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Original Article

Effects of pelvic compression belts on the kinematics and kinetics of the lower extremities during sit-to-stand maneuvers

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Abstract. [Purpose] To investigate the effects of a pelvic compression belt (PCB) and chair height on the kinematics and kinetics of the lower extremity during sit-to-stand (STS) maneuvers in healthy people. [Subjects and Methods] Twenty-two people participated in this study. They were required to perform STS maneuvers under four conditions. Hip joint moment and angular displacement of the hip, knee, and ankle were measured. A PCB was also applied below the anterior superior iliac spine. [Results] The angular displacement of the ankle joint increased while performing STS maneuvers from a normal chair with a PCB in phase 1, and decreased during phase 2 when performing STS maneuvers from a high chair. The overall angular displacement in phase 3 was decreased while rising from a chair with a PCB and rising from a high chair. When performed STS maneuvers from a high chair, the angular displacement of the hip, knee, and ankle joint decreased considerably in phase 3. This decreased lower extremity motion in phase 3 indicated that participants required less momentum to complete the maneuver. [Conclusion] The results of this study suggest that a PCB might be appropriate for patients with pelvic girdle pain and lower back pain related to pregnancy.

Key words: Pelvic compression belt, Kinematics and kinetics of the lower extremity, Sit-to-stand

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INTRODUCTION

Pelvic girdle pain and lower back pain related to pregnancy can be relieved by applying a pelvic compression belt (PCB)[1, 2]. The major benefit of PCBs is that they provide stability via external compression force through the ilium bone to the sacroiliac joint (SIJ)[3]. The SIJ is an axial joint surrounded at the iliac bone by synovial fluid[4]. The SIJ is inherently vulnerable to vertical shearing force loads because of its shape. Furthermore, the entire weight-bearing pressure is transmitted to the hip joint via the SIJ during standing.

It has been suggested that the stability of the SIJ depends on force closure, referred to as 'the self-bracing mechanism against shear'[5, 6]. Additional muscular systems and ligament forces in the region of the SIJ are essential for force closure[5, 6]. Because the self-bracing mechanism requires a transverse plane-oriented force, it has been assumed that contraction of the transverse and oblique abdominal muscles decreases SIJ laxity[7]. A PCB could also provide a reduction of SIJ laxity. A number of studies have investigated the effects of PCBs on SIJ laxity in pelvic girdle pain patients[1, 2] and asymptomatic

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individuals[8]. There is a significant decrease in SIJ laxity associated with the position of the PCB, rather than its tension[8], and it has been suggested that the application of a PCB just below the anterior superior iliac spine (high position) was more effective than at the level of the pubic symphysis (low position).

Manual pelvic compression or the use of a PCB might improve the active straight leg raise (ASLR) maneuver[1, 3], which is facilitated by the proper activation of muscles, including the abdominis, gluteus maximus, and biceps femoris. A significant reduction of the activity of transverse and oblique abdominal muscles (rectus femoris and biceps femoris) has been observed when a PCB is applied during ASLR and treadmill walking[9], and an increase in gluteus medius and lumbar multifidus muscle activities was demonstrated during side-lying hip abduction[10]. It has been suggested that these changes in muscle activation might encourage lumbo-pelvic stability and support the force closure theory.

Even though many previous studies have examined various aspects of the effect of PCBs, including ASLR-related[3] muscle activation[9] and SIJ laxity[2, 8], almost all experiments were conducted in the supine or prone position. These positions can lead to relaxation of the muscles and some related ligaments (e.g. the sacrotuberous ligament)[11] essential for lumbo-pelvic stability. Therefore, it is necessary to conduct experiments under dynamical conditions. The functional and biomechanical aspects of these movements have received much less attention. Sit-to-stand (STS) maneuvers are an essential prerequisite condition for walking[12] and many functional independence tasks[13]. Biomechanically, the generation of a propulsive impulse is an essential factor, and because STS is related to weight transfer, adequate reverse impulse must be necessary[14]. STS also requires both relatively large joint momentum and the ability to control balance[15].

