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Posterior Pelvic Tilt in Barbell Back Squats.

A Biomechanical Analysis.

Master thesis in Sport Sciences
Department of Physical Performance
Norwegian School of Sport Sciences, 2015

SUMMARY

Background: The squat is one of the most used exercises in both performance and rehabilitation exercise programs (37). Squatting with a full ROM is beneficial for increasing strength and cross sectional area of the working muscles (3, 32). However, not everyone is able to perform a full range of motion squat without curving his or her back. Trunk flexion, or posterior pelvic tilt, in squat seem to increase shear forces on the lumbar segment, and can potentially increase risk of spinal injury. This study aimed to compare two groups subjectively evaluated to excessive- and no pelvic tilt. Secondly, quantify degree of pelvic tilt, and investigate how different foot positions alter the kinematics of barbell back squats.

Method: Seventy-eight subjects were recruited for a video recording and subjective assessment of posterior pelvic tilt while performing squats. Subjects were then categorized into three groups: excessive-, medium-, and low posterior pelvic tilt. Forty-three subjects from the excessive- and low posterior pelvic tilt group completed a second session, consisting of a 3D motion analysis performing squats in three different foot positions: Narrow stance (NS), Plantar Flexed stance (PFS), and wide & externally rotated (WS).

Results: AUC of 0.670 was found describing the relationship between the subjective assessment and the 3D kinematic analysis of pelvic tilt. Decrease in posterior pelvic tilt and trunk lean angle was found for WS compared to NS ($P < 0.05$) in the mid portion of the squat. Only forward trunk lean was smaller in PFS compared to NS in the mid part of the squat. No differences were found in any of the segments at 90° femur incline between the squat types. PFS & WS allowed the subjects to squat down to femur parallel with ground (~ 60% of subjects) compared to NS (~ 40% of subjects).

Conclusion: We found large variations in pelvic tilt (0-25°) between the 41 subjects. Poor agreement was found between the subjective assessment of pelvic tilt and the objective measures from the 3D analysis. Wide and externally rotated stance significantly reduced pelvic tilt at 70° femur inclination. However, when subjects reached femur parallel to ground no statistical differences between squat types were found. Importantly, squats on a wedge and wide & externally rotated stance allowed more of the subjects to go deeper in the squat compared to Narrow stance.

PREFACE

To all that have contributed, thank you!

Thanks to Tron Krosshaug Ph.D. for thorough guidance, critical and constructive feedback. Kam Ming Mok M.Phil for extensive help in MatLAB, and Senior Engineer Vidar Jacobsen for Biomechanical counseling in the laboratory. Thanks to fellow student Øystein Mjelde Skipenes for cooperation on data collection.

Thanks to all fellow students, for shared joy and frustration. For time spent outside and inside the office the last year. For 5 years of fun, and strenuous hard work in school and in the gym. Great work this far, and good luck with all your future endeavors.

Lastly. To Friends and Family, for being patient in my absence, and at times, my frequent lack of response. Thank you!

Honorable mentions

To Ali, you kept me awake through rough mornings and late nights. To Lady Gray when Ali just wasn't enough. My cup was never empty. To Fredrik for providing Spenol, it keeps all promises, both lasting and effective after long days in the office or lifting weights in the gym. Thank you!

TABLE OF CONTENTS

ABBREVIATIONS

AL	Anatomical landmarks
ASIS	Anterior Superior Iliac Spine
AUC	Area Under Curve
BW	Body Weight
COM	Centre Of Mass
EMG	Electromyography
IAP	Intra Abdominal Pressure
ICC	Intra Class Correlation
n	number of subjects
NS	Narrow Stance
PFS	Plantar Flexed Stance
PSIS	Posterior Superior Iliac Spine
ROC	Receiver Operating Characteristic
ROM	Range Of Motion
SD	Standard Deviation
WS	Wide and externally rotated Stance

1. EXTENDED THEORY & METHOD

1.1 BACKGROUND

The squat is one of the most popular exercises in both performance and rehabilitation exercise programs (37). Several studies have shown that the training effect of squatting is greater when the exercise is performed through its whole range of motion, increasing both strength and the cross sectional area of the working muscles (3, 32). However, not everyone is able to perform a full range of motion squat without curving his or her back. Curving of the back occurs when the pelvis tilts posteriorly in the deeper portion of the squat. Posterior pelvic tilt in a deep squat, especially with external weight, will increase shear-forces on the lumbar spine (35). This can potentially increase the risk of lower back pain (37). An increase in external load in deep squats with 8-160% of body weight has been shown to increase compressive forces 6-10 times body weight (BW) at the L3-L4 spine segment (6). Therefore it is not surprising that the squat exercise has been reported to be the most predominant in terms of injury risk (22). Squats can be performed with different techniques, but in this study we will be investigating the barbell back squat. Few studies have investigated the pelvic-lumbar motion of squat biomechanics (6, 9, 22, 26, 43), but it is often discussed in popular media. Even though popular media have discussed elements of the squat that might be valid, little has been scientifically proven in regard to the posterior pelvic tilt in squats. However, several studies have had a scientific approach to analyzing the squatting movement (1, 13, 15, 23, 27, 28, 42), most of which have investigated change in the lower extremity.

CAUSES OF POSTERIOR PELVIC TILT

Due to lack of scientific investigations of the pelvic-lumbar motion of the squat, it is hard to find scientific arguments why the posterior pelvic tilt motion occurs. Posterior pelvic tilt seems to be a result of lack in hip flexion ROM between the femur and the pelvis. In the descent-phase of squatting, the hip flexes, and at one point the hip flexion reaches its end ROM. For a continued downward translation in the squat, the pelvis has to start rotating posteriorly on the hip joint. In some cases, we cannot exclude that individual motor pattern influences the posterior pelvic tilt. However, the pelvic tilt is also seen in proficient lifters and is usually assumed to be an anatomical restriction.

What causes the end point of ROM is still unclear, however popular beliefs has been proposed such as tight hamstring musculature, tight adductor musculature, weak erector spine or weak abdominal musculature to contribute to the pelvic tilt. Some believe that posterior pelvic tilt occurs as a result of bone-to-bone motion between the femoral head and the pelvis. If this is the case, the degree of posterior pelvic tilt is dependent on the genetically given anatomy for each subject, and cannot be affected. However, changing foot positions may give the hip-pelvis structure the best possible environment for movement when squatting.

Tight hamstring musculature has been proposed as one of the factors influencing pelvic tilt in squat. However, hamstring has shown to be only moderately active when performing squats (37). Because the hamstring function both as a hip extensor and a knee flexor the overall length of the muscle stays fairly constant when squatting (37). Thus, it is unlikely to be a contributor to increased posterior pelvic tilt in squats. Tight adductor musculature has been proposed as a contributor to pelvic tilt as well, but not scientifically proven.

Both weak erector spine- and abdominal musculature has been proposed factors for posterior pelvic tilt. Keeping the back in a neutral position is key to avoid increased shear forces on the spine (9, 37). These shear forces are thought to be the result of upper body weight and the external load. As the upper body flexes, the moment arms increase the shear stress on the spinal segment (9). Therefore, an upright position is advisable when performing externally loaded squats. Squatting with a flexed lumbar spine decreases the moment arms and increases the stress on the erector spinae in order to be able to resist the lumbar flexion (37). If the erector spinae is not able to resist this stress, a lumbar flexion might occur. Weak abdominal musculature will affect the intra abdominal pressure (IAP). McGill, Norman and Sharratt (25) found that increasing IAP, by holding the breath, decreased erector spinae activity when performing squats. The idea is that the IAP acts as a balloon anterior on the spine that doesn’t allow the spine to flex when forces are exerted on the anterior part of the lumbar region (37). With no possibility to test for either IAP or erector spinae strength in the current study, we cannot rule them out as an indirect cause for posterior pelvic tilt.

FOOT ORIENTATION

Some researchers have investigated how squat technique alters stress on muscle and bone structures. Although controversies exist concerning the safety of the heavy loaded squat exercise, proper squatting technique will at least minimize the risk of injuries. Many researchers have investigated knee kinematics and muscle activation in squats (1, 13, 15, 23, 27, 28, 42). Even though it might be, at times, desirable to decrease amount of load on the knees, correcting technique to optimize the environment for the lower back should be emphasized. Fry, Smith and Schilling (13) suggests there might be a trade off between optimal knee-and lower back positions in the deep squat. They tested how restricting forward movement of the knee in the barbell back squat affected torque on the knee and hip. Restricting the knees forward translation led to increased hip extensor moments and decreased knee extensor moments compared to the unrestricted squat. An increase in trunk forward lean was also found when restricting knee motion. The trunk forward lean has been suggested as an undesirable motion due to the increased risk of shear forces in the lower back (35). A study by List, Gulay, Stoop and Lorenzetti (22) found that restricting forward motion of the knee while performing a back squat in both weight bearing, and none weight bearing, increased lumbar flexion. It seems that a more upright position of the back would decrease lumbar load.

A study by Sato, Fortenbaugh and Hydock (36) increased ankle dorsiflexion ROM availability by testing the effect of weightlifting shoes. Weightlifting shoes are specially made shoes, with a higher heel and a stiffer sole than normal running shoes. Weightlifting shoes, compared to running shoes, significantly decreased the amount of forward trunk displacement relative to hip posterior displacement, resulting in decreased forward lean. The shank segment angle was also significantly greater in weightlifting shoes than in running shoes. We might therefore expect a decrease in upper trunk segment angle (less forward lean), a smaller hip flexion angle (relatively less total hip flexion) and an increase in shank segment angle when using a wedge under the heel for increased ankle ROM.

