Gait & Posture 42 (2015) 518–522

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Influence of orthosis on the foot progression angle in children with spastic cerebral palsy

Barry Danino [a,*], Snir Erel [b], Meital Kfir [b], Sam Khamis [b], Reuven Batt [b], Yoram Hemo [a], Shlomo Wientroub [a], Shlomo Hayek [a]

[a] Department of Pediatric Orthopaedics, Dana Children's Hospital, Tel-Aviv Sourasky Medical Center, and the Sackler Faculty of Medicine, Tel-Aviv University, Tel-Aviv, Israel

[b] The Gait and Motion Analysis Laboratory, Dana Children's Hospital, Tel-Aviv Sourasky Medical Center, and the Sackler Faculty of Medicine, Tel-Aviv University, Tel-Aviv, Israel

ARTICLE INFO

Article history:
Received 10 December 2014
Received in revised form 9 July 2015
Accepted 8 August 2015

Keywords:
Gait analysis
Foot progression angle
Orthosis
CP

ABSTRACT

We retrospectively assessed the effect of ankle–foot orthosis (AFO) on the foot progression angle (FPA) of 97 children with spastic cerebral palsy (CP) who had undergone comprehensive computer-based gait analysis both barefoot and with their orthosis, during the same session. The physical examination results and the gait study temporal and kinematic parameters comprise the study data. We focused on the peak FPA reached during stance and swing phases and at mid-stance and mid-swing, and also measured the transverse rotations of the pelvis, the femur and the tibia. AFOs improved gait, as reflected by improved temporal parameters, but they also increased internal rotation of the feet in diplegic CP children by 4.29 degrees for mid-stance, and by 3.72 degrees for mid-swing. The correlation between components of the rotational profile and FPA was significant for the diplegic group. AFOs did not produce any noteworthy differences between walking barefoot and walking with the brace in the hemiplegic group in what concerns FPA. Children with diplegic CP who use AFOs walk with increased internal FPAs in their orthoses. These findings might be explained by anatomical attributes as well as dynamic features during gait.

1. Background

Cerebral palsy (CP) is a permanent motor disorder due to a non-progressive defect, or a lesion of the brain occurring in the early stages of development (definition of the 4th International Congress of the Study Group on Child Neurology and Cerebral Palsy, Oxford 1964). It is therefore a complexity of symptoms rather than a specific disorder. Neuromuscular impairments in CP, such as spasticity, diminished motor control, and impaired proprioception, may compromise gait function [1]. Ankle foot orthoses (AFOs) are used to correct flexible ankles or subtalar malposition deformities as well as to control proximal joints. Their two functions in neuro-orthopaedics are to provide stability at the base of support and to simultaneously correct abnormal function and/or shape [2]. They may also be worn at night to serve as passive splints to prevent Achilles contracture. The use of ankle–foot orthoses (AFOs) is widely recommended to prevent the development or progression of deformity and to improve dynamic efficiency of the child's gait. The efficacy of an AFO in improving the walking ability of children with CP has been demonstrated in many gait investigations [3–6]. At the same time, however, it has been our impression that children with CP who wear an AFO seem to walk with increased in-toeing.

The purpose of this study was to evaluate whether AFOs may deleteriously affect the FPAs of children with spastic CP. The study was initiated after parents and physiotherapists complained about increased in-toeing after applying the ankle foot orthosis (that has not been noticed before). Due to recurrent complains we wanted to check whether there is evidence for the clinical observation.

We used computer-based gait studies consisting of motion analyses of three-dimensional segment and joint kinematics, a methodology that has been validated for evaluating gait variations in CP [12,13].

2. Patients and methods

This retrospective study was reviewed and approved by our Hospital Ethics Committee. The study population included

* Corresponding author. Tel.: +972 3 6974056; fax: +972 3 6974542.
E-mail address: barrydanino@hotmail.com (B. Danino).

http://dx.doi.org/10.1016/j.gaitpost.2015.08.006
0966-6362/

97 consecutive pediatric patients who underwent comprehensive gait analyses at the Dana Children's Hospital, Tel-Aviv Sourasky Medical Center between January 2002 and July 2010. Inclusion criteria covered subjects with a diagnosis of either diplegic or hemiplegic spastic CP who were independent walkers (GMFCS I-III). All subjects underwent a physical examination followed by a gait analysis that involved walking with and without an AFO, both during a single visit. Details on four groups of parameters (Demographics, physical examination, temporal and kinematic parameters) were obtained for analysis from the children's medical records at the gait and motion analysis laboratory.

AFO were all done at the same workshop using the same method: the child is sitting on an examination table while his legs fall out of the bed under the influence of gravitation. The technician makes a thin layer using plaster of Paris as a model for the AFO without trying to correct the alignment—accepting the foot deformity as is, and supporting only ankle dorsiflexion.

