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Spatiotemporal and Joint Kinematic Analyses in Hemiparetic Cerebral Palsy Children During Stance Phase

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Abstract - The aim of this study is to identify and quantify spatiotemporal and joint kinematics in hemiparetic cerebral palsy children by three dimensional gait analysis (3DGA). Gait strategy of 36 Hemiparetic and 31 healthy children was quantified by the new anatomically based protocol of 3DGA. Spatiotemporal and joint kinematics of lower limbs were identified and calculated. Results revealed that, the gait pattern of the paretic and non paretic sides of hemiparetic children were different compared to healthy subjects. Shorter stance phase was noted on the paretic side compared to non paretic and healthy subjects ($P<0.05$). Hemiparetic children walked with significantly reduced velocity, stride length, step length and cadence compared to healthy subjects. However step width increased considerably in the hemiparetics compared to healthy children. Joint kinematics during stance indicated that hemiparetic children walked with significantly increased anterior trunk tilt, pelvic tilt and pelvic retraction compared to healthy subjects ($P<0.05$).

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Abstract - The aim of this study is to identify and quantify spatiotemporal and joint kinematics in hemiparetic cerebral palsy children by three dimensional gait analysis (3DGA). Gait strategy of 36 Hemiparetic and 31 healthy children was quantified by the new anatomically based protocol of 3DGA. Spatiotemporal and joint kinematics of lower limbs were identified and calculated. Results revealed that, the gait pattern of the paretic and non paretic sides of hemiparetic children were different compared to healthy subjects. Shorter stance phase was noted on the paretic side compared to non paretic and healthy subjects ($P<0.05$). Hemiparetic children walked with significantly reduced velocity, stride length, step length and cadence compared to healthy subjects. However step width increased considerably in the hemiparetics compared to healthy children. Joint kinematics during stance indicated that hemiparetic children walked with significantly increased anterior trunk tilt, pelvic tilt and pelvic retraction compared to healthy subjects ($P<0.05$). Nevertheless; hemiparetics displayed higher values of hip flexion than healthy subjects with reduction of both knee flexion and ankle dorsal flexion abilities on the paretic side than non paretic. To conclude, Hemiparetic cerebral palsy children generally present a unique motor strategy due to the pathology and search of better stability to optimize gait.

Keywords : Hemiparetic cerebral Palsy; Gait analysis; Spatiotemporal; Joint kinematics.

I. Introduction

Hemiparetic cerebral palsy (CP) is a form of spastic cerebral palsy in which one arm and leg on either the right or left side of the body is affected. It is the most common syndrome in children born at term and is second in frequency only to spastic diplegia among preterm infants (Kulak and Sobaniec, 2004). Patients with spastic hemiplegia have unilateral prehensile dysfunction as a consequence of lesions within sensorimotor cortex and corticospinal tract. Children whose hemiparesis involves the upper limb to a greater extent than the lower (arm-dominant hemiparesis) are much more likely to experience learning difficulties than those whose clinical pattern is leg-dominant (Galli et al., 2010).

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Three dimensional Gait analysis can provide a more objective evaluation including kinematic, kinetic, and dynamic electromyographic assessment. Hence enabling clinicians to differentiate gait deviations objectively and understand the primary problem behind a complex disorder more accurately.

In literature some studies examined quantitatively the spatiotemporal and joint kinematics of hemiparetic cerebral palsy children, these studies mainly focused on comparing functional motor evaluations of the right and left hemiplegic gaits. Galli et al. (2010) compared right and left hemiplegic gaits using 3DGA to analyze the difference in patterns, the results demonstrated that right hemiplegic gait walked with higher velocity than left hemiplegic gait. Wheelwright et al. (1993) assessed spatiotemporal parameters of gait in hemiparetic children and reported that, hemiparetic children walked more slowly with shorter step length, decreased cadence and longer swing time than normal children. Motor functions of right versus left hemiplegic children together with other intellectual, verbal and non-verbal functions were investigated. The results revealed that both groups showed overall slight or moderate impairments in motor function but the left hemiplegic group had more severe motor limitation than the right hemiplegic group (Carlsson et al., 1994). Cimolin et al. (2007) analyzed gait strategy of uninvolved limb in children with spastic hemiplegia and reported that uninvolved limbs had significant longer stance phase, knee joint more flexed, hip joint presented high flexion at the beginning of gait cycle and ankle kinematics presented values closed to normal. It appears evident that literature did not point out works on distinguishing quantitatively spatiotemporal and joint kinematics in hemiparetic cerebral palsy children during stance phase. A deeper understanding of their motor disability may generate rehabilitative strategies and treatment on improvement of gait. 3DGA is nowadays the most accurate tool in defining peculiar motor characteristic in children with CP.