STANCE WIDTH

Foot position can indeed change the environment for the hip and possibly alter degree of forward trunk lean (37). The human body is a kinetic chain with joints dependent on each other. Studies have shown a relationship between the foot and pelvic position in both unilateral and bilateral standing positions, however not while performing squats (18, 33, 41). Change in foot position is often seen between individuals performing squats. Foot position can either be altered in stance width or varying the amount of forefoot rotation. Escamilla, Fleisig, Zheng, Barrentine, Wilk and Andrews (12) reported a preferred squat stance width of approximately 40 ± 8cm, with external rotation of 22 ± 11cm measured from the inside of the feet. Only a few studies have investigated stance widths effect on squat biomechanics, and most of them have investigated EMG activity (1, 12, 24, 31). Only one study found increased hip adductor muscle activation when subjects were performing deep squats (60-90° hip flexion) in wide stance compared to squat in narrow stance (31). Escamilla, Fleisig, Lowry, Barrentine and Andrews (11) found changes in extensor moments over the knee and hip but found no change in trunk lean angle when varying stance width. A smaller forward translation of the knee in wider stance variants was found, and was suggested to lead to less shear force at the knee. Another study done by Almosnino, Kingston and Graham (1) concluded with no clinical applicable change in knee moments between squats with external rotation or wide stance compared to shoulder width stance. The results are therefore not unambiguous. Many trainers do however tell their athletes to both externally rotate their feet and have a wider stance width. It will therefore be interesting to see if foot orientation and stance width will alter the squat kinematics, and finally the degree of posterior pelvic tilt.

In squatting, one always needs to keep the Centre of Mass (COM) above the supporting area of feet to avoid falling. Because most of the mass move posterior on the feet in the descent of a normal squat, it is hard to keep the torso upright and maintain the center of mass above the feet. If one were to change the foot position to gather more of the mass anteriorly on the feet, we believe it would be easier to stay upright with the torso. We believe that externally rotating the feet would theoretically do this by allowing the center of mass still be right above the feet. Since decreasing forward trunk lean might reduce trunk flexion, externally rotated feet may also decrease posterior pelvic tilt.

The degree of posterior pelvic tilt during the squat seems to be very different between individuals. So far, no one has quantified the amount of posterior pelvic tilt that is occurring in barbell back squats, or why this is occurring. This study aims to compare two groups subjectively evaluated to excessive- and low pelvic tilt. Secondly, quantify degree of pelvic tilt, and investigate how different foot positions alter the kinematics of barbell back squats.

1.2 THEORETICAL BASIS OF METHOD

There are several ways to quantify motion in biomechanical research. The method of choice depends, first and foremost, on the research question at hand, but also equipment availability, cost and time parameters. Movement analysis is not free from errors but is in constant development to become as valid and reliable as possible.

MOTION ANALYSIS

Motion analysis can be operated in either two or three dimensions. A 2D motion analysis is usually the simplest and is in need of only one camera. Two dimensional movement analyses usually fit for more simple movements of the extremities, often in the sagittal plane where the movement is limited to flexion and extension. 2D analysis has therefore been used for description of the squatting exercise since it can be viewed as a sagittal plane motion (11, 13, 28, 36). However, 2D motion analysis has also been discussed as a limitation when analyzing squatting kinematics (11, 36), mostly due to the increased restriction in foot positioning when performing squats. 2D motions are therefore in need of greater standardizations and movement restrictions in the data collection to be able to evaluate the data between trials and individuals. Because subjects tend to move a bit out of the sagittal plane when squatting Escamilla, Fleisig, Lowry, Barrentine and Andrews (11) reported of greater kinematic errors in 2D compared to 3D motion analysis.

3D motion analysis is a popular tool in biomechanical research describing joint motion in functional activities. This tool is used in research and in clinical settings and can be applied to large multi-plane movements. 3D motion analysis is most often applied to understand biomechanics of gait and running. Such analyses can be time consuming, but also a helpful tool to describe movement dysfunction in patients or for research purposes. There are different methods for the use of 3D motion analysis. Some researchers have used magnetic tracking devices to capture joint relative movement (26, 27), others use stereo photogrammetry with the use of simple video cameras that are synchronized with each other (11). One of the most commonly used methods of stereo photogrammetry, use markers that reflect infrared light emitted from the cameras (22, 23). Such reflective markers can either be attached directly on the skin or nailed into the bone of the subject. Bone pin markers are more accurate, but also more invasive and cannot always be applied in human motion research, especially in the spinal segment. Surface skin markers are therefore most applicable when looking at whole body motions such as the squat. However, because the markers lie outside of the skin, they are not demonstrating the true bone motion. Therefore, skin tissue artifacts have been reported to be the most critical source of error is kinematic research (4). The use of markers does often require ad hoc programming to extract the kinematic data needed to describe joint movement and accelerations, making it time consuming. Reliability of marker-based stereo photogrammetry has previously been challenged (5, 14). Only the sagittal plane motion of flexion and extension has been proven reliable (34, 40).

HIP JOINT KINEMATICS

An important factor for joint kinematics is the definition of Hip Joint Center (HJC). Accurately defining HJC is important when analyzing movement including hip joint and lower extremities (38). HJC can be defined using two different methods: the predictive method (2) and the functional method (20). The predictive method is based on a series of regression equations. These equations, estimate the coordinate of the HJC as a function of anthropometric quantities. The anthropometrics or main anatomical landmarks (AL) used for the predictive equations are the position of the Anterior Superior Iliac Spine (ASIS) and Posterior Superior Iliac Spine (PSIS). In addition, the use of trochanter major, femoral lateral epicondyle or even pubic symphysis has been suggested to increase accuracy to the equations (30). However, the latter AL is not applicable for use in a human movement setting, for obvious reasons.

For the functional method, a set of singular plane movement has to be conducted for each subject to define a geometric sphere for the femoral head on the pelvis. The functional method seems to be slightly more accurate than any other predictive method, but is in need of extra functional calibration trials (17). These calibrations can be conducted by subjects having adequate hip ROM, corresponding to 60° sagittal plane flexion- extension and 40° abduction- adduction. This can become a problem for those subjects restricted to less ROM (17). The ISB recommends the functional method for calculating the HJC (45). However, due to the extra effort required in conducting and calculating the calibration trials, it is doubtful whether it is worth using the functional methods when it is just slightly more accurate than the best predictive methods. The prediction method proposed by Bell, Pedersen and Brand (2) was reported to have an accuracy within 1.9cm (SD ±1.2 cm) from the true value of HJC. Harrington, Zavatsky, Lawson, Yuan and Theologis (16) suggested an additional method for predicting HJC and reported of a higher accuracy than in previous methods. With the use of pelvic depth, pelvic width and leg length an improvement of 7mm accuracy was reported (16).

ARTICLE

2. ABSTRACT

Background: Trunk flexion and posterior pelvic tilt in squat seem to increase shear forces on the lumbar segment, and can potentially increase risk of spinal injury. This study aimed to compare two groups subjectively evaluated to excessive- and no pelvic tilt. Secondly, quantify degree of pelvic tilt, and investigate how different foot positions alter the kinematics of barbell back squats. **Method:** Seventy-eight subjects were recruited for a subjective assessment of posterior pelvic tilt while performing squats. Subjects were then categorized into three groups: excessive-, medium-, and low posterior pelvic tilt. Forty-three subjects from the excessive- and low posterior pelvic tilt group completed a second session, consisting of a 3D motion analysis performing squats in three different foot positions: Narrow stance (NS), Plantar Flexed stance (PFS), and wide & externally rotated (WS). **Results:** AUC of 0.670 was found describing the relationship between the subjective assessment and the 3D kinematic analysis of pelvic tilt. Decrease in posterior pelvic tilt and trunk lean angle was found for WS compared to NS ($P < 0.05$) in the mid portion of the squat. Only forward trunk lean was smaller in PFS compared to NS in the mid part of the squat. No differences were found in any of the segments at 90° femur incline between the squat types. PFS & WS allowed the subjects to squat down to femur parallel with ground (~ 60% of subjects) compared to NS (~ 40% of subjects). **Conclusion:** We found large variations in pelvic tilt (0-25°) between the 41 subjects. Poor agreement was found between the subjective assessment of pelvic tilt and the objective measures from the 3D analysis. Wide and externally rotated stance significantly reduced pelvic tilt at 70° femur inclination. However, when subjects reached femur parallel to ground no statistical differences between squat types were found. Importantly, squats on a wedge and wide & externally rotated stance allowed more of the subjects to go deeper in the squat compared to Narrow stance.

Key Words squat, posterior pelvic tilt, kinematics, range of motion, foot position

3. INTRODUCTION

The squat is one of the most used exercises in both performance and rehabilitation exercise programs (37). Several studies have shown that training effect of squatting is greater when the exercise is performed through its whole range of motion, increasing both strength and cross sectional area of the working muscles (3, 32). However, not everyone is able to perform a full range of motion squat without curving his or her back. Curving of the back occurs when the pelvis posteriorly rotates in the deeper portion of the squat. Posterior pelvic tilt in a deep squat, especially with external weight, will increase shear-forces on the lumbar spine (35) and can potentially increase the risk of lower back pain (37). Controversy exists concerning the safety of the heavy loaded squat exercise. The increase in external load, of 8-160% of body weight, in deep squats have been reported to increase compressive forces 6-10 times body weight (BW) at the L3-L4 spine segment (6). Therefore, it is not surprising that the squat exercise has been reported to be the most predominant in terms of injury risk (22). Different techniques are used for performing the squat exercise. However, in this study we will be looking at the high barbell back squat.

