

Tensile Force Transmission from the Upper Trunk to the Contralateral Lower Leg throughout the Posterior Oblique Sling System

Wootae Lim^{1,2}

¹College of Health and Welfare, Woosong University, Daejeon, 34606, Republic of Korea

²Woosong Institute of Rehabilitation Science, Woosong University, Daejeon, 34606, Republic of Korea

Received December 20, 2020; Revised March 3, 2021; Accepted March 23, 2021

Cite This Paper in the following Citation Styles

(a): [1] Wootae Lim, "Tensile Force Transmission from the Upper Trunk to the Contralateral Lower Leg throughout the Posterior Oblique Sling System," *International Journal of Human Movement and Sports Sciences*, Vol. 9, No. 2, pp. 294 - 300, 2021. DOI: 10.13189/saj.2021.090217.

(b): Wootae Lim (2021). *Tensile Force Transmission from the Upper Trunk to the Contralateral Lower Leg throughout the Posterior Oblique Sling System*. *International Journal of Human Movement and Sports Sciences*, 9(2), 294 - 300. DOI: 10.13189/saj.2021.090217.

Copyright©2021 by authors, all rights reserved. Authors agree that this article remains permanently open access under the terms of the Creative Commons Attribution License 4.0 International License

Abstract Although recent studies have confirmed that muscles of the upper body are obliquely linked with the muscles of the contralateral lower extremity through posterior oblique sling (POS) system, the upper portion of the POS connected to the lower leg below the hamstring is yet to be determined. In the supine position, the active maximum dorsiflexion (DF) angles of the right and left legs were randomly measured. During passive trunk rotation performed by the therapist, the active maximum DF angles of the right leg (contralateral side) and left leg (ipsilateral side) were measured. In a long sitting position with and without trunk rotation, the active maximum DF angles in both legs were measured. The left upper body was made to rotate rightward in trunk rotation. In the contralateral lower extremity, the DF ROM in the sitting position with trunk rotation was significantly different compared with those in the sitting position without trunk rotation, and in the supine position with trunk rotation. In the comparison between the ipsilateral and contralateral lower extremity, significant differences were found in the DF ROM in the sitting position with trunk rotation. This study indicates that the tensile force generated by trunk rotation is transmitted to the contralateral terminal end by examining changes in DF ROM. Since the upper portion of the POS is connected all the way down to the contralateral calf, the POS must be considered during the clinical treatment of patients with restricted DF mobility.

Keywords Ankle Joint, Lumbar Fascia, Pelvis, Range of Motion

1. Introduction

Decreased ankle range of motion (ROM), especially in dorsiflexion (DF), has been widely reported after ankle injuries ranging from mild sprain injury to severe ankle fracture and Achilles tendon rupture [1–3]. As adequate functional ROM at the ankle joint is required during activities of daily living, the effect of restricted DF ROM goes beyond just functional loss and actually hinders independent activity. In a study by Crosbie, stride velocity and step length significantly correlated with maximum ankle DF; thus, shortened step length and single limb support time were observed on the involved side [4]. The ankle ROM deficit during gait produces a compensatory movement that can lead to genu recurvatum in the standing position after repetitive exposures [5]. Furthermore, along with the increase in knee extensor torque, there is a potential risk of developing medial compartment osteoarthritis [6,7].

According to the numerous studies conducted so far, to treat restricted DF ROM, although parameters such as type, frequency, and duration were used with some

