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Three-dimensional evaluation of heel raise test in pediatric planovalgus feet and normal feet

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ABSTRACT

Planovalgus foot is a common pediatric deformity which may be associated with pain. To evaluate flexibility of the foot, the heel raise test is used. During this test the arch and hindfoot are assessed. Several studies have described planovalgus foot based on 3D gait and standing analysis. However, no studies have evaluated foot flexibility during heel raise using an objective 3D analysis. Therefore, the purpose of this study is to evaluate the flexibility of planovalgus feet during the heel raise test using an objective 3D assessment and to determine whether any hypotheses can be generated about potential differences between painful and painless flexible planovalgus feet and reference feet.

Here, 3D foot analysis was conducted in 33 children (7 reference feet, 16 painless, and 10 painful flexible planovalgus feet) during the heel raise test. To identify the characteristics of planovalgus foot, the concept of 3D projection angles was used as introduced in the Heidelberg Foot Measurement Method (HFMM), with a modified marker set.

All feet showed dynamic movements of the medial arch and hindfoot from valgus to varus position during heel raise. Reference feet had the smallest range of motion, perhaps due to joint stability and absence of foot deformity. Painful and painless flexible planovalgus feet demonstrated similar movements. No significant differences were found between the painful and painless groups. However, the kinematics of the pain group seemed to differ more from those of the reference group than did kinematics of the painless group.

This assessment is a new, practical, and objective method to measure the flexibility of small children's feet.

1. Introduction

Parents often seek medical help when their children present with a planovalgus foot. In fact, the prevalence of flexible planovalgus feet in 3- to 6-year-olds is 44%. However, less than 1% of cases is considered pathologic [1] whereas the others are seen as a developmental variation [1,2]. The younger the children, the more hindfoot valgus is found and boys tend to present with planovalgus feet more often than girls [1]. This foot deformity may also be associated with symptoms such as pain [2]. Although there is a high variability of hindfoot valgus in children, the absence of hindfoot deformity typically is defined in the range 0–5° [1,3].

The heel raise test is commonly used to clinically test flexibility in planovalgus feet [2,4,5]. During this test, the arch, heel valgus/eversion, and prominence of the medial column of the midfoot/talar head prominence are observed. Based on this and other functional tests as well as additional radiographic assessment, different types of pediatric planovalgus feet were identified in past investigations, leading to different treatment recommendations: flexible planovalgus foot, rigid planovalgus foot, congenital vertical talus, tarsal coalition, skewfoot, and planovalgus foot due to other causes [4,5]. However, in these investigations, the evaluation of specific anatomical characteristics of the planovalgus foot was based on subjective visual observation. As a consequence, treatment recommendations still depend on these subjective observations.

A few studies described planovalgus feet movement based on a 3D gait and foot analysis [6–10]. These studies give the same results in adults as in children and when using different foot models. The hindfoot in relation to the tibia is more everted and internally rotated in planovalgus feet than in "normal" feet [6–8]. In relation to

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the hindfoot, the forefoot is more inverted/supinated and abducted in planovalgus feet than in "normal" feet [6–9]. In comparison to "normal" feet, the arch is decreased [8,9]. Kerr et al. [10] demonstrate the position of pediatric planovalgus feet during standing using the Oxford Foot Model. In this study, the hindfoot is more everted, the forefoot more abducted and supinated in severe and in symptomatic planovalgus feet. However, no studies have quantified the flexibility of pediatric planovalgus feet during the heel raise test using an objective 3D foot analysis.

In this study, the primary aim, therefore, was to quantitatively monitor the foot motion characteristics of pediatric planovalgus feet during the heel raise test and thus to establish a feasible method of assessment. A secondary aim was to detect potential differences between painful flexible, painless flexible planovalgus feet, and asymptomatic reference feet to develop specific hypotheses for distinguishing symptomatic from asymptomatic feet by using this functional test. To this end, the Heidelberg Foot Measurement Method (HFMM), an objective 3D foot model [11], was applied with a modified marker set for young children with planovalgus feet.

2. Subjects and methods

2.1. Subjects

We recruited children aged between 3 and 11 years both from the general public and from the pediatric orthopedic outpatient clinic who presented with planovalgus feet within the last 5 years before recruitment. The goal was to obtain a range of children's feet from "reference" feet, i.e., without any foot deformity, to flexible flatfeet for further analysis. Excluded were patients with neurologic disorders or metabolic diseases. All children were examined (or re-examined) for a flexible planovalgus foot deformity. Bony coalitions were excluded by X-ray examination, and in critical cases MR imaging was also performed to exclude any further coalition.