Several studies have investigated how foot positions alter biomechanics of the squat. Results indicate that both a wider stance width and increased dorsiflexion ROM can change the squat kinematics (13, 22). Alterations in foot position may be beneficial for decreasing stress on lower spine segments in a squat, but at the same time might also be increasing stress on the knee structure (11, 13, 37). One study found increased adductor myoelectric activity when performing deep squats (60-90° hip flexion) in wide stance compared to narrow stance (31). Almosnino, Kingston and Graham (1) however, found no clinical applicable change for knee kinematics between squats with external rotation or wide stance compared to shoulder width stance in body weight squats. This indicates that the results are not unambiguous.

There are not many studies that have investigated what happens in the pelvis and the lower back in squats (13, 22, 26, 36). Of those studies, some have suggested, the forward trunk lean as the main factor for increased lumbar-spine shear forces in the lower portion of the squat (13, 22). The remaining studies, including one of the latter, found that restricting knee anterior translation also increased the demands for motion around the hips and lower back (22, 26, 36). We therefore expect a decrease in forward trunk lean when using a wedge under the heel for increased ankle dorsiflexion range of motion (ROM). No one has previously investigated foot external rotations effect on pelvic tilt and forward trunk lean.

So far, no one has investigated what causes posterior pelvic tilt to occur when squatting. At one point, in the deeper portion of the squat, the hip flexion reaches its end ROM making the pelvis posteriorly rotate. What causes the hip flexion ROM to end is often discussed in popular media, but hasn't yet been investigated with a scientific approach. Popular assumptions have been made proposing tight hamstring musculature, tight adductor musculature, and weak erector spine- or abdominal musculature to be the cause of pelvic tilt. Another popular assumption is that a bone-to-bone motion occurs between the femoral head and the pelvis, forcing a posterior rotation of the pelvis. If the latter one is correct, posterior pelvic tilt is a result of our given anatomy and little can be done improving pelvic tilt. Foot position however might have the ability to quickly improve the environment for the hip-pelvis complex to decrease degree of pelvic tilt.

The degree of posterior pelvic tilt when performing squat seems to be very different between individuals. So far, no one has quantified the amount of posterior pelvic tilt that occurs in barbell squats, and why this is occurring. Understanding why posterior pelvic tilt occurs in squats lets the athletes and trainers optimize technique for the best possible performance and reduce risk of injury. This study aims to compare two groups subjectively evaluated to excessive- and low pelvic tilt. Secondly, quantify degree of pelvic tilt, and investigate how three different foot positions alter the kinematics of barbell back squats.

4. METHOD

4.1 STUDY DESIGN

In this cross sectional study, of young males performing squats, posterior pelvic tilt was quantified by 3D motion analysis. The test subjects attended for one or two sessions. The first session contained a simple subjective assessment where two examiners evaluated onset of posterior pelvic tilt in the barbell squat. They were categorized into three different groups: excessive pelvic tilt, medium pelvic tilt, and low degree of pelvic tilt. For the second session, only subjects from the excessive pelvic tilt- and low degree of pelvic tilt group were invited to conduct a 3D motion analysis while performing three different squat types.

4.2 SUBJECTS

For the subjective assessment 78 healthy men, 18-40 years old, familiar with the squat exercise volunteered for the study. Students and employees were recruited from the Norwegian School of Sport Sciences, Oslo College University and Oslo Police Academy. We informed the subjects of the experimental risks, and obtained written consent under the guidelines provided by the regional ethics committee. The study was reviewed by the South East Regional committee for medical and health research ethics, and judged to fall outside of their scope.

Based on the subjective assessment 47 of the 78 subjects (mean ± SD; age = 24.9 ± 3.7 years; body mass = 81.2 ± 9.6kg; height= 181 ± 5.6cm) were asked to come in for the second session due to their excessive, or lack of, pelvic tilt during the squat. 44 of the 47 subjects asked, met for the motion analysis. This left three drop- outs because of injuries sustained in between sessions, and unrelated to the study.

4.3 VISUAL ASSESSMENT

The first session included a simple video recording of the subjects performing barbell squats (20kg). The subjects were recorded from a side view while conducting squats, because the posterior pelvic tilt mainly is a sagittal plane motion. A DSLR camera (Nikon

D7000, Nikon Corp, Japan) was used for the video recording (50Hz), and was placed 5m from where the subjects squatted. Degree of pelvic tilt was then decided by an assessment of the video recordings. The subjects also completed a questionnaire regarding their previous training habits and injury history. The questionnaire aimed to give an overview of how long, and how often the subjects performed strength training prior to the motion analysis. How often the squat exercise was included in their exercise regime, if they had any pain related to exercise, and when and how the onset of this pain occurred was also of interest. This was done to exclude those who did not regularly exercise, or those who had injuries. The subjects were required to have performed strength exercise, in general, at least once per week in the last two years. They also needed to be able to squat with 75% of body weight (BW) as external weight without pain. For both sessions, the barbell and weights, was equipment from Eleiko (Eleiko Sport, Chicago, IL, USA).

Prior to the data collection the examiners calibrated their evaluation criteria by evaluating posterior pelvic tilt in a pilot of ten voluntary women. They performed light loaded barbell squats similar to the men’s first session. Women were recruited for the pilot to avoid limiting the availability of male participants for this study. The examiners evaluation criteria were based on when posterior pelvic tilt occurred in the squat and if the subjects were able to squat down to the depth of horizontal femur. The subjects were subjectively selected into three different groups: excessive pelvic tilt, medium pelvic tilt and low degree of pelvic tilt. Subjects with posterior pelvic tilt occurring early in the squat, between ≈ 50-70° femur inclination were selected to the excessive pelvic tilt group. Subjects with no obvious posterior pelvic at 90° of femur inclination was put in the low degree of pelvic tilt group. The rest of the subjects were put into the medium pelvic tilt group. Test subjects that were considered to have medium degree of pelvic tilt were not asked to attend for further scrutiny and were disregarded from the study. This was done for subsequent evaluation of the two extremes of posterior pelvic tilt. In the subjective selection of the subjects, the examiners, independent of each other, examined the video recordings and selected the groups. In this selection the examiners agreed upon 78% (61 test subjects) that were directly put into the respective groups. In the cases where the examiners disagreed (22% or

16 test subjects), they watched the recordings together and came to an agreement, or called upon an additional independent examiner to solve the matter (4% or 1 test subject).

The squats were conducted barefoot with 50 cm stance width, and no internal or external rotation of the foot allowed. However, the 50 cm was measured from the lateral side of the Cuboid bone on the left foot to the lateral side of Cuboid bone on the right foot, and not between the inside of the feet. The most lateral part of the Calcaneus and the lateral part of the Cuboid bone was used to indicate foot transverse plane rotation. Premeasured adhesive tape was put on the floor for the subjects to stand on. When the lateral part of the Calcaneus and the Cuboid bone was aligned with the adhesive tape there was no internal or external rotation of the foot. Three repetitions of squats were conducted for each trial with the barbell (20 kg) as external load on the shoulders. A test leader approved the trial when the subject reached the depth of femur parallel to the ground, but did not give any feedback regarding degree of posterior pelvic tilt or technique of the squat.

4.4 3D MOTION ANALYSIS

3D motion analysis was used to quantify segment motion in the different squats. Upon arrival weight and height were measured, and reflective skin markers were attached to the subjects. Thirty-five reflective skin markers were placed on the subjects' anatomical landmarks (*table 1 & figure 1*) according to Kristianslund, Krosshaug and van den Bogert (19). Additionally we added markers placed on the most lateral part of the Iliac Crests, which was used to reconstruct the ASIS markers in the deepest squatting position, where markers often are covered by soft tissue. An infrared-based motion analysis system with 10 Oqus 4 cameras (Qualisys, AB, Gothenburg, Sweden) was used to capture movement of the 9mm reflective markers at 480 Hz with an exposure time of 150µm. The calibration for this setup was done with a 0.75m wide calibration wand over an area of approximately 15m^3 (3m long, 2.5m wide and x 2m high). Motion data was directly exported into Qualisys track manager software (Qualisys AB, Gothenburg, Sweden).

