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Effect of feet hyperpronation on pelvic alignment in a standing position

Sam Khamis[a,*], Ziva Yizhar[a,b]

[a] *Gait and Motion Analysis Laboratory, Dana Children's Hospital, Tel-Aviv Medical Center, Tel Aviv, Israel*
[b] *Department of Physical Therapy, Sackler Faculty of Medicine, Tel-Aviv University, Israel*

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Abstract

Hyperpronation may cause malalignment of the lower extremity, frequently leading to structural and functional deficits both in standing and walking. Our aim was to study the effect of induced foot hyperpronation on pelvic and lower limb alignment while standing. Thirty-five healthy subjects were requested to remain in a natural standing position for 20 s in four different modes: feet flat on the floor, and on wedges angled at 10°, 15° and 20°, designed to induce hyperpronation. Sequencing was random, repeated three times and captured by eight computerized cameras using the VICON® three-dimensional motion analysis system. We found that standing on the wedges at various angles, induced hyperpronation, with 41% to 90% of the changes attributable to the intervention. In addition, a statistically significant increase (paired *t*-test) in internal shank rotation ($p < 0.0001$), internal hip rotation ($p < 0.0001$) and anterior pelvic tilt ($p < 0.0001$) was identified. A strong correlation was found between segmental alignment in every two consecutive modes at all levels ($r = 0.612$–0.985; $p < 0.0001$). These findings suggest that alignment of the lower extremity up to the pelvic girdle, can be altered, due to forces acting on the foot. Interaction between the foot and pelvis occurs in a kinematic chain reaction manner. Although this study was limited to healthy subjects, clinicians should be aware that when addressing pelvis and lower back dysfunction, foot alignment should be examined as a contributing factor.

Keywords: Hyperpronation; Malalignment; Feet; Pelvis; Wedges

1. Introduction

The functional structure of the human foot is adapted for bipedal locomotion [1] as foot alignment plays a crucial role in standing and walking. The subtalar movement allows the foot to change from a flexible to rigid structure during normal gait, enabling the foot to adapt to uneven terrain and act as a rigid lever for force transition [2–4].

The subtalar axis produces six degrees of freedom movement capacity, eliciting three plane movements, supination and pronation [5,6]. In a normal gait cycle, pronation occurs immediately after initial contact, permitting foot flexibility at loading response, shock absorption and adaptation of the foot to the weight-bearing surface [2]. Normal rearfoot pronation while walking has been found to fluctuate between single leg standing and subtalar neutral position [7,8,9], with maximum eversion of 6.3° (3.2°) [7] occurring at 37.9% of the stance phase [9]. The normal biomechanics of the foot might be disrupted, as a result of abnormal function of the subtalar joint, namely, excessive pronation or hyperpronation. Hyperpronation is defined as rearfoot pronation that is excessive, prolonged, and, as a result, causing the foot to remain in maximum pronation, to late or never resupinate in terminal stance for push off [2,10,11].

Measuring kinematics of the subtalar joint is difficult since foot segments and range of motion are comparatively small, with movement simultaneously occurring in three different planes. Recently, several biomechanical models were developed to measure foot motion; however, their suitability to be integrated into a full lower limb assessment

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* Corresponding author at: Gait and Motion Analysis Laboratory, Dana Children's Hospital, Tel-Aviv Medical Center, 6 Weitzman St., Israel. Tel.: +972 3 6947279/972 50 5452699; fax: +972 4 6467665.
E-mail address: khamisam@gmail.com (S. Khamis).

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is limited. A clinical method originally described by Root et al. [12] has been accepted in many studies [10,13–17] as a measurement of the rearfoot coronal component, eversion and inversion (Fig. 1). Two lines bisecting the leg and the heel form the angle of the coronal component, representing pronation and supination.

The subtalar joint is the functional unit connecting the foot and shank. It has been postulated that subtalar movement and position influence the function of the foot and lower limb biomechanical alignment [11,18]. Subtalar joint pronation is correlated with internal rotation of the shank, whereas supination is correlated with external rotation [13,16,19,20]. Tiberio [11] maintained that excessive pronation of the foot during weight bearing causes internal rotational stress at the lower extremity, and may lead to increased strain on soft tissue and compression forces on the joints, which can become symptomatic. A review of the literature indicates that a relationship exists between hyperpronation of the foot and shank rotation, patella and knee joint alignment [11,13,16,18,20].

