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Kinematic gait analysis in children with valgus deformity of the hindfoot

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Deformities of the feet in children can influence not only optimal foot development but also the development of other body segments. The aim of the study was to compare the hip and pelvis kinematics in groups of children with and without valgus deformity of the hindfoot. Three groups of children participated in the study: bilateral hindfoot valgosity (11 children, age 5.4 ± 1.4 years), unilateral hindfoot valgosity (14 children, age 5.6 ± 1.6 years) and the control group (8 children, 4.8 ± 1.2). Hindfoot valgus angle was measured clinically during standing. Hindfoot valgosity was considered in the range of 6 to 20 degrees. Kinematic data from five trials for each child was obtained using the Vicon MX system (six infrared cameras, frequency 200 Hz, Vicon Motion Systems, Oxford, UK). The results of our study showed significantly higher pelvic anteversion during the whole gait cycle for both unilateral and bilateral hindfoot valgosity children and significantly higher hip external rotation during the first half of the stance phase in bilateral deformity. The differences in the hip and pelvis kinematics, when compared to the control group, are higher for the group with bilateral deformity than in the group with unilateral deformity.

Key words: *walking, calcaneal eversion, heel, flatfoot, biomechanics*

1. Introduction

The human foot plays a fundamental role by linking the body with the ground and therefore, it is a significant contributing factor in the overall development of the musculoskeletal system in children [1]. If a child has some abnormal foot loading during basic movement activities such as gait, then the earlier neutralization of such abnormality can increase the chance of more normal development to occur [2].

A wide variety of lower extremity morphological and pathological variations can result in deviations from optimal gait performance. Many studies have been engaged in subjects with flat foot [3], [4], which is very often associated with valgus deformity of the hindfoot.

The degree of valgus in the heel during weight-bearing (the hindfoot angle) is commonly used as an angular criterion in the evaluation and treatment of flatfoot in children and adults [5]. In children with flexible flatfoot, a valgus position of <20° is prevalent whereas in children with pathological flatfoot, the condition is defined by a valgus position of >20°.

Development of children's feet has been assessed by many methods in both static and dynamic conditions [1], [3], [4], [7]. The effect of arch height on kinematic coupling during walking was studied by Wilken et al. [8].

In this type of studies, the foot is often considered as a separate element; however hindfoot valgus, as other foot deformities, can influence not only foot movement, but also movement of other body segments.

In this research area some observations of the relationships between foot structure (position) and hip and pelvic movements can be found in the adult population. Pinto et al. [9] reported the relationships

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between unilateral increase in calcaneal eversion and pelvic alignment in healthy adults during standing position.

While many previous reports are based on investigations of the paediatric foot, research concerning relationships between valgus deformity of the hindfoot in children and gait kinematics of the hip and pelvis is lacking. Therefore, the aim of this study was to evaluate the influence of hindfoot valgosity in children on the hip and pelvis movement during gait.

2. Materials and methods

2.1. Subjects

Thirty three children participated in the study. All participants were recruited from nursery and primary schools. The criteria for inclusion in the study were age from 3 to 8 years and the ability to stand and walk independently for 30 s period. The criteria for exclusion consisted of current or previously known neurological, cognitive or other diagnoses or medications affecting balance.

Hindfoot position was classified by the angle between the bisection of the calcaneus and the floor with the child standing [10]. It was measured clinically on both lower limbs in all subjects by the same experienced person. The study of Barton et al. [11] showed that intraclass correlation coefficients for healthy subjects (control group) in three raters were relatively high (ICC $\geq$ 0.8 for all raters), thus we expected that this measurement is reliable for our purposes.

The study of Sobel et al. [12] showed that the mean relaxed calcaneal stance position in children was 5.6 ± 2.9 degrees valgus, hindfeet with five degrees of valgosity was considered as without valgosity. Hindfoot with valgosity was considered in the range of 6 to 20 degrees.

The description of the research groups is presented in Table 1.

The Ethics Committee at the Faculty of Physical Culture of Palacky University Olomouc gave approval for this study. Parents of all measured subjects signed informed consent.