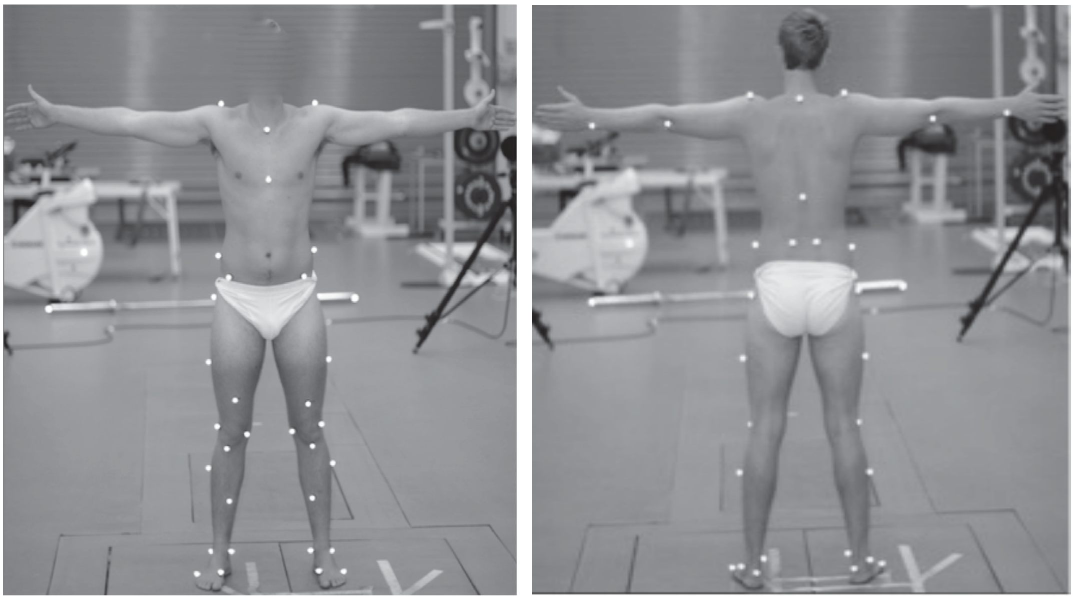

Figure 1: *Shows marker placement for anterior (left) posterior (Right) view.*

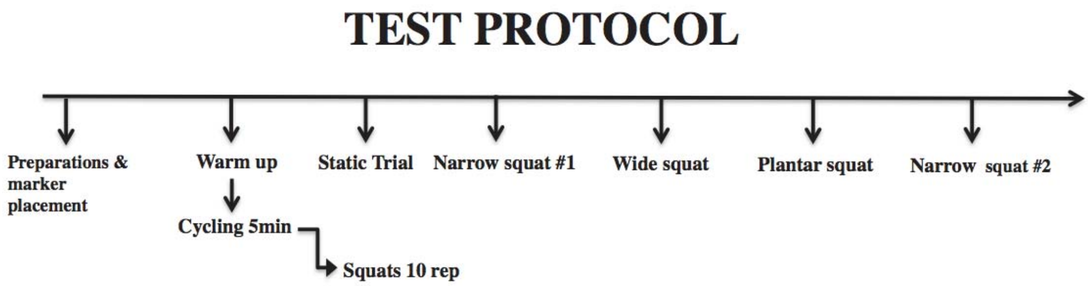

Figure 2: *Displays the test protocol in the chronological order*.

A standard warm-up protocol was conducted with 5 minutes of cycling on an ergometer cycle with low resistance (1-2Kpa) in a self-selected pace. Additionally, ten repetitions of squats with the barbell (20kg) as external load were performed (*figure 2*). The subjects conducted a static trial (ST) before conducting four series of squats in three different foot positions: Narrow stance squat (NS), Wide stance squat with external rotation (WS), and squat on a wedge (PFS); increasing the Plantar Flexion in the ankle joint (*figure 3*).

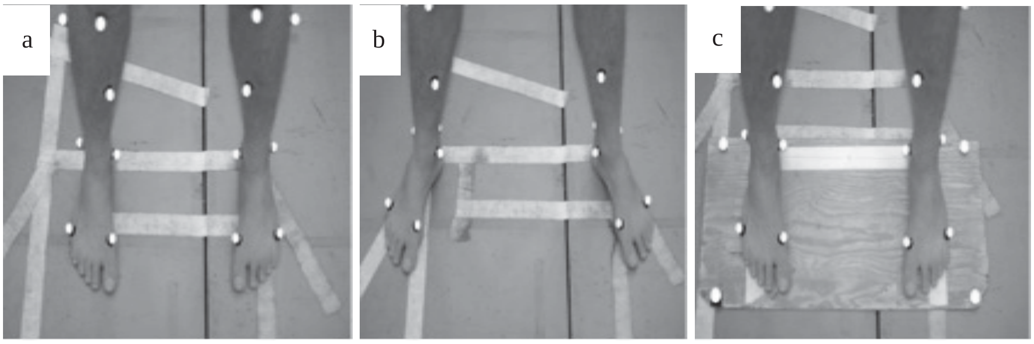

Figure 3**:** *a (left) displays foot position for narrow squat (NS), b (middle) displays foot position for wide stance with external rotation (WS), and c (Right) displays foot position for increased plantar flexion on a wedge (PFS).*

All the squats were conducted barefoot with 75% of body weight as external load with a barbell on their shoulders. The subjects were instructed to keep their heels touching the ground when performing the squats. NS (*Figure 3a*) was standardized to 40cm between the lateral part of the Calcaneus and Cuboid bone on both feet, with no internal or external rotation of the foot. Premeasured adhesive tape was placed on the floor for the subject to stand on. The test leader made sure the direction from the lateral part of Calcaneus to the Cuboid bone aligned with the adhesive tape on the floor before conducting the squat. The subjects were told to perform at least three squats. The NS was conducted twice; once right after ST, and a second time after all the other squat series (*Figure 2*). This was done to check if the repeated series of squats affected the squat kinematics. WS (*Figure 3b*) was standardized to 50cm between lateral side of the calcaneus on both feet, and outwardly rotated 30° measured from the Cuboid bone relative to the calcaneal position on both feet. PFS was standardized the same way as NS, but on a wedge with an inclination of 7.5 ° (*figure 3c*).

4.5 DATA PROCESSING & BIOMECHANICAL MODEL

Test subjects had to complete at least one successful trial of all the squat types to be included in the statistical analysis. Three squats, per squat type, for each subject was used for data processing. Trajectories were further tracked and labeled in Qualisys before exported to Matlab (MathWorksInc. Natick, MA, USA). A smoothing spline with a cut off frequency of 15Hz was used to process the trajectory data (44).

	Segments					
	Foot	**Shank**	**Thigh**	**Pelvis**	**Lower back**	**Upper Trunk**
Markers	Med. toe	Ant. shank	Lat. Femur epicondyle	PSIS	Back	Shoulders
	Lat. toe	Lat. shank	Ant. thigh	ASIS	PSIS	C7
	Lat. Malleolus	Tibial tuberosity	Lat. thigh	Iliac Crest		Back
	Heel		Major Trochanter			

Table 1: *Displays the markers used for construction of each segment.*

* Lat = Lateral; Med = Medial; Ant = Anterior; ASIS = Anterior Superior Iliac Spine; PSIS = Posterior Inferior Iliac Spine.

Trajectory gap fill was accepted for less than 20 frames at times where trajectory was found missing. Segments were then constructed in Matlab for feet, shanks, femurs, pelvis, back and upper trunk respectively (*Table 1*), as described recently in Kristianslund, Krosshaug and van den Bogert (19). Hip joint center (HJC) was calculated using the method proposed by Bell, Pedersen and Brand (2). For ankle & knee joint centers we used mid-part of the two malleolus, and mid-part between the epicondyles respectively (8, 10). Anatomical coordinate systems were created from the static trial. Vertical axis was defined as the direction from the distal joint center to the proximal joint center. The anterior-posterior axis was defined perpendicular to the vertical axis, in the purely sagittal plane of the subject. The third axis was constructed as the cross product of these two, creating the medio-lateral axis (19). Singular value decomposition was used to find the segment positions even when markers were briefly undetectable for the cameras during the dynamic squats (39). A custom script in Matlab was used for the calculation of kinematic data. Pelvic tilt was calculated as pelvic angle minus the upper trunk angle. The femur inclination was defined as 90° when the vertical axis of the femur was horizontal. Typically, maximal anterior tilt was seen at approximately 30° femur inclination. To account for this pre-pelvic rotation, degree of pelvic tilt ROM was displayed from an offset at 30° femur inclination. Because surprisingly few of the subjects actually reached the depth of 90° femur inclination, pelvic tilt ROM data was extracted between 30-70°, 80° and 90° of femur inclination. The shank angle (α1), hip flexion angle (α3) and upper trunk segment angle (α5) was set to 0° when vertical in reference to the room (*figure 4*). The pelvis segment (α4) and femur incline (α2) was set to 0° when horizontal. Pelvic tilt (α6) was the result of upper trunk segment (α5) minus pelvis incline angle (α4).

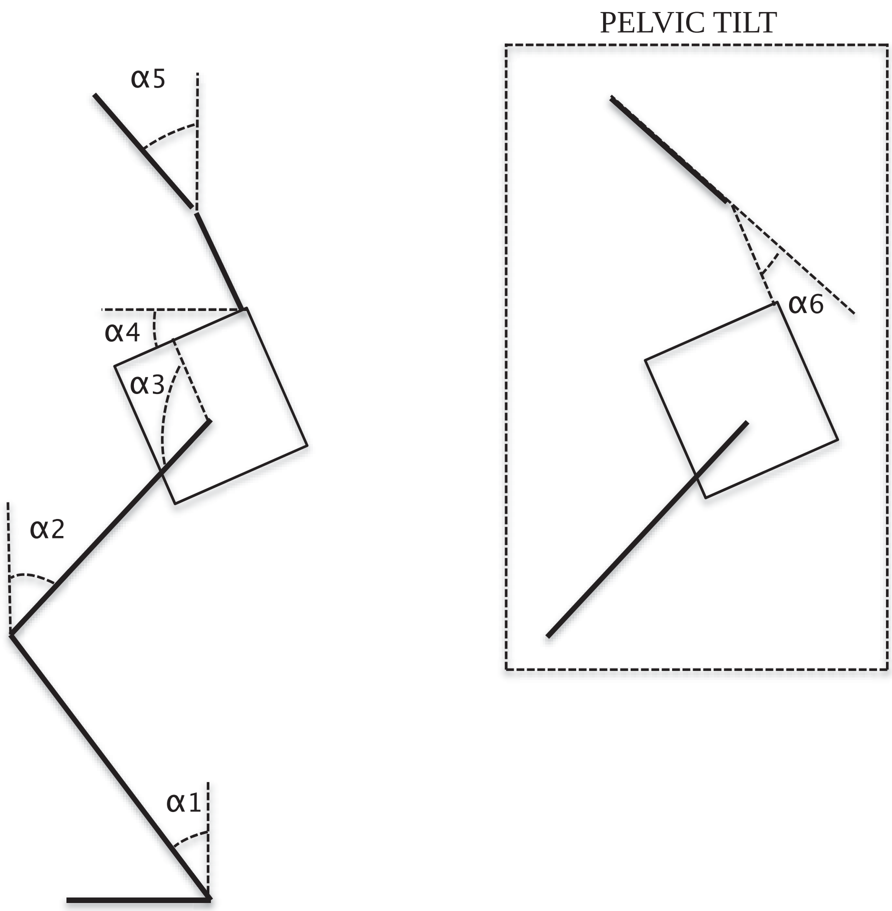

Figure 4: Displays segment angle design for all segments (left): *α1= Shank incline*, *α2= femur incline, α3= hip flexion angle, α4= pelvis incline, α5=upper trunk. Pelvic tilt angle calculation (α6) (Right): upper trunk (α5) minus pelvis incline (α4)*

4.6 STATISTICAL ANALYSIS

Statistical analysis was performed in SPSS 21 (SPSS Inc., Chicago, IL, USA). Graphical display was developed in Excel 14 (Microsoft Co, Redmond, WA, USA) and Prism 6 (GraphPad Software Inc., La Jolla, CA, USA). All descriptive statistics are given as mean and standard deviation (SD).

