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Kinematic Gait Analysis of Upper and Lower Limbs Joints in Hemiplegic Children

Zeinab A.Hussein, Manal S. Abd El-Wahab, and Shorouk A. W. El-Shennawy

***Abstract*—**Children with hemiplgic cerebral palsy often walk with diminished reciprocal arm swing so the purpose of this study was to describe kinematic characteristics in children with hemiplegic cerebral palsy (CP) during the gait suphases, and find if there is a correlation between upper(shoulder and elbow) and lower(hip, knee, and ankle) limb joints either in involved or uninvolved.48 children with hemiplegic cerebral palsy (18boys, 30girls) with an average age of (5.1±0.87) years were selected randomly to evaluate joint angles during gait by 3D motion analysis system with 6 pro reflex cameras in a sagittal plane for both sides of the body. The results showed increased shoulder and elbow flexion, increased hip angular displacement, decreased knee and ankle arcs during gait cycle, also there is correlation between shoulder and elbow to hip, knee, and ankle joints during various subphases of gait.

***Keywords*—**Cerebral palsy, Gait, Hemiplegia, Motion analysis.

I. Introduction

CEREBRAL palsy (CP) is a common developmental disability this condition is considerable diagnostic and therapeutic challenges to the physician with degree of involvement ranging from mild with minimal disability to severe associated with several co-morbid conditions. It is one of the most common lifelong developmental disabilities, the other two being autism and mental retardation causing considerable hardship to affected individuals and their families [1].

Cerebral palsy results from an injury to the developing central nervous system, which may occur in uterus, during delivery or during the first two years of life. The clinical manifestations depend on the magnitude, extent and location of the insult that cause the irreversible damage to the brain, brain stem, or spinal cord [2].

Hemiplegia is a condition that affects one side of the body in cerebral palsy patients, it affects either the right or left side of the body but the right side is more affected than left side [3].The most common pattern of spastic hemiplegia in which the leg shows hip adduction and flexion, knee flexion, ankle equines, hind-foot valgus, and metatarsal varus with hallux valgus [4].

The prerequisites for any motor function, including gait, develop as central nervous system matures and body grows, producing physiologic changes in mechanics and the neurophysiology of the system. The attributes of typical gait are lost in pathological conditions such as cerebral palsy because of the primary impairments of loss of selective motor control and balance, abnormal tone and sensation, muscle weakness, and secondary impairments such as bony deformities and loss of range of motion [5].

Gait in CP has classic patterns that are characteristic of different types of cerebral palsy. Variations do exist within each type. Asymmetry is the almost obvious of the gait of a child with hemiplegia, with the most body weight born on the uninvolved lower extremity. Limbs on the involved side are retracted or rotated posteriorly, when compared with the shoulder and pelvis on the contralateral side. Arm swings occur only on the uninvolved side, with the involved upper extremity held in shoulder hyperextension and elbow flexion as a part of associated reaction [6].

II. Procedure

A. Subjects

48 spastic hemiplegic cerebral palsied children from both sexes participated in this study. They were selected from outpatient clinic of faculty of physical therapy, Cairo University. Children (18 males and 30 females) were 5.1±0.87years old, with 1 to1+grade of spasticity according to modified Ashowrth scale. They were able to walk alone about 10 steps. They neither had fixed musculoskeletal deformities, visual, auditory, or behavioral disorders.

B. Methods

Gait evaluation was done by using 3D motion analysis system with 6 pro reflex cameras to measure kinematics parameters of gait. Qualysis motion capture system model OR67; AMTI; USA; qualysis company, Sweden, 2001 that consist of: Three infrared cameras- pro-reflex 120: served as 3-dimentional camera used to record the gait cycle, a wand-kit: model number 130440. It provides the camera system with measurement points to be used for calibration, and Computer system: composed of a computer, an ACB- 530serial interfere adaptor with communication card which is mounted in PC and an APC computer with QTrace soft ware. The six cameras were used along the 8 meters along walkway three on each side, with distance 6 meters approximately between each one. The child was asked to stand in the middle of the Walking tray (An eight meters wooden walkway) while the cameras were fixed at 1.5- 2 meters height. The camera system calibrated through moving a wand kite in three planes X plane, Z plane, and Y plane to assure accuracy of the values obtained by viewing the dots on three cameras on each side. The reflected dots (markers put on bonny prominence stacked by adhesive tape) were applied on the following points according to the

Z. A. Hussein is with the Pediatrics Department, Faculty of Physical Therapy, Cairo University, Egypt (phone: 202-01002743142; fax: 202-37617692; e-mail:z3256929@yahoo.com).

M. S. Abd El-Wahab is with the Pediatrics Department, Faculty of Physical Therapy, Cairo University, Egypt (phone: 202-01222843564; fax: 202-37617692; e-mail: manalsalah98@yahoo.com).