2.2. Method and experimental procedure

Prior to the measurement, 16 reflective markers (PlugIn Gait Model) were placed on the subject's lower limbs and the pelvis. For each subject, five trials of gait were measured. For each trial one gait cycle in the middle of the walkway was assessed. Kinematic data was obtained using the Vicon MX system (six infrared cameras, frequency 200 Hz, Vicon Motion Systems, Oxford, UK).

2.3. Data processing

The observed data was analyzed by Vicon Nexus and Vicon Polygon software. Movement at the hip and the pelvis in the sagittal, frontal and transversal planes was evaluated. Hip position during standing was used as reference for hip movement during gait. It means that the angular value of 0 degrees indicated relaxed standing position of the subject in each plane. From kinematics data, the following variables were determined: maximal hip flexion, maximal hip extension, hip range of movement (ROM) in sagittal plane, maximal hip adduction, maximal hip abduction, hip ROM in frontal plane, maximal external rotation, maximal internal rotation, hip ROM in transversal plane, maximal pelvis anteversion, minimal pelvis anteversion, pelvis ROM in sagittal plane, maximal pelvis upward obliquity, maximal pelvis downward

Table 1. Description of the research groups (mean ± 95% confidence interval)

Variable	Group			*p* value for differences between groups (Kruskal–Wallis ANOVA)
	Bilateral hindfoot valgosity	Unilateral hindfoot valgosity	Control	
Number	11	14	8	
Gender ratio [boys/girls]	6/5	6/8	5/3	
Age [years]	5.4 ± 1.0	5.6 ± 1.0	4.8 ± 1.2	0.493
Height [cm]	114.0 ± 9.8	117.3 ± 6.5	106.8 ± 6.6	0.103
Weight [kg]	22.1 ± 5.3	21.6 ± 2.3	17.2 ± 2.7	0.101
BMI [kg.m^{-2}]	16.5 ± 1.5	15.6 ± 0.7	15 ± 0.9	0.383

obliquity, pelvis ROM in frontal plane, maximal pelvis internal rotation, maximal pelvis external rotation, pelvis ROM in tranversal plane.

Before statistical processing (Statistica, Version 9.0, Stat-Soft, Inc., Tulsa, USA), the values of each variable from five trials were averaged for each subject. The normality of all variables was evaluated using the Shapiro–Wilk test. Because some variables demonstrated non-normal distribution non-parametric testing procedure was chosen. For statistical comparison between the groups, the Mann–Whitney U test was performed. Significant differences between the limbs with and without hindfoot valgosity in the group with unilateral valgosity were assessed by paired Wilcoxon test.

3. Results

The mean values and standard deviations of selected kinematic variables for all three groups are presented in Table 2.

3.1. Experimental groups and control group

Higher maximal external rotation during the first half of the stance phase (Fig. 1) in comparison with control group was found for the group with bilateral hindfoot valgosity. Differences in hip movement in the sagittal and frontal planes were not significant.

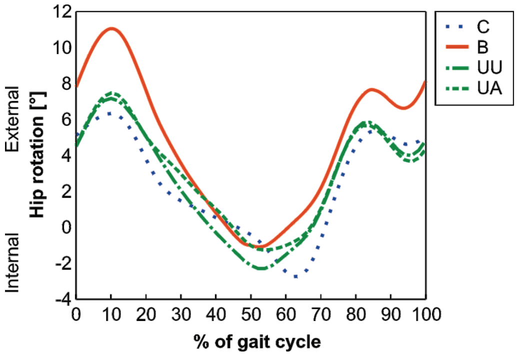

Fig. 1. Hip rotation in gait cycle: C – controls, B – bilateral hindfoot valgosity, UU – unilateral valgosity unaffected limb, UA – unilateral valgosity affected limb