We conducted a ROC analysis to describe the relationship between the subjective evaluation of pelvic tilt and the kinematic results from the motion analysis. The ROC analysis explains how well the subjective assessment predicts the results from the motion analysis. Results of the ROC analysis were given as Area Under the Curve (AUC) with 95% CI. An AUC value of 0.5 shows no apparent distributional difference. An AUC value of 1.0 shows perfect separation of the test values, indicating that the subjective assessment perfectly predicts results from the motion analysis. AUC value of 0.6-0.7 is usually considered as poor, 0.7-0.8 is considered as fair, and 0.8-0.9 as good accuracy. The data used for the ROC analysis was the Pelvic tilt ROM at 30-70° femur inclination. For the same data, an independent t-test was conducted to compare the mean of the groups.

ANOVA with Bonferroni correction was applied to compare all segment motion in the different squat types. An α level of <0.05 was considered statistically significant for all the statistical tests, and Cohen´s d was given for pelvic tilt measures. Repeatability was shown as ICC with 95% CI for the three squats with-in the first NS, and between first and second NS.

All but one subject completed the second session. The subject felt discomfort in deep squats in narrow stance and was therefore disregarded from the results. Data from 43 subjects was therefore collected from the 3D motion analysis. Due to gaps in marker trajectories and one failed recording, data from 41 subjects, out of the 43 tested, were used for statistical analysis.

5. RESULTS

BETWEEN LOW & EXCESSIVE PELVIC TILT

The relationship between the subjective assessment and the 3D motion analysis is described by the results from the ROC analysis. An AUC of 0.670 (0.611-0.707) was found, indicating poor test sensitivity.

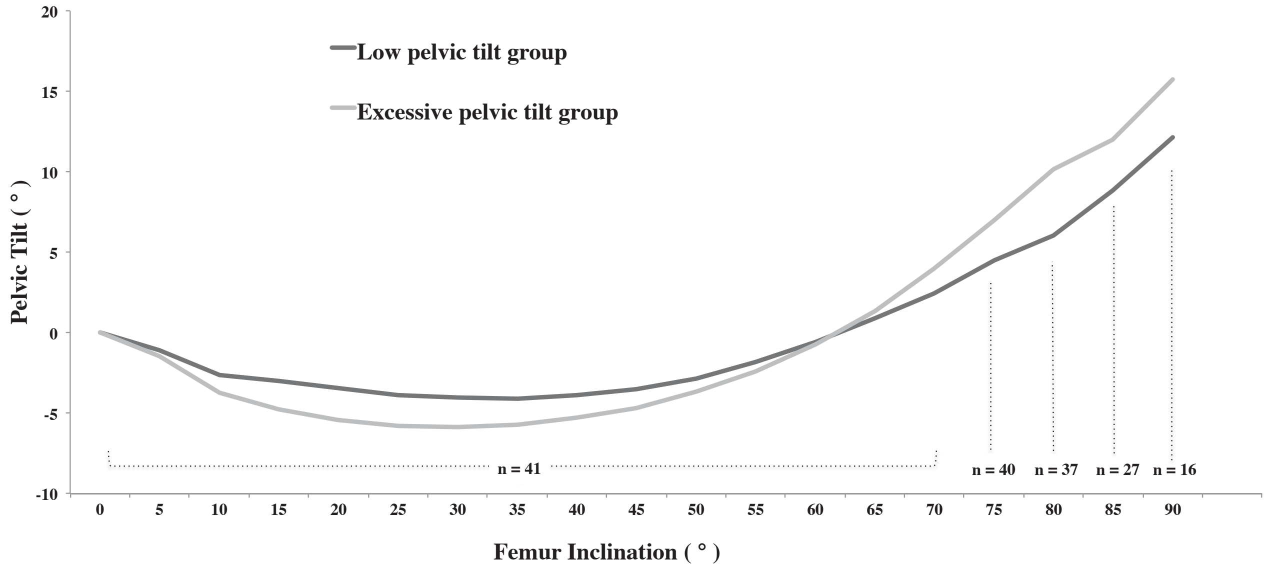

***Figure 5**: Shows the mean pelvic tilt values and the number of subjects (n) able to go down in a deep narrow squat at various intervals between the excessive pelvic tilt and low pelvic tilt group.*

Figure 5 shows pelvic tilt motion in the descent phase of the NS squat for the low pelvic tilt and the excessive pelvic tilt group, and the number of subjects (n) that reached various interval depths between 0-90° femur inclination. Maximum anterior pelvic tilt was usually found around 30° femur inclination. Therefore, individual results for pelvic tilt ROM with 30° femur inclination as offset, was reported to compare the different squat types (*table 2*).

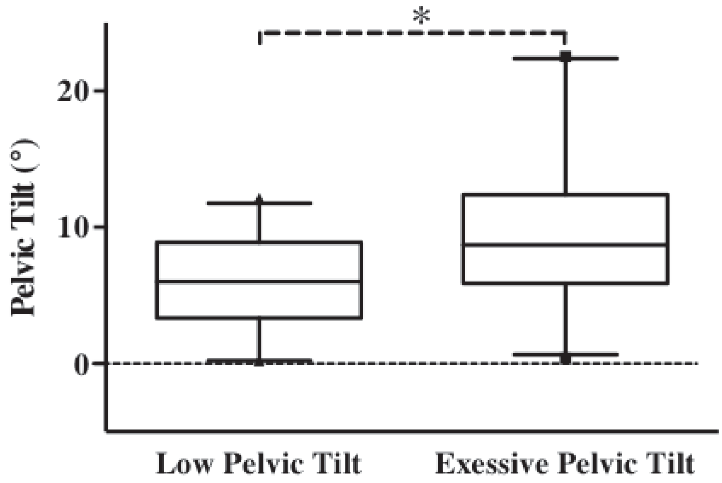

Figure 6: *The box plot displays the median, 1 & 3-quartile distribution (whiskers at 2 & 98 percentile) for pelvic tilt ROM in narrow squat, between the two groups selected in the subjective assessment. ROM was set as 30-70° femur inclination.*
********Significant differences between groups.*

An independent t-test revealed significant differences with a good effect size (*P < 0.05, Cohen's d = 0.891*) between the subjectively assessed low and excessive- pelvic tilt group (*figure 6)*. Large between-subject variations in pelvic tilt ranged from 0-25°.

SQUAT TYPES

Descriptive data for all segments, in all squat types, extracted at 70°, 80° and 90° femur inclination are shown in *table 3*. No statistical difference was found in pelvic tilt between the squat types in any femur depth for absolute values.

ANOVA revealed significant differences with a moderate effect size in pelvic tilt ROM at 70° femur inclination between WS & NS ($p < 0.01$, *Cohen's d* = 0.513). Significant differences were also found between WS & PFS ($p < 0.01$, *Cohen's d* = 0.798) in 80° femur inclination, favoring WS in both cases (*table 2*). No difference in pelvic tilt ROM was found between NS & PFS (*p = 0.65).* At 90° femur inclination, no differences in pelvic tilt ROM was found between squat types.

A moderate ICC of 0.771 (0.611-0.872) was found for with-in the first NS squat, and a high ICC of 0.900 (0.810-0 .948) was found between the mean of first and second NS trial. Therefore, data from the first NS trial will be used to compare with WS & PFS squat kinematics.

Table 3 shows that pelvic inclination angle was significantly reduced in both PFS & WS at 70° femur inclination compared to NS. Hip flexion angle significantly decreased in PFS compared to NS. Hip flexion did also significantly decrease in WS compared to both NS and PFS at 70° femur inclination. Upper trunk segment angle also showed a significant decrease in PFS & WS compared to NS at 70° femur inclination. No change in shank segment angle was found between the squats in any of the squat depths.

At 90° femur inclination no differences were found in any segment between the squat types. For NS squat, only 39% of the test subjects were able to squat down to the depth of femur being horizontal. 58% of the subjects reached horizontal femur depth when foot position was set to PFS. When foot position was changed to WS, 64% of the test subjects reached horizontal (*table 3*).