The aim of this study is furthermore to identify and quantify gait pattern of hemiparetic CP children and compare their results with those obtained in a group of healthy children.

II. Methods

a) Subjects

Thirty six hemiparetic CP children participated in the study with age range of 2-15years, among them 27 were right hemiparetic and 9 left hemiparetic .The age, weight and height of hemiplegic children were 7.8 ± 3.8 years, 26.2 ± 13.5 kg and 122.1 ± 22.5 cm respectively. According to (Arguelles et al., 1995) in terms of the assessment of degree of CP severity, all children had a mild severity (can walk unaided); in addition all patients were leg-dominant lower limb primarily involved with relative sparing of the upper limb. They had no history of functional lower limbs surgery and absence of pharmacological treatments in the last year.

A control group of thirty one healthy children were investigated; their age, weight and height were 8.4 ± 4.1 years, 28.9 ± 13.2 kg and 126.9 ± 22.5 respectively. Selection criteria for this group included no prior history of cardiovascular, neurological or musculoskeletal disorders. They exhibited normal range of motion, muscle strength, and had no apparent postural or motor deficits.

All subjects were volunteers and their parents gave written consent to the children's participation in this study. This study was approved by Ethics Committee of the Children's Hospital of Chongqing Medical University in China.

b) Data collection

The assessment composed of three dimensional gait analysis which was conducted in a laboratory equipped with 9m linear walkway and 6 infrared cameras operating at 60 HZ frequency. 2 Force plates embedded at the centre of the walkway used to determine foot contact and foot-off events synchronized with the system made from motion Analysis Company (Helen Hayes model). Reflective markers (10mm in diameter) were placed according to anatomical landmarks as shown in fig 1. (Motion analysis version 11 user's manual).

Anthropometric measures were taken and preparation of patient followed by inserting 26 markers directly on the subject's skin for measurement of static phase. The walking phase involved removal of 4 markers named (R. ankle medial, L. ankle medial, R. knee medial and L knee medial) from the subject's body leaving 22 markers as the new anatomically based protocol suggests (Leardini et al., 2007).

Subjects were allowed to walk barefoot at their self-selected speed along 9m walkway. Seven trials were recorded for each child in order to guarantee the consistency of the results. The following parameters were identified and calculated for each subject.

