Trunk Kinematic Analysis during Gait in Cerebral Palsy Children with Crouch Gait Pattern

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ABSTRACT

Background: Deficits in upper body movement have received little attention during gait in cerebral palsy (CP) children with crouch gait pattern (CGP).

Objective: Purpose of this research is to describe the correlation of trunk movement with the excessive knee flexion and ankle kinematic in CP children with CGP.

Material and Methods: Gait analysis data from 57 limbs of diplegic CP children with CGP and 26 limbs of normal children was gathered. Kinematic parameters of trunk in relation to the pelvis were extracted in the sagittal, transverse and coronal planes. CP limbs were clustered using K-means cluster analysis according to the knee flexion angle at initial contact and the mean position of ankle joint during the stance phase of gait cycle, to three clusters. Pearson correlation coefficient between knee, ankle and trunk kinematic variables was assessed. Differences between clusters were analyzed with Kruskal–Wallis and post hoc tests.

Results: The results revealed: 1) crouch clusters had more trunk obliquity and rotation mean position than normal; 2) the range of motions of the trunk obliquity and rotation exhibited significant differences between crouch and normal clusters; 3) the level of excessive knee flexion had positive correlation with the trunk mean position in all planes; 4) the ankle kinematic at stance phase was associated with the trunk mean position in all planes.

Conclusion: The results revealed the trunk mean position is correlated with the excessive knee flexion severity and ankle joint kinematic in CP children with CGP.

Keywords

Trunk Kinematic, Cerebral Palsy, Crouch Gait Pattern, Excessive Knee Flexion, Gait

Introduction

Crouch gait pattern (CGP), one of the most common gait pathologies in patients with cerebral palsy (CP)[1] is characterized by increased knee flexion throughout stance phase and frequently increased hip flexion and internal rotation [2]. The ankle joint in these children can have different kinematic patterns.

Determining the causes of progressive crouch gait and the appropriate corrective treatment is difficult because the motions generated by muscle forces during crouch gait are not obviously understood [3, 4]. that is apparent in CP children ambulation that muscles of different segments have compensatory functions for covering other segments muscles in-

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sufficiency [3].

The trunk greatly influences the dynamics of the body, as it accounts for more than half of the body mass [5]. Active neuromuscular control of trunk motion causes stability maintaining during walking [6]. A developmental association has also been confirmed between dynamic trunk stability and lower limb intersegmental coordination [7]. Pathological trunk motion is common in children with CP [8]. Cerebral Palsy children have poor control of trunk postural muscles [9]. Trunk muscle dysfunction causes compensation by the extremities muscles to assist maintaining upright posture. Therefore, extremities muscles capability in functioning as prime movers of extremities reduces [10].

A few studies have classified crouch gait pattern to some homogenous clusters and have labelled the clusters in order to increase gait pathology of lower extremities and knee flexion severity [11, 12]. In CP children with CGP in addition to knee flexion severity, the ankle kinematic is also different in different cases. Previous studies did not investigate the trunk kinematic in accordance with knee flexion severity and ankle joint kinematic in CP children with CGP. Therefore, the global objective of this study was to examine the 3D trunk kinematics during gait of CP children with CGP with different knee flexion severity and ankle joint kinematic. The specific objectives were to assess the existence of correlation of excessive knee flexion and ankle joint kinematic in stance phase during gait with the trunk kinematic variables.

Material and Methods

Patients

Gait analysis data were obtained from 42 subjects, from which 84 limbs were suitable for analysis. Twenty-nine children (58 limbs) with diplegic CP (15 girls, 14 boys, age range 6-12 years, mean 8.39 years) were recruited from rehabilitation centers. Fourteen neurologically intact children (28 limbs) with no gait abnormalities (5 girls, 9 boys, age range 6-13 years, mean 9.38) were recruited to provide normal gait data. Ethical approval was obtained from Medical Sciences Committee. Informed consent was obtained from parents and patients' privacy maintained. The inclusion criteria of spastic diplegic CP children were that all walks with crouch pattern with more than 20-degree knee flexion at initial contact. However, children with mental retardation, dystonia, ataxia, history of orthopedic surgery, visual impairments and obedience were excluded.

