due to the difference in their muscle activity, as shown by the EMG signals [112]. The EMG signal amplitude for the erector spinae reduces when asymptomatic people sit in a lumbar flexion or kyphosis position, but it increases when they adopt an extended or lordotic position. Most studies related to the sitting of individuals with low back pain focus on the superficial abdominal and paraspinal muscles, but they do not consider that the QL muscle and psoas major muscles can be affected.

The study uses a different ways to activate the QL muscle and psoas muscles in orders to find out whether these muscles are affected when a person with sitting. The study collected myoelectric signals when the participants were in three different postures. The study found that there was a redistribution of muscle activity in the muscles involved in the possible trunk extension which is an adaptation to pain for people with low back pain. The study concluded that clinical intervention that was aimed at reducing the psoas major and QL muscle activity through stretching, botulinum injections, and manipulation could help such patients. These patients can also benefit from activities that strengthen their QL muscle and psoas major muscles [112, 113].

Another study finds that nonspecific low back pains can lead to increase the erector spinae muscle activity. It concluded that the EMG data of the erector spinae activity full flexion and flexion-relaxation ration could be used to differentiate between non-specific low back pains and healthy people and it can also be used to find the suitable physiotherapy rehabilitation program. The change of the postural strategy seen in individuals with this condition can be caused by various factors which predispose the patient to back problems. These patients can be trained using suitable treatment programs [6].

Sitting extension activities are said to be suitable for strengthening the low back musculature because the use of specialized equipment can help increase resistance progressively. These exercises are reported to activate the low back muscles when the pelvis is systematically stable to ensure the extensions come from the spine and not the hip extensors. The prone lower and upper extremity lifts are also popular rehabilitation exercise programs. These exercises are reported to produce EMG amplitudes in the lumbar multifidus and longissimus thoracic muscles at a range of 29 percent to 45 percent. Side-bending exercise, on the other hand, is said to be perfect rehabilitations exercise due to their production of co-contraction of the low back paraspinal, abdominal muscles, and quadratus lumborum. Side-bending and side bridge were reported to produce EMG signal amplitudes within the range of 32 and 58 percent in a person’s low back muscles. The study also evaluates three bridging exercises which were the supine bridge with the knees flexed and feet on the floor, bridge with feet on the gymnastic ball, a bridge with the shoulders lying on a gymnastic ball. For these three bridging exercises, the EMG signal amplitudes were with the range of 35 and 44 percent The findings in this study can be used by therapists to guide the patient in their spinal pain rehabilitation programs. The therapist can start with exercises that produce low muscle activity, then progress to those that cause more muscle activation. However, it is always important to ensure that the exercises are individualized based on a patient’s needs and capability [4].

LLD has been defined as the existence of a difference between a person's legs that can be classified into mild, severe or moderate. People with this condition are prone to other issues like lower back pain trochanteric bursitis, and hip pain. The conditions can also be experienced by cyclists who endure the repetitive and consistent cycling movements for an extended period. The basis of these injuries is associated with the use of poor techniques, a lot of training, and incorrect bicycle setup. Considering the development of these injuries, the riders can tilt their pelvis in an attempt to compensate for the shorter leg, and this can, in turn, create a difference in the functioning of the hips, legs, ankles, pelvis, and torso. The differences could be as a result of anatomical LLD. A study begins by making various hypotheses. They hypothesize that the existence of functional or true leg length discrepancy can cause mechanical asymmetries and that this would lead to the implementation of compensatory strategies that would equalize these differences and also improve the cyclist's overall efficiency. The study selected seven well-trained cyclists as their participants. The data collection process involved the synchronization of EMG, torque, and digitized video, which was used for the ISO50 test. In this trial, 10 seconds epochs were collected on the 5th, 10th, and 15th minute. The torque analysis evaluated the SRM medical cranks using the SRM ergometer, which was analyzed using the Power Control IV unit. The EMG analysis focused on the Vastuslateralis muscle is primarily used to exert force during cycling and knee extension. The time is taken between pedaling, and the activation of the vastus lateralis muscle was referred to as the down stroke or propulsive phase. Surface electrodes were used to record the EMG activity on both legs. The surface electrodes had a 10mm diameter, and they were 12mm apart. They were placed at a muscle fiber pennation angle, 5cm near the patella's superior lateral border. The participants' skins were shaved to ensure the electrodes had the desired contact and to decrease impedance. The researchers also band-pass filtered the EMG signals between 20 and 48Hz. They were then amplified and converted digital signals at a sampling rate of 1 kHz. The rest of the EMG raw data was changed to RMS and normalized, and it was expressed as a percentage of the highest productive EMG activity [114].