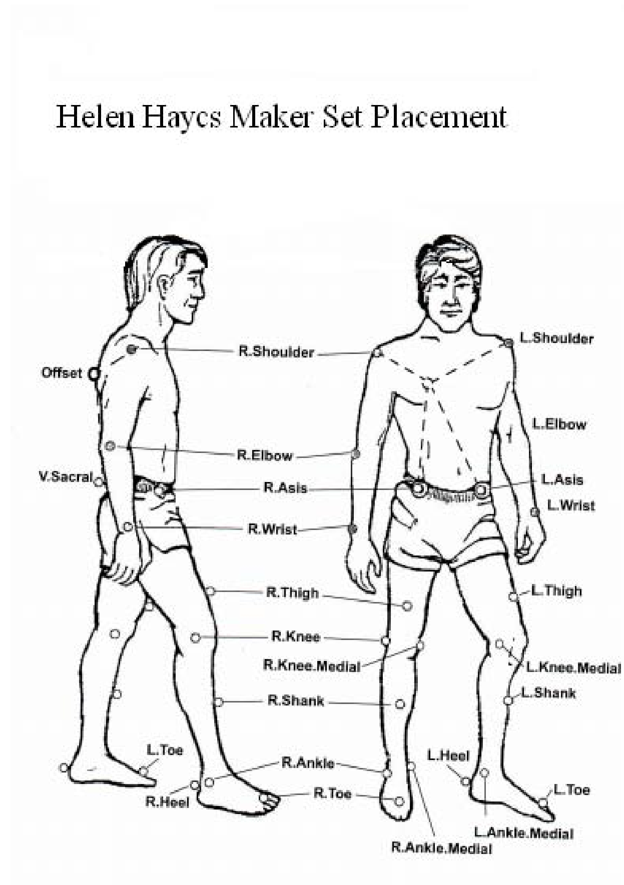

Fig. 1 : R - Right L - Left

Spatiotemporal parameters

Step length, step width, stride length, cadence, velocity, support time, non support time and double support time.

Kinematics : joint angles during stance phase

Trunk and Pelvis : Lateral tilt, forward tilt and rotation. Hip, knee and ankle: Flexion, extension, abduction, adduction and rotation.

c) Data analysis

Cortex1.1.4 software and orthotrack software version 6.6.1 were used to define gait parameters and estimate kinematics.

All previously defined spatiotemporal parameters and joint kinematics were computed for each subject. Comparison was made between non paretic and paretic sides of hemiparetic children with the right limb of healthy subjects.

d) Statistical analysis

SPSS version 19 was used for statistical analysis and data was analyzed by student's T-test. Statistical significance difference was defined as $P < 0.05$.

III. Results

Age, body weight and height were not significantly different among hemiparetic and healthy children. Table 1 displays the mean (standard deviation) of the spatiotemporal, ankle, knee and hip kinematics for hemiparetic group with the distinction between paretic and non paretic sides and those for healthy subjects. Table 2 displays trunk and pelvic kinematics.

a) Spatiotemporal parameters

Shorter stance phase was noted on the paretic side compared to non paretic and healthy subjects, Hemiparetic children walked with significant reduced velocity compared to healthy. Cadence, step length and stride length revealed significant lower values in comparison to healthy subjects ($P < 0.05$). For double support time, there was no significant difference in the two groups. Step width increased considerably in the hemiparetics compared to healthy children.

Table 1 : Summary of Gait parameters for hemiparetic children and healthy subjects.

	Hemiparetics N=36		
	Non paretic side	Paretic side	Healthy N=31
spatial temporal parameters			
Stance (%gait cycle)	62.24 (4.15) †	57.72 (2.82) •†	60.29 (2.20)
Swing ((%gait cycle	37.76 (4.15) †	42.28 (2.82) •†	39.71 (2.20)
Velocity (cm/s)	84.23 (24.20)	82.88 (24.90) •†	94.13 (21.28)
Stride length	81.59 (21.37) †	80.01 (21.71) †	92.45 (17.32)
Cadence	113.95 (17.18)	112.18 (16.06) †	122.39 (18.53)
Step length	39.44 (11.02) †	41.83 (12.11) †	47.13 (9.21)
Double support time	11.58 (3.88)	10.45 (4.54)	10.70 (1.82)
Step width		15.24 (4.68) †	12.87 (3.00)
Kinematics			
Ankle joint			
dorsal flexion	27.22 (21.91)	17.70 (15.04) •†	25.63 (11.88)
plantar flexion	-4.26 (5.20)	-6.95 (5.18) •	-7.57 (7.96)
Ankle abduction	11.81 (11.94)	17.07 (15.31) †	10.29 (10.57)
Ankle adduction	-7.46 (10.14)	-3.67 (18.09)	-5.63 (9.26)
Ankle internal rotation	10.83 (33.64)	12.14 (26.86)	8.58 (10.87)
Ankle external rotation	-35.97 (30.87)	-34.37 (31.70)	-31.21 (21.30)
Knee joint			
Knee flexion	38.70 (8.62) †	33.93 (10.38)•	31.47 (10.92)
Knee extension	11.05 (8.97) †	7.00 (9.12) •	4.88 (7.60)
Knee valgus	7.68 (5.09)	7.84 (5.39)	5.66 (5.70)
Knee varus	-5.90 (5.57)	-5.01 (4.82)	-5.40 (6.89)
Knee internal rotation	22.57 (32.57)	17.48 (34.96)	19.35 (23.65)
Knee external rotation	-21.81 (26.91)	-28.02 (32.89)	-22.79 (16.02)
Hip joint			
Hip flexion	47.60 (10.69) †	44.24 (11.12) •†	37.63 (9.39)
Hip extension	-9.76 (10.10)	-7.87 (12.05)	-8.55 (6.88)
Hip abduction	5.17 (5.59)	4.15 (6.45)	5.50 (4.40)
Hip adduction	-6.10 (6.33)	-6.50 (6.21)	-4.95 (3.92)

