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The influence of passive extensibility of the posterior oblique sling's upper portion on contralateral knee extension

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Abstract

Introduction. The posterior oblique sling (POS) serves to improve stability by transferring the force and load during an active movement in muscle contraction. The purpose of this study was to investigate the influence of pelvic positions on the knee extension range of motion (KE ROM) and the influence of trunk positions on the mobility of the lower extremity.
Methods. Sixteen subjects (age 21.0 ± 1.9 years, height 165.3 ± 7.6 cm, weight 59.56 ± 7.9 kg) participated in this study. The therapist measured the active KE ROM of the dominant leg at three different pelvic positions (neutral position, maximal anterior, and posterior pelvic tilt) and at two different trunk positions (trunk flexion and trunk rotation) using a Bluetooth embed inertial measurement unit sensor. A 10-minute rest was taken between positions. During trunk flexion and trunk rotation, the pelvis was maintained in a neutral position to prevent the change in length of the hamstring muscles. Statistical significance was set at $p < 0.05$.
Results. In comparison to the neutral position, the anterior and posterior pelvic tilt significantly decreased ($p < 0.001$) and increased the KE ROM ($p < 0.001$). In addition, the trunk rotation significantly decreased the KE ROM ($p = 0.002$). However, the trunk flexion did not significantly change the KE ROM.
Conclusions. The findings in this study indicate that the changes in the length of the POS significantly influenced the functional mobility in the lower extremity. In clinical practice, the flexibility of POS must be considered during reciprocal movements involving the upper body and contralateral lower extremities.
Key words: lumbar fascia, pelvis, range of motion, thorax

Introduction

The human body is a multi-segment network that has components with reciprocal influence on each other [1, 2]. An analytical approach to assess only individual segments limits the interpretations of body movement because the body functions as a complex system of inter-collaborative parts [3]. Thus, body movement is dependent on the simultaneous actions of different interconnected components. A muscle contraction produces a force that spreads beyond the origin and insertion of the active muscle. Stability is achieved when these active muscle tissues produce body movements and simultaneously passive connective tissues adequately transmit this generated force to other segments [4]. Among these passive connective tissues that cross multiple segments, the development of structures according to their functional demands are specifically known as anatomy slings [5]. Anatomy slings are groupings of muscles and structures that are essential for the stability and support of movement in our daily actions. The anterior oblique sling (AOS) and posterior oblique sling (POS) are among the key anatomy slings. The POS is considered particularly important in clinical practice because a dysfunction of this sling reduces lumbopelvic stability and causes lower back pain [6–8].

The POS is the back functional line that links the upper body, which includes the trapezius and latissimus dorsi and the contralateral lower extremity, which includes the gluteus maximus and hamstrings [6, 9]. The interconnecting thoracolumbar fascia (TLF), located in the middle of the POS, helps to transmit the force from the lower to the upper body, and vice versa. The POS is a complex multi-layered network composed of passive connective tissues, fascia and aponeurosis, that functions for the storage and release of energy to other segments with the utilization of tension produced from lengthened tissues. Additionally, recent studies focused on the changes in muscle activity of the ipsilateral side while the contralateral side muscles concentrically contracts. In the study by Kim et al. [8], individuals with chronic low back pain demonstrated greater activity in the contralateral muscles of the upper body during prone hip extension. Additionally, in the study by Ha and Jeon [10], the investigation of EMG activity during prone hip extension with shoulder abduction positioned at three different degrees resulted in the observation of increased contralateral force of the gluteus maximus at a 125° shoulder abduction. Few recently published studies also examined the muscle activity of the contralateral side interconnected to the sling system during concentric contractions [11, 12]. Although these studies have confirmed that muscles of the upper body are obliquely linked with the muscles of the contralateral lower extremity through the POS system examination, they have not been able to confirm the role of POS as a passive component.