The study also supports previous studies that have reported on the importance of the knee, ankle, and hip in a cyclist's performance. This is supported through the contribution of hip, knee, and ankle flexors and extensors through the flexion and extension movements. The analysis of the digital 2D video of the cyclists in that research identified a continuous difference at the knee, hip, and ankle under various conditions. This analysis together with the knowledge that torque imbalance was approximately 3.6 percent and that the EMG signals of the vastus lateralis were around 6.3 percent shows the increase of total work output of one leg in comparison to the other. Other study before this that have focused on walking instead of cycling have found that the correction of LLD up to 10mm does not always produce favorable results. Some of the reasons for these results is the development of compensatory mechanisms for people with this condition in an attempt to overcome the mechanical differences. It is expected that this would be the same for activities such as cycling [114].

A study aimed to evaluate the myoelectric function of the back's erector spinae muscle to determined if the flexion relation movement occurs when in forward flexion. The data was collected during two flexions extension tasks which required the subjects to stand in full forward flexion and to seat in forward flexion. The study used a computer to record the signal when the subjects took this position. Each subject was given 3 seconds to attain the desired flexed posture and they were required to maintain the position for 10 seconds. The processing of the EMG signals involved digital full waves rectifications following by a butterworth low pass filter to generate a linear envelope. These filter signal was normalized to the highest muscles activity level and then the numbers of sample was reduced to 20.5 Hz with the aim to align the EMG data with the ISOTRAK signals. The 6 points collected were defined in the starting and end of flexion, start and end of the extension, and the end. Ensemble averaging was used to normalize a trial to 100 percent and to align selected movements to eliminate variations that would increase variability by finding the average. The researcher considered the muscle to have reached forward relaxation when standing flexion if the EMG values were around 1 percent of the maximum voluntary contraction when standing up. The erector spinae muscles were reported to very active when in an upright sitting position compared to when a person is in an upright standing position. The use of wavelet analysis involves the use of a wavelet transform which is a mathematical tool used in the local analysis of fast and nonstationary signals [115].

Using the power spectral density to analyze the EMG signals, we found that the right side upper pelvis crista iliac position EMG signals were higher in the right than the left side of the quadratus lumborum muscle. The left side upper pelvis crista iliac position had higher EMG signals on the right side than on the left side of the quadratus lumborum muscle. The relationship between muscular tension and length is important in body biomechanics. The disruption of this relationship causes a postural abnormality in the individual. The differences in the left and right EMG activation are associated with the biomechanical lesion [6].

It is normal for the body to have dominant and non-dominant strength imbalances where the physical muscle properties can be asymmetric in activity patterns and postures. This difference does not only exist in people with low back pains but also in healthy individuals. Not all the neuromuscular imbalances can be attributed to the underlying pathological abnormalities. The unilateral muscular and neuronal adjustments are said to preconditions present in athletes. The alteration of the muscles pattern could be induced by training where right-handed athletes are likely to show significantly lower EMG signal measurement on the erector spinae of their left side and vice versa. As such, the asymmetric trunk loading resembles neuromuscular imbalances that cause the reduction of EMG function patterns on an individual’s nondominant side. It is unclear whether these neuromuscular imbalances low back pains. However, according to, based on degrees of asymmetries observe in people with low back pains, it safe to assume that there are additional elements that contribute to the imbalance of activity patterns for people with low back pain [6, 115].