Hip internal rotation	18.24 (9.42)	22.97 (11.69) •	16.56 (13.87)
Hip external rotation	-6.38 (11.91)	-1.01 (11.99) †	-8.25 (15.42)

•p value < 0.05, compared between paretic and non paretic sides of hemiparetic patients, †p value < 0.05, compared with healthy subjects.

Table 2 : Summary of Pelvic and Trunk kinematics for hemiparetic children and healthy subjects.

		Hemiparetics N=36	Healthy N=31
Pelvic kinematics			
Pelvic lateral tilt (pelvic obliquity)	Hip up	7.07 (9.67)	4.67 (2.63)
	Hip down	-7.60 (6.85)	-5.66 (3.17)
Pelvic forward tilt (pelvic tilt)	Hip anterior	20.23 (8.77) †	13.06 (5.10)
	Hip posterior	9.38 (9.19)	8.36 (4.60)
Pelvic rotation	Hip forward	9.44 (8.86)	8.66 (3.60)
	Hip trailing	-7.61 (3.77) †	-11.14 (7.06)
Trunk kinematics			
Trunk lateral tilt	Shoulder up	3.55 (2.54)	3.03 (2.05)
	Shoulder down	-4.35 (3.42)	-3.32 (2.01)
Trunk forward tilt	Shoulder anterior	8.90 (4.71) †	5.30 (3.11)
	Shoulder posterior	-0.60 (4.11)	-2.14 (3.45)
Trunk Rotation	Shoulder forward	7.98 (8.49)	7.23 (5.13)
	Shoulder trailing	-9.31 (7.68)	-7.50 (6.45)

† *p* value < 0.05, compared between Hemiparetic children with healthy subjects.

b) Kinematics : joint angles during stance phase

Ankle joint, Reduced dorsal flexion ability was generally present on the paretic side compared to non paretic and healthy ($P < 0.05$) with excessive plantar flexion on the non paretic side than paretic. The paretic side displayed comparatively higher values of ankle abduction than healthy subjects. No significant difference was observed in the other parameters (adduction and rotation).

The knee joint displayed quite significant differences in flexion and extension ability. The paretic side showed lower flexion ability compared to non paretic ($P< 0.05$) with significant hyperextension on the non paretic side than paretic and healthy subjects. However both paretic and non paretic sides highlighted mean values of rotation, varus and valgus closed to healthy subject's data.

Regarding the hip joint, Hemiparetic children showed significant increased values of flexion ability compared to healthy subjects. Significant differences were found in terms of the hip rotation, the paretic side revealed high values of external rotation compared to healthy subjects ($P<0.05$) with slight increase in internal rotation compared to non paretic side. No significant differences were observed in abduction and adduction ability in the two groups.

As concerns the pelvic and trunk kinematics, Hemiparetic children walked with significant increased anterior pelvic and trunk tilt compared to healthy subjects ($P<0.05$). Pelvic rotation with hip trailing (pelvic external rotation) revealed comparatively higher values in the hemiparetics than healthy subjects. No significant differences were observed in pelvic obliquity, lateral trunk tilt and trunk rotation between the two groups.

IV. Discussion and Conclusion

Hemiparetic cerebral palsy has functional consequences that are varied and can potentially affect all activity of daily living. About 33% of CP children have hemiplegia with weakness and spasticity predominantly affecting one side of the body and the deficit concerns the motor ability of the body's side opposite to the site of cerebral lesion (Hagberg et al., 2001; Liptak and Accardo, 2004; Nashner et al., 1983).