Table 2: *Pelvic tilt ROM values from an offset of 30° femur inclination for Narrow stance, Plantar Flexed & Wide stance squat. n is the number of subjects able to squat down to this depth.*

Pelvic tilt ROM values in different squat types †

	Narrow			**Plantar Flexed**			**Wide**			**Significant differences**		
Femur incline	n=41 **70°**	n=26 **80°**	n=15 **90°**	n=41 **70°**	n=39 **80°**	n=24 **90°**	n=41 **70°**	n=40 **80°**	n=26 **90°**	**70°**	**80°**	**90°**
Pelvic tilt ° ROM	7.9 ± 4.8	12.6 ± 6.2	15.6 ± 5.1	9.3 ± 4.7	11.6 ± 5.6	17.2 ± 6.6	5.5 ± 4.8	9.5 ± 5.3	14.8 ± 6.0	*b	*b,c	

† = Results are given as mean ± SD

* Significant differences (*P < 0.05*)

a Plantar Flexed vs Narrow; b Wide vs Narrow; c Wide vs Plantar Flexed

Table 3: *Absolute values for all segments extracted at 70°, 80° and 90° femur inclination for all squat types. n is the number of subjects able to squat down to this depth. Shank, pelvis and upper trunk are segment angles. Hip flexion and pelvic tilt are joint angles.*

Segment absolute values in different squat types †

	Narrow			**Plantar Flexed**			**Wide**			**Significant differences**		
Femur incline	n=41 **70°**	n=27 **80°**	n=15 **90°**	n=41 **70°**	n=39 **80°**	n=24 **90°**	n=41 **70°**	n=40 **80°**	n=26 **90°**	**70°**	**80°**	**90°**
Shank °	32.8 ± 3.5	33.6 ± 3.6	34.1 ± 3.1	33.3 ± 4.7	34.3 ± 3.4	34.4 ± 3.7	32.8 ± 3.3	33.5 ± 3.2	33.2 ± 3.1			
Pelvis °	53.1 ± 5.7	49.3 ± 5.5	44.7 ± 3.9	49.5 ± 7.1	47.5 ± 5.6	43.6 ± 5.3	50.1 ± 5.3	47.9 ± 5.3	44.0 ± 5.5	*****a,b	*a,b	
Upper Trunk °	43.7 ± 8.4	44.9 ± 9.3	43.1 ± 9.1	40.1 ± 8.0	42.4 ± 7.6	44.0 ± 9.3	38.9 ± 7.2	40.5 ± 7.5	41.7 ± 9.5	*a,b	*b	
Hip flexion °	122.3 ± 5.8	129.1 ± 5.5	134.2 ± 3.9	119.1 ± 5.6	126.7 ± 5.3	133.1 ± 5.3	117.3 ± 5.3	126.1 ± 5.3	133.5 ± 5.5	*****a,b,c	*a,b	
Pelvic tilt °	-9.3 ± 7.1	-4.8 ± 8.3	-1.7 ± 8.6	-9.4 ± 6.9	-5.1 ± 7.4	0.4 ± 8.1	-11.2 ± 7.0	-7.3 ± 7.4	-2.3 ± 8.0			

† = Results are given as mean ± SD

* Significant differences (*P < 0.05)*

a Plantar Flexed vs Narrow; b Wide vs Narrow; c Wide vs Plantar Flexed

6. DISCUSSION

The aim of this study was to identify and quantify the occurrence of posterior pelvic tilt in deep a barbell back squat. No scientific studies have previously looked at posterior pelvic tilt in loaded barbell squat kinematics, and how this changes with different foot positions. A deeper understanding of squat kinematics, and why pelvic tilt is occurring would help trainers give the best advice for performance and injury-free training for their athletes. The first objective of this investigation was to compare the results from a subjective assessment of the video recordings, with a 3D motion analysis of pelvic tilt in squats. We were surprised to find a poor AUC, describing our inability to subjectively predict the results of the 3D motion analysis for each subject. An independent t-test showed significant difference for pelvic tilt ROM between the low and excessive pelvic tilt group. However, there was a large overlap in distribution of pelvic tilt ROM between the two groups (*figure 6*). Statistical analysis was therefore grouped into one dataset for testing the second aim of this study. The second objective of this study was to investigate how different foot positions altered pelvic tilt in a deep squat. As expected, a significant decrease in pelvic tilt ROM was found between WS squat compared to NS in 70° femur inclination. We also found a significant decrease in WS compared to both PFS & NS squat at pelvic tilt ROM for 80° femur inclination (table 2). We further expected the changes found in 70° & 80° femur incline to become greater at 90° femur incline. At 90° femur inclination however, no changes were found between squat types in any of the segments. Previous research has found that squatting with increased ankle joint plantar flexion decreases trunk lean (36). We therefore expected a lower forward trunk lean, and less posterior pelvic tilt for PFS compared to NS. However, no difference in pelvic tilt ROM was found in any of the squat depth between PFS and NS. For WS and PFS, more subjects were able to squat down to parallel femur with ground than in NS. This indicates that WS & PFS can be valuable tools for athletes and trainers with the aim of performing full ROM squats. We also tested the squat movement repeatability and found that it can be reliably measured for those researchers who later will be investigating squatting kinematics

SUBJECTIVE ASSESSMENT

Surprisingly, we were not able to use the subjective assessment of pelvic tilt to successfully predict the kinematic measures of pelvic tilt in this study. This might originate from different causes. We believe the success of the subjective assessment would have been greater if the examiners had been stricter with their selection strategy. An option could have been to exclude those subjects that the examiners initially disagreed upon. Including those subjects might have created the large overlap of the groups, found in the results (*figure 6)*.

Our aim was for all subjects to reach parallel femur with the ground. However, the results show that many of the subjects, were not able to squat down to femur parallel with ground (*table 3)*. We were not able to measure true femur inclination in the subjective assessment, and differences in body mass may have influenced the results. We experienced it as more difficult to accurately describe inclination of the femur for subjects with greater mass around the hip area. Furthermore, we cannot rule out that skin tissue artifacts around the hip induced an error on the results from the 3D motion analysis.

The purpose of such subjective assessments is that trainers can use the test to define movement limitations in their athletes. Unfortunately, our subjective assessment did not prove valid, comparing with the results from the motion analysis. We encourage researchers having similar approaches to be strict with their criteria in subjective analyses.

SQUAT TYPES & PELVIC TILT

No difference was found in pelvic tilt ROM, or in absolute values, between any of the squat types at 90° femur inclination. As we see in *figure 5,* the maximum anterior pelvic tilt for most subjects occurred at about 30° femur inclination. Pelvic tilt ROM with an offset at 30° femur inclination was therefore considered the most important measure of pelvic tilt in this study. Increase in forward trunk lean has been associated with increased lumbar spine shear forces (37). Upper trunk angle, or trunk lean, has been shown to decrease using weightlifting shoes compared to running shoes (36), and increase when restricting ankle dorsiflexion (13, 22). Weightlifting shoes are shoes with a stiffer sole and higher heels. Squatting using weightlifting shoes is therefore not that different from our environment for

PFS. In this study, trunk lean was also one of two segments constructing posterior pelvic tilt angle. Hence, a reduction in upper trunk lean and pelvic tilt was expected for PFS.

We were surprised that standing on a wedge when squatting, such as in PFS, didn't have any significant effect on pelvic tilt ROM (*table 2*). At 70° femur inclination the upper trunk angle decreased in PFS compared to NS in line with our expectations (*table 3)*. Similar findings was also reported previously (36). However, the second segment directly influencing pelvic tilt, pelvic inclination angle, decreased significantly in PFS compared to NS in 70° femur incline (*table 3*). Therefore, since no relative motion between trunk angle and pelvic angle occurred, no difference was found in pelvic tilt ROM for PFS compared to NS. The difference in forward trunk lean found at 70° femur inclination for PFS was equaled out when the subjects reached 80° & 90° femur incline.

Pelvic tilt ROM was significantly lower in WS compared to NS in 70° & 80° femur inclination, as expected (*table 2*). WS pelvic tilt ROM was also significantly lower compared to PFS at 80° femur inclination. Upper trunk angle, or trunk lean, was significantly decreased in WS compared to NS at 70° & 80° femur inclination. The reduction seen in trunk lean for WS squat (*table 3)*, contradicts the results from Escamilla, Fleisig, Lowry, Barrentine and Andrews (11). They did not find any difference in forward trunk lean between medium or wide stance squat compared to narrow squat (11). Data collection in their study was performed during a weightlifting competition where they measured stance width, while neither footwear nor foot position were standardized in regard to external rotation of the foot. The differences found in pelvic tilt between WS and NS & PS can probably be explained by the decrease in trunk lean. However, as the squat reaches 90° femur incline in our study, we can report no statistical difference in pelvic tilt ROM or trunk angle between the squat types. Although not significant, there seems to be a trend in our results that the trunk is in a more upright position in WS (*table 3*) compared to NS & PFS. The real mean difference in upper trunk angle between the squat conditions was somewhat the same for 70°, 80° and 90° femur inclination.

The large reduction of subjects able to squat down to 90° femur inclination, might be a reason why no statistical differences were found for pelvic tilt ROM and upper trunk segment angle (*table 2*). Comparing the reported results from Escamilla, Fleisig, Lowry, Barrentine and Andrews (11) with our own, external rotation of the feet could be an important attribute for reducing forward trunk lean and possibly posterior pelvic tilt in squats.

Upper trunk angle and pelvic inline angle seem to be equal factors deciding posterior pelvic tilt of the squat. While pelvic incline angle stayed the same between WS & PFS, pelvic tilt ROM decreased at 70° & 80° in WS compared to PFS. At first this indicated that trunk angle seemed to be the decisive factor for pelvic tilt. However, as previously discussed, the trunk forward lean was significantly decreased in PFS compared to NS at 70° femur inclination even though pelvic tilt didn't change. The decrease in pelvic incline angle therefore cancelled out the relative motion between the segments.