Data Collection

Thirty-nine retro reflective technical markers were mounted to determine position and orientation of body segments in relation to the calibrated volume in the laboratory. Reflective markers were attached to the calcaneum, first metatarsal head, second and fifth metatarsal head, navicular, fifth metatarsal base, lateral maleolus and medial maleolus. Three markers on a rigid plate were attached to both the thigh and shank segments using elastic strap. Two markers were attached to medial and lateral femoral epicondyles. Three markers were attached to right and left anterior superior iliac spine and midway between both posterior superior iliac spines. A marker was attached to the sternum, two markers to left and right acromions and one marker to the center of the frontal bone. These formed the marker set that was applied throughout all data collection. Ten experimental walking trials along a 7-m walkway were collected at 120 HZ while children were walking at their self-selected speed. The motion data were captured with eight infrared cameras of Qualisys motion analysis system (Qualisys®Ltd, Sweden).

To enable the motion data from the technical markers to have anatomical relevance, Opensim 3.1 software [13] was used. In order to calculate chosen gait variables, first, raw marker data was extracted from .qtm files obtained from qualysis tracking movement software, and then converted to C3D files. The C3D files were changed to .trc files using MOKKA software. Then, .trc files were exported to Opensim 3.1. In Opensim software, data were transformed, then scaled to make a static model and while using inverse kinematic tool, the joint angular motion was calculated. Each one-trial motion file was loaded on a created static model and one of them that had more successful gait cycles was selected. Between 3 and 6 consequent gait cycles for each limb were used for kinematic variable selection. The considered kinematic variables were extracted for each cycle and then averaged to produce one single dataset for ankle, knee, hip, pelvis and trunk.

The CP children did not have clean hits on force plate, therefore, high pass algorithm (HPA) technique [14] was used to recognize the gait phases from kinematic data. For doing the high pass algorithm, MATLAB software and the orientation data of heel and metatarsal markers were used.

Statistical Analysis

Clustering of CP Limbs

Angles of knee flexion at initial contact and the mean position of ankle joint during stance phase of gait cycle were extracted for all limbs. K-means cluster analysis was applied according to these two variables in order to define three clusters of CP limbs with CGP and one homogenous cluster of normal limbs. So, each cluster with different knee flexion severity at initial contact was named as mild, moderate and severe. K-means cluster analysis was done using SPSS software version 23.

Extraction of Trunk Data

In this study, the purpose was to evaluate the correlation of trunk movement according to the knee and ankle joints kinematic variables of each limb apart from other limbs. Therefore, the trunk kinematic has been considered according to each limb kinematics in gait cycle of itself. The kinematic parameters of the trunk were extracted from the trunk segment relative to the pelvis angles in the sagittal (tilt), coronal (obliquity) and transverse (rotation) planes. The selected kinematic parameters for the trunk were the range of motions (RoMs) and mean positions over the gait cycle in three planes. As the distribution was not normal, statistical analysis to compare the groups was performed using Kruskal–Wallis and post hoc tests. Pearson correlation coefficients were calculated between the kinematic parameters of the trunk to estimate the associations between the knee and ankle joint angles and trunk kinematics. Statistical analyses were performed using SPSS software version 23.

It should be noted that normal and CP children were not significantly different in terms of age, weight, height and BMI when recruited to the study (p-value>0.05).

Results

Table 1 shows the age, height, weight and BMI of normal and CP group.

The trunk kinematic data for the sagittal, coronal and transverse planes for CP limbs and normal limbs are described in Table 2. The knee flexion angle at initial contact, knee and ankle joint mean position during stance phase of gait cycle also are reported.

The Comparison of trunk movements of CP limbs with CGP and normal limbs revealed insignificant differences in the RoM of trunk tilt. The trunk obliquity and rotation RoMs of crouch limbs were significantly lower than normal limbs. Crouch group had significantly more trunk bending and rotation mean position than the normal group.

