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Crouch gait changes after planovalgus foot deformity correction in ambulatory children with cerebral palsy

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ABSTRACT

Ambulatory children with cerebral palsy (CP) may present with several gait patterns due to muscular spasticity, commonly with crouch gait. Several factors may contribute to continuous knee flexion during gait, including hamstring and gastrocnemius contracture. In planovalgus foot deformity, the combination of heel equinus, talonavicular joint dislocation, midfoot break and external tibial torsion also contribute to crouch gait as part of lever arm dysfunction. In this retrospective cohort study, we assessed 21 children with CP (34 feet) who underwent planovalgus foot correction as a single level surgery. Fifteen feet underwent subtalar fusion and 19 feet had lateral calcaneal lengthening. Patients who underwent knee, hip or pelvis surgeries were excluded from the study. The aim was to examine the changes in gait pattern and the correlation between the changes of knee flexion at stance phase with the other kinematic and kinetic parameters after foot surgery. Post surgery change of Maximum knee extension at stance (MKE-dif) was the outcome of interest. The magnitude of change in MKE after surgery increased (less crouch after surgery) in patients who had milder preoperative planovalgus feet and higher preoperative ankle maximum dorsiflexion at stance and ankle power. The gain of knee extension after surgery correlated with correction of ankle hyperdorsiflexion and with increase of knee extension at initial contact and knee power. Patients with high preoperative ankle maximum dorsiflexion may benefit from surgical foot deformity correction to achieve decreased ankle dorsiflexion with no knee surgical intervention.

1. Introduction

Ambulatory children with cerebral palsy (CP) present with different gait patterns due to muscular spasticity and contractures and subsequent limited range of motion leading to loss of functional abilities [1,2]. Crouch gait is one of the most common gait patterns in ambulatory children with CP and is contributed to several factors [3]. Erect posture during gait is accomplished by concentric contraction of hip extensors, knee extensors and ankle plantar flexors. The mechanical effect is to keep the ground reaction force in front of the knee joint during the stance phase [4]. Continuous knee flexion during gait is commonly described as crouch gait regardless of ankle joint status during stance. Rodda et al. described five patterns of gait in spastic diplegic patients based on pelvis, hip, knee, and ankle position during stance [5]. With a simplified definition of crouch gait as knee flexion during stance larger than 20°, Rozumalski et al. described five clusters of crouch gait (with and without equinus) that represent increased severity of crouch gait [6]. In Rodda's classification, moving from true equinus to crouch gait involves less equinus and more knee and hip flexion, but does not represent change is severity of the patient involvement.

Crouch gait may result from muscular imbalance including hamstring or gastrocnemius contracture and ankle plantar flexor weakness [4,7]. Tibial rotational deformities affect the limb posture at stance and lead to diminished effect of knee extension/ankle plantar flexion couple followed by lack of achieving full knee extension during the stance phase (lever arm dysfunction) [8]. The mechanical reason is the alteration of the ground reaction force vector being more posterior to the knee which generates flexion knee moment and increased demand on the quadriceps [4].

Planovalgus foot deformity involves a combination of equinus, talonavicular joint dislocation (midfoot break), and external tibial torsion leading to imbalance and lever arm dysfunction which contribute to crouch gait [4]. Children with CP and planovalgus deformity are managed conservatively with braces and orthoses to realign the foot and provide stability to the ankle joint. Ankle foot orhosis (AFO) is the most common orthoses utilized in children and can be rigid, articulated (hinged), or ground reaction force. AFOs

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improve foot and ankle movement during gait compared to barefoot walking [9]. While both fixed and articulated AFOs may affect ankle joint dorsiflexion during stance, ankle power and ankle plantar flexion moment, both types of AFOs do not affect on proximal joints movement during gait [10]. Ground reaction AFO was found to be effective in improving knee and ankle movement during gait [11]. When orthoses and braces fail to correct the foot deformity; or are not tolerated by the patient, surgery is indicated with options including calcaneal lengthening or subtalar fusion. Other concomitant procedures may include gastrocnemius recession, Achilles tendon lengthening, and tibial osteotomy [12–14]. Multilevel surgeries are commonly used to correct lower-limb alignment, including hip and knee surgeries [15]. While correcting planovalgus foot deformity improves foot and ankle movement during gait and pedobarograph pattern [13,16], the effect on the proximal joints, specifically the knee is not well understood. The aim of this study was to assess the changes of knee extension during stance phase after the surgical correction of planovalgus foot deformity in children with CP. Our hypothesis was that correction of plannovalgus foot would affect proximal joints and improve patient's gait.