A previous study found that rising from a chair produces large moment magnitudes, especially at the hip and knee joints[16]. The magnitude of angular displacement and moment at the hip joint was even greater during STS maneuvers than those during stair-climbing or walking[17]. Many patients with pelvic girdle pain or lower back pain experience severe pain even during normal activities, such as sitting and walking[6], in addition to during dynamic activities such as STS maneuvers.

Although PCBs might be useful devices for these patients, the literature regarding the biomechanical aspects of the use of PCBs is currently insufficient. Many previous studies of STS maneuvers have indicated that the overall mechanical demand imposed on the lower extremities decreases with increased seat height and the use of a hand rail[18, 19]. If a PCB does provide stability via external compression forces (surrounding the SIJ area) and increasing SIJ laxity, the angular displacement and moment of the lower extremities will be reduced during dynamic activities such as STS maneuvers. Furthermore, reductions in joint moment are related to reduced damage to the joint structures[20]. Therefore, it is important to investigate the influence of applying PCBs and the continuous dynamic interactions between the hip, knee, and ankle joint while subjects perform STS maneuvers.

With the above in mind, the aim of the present study was to investigate the effects of PCBs and chair height on lower extremity mechanics during STS maneuvers in asymptomatic adults. It was hypothesized that the application of PCBs and two different chair heights would reveal differences in the kinematics and kinetics of the lower extremities during STS maneuvers. Specific differences were as follows: (1) the reduction of ankle angular displacement in phase 1; (2) the reduction of ankle and knee angular displacement in phase 2; and (3) the reduction of hip angular displacement and moment in phase 3.

SUBJECTS AND METHODS

Twenty-two healthy volunteers (mean age=30.1 ± 5.1 years, age range: 23–39) were recruited. Table 1 describes the physical characteristics of the participants. The inclusion criteria for participation were as follows: (1) leg length discrepancy<1 cm; (2) within the normal range of 8–15 degrees on the Craig test; and (3) range of motion at the hip joint within the normal range (30–45 degrees). The exclusion criteria for participation were as follows: (1) difficulty performing ASLR; (2) nonspecific lower back pain with the following symptoms: SIJ pain, nerve root irritation, neurogenic claudication; and (3) history of spinal surgery. Before the experiment, all participants were fully informed of the purpose of the trial and the potential risks. They then signed informed consent forms. Participants who requested to withdraw during the course of the study were excluded from the analysis and their data are not presented. This study was conducted with the permission of the Korea University Institutional Review Board (IRB No: KU-IRB-13–15-A-2).

One force plate (AMTI OR6-7, Newton, MA, USA) was used to measure the ground reaction force at a sampling rate of 1,000 Hz. The three-dimensional kinematics of the lower extremities were captured using VICON motion systems cameras (six-camera T10 model, Oxford Metrics Ltd., Oxford, UK) at a sampling rate of 100 Hz. These two devices were synchronized with each other, and Nexus software (1.7.1, Oxford Metrics Ltd., Oxford, UK) was used to collect the readings.

According to the Plug in Gait Full Body Marker Set instructions[21], 35 infrared reflective markers (14-mm spheres) were placed at specific anatomical landmarks, and the 5-marker wand and L-frame bar were used in the calibration process. Head marker locations included the left and right front of the head (temple) and the back of the head (back of the temple). Torso marker locations included the 7th cervical spinous process (C7), the thoracic spinous process (T10), the clavicle, the sternum, and the right of the back. Upper limb marker locations included the left and right shoulders, upper arm, elbow, forearm, wrist A-B, and finger. Lower body marker locations included the left and right anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS). Lower limb markers included the left and right thigh, knee, tibia, ankle (along the lateral malleolus), heel (on the calcaneus), and toe (over the second metatarsal head).