After K-means cluster analysis according to knee flexion angle at initial contact and mean ankle angle during stance phase, the limbs with crouch gait pattern were placed in three clusters. All normal limbs also were placed in a homogenous cluster after K-means cluster analysis. The clusters were named according to the amount of knee flexion at initial contact to mild, moderate and severe. The ankle joint was constantly plantar flexed in mild and se-

Table 1: Median and interquartile range of CP and normal group describing population characteristics.

		Age (years)	Height (cm)	Weight(Kg)	BMI
CP	Median	8	116	26	17.87
	Interquartile Range	4	29.75	17.85	6.23
Normal	Median	9.50	131.5	26.2	16.49
	Interquartile Range	3.25	22.13	18.30	3.65

BMI = Body Mass Index (mass (kilogram)/height2 (meter)).

Table 2: Median, Interquartile Range and P-value representation of trunk kinematic variables (range of motion (RoM) and mean position of trunk) and knee and ankle kinematic parameters (knee flexion angle at initial contact and mean angle of knee and mean angle of ankle at stance phase) for CP limbs and normal group. (P<0.05)

	Limbs with crouch gait pattern		Normal limbs		p-value
	Median	Interquartile Range	Median	Interquartile Range	
Tilt RoM	6.57	11.43	10.48	8.74	0.07
Obliquity RoM	4.61	13.98	11.64	9.20	<.001
Rotation RoM	7.97	20.26	18.94	7.35	<.001
Tilt (°) Mean position	0.00	12.63	-10.98	6.62	<.001
Obliquity — absolute value (°)	3.17	2.90	1.01	2	<.001
Rotation — absolute value (°)	3.77	6.01	2.10	2.35	0.01
Knee mean flexion St	37.30	35.30	23.34	55.58	<.001
Knee flexion IC	34.93	51.64	3.62	12.39	<.001
Ankle mean position	3.09	24.7	-3.64	10.17	0.03

IC= Initial Contact; St=Stance phase

vere crouch clusters but was constantly dorsi flexed in moderate cluster. The descriptive characteristics of each cluster and P-values of their differences are reported in Table 3.

Trunk movements of the children with crouch gait pattern were significantly different between mild and moderate crouch clusters in trunk tilt mean position. The trunk mean position in mild cluster was in about 6-degree extension and in cluster moderate, trunk had about 3-degree flexion. Severe crouch cluster had the greatest amount of trunk bending mean position. The mean trunk rotation of all crouch clusters was more than normal but was not significantly different. The trunk obliquity RoM in mild crouch cluster was about normal value but clusters moderate and severe had significantly less obliquity RoM compared to normal. Trunk rotation RoM of mild crouch cluster was near normal value but moderate and severe crouch clusters had significantly lower rotation RoMs.

Correlations between overall Knee and Ankle parameters and trunk deviations are shown in Table 4.

Levels of excessive knee flexion and ankle

Table 3: Median, interquartile range and P-value representation of trunk kinematic variables (range of motion (RoM) and mean position of trunk) and knee and ankle kinematic parameters (knee flexion angle at initial contact and mean angle of knee and mean angle of ankle at stance phase) for three crouch clusters and normal cluster. (P<0.05)