variations, they all commonly included performing calf muscle stretching [8–10]. After calf muscle stretching, partial improvements in static condition could be observed, but some limitations in dynamic condition remain. In a study by Johanson, gastrocnemius stretching was performed to increase knee and ankle ROM, and changes in DF ROM during gait were examined [11]. Although a significant increase in passive DF ROM was observed, no significant differences in maximum DF and knee extension angles and electromyographic activity of the gastrocnemius were found during the stance phase of gait. This might be because active contractile components and non-contractile components are complexly involved during gait. During erect bipedalism, one arm moves forward and the contralateral leg also moves in the same direction simultaneously, exhibiting a reciprocal pattern. During such movements, the posterior tissues of the body are obliquely lengthened owing to the crossed arm and leg. Lengthened passive connective tissues assist the deceleration of the rapidly moving arms and legs, and energy is stored during the deceleration according to viscoelasticity and elasticity properties [12]. Stored energy is released upon movement in the opposite direction and is used to support initial motion [13–16]. Previous studies that examined the passive connective system linking the hip to the ankle confirmed the significant effect of hip positions and/or spinal curvature on DF ROM and the effect of ankle positions on hip flexion ROM and vice versa [17–22]. However, most precedent studies focused only on the unilateral lower extremity linking the ankle to the hip joint or the influence of upper body motion in the sagittal plane when including the upper body. Recent studies demonstrated that the latissimus dorsi is connected to the contralateral gluteus maximus through the posterior oblique sling (POS) system, which is distally connected to as far as the hamstring [23–26]. Anatomically, the hamstring is also linked to the terminal end by passive connective and neural tissues [27,28]. Comprehensively, it is possible to infer from precedent studies that changes in the length of the soft tissues located at the posterior upper trunk cross through the POS and can affect the contralateral lower leg.

The purpose of this study was to examine the transmission of tensile force at passive connective tissues of the posterior upper trunk to the contralateral terminal end in the supine and sitting positions. On the basis of the anatomical characteristics of the POS, trunk rotation in the transverse plane is applied instead of flexion or extension in the sagittal plane.

2. Materials and Methods

2.1. Subjects

A total of 19 healthy adults (8 males and 11 females)

voluntarily participated in this study (Table 1). Only those who did not experience pain, injury, and surgery in the hip, knee, and ankle joints in the last 6 months were allowed to participate in the experiment. The present study was approved by the institutional review board of Woosong University. Informed consent was obtained from all the participants.

Table 1. Characteristics of the patients

	Age (y)	Height (cm)	Weight (kg)	Body mass index (kg/m ³)
Mean	20.8	165.8	62.4	22.5
Standard deviation	1.1	8.6	12.7	3.0

2.2. Procedures

The participants were randomly assigned either the supine or sitting position. The DF ROM in each position was measured with and without trunk rotation, without a particular order in performing trunk rotation. A 10-minute break was given after the measurements were taken in a position and before moving on to the next one.

In the supine position without trunk rotation (Figure 1a), the participants lied down on the treatment table, extending their ankle joints over the base line of the treatment table. In a relaxed state, the active maximum DF angles of the right and left legs were randomly measured. A Bluetooth embed IMU sensor (Re-live Inc., Kimhae, Korea) was used to measure the DF ROM [29], and pain levels were measured using the visual analog scale (VAS). Trunk rotation was performed passively by the therapist, with the participant lying down on the treatment table, and the left upper body was made to rotate rightward. During this procedure, a belt fixed the position of the pelvis to prevent it from elevating off the treatment table (Figure 1b). While maintaining trunk rotation, the active maximum DF angles of the right leg (contralateral side) and left leg (ipsilateral side) and the VAS scores were measured.

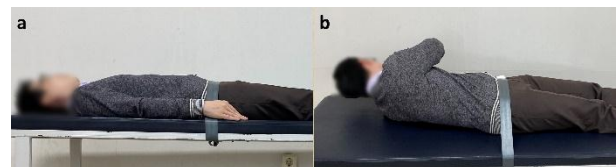


Figure 1. Supine position (A) without and (B) with trunk rotation

In a long sitting position without trunk rotation on the treatment table, the participants extended their ankle joints over the base line of the treatment table. While maintaining the pelvis in neutral position, the active maximum DF angles in both legs and the VAS scores were measured. The left upper body was made to rotate

rightward in trunk rotation. Trunk rotation was only applied to the upper trunk, and caution was taken to prevent an anterior or posterior tilt due to the axial rotation of the lower trunk. A belt fixed the position of the upper limb to prevent the pelvis from elevating off the treatment table during trunk rotation. While maintaining trunk rotation, the active maximum DF angles of the right leg (contralateral side) and left leg (ipsilateral side) and the VAS scores were measured.

2.3. Data Analysis

The Shapiro-Wilk test was performed for normality. The Friedman test was performed to compare the DF ROM and VAS score among the different postures in each leg. The post hoc Wilcoxon signed-rank test was performed and the significance level was set at $p < 0.05$. In addition, Wilcoxon signed-rank tests were performed to compare the DF ROM and VAS score between the ipsilateral and contralateral lower extremities. Data analysis was performed using IBM SPSS Statistics 25 (IBM Corp., Armonk, NY, USA).