The latissimus dorsi, originating from the TLF and iliac crest, is the primary muscle comprising the upper portion of the POS. The POS consists of the latissimus dorsi, contralateral gluteus, and the interconnecting thoracolumbar fascia. Thus, the tightness of the POS for the upper body might directly impact the extensibility of the gluteus maximus and hamstrings through the TLF [10] and indirectly influences pelvis rotation, thereby having a secondary impact on the range

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of motion (ROM) in terminal knee extension (KE). In the study by Sullivan et al. [13], the significant increase in hamstring flexibility was only observed after stretching with an anterior pelvic tilt, not with a posterior pelvic tilt, regardless of stretching methods. All hamstring muscles, except for the short head of the biceps femoris, originate from the ischium tuberosity and rotate the pelvis posteriorly when tightened during hip flexion. The POS is anatomically positioned obliquely; hence, it may also be influenced by the trunk position in the transverse plane. Previous studies generally focused on evaluating the effects of cervical, thoracic, and/or lumbar spine flexion on terminal knee extension angle [14–16]. Though previous studies have confirmed that full flexion of the spines evidently restricts KE ROM, the effect of the motion in the transverse plane is still unclear.

The purpose of this study was to investigate the effect of different pelvic positions to the KE ROM in the sagittal plane and the effect of different trunk positions to the KE ROM in both the sagittal plane and transverse plane.

Subjects and methods

Subjects

A total of 16 healthy volunteers (aged 21.0 ± 1.9 years, height 165.3 ± 7.6 cm, weight 59.56 ± 7.9 kg) with a BMI range of 18.5–24.9 [17] and no history of lumbopelvic pain and low back pain participated in this study. The informed consent of each participant was obtained accordingly. This study was approved by the Institutional Review Board of Woosong University.

Procedures

The subjects were positioned in a sitting position where the popliteal region of the knee did not come into contact with the treatment table (Figure 1a). The therapist measured the active KE ROM of the dominant leg at three different pelvic positions (neutral position, anterior pelvic tilt, and posterior pelvic tilt) using a Bluetooth embed IMU sensor (Re-live Inc., Kimhae, Korea) [18]. During the anterior and posterior pelvic tilt, the subjects were asked by the therapist to rotate the pelvis to its maximum. If the knee was fully extended, the KE ROM was recorded as 0°. In the KE ROM measurement, pain was also measured using the visual analogue scale (VAS). Three different pelvic positions were randomly selected and a 10-minute rest was taken in between positions. Randomization of two different trunk positions (trunk flexion and trunk rotation) was also applied. During trunk flexion and trunk rotation, the pelvis was maintained in a neutral position to prevent the change in length of the hamstring muscles caused by the change in pelvic position. The upper thoracic region was allowed to flex during trunk flexion (Figure 1b). Additionally, the motion of the lower lumbar region was also prohibited because it induces pelvic rotation during trunk flexion. The KE ROM and VAS were measured at maximum trunk flexion. During trunk rotation, the subjects crossed their arms over their shoulder while the therapist assisted right rotation in the transverse plane. The KE ROM and VAS were measured at maximum trunk rotation.

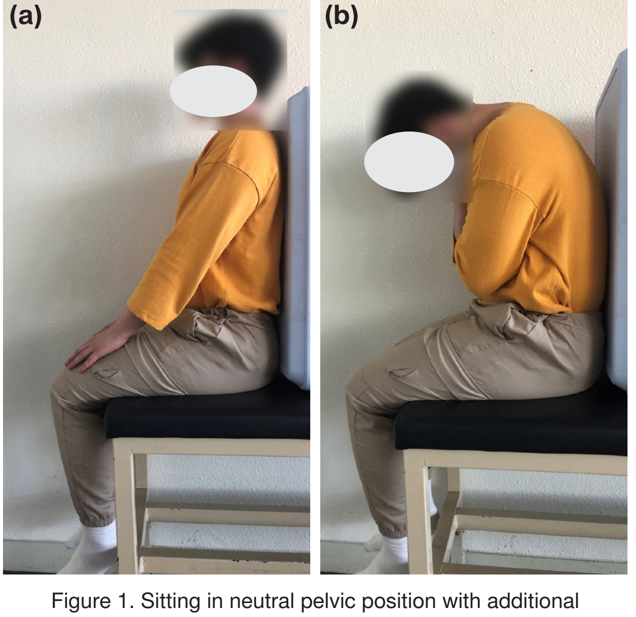


Figure 1. Sitting in neutral pelvic position with additional apparatus to maintain the neutral pelvis position (a) and with trunk flexion (b)