Table 2. Kinematics of hip and pelvis in experimental and control groups

Group	C		B		UU		UA		*P* values			
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD	C × B	C × UU	C × UA	UU × UA
H_S_max	35.0	3.3	33.6	6.3	33.3	5.8	33.1	6.5	0.589	0.193	0.101	0.874
H_S_min	–13.1	4.6	–12.4	5.1	–11.2	6.7	–12.5	6.9	0.549	0.313	0.667	0.769
HR_S	48.1	3.7	46.1	6.6	44.6	8.2	45.5	7.4	0.201	0.154	0.423	0.769
H_F_max	7.7	3.4	6.5	3.2	7.1	3.8	8.8	4.1	0.258	1.000	0.580	0.511
H_F_min	–6.9	3.9	–8.0	3.2	–7.0	4.5	–5.8	3.9	0.258	0.854	0.637	0.635
HR_F	14.7	2.7	14.5	2.4	14.1	3.2	14.6	4.0	0.529	0.854	0.790	0.982
H_T_max	6.9	4.8	10.1	4.7	7.4	4.2	8.3	4.4	0.036	0.759	0.334	0.603
H_T_min	–4.3	4.1	–3.9	4.7	–4.9	4.9	–4.4	3.3	0.849	1.000	0.822	0.910
HR_T	11.2	3.0	14.1	4.6	12.3	3.5	12.7	4.8	0.122	0.473	0.355	0.667
P_S_max	7.7	3.8	15.3	4.9	11.1	1.9	12.9	2.0	0.000	0.008	0.000	0.024
P_S_min	6.5	3.7	13.8	4.7	10.9	1.9	10.7	2.6	0.000	0.001	0.005	0.804
PR_S	5.1	1.2	5.0	1.4	5.0	1.5	5.1	1.5	0.569	0.790	0.951	0.635
P_F_max	4.1	2.4	4.3	2.6	4.5	2.2	3.9	2.5	0.759	0.697	1.000	0.701
P_F_min	–4.3	2.2	–4.2	2.5	–3.7	2.4	–4.4	2.5	1.000	0.473	1.000	0.454
PR_F	8.3	1.6	8.5	2.5	8.2	3.3	8.3	3.5	0.895	0.822	0.728	1.000
P_T_max	8.0	5.2	7.4	4.7	9.0	2.8	8.0	2.4	0.919	0.355	0.667	0.376
P_T_min	–7.3	5.4	–6.2	4.6	–6.9	2.2	–7.9	2.8	0.737	0.697	0.423	0.137
PR_T	15.3	2.8	13.6	4.3	15.9	3.2	15.9	3.7	0.162	0.759	0.525	0.874

Legend: C – controls, B – bilateral hindfoot valgosity, UU – unilateral valgosity unaffected limb, UA – unilateral valgosity affected limb, SD – standard deviation, C x B – difference between group C and group B, H_S_max – maximal hip flexion, H_S_min – maximal hip extension, HR – hip range of movement (ROM) in sagittal plane, H_F_max – maximal hip adduction, H_F_min – maximal hip abduction, HR_F – hip ROM in frontal plane, H_T_max – maximal external rotation, H_T_min – maximal internal rotation, HR_T – hip ROM in transversal plane, P_S_max – maximal pelvis anteversion, P_S_min – minimal pelvis anteversion, PR_S – pelvis ROM in sagittal plane, P_F_max – maximal pelvis upward obliquity, P_F_min – maximal pelvis downward obliquity, PR_F – pelvis ROM in frontal plane, P_T_max – maximal pelvis internal rotation, P_T_min – maximal pelvis external rotation, PR_T – pelvis ROM in tranversal plane, $p < 0.05$.

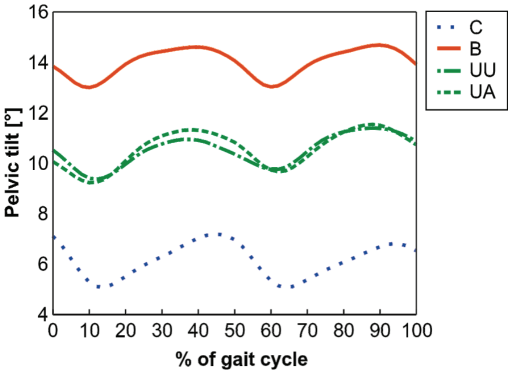

Fig. 2. Pelvic tilt in gait cycle:
C – controls, B – bilateral hindfoot valgosity,
UU – unilateral valgosity unaffected limb,
UA – unilateral valgosity affected limb

Both bilateral and unilateral experimental groups showed greater anteversion of the pelvis in comparison with the controls during the whole gait cycle (Fig. 2).