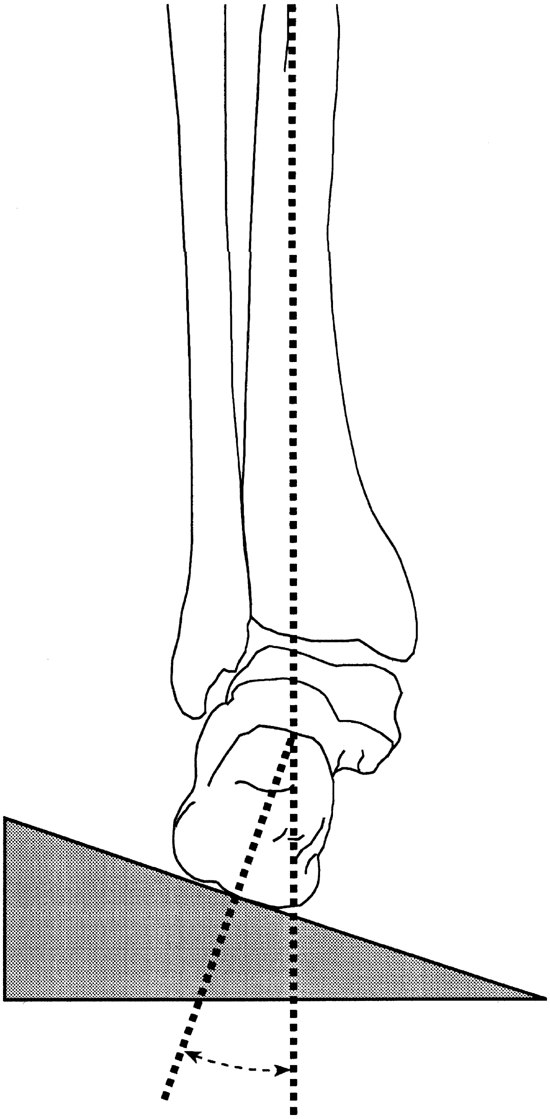

Fig. 1. Posterior view of induced eversion as measured between the bisection of the shank and the calcaneus (dotted lines).

To the best of our knowledge, there is no documented evidence describing the relationship between hyperpronation and alignment of the pelvis and lumbar spine. However, several researchers suggest this possibility [2,11,14,18,21]. According to clinical observation hyperpronation is found to be highly prevalent. Thus, the purpose of this study was to examine the immediate effect of induced hyperpronation of the feet on the pelvis and lower limb alignment in the standing position.

2. Materials and methods

2.1. Subjects

Thirty five healthy subjects (15 men, 20 women), aged 23–33 years, weight 50–91 kg, height 155–185 cm), physiotherapists from nearby clinics and physiotherapy students, volunteered to take part in the study. There was no history of musculoskeletal injuries. The study was approved by the institutional ethics (Helsinki) Committee, and all subjects signed an informed consent form.

The study was conducted at a gait and motion analysis laboratory. Each subject underwent a thorough musculoskeletal evaluation that included lower extremity range of motion, anthropometric and skeletal alignment measurements. Following initial screening, excluding criteria were: limited subtalar eversion (<6.6°) [17], leg length discrepancy (>5 mm) [22] and abnormal foot alignment (pes planovalgus or pes planovarus).

2.2. Measures and procedures

Three dimensional motion analysis was applied according to the biomechanical model PlugInGait developed by Vicon® (based on the work of Murali Kadaba and Helen Hayes Hospital) [23]. Three retro-reflective markers were used to spatially define the pelvis, thigh, shank and foot. Joint centers were calculated according to marker placement and subject's anthropometric parameters. Pelvic orientation was defined according to the lab's zero reference point, thigh rotation defined in respect to the pelvis, and shank rotation defined in respect to the thigh position. Eversion–inversion of the calcaneus was measured using a two dimensional algorithm based on the clinical model proposed by Root et al. [12], where the coronal angle is measured between the shank and the calcaneus. The shank was represented by a line connecting the knee and ankle joint centers, in relation to the line formed by two markers applied to the calcaneal bisection (Fig. 2). This algorithm was confirmed by goniometry measurement and found to be highly accurate. To induce hyperpronated alignment, three wooden wedges (58 cm × 58 cm), built from two equal slopes, at 10°, 15°