5. CONCLUSION AND RECOMMENDATIONS

In conclusion, the pelvis is an important structure in the human body that is made up of rings of bones and other innominate bones. The pelvis has various functions like preventing urine incontinence, allowing childbirth in women and supporting the pelvic organs like the urethra and bladder. The pelvis is made up of various bones, ligaments, nerves, and bones all which contribute to ensuring it provides its functions efficiently. Pelvic asymmetry occurs when there is a different biomechanical loading in the lower extremities. Due to these differences, the body attempts to compensate, and this affects other parts like the hips and knees, which can then results in the development of lower back pain. LLD is a condition where one lower limb is longer than the other lower limb, and it affects the hips, back, and sacroiliac. Pelvic asymmetry and LLD can influence the lumbopelvic region, including the QL and lumbar spine, and it can also lead to the development of lower back pain.

The pelvic tilt can occur anteriorly, laterally, and posteriorly. Sometimes the pelvis can be tilted anteriorly or posteriorly, and it can also be rotated in a way that one of the pelvic bones is forward, but the other is not in that direction. This placement is referred to as the lateral pelvic tilt, and it is associated with people with scoliosis or leg length discrepancy. In this form of tilt, a person’s hip may appear higher on one side due to the postural deviation where one side of the pelvis is tilted to the right or left. The diagnosis of this condition requires that the physician notes the lateral pelvic shift and tilt, arm position, the position of the trunk, and identify the non-weight bearing leg [116].

Most pelvis drawings illustrate it as a symmetrical part of the body. However, according to a sduty, the pelvis is neither equal nor symmetric [48]. Symmetry is the arrangement of an object in a way that it can be divided into two parts, and these parts would be mirror images of each other. The asymmetry of the human pelvis is attributed to external factors like biomechanical loading and internal reasons like genetics. Directional asymmetry is said to be a response to loading where the pelvis is subjected to more biomechanical loads that the legs.

Hip instability and asymmetrical pelvic tilt are said to be associated. A medical professional can check the extent of the patient's pelvic tilt by palpating the anterior superior iliac spine and the posterior superior iliac spine. The palpation checks for the segment's attempt to compensate for the asymmetry. In the case where the results show an uncompensated pelvic result, this indicates that the pelvic tilt occurred towards the no-weight bearing side. In the case where it shows a compensated positive test may indicate flexion on the weight-bearing side [116].

Leg length discrepancies can result in each lower extremity bearing a different amount of the load [117]. The skeletal misalignment caused by LLD can change the distribution of the load, and this could affect the distribution of the contact pressure on the nearby joints. According to a study when LLD is found in asymptomatic patients, it is important to inform them that the shorter leg can lead symptoms in the future which need to be corrected. Since LLD is associated with load weight differences for the lower extremities, these differences can cause further dysfunctions in the pelvis, lumbar spine, and sacrum [13].

For people suffering from lower back pain, the QL muscle is said to be overactive, which is expected in a case of nutation lesion that promotes counternutation. It is also said to increase its activity with the increased axial loading on the spine, which in turn causes nutation. It is difficult for investigations to be conducted on the QL muscle using the EMG, and this is attributed to the thickness and the depth of the fascia surrounding this muscle. However, the use of the fine wire EMG shows that the increased axial loading on the spine increases the QL muscle activity [36]. The axial loading causes nutation at the sacroiliac joint. Normally, the sacroiliac joint does not have an overactive counternutation response, but in nutation, the QL muscle, together with other counternutation muscles increase the activity to the extent of stress that induces nutation. The QL muscle is also said to be activated in conjunction with the deep erector spinae, which is a counter-nutator. During these movements, the superficial erector spinae, which is the nutator, does not have a lot of activity. This shows that the QL muscle induces counternutation because it has similar functions as the deep erector spinae Straining the quadratus lumborum is said to lead to chronic pain on a person's lower back. This can be caused by various reasons, including sitting at the desk or a reclined chair that causes the back muscles to weaken over time region [118]. The QL muscle attempts to compensate for the weak muscles, and this can cause the muscle to stiffen, which is painful.

Other conditions that make the pelvis or spine imbalances like the leg length discrepancy can cause the QL muscle to attempt to stabilize the imbalance.

The anterior band of the iliolumbar ligament is said to come from the QL muscle. The iliolumbar ligaments that hinder nutation are formed from the QL muscle fibers and are only considered ligaments after 25 years. The calcification of a ligament is said to be an adaptation to chronic stress, and it suggests that pain causes postural decompensation at its attachments as a result of the gravitational pressure. The quadratus lumborum is said to induce a counternutation effect on the gravitational forces that cause nutation. As such, calcification can be seen to be a result of a long counternutation response to nutation lesion. This would further suggest that the increased occurrence of iliolumbar calcification of people in the society indicates the prevalence of the nutation syndrome even though it is seen as a regular occurrence [36].