More of the subjects came deeper in the squat in PFS and WS compared to NS (*table 3*). The fact that feet position alters biomechanics of the squat is not a new finding, and has been previously studied in several articles (1, 11, 13, 23, 29, 36). The most surprising finding in this study is that foot positions did not have any effect on the shank inclination, or any other segment in 90° femur inclination (*table 3*). Max shank angle was also reached prior to 80° femur inclination for all conditions. An additional investigation was conducted to se if the ankle dorsiflexion changed during the squats. Ankle dorsiflexion, constructed as the relative motion between the foot segment and the shank angle, was significantly lower ($p < 0.01$, ≈ 5°) in PFS squat compared to NS & WS. This was also found by Sato, Fortenbaugh and Hydock (36) who reported an increase in foot segment angle, or plantar flexion using weightlifting shoes. Because none of the segment angles above the ankle changed between NS & PFS, the ankle joint needs to be responsible for the increase in squat depth among our subjects in PFS. We propose the reason for this, is that when the subjects were standing on a wedge, the ankle joint moves anterior and superior in space. That would originally put the shank in a more vertical position. However, data in *table 3* showed that no change in shank angle occurred. Comparing PFS to NS, the whole system relative to the ankle had to be shifted forward in PFS to make the shank angle similar to

NS. A premise to avoid falling backward when squatting is that the Centre of mass needs to stay inside the supporting area of the feet. We believe that such an anterior shift of the system would move the Centre of mass anterior, allowing the subjects to move their mass posterior and deeper. Furthermore, restricted ankle dorsiflexion ROM has previously been reported to reduce knee flexion in squats (23). Knee flexion however, did not change in our data. These results indicate that insufficient ankle dorsiflexion ROM can be a restriction for squat depth. However, a deeper investigation showed no correlation between squat depth and maximal shank angle in our results.

WS squat also had a similar, and even larger, number of subjects reaching 90° femur inclination than PFS (*table 3*). We believe this is due to a smaller distance between the Centre of mass and the mid part of the foot. When looking from a side view, by externally rotating the feet out to the side, the Centre of mass would be closer to the mid part of the feet in the sagittal plane. We believe an anterior shift of the mass will occur, relative to the feet, and allow the subject to sit back without falling. This would also allow the upper trunk to stay more upright.

6.1 LIMITATIONS OF STUDY

Accuracy of marker placement and skin tissue artifact is usually pointed out as the most critical sources of error in kinematics, especially in high-speed movements (21, 34). We were not able to conduct test-retests or an inter-rater reliability evaluation, but the same test leader found all anatomical landmarks on all subjects to minimize marker placement errors. Reliability of kinematic measures has previously been challenged (5, 14), and we are uncertain how much our results were influenced by skin tissue artifacts. Though, the sagittal plane has been reported as the only plane of motion with good reliability (34, 40). The current study can report good movement repeatability with a high ICC of 0.900 (0.810-0 .948). The skin marker set up used in this article therefore seems to be a reliable tool for the squatting movement. We did not report instrumental measurement accuracy, but has previously been reported to be highly accurate if done correctly (7). To account for this, we tried to minimize errors by conducting calibration trials prior to the testing. Some of the subjects may have felt the stance width to be either too narrow or too wide. Stance width was not normalized to the height of the subjects. This means that a tall subject would probably find the stance relatively narrower than a shorter subject. This may have affected the individual segment motion.

6.2 PRACTICAL APPLICATION

For an optimal squat technique, minimizing shear forces at the lower back and at the knee should be the primary goal, avoiding unnecessary risk of injuries. Reducing forward trunk lean, to avoid shear forces at the lumbar spine, seems to be the main factor in avoiding spinal injuries. For the knees, the literature suggests that shear forces increases at the knees in a more upright position of the trunk. One should therefore consider the purpose of the exercise when choosing squat technique and foot position.

Hypothetically, a combination of the foot positions WS & PFS could give the most advantageous position to go deeper in squats, especially for those subjects with insufficient ankle dorsiflexion ROM. The squatting movement does also seem to be highly repeatable for researchers choosing to further investigate the biomechanics in squats. At last we encourage researchers, using subjective assessments to predict objective measures, to be strict with their evaluation criteria.

6.3 CONCLUSION

We found large variations in pelvic tilt (0-25°) between the 41 subjects. Poor agreement was found between the subjective assessment of pelvic tilt and the objective measures from the 3D analysis (AUC 0.670). Wide and externally rotated stance significantly reduced pelvic tilt at 70° femur inclination. However, when subjects reached femur parallel to ground no statistical differences between squat types were found. Importantly, squats on a wedge and wide & externally rotated stance allowed more of the subjects to go deeper (~ 60% of subjects) in the squat compared to Narrow stance (~ 40% of subjects).

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LIST OF FIGURES

LIST OF TABLES

APPENDIX

Appendix #1: Questionnaire for subjects regarding training history and injuries

Appendix #2: Informed consent scheme

Appendix #3: Regional Ethics Committee application decision

Appendix #4: Marker placement description.

Appendix #5: Illustration of marker placement

Treningserfaring og tidligere skader

Informasjonen knyttet til dette spørresjemaet skal kun benyttes i prosjektet «Bekkentilt i knebøy». Etter endte dataanalyser vil alle persondata bli slettet.

Spørreundersøkelsen består av 10 spørsmål og du står fritt til å svare ”usikker” hvis spørsmålet som spørres er uklart eller et svar ikke er mulig å oppgi.

1) Hvordan vil du selv rangere din fysiske helsetilstand?

Dårlig ○ ○ ○ ○ ○ ***Bra*** ***Usikker*** ○

2) Har du eller har du tidligere hatt ubehag eller smerter i knær, hofte eller rygg? Hvis ”Ja” kryss av en eller flere av sirklene under.

Ja ○ ***Nei*** ○ ***Usikker*** ○

Knær ○ Hofte ○ Rygg ○

3) Hvis ”Ja” på spørsmål 2: Hvor lenge siden er det problemene oppsto?

0-6mnd	***6-12mnd***	***1-2år***	***2-5år***	***Usikker***
○	○	○	○	○

4) Hvis ”Ja” på spørsmål 2: Hvor lenge siden er det problemene eller smertene avtok?

0-6mnd	***6-12mnd***	***1-2år***	***2-5år***	***Usikker***
○	○	○	○	○

5) Er du i eller har du hatt smerter i knær, rygg eller hofte den siste måneden?

Ja	***Nei***	***Usikker***
○	○	○

Knær	Hofte	Rygg
○	○	○

6) Hvis ”Ja” på spørsmål 5: I hvor stor grad plages du av smertene under fysisk aktivitet?

Veldig				***Ikke i det hele tatt***	**Usikker**
○	○	○	○	○	○

7) Har du eller har du hatt smerter i knær, rygg eller hofte den siste måneden?

Ja ○ ***Nei*** ○

Knær ○ Hofte ○ Rygg ○

8) Har du opplevd smerte i knær, hofte eller rygg under gjennomføringen av øvelsen Knebøy de siste 6mnd?

JA ○ ***Nei*** ○

9) Andre opplysninger som du mener er relevant kan skrives nedenfor:

Takk for at du gjennomførte. Før i tillegg inn informasjon om deg på punktene under.

Alder:__________ Vekt:______________Høyde:____________________

FP nr:

Navn/tlf:____________________________/__________________________

Epost:____

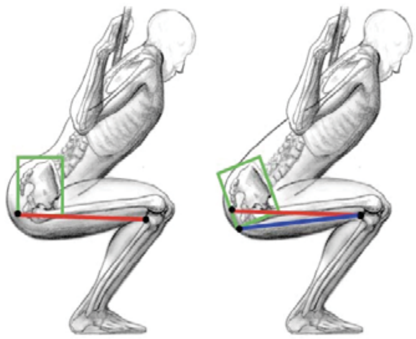
Appendix 1: Questionnaire for subjects regarding training history and injuries

Forespørsel om deltakelse i forskningsprosjekt: Bekkentilt i knebøy

Er du en mann mellom 18 og 40 år som er interessert i å få kartlagt din knebøyteknikk med 3D-analyse og CT-scanning? Da er dette studien for deg!

Bakgrunn og hensikt
En rekke studier viser at effekten av knebøy er bedre med fullt bevegelsesutslag. Mange er imidlertid ikke i stand til å gjennomføre en dyp knebøy uten å krumme ryggen – dvs at man får en posterior tilt av bekkenet relativt til ryggsøylen (Fig 1). Denne bevegelsen har vist seg å gi uheldige belastninger på ryggen som igjen kan føre til skader.

Vi ønsker å undersøke årsaken til at posterior bekkentilt forekommer under knebøy. Vi søker derfor skadefrie menn i alderen 18 til 40 år som har erfaring med knebøy fra før.



Figur 1 Posterior bekkentilt i bunnposisjonen av en knebøv

Hva innebærer studien?
Studien gjennomføres i løpet av 2 dager. Dag 1, ved Norges idrettshøgskole, innebærer tredimensjonal analyse av din knebøyteknikk samt bevegelighetstester og vil ta ca 2t. Du vil utføre knebøy med lett belastning, det vil si 50 % av egen kroppsvekt. Markører vil bli plassert på kroppen din for at kameraene på laboratoriet skal kunne registrere bevegelse (Fig 2). Dag 2 innebærer CT-scan av hofteleddet ved Ullevål universitetssykehus der du bør sette av ca 1t.

Mulige fordeler og ulemper
Denne studien har til hensikt å avdekke mulige årsaker til korsryggproblemer relatert til utførelse av knebøy. Du vil få kartlagt din egen knebøyteknikk og mulige anatomiske og fysiologiske begrensninger. Datainnsamlingen er lite tidkrevende og knebøy-forsøkene innebærer minimal skaderisiko da belastningen er lav.