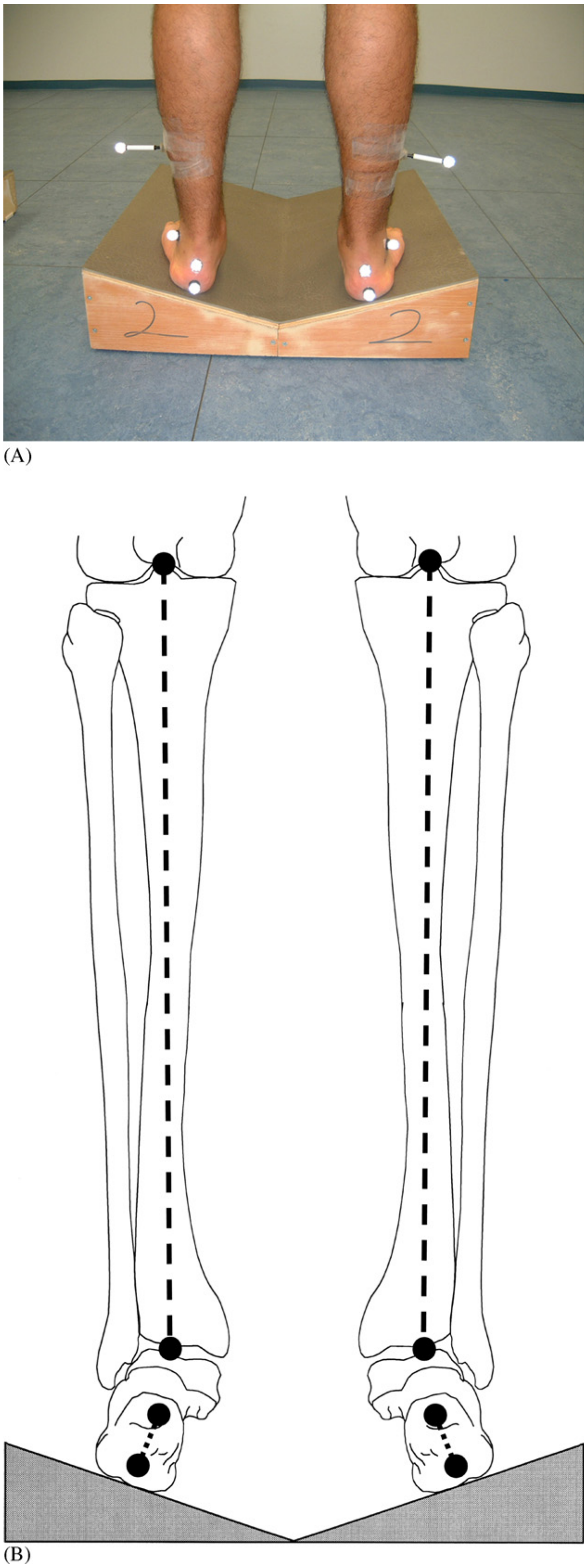

Fig. 2. (A) Subject standing on a wedge with applied markers while capturing data. (B) A figure as represented by the VICON motion analysis system: the upper line showing the shank bisection; the lower line showing the calcaneal bisection.

and 20°, were tilted inward, connected in the center at their lowest point and covered with EVA (non slippery material) (Fig. 1). The wedges were arranged in the center of the lab's capturing volume. Four standing modes (standing directly on the floor and three wedges at different angles) randomly sequenced were set up for each subject prior to assessment. Twenty-four permutations for the four modes were randomly selected using a commercial spreadsheet program (RAND function) (Excel, MS®, version 2003).

Subjects were asked to stand for 10 s in a relaxed position, to obtain the same base of support according to their pelvic width and the same natural foot alignment, in all four modes. Capturing then began for an additional 10 s. Each mode was repeated three times.

Changes in lower extremity and pelvic alignment were captured and processed by eight computerized cameras using the VICON® 612 motion analysis system at 120 Hz, and a capturing volume of 3.5 m × 3.5 m × 2.5 m. The calcaneal eversion angle at the coronal plane, shank and thigh rotation angle at the transverse plane, and pelvic tilt angle at the sagittal plane were measured in each position. Computer output included graphic plot angles with respect to time, supported by commercial spreadsheet software (Excel, MS® version 2003).

2.3. Data reduction, processing and statistics

Ten seconds were captured in each position for further analysis. In view of the considerable amount of data, a sample of 4 s (from the 4th to the 7th second in every mode) was taken. Baseline comparison was natural standing directly on the floor.