Data analysis

Data analysis was performed using IBM SPSS Statistics 25 (IBM Corp., Armonk, NY, USA). The Shapiro–Wilk test for normality was conducted. The difference in knee extension angle among the different positions was analysed by repeated measures of ANOVA with pairwise post hoc comparison. The difference in VAS among different positions was analysed by Friedman's test with a Wilcoxon signed-rank post hoc test. Bonferroni correction was applied, resulting in a significance level set at $p < 0.005$. The KE ROM (ΔKE ROM) and VAS (ΔVAS) measurements during anterior pelvic tilt, posterior pelvic tilt, trunk flexion, and trunk rotation were normalized to the baseline values obtained during the neutral pelvic position. The correlation between ΔKE ROM and ΔVAS was calculated by Pearson Correlation. Statistical significance was set at $p < 0.05$ and all values were reported as mean ± standard deviation.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Institutional Review Board of Woosong University (approval No.: 1041549-200107-SB-82).

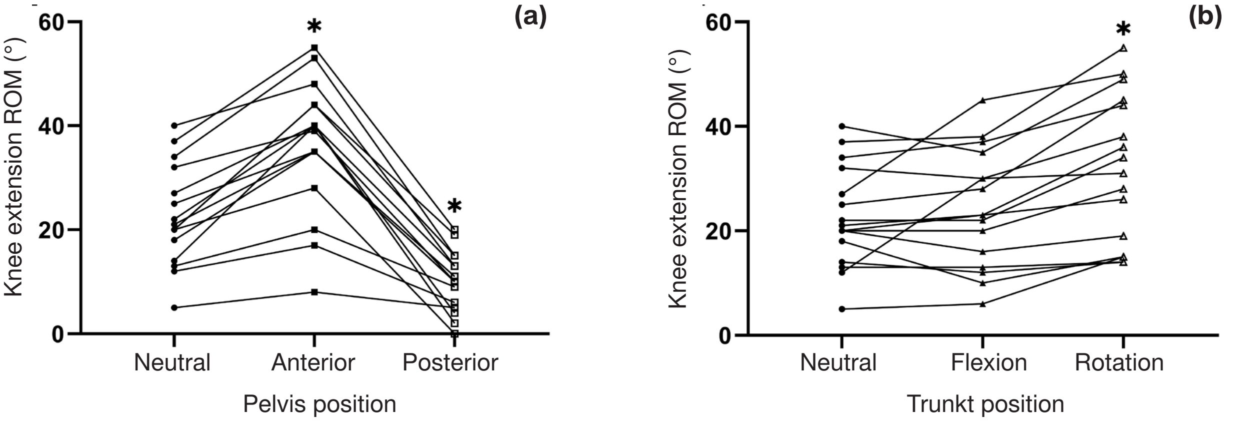
Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

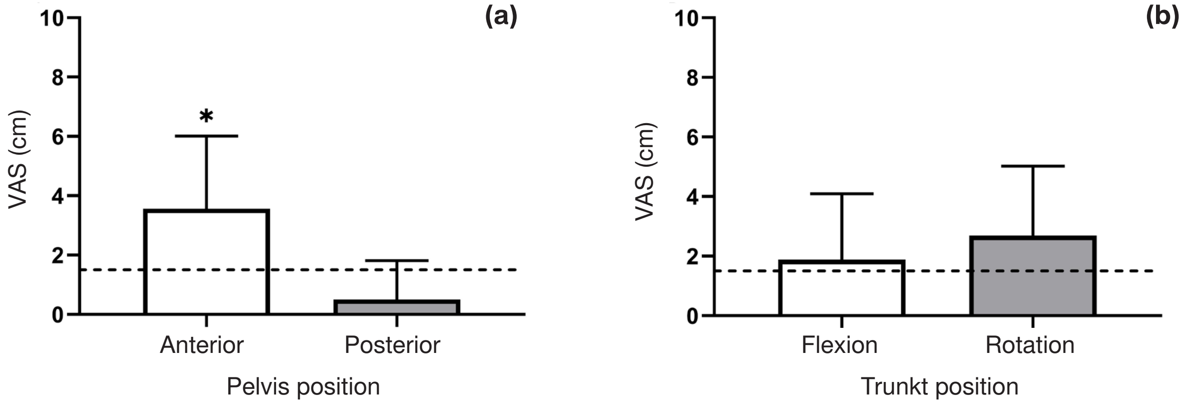
The pelvic and trunk positions had significant effects on KE ROM [$F(2.105, 31.572) = 32.283$, $p < 0.001$]. Post hoc tests using the Bonferroni correction revealed that anterior and posterior pelvic tilt significantly decreased ($p < 0.001$) and increased the KE ROM ($p < 0.001$), respectively (Figure 2a) and the trunk rotation significantly decreased the KE ROM ($p = 0.002$) (Figure 2b). However, there was no statistically significant difference in trunk flexion to the neutral position ($p = 1.000$). There was no significant difference in KE ROM between the anterior pelvic tilt and trunk rotation ($p = 1.000$).