Sh. A.W. El-Shennawy is with the Pediatrics Department, Faculty of Physical Therapy, Cairo University, Egypt (phone: 202-01001584522; fax: 202-37617692; e-mail:shoroukelshennawy@gmail.com).

manual chart, Spine of the seven cervical vertebra, Lateral border of acromion, Styloid process of ulna, At the level fifth metacarpophalengeal joint, Upper border of iliac crest (lateral border), Greater trochanter, Lateral border of knee articulation, Syloid process of fibula, At the level of fifth metatarsophalengeal joint.

Special considerations were taken out during capture such as the child should not be subjected to any distraction (noise, over light). Each child was asked to start walking from a position far enough from the measurement volume to enable him or her to reach a natural walking pattern. All entire gait cycle was captured within the measuring volume from initial contact of one foot to the second toe-off of the other foot. One gait cycle was selected, would be entered to the Q Trace software, to import the name list of the markers. Then export data imported into TSV file and saved it to be analyzed.The data displayed enter the Q tools software. Then angular graphs were selected to analyze angular displacement. The angular analysis allows creating a joint angle or an angle relative to another segment or plane. The angle vs. time, and the stepwise derivatives, velocity and acceleration are available to calculate any angle.

III. Results

Results of the angular displacements in sagital plane during stance phase in expressed as mean and standard deviation to show kinematic analysis during each gait subphase and correlation between shoulder and elbow to other joints.

TABLE I
Mean Values of Angular Displacements in Sagittal Plane (Extension & Flexion) for Shoulder, Elbow, Hip, Knee, and Ankle in the Uninvolved Side

Uninvolved side	Shoulder	Elbow	Hip	Knee	Ankle
IC	-11.26 ±8.09	20.62±7.95	15.52±6.64	20.96±9.60	9.00±5.54
LR	-8.77±8.23	20.85±10.67	16.82±9.22	24.69±9.04	1.08±8.52
MS	-5.38±4.48	23.50±8.16	6.85±5.13	15.37±5.10	9.07±3.90
TS	0.17±4.36	23.53±11.34	-2.53±9.21	12.71±8.02	6.28±4.27
PS	2.34±5.83	33.00±14.80	0.69±6.00	28.89±12.60	-11.60±10.19
IS	-15.04±14.95	22.91±10.94	22.74±6.99	29.62±10.80	-13.17±8.15
MS	-13.3±9.9	25.22±10.70	24.31±11.15	21.74±8.38	-8.72±7.43
TS	-8.56 ±8.95	24.17±9.53	19.61±6.70	22.07±8.44	-2.32±4.20

IC: initial contact, LR: loading response, MS: midstance, PS: preswing, TS: terminal stance, IS: initial swing, MS: midswing, TS: terminal swing, x: mean, SD: standard deviation.

TABLE II
Mean Values of Angular Displacements in Sagittal Plane (Extension & Flexion) for Shoulder, Elbow, Hip, Knee, and Ankle in the Involved Side

Involved side	Shoulder	Elbow	Hip	Knee	Ankle
IC	8.88±5.83	24.50±11.99	16.53±6.45	6.48±3.58	-12.87±5.33
LR	3.62±4.32	29.15±13.08	16.37±6.67	4.46±4.62	-14.12±5.26
MS	18.59±6.81	49.50±18.88	13.90±7.71	4.28±4.53	-9.97±5.60
TS	16.27±6.09	43.02±20.49	-14.72±7.66	5.29±4.30	-16.18±7.44
PS	14.20±6.07	50.23±20.69	10.06±5.27	17.33±7.67	-23.69±10.36
IS	11.64±5.70	36.98±19.43	22.48±7.89	24.70±9.61	-21.59±12.11
MS	11.80±4.77	34.23±17.16	16.89±6.71	18.47±7.54	-20.50±11.01
TS	13.13±4.37	17.79±12.03	18.79±9.37	22.59±8.35	-17.99±9.60

IC: initial contact, LR: loading response, MS: midstance, PS: preswing, TS: terminal stance, IS: initial swing, MS: midswing, TS: terminal swing, x: mean, SD: standard deviation.

TABLE III
CORRELATION BETWEEN SHOULDER AND OTHER JOINTS IN INVOLVED AND UNINVOLVED SIDE

Shoulder	Elbow In	Un	Hip in	Un	Knee In	un	Ankle In	Un
IC	0.277 (0.057)	-.291* (0.045)	.352* (0.014)	0.002 (0.987)	0.088 (0.554)	-0.127 (0.39)	0.078 (0.597)	0.255 (0.08)
LR	0.245 (0.094)	0.097 (0.513)	0.072 (0.625)	-0.021 (0.887)	0.12 (0.416)	0.001 0.993	0.148 (0.314)	.371** (0.009)
MS	0.233 (0.11)	-0.161 0.276	.352* (0.014)	0.013 0.931	0.194 (0.187)	-0.108 (0.465)	-0.006 (0.967)	0.171 (0.246)
TS	.460** (0.001)	.286* (0.049)	-0.072 (0.628)	0.077 0.603	.353* (0.014)	-0.001 0.996)(	-0.014 (0.924)	.295* (0.042)
PS	0.151 (0.304)	0.02 0.892	.334* (0.02)	0.04 0.789	-0.099 (0.503)	0.203 (0.167)	-0.169 (0.252)	0.239 (0.102)
IS	0.082 (0.58)	0.195 (0.185)	0.206 (0.159)	0.057 0.7	.305*(0.035)	-0.112 0.447)(	0.041 (0.784)	.332* 0.021
MS	0.083 (0.576)	0.042 (0.775)	0.134 (0.363)	0.136 0.356	.341*(0.018)	0.167 0.258	0.082 (0.578)	.404** (0.004)
TS	0.264 (0.07)	-0.013 (0.928)	0.175 (0.234)	-0.046 0.754	,383** (0.007)	0.148 (0.31)	-0.105 (0.476)	.492** (0)