The average of the 4 s sampling data was calculated from the three captured trials in each mode, and the maximal calcaneal, shank, thigh, and pelvic angles were chosen. Statistical analysis and graphic presentation were prepared using software SPSS for Windows, version 11.5, Chicago, IL. Significance of the change in the segmental alignment between modes was performed using the paired *t*-test. Cumulative influence of increasing wedge angle on the segmental alignment change was examined using *t*-test for repeated measurements. Significance level was adjusted by Bonferroni's equation for multiple comparisons. Correlation between segmental alignment in every two consecutive modes, at the calcaneus, shank, thigh and pelvis was examined using the Pearson correlation. The level of significance was set at $p < 0.05$.

3. Results

3.1. Inducing hyperpronation by using wedges: change in the calcaneal alignment

The average change in eversion due to standing on the wedges is documented in Table 1. A significant increase in

Table 1
Changes in segmental alignment (degrees) between modes

	Left mean (S.D. error mean)	Left sig.	Right mean (S.D. error mean)	Right sig.
Calcaneal eversion angle				
W0	7.18 (0.54)	<0.0001	7.58 (0.57)	0.052
W1	9.78 (0.71)		8.77 (0.72)	
W1	9.78 (0.71)	<0.0001	8.77 (0.72)	0.286
W2	11.66 (0.82)		9.31 (0.89)	
W2	11.66 (0.82)	<0.0001	9.31 (0.89)	<0.0001
W3	14.24 (1.03)		13.52 (1.04)	
W0	7.18 (0.54)	<0.0001	7.58 (0.57)	<0.0001
W3	14.24 (1.03)		13.52 (1.04)	
Shank rotation angle				
W0	−8.34 (1.04)	<0.0001	−8.36 (0.95)	<0.0001
W1	−5.99 (1.09)		−5.92 (1.01)	
W1	−5.99 (1.09)	<0.0001	−5.92 (1.01)	<0.0001
W2	−4.11 (1.06)		−4.47 (1.00)	
W2	−4.11 (1.06)	0.005	−4.47 (1.00)	0.002
W3	−3.39 (1.04)		−3.61 (1.06)	
W0	−8.34 (1.04)	<0.0001	−8.36 (0.95)	<0.0001
Hip rotation angle				
W0	−2.48 (0.73)	<0.0001	−3.66 (1.07)	<0.0001
W1	−1.11 (0.83)		−1.57 (1.06)	
W1	−1.11 (0.83)	0.002	−1.57 (1.06)	<0.0001
W2	−0.43 (0.85)		−0.19 (1.04)	
W2	−0.43 (0.85)	<0.0001	−0.19 (1.04)	0.009
W3	0.43 (0.82)		0.55 (1.06)	
W0	−2.48 (0.73)	<0.0001	−3.66 (1.07)	<0.0001
W3	0.43 (0.82)		0.55 (1.06)	

W0: standing directly on the floor, W1: first wedge (10° angle), W2: second wedge (15° angle), W3: third wedge (20° angle). Level of significance: $p < 0.05$.

calcaneal eversion occurred (left: $p < 0.0001$, right: $p < 0.052$, with the exception of the change occurring on the transition to the second wedge $p = 0.286$), corresponding with the increase in the slope's angle, and reached a cumulative change in the calcaneal angle of 7.06° on the left, and 5.94° on the right. Fig. 3 demonstrates a slight drift towards the upper values with an increase of variance related to the increase in the wedge's inclination, despite the fact that the subject's measurements distributed normally at the various modes. A high positive linear correlation was confirmed between calcaneal alignment in every two consecutive modes on both sides (left: $r = 0.643–0.945$, $p < 0.0001$; right: $r = 0.612–0.828$, $p < 0.0001$) supporting the use of external intervention (wedge) as a tool to induce hyperpronation while standing.

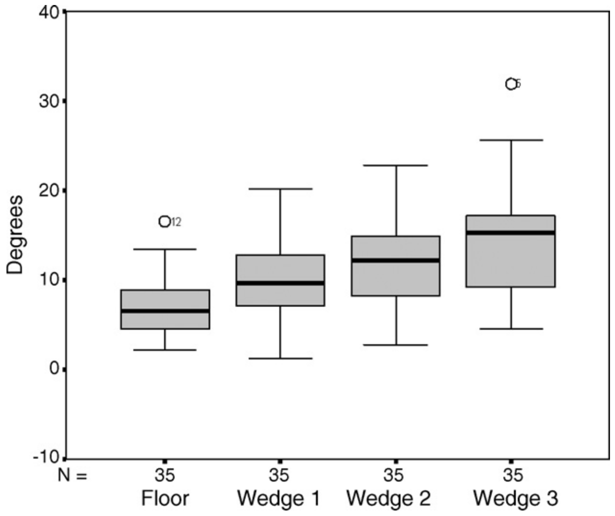

Fig. 3. The change in median, quartiles, extreme values and outlier subjects (O5, O12) in left calcaneal eversion, in all modes.

