Kinematic analysis for describing gait patterns of children with cerebral palsy

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Abstract

Cerebral palsy (CP) is a non-progressive condition comprising a broad group of disorders that alter movement, posture, spasticity, rigidity and cause a decrease in coordination and motor control. This work presents a kinematic gait analysis of Chilean children diagnosed with cerebral palsy to determine the parameters that quantitatively characterize the different gait patterns. For the analysis, the capture of the extraction of the angles of movement of the joints (hip, ankle, and the knee) and the foot's progress were measured. Some characteristic ranges were found for the different types of gait. In the case of Winters I, the hip flexion is between 38 and 45 degrees and that of the knee between 52 and 60 degrees, while in Winters type II the hip flexion is less than 30 degrees and in the knee less than 42 degrees. Finally, in Winters type III, the hip flexion has an angle between 44 and 54 degrees and the knee between 69 and 78 degrees. There is also evidence of plantar flexion of the ankle up to -12 degrees.

Keywords: Cerebral palsy, gait kinematics, gait classification

1. Introduction

The most common disability in children is cerebral palsy (CP). According to MyChild, the organization charged with providing information and resources on cerebral palsy in the United States, it is estimated that 3 out of every 1,000 live births have it (MyChild, 2021). Despite being a non-progressive condition, CP is considered disabling, as it comprises a broad group of disorders altering children's movement, posture, coordination, and motor skills (Zhang et al., 2020). The study aims to use different computer tools and motion analysis techniques to perform kinematic analysis of a group of Chilean children diagnosed with cerebral palsy, intending to establish the parameters that characterize the different gait patterns in spastic hemiplegia.

2. Development

2.1 Theoretical framework

Different criteria have been adopted to classify Cerebral palsy, such as the degree of incidence in mobility (GMFCS scale). This classification consists of a five-level scale where level I is the lowest degree of mobility compromise and level V is the highest. Children in levels I and II of the GMFCS scale can walk independently, and in level III can walk with the aid of orthopedic devices. However, they present difficulties performing activities related to the gross motor system such as jumping, activities that require balance, and coordination. In some cases, the children may also present difficulties walking on inclined surfaces or in confined spaces, as considered by Vidarte et al. (2010). Some patterns have been divided into true equinus, jump gait, apparent equinus, and crouch gait. Children in true equinus present full knee extension and equinus ankle referring to limited dorsiflexion of the ankle or plantarflexion of the foot. Jump gait presents equinus ankle especially in the late stance phase, knee and hip excessively flexed in the initial position. Apparent equinus have a standard range ankle and the knee excessively flexed in stance phase. Finally, a crouch gait corresponds to excessive dorsal flexion of the ankle and excessive flexion of the knee and hip (Armand, 2016).

On the other hand, the most frequent subtype of CP is spastic, which can be hemiplegic (i.e., one side of the body affected) or diplegic (i.e., two sides of the body affected) (Cans, 2000). Alterations in muscle spasticity characterize spastic CP. They have a highly variable gait pattern that can be classified with the Winters system consisting of 4 homogeneous groups. In spastic hemiplegic CP, Winters type I and II gait patterns predominate: Winters type I is characterized by plantar flexion of the ankle during the swing phase, and type II, which presents an equinus gait pattern but with spastic or contracted plantar flexors (Agostini, 2015).

2.2 Problem statement

The rehabilitation for patients with CP seeks to develop alternatives for patients diagnosed with cerebral palsy to develop a certain degree of autonomy. Thus, the patient's possibilities to adapt and evolve in his social and personal life increase when he receives the appropriate treatment. It is essential to know efficiently how the disability affects their mobility to carry out an early and proper classification of the patient's CP. Similarly, it is crucial to perform a correct kinematic characterization of the child both for an early classification and to evaluate its evolution.

2.3 Methodology

The study included 11 Chilean children diagnosed with spastic cerebral palsy (hemiplegic) in Chile. The inclusion criteria considered participants with walking independence and clinically diagnosed at GMFCS scale levels I and II. Through the VICON system, the kinematic capture of each child was obtained during dynamic walking on a walkway without inclines and in a straight line at a self-selected speed. The anatomical landmarks points for the acquisition system and the markers were located in the iliac spines, thighs, tibias, ankles, toes, and heels (Gomez et al., 2021). The data processing was carried out using the Matlab R2020b software was implemented along with the BTK biomechanical toolkit, an open-source library developed on GitHub since 2009 for data processing.