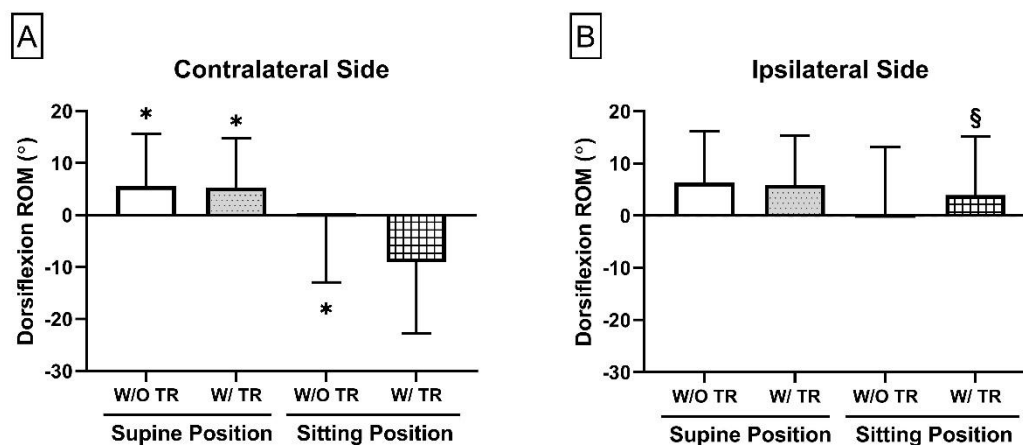
3. Results

In the four different postures, significant differences were observed in the DF ROM in the contralateral leg

($\chi^2(3)=20.323$, $p < 0.001$), VAS score in the contralateral leg ($\chi^2(3)=39.906$, $p < 0.001$), and VAS score in the ipsilateral leg ($\chi^2(3)=28.276$, $p < 0.001$), but not in the DF ROM in the ipsilateral leg ($\chi^2(3)=7.034$, $p=0.071$).

In the contralateral lower extremity, the DF ROM in the sitting position with trunk rotation was significantly different compared with those in the sitting position without trunk rotation ($Z=-3.283$, $p=0.001$), in the supine position with trunk rotation ($Z=-3.262$, $p=0.001$), and in the supine position without trunk rotation ($Z=-3.246$, $p=0.001$; Figure 2a). The VAS score in the sitting position with trunk rotation was significantly different from those in the sitting position without trunk rotation ($Z=-3.736$, $p < 0.001$), in the supine position with trunk rotation ($Z=-3.564$, $p < 0.001$), and in the supine position without trunk rotation ($Z=-3.481$, $p < 0.001$; Figure 3a). In addition, the VAS score in the sitting position without trunk rotation was significantly different from that in the supine position without trunk rotation ($Z=-3.461$, $p=0.001$).

In the ipsilateral lower extremity, the VAS score in the sitting position with trunk rotation was significantly different from those in the supine position with trunk rotation ($Z=-2.994$, $p=0.003$) and in the supine position without trunk rotation ($Z=-3.429$, $p=0.001$; Figure 3b). In addition, the VAS score in the sitting position without trunk rotation was significantly different from that in the supine position without trunk rotation ($Z=-2.992$, $p=0.003$).