3.2. Changes in the shank and thigh alignment

The results indicate that an increase in internal shank and thigh rotation occurred on both sides while standing on the wedges ($p < 0.005$) (Table 1). Furthermore, a significant increase in shank and thigh rotational angle occurred, between every two consecutive modes leading to the sum of 4.95° and 4.75° on the left and right shanks respectively, and 2.91° and 4.21° on the left and right thigh, respectively. A high correlation was found for shank and thigh rotation angles measured between each two consecutive modes, and between the first and last mode (shank: $r = 0.943–0.984$, $p < 0.0001$; thigh: $r = 0.954–0.983$, $p < 0.0001$).

3.3. Changes in pelvic alignment

Standing on the wedges induced an anterior tilt of the pelvis. A significant increase in pelvic tilt was observed

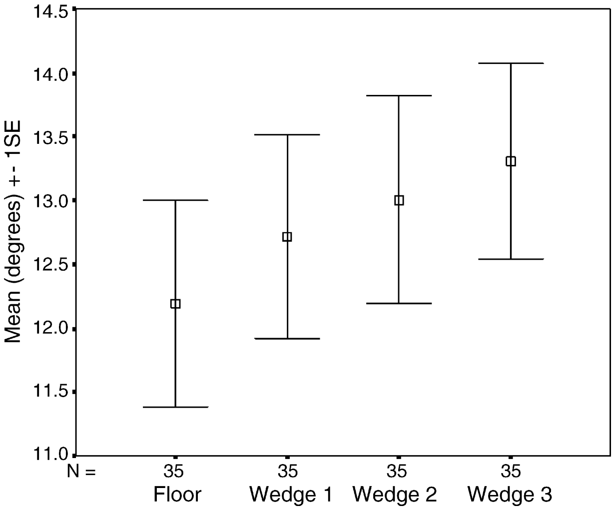

Fig. 4. The average change in sagittal pelvic alignment in all modes. Vertical lines indicate standard error.

Table 2
Changes in sagittal pelvic alignment (degrees) between modes

	Mean (S.D. error mean)	Sig.
Pelvic tilt angle		
W0	12.19 (0.81)	0.002
W1	12.71 (0.80)	
W1	12.71 (0.80)	0.046
W2	13.00 (0.81)	
W2	13.00 (0.81)	0.106
W3	13.30 (0.76)	
W0	12.19 (0.81)	<0.0001
W3	13.30 (0.76)	

W0: standing directly on the floor, W1: first wedge (10° angle), W2: second wedge (15° angle), W3: third wedge (20° angle). Level of significance: $p < 0.05$.

between every two consecutive modes ($p < 0.046$), except for the transition from wedge two to wedge three ($p = 0.106$) (Fig. 4). The most significant change occurred between two consecutive modes measured between standing directly on the floor and wedge one ($p < 0.0001$). *t*-Test for repeated measurements, demonstrated a high correlation between every two consecutive modes, between the first and last mode ($r = 0.969$–0.985, $p < 0.0001$), and significant cumulative anterior pelvic tilt ($p < 0.0001$) (Table 2).

4. Discussion

Our main finding was that pelvic alignment is influenced by foot alignment irrespective of plane of motion. In terms of biomechanics, the human body is a multi-segmental structure initiating major and powerful interactions between adjacent segments. Interaction between segments that are further apart may also hold a high significance for symptom free musculoskeletal function.

The pelvis, an important segment, situated in the center of the body, connects the upper body to the lower limbs. Due to the complexity of measuring lumbar spine movement, only pelvic movement was measured. However, pelvic position has been found to highly correlate with the lumbar position [24].

Hyperpronation was induced by external forces (wedges), similar to Lattanza's concept [17]. It should be noted that exposing normal subjects to induced hyperpronation, emphasizes the immediate effect on normal intersegmental relationship and not necessarily a prolonged adaptive effect.