The PCB (COM-PRESSORTM, OPTP, Minneapolis, USA) used is shown in Fig. 1. The height of a standard chair (arm-

Table 1. Summary of subject demographics

Subjects (n=22)	Mean ± SD	Range
Age (years)	30.1 ± 5.1	
Gender	Male 11	
	Female 11	
Weight (kg)	66.2 ± 9.7	52–85
Height (cm)	171.6 ± 7.6	160–184
Leg length (mm)*		
Right leg	892.9 ± 50.7	825–990
Left leg	894.5 ± 50.6	830–990

Values are in mean, SD: standard deviation.
*measured from both anterior superior iliac spine to medial malleolus.

Fig. 1. Pelvic compression belt

less and backless and the same as the height of a subway chair) was defined as 0.44 m[22] from the floor, and the height of a high chair was determined by adding 0.24 m[23] to the standard chair. The PCB is an adjustable body belt with four elastic compression bands, which can vary the magnitude and location of the pressure applied by the belt. We used the ASLR test to determine the position of compression[24]. In the ASLR procedure, all subjects were asked to raise both legs (no more than 12 inches) with ankle dorsiflexion and to determine which leg felt heavier or more difficult to lift. The examiner then placed his/her hands in four locations (on the transverses abdominis, multifidus, right transverses abdominis and left multifidus, and left transverses abdominis and right multifidus). The examiner determined where the compression was needed on the participant's pelvis by observing which hand placement location made it the easiest for the subject to lift the relevant leg.

Prior to the experiment, body segments were measured using an anthropometer (Model 21291, Lafayette Instrument Company, IN, USA). True leg length was measured from the ASIS to the highest point of the medial malleolus on each leg. The height of the standard chair was adjusted to 80% of each participant's knee height[22] and the initial degree of the ankle was 15° of dorsiflexion[25]. The crossed hand position may alter the center of mass (COM), especially in the anterior and upward direction[26]. Therefore, the participants sat in an upright posture with bare feet (both feet on the force-plate), with their hands placed freely on the hip or thigh and with the thigh parallel to the ground to prevent forward momentum (Fig. 2).

The participant was then instructed to stand in a comfortable manner according to a metronome-determined (PC 9 virtual metronome, Chord Pulse, Germany) speed (69 clicks/min). Total movement time was set as three beats[27]. In order to provide visual information, participants were requested to look at the metronome monitor located 3 m in front of them. Participants performed several trials before the actual measurements were taken. STS was repeated five times, and appropriate rest was allowed between each trial to avoid fatigue. The experiment was conducted under four conditions: (1) STS; (2) STS with a belt (STS Belt); (3) STS on a high chair (STS High); and (4) STS with a belt on a high chair (STS Belt High).

In this study, the experiments were organized into three consecutive phases. In the first phase, the trunk and pelvis rotated anteriorly (forward flexion) until the buttocks lifted off the chair, while the lower segments remained stationary. In the second phase, the flexion-momentum of the upper body transferred in the upward and anterior directions and the COM moved anteriorly and upward (initiation of weight transfer from the chair to the feet). In the last phase, the COM moved almost vertically[22]. The actions used to define the three phases are as follows: phase 1: from the initial anterior movement of the C7 until the buttocks lifted off the seat; phase 2: from initial movement of the buttocks to maximum ankle dorsiflexion; and phase 3: from maximum ankle dorsiflexion to knee extension, hip extension, and finally trunk extension[22] (Fig. 3).

All experimental trials were conducted five times per participant, and the three most consistent data points were used in the analysis. If a separation of marker trajectory was indicated, BodyBuilder software was used to perform marker swapping. The butterworth filter was applied to kinematic and kinetic data after collection. The total duration of STS maneuvers was normalized to a 100% scale using polygon software (Oxford Metrics Ltd., Oxford, UK). Polygon software requires the events that are associated with the time-dependent data in order to identify key points in time when significant actions occur. Thus, three key events were used in the normalization process. Angular displacement of the hip, knee, and ankle joint was estimated as the maximum rotational angle minus the minimum rotational angle at each phase, and only the sagittal plane was considered.