	Cluster 1(C1) mild		Cluster 2(C2) moderate		Cluster 3 (C3) severe		Cluster 4(C4) normal		P-values
	Median	Interquartile Range	Median	Interquartile Range	Median	Interquartile Range	Median	Interquartile Range	Post hoc comparison α = 0.05
Trunk Tilt RoM	9.95	9.43	3.50	10.60	9.09	13.36	10.48	8.74	
Trunk Obliquity Rom	13.21	13.66	3.20	14.51	5.50	11.73	11.64	9.20	C3/C4; C2/C4;
Trunk Rotation RoM	13.69	20.07	5.14	20.03	11.55	20.65	18.94	7.35	C2/C4; C3/C4
Trunk Tilt mean position	6.27	7.79	-3.28	13.38	.00	8.10	-10.98	6.62	C3/C4; C1/C4;C1/C2
trunk Obliquity mean position	2.42	2.79	3.33	5.84	3.41	2.38	1.01	2	C3/C4; C2/C4; C1/C2
trunk Rotation mean position	4.49	3.18	3.0	5.54	5.44	11.24	2.10	2.35	
Knee mean flexion St	28.62	15.42	32.16	21.88	49.40	9.17	23.34	10.21	C3/C4; C1/C4; C2/C4;C1/C1; C3/C2
Knee flexion IC	26.66	18.40	34.93	19.59	45.92	18.40	3.62	5.56	C1/C2; C4/C2; C3/C2
Ankle mean position St	-6.35	13.23	17.27	8.55	-6.87	9.98	-3.64	10.17	C1/C4; C2/C4; C3/C4;C3/C1

IC= Initial Contact; St=Stance phase

joint mean position were not correlated with trunk RoMs in each of three planes. The trunk mean positions in all three planes were correlated positively with the knee joint flexion angle. The trunk tilt and rotation mean position had negative correlation with the ankle joint mean position during stance phase of gait cycle. The trunk obliquity mean position was positively correlated with ankle joint mean position.

Discussion

The objective of this study was to determine the characteristics of trunk movement in CP children with a crouch gait pattern in terms of knee flexion severity at initial contact and ankle joint kinematic during stance phase.

Firstly, the comparison of CP limbs with CGP and normal limbs revealed that trunk tilt RoM is not significantly different. In addition, trunk bending and rotation in CP limbs were

Table 4: Correlation coefficient between mean flexion angle of knee, knee flexion angle at initial contact, mean ankle angle at stance phase and trunk range of motion (RoM) and mean position for the tilt, obliquity and rotation movements.

		Ankle mean position St	Knee mean flexion St	Knee flexion IC
Trunk Tilt RoM	Pearson Correlation	-0.015	-0.041	0.037
	Sig.	0.446	0.357	0.368
Trunk Obliquity Rom	Pearson Correlation	0.037	-0.030	0.045
	Sig.	0.369	0.393	0.344
Trunk Rotation RoM	Pearson Correlation	-0.132	-0.044	0.007
	Sig.	0.117	0.347	0.475
Trunk Tilt mean position	Pearson Correlation	-0.273*	0.101	0.280*
	Sig.	0.006	0.182	0.005
Trunk Obliquity mean position	Pearson Correlation	0.413*	0.353*	0.413*
	Sig.	<0.0001	0.001	<0.0001
Trunk Rotation mean position	Pearson Correlation	-0.198*	0.276*	0.264*
	Sig.	0.036	0.006	0.008

IC= Initial Contact; St=Stance phase

*. Significant correlation.

significantly lower than normal. The average position of trunk in CP group was more extended than normal and trunk obliquity, and rotation mean positions were significantly more than normal.

Secondly, we clustered CP limbs to know trunk behavior in different clusters with different ankle joint patterns and different severity of knee flexion. The results of K-means cluster analysis revealed that limbs with CGP could be placed in three clusters. Cluster 3 had the greatest amount of excessive knee flexion and the ankle joint was plantar flexed in this cluster. Cluster 2 had moderate excessive knee flexion among three clusters and the ankle was constantly dorsi flexed. Cluster 1 had minimum excessive knee flexion among clusters and the ankle was plantar flexed too. Therefore, cluster 1 had a mild crouch pattern, cluster 2 had a moderate crouch pattern and cluster 3 had a severe crouch pattern. The mild cluster had trunk obliquity RoM more than the normal group but not statistically different. Our results showed that trunk segment mean position in the mild cluster was in extension, in moderate cluster was in flexion and in sever cluster had no flexion and extension.