4.1. Validity of inducing hyperpronation by wedges

The concept of employing wedges to alter foot alignment has been widely used in standing, walking and running [2,10,14,15,17], where the tilt was chosen to either change subtalar joint alignment or range of motion. The change in calcaneal alignment was consistent, significant and uni-directional towards calcaneal eversion. An increasing slope angle resulted in a significant increase in eversion. A tilt of 10° caused a significant change of approximately 2° in calcaneal alignment, substantially smaller than the wedge slope gradient. The 5° change in eversion measured on transition to wedge two and three can be attributed in 90% of the cases to wedge intervention ($r = 0.612$–0.945, $p < 0.0001$). However, the transition from floor mode to the first wedge, revealed a significant change with moderate correlation ($r = 0.613$–0.643, $p < 0.0001$) justifying only 41.34% of the phenomenon. Therefore, the results suggest that the wedges induced bilateral eversion, validating our method. The minimal difference between left and right sides could be due to functional asymmetry [25] and a stiffer right side.

This finding has practical implications since it supports the common intervention of a small tilted wedge for changing calcaneal alignment.

4.2. Change in shank alignment

Change in shank alignment was significantly increased towards internal rotation. An increase in the slope's angle occurred with an increase in tibial internal rotation corresponding with the increase in calcaneal eversion angle. These findings are in agreement with previous studies correlating foot position with tibial rotation, the interaction with knee joint and patellofemoral alignment and their reliance on calcaneal eversion angle [13,16,20]. These results are also supported by Inman's model [19] where foot pronation causes internal shank rotation through internal talar rotation.

An increase of 10° in the slope's angle was sufficient to cause a significant change in shank alignment. This change was the main effect of the current intervention on both sides, compared to other segments at all transitions (an average change of 2.33° (0.25–5.26) on the left and 2.44° (0.18–5.75) on the right). This may have been due to a mobile knee joint whose stability relies mainly on soft tissues, in contrast to the bony congruency of the subtalar joint. Due to the high correlation between modes, it can be assumed that the wedges are the main cause for changes in shank alignment, contributing more than 88% to the study intervention.

From a clinical point of view, our results support the claim made by many clinicians suggesting a correction of foot hyperpronation to prevent musculoskeletal injuries due to excessive internal shank rotation [2,11,16,18,20,21].

4.3. Change in the thigh alignment

The effect of foot alignment on the thigh was unclear prior to this study, even though such a correlation had been previously suggested [11,18]. Thigh internal rotation angle significantly increased with the increase in the slope's angle. The change in hip angle was smaller than the changes occurring in the segments below, as the segment was located further away from the wedge.

The clinical significance of the change in hip internal rotation may be vague, as no other comparative detailed data in the literature were found for symptomatic or asymptomatic groups. However, this finding supports the theoretical claim linking foot alignment to symptoms at the hip as suggested by Tiberio [11,18]. When the foot is induced into hyperpronation, symptoms might appear at the hip due to excessive internal rotation.

4.4. Change in the pelvic alignment

The main finding of the present study is that pelvic tilt is affected by bilateral induced hyperpronation while in a standing position. In the current study, pelvic alignment changed concurrently with changes in the distal segments. The changes were consistent, unidirectional towards anterior pelvic tilt, and varied among subjects. The most significant alteration in pelvic alignment occurred in the transition from