Statistical analyses were completed using SPSS 18 (PASW Statistics 18). Normality was assessed for each of the dependent variables. Two-way analysis of variance was used to assess the relationships between the independent variables (PCB, chair height) and dependent variables, including angular displacement of the hip, knee, and ankle joint, and hip moment. For all statistical tests, the type-I error rate was set at 0.05.

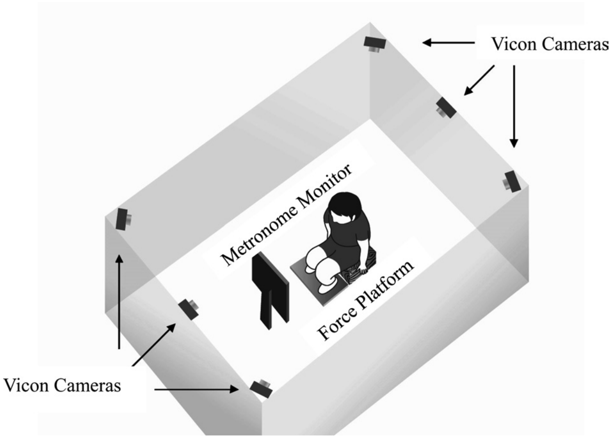

Fig. 2. Experimental set-up

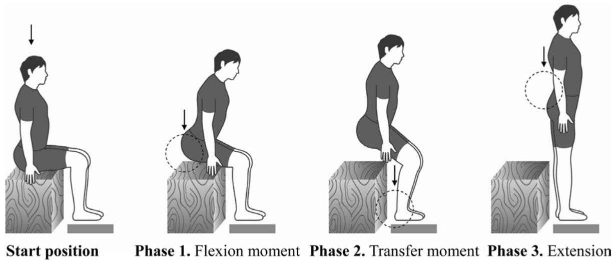

Fig. 3. Three phases of sit-to-stand maneuvers
Phase 1: move C7 anteriorly to until the buttocks lift off from the chair.
Phase 2: lift buttocks until maximum ankle dorsiflexion is achieved.
Phase 3: maximum ankle dorsiflexion to full hip extension.

RESULTS

Three phases were identified from the frame at which each critical event occurred. The first phase, in which maximal trunk flexion occurred, is illustrated in Fig. 3. The angular displacement during STS Belt High was nearly the same as that during STS in all three segments. The angular displacement of the hip and knee was slightly decreased during STS Belt. Increased angular displacement at the ankle joint ($F_{1,84}$=4.470, $p<0.05$) was observed, even while wearing the PCB.

Phase 2 was characterized by the buttocks leaving the chair (Fig. 3). This stage plays a crucial role in transferring flexion momentum in the vertical direction. During STS Belt High, the angular displacement of the hip and ankle joints decreased (as during STS Belt). When rising from a high chair, the most significantly decreased angular displacement was found at the ankle joint ($F_{1,84}$=11.671, $p<0.05$).

Full trunk extension was determined according to maximum ankle dorsiflexion in phase 3 (Table 2). This third phase was completed as the C7 marker reached its maximum posterior as well as the anterior superior iliac spine. The overall tendency of angular displacement was to decrease while the belt and two different heights of a chair were used. The angular displacement of the hip joint significantly decreased during STS Belt ($F_{1,84}$=4.087, $p<0.05$) and STS High ($F_{1,84}$=4.401, $p<0.05$). When participants performed STS maneuvers from a high chair, the angular displacement of the knee ($F_{1,84}$=28.703, $p<0.05$) and ankle joint ($F_{1,84}$=15.043, $p<0.05$) decreased dramatically. The overall rotational angles for the hip, knee, and ankle joints along the sagittal plane are presented in Table 2.

The results of transverse moment measurements are presented in Table 3. Regardless of the phase of the STS maneuvers, the overall values decreased more during STS Belt than during STS High. A statistically significant difference was found at STS Belt at phase 3 ($F_{1,84}$=4.680, $p<0.05$).