Some reseaches which have studied head and trunk movements during gait found increased range of motion (ROM) in different planes in CP children [15, 16]; it should be noted that these studies have been conducted on CP children regardless of the type of cerebral palsy in details. Our included subjects were CP children with the crouch gait pattern exclusively. Attias et al. (2015) in their research tried to differentiate trunk movements between hemiplegic and diplegic CP children but they did not separate the type of diplegic CP [17]. However, our results demonstrated that trunk tilt, obliquity and rotation RoMs in mild cluster with less excessive knee flexion were greater than moderate and severe clusters, these were not statistically significant. Hence, we hypothesize that in severe crouch gait patterns, the alterations of knee and hip flexion are mechanisms to promote coordination of step length to support forward progression instead of the trunk movement. Probably the flexion alterations of knee and hip joint can compensate for trunk RoMs deficit with an increase of excessive knee flexion. Changing knee flexion and ankle angle can assist the body forward progression. Previous studies were not focusing on the knee and ankle joint behavior while studying trunk kinematic. Moreover, different types of trunk compensations have been described in the literature. Perry et al. explained that “the phasic changes in thorax alignment recorded during walking represent postural adaptations to inadequate mobility or faulty muscle control at the hip, knee or ankle”[18]. Therefore, knee biomechanics influence trunk movements.

We found that clusters with more knee flexion had more trunk obliquity and the rotation mean position. This may be associated with trunk deviation and scoliosis in severe CP children with CGP.

Lamoth et al. (2002) and Swinnen et al. (2013) reported decreases in the RoMs of the thorax and pelvis movements as walking speed decreases [19, 20]. Hence, in our study controlling walking speed could be beneficial.

Most of the studies reveal that the trunk compensates for lower limb alterations to maintain head stability needed to preserve the vestibular system [15, 18, 21, 22], but we hypothesized that probably in a pure crouch gait pattern, the knee compensates for trunk control deficits. Crouch gait is generally considered unfavorable for children with cerebral palsy; however, a crouched posture may allow biomechanical advantages that lead some children to adopt a posture that may allow to generate new movements to compensate for the impairments associated with cerebral palsy, such as motor control deficits [23]. Maybe hip, knee and ankle joints interact to control trunk postural deficits to maintain trunk in a posture near normal.

We showed that children with less excessive knee flexion are greater but not significant RoM of trunk obliquity and rotation compared to clusters with more excessive knee flexion. Maybe with fewer lower-extremity joints involvement, the trunk still tries to return to the upright posture. Gradually with an increase in the level of impairment, the trunk capability to compensate diminishes.

The CP group had more bending and the rotation mean position compared to the normal group but less tilt mean position; probably they try not to perturb trunk location in the sagittal plane.

Cluster 2 with dorsi flexed ankle had the minimum trunk RoMs in three planes among clusters. Perhaps the ankle and trunk interaction and the relationship are more than what has been thought yet.

Increases in the RoM of the trunk likely result in the appearance of deformations and pain in the spine[17]. Maybe children with the severe crouch gait pattern have learned to decrease their trunk range of motions to decrease their pain and discomfort.

The first limitation of this study is that the trunk was considered as a single rigid segment, and we considered just trunk movements related to the pelvis. Maybe considering thorax movement related to lab also could be beneficial. To simplify the analysis, the assumption that the trunk is a rigid segment is generally used for the clinical gait analysis [24]. The second limitation was concerned on walking speed, which varied across subjects and that walking speed influences trunk movements [20, 25], and it was better to be monitored. Different walking speeds of CP children can influence thorax kinematics [17].

Conclusion

Study of 57 limbs of CP children with the crouch gait pattern revealed that the RoMs of the trunk segment were lower than the normal group and decreased with increasing the level of excessive knee flexion. Moreover, we found a correlation between ankle joint and trunk kinematic. Whatever plantar flexion of ankle increased, the trunk tended to be in more extension and with ankle dorsi flexion increased, the trunk became more flexed. Future studies will needed to recognize the detailed reciprocal strategies between the lower limbs and upper body that lead to alterations to optimize treatment strategies.

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Conflict of Interest

The authors declare no conflict of interest.

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