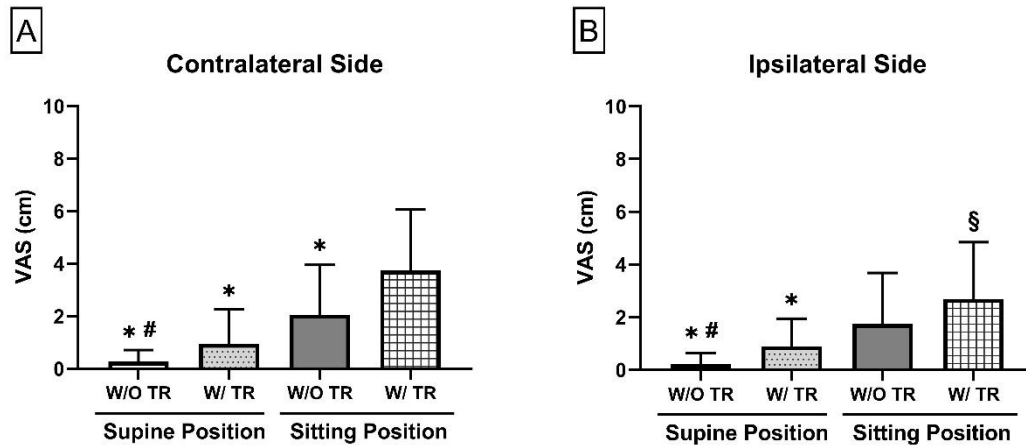


ROM, range of motion; W/O TR, without trunk rotation; W/TR, with trunk rotation

*Significantly different compared with the dorsiflexion ROM in the sitting position with trunk rotation

\$Significantly different compared with the dorsiflexion ROM on the contralateral side

Figure 2. Changes in dorsiflexion range of motion in the contralateral (A) and ipsilateral lower extremities (B)



VAS, visual analog scale; W/O TR, without trunk rotation; W/TR, with trunk rotation

*Significantly different compared with the VAS in the sitting position with trunk rotation

#Significantly different compared with the VAS in the sitting position without trunk rotation

§Significantly different compared with the VAS on the contralateral side

Figure 3. Changes in pain in the contralateral (A) and ipsilateral lower extremities (B)

In the comparison between the ipsilateral and contralateral legs, significant differences were found in the DF ROM ($Z=-3.745$, $p<0.001$) and VAS score ($Z=-3.064$, $p=0.002$) in the sitting position with trunk rotation.

4. Discussion

The POS is composed of passive connective tissues such as fascia and aponeurosis that link the upper body to the lower limb posteriorly by connecting the latissimus dorsi, thoracolumbar fascia, and hamstrings [30,31]. Passive tension produced during dynamic movement can be stored in passive connective tissues as they are lengthened and released as they are shortened. This mechanism plays a crucial role in the optimal energy cost [13–16]. Previous studies showed the relationships between the upper body and gluteus maximus during gait and between the upper body and hamstrings during prone hip extension [23,24,32]. However, whether the upper portion of the POS is connected to the lower leg below the hamstring, including the ankle joint, is yet to be determined. Most previous studies examined either changes in ankle ROM according to the pelvic, hip, and knee position and/or spinal curvature or the opposite of hip flexion according to ankle position [17–22]. To understand the POS, it is more fitting to verify changes in DF ROM after setting the rotation in the transverse plane as an independent variable instead of flexion/extension in the sagittal plane because it obliquely crosses the upper and lower limb posteriorly. This study verified whether tensile force generated by trunk rotation is transmitted to the contralateral terminal end by examining changes in DF ROM.

In the contralateral lower extremity, significant differences in DF ROM and VAS score were found. However, a significant decrease was only observed in the sitting position with trunk rotation. In the supine position, trunk rotation did not affect the DF ROM. It might be difficult to make tissues such as the POS that travel long distances taut through only motions occurring at a single joint. The entirety of the elongated tissue must be sufficiently lengthened to transmit tensile force [33]. Taken together, it can be assumed that the length of the POS is not short because the influence of the POS was limited in the supine position. Without trunk rotation from the supine to the sitting position, the DF ROM was decreased by 5.9° , but not statistically significantly. Previous studies showed that hip position significantly influenced ankle ROM. Mitchell reported a significant decrease in active ankle ROM when the position was changed from supine to long sitting. In other studies, lesser hip flexion was observed when the ankle was fixed in the DF than in plantar flexion [17,21]. Although decreased ankle ROM in the sitting position was similarly observed in this study, no significant difference was found. The inconsistency with the previous studies might be due to the small number of participants in the present study having low statistical power. In addition, approximately 98° hip flexion can be allowed even at DF with full knee extension [17]; therefore, hip flexion might not be enough to induce passive tension significantly affecting ankle ROM. In the sitting position with trunk rotation, the DF ROM significantly decreased compared with those in the supine position with trunk rotation and in the sitting position without trunk rotation. In the sitting position, hip flexion makes the contractile and non-contractile and/or neural tissues of the posterior body taut [18,21,33], and any additional trunk rotation will produce tensile force in

a diagonal direction, which will significantly influence the DF ROM on the contralateral side. The fact that the greatest pain occurred during DF in the sitting position with trunk rotation indicates that the tissue in this position experiences the greatest tautness. Some studies examined the interconnection between the latissimus dorsi and hamstrings by the POS [23,24,32]. However, whether the POS is connected by the terminal end of the extremity has not been examined yet. The present study demonstrated that the posterior upper body is anatomically connected to the contralateral lower leg by the POS through restricted DF ROM during trunk rotation in the contralateral lower extremity.