The use of the electromyography allows researchers to measure the impact of these conditions on the lumbopelvic region. LLD can lead to changes in the pelvic position and spinal posture. LLD causes a person’s body to compensate in a different way such as tilting the pelvis on the frontal plane, increased plantar flexion of the shorter leg’s ankle, and knee joint and hip extensor flexion on the longer leg. The compensation is an attempt to attain balanced body alignment and reduce the energy spent when walking. The study found that the LLD caused a pelvic tilt and pelvic torsion due to the changes in the coronal and sagittal plane, respectively. There were no significant shifts in the subjects’ trunks, but there are changes in the spine which indicate that more compensation is likely to take place in the pelvis instead of the trunk [18].

Different scholars support the association of LLD to the emergence of low back pain and the misalignment of the lumbar spine, pelvis, and sacrum. Some pelvic asymmetry conditions like having a low iliac crest or pelvic rotations are associated with the leg length discrepancies. Most chiropractors and osteopathic physicians use standing postural radiography to check for symptoms of functional LLD in patients. Asymptomatic people who do have not experienced any trauma or developed structural abnormalities like scoliosis may show LLD symptoms [119]. Such patients are not likely to go for treatments regardless of the development of functional LLD. People who develop functional LLD in an attempt to compensate for their posture may experience chronic pain. This type of LLD can cause musculoskeletal issues due to bearing unequal load [13].

5.1. RECOMMENDATIONS FOR FUTURE RESEARCH

Pelvic asymmetry and/or overactivity/spasm of the QL muscle can cause LLD, which can result in serious injury to the lower extremities and lumbar vertebrae. After standardization of some parameters, our joint methodology may become an essential and irreplaceable test to diagnose and follow up QL muscle activity in clinical populations. Because when functional LLD is found, even in asymptomatic patients, it is very important to advise them that the shorter leg can lead to secondary symptoms in the future which needs to be corrected.

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APPENDICES

Appendix I: Etik Kurul Raporu

T.C. SAĞLIK BAKANLIĞI
BAKIRKÖY DR. SADİ KONUK EĞİTİM VE ARAŞTIRMA HASTANESİ

BAKIRKÖY DR. SADİ KONUK EĞİTİM VE ARAŞTIRMA HASTANESİ

KLİNİK ARAŞTIRMALAR ETİK KURUL DEĞERLENDİRME FORMU

K-Q TSE-ISO-EN 9000

BAŞVURU BİLGİLERİ		
	ARAŞTIRMANIN AÇIK ADI	**Pelvis asimetrisi olan kişilerde Quadratus Lumborum kasından ölçülen EMG'lerin analizi**
	ARAŞTIRMA PROTOKOL KODU	**2015/98**
	KOORDİNATÖR/SORUMLU ARAŞTIRMACI UNVANI/ADI/SOYADI	**Öğr.Gör.Sevim Eryiğit,Prof.Dr.Sadık Kara,Doç.Dr.İlhan Karacan**
	KOORDİNATÖR/SORUMLU ARAŞTIRMACININ UZMANLIK ALANI	**Gelişim Üniversitesi**
	KOORDİNATÖR/SORUMLU ARAŞTIRMACININ BULUNDUĞU MERKEZ	**Gelişim Üniversitesi**
	DESTEKLEYİCİ /DESTEKLEYİCİNİN YASAL TEMSİLCİSİ	**Fatih Üniversitesi**
	PROJE YÜRÜTÜCÜSÜ/UNVANI/ADI/SOYADI (TÜBİTAK vb. gibi kaynaklardan destek alanlar için)	
	ARAŞTIRMANIN FAZI	
	ARAŞTIRMANIN TÜRÜ	Diğer ise belirtiniz: Tanımlayıcı
	ARAŞTIRMAYA KATILAN MERKEZLER	TEK MERKEZ ☐ ÇOK MERKEZLİ ☒ ULUSAL ☐ ULUSLAR ARASI ☐