2.4 Results

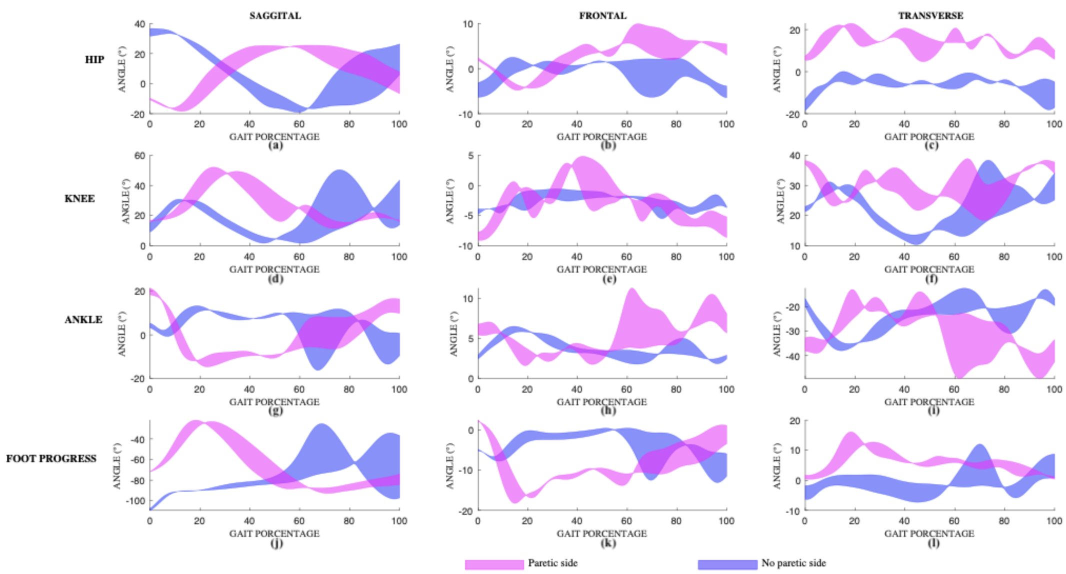
The angles of movement of the main joints in each of the body planes were recorded and were found to be within the ranges presented in Table 1. In addition, the mean and standard deviation between the different gait cycles of each participant were plotted as shown in Figure 1.

Table 1. *Joints' maximum and minimum ranges of movement throughout the recorded gait cycles among all participants.*

Joint	Saggital plane	Frontal plane	Transverse plane

	Min (°)	Max (°)	Min (°)	Max (°)	Min (°)	Max (°)
Left hip	-24.06	63.37	-23.03	22.18	-62.56	47.60
Right hip	-25.61	63.17	-28.54	17.60	-38.24	45.32
Left knee	-5.46	78.17	-35.30	25.72	-17.43	46.03
Right knee	-10.79	94.82	-14.40	19.74	-186.13	72.57
Left ankle	-49.91	26.09	-13.21	10.16	-45.21	33.74
Right ankle	-154.52	24.41	-33.06	33.71	-65.09	64.84

Figure 1. *Angles of motion during a gait cycle in the sagittal, frontal and transverse planes. (a, b, c) angles of hip movement in the sagittal, frontal plane, and transverse plane,(d, e, f) angles of knee movement in sagittal, frontal plane, and transverse plane,(g, h, i) angles of ankle movement in the sagittal in sagittal, frontal plane, and transverse plane, (j, k, l) angles of foot progress in the sagittal in sagittal, frontal plane, and transverse plane.*



In the records analyzed, it was found that 44% of the participants showed a gait pattern corresponding to Winters type I, with ankle flexion between 13 and 22 degrees, hip flexion between 38 and 45 degrees, and knee flexion between 52 and 60 degrees. Moreover, 44% of patients were classified in Winters type III. The main differences with the group I are presented in the ankle angles with a plantarflexion up to -12 degrees, the maximum hip extension between 44 and 54 degrees, and knee flexion between 69 and 78 degrees. The 11% of the participants presented a Winters type II gait pattern. There were no differences in the ankle angles, but there was less flexion in the hip (i.e., less than 30 degrees) and in the knee (i.e., less than 42 degrees) concerning the Winters type III and type I gait patterns.

2.5 Discussion

Table 1 shows the joints' ranges of motion in the sagittal, frontal and transverse planes. However, in the frontal and transverse planes, the ranges of motion are minimal for some joints. This means that the frontal and transverse planes do not reflect some joints' full range of motion. For this reason, the sagittal plane can be considered the best plane for kinematic analysis because all the joints evaluated show significant variations in this plane. Additionally, there is no reference literature for the case of gait patterns in the frontal and transverse planes since these planes have been excluded from the kinematic analysis for the reasons mentioned above. The effectiveness of the kinematic analysis on the sagittal plane can also be corroborated by Figure 1. It is evident that the difference between the angles of motion of the joints of interest between several gait cycles is smaller for the sagittal plane than in the frontal and transverse planes. The results obtained on the kinematics of the joints in the sagittal plane are consistent with the gait patterns presented by (Armand et al., 2016) and (Rodda et al. 2004), i.e., if there is a similarity between the different gait patterns of patients diagnosed with CP. However, in the case of the study by Rodda et al. (2004), there is greater variability in the gait pattern between the different gait cycles of the participants. This may be related to the degree of development of CP of the participants or the homogeneity of the population since these studies used larger populations and were not limited to a specific degree of CP development as long as the patients could walk.

3. Conclusions

In the first place, it was established that before the analysis of kinematic data, it is essential to perform the proper segmentation of the samples. In the case of patients with hemiplegia, it is necessary to indicate which hemisphere is affected. Likewise, it was established that the fundamental parameters for the characterization of gait patterns in patients with CP should focus on the angles of motion in the sagittal plane of the hip, ankle, and knee and focus on the toe-off stage of the gait cycle or during the swing phase. The kinematic analysis performed in this work can be the basis for the formulation of new projects, such as developing a method for automatic classification of gait kinematics according to the clinical subtype of cerebral palsy.

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