2.1. Demographics

Data were retrieved on age, gender, physical CP classification (hemiplegia or diplegia), functional level as determined by the Gross Motor Function Classification System (GMFCS) [7], and the use of assisted devices (single or double crutches, walker).

2.2. Physical examination

The physiotherapy team at the gait and motion laboratory had carried out physical examinations on all subjects. The analyzed data included hip internal and external rotation with the patient supine in hip extension, femoral anteversion (measured by the trochanteric prominence angle test), and tibial torsion (measured by the bimalleolar tibial angle).

2.3. Temporal data

Measurements of cadence, step length, stride length and walking speed were recorded for each child.

2.4. Kinematic data

Three-dimensional kinematic and kinetic gait data were collected bilaterally with an 8-camera Vicon nexus system (Oxford Metrics Ltd, Oxford, UK) sampling at 100 Hz, and 4 AMTI (Advanced Medical Technology Inc.,Newton, MA) four force-plates sampling at 500 Hz. Three dimensional motion analysis was applied according to the biomechanical model PlugInGait developed by Vicon1 (based on the work of Murali Kadaba and Helen Hayes Hospital) [16]. 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.

Changes in lower extremity and pelvic alignment were captured and processed by eight computerized cameras using the VICON1 612 motion analysis system at 120 Hz, and a capturing volume of 4 m × 3 m × 2.5 m.

The subjects themselves selected the speed at which they were tested.

The FPA is defined as the angular difference between the axis of the foot and the line of progression. It is measured in the gait laboratory by the angle of the foot relative to the walkway, and the normal values are about 10–15 degrees of external rotation. The FPA at the transverse plane, shank and thigh rotation angle in the transverse plane, and the pelvic tilt and knee angles in the sagittal plane were measured during gait with and without AFOs. The measurements and calculations selected for analysis were those of the best attempt, i.e., with the highest number of steps on the force plate. Kinematic analysis was performed by averaging the results of all the steps during the chosen trial. The maximal FPA was calculated at mid-stance and at mid-swing periods. Pelvic, hip and knee rotation were calculated at the same point at mid-stance when the maximal FPA was determined. Data from the gait analysis were obtained on both legs in all subjects. The results of the affected leg in the hemiplegic subject and both legs in the diplegic subjects will be reported.

All children had undergone comprehensive computer-based gait analysis both barefoot and with their orthosis, during the same session. Data was analyzed for hemiplegic and diplegic subjects separately. Due to small numbers which results without statistical significance, no further subgroup analysis was done (i.e. patients who walk with/without aids).

2.5. Statistical analysis

Regression and analysis of variance were used to compare results of walking with and without the AFO and for relating them to relevant demographic variables (e.g., age, sex, body mass index [BMI]). Appropriate transformations were made to achieve responses with an approximately normal distribution. In the absence of such transformations, nonparametric methods, such as Wilcoxon's signed rank test, were used to compare gait outcomes with and without the AFO.

3. Results

3.1. Demographic data

The 97 study children underwent 111 examinations (10 children had two different tests, and two children had three different tests, all with different AFOs and at separate visits). Their average age was 8.5 years (range 3.3 to 16.5), 58 were boys and 39 were girls. There were 68 subjects classified as diplegic and 29 as hemiplegic. The GMFCS classifications for the diplegic subjects were 33 as level I, 13 as level II and 22 as level III. Thirty-three of the diplegic children walked without aids, 2 used a single crutch, 11 used a pair of crutches, and 22 children used a walker. Thirty-nine of the diplegic children wore a hinged AFO, 22 wore solid AFOs, 6 wore dynamic AFOs and one wore a posterior spring leaf-type brace. In the hemiplegic group, 28 children walked without aids and one used a single crutch. Twenty-one of the hemiplegic children wore a hinged AFO, 7 wore solid AFOs, and one wore a dynamic AFO.

3.2. Temporal data

Fig. 1 summarizes the comparative temporal parameters while walking with AFOs and while walking barefoot. AFOs significantly increased walking velocity by at least 10% for all subjects: specifically, by 7 cm/min ($p = 0.006$) for the diplegic subjects and by 11 cm/min ($p = 0.003$) for the hemiplegic subjects. AFOs increased step length by 4 cm in the diplegic group ($p < 0.001$) and by 9 cm ($p = 0.001$) in the hemiplegic group. They also significantly increased stride length in the diplegic group (by 9 cm, $p < 0.001$) as well as in the hemiplegic group (by 15 cm, $p < 0.001$). The use of AFOs reduced cadence by about 7% (9 steps per minute) in the hemiplegic group, but failed to produce any change in the diplegic group