DISCUSSION

Laxity of the SIJ is reported to be the main cause of lower back pain, and pregnancy-related pelvic girdle pain in particular[28)]. Because the major role of the SIJ is stability rather than mobility, this large joint is well suited to helping with weight transfer from the torso[29)]. A PCB may provide symptomatic relief by increasing the intra-articular compression force of the SIJ[1)]. STS maneuvers are a biomechanically valid and reliable task for assessing load transfer through the pelvis[30)], and are therefore well suited to determining how much load is put on the lower leg segments.

This is the first study to examine the combined effects of PCBs and different chair heights. In this study, angular displacement and moment were examined during STS maneuvers to determine the effect of PCBs and chair height. Kinematic and kinetic values decreased in all PCB and chair height conditions during STS maneuvers. Reductions in moment and angular displacement have been reported when a high chair (0.64 m) is used instead of a normal chair (0.43 m)[23)]. The results of the present study indicated that the kinematic values of the hip, knee, and ankle joints considerably decreased during phase 3. This finding was similar to those of previous studies[16)]. A reasonable explanation for this could be that decreased joint angle shortens the lever arm. This shorter lever arm then decreases angular displacement. The reduced lower extremity motion observed during phase 3 suggests that participants required less momentum to rise from a high chair than a normal chair. This represents the best compromise in decreasing muscular effort, and is an effective strategy for helping relevant patients to stand up[19)].

Contrary to our expectations, an increase in ankle angular displacement was observed with the use of a PCB during phase 1. This finding was inconsistent with the results of Burdett's study[23)] and consistent with the findings of Munro's study[31)].

Table 2. Means and standard deviations of the lower extremity angular displacement during three phases

Joint segment	Standard chair Without belt	With belt	High chair Without belt	With belt
Hip angle (°)				
Phase 1	5.7 ± 4.3	4.3 ± 2.8	5.1 ± 3.2	5.8 ± 4.6
Phase 2	19.2 ± 4.6	18.5 ± 3.6	19.1 ± 4.9	17.9 ± 4.7
Phase 3¶*	69.3 ± 8.7	65.5 ± 10.1	65.3 ± 13.0	59.9 ± 10.3
Knee angle (°)				
Phase 1	1.1 ± 0.7	1.0 ± 1.2	1.1 ± 1.1	1.1 ± 1.5
Phase 2	20.6 ± 7.0	19.2 ± 8.4	19.6 ± 8.5	20.7 ± 7.8
Phase 3¶	66.4 ± 9.8	65.9 ± 10.3	54.3 ± 13.1	54.4 ± 9.4
Ankle angle (°)				
Phase 1*	1.1 ± 0.7	1.4 ± 1.0	1.0 ± 0.7	1.4 ± 1.2
Phase 2¶	12.8 ± 6.1	13.6 ± 4.8	9.6 ± 4.5	10.1 ± 3.8
Phase 3¶	22.1 ± 7.0	21.7 ± 6.4	16.1 ± 7.2	17.1 ± 6.0

*Significant main effect for with belt condition (p<0.05).
¶Significant main effect for height of chair condition (p<0.05).

Table 3. Maximum means and standard deviations of the hip joint moment during three phases

Three phases	Standard chair Without belt	With belt	High chair Without belt	With belt
Phase 1	0.16 (0.10)	0.13 (0.10)	0.14 (0.09)	0.12 (0.09)
Phase 2	0.16 (0.10)	0.13 (0.10)	0.14 (0.08)	0.12 (008)
Phase 3*	0.11 (0.06)	0.09 (0.06)	0.10 (0.06)	0.08 (0.05)

Values are in Nm/body mass.
*Significant main effect for belt condition (p<0.05).