Subsequently, 33 children, 7.2 ($\pm$2.3) years of age, were allocated to three different groups according to the following examination scheme: asymptomatic cases who neither had a navicular drop to the medial side in relation to the calcaneus, assessed by visual observation from the frontal perspective (compare Fig. 2), nor a vertical drop to the ground, tested by attempting to fit a finger beneath the medial longitudinal arch were regarded as reference feet (5 girls and 2 boys; 7.6 ($\pm$1.9) years of age; "reference group"). Depending on their report of specific foot pain or other foot problems, the remaining cases were allocated either to the group "painless flexible planovalgus feet" (8 girls and 8 boys; 6.4 ($\pm$2.3) years of age; "painless group") or "painful flexible planovalgus feet" (5 girls and 5 boys; 8.0 ($\pm$2.5) years of age; "pain group"). For statistical evaluation only right feet were analyzed.

2.2. Methods

An instrumented 3D foot analysis was carried out in all children during a heel raise test monitored by a 12-camera Vicon system (Vicon 612 (120 Hz), Oxford Metrics, Oxford, UK). For this heel raise test, the children stood in the middle of the room in upright position. They used two crutches for improving balance but without putting weight on them. The children were asked to raise their heels as high as possible at self-selected speed. The heel raise was monitored via the sole angle defined as the angle between the long foot axis (represented by markers HEE and TOE) to the ground.

To identify the characteristics of a planovalgus foot during the heel raise, heel and medial arch movements were evaluated according to the concept of 3D projection angles as introduced in the Heidelberg Foot Measurement Method (HFMM) [11]. Seven reflected markers were fixed on each foot and two markers on the shank as shown in Fig. 1 (white and black dots), representing a marker set from the HFMM [11] that was modified to ensure applicability on younger children's feet. Consequently, angular definitions were modified so that they would most closely resemble parameters of the original method: Instead of subtalar inversion (HFMM), hindfoot obliquity and hindfoot valgus (modHFMM) were computed to detect the movement of the heel in the frontal plane. The hindfoot obliquity describes the orientation of the heel in the frontal plane via the projection angle of the connection line between LCL and MCL to the ground whereas hindfoot valgus describes the angle of this line with respect to the longitudinal axis of the shank, defined by the anterior shank markers as illustrated in Figs. 1 and 2(a, c). To evaluate the movement of the medial column in the frontal plane, the medial column inclination was calculated. Instead of medial arch inclination (HFMM), medial column inclination (modHFMM) is defined as the attitude of the medial arch plane (triangle of the foot markers D1T, NAV, and MCL) in relation to the shank-foot plane (triangle of HEE, TOE, and TTU) (Fig. 2b and d).

In order to test the similarity between parameters calculated by the HFMM with those calculated by the modified HFMM (modHFMM), seven measurements were made in a 21-year-old healthy woman during walking and heel raise with the full HFMM marker set, which also allowed calculation of the modHFMM. A minimum of 10 valid strides in walking and 10 heel raises on each measurement were recorded. All measurements were done by one specially trained physiotherapist and one technical assistant with long-term experience in gait and motion analysis as well as clinical examination in children (five times physiotherapist and two times technical assistant).

2.3. Data analysis

To verify the clinical (i.e., observational) assessment for group allocation ("reference" versus "painless"/"painful"), the respective angles of the 3D motion capture in the static standing trial were

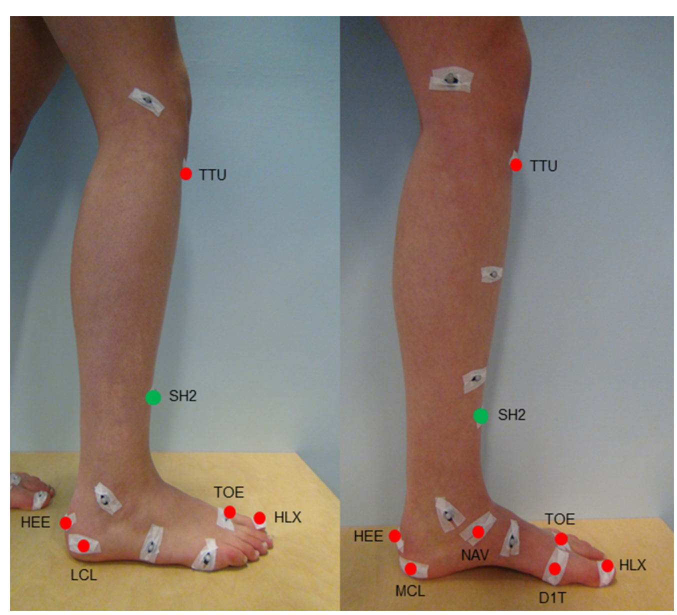

Fig. 1. The dark red and grey dots illustrate the original HFMM marker-set. The dark red and light green dots represent the modified reduced marker set (modHFMM). The light green dot demonstrates the changed distal shank marker. Left picture: lateral view, right picture: medial view. (For interpretation of reference to color in this figure legend, the reader is referred to the web version of this article.)