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Repeatability of the Oxford Foot Model in children with foot deformity☆

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ABSTRACT

Introduction: The Oxford Foot Model (OFM) is a multi-segment, kinematic model developed to assess foot motion. It has previously been assessed for repeatability in healthy populations. To determine the OFM's reliability for detecting foot deformity, it is important to know repeatability in pathological conditions. The aim of the study was to assess the repeatability of the OFM in children with foot deformity.

Methods: Intra-tester repeatability was assessed for 45 children (15 typically developing, 15 hemiplegic, 15 clubfoot). Inter-tester repeatability was assessed in the clubfoot population. The mean absolute differences between testers (clubfoot) and sessions (clubfoot and hemiplegic) were calculated for each of 15 clinically relevant, kinematic variables and compared to typically developing children.

Results: Children with clubfoot showed a mean difference between visits of 2.9° and a mean difference between raters of 3.6° Mean absolute differences were within one degree for the intra and inter-rater reliability in 12/15 variables. Hindfoot rotation, forefoot/tibia abduction and forefoot supination were the most variable between testers. Overall the clubfoot data were less variable than the typically developing population.

Children with hemiplegia demonstrated slightly higher differences between sessions (mean 4.1°), with the most reliable data in the sagittal plane, and largest differences in the transverse plane.

Conclusions: The OFM was designed to measure different types of foot deformity. The results of this study show that it provides repeatable results in children with foot deformity. To be distinguished from measurement artifact, changes in foot kinematics as a result of intervention or natural progression over time must be greater than the repeatability reported here.

1. Introduction

Foot deformities are prevalent in children and can be either congenital or acquired. Clubfoot is the most common congenital musculoskeletal deformity in children occurring in 1–2 out of 1000 live births [1]. It can result in foot and ankle stiffness, pain and arthritis which tend to increase over the lifespan [2]. Other examples of congenital foot deformities include vertical talus, cavus and metatarsus adductus. Flat foot deformity can be acquired, first becoming obvious as a child begins to walk. In general it is noted that the majority of toddlers have flat feet [3,4] which improves as they mature such that the adult prevalence is nearer 20% [5]. Acquired foot deformity is also very common in children with neurological problems such as cerebral palsy. Cerebral palsy (CP) is the most common motor disability in childhood with international prevalence estimates ranging from 1.5 to more than 4 per 1000 live births [6]. At birth CP children's feet have normal postures, but over time the effects of their abnormal neurology leads to increasing lower limb deformity [7].

Three-dimensional gait analysis is an assessment tool to measure dynamic deformity in the lower limbs. It is widely used to identify lower limb deformity in children with clubfoot [8–14] and cerebral palsy [15,16] to assist in treatment planning. Traditionally the foot has been measured as a single rigid segment in a two-dimensional kinematic model. More recently, three-dimensional multi-segment foot models have been developed to improve our understanding of foot motion during gait. Fifteen foot models have been reported in the literature [17] with up to 9 segments being proposed [18]. Baker [18] reports 3 or 4 segment foot models are gaining preference for use in clinical gait analysis. Despite numerous foot models being available in the literature, very few are being used in centres outside of where they were developed [18].

The Oxford Foot Model (OFM) is a multi-segment, three-dimensional kinematic model that assesses dynamic motion of the foot [19]. It was developed to measure tibia, hindfoot, forefoot and hallux motion in a clinical setting. It can identify the presence of dynamic deformity compared to a healthy population, monitor change of an individual's

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foot posture over time, and measure change in foot motion before and after intervention. Published literature confirms the OFM is being used world-wide to evaluate various populations with foot deformity such as flat foot [20,21,22] clubfoot [23] and calcaneal fractures [24]. The OFM has already been shown to be repeatable in healthy populations (adults and children) for both intra-tester and inter-tester repeatability [19,25,26,27]; however to date there is no published literature of its repeatability in pathological conditions. The aim of this study was to assess the repeatability of the OFM in children with hemiplegic cerebral palsy and in children previously treated for clubfoot deformity, and compare it to a healthy population. Our hypothesis is that the repeatability of the OFM in children with foot deformity will be similar to previously reported values of the OFM's repeatability in healthy populations in the literature. For the purpose of this study, repeatability is defined as the difference between two repetitions of testing.

2. Methods

2.1. Subjects

2.1.1. Typically developing

Fifteen typically developing children (mean age 9.5 years, range 6–14 years; 10 female and 5 male) were assessed with the OFM during level walking at self-selected velocity using a 12 camera Vicon 612 system (sampling at 100 Hz) and 14 mm passive markers. Each child was measured on two occasions by the same tester with the visits spaced between two and four weeks apart. The typically developing children were recruited from friends and colleagues of the Oxford Gait Laboratory.