Because flexion momentum in phase 1 was inherently stable, it was interesting that ankle angular displacement increased even by 3 degrees. In the present study, it is possible that participants could not stand up without gaining momentum when using a PCB. A PCB might compress the hip joint, thus reducing the motion of the joint. This will lead to the need for external compensation force at the ankle joint, particularly during flexion momentum. As a result, a fixed hip joint might lead to an increase in ankle angular displacement.

Regardless of seat height or PCB use, displacement of the COM was especially critical in phase 2. The momentum transfer in phase 2 requires the COM to be far away from the body. Many studies have reported that decreased displacement of the COM allows participants to locate the body weight near the base of support, providing greater stability[15, 32]. In phase 2, the body begins to rely on dynamic stability[22]. In order to maintain dynamic stability, minimum displacement of the COM and lower segments must be achieved. In phase 2, the significant main effect of angular displacement was presented at the ankle joint during STS maneuvers. While reductions of hip and knee angular displacement were present, there was no significant difference between the conditions. It seems that considerably reduced angular displacement of the ankle joint might help patients to stand up effectively and support dynamic stability.

The third phase is biomechanically distinct in that the COM of the entire body translates vertically. Therefore, angular displacement is very large in this phase in order to keep the torso upright. For this reason, the largest reduction in moment and angular displacement was expected in phase 3. In all conditions (PCB and chair height), a significant reduction of angular displacement at the hip joint was found in phase 3. Since the ability to rise from a chair requires the greatest horizontal momentum at the hip joint[16], only the hip joint was analyzed. It is widely accepted that a high chair can positively influence dynamic activities such as STS maneuvers. Greater reductions in moment were detected while participates rose from a chair while wearing a PCB than when participants performed the same action without the PCB. A statistically significant difference was found at phase 3 between the two conditions. These results indicated that the distribution of joint moment can be manipulated by wearing a PCB. Although decreased moment values at phases 1 and 2 in the three conditions were observed, no significant differences were found. The reduction of hip angular displacement and moment at phase 3 may indicate that the SIJ does not a require degree of large motion or effort in order to extend the hip. It is possible that stability of the SIJ can be achieved by reducing the movement of the SIJ using a PCB during STS maneuvers. We measured the maximum ground reaction force (MGRF) only in the vertical plane. Although a decrease in MGRF was evident in both PCB and chair height conditions, there were no statistically significant differences.

There are several limitations in the present study that should be discussed. First, the speed at which patients rose from the chair using a metronome was controlled. Although this allowed us to normalize the data compared to those obtained during natural maneuvers, the unnatural movement may have influenced the results. Second, the four conditions in this study were each examined five times sequentially. Therefore, the learning effect was not controlled. Furthermore, the participants of this study were recruited based on their overall health. Thus, it is probable that the results of this study cannot be generalized to the wider population. Finally, only the lower segments were considered in this study. In order to clarify the findings of this study, future work should focus on assessing the relationships between the lower and upper segments.

In conclusion, the results of this study demonstrated the effect of a PCB and chair height on the kinematics and kinetics of the lower extremities during STS maneuvers. To determine whether kinetic and kinematic changes occurred, we measured the angular displacement and moment of the lower extremities (hip, knee, and ankle joints). Both seat height and the use of a PCB decreased angular displacement and moment. Although significantly increased ankle angular displacement was detected at phase 1, an overall reduction was detected in phases 2 and 3 at the hip, knee, and ankle joints.

The most significant finding of this study was the reduction of angular displacement and moment at the hip joint during phase 3. The implication of these findings is that PCBs might provide stability by decreasing exertion at the hip joint. However, it should be considered that the potential risk that applying PCBs may cause muscle weakness. Thus, further research is required to determine the negative effects of PCB use. A high chair (0.68 m) was also an effective therapeutic device when compared with a standard chair (0.44 m) because it led to a reduction of angular displacement in the lower extremity. The results of this study indicate that PCBs could be used as therapeutic instruments by both clinicians and patients with pregnancy-related pelvic girdle pain. PCBs can also be recommended for even asymptomatic individuals who have difficulty in standing up effectively.