2. Patients and methods

After approval from the Institutional Board Review of our institution, a retrospective cohort (case-only) study was conducted on children with CP who underwent a primary foot surgery to correct planovalgus foot deformity. To be included in this study, patients needed to have gait analysis within one year before surgery and less than four years after foot surgery (short-term follow-up). Patients were excluded if they had any other lower extremity procedure on the hip, femur, or knee. Also patients were excluded if they had undergone a prior foot surgery. The patient cohort was selected from the medical record registry and gait laboratory records in the period between 1994 and 2011. We identified 536 patients and only 21 patients met the inclusion criteria and constituted the study population. All the patients were consecutive and surgeries were performed by two surgeons. The decision to perform the surgery was made at the surgeon's discretion with no specific criteria of gait analysis or radiograph, however all patients had gait analysis and were not felt to have other problems causing flexed knee gait that required surgical correction. Foot correction was performed utilizing calcaneal lengthening or subtalar fusion and both surgeries were previously proved efficient in planovalgus deformity correction [12–14]. After correction of foot deformity, tibial osteotomy was added if the thigh–foot axis was more than 20° internal or external [13].

Clinical data on hip, knee, and ankle joints range of motion were measured by the physical therapists and were collected from the gait laboratory records (Appendix 1). Body mass index was calculated, and patients were based on Center of Disease Control and Prevention (CDC) categories [17]. Patients' functional abilities were assessed based on use of walking assistive devices and were classified using the Gross Motor Function Classification System (GMFCS) [18]. Data from the gait laboratory included kinetics, kinematics, and pedobarographic measurements. Foot pressure (pedobarograph) was measured using a Tekscan High-Resolution Pressure Assessment System (Tekscan, Boston, MA). Coronal plane pressure index (CPPI) was calculated by subtracting lateral foot pressure from medial foot pressure divided by the sum of mid- and forefoot pressures [19]. Normal CPPI range is (−30 to 12); values less than −30 and more than 12 indicate varus and valgus foot deviations respectively. Motion analysis was done based on an eight-camera system (Motion Analysis, Santa Rosa, CA) with Real Time and Orthotrack software. Pedobarographic, kinetic and kinematic data represent the mean of multiple cycles of measurements that were done on the same day with the patient walking bare feet. Normal ranges of gait parameters were age specific and were based on the parameters of 120 normal children aged from 4 to 18 years of age. Positive values of maximum knee extension during stance (MKE) and knee extension at initial contact (KEIC) implied the knee was in hyper-extension, and negative values implied the knee was in flexion. Increase in ankle maximum dorsiflexion at stance (AMDF) meant increase in ankle dorsiflexion. Positive and negative values of foot progression angle (FPA) implied internal and external rotation of the lower limb during stance phase, respectively. Therefore, the increase of FPA meant moving from external torsion toward neutral then internal torsion.

3. Gait patterns

Gait pattern was identified for the preoperative and postoperative status based on knee extension and ankle dorsiflexion at stance [5]. MKE and AMDF for each patient were compared to the normal range. When MKE or AMDF fell between (+1 SD and −1 SD), these parameters were considered normal. Patients with normal MKE and normal AMDF were described as mild gait [5]. Recurvatum pattern (back knee gait) was added to the gait patterns in our study specified by increased MKE (hyperextension) and normal AMDF. Therefore six gait patterns of gait were identified in this study (Table 1).

3.1. Study calculated parameters

Maximum knee extension during stance was used to assess knee flexion changes before and after surgery. We calculated the difference of MKE between postoperative and preoperative measurements (i.e., knee extension difference (MKE-dif) = postoperative MKE − preoperative MKE). Changes after surgery were also calculated for the other kinematic and kinetic measurements. Positive values of MKE-dif and KEIC-dif implied increased extension (less knee flexion), and negative values implied increased knee flexion. Negative values of AMDF-dif implied moving from hyper dorsiflexion to plantar flexion and vise versa.

3.2. Statistical analysis

Range of motion and gait parameters were examined on a continuous scale and were tested for normality based on skewness and kurtosis. Paired *t*-test was utilized when data was normally distributed and Wilcoxon rank sum test if data was not normally distributed.

Pearson and Spearman correlation coefficients were computed based on the normality of the specified variables, and the variable of interest was the change in maximum knee extension after surgery (MKE-dif). Correlation analysis was done between MKE-dif and: 1 – the preoperative kinematic and kinetic parameters, 2 – the difference of the kinematic and kinetic parameters which was

Table 1
Gait patterns.

	Ankle maximum dorsiflexion at stance (AMDF)	Maximum knee extension at stance (MKE)
Mild gait	Normal	Normal
True equinus	Decreased	Normal or increased (recurvatum)
Jump gait	Decreased	Decreased (knee flexion)
Apparent equinus	Normal	Decreased (knee flexion)
Crouch gait	Increased	Decreased (knee flexion)
Recurvatum	Normal	Increased (recurvatum)