2.1.2. Hemiplegia

Fifteen children with hemiplegic CP (mean age 10.2 years, range 6–15 years; 9 male, 6 female; 8 left side and 7 right side affected) were assessed with the OFM during level walking at self-selected velocity using a 12 camera Vicon 612 system (sampling at 100 Hz) and 14 mm passive markers. This was a convenience sample and we did not exclude any subjects on the basis of severity of foot deformity. The data was collected from routine clinical referrals- children referred to the gait laboratory for consideration of further management. The referrals were asking for clarification on orthotic management as well as potential surgical management for both populations- indicating a range of severity. Inclusion criteria were a confirmed diagnosis of hemiplegic cerebral palsy, presence of foot deformity on the affected side, appropriate level of co-operation and behaviour with no subjective reported deterioration or botulinum toxin/surgery between visits. Each child was measured on two occasions by the same tester with visits spaced no more than six months apart as a part of their clinical pathway. Written, informed consent was obtained from subjects agreeing to participate in the project on the day of their first appointment in the gait laboratory.

2.1.3. Clubfoot

Fifteen children with clubfoot were assessed (mean age 8.8 years, range 4–14 years; 8 male, 7 female; 9 bilateral, 2 left, 4 right side affected). For the bilateral subjects- 1 side was randomly chosen resulting in 8 left and 7 right feet for analysis. OFM data were collected during level walking at self-selected velocity using a 16 camera Vicon MX/T-series system and 9.5 mm passive markers. The subjects were chosen from consecutive routine clinical referrals- children referred to the gait laboratory for consideration of further management. The referrals were asking for clarification on orthotic management as well as potential surgical management indicating a range of foot deformity. We did not exclude any subjects on the basis of severity of foot deformity. Inclusion criteria were a confirmed structural idiopathic clubfoot deformity diagnosed at birth, no other musculoskeletal or neurological diagnoses, and the children and parents reported no change in symptoms between gait analysis visits.

Each child was measured on two occasions by the same tester, and once by a second tester. Written, informed consent was obtained prior to placing markers during their clinical visit to the gait laboratory. After clinical data collection was complete and the markers were removed by the primary marker placer, they had the markers replaced by the secondary placer for inter-rater repeatability with 6 new walking trials recorded. On a separate occasion, the child revisited the gait lab to complete 6 walks again with the primary marker placer (intra-rater data). On average the visits were 2.5 months a part (SD 1.9). Written, informed consent was obtained from subjects agreeing to participate in the project on the day of their first appointment in the gait laboratory.

2.1.4. Data collection

The typically developing and hemiplegic groups were collected at the time when the Oxford Foot Model was being initially validated in 2002–2003 by a single tester with approximately 1 year of experience in placing OFM markers (JS). The clubfoot group was collected more recently (2013–2015) by someone with 7+ years experience with the OFM (JM) as the primary marker placer who put the markers on twice for each subject (intra-rater), and a third tester (JL) (3+ years experience with the OFM), who placed the markers once on each subject (inter-rater).

2.1.5. Data processing

All data were processed for all populations by one of the authors (JS) who was also the tester during the initial phase of data collection (CP and TD groups). Three representative trials were chosen for analysis for each subject as the trials closest to the mean for that subject (i.e. with the lowest root mean square difference to the mean trace). The intra-tester repeatability was analysed for the hemiplegia, clubfoot and healthy populations, and the inter-tester repeatability was analysed for the clubfoot population. The data from both the hemiplegia and clubfoot populations were compared to the data of the typically developing children.

Fifteen clinically relevant kinematic variables (Table 1) were calculated and then averaged across the three trials. The mean absolute differences between sessions were calculated for each variable for all three populations, and as well as the mean absolute differences between raters for each variable for the clubfoot population.

We chose to report 15 kinematic variables which we deem to be clinically relevant when interpreting the Oxford Foot Model, and are consistent with the variables reported in Stebbins et al. [19]. These incorporate all three anatomical planes and report on five variables each for hindfoot motion relative to the tibia, forefoot motion relative to the hindfoot, and forefoot motion relative to the tibia. In the sagittal plane we reported on range of dorsiflexion as well as maximum dorsiflexion achieved in stance and in swing. In the coronal and transverse planes we reported on average positioning of the segments due to less overall foot motion expected in these planes- with the position (i.e. supinated/abducted) being more clinically relevant.

3. Results

3.1. Hemiplegia

Children with hemiplegic cerebral palsy were assessed for intra-rater repeatability across two sessions. The mean difference across all

Table 1
Mean absolute differences in degrees averaged across all the fifteen kinematic variables and their standard deviations.

TD – (intra)	4.8 (2.2)
Hemiplegia – (Intra)	4.1 (2.2)
Clubfoot – (Intra)	2.9 (1.2)
Clubfoot – (Inter)	3.6 (2.0)