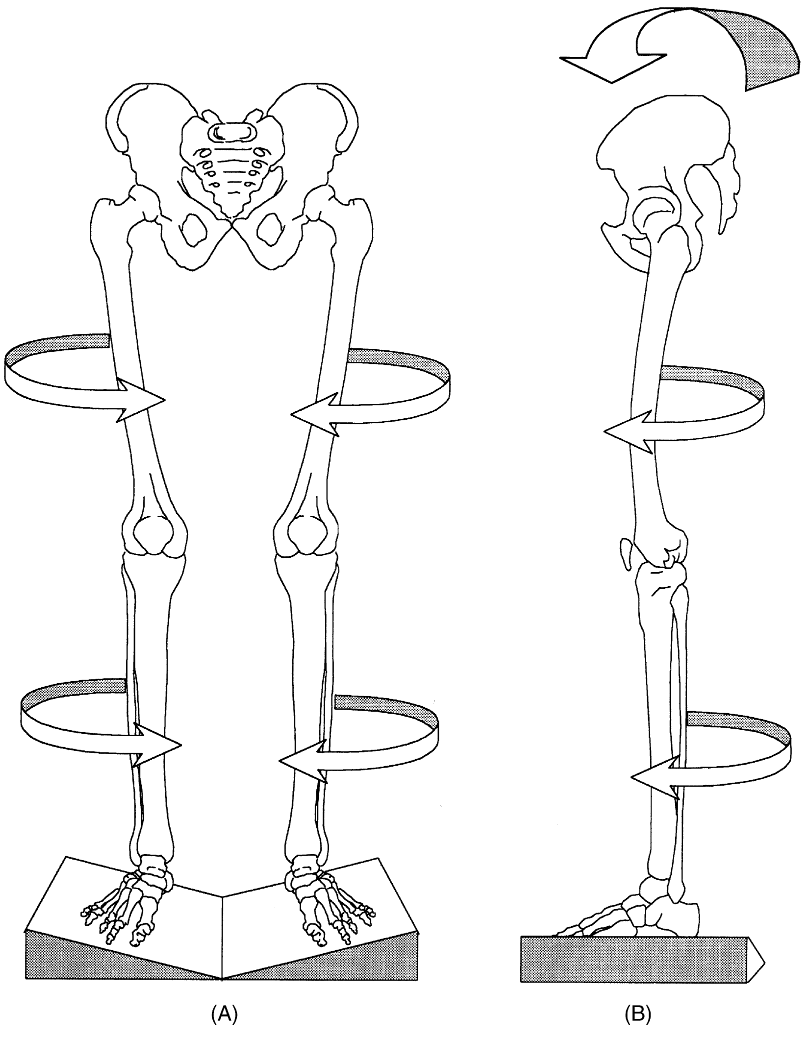

Fig. 5. Schematic representation of the proposed chain reaction of the upper segments to induced hyperpronation: (A) internal rotation at the tibia through the subtalar joint, inducing internal thigh rotation through the knee joint; (B) bilateral internal rotation of the thigh imposing anterior tilt of the pelvis.

standing directly on the floor to standing on a 10° wedge. An additional 5° led to an additional significant change in pelvic alignment. However, transition to the steepest wedge did not lead to significant change, implying that the pelvis reached its optimal postural adjustment at the second wedge.

In all cases, the change measured in pelvic alignment was significantly higher than the system's error, 0.16° ($p = 0.0001$) (quoting from the proceeding of the comparison meeting of motion analysis systems, Nippon Engineering College, Tokyo 2002). In 40% of the cases, a change of 2°–3° was measured at the pelvis.

In a relaxed standing position, pelvic alignment at the sagittal plane is approximately 10° anteriorly tilted, and during normal gait cycle it varies within 4° of motion at the sagittal plane [4]. Additional change of 2°–3° introduces 20%–30% change in pelvic alignment while standing, and 50%–75% while walking. We assume this to be sufficient to cause functional changes, symptoms and limitations at the hip, pelvis and lower back [21,22]. Consequently, these subjects might be the population at risk. Since anterior pelvic tilt has been found to highly correlate with increased lumbar curvature [24], the change in foot alignment might also influence lumbar spine position. Potentially, wedges can be used to correct foot alignment, not just for the lower extremities but for the pelvis and lumbar spine as well.

The change in pelvic alignment towards anterior tilt can be attributed to postural adjustment. However, the trend toward anterior tilt should be analysed further. Assuming one hip was internally rotated, it could lead to ipsilateral pelvic internal rotation. Since both hip joints were internally rotated, the torque acting on the vertical axis of the pelvic girdle was eliminated. On the other hand, in bilateral hip internal rotation, the supporting points of the pelvis on the hip joints are shifted backwards, imposing anterior tilt of the pelvis (Fig. 5). The high variance in pelvic alignment in healthy subjects, as demonstrated in the current study, could have been affected by a femoral anteversion angle, acetabular orientation, lumbar spine alignment and soft tissue flexibility.

5. Conclusions

Our results support the existence of a kinematic chain in healthy subjects, where hyperpronation can lead to an immediate shank and thigh internal rotation and change in pelvic position. This interaction was evaluated while standing and should be examined in other tasks such as walking, running, climbing and descending stairs, where higher forces are applied, leading to larger kinematic changes. Furthermore, an asymmetrical change in foot alignment should be considered since it may cause asymmetrical pelvic change and pelvic torsion, which might enhance symptoms or dysfunction. The clinical implication of this study advocates that when addressing pelvic and lower back dysfunction, alignment of the foot should be considered as a contributing factor.