The pelvic position had a significant effect on pain [$\chi^2(4) = 36.407$, $p = 0.022$]. In contrast to the posterior pelvic tilt, there was a significant increase in pain during anterior pelvic tilt ($p < 0.001$) (Figure 3a). However, there was no statistically significant difference of trunk rotation on pain ($p = 0.008$)



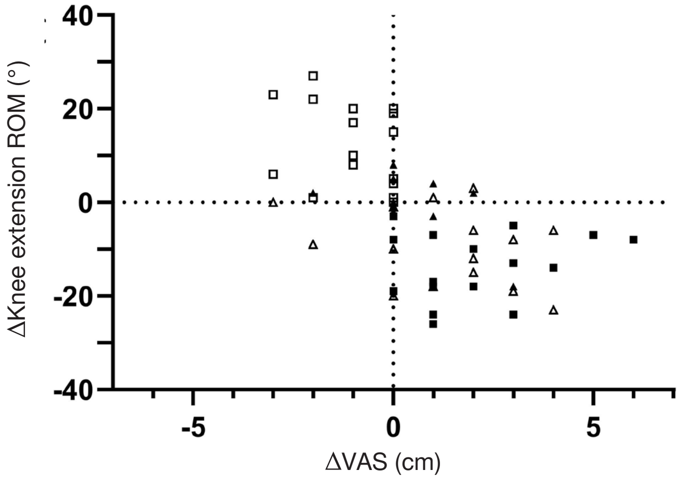
ROM – range of motion
* significant difference compared to that in neutral position

Figure 2. Changes in knee extension ROM depending on pelvis and trunk position



VAS – visual analogue scale
* significant difference compared to that in neutral position Broken lines show the VAS in neutral position

Figure 3. Influence of pelvis and trunk position on pain VAS, visual analogue scale



ROM – range of motion
KE – knee extension
VAS – visual analogue scale

Figure 4. Relationship between ΔKE ROM and ΔVAS

(Figure 3b). There was a statistically significant correlations between ΔKE ROM and ΔVAS ($r = -0.633$, $p < 0.001$) (Figure 4).

Discussion

The lumbosacral complex provides stability against perturbation coming from internal and external environmental factors during dynamic motion [19]. The axial skeleton and active muscular structures are not sufficient to solely maintain this stability, thus additional support from other passive structures, such as the myofascia and aponeuroses, is essential [20, 21]. According to recent studies, the POS crosses approximately at the level of the sacro-lumbar junction in the pelvic region and this serves to improve stability by transferring the force and load during active movement in muscle contraction [22, 23]. This structural property of a vector force transmission through structures within an anatomical sling is a focus of interest in previous studies, wherein the muscle activity changes related with the POS while the contralateral muscles contract were investigated [10, 24]. The POS is a complex of several tissues including muscle, fascia, and ligaments synergistically working together to create stability and mobility. Particularly, the fascia (irregularly arranged collagen fibres) and aponeuroses (regularly arranged collagen fibres) are components that are prominent in tension resistance in various directions [25–27]. As an extensive multi-layered passive connective tissue, further investigation about the influence on the mobility of structures linked between the upper body and lower limb is needed. This study aimed to investigate (1) the influence of pelvic positions linking the upper body and the contralateral lower portion of the POS on KE ROM and (2) the influence of trunk positions composing the upper portion of the POS, with a neutrally fixated pelvis, on the mobility of the lower extremity. The findings in this study revealed that the upper portion of the POS significantly influences the mobility of the lower extremity and approximately the same degree of influence is affected by the pelvis.