En CT-skanner er et avansert røntgenapparat som kan gi detaljerte 3D-bilder av hoftas utforming og er hyppig benyttet innen medisin. En CT-scan innebærer røntgenstråling. All stråling kan gi økt risiko for fremtidig kreft. En enkelt CT scanning av hofta innebærer ca 6 mSv, hvilket er langt under det som ansees å være en lavdose for voksne mennesker (100 mSv). 6 mSv tilsvarer til den dosen med radioaktiv stråling man naturlig utsettes for i løpet av 2 år. Det er estimert at en 6 mSv kan gi en 20 år gammel mann en økning i fremtidig kreftfare på 0,6%.

Figur 2 Markørkørplassering

Hva skjer med informasjonen om deg?
Informasjonen som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. Etter endte dataanalyser vil alle persondata bli slettet.

Kompensasjon
Det gis intet honorar eller noen form for kompensasjon for å delta i studien. Vi kan dekke eventuelle reise- og diettutgifter.

Frivillig deltakelse
Det er frivillig å delta i studien. Du kan når som helst og uten å oppgi noen grunn trekke ditt samtykke til å delta i studien. Dersom du ønsker å delta, undertegner du samtykkeerklæringen på siste side. Dersom du ønsker å melde deg på eller har spørsmål til studien, kan du kontakte

Stian Rekdal Nielsen: stianrn@student.nih.no, 91703734
Øystein Mjelde Skipenes: oystein.mjelde.skipenes@gmail.com, 99386661
Tron Krosshaug: tron.krosshaug@nih.no, 456 60 046

Appendix 2: Informed consent scheme

REK
REGIONALE KOMITEER FOR MEDISINSK OG HELSEFAGLIG FORSKNINGSETIKK

Region:	Saksbehandler:	Telefon:	Vår dato:	Vår referanse:
REK sør-øst	Silje U. Lauvrak	22845520	11.09.2014	2014/126 REK sør-øst
			Deres dato:	**Deres referanse:**
			17.06.2014	Vår referanse må oppgis ved alle henvendelser

Tron Krosshaug
Norges Idrettshøgskole
Postboks 4014 Ullevål Stadion
0806 Oslo

2014/1269 Bekkentilt i knebøy

Vi viser til søknad om forhåndsgodkjenning av ovennevnte forskningsprosjekt. Søknaden ble behandlet av Regional komité for medisinsk og helsefaglig forskningsetikk (REK sør-øst) i møtet 20.08.2014. Vurderingen er gjort med hjemmel i helseforskningsloven § 10, jf. forskningsetikklovens § 4.

Forskningsansvarlig: Norges idrettshøgskole
Prosjektleder: Tron Krosshaug

Prosjektomtale (original):
En rekke studier viser at effekten av knebøy er bedre med fullt bevegelsesutslag. Mange er imidlertid ikke i stand til å gjennomføre en dyp knebøy uten å krumme ryggen – dvs at man får en posterior tilt av bekkenet relativt til ryggsøylen. Denne bevegelsen har vist seg å gi uheldige belastninger på ryggen som igjen kan føre til skader. Hensikten med denne studien er å undersøke årsaken til at posterior bekkentilt forekommer under knebøy. I tillegg vil vi undersøke hvorvidt enkle teknikkvariasjoner kan redusere bekkentilt. Studien gjennomføres i over 2 dager. Dag 1, ved Norges idrettshøgskole, innebærer tredimensjonal bevegelsesanalyse av knebøyteknikk samt bevegelighetstester av hofte og ankelledd. Forsøkspersonene vil utføre knebøy med lett belastning, det vil si 75 % av egen kroppsvekt. Dag 2 innebærer CT-scan av hofteleddet ved Ullevål universitetssykehus.

Vurdering
Formålet med prosjektet er å undersøke årsaken til at bekkentilt forekommer under knebøy. Komiteen vurderer at prosjektet ikke vil gi ny kunnskap om helse og sykdom som sådan, men at det snarere vil gi kunnskap om knebøyteknikk og ryggbelastning ved knebøy. Prosjektet faller derfor utenfor REKs mandat etter helseforskningsloven, som forutsetter at formålet med prosjektet er å skaffe til veie ny kunnskap om helse og sykdom.

Det kreves ikke godkjenning fra REK for å gjennomføre prosjektet. Prosjektet kommer inn under de interne regler som gjelder ved forskningsansvarlig virksomhet.

Vedtak
Prosjektet faller utenfor helseforskningslovens virkeområde da det ikke oppfyller formålet, jf. § 2. Det kreves ikke godkjenning fra REK for å gjennomføre prosjektet.

Vi ber om at alle henvendelser sendes inn med korrekt skjema via vår saksportal:

Besøksadresse:
Gullhaugveien 1-3, 0484 Oslo

Telefon: 22845511
E-post: post@helseforskning.etikkom.no
Web: http://helseforskning.etikkom.no

All post og e-post som inngår i saksbehandlingen, bes adressert til REK sør-øst og ikke til enkelte personer

Kindly address all mail and e-mails to the Regional Ethics Committee, REK sør-øst, not to individual staff

http://helseforskning.etikkom.no. Dersom det ikke finnes passende skjema kan henvendelsen rettes på e-post til: post@helseforskning.etikkom.no.

Vennligst oppgi vårt referansenummer i korrespondansen.

Klageadgang
Komiteens vedtak kan påklages til Den nasjonale forskningsetiske komité for medisin og helsefag, jf. helseforskningsloven § 10 tredje ledd og forvaltningsloven § 28. En eventuell klage sendes til REK sør-øst D. Klagefristen er tre uker fra mottak av dette brevet, jf. forvaltningsloven § 29.

Med vennlig hilsen

Finn Wisløff Professor
em. dr. med.
Leder

Kopi til: turid.sjostedt@nih.no Silje U. Lauvrak rådgiver
Norges idrettshøgskole ved øverste administrative ledelse: postmottak@nih.no

Appendix 3: Regional Ethics Committee application decision

Marker Placement

Front	Insicura jugularis	
	Acromion, most lateral point	bilateral
	Lateral epicondyl humerus, most distal point	bilateral
	Caput ulnae lateral, most distal point	bilateral
	ASIS, inferior point	bilateral
	Crista iliaca, 8 cm. posterior from ASIS	bilateral
Back	C7	
	PSIS	bilateral
	⅔ of distance C7 – midpoint PSIS	
Thigh	Trochanter major, most superior	bilateral
	Lateral femur epicondyle	bilateral
	½ of distance trochanter major - femur epicondyle (A)	
	o *2 cm. posterior*	bilateral
	o 2 cm. anterior	bilateral
	o *Front of thigh*	bilateral
	½ of distance trochanter major – A, lateral thigh	bilateral
	⅓ of distance A – femur epicondyle, lateral thigh	bilateral
	⅔ of distance A – femur epicondyle, lateral thigh	bilateral
	½ of distance A – femur epicondyl, front of thigh (B)	bilateral
	Patella midpoint	bilateral
	½ of distance B – midpoint patella, front of thigh	bilateral
Shank	Tuberositas tibia, most prominent point	bilateral
	Lateral malleol, 2 cm. proximal to most distal point	bilateral
	½ of distance tuberositas tibia – lateral malleol, medial tibia (C)	bilateral
	½ of distance tuberositas tibia – (C), lateral shank	bilateral
Foot	Caput 5th metatarsal	bilateral
	Caput 1th metatarsal, adjust lateral to avoid kicking off marker	bilateral
	Calcaneus, most posterior point	bilateral

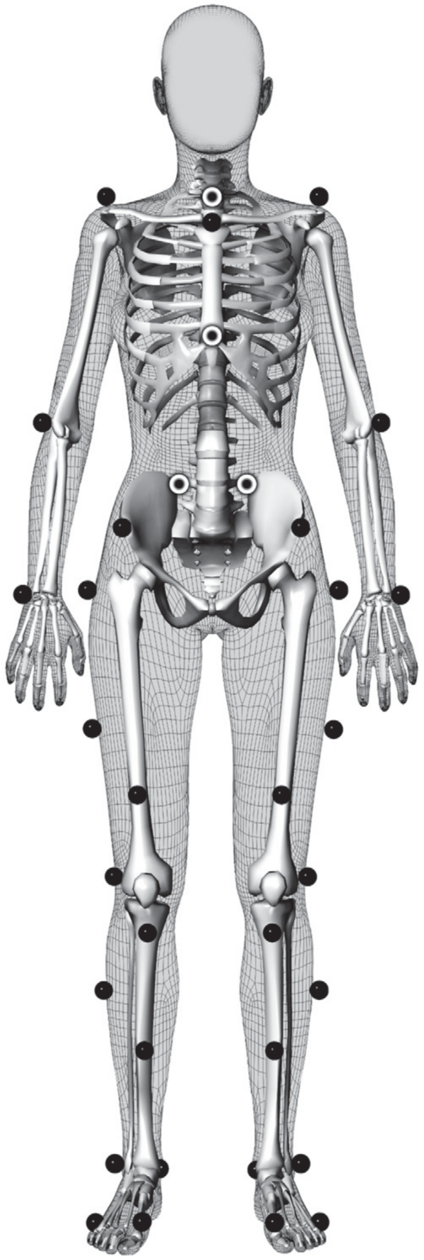
Adjust caput markers posteriorly to avoid joint line

Numbers of markers with/without extra markers: (.... = extra markers)

Front: 11/9 **Back:** 4/4 **Thigh:** 22/8 **Shank:** 8/8 **Foot:** 6/6 **Total:** 51/37

Procedure:
Clean with Isopropanol. Mark landmark with waterproof marker. Put on marker. Warm-up.

Appendix 4: Marker placement description.



Appendix 5: Illustration of marker placement: Krosshaug T. provided the illustration from the following article *"Kristianslund E, Krosshaug T, and van den Bogert AJ. Effect of low pass filtering on joint moments from inverse dynamics: implications for injury prevention. Journal of biomechanics 45: 666-671, 2012."*