DEĞERLENDİRİLEN BELGELER	Belge Adı	Tarihi	Versiyon Numarası	Dili
	ARAŞTIRMA PROTOKOLÜ	08.05.2015	1	Türkçe ☒ İngilizce ☐ Diğer ☐
	BİLGİLENDİRİLMİŞ GÖNÜLLÜ OLUR FORMU	08.05.2015	1	Türkçe ☒ İngilizce ☐ Diğer ☐
	OLGU RAPOR FORMU	08.05.2015	1	Türkçe ☒ İngilizce ☐ Diğer ☐
	ARAŞTIRMA BROŞÜRÜ			Türkçe ☐ İngilizce ☐ Diğer ☐

DEĞERLENDİRİLEN DİĞER BELGELER	Belge Adı		Açıklama
	ARAŞTIRMA BÜTÇESİ	☒	Çalışma için Kullanılacak olan EMG Cihaz Kullanım İzni ,Çalışma Dosyasında yer almaktadır.
	DİĞER:	☐	

KARAR BİLGİLERİ		
	Karar No:2015/08/05	**Tarih:11.05.2015**
	Yukarıda bilgileri verilen klinik araştırma başvuru dosyası ile ilgili belgeler araştırmanın gerekçe, amaç, yaklaşım ve yöntemleri dikkate alınarak incelenmiş çalışmanın başvuru dosyasında belirtilen merkezlerde gerçekleştirilmesinde etik ve bilimsel sakınca bulunmadığına **bütçe desteğinin onayının alındıktan sonra çalışmanın başlamasının uygun olduğuna** toplantıya katılan Etik Kurul üye tam sayısının salt çoğunluğu ile karar verilmiştir. Klinik Araştırmalar Hakkında Yönetmelik kapsamında yer alan araştırmalar/çalışmalar için Türkiye İlaç ve Tıbbi Cihaz Kurumu'ndan izin alınması gerekmektedir.	

BEAH KLİNİK ARAŞTIRMALARI ETİK KURULU	
ÇALIŞMA ESASI	Klinik Araştırmalar Hakkında Yönetmelik, İyi Klinik Uygulamaları Kılavuzu
BAŞKANIN UNVANI / ADI / SOYADI:	**Uz. Dr. Gülsüm Oya HERGÜNSEL**

Unvanı/Adı/Soyadı	Uzmanlık Alanı	Kurumu	Cinsiyet		İlişki *		Katılım **		İmza
Uz. Dr. Gülsüm Oya HERGÜNSEL	Anesteziyoloji	BEAH	E ☐	K ☒	E ☐	H ☒	E ☐	H ☐	
Doç. Dr. Sadık Sami HATİPOĞLU	Çocuk Hastalıkları	BEAH	E ☒	K ☐	E ☐	H ☒	E ☑	H ☐	
Prof.Dr. Ayşe KAVAK	Dermatoloji	BEAH	E ☐	K ☒	E ☐	H ☒	E ☑	H ☐	
Prof.Dr. Fatma Tülin KAYHAN	K.B.B.	BEAH	E ☐	K ☒	E ☐	H ☒	E ☐	H ☐	
Doç.Dr. Özlem KAPTANOĞULLARI	İç Hastalıkları	BEAH	E ☐	K ☒	E ☐	H ☒	E ☐	H ☐	
Prof.Dr. Osman KARAKAYA	Kardiyoloji	BEAH	E ☒	K ☐	E ☐	H ☒	E ☑	H ☐	
Uzm. Dr. Asuman GEDİKBAŞI	Biyokimya	BEAH	E ☐	K ☒	E ☐	H ☒	E ☐	H ☐	
Prof.Dr. Ufuk EMEKLİ	Plastik Ve Estetik Cerrahi	İ.Ü.İst. Tıp Fak.	E ☒	K ☐	E ☐	H ☒	E ☐	H ☐	
Prof.Dr. Gülsüm Nurhan İNCE	Halk Sağlığı	İ.Ü.İst. Tıp Fak.	E ☐	K ☒	E ☐	H ☒	E ☐	H ☐	
Uz. Dr. Gülay ÖZGÖN	Farmakolog	İ.Ü.Cerrahpaşa Tıp Fak.	E ☐	K ☒	E ☐	H ☒	E ☐	H ☐	
Prof.Dr.Abdülbaki KUMBASAR	İç Hastalıkları	İ.Ü.İst. Tıp Fak.	E ☒	K ☐	E ☐	H ☒	E ☐	H ☐	
Can ÇELİK	Biyomedikal	Dijimed Bil.Çöz.	E ☒	K ☐	E ☐	H ☒	E ☐	H ☐	
Avukat Özkan TÜM	Hukuk	İst. Sağ. Müd.	E ☒	K ☐	E ☐	H ☒	E ☑	H ☐	
Selim ÖZDEMİR	Eğitim Görevlisi	Şükrü Balcı MYO	E ☒	K ☐	E ☐	H ☒	E ☐	H ☐	