In contrast to the neutral position of pelvis, there was a significant decrease in KE ROM in maximal anterior pelvic tilt and a significant increase in KE ROM in maximal posterior pelvic tilt. In the normalization to the baseline of the KE ROM in the neutral position of the pelvis, the KE ROM was decreased by 8.8% in anterior pelvic tilt and increased by 8.2% in posterior pelvic tilt. There are three main factors that influence the KE ROM, the contractile tissues including hamstrings and other hip extensors, non-contractile tissues including POS and other connective tissues located on the lower back and posterior thigh, and neural tissues including the sciatic and tibial nerve [15, 28]. Neural tissues can be elongated with full flexion of cervical, thoracic and lumbar spine and tension occurred in these tightened tissues [15, 29, 30]. However, in this study the upper trunk was fixated with no unnecessary movement in the adjustment of pelvic positions, thereby implying that the neural tissues probably only had a minimal impact. Thus, the changes in KE ROM are inclined to be caused by the contractile and/or noncontractile tissues. It is important to understand the anatomical properties of the tissues that lie inferior to the pelvis and the tissues that connect the hip and knee joints. Monoarticular hip extensors originate from the gluteal surface of the ilium and insert into the greater trochanter of the femur and iliotibial tract. These structures would lengthen in the anterior pelvic tilt and correspondingly shorten in the posterior pelvic tilt. On the other hand, biarticular hip extensors, like the hamstrings, originate from the ischial tuberosity and insert into the medial and lateral epicondyle of the tibia with the exception of the short head of the BF. Thus, the length of these muscles is directly affected by the knee extension angle. In the study by Bohannon, posterior pelvic tilt was observed at 9° hip flexion during a passive straight raise in prone position with full knee extension [31] and this indicated that biarticular muscles crossing the hip and knee joints affect the pelvis tilt during full knee extension even with a slight hip flexion. Conversely, the present study shows that pelvic tilt may affect terminal knee extension; thus, the proximal fixation impacts distal mobility. In the composition of the three different pelvic positions, the soft tissues superior to the pelvis only showed a minimal effect, unlike the hip extensors. The upper portion of the POS becomes loose during a pelvis anterior tilt, which may partially contribute to increased KE ROM. However, the mobility of the lower extremity was lowest during an anterior pelvic tilt and greatest during a posterior pelvic tilt. As the POS crosses the pelvis obliquely, the motion in the sagittal plane may not be the appropriate reference to generate changes in the length of the POS [7]. In order to observe whether the length of the POS affects the mobility of the lower extremity, the experiments were conducted in the trunk position including rotation in the transverse plane as opposed to different pelvic positions in the sagittal plane.