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REFERENCES

1) Mens JM, Damen L, Snijders CJ, et al.: The mechanical effect of a pelvic belt in patients with pregnancy-related pelvic pain. Clin Biomech (Bristol, Avon), 2006, 21: 122–127. [Medline] [CrossRef]
2) Pel JJ, Spoor CW, Goossens RH, et al.: Biomechanical model study of pelvic belt influence on muscle and ligament forces. J Biomech, 2008, 41: 1878–1884. [Medline] [CrossRef]
3) Beales DJ, O'Sullivan PB, Briffa NK: The effects of manual pelvic compression on trunk motor control during an active straight leg raise in chronic pelvic girdle pain subjects. Man Ther, 2010, 15: 190–199. [Medline] [CrossRef]
4) García Díez AI, Tomás Batllé X, Pomés Talló J, et al.: [Sacroiliac joints: osteoarthritis or arthritis]. Reumatol Clin, 2009, 5: 40–43. [Medline]
5) Snijders CJ, Vleeming A, Stoeckart R: Transfer of lumbosacral load to iliac bones and legs Part 1: biomechanics of self-bracing of the sacroiliac joints and its significance for treatment and exercise. Clin Biomech (Bristol, Avon), 1993, 8: 285–294. [Medline] [CrossRef]
6) Snijders CJ, Vleeming A, Stoeckart R: Transfer of lumbosacral load to iliac bones and legs Part 2: loading of the sacroiliac joints when lifting in a stooped posture. Clin Biomech (Bristol, Avon), 1993, 8: 295–301. [Medline] [CrossRef]
7) Richardson CA, Snijders CJ, Hides JA, et al.: The relation between the transversus abdominis muscles, sacroiliac joint mechanics, and low back pain. Spine, 2002, 27: 399–405. [Medline] [CrossRef]
8) Damen L, Spoor CW, Snijders CJ, et al.: Does a pelvic belt influence sacroiliac joint laxity? Clin Biomech (Bristol, Avon), 2002, 17: 495–498. [Medline] [CrossRef]
9) Hu H, Meijer OG, van Dieën JH, et al.: Muscle activity during the active straight leg raise (ASLR), and the effects of a pelvic belt on the ASLR and on treadmill walking. J Biomech, 2010, 43: 532–539. [Medline] [CrossRef]
10) Park KM, Kim SY, Oh DW: Effects of the pelvic compression belt on gluteus medius, quadratus lumborum, and lumbar multifidus activities during side-lying hip abduction. J Electromyogr Kinesiol, 2010, 20: 1141–1145. [Medline] [CrossRef]
11) Vleeming A, Stoeckart R, Snijders CJ: The sacrotuberous ligament: a conceptual approach to its dynamic role in stabilizing the sacroiliac joint. Clin Biomech (Bristol, Avon), 1989, 4: 201–203. [CrossRef]
12) Khemlani MM, Carr JH, Crosbie WJ: Muscle synergies and joint linkages in sit-to-stand under two initial foot positions. Clin Biomech (Bristol, Avon), 1999, 14: 236–246. [Medline] [CrossRef]
13) Burnett DR, Campbell-Kyureghyan NH, Cerrito PB, et al.: Symmetry of ground reaction forces and muscle activity in asymptomatic subjects during walking, sit-to-stand, and stand-to-sit tasks. J Electromyogr Kinesiol, 2011, 21: 610–615. [Medline] [CrossRef]
14) Pai YC, Rogers MW, Naughton BJ, et al.: Control of body centre of mass momentum during sit-to-stand among young and elderly adults. Gait Posture, 1994, 2: 109–116. [CrossRef]
15) Fujimoto M, Chou LS: Dynamic balance control during sit-to-stand movement: an examination with the center of mass acceleration. J Biomech, 2012, 45: 543–548. [Medline] [CrossRef]
16) Rodosky MW, Andriacchi TP, Andersson GB: The influence of chair height on lower limb mechanics during rising. J Orthop Res, 1989, 7: 266–271. [Medline] [CrossRef]