Acknowledgements

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References

[1] Wang WJ, Crompton RH. Analysis of the human and ape foot during bipedal standing with implications for the evolution of the foot. J Biomech 2004;37(12):1831–6.

[2] Donatelli R. The biomechanics of the foot and ankle Philadelphia: F.A. Davis Company; 1996.

[3] Levangie PK, Norkin CC. Joint structure and function: a comprehensive analysis Philadelphia: F.A. Davis Company; 2001.

[4] Perry J. Gait analysis: normal and pathological function New Jersey: SLACK Incorporated; 1992.

[5] Sammarco GH, Hockenbury RT. Biomechanics of the foot and ankle. In: Nordin M, Frankel VH, editors. Basic biomechanics of the musculoskeletal system. Philadelphia: Lippincott Williams & Wilkins; 2001.

[6] Taylor KF, Bojescul JA, Howard RS, Mizel MS, McHale KA. Measurement of isolated subtalar range of motion: a cadaver study. Foot Ankle Int 2001;22(5):426–32.

[7] McPoil TG, Cornwall MW. Relationship between three static angles of the rearfoot and the pattern of rearfoot motion during walking. J Orthop Sports Phys Ther 1996;23(6):370–5.

[8] Torburn L, Perry J, Gronley JK. Assessment of rearfoot motion: passive positioning, one-legged standing, gait. Foot Ankle Int 1998; 19(10):688–93.

[9] McPoil T, Cornwall MW. Relationship between neutral subtalar joint position and pattern of rearfoot motion during walking. Foot Ankle Int 1994;15(3):141–5.

[10] Donatelli R, Hurlbert C, Conway D, Pierre RS. Biomechnical foot orthotics: a retrospective study. J Orthop Sports Phys Ther 1988;10(6): 205–12.

[11] Tiberio D. Pathomechanics of structural foot deformities. Phys Ther 1988;68(12):1840–9.

[12] Root ML, Weed JH, Orien WP. Neutral position casting techniques Los Angeles: Clinical Biomechanics Corp; 1971.

[13] Cornwall MW, McPoil TG. Footwear and foot orthotics effectiveness research: a new approach. J Orthop Sports Phys Ther 1995;21(6): 337–44.

[14] Genova JM, Gross MT. Effect of foot orthotics on calacneal eversion during standing and treadmill walking for subjects with abnormal pronation. J Orthop Sports Phys Ther 2000;30(11):664–75.

[15] Johanson MA, Donatelli R, Wooden MJ, Andrew PD, Cummings GS. Effects of three different methods on controlling abnormal subtalar pronation. Phys Ther 1994;74(2):149–58.

[16] Klingman RE, Liaos MS, Hardin KM. The effect of subtalar joint posting on patellar glide position in subjects with excessive rearfoot pronation. J Orthop Sports Phys Ther 1997;25(3):185–91.

[17] Lattanza L, Gray GW, Kantner RM. Closed versus open kinematic chain measurements of subtalar joint eversion: implications for clinical practice. J Orthop Sports Phys Ther 1988;9(9):310–4.

[18] Tiberio D. The effect of excessive subtalar joint pronation on the patellofemoral mechanics: a theoretical model. J Orthop Sports Phys Ther 1987;9:160–5.

[19] Inman VT. The joints of the ankle Baltimore: Williams & Wilkins; 1976.

[20] Stergiou N, Bates BT. The relationship between subtalar and knee joint function as a possible mechanism for running injuries. Gait Posture 1997;6:177–85.

[21] Rothbart BA, Estabrook L. Excessive pronation: a major biomechanical determinant in the development of chondromalacia and pelvic lists. J Manipulative Physiol Ther 1988;11(5):373–9.

[22] ten Brinke A, van der Aa HE, van der Palen J, Oosterveld F. Is leg length discrepancy associated with the side of radiating pain in patients with a lumbar herniated disc? Spine 1999;24(7):684–6.

[23] Kadaba MP, Ramakrishnan HK, Wootten ME. Mesurement of lower extrimity kinematics during level walking. J Orthop Res 1990;8(3): 383–91.

[24] Levine D, Whittle MW. The effect of pelvic movement on lumbar lordosis in the standing position. J Orthop Sports Phys Ther 1996; 24(3):130–5.

[25] Sadeghi H, Allard P, Prince F, Labelle H. Symmetry and limb dominance in able-bodied gait: a review. Gait Posture 2000;12(1): 34–45.