As two links symmetrically cross each other in the POS to connect the upper body and lower limb (as in the form of butterfly wings), this should be further examined on the ipsilateral side [31]. In the ipsilateral lower extremity, although a significant difference in VAS score was found, no significant difference in DF ROM was observed. In the supine position, trunk rotation did not significantly affect the DF ROM in the ipsilateral lower extremity because tissues in the posterior body are already loose enough in the supine position. That is, even when the POS is additionally loosened through trunk rotation, it does not cause an increase in DF ROM. Similar to the contralateral lower extremity, the DF ROM was decreased by 6.1° in the sitting position compared with that in the supine position. The most important finding on the ipsilateral side was that the DF ROM in the sitting position increased by 3.6° when comparing between with and without trunk rotation. When comparing the DF ROM in the contralateral and ipsilateral lower extremities, a statistically significant difference was observed only in the sitting position with trunk rotation. Trunk rotation in the sitting position lowers the mobility of the contralateral lower extremity, while partially increasing the mobility of the ipsilateral lower extremity. According to the anatomical structure of the POS during rotation in the transverse plane, one of the links is lengthened and made taut, while the other is shortened and made loose. In other words, the increased DF ROM in the ipsilateral lower extremity in this study also demonstrates that the anatomical characteristics of the POS influence the DF ROM. In a cadaver dissection, passive connective tissues linking the thigh to the lower leg were found, composed of the fascia lata, femoral intermuscular septa, crural intermuscular septa, and interosseous membrane [27]. In addition, tensions induced by changes in hip and ankle positions are transmitted along the neural tissues such as the sciatic, tibial, and plantar nerves from the hip to ankle [28]. These connective systems with the POS play a role in transmitting tensile forces at the upper body to the contralateral ankle and feet. Pain was highest in the sitting position with trunk rotation and significantly lower than that in the contralateral lower extremity. In the sitting position with trunk rotation, although partial increase in

DF ROM due to laxity of the POS was observed, the VAS score did not decrease and was actually highest in this position. This is probably due to the fact that the measured pain did not exclusively arise from the ipsilateral lower extremity. In a previous study, the location of the pain or discomfort that occurred during a slump test was not limited to the posterior leg, and the same finding was observed in healthy adults with no neurological history and symptoms [34,35].

Active DF was used in this study in the measurement of ankle ROM. Pain and/or discomfort may occur before reaching the end range during active DF, which may cause a reluctance in or cessation of movement even though additional movement is possible. Using passive DF to measure ankle ROM may have been more appropriate because this study aimed to verify whether the upper body and lower limb are crossly linked by the POS. In addition, when pain was assessed, the quantitative measurement of pain was verified but not the area of occurrence. In a study by Kuilart, pain or discomfort occurred in various areas during a slump test and was most frequent in the posterior knee by 66.7%, followed by the posterior thigh, posterior leg, buttocks, and lumbar in the respective ratios of 35.7%, 33.3%, 14.3%, and 11.8% [34]. The areas of pain occurrence must be accurately recorded in the following studies.

In the sitting position with trunk rotation, a significant decrease in DF ROM in the contralateral lower extremity and a slight increase DF ROM in the ipsilateral lower extremity were observed. Such findings signify that the upper portion of the POS passes through thoracolumbar fascia and is connected all the way down to the contralateral hamstrings and calf. Furthermore, because the two links of the POS are symmetrical to each another, they can partially affect the ipsilateral lower extremities. Rather than solely relying on stretching the calf muscles, the POS must be considered during the clinical treatment of patients with restricted DF mobility.

Acknowledgements

This research was supported by 2020 Woosong University Academic Research Funding.