In comparison to the neutral position of the trunk, there was no significant difference in KE ROM in trunk flexion but there was a significant decrease in KE ROM in trunk rotation. Additionally, there was no significant difference in KE ROM between anterior pelvic tilt and trunk rotation. A minimal decrease in KE ROM was observed during the maximal upper trunk flexion; however, this was not significant. The absence of change in the KE ROM during trunk flexion implies that the changes in length of neural tissue and/or POS in the sagittal plane did not affect the mobility of the lower extremity. It is known that during trunk flexion, the vertebral canal is lengthened, and the spinal dura is elongated. Hence, the spinal cord and/or nerve roots are taut and subsequently restrict the terminal knee extension during full flexion of the trunk [15]. However, in this study there was no change in KE ROM during trunk flexion because only the upper trunk flexion was allowed and there might not be enough neural tissues to be taut. In a previous study investigating passive connective structures, the length of the TLF increased by approximately 30% in full flexion of the spine [32]. Hence, the lack of change in KE ROM in the present study can be attributed to the limitation of the upper trunk flexion without lumbosacral flexion, which were inadequate to produce significant changes or to the possibility that the tensile force delivered to the lower portion of the POS might have been blocked by the pelvis fixation during trunk flexion. The first assumption can be supported by the limited mobility of the thoracic spine, as the entire thoracic vertebrae only allow about 30° to 40° of flexion and relatively less motion at each segment than the lumbar and cervical vertebrae [33]. Additionally, the POS runs diagonally so the upper trunk motion in sagittal plane, such as pelvis motion, may not be adequate to induce tension in loosened tissues. In contrast to the first assumption, the second assumption is questionable because KE ROM significantly decreased during trunk rotation despite the neutral pelvis fixation. During trunk rotation, the KE ROM decreased by 9.6° and this was not statistically significant from the changes in the anterior pelvic tilt. The decrease in KE ROM may have resulted from the restriction of the contralateral lower extremity mobility due to tightening of the POS upper portion during trunk rotation. In previous studies, the activity of the gluteus maximus in the contralateral leg had the tendency to increase during shoulder abduction, as the lower trapezius, which partially comprises the upper POS, is anatomically linked to the contralateral gluteus maximus [10, 24]. Additionally, the eccentrically lengthened muscles of the upper body control the movement of the contralateral lower extremity during hip flexion [34] and these tightened connective tissues store the elastic energy and release it to help movement initiation during hip extension [35, 36]. In particular, the posterior layer of the thoracolumbar fascia, which is a component of the POS, is known to contribute to spine stability by transferring forces from the trunk to the lower extremity during trunk rotation [35]. All of these relationships between the POS and its corresponding components serve an important mechanism in efficient energy expenditure. In conclusion, it was demonstrated that tension in the upper portion of POS during trunk rotation can directly influence the degree of terminal knee extension. These results suggest that the dysfunction in the upper portion of the POS would restrict the mobility of the contralateral lower extremity. In clinical practice, cases with mobility loss in the lower extremity required examination of the shortness or tightness of the contralateral upper portion of the POS.

If soft tissues are repeatedly exposed to excessive tension and/or load, it may result in micro-tears and pain. It is also known that the POS contains nociceptive endings, thus it is susceptible to irritations from micro-injuries and this eventually leads to pain [37, 38]. In the present study, VAS was additionally measured at each position to examine pain caused by tightness of tissues located at the lower back and posterior thigh. In consideration of the KE ROM results, the pain was most severe during the anterior pelvic tilt. The majority of the subjects expressed pain during the anterior tilt (87.5%), followed by pain during trunk rotation (75%), and the minority of the subjects expressed pain during the posterior pelvic tilt (18.8%). In addition, a significant relationship was observed between ΔKE ROM and ΔVAS, which indicates that changes in the pelvic and/or trunk positions influence the amount of pain caused due to the lengthening of the soft tissues in the lower extremity.

Limitations

The methodology was limited because the degree of pelvic tilt can vary across individuals. The effect of pelvis and trunk positions on KE ROM may differ among those with hyperlordosis or hypolordosis. Subsequent studies should consider the baseline homogeneity of the subjects by measuring the degree of pelvic tilt. Future studies should include large samples and further analysis would have been possible if the EMG activity and strength and length of muscles related with the POS were also considered and subsequently measured.

Conclusions

Understanding the movement of the human body can be restrictive and incomplete if analysed only according to each segment as opposed to taking a whole-body approach. Synergistic components of the complex system function effectively because the movement in the joints are influenced not only by adjacent structures but also by more distant soft tissues. Anatomy slings composed of several structures connect multi-segments; thus, the POS is a key network that anatomically connects the posterior upper body and the contralateral lower limb which produces functional interactions. In this study, the changes in the length of the POS caused by the motions in the transverse plane significantly influenced the functional mobility in the lower extremity and is potentially linked to pain in the lower extremity. The POS functions as a modulator during reciprocal movements in the gait and stabilizes the upper back in situations where unidirectional rotation is repeatedly required (for example, in the workplace). Thus, the flexibility of POS must be considered during reciprocal movements involving the upper body and contralateral lower extremities in clinical practice. Further understanding of the roles and features of the POS would contribute to the discovery and development of effective treatment strategies.

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Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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