Although the term "hemiplegia" connotes involvement of only one side, hemiparetic children often have motor involvement not only on affected side, but also on the non affected side as well, particularly in those cases with more severe types of hemiplegia which demonstrates an altered gait pattern of lower limb (Gage, 2004). In literature, few studies have examined quantitatively some aspects of motor control during gait in hemiplegic children (Carlsson et al., 1994; Cimolin et al., 2007; Galli et al., 2010; Wheelwright et al., 1993). Gait analysis focused mainly on comparing functional motor evaluations in right and left gait types. No studies have investigated quantitatively spatiotemporal and joint kinematics in hemiparetic cerebral palsy children during stance phase. Nevertheless; the non affected side (non paretic) was neglected. Hence there is clinical need to identify and investigate both sides of hemiparetic children for developing either deficit-specific or rehabilitative strategies. The aim of this study was the quantification of spatiotemporal and joint kinematics in hemiparetic children during stance phase.

With regard to spatiotemporal parameters hemiparetic children walked more slowly than healthy children with shorter step length, decreased cadence and longer step width. Walking velocity is the product of step length and cadence, hence reduction in either one parameter may account for gait slowing and it might be considered a strategy in order to obtain a better stability and equilibrium during walking. The shorter stance phase on the paretic side compared to non paretic and healthy children is related to the deficient ability to load and transfer weight through their affected leg. It has been proposed that improving weight transfer through the affected leg during progressive training with the feet of the patients placed in a variety of diagonal position may improve gait symmetry in hemiplegics (Olney et al., 1991). Ankle joint showed an asymmetry pattern, the paretic side revealed reduced dorsal flexion ability and increased abduction during stance phase compared to non paretic side. This pattern is common in hemiplegic patients with equinovarus foot deformity. The deformity can be explained by the premature onset of the gastrocnemius medialis muscle (Boulay et al., 2012). As for pelvic, hip and knee kinematics, the significant reduced knee flexion during stance may necessitate such compensatory maneuvers as hip circumduction, hip hiking, and contra lateral vaulting with excessive elevation of the pelvis to avoid toe drag (Kim et al., 1994; Perry, 1969). Hemiparetic children walked with significant increased anterior pelvic tilt with increased pelvic external rotation compared to healthy subjects. The external pelvic rotation is also known as pelvic retraction. Hemiparetic children often walk with abnormal pelvic motion patterns including increased anterior pelvic tilt (Saunders et al., 1953; Winters et al., 1987) and retraction of the affected side (Aminian et al., 2003; O'Sullivan et al., 2007; Park et al., 2006). These alterations can occur as a result of one or a combination of different variables such as weakness, skeletal deformities, abnormal muscle activation pattern and compensatory mechanisms. The significant higher values of hip flexion displayed by hemiparetic children compared to healthy subjects with slight increased internal hip rotation on the paretic side than non paretic is due to increased protraction of the pelvis. Pelvis is a single segment; increase protraction may result in internal hip rotation. The most prominent feature observed in trunk kinematics was significant increased anterior trunk tilt on the hemiparetics compared to healthy subjects. Hemiparetic children walk with increased anterior trunk tilt as a compensatory mechanism to maintain balance and forward progression. Cerebral palsy children frequently show impaired trunk control and stability, which can affect performances of activities of daily life such as sitting, reaching and walking. In contrast, literature on trunk control in children with hemiparetic cerebral palsy (leg dominant) is scarce (Hadders-Algra and Brogren, 2008; Prosser et al., 2010; van der Heide et al., 2005).

A potential weakness of this study may be; lack of classification of the patients according to (Winters et al., 1987) into 4 gait strategies based on saggital plane kinematics, even though the use of classification system resulted in small subject numbers being allocated to some gait types.

However our results support previous observations which showed that analysis of gait pattern of hemiparetic CP children generally presents a unique motor strategy different from healthy subjects (Cimolin et al., 2007).

From clinical perspective, the identification and precise quantification of gait pattern in hemiparetic CP children is important for development of effective and specific rehabilitative programs.

V. Acknowledgements

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VI. Conflicts of Interest

None

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