REFERENCES

- [1] I. Reuter, O. Lorbach, S. Mehnert, M. Kaps, M. Engelhardt. Botulinum toxin improves reduced dorsiflexion after Achilles tendon surgery, *Knee Surg Sports Traumatol Arthrosc*, 18, 265–268, 2010.
- [2] J.W. Youdas, T.J. McLean, D.A. Krause, J.H. Hollman. Changes in active ankle dorsiflexion range of motion after acute inversion ankle sprain, *J Sport Rehabil*, 18, 358–374, 2009.

- [3] C.-W.C. Lin, A.M. Moseley, R.D. Herbert, K.M. Refshauge. Pain and dorsiflexion range of motion predict short- and medium-term activity limitation in people receiving physiotherapy intervention after ankle fracture: an observational study, *Aust J Physiother*, 55, 31–37, 2009.
- [4] J. Crosbie, T. Green, K. Refshauge. Effects of reduced ankle dorsiflexion following lateral ligament sprain on temporal and spatial gait parameters, *Gait Posture*, 9, 167–172, 1999.
- [5] M. Svehl k, E.B. Zwick, G. Steinwender, V. Saraph, W.E. Linhart. Genu recurvatum in cerebral palsy--part A: influence of dynamic and fixed equinus deformity on the timing of knee recurvatum in children with cerebral palsy, *J Pediatr Orthop B*, 19, 366–372, 2010.
- [6] D.C. Kerrigan, L.C. Deming, M.K. Holden. Knee recurvatum in gait: a study of associated knee biomechanics, *Arch Phys Med Rehabil*, 77, 645–650, 1996.
- [7] S.C. Landry, K.A. McKean, C.L. Hubley-Kozey, W.D. Stanish, K.J. Deluzio. Knee biomechanics of moderate OA patients measured during gait at a self-selected and fast walking speed, *J Biomech*, 40, 1754–1761, 2007.
- [8] D. Porter, E. Barrill, K. Oneacre, B.D. May. The effects of duration and frequency of Achilles tendon stretching on dorsiflexion and outcome in painful heel syndrome: a randomized, blinded, control study, *Foot Ankle Int*, 23, 619–624, 2002.
- [9] J.A. Radford, J. Burns, R. Buchbinder, K.B. Landorf, C. Cook. Does stretching increase ankle dorsiflexion range of motion? A systematic review, *Br J Sports Med*, 40, 870–875, 2006.
- [10] D.M. Medeiros, T.F. Martini. Chronic effect of different types of stretching on ankle dorsiflexion range of motion: Systematic review and meta-analysis, *Foot (Edinb)*, 34, 28–35, 2018.
- [11] M.A. Johanson, B.J. Cuda, J.E. Koontz, J.C. Stell, T.A. Abelew. Effect of stretching on ankle and knee angles and gastrocnemius activity during the stance phase of gait, *J Sport Rehabil*, 18, 521–534, 2009.
- [12] F.H. Silver, G.P. Seehra, J.W. Freeman, D. DeVore. Viscoelastic properties of young and old human dermis: A proposed molecular mechanism for elastic energy storage in collagen and elastin, *Journal of Applied Polymer Science*, 86, 1978–1985, 2002.
- [13] A. Vleeming, R. Stoeckart. The role of the pelvic girdle in coupling the spine and the legs: a clinical–anatomical perspective on pelvic stability, in: *Movement, Stability & Lumbopelvic Pain*, Elsevier, 2007: pp. 113–137.
- [14] T.A. Dorman. Storage and release of elastic energy in the pelvis: dysfunction, diagnosis and treatment, *Journal of Orthopaedic Medicine*, 14, 54–62, 1992.
- [15] Y.S. Yoon, J.M. Mansour. The passive elastic moment at the hip, *J Biomech*, 15, 905–910, 1982.
- [16] T.J. Roberts. Contribution of elastic tissues to the mechanics and energetics of muscle function during movement, *J Exp Biol*, 219, 266–275, 2016.
- [17] T.B. Palmer, K. Akehi, R.M. Thiele, D.B. Smith, A.J. Warren, B.J. Thompson. Dorsiflexion, plantar-flexion, and neutral ankle positions during passive resistance assessments of the posterior hip and thigh muscles, *J Athl Train*, 50, 467–474, 2015.
- [18] [B. Mitchell, E. Bressel, P.J. McNair, M.E. Bressel. Effect of pelvic, hip, and knee position on ankle joint range of motion, *Phys Ther Sport*, 9, 202–208, 2008.