3.2. Limbs with and without hindfoot valgosity in unilateral group

In the comparison of the angle variables between the affected and unaffected limbs in the group with unilateral hindfoot valgosity, only one statistical difference (p = 0.024) was found. The affected limb showed higher value for pelvic tilt (higher anteversion).

4. Discussion

The recent scientific literature suggests a relationship between proximal and distal lower limb function [9], [13], [14]; however, most of them studied these relationships only during standing.

Eversion of the feet while standing causes subtalar pronation relative to the neutral position and it subsequently results in increased internal knee and hip rotation [14]. Significant correlations were found between subtalar angle and knee rotation (R = 0.69) and hip rotation (R = 0.80) [14]. The effect of placing the feet in inversion is the opposite. Bilateral and unilateral increases in calcaneal eversion led also to small but significant changes in pelvic alignment [9]. The bilateral and unilateral conditions caused increased pelvic anteversion; the unilateral condition led to lateral pelvic tilt, thus the presence of excessive calcaneal eversion at the foot-ankle complex may be considered as a contributing factor in pelvic misalignments during maintenance of the standing position [9]. The influence of medially tilted wedge was also observed during unilateral weight-bearing [13]. The increase in calcaneal eversion in these conditions results in differences at the hip, the pelvis and the trunk increasing of hip flexion, hip internal rotation and pelvic anterior tilt.

The results of our study showed different gait performance in children with valgus hindfoot. Significant differences were found for hip rotation and the pelvic tilt.

On the basis of the above mentioned studies performed during standing, we can suppose that children with hindfoot valgosity have higher hip internal rotation during standing. In our study, the value during standing was used as reference (its value is 0 degrees). Thus, higher external rotation peak during the first half of the stance phase suggests that these children perform greater external rotation from a more internally rotated position. The graph of hip rotation shows that the greatest difference between the observed groups is in the loading response and in the terminal swing when the limb is preparing for the load. Another significant difference was found for the pelvic tilt. This finding is similar as in the studies under static conditions and can be considered more as change in the pelvis position rather than a change in the pelvis movement during gait. From Fig. 2 it is apparent that the pelvic tilt angle is higher for the whole gait cycle. The effect of hindfoot valgosity on the pelvis position was found also in the group of children with unilateral hindfoot valgosity.

Similar differences, as between the groups with and without hindfoot valgosity (varosity), would be expected when using some types of insoles (pronation, supination insoles); however, the results of studies did not show significant effects on the hip and pelvic kinematics. Chen et al. [15] did not find any significant differences in the peak values of flexion, extension, abduction and adduction at the hip joint using insoles, which were moulded by clinical podiatrists with the aim of reducing foot pronation. A similar study of Nester et al. [16] showed that the effects of medial and lateral wedge on the hip and pelvic kinematics are generally minimal.

The different results in our study can be attributed to varying gait performance in children or due to different study design. In our study, two groups with different foot structure were compared while in the above mentioned studies only one group in various conditions was evaluated.

Vázquez et al. [17] suggested the use of several compensatory patterns in gait performance, although significant differences were found only for the mean values of hip adduction/abduction during load response and midstance, and hip flexion/extension during pre-swing.

5. Conclusion

The results of this study showed significant differences between the observed groups, which indicate significant relationships between hindfoot valgosity and hip rotation and the pelvic tilt. In comparison with the control group, the differences are higher in the group with bilateral deformity than with unilateral deformity. These findings suggest that in children with hindfoot valgosity, clinicians need to pay close attention not only to the foot but also to the hip and the pelvis.

Limitations and future research

The main limitations of the study can be considered the relatively large range of age from 3 to 8 years. The foot in this period changes rapidly. For example, the arch-index can keep changing up to 5 years age and then remains constant [7]. However, the mean age in the experimental and control groups was similar. Also, the number of subjects in the groups could be higher. For better interpretation of the data, detailed kinematics of the foot would be useful.