Appendix II: Bilgilendirilmiş Onam Formu

BİLGİLENDİRİLMİŞ GÖNÜLLÜ OLUR FORMU

Çalışmanın Amacı Nedir?

Pelvis asimetrisi olan kişilerde Quadratus Lumborum kasından kaydedilen EMG sinyallerinin analizinin yapılması. Bu çalışmaya dahil edilebilme kriterleri 18-35 yaş arasında olmak, gönüllü olmak, Üniversite öğrencisi olmak.

Ölçüm sahasına rahat kıyafetler giyerek geliniz. Bu ölçümde size EMG ölçümü BİOPAC cihazı ile (yüzeyel elektrotlar ile kas sinyallerinin alınması) ve bacak boyu uzunluk ölçümü mezura ile ölçülecek ve pelvis asimetrisi ise pelvik inclinometer ile değerlendirilecektir. Bu ölçümlerin sağlığınıza herhangi bir yan etkisi yoktur. Erkekseniz ve bel bölgenizde aşırı kıl varsa ölçümlerin objektifliğini sağlamak için bel bölgenizdeki kılları temizlemeniz gerekmektedir. Ölçümlerin süresi yaklaşık bir saattir.

Araştırma ile ilgili olarak yapılan değerlendirmelerde kullanılan ölçüm aletlerinin standartlarına uyulmuştur. Bu koşullara uymadığınız durumlarda araştırıcı sizi uygulama dışı bırakabilme yetkisine sahiptir. Araştırmada yer alacak gönüllülerin sayısı 120'dir.

Bu araştırmada quadratus lumborum kası üzerinden yüzeyel elektrot ile EMG sinyalleri kaydedilecektir. Vücuda herhangi bir uyarı verilmeyecektir. Bu nedenle uygulama ile ilgili gözlenebilecek hiçbir yan etki yoktur.

Araştırmaya bağlı bir zarar söz konusu olduğunda, bu durumun tedavisi sorumlu araştırıcı tarafından yapılacak, ortaya çıkan masraflar Uzm. Fzt. Sevim ERYİĞİT tarafından karşılanacaktır. Uygulama süresince herhangi bir sorun, istenmeyen etki ya da diğer rahatsızlıklarınız için 0505 826 50 21 numaralı telefondan Uzm. Fzt. Sevim Eryiğit'e başvurabilirsiniz.

Yapılacak her tür tetkik, fizik muayene ve diğer araştırma masrafları size veya güvencesi altında bulunduğunuz resmi ya da özel hiçbir kurum veya kuruluşa ödetilmeyecektir.

Bu araştırmaya katılmanız için sizden herhangi bir ücret istenmeyecektir. Çalışmaya katıldığınız için size ek bir ödeme de yapılmayacaktır.

Bu araştırmaya katılımınız tamamen gönüllü olup, katılmanız için herhangi bir zorlamayla karşılaşmayacaksınız. Araştırmada yer almayı reddedebilirsiniz ya da her hangi bir aşamada araştırmadan ayrılabilirsiniz. Elde edilecek kişisel bilgiler kimseyle paylaşılmayacak, tez çalışmasında ise sadece verilerin ortalaması, (kime ait olduğu belirtilmeksizin) maksimum ve minimum değerleri belirtilecektir. Araştırmanın sonuçları bilimsel amaçla kullanılacaktır; çalışmadan çekilmeniz ya da araştırıcı tarafından çıkarılmanız durumunda, sizle ilgili tıbbi veriler de gerekirse bilimsel amaçla kullanılabilecektir.