17) Turcot K, Armand S, Fritschy D, et al.: Sit-to-stand alterations in advanced knee osteoarthritis. Gait Posture, 2012, 36: 68–72. [Medline] [CrossRef]
18) O'Meara DM, Smith RM: The effects of unilateral grab rail assistance on the sit-to-stand performance of older aged adults. Hum Mov Sci, 2006, 25: 257–274. [Medline] [CrossRef]
19) Roy G, Nadeau S, Gravel D, et al.: The effect of foot position and chair height on the asymmetry of vertical forces during sit-to-stand and stand-to-sit tasks in individuals with hemiparesis. Clin Biomech (Bristol, Avon), 2006, 21: 585–593. [Medline] [CrossRef]
20) Fleckenstein SJ, Kirby RL, MacLeod DA: Effect of limited knee-flexion range on peak hip moments of force while transferring from sitting to standing. J Biomech, 1988, 21: 915–918. [Medline] [CrossRef]
21) Davis RB III, Ounpuu S, Tyburski D, et al.: A gait data collection and reduction technique. Hum Mov Sci, 1991, 10: 575–587. [CrossRef]
22) Jeng SF, Schenkman M, Riley PO, et al.: Reliability of a clinical kinematic assessment of the sit-to-stand movement. Phys Ther, 1990, 70: 511–520. [Medline] [CrossRef]
23) Burdett RG, Habasevich R, Pisciotta J, et al.: Biomechanical comparison of rising from two types of chairs. Phys Ther, 1985, 65: 1177–1183. [Medline] [CrossRef]
24) Mens JM, Vleeming A, Snijders CJ, et al.: Reliability and validity of the active straight leg raise test in posterior pelvic pain since pregnancy. Spine, 2001, 26: 1167–1171. [Medline] [CrossRef]
25) Vander Linden DW, Brunt D, McCulloch MU: Variant and invariant characteristics of the sit-to-stand task in healthy elderly adults. Arch Phys Med Rehabil, 1994, 75: 653–660. [Medline] [CrossRef]
26) Seven YB, Akalan NE, Yucesoy CA: Effects of back loading on the biomechanics of sit-to-stand motion in healthy children. Hum Mov Sci, 2008, 27: 65–79. [Medline] [CrossRef]
27) Roebroeck ME, Doorenbosch CA, Harlaar J, et al.: Biomechanics and muscular activity during sit-to-stand transfer. Clin Biomech (Bristol, Avon), 1994, 9: 235–244. [Medline] [CrossRef]
28) Haugland KS, Rasmussen S, Daltveit AK: Group intervention for women with pelvic girdle pain in pregnancy. A randomized controlled trial. Acta Obstet Gynecol Scand, 2006, 85: 1320–1326. [Medline] [CrossRef]
29) O'Sullivan PB, Beales DJ, Beetham JA, et al.: Altered motor control strategies in subjects with sacroiliac joint pain during the active straight-leg-raise test. Spine, 2002, 27: E1–E8. [Medline] [CrossRef]
30) Aissaoui R, Ganea R, Aminian K: Conjugate momentum estimate using non-linear dynamic model of the sit-to-stand correlates well with accelerometric surface data. J Biomech, 2011, 44: 1073–1077. [Medline] [CrossRef]
31) Munro BJ, Steele JR, Bashford GM, et al.: A kinematic and kinetic analysis of the sit-to-stand transfer using an ejector chair: implications for elderly rheumatoid arthritic patients. J Biomech, 1998, 31: 263–271. [Medline] [CrossRef]
32) Mathiyakom W, McNitt-Gray JL, Requejo P, et al.: Modifying center of mass trajectory during sit-to-stand tasks redistributes the mechanical demand across the lower extremity joints. Clin Biomech (Bristol, Avon), 2005, 20: 105–111. [Medline] [CrossRef]