In future research, the evaluation of the relationships between the segments could be observed more comprehensively. For example, there are some possibilities of data processing that can bring new findings to light, such as the application of angle-angle diagrams [18].

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References

[1] Bosch K., Gerß J., Rosenbaum D., *Development of healthy children's feet–Nine-year results of a longitudinal investigation of plantar loading patterns*, Gait Posture, 2010, 32, 564–571.

[2] Pratt D.J., Sanner W.H. *Paediatric foot orthoses*, The Foot, 1996, 6, 99–111.

[3] García-Rodríguez A., Martín-Jiménez F., Carnero-Varo M., Gómez-Gracia E., Gómez-Aracena J., Férnandez-Crehuet J., *Flexible Flat Feet in Children: A Real Problem?*, Pediatrics, 1999, 103, 1–3.

[4] Hernandez A.J., Kimura L.K., Laraya M.H.F., Fávaro E., *Calculation of staheli's plantar arch index and prevalence of flat feet: a study with 100 children aged 5–9 year*, Acta Ortop. Bras., 2007, 15, 68–71.

[5] Sobel E., Levitz S., Caselli M., Brentnall Z., Tran M.Q., *Natural history of the rearfoot angle: preliminary values in 150 children*, Foot Ank. Int., 1999, 20(2), 119–125.

[6] Pfeiffer M., Kotz R., Ledl T., Hauser G., Sluga M., *Prevalence of Flat Foot in Preschool-Aged Children*, Pediatrics, 2006, 118, 634–639.

[7] Müller S., Carlsohn A., Müller J., Baur H., Mayer F., *Static and dynamic foot characteristics in children aged 1–13 years: A cross-sectional study*, Gait Posture, 2012, 35, 389–394.

[8] Wilken J., Rao S., Saltzman C., Yack H.J., *The effect of arch height on kinematic coupling during walking*, Clin. Biomech., 2011, 26, 318–323.

[9] Pinto R.Z.A., Souza T.R., Trede R.G., Kirkwood R.N., Figueiredo E.M., Fonseca S.T., *Bilateral and unilateral increases in calcaneal eversion affect pelvic alignment in standing position*, Manual Therapy, 2008, 13, 513–519.

[10] Shrader J.A., Siegel K.L. *Nonoperative Management of Functional Hallux Limitus in a Patient With Rheumatoid Arthritis*, Phys. Ther., 2003, 83, 831–843.

[11] Barton C.J., Bonanno D., Levinger P., Menz H.B., *Foot and ankle characteristics in patellofemoral pain syndrome: a case control and reliability study*, J. Orthop. Sports Phys. Ther., 2010, 40(5), 286–96.

[12] Sobel E., Levitz S.J., Caselli M.A., Tran M., Lepore F., Lilja E., Sinaie M., Wain E., *Re-evaluation of the relaxed calcaneal stance position – Reliability and normal values in children and adults*, J. Am. Podiatr. Med. Assoc., 1999, 89, 258–264.

[13] Tateuchi H., Wadab O., Ichihashi N. *Effects of calcaneal eversion on three-dimensional kinematics of the hip, pelvis and thorax in unilateral weight bearing*, Hum. Mov. Sci., 2011, 30, 566–573.

[14] Duval K., Lam T., Sanderson D., *The mechanical relationship between the rearfoot, pelvis and low-back*, Gait Posture, 2010, 32, 637–640.

[15] Chen Y., Lou S., Huang Ch., Su F., *Effect of foot orthoses on gait patterns of flat feet patients*, Clin. Biomech., 2010, 25, 265–270.

[16] Nester C.J., van der Linden M.L., Bowker P., *Effect of foot orthoses on the kinematics and kinetics of normal walking gait*, Gait Posture, 2003, 17, 180–187.

[17] Vázquez A.A., Villarroya M.A., Franco M.A., Asín J., Calvo B., *Kinematic assessment of paediatric forefoot varus*, Gait Posture, 2009, 29, 214–219.

[18] Kutilek P., Farkasova B., *Prediction of lower extremities' movement by angle-angle diagrams and neural networks*, Acta Bioeng. Biomech., 2011, 13, 57–65.