Çalışmaya Katılma Onayı:

Lütfen aşağıdaki açıklamayı okuyunuz

Bilgilendirilmiş Gönüllü Olur Formundaki tüm açıklamaları okudum. Bana, konusu ve amacı belirtilen araştırma ile ilgili yazılı ve sözlü açıklama, aşağıda adı belirtilen kişi tarafından yapıldı. Araştırmaya gönüllü olarak katıldığımı, istediğim zaman gerekçeli veya gerekçesiz olarak araştırmadan ayrılabileceğimi ve kendi isteğime bakılmaksızın araştırmacı tarafından araştırma dışı bırakılabileceğimi biliyorum. Bu formun imzalı ve tarihli bir kopyası bana verildi.

GÖNÜLLÜNÜN		**İMZASI**
ADI & SOYADI		
ADRESİ		
TEL.		
TARİH		
AÇIKLAMALARI YAPAN ARAŞTIRICININ		**İMZASI**
ADI & SOYADI	**Uzm. Fzt.Sevim Eryiğit**	

Appendix III: Vaka Değerlendirme Formu

VAKA DEĞERLENDİRME FORMU

Adı –Soyadı : **Cinsiyeti:** **Doğum Tarihi:**

Tel. No: **Boy (cm) :** **Kilo (kg):**

Eğitim Düzeyi: **Sigara kullanımı:** **evet ise günde kaç paket ( )**

Medeni Hali: **Alkol kullanımı:**

Meslek: **Dominant El:**

BKİ= Ağırlık (kg) / Boy (m²):

Daha önce geçirilmiş Hastalık:

Kullanılan ilaçlar:

Sağ alt ekstremite Uzunluk Ölçümü (cm)	Sol alt ekstremite Uzunluk Ölçümü (cm)	EMG Ölçüm Değerleri	
Umblicus-Medial Malleol	Umblicus-Medial Malleol	SAĞ	SOL
		Quadratus Lumborum	Quadratus Lumborum
Spina iliaca Anterior Süperior-Medial malleol	Spina iliaca Anterior Süperior-Medial malleol	İstirahat pozisyonunu	Maksimal izometrik kontraksiyon pozisyonu

Manuel Pelvis Ölçümü	Sağ	Sol
Crista iliaca seviyesi	Up ( ) Down ( )	Up ( ) Down ( )
SİPS	Up ( ) Down ( )	Up ( ) Down ( )
SİAS	Up ( ) Down ( )	Up ( ) Down ( )

Pelvic İnclinometer Ölçüm Değerleri	
Sağ	Sol

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Publications
Sevim Eryigit, Abdullah al Kafee, Aydin Akan.Effect of functional leg length inequality on the quadratus lumborum muscle by using EMG signal on asymptomatic population. Int J Clin Exp Med 2018;11(10):10667-10672 www.ijcem.com /ISSN:1940-5901/IJCEM0069500
Sevim Eryiğit, Abdullah Al Kafee, Mustafa Selman Yıldırım and Aydın Akan. Analysis of EMG Signals in the Quadratus Lumborum Muscle of Healthy Subject with Functional Leg Length Discrepancy. Tıp Tekno' 17 Sözel Sunum.

Abdullah Al Kafee, Sevim Eryiğit and Aydın Akan. Electrogastrography in Patients with Diabetic Gastroparesis. Tıp Tekno' 17 Sözel Sunum.

Sevim Eryiğit, Abdullah Al Kafee, Mustafa Selman Yıldırım and Aydın Akan. Analysis of EMG Signals in the Quadratus Lumborum Muscle of Healthy Subject with Functional Leg Length Discrepancy. **IEEE*Xplore*:**25 December 2017 **Accession Number:**17434744 **DOI:**10.1109/TIPTEKNO.2017.8238058.

Abdullah Al Kafee, Sevim Eryiğit and Aydın Akan. Electrogastrography in Patients with Diabetic Gastroparesis. **IEEE*Xplore*:**25 December 2017 **Accession Number:**17434714 **DOI:**10.1109/TIPTEKNO.2017.8238068.