- [19] A. Breig, J.D. Troup. Biomechanical considerations in the straight-leg-raising test. Cadaveric and clinical studies of the effects of medial hip rotation, *Spine*, 4, 242–250, 1979.
- [20] [20] T. Hall, M. Zusman, R. Elvey. Adverse mechanical tension in the nervous system? Analysis of straight leg raise, *Manual Therapy*, 3, 140–146, 1998.
- [21] [21] R.L. Gajdosik, B.F. LeVeau, R.W. Bohannon. Effects of ankle dorsiflexion on active and passive unilateral straight leg raising, *Phys Ther*, 65, 1478–1482, 1985.
- [22] R.A. Boland, R.D. Adams. Effects of ankle dorsiflexion on range and reliability of straight leg raising, *Aust J Physiother*, 46, 191–200, 2000.
- [23] J.-K. Lee, J.-H. Hwang, C.-M. Kim, J.K. Lee, J.-W. Park. Influence of muscle activation of posterior oblique sling from changes in activation of gluteus maximus from exercise of prone hip extension of normal adult male and female, *J Phys Ther Sci*, 31, 166–169, 2019.
- [24] I. Jeon, S. Ha, U. Hwang, S. Jung, H. Kim, O. Kwon. Comparison of EMG activity of the posterior oblique sling muscles and pelvic rotation during prone hip extension with and without lower trapezius pre-activation, *Physical Therapy Korea*, 23, 80–86, 2016.
- [25] S.-M. Ha, I.-C. Jeon. Comparison of the electromyographic recruitment of the posterior oblique sling muscles during prone hip extension among three different shoulder positions, *Physiotherapy Theory and Practice*, 1–8, 2019.
- [26] D. Kang, Y.-I. Hwang. Comparison of muscle activities of the posterior oblique sling muscles among three prone hip extension exercises with and without contraction of the latissimus dorsi, *Journal of the Korean Society of Physical Medicine*, 14, 39–45, 2019.
- [27] U.J. Gerlach, W. Lierse. Functional construction of the superficial and deep fascia system of the lower limb in man, *Acta Anat (Basel)*, 139, 11–25, 1990.
- [28] M.W. Coppieters, A.M. Alshami, A.S. Babri, T. Souvlis, V. Kippers, P.W. Hodges. Strain and excursion of the sciatic, tibial, and plantar nerves during a modified straight leg raising test, *J Orthop Res*, 24, 1883–1889, 2006.
- [29] D. Oh, W. Lim, N. Lee. Concurrent Validity and Intra-Trial Reliability of a Bluetooth-Embedded Inertial Measurement Unit for Real-Time Joint Range of Motion, *International Journal of Computer Science in Sport*, 18, 1–11, 2019.
- [30] P.J. Barker, C.A. Briggs. Attachments of the posterior layer of lumbar fascia, *Spine*, 24, 1757–1764, 1999.
- [31] A. Vleeming, A.L. Pool-Goudzwaard, R. Stoeckart, J.P. van Wingerden, C.J. Snijders. The posterior layer of the thoracolumbar fascia. Its function in load transfer from spine to legs, *Spine*, 20, 753–758, 1995.
- [32] S.-J. Shin, T.-Y. Kim, W.-G. Yoo. Effects of various gait speeds on the latissimus dorsi and gluteus maximus muscles associated with the posterior oblique sling system, *J Phys*

Ther Sci, 25, 1391–1392, 2013.

- [33] E.K. Johnson, C.M. Chiarello. The slump test: the effects of head and lower extremity position on knee extension, *J Orthop Sports Phys Ther*, 26, 310–317, 1997.
- [34] K.E. Kuilart, M. Woollam, E. Barling, N. Lucas. The active knee extension test and Slump test in subjects with perceived hamstring tightness, *International Journal of Osteopathic Medicine*, 8, 89–97, 2005.
- [35] D.S. Davis, I.B. Anderson, M.G. Carson, C.L. Elkins, L.B. Stuckey. Upper limb neural tension and seated slump tests: the false positive rate among healthy young adults without cervical or lumbar symptoms, *J Man Manip Ther*, 16, 136–141, 2008.