IC: initial contact, LR: loading response, MS: midstance, PS: preswing, TS: terminal stance, IS: initial swing, MS: midswing, TS: terminal swing, x: mean, SD: standard deviation, In: involved side, un: uninvolved side

TABLE IV
CORRELATION BETWEEN ELBOW AND OTHER JOINTS IN INVOLVED AND UNINVOLVED SIDE

Elbow	Shoulder In	Un	Hip In	un	Knee In	Un	Ankle In	Un
IC	0.277 (0.057)	-.291* (0.045)	.352* (0.014)	.363* (0.011)	(.420**) (0.003)	.491** (0)	0.149 (0.313)	0.179 (0.223)
LR	0.245 (0.094)	0.097 (0.513)	0.072 (0.625)	0.179 (0.223)	0.07 (0.638)	.435** (0.002)	0.018 (0.901)	0.114 (0.44)
MS	0.233 (0.11)	-0.161 (0.276)	.352* (0.014)	.290* (0.045)	.396** (0.005)	.446** (0.002)	-0.061 (0.678)	0.282 (0.052)
TS	.460** (0.001)	.286* (0.049)	-0.072 (0.628)	0.07 (0.635)	0.274 (0.059)	0.206 (0.16)	0.103 (0.485)	0.163 (0.267)
PS	0.151 (0.304)	0.02 (0.892)	.334* (0.02)	0.272 (0.062)	0.139 (0.345)	0.086 (0.563)	-0.059 (0.69)	0.005 (0.974)
IS	0.082 (0.58)	0.195 (0.185)	0.206 (0.159)	0.273 (0.061)	.316* (0.029)	.467** (0.001)	0.197 (0.18)	0.135 (0.361)
MS	0.083(0.576)	0.042 0.775)(	0.134 (0.363)	0.242 0.098	0.109 (0.461)	0.26 0.074)(	-0.108 (0.465)	0.099(0.504)
TS	0.264 (0.07)	-0.013 (0.928)	0.175 (0.234)	.533** (0)	0.22 (0.134)	.401** (0.005)	0.107 (0.47)	0.176 (0.232)

IC: initial contact, LR: loading response, MS: midstance, PS: preswing, TS: terminal stance IS: initial swing, MS: midswing, TS: terminal swing, x: mean, SD: standard deviation, In: involved side, un: uninvolved side

IV. DISCUSSION

The study was conducted to evaluate the angular displacements in shoulder, elbow, hip, knee, and ankle joints, and also seek if there is a relation between shoulder and other joints during gait. Forty eight spastic hemiplegic children were chosen from the Outpatient clinic, Faculty of Physical Therapy, Cairo University. Both sexes were involved. It is noticed that the shoulder joint in involved side remain in flexion throughout the gait cycle from 8.88±5.83 to 13.13±4.37 degrees while the uninvolved move in extension from-11.26 ±8.09 to slight flexion2.34±5.83. The deviation of angular displacements occurred in hemiplgic cp children from normal at different joint levels may be due to abnormal muscle tone, abnormal patterns and abnormal proprioceptive sensations that the Lack of voluntary control, sensory impairment, muscular imbalances caused by spasticity and weakness, joint contractures, and articular instabilities all contribute to the upper extremity problem in CP. The child has difficulty using the hand. The shoulder is in flexion, internal rotation, and adduction, elbow in flexion, forearm in pronation, In the leg, hip flexion, and adduction, knee flexion, ankle equinus, hindfoot valgus, and toe flexion are the most common posture [7].

Elbow joint either in involved or uninvolved joint moves in flexion but reaches to maximum flexion 50.23±20.69 and 33.00±14.80 degrees respectively (Table I and II) these values are greater than the maximum degrees of normal elbow flexion which is due to presence of spasticity which make flexion uncontrollable that lack of isolated or discrete movements and fine motor coordination as in CP children whose impairment the dynamic postural control due to the following loss of selective muscle control and relative imbalance between muscle agonists and antagonists across joints [8].

The hip joint in involved side kept in flexion (Table II) with minimum degrees at midstance 13.90±7.71 to maximum degrees22.48±7.89 at initial swing while the uninvolved side (Table I), move from flexion at initial contact to extension -2.53±9.21 at terminal stance then towards flexion at swing phase with 24.31±11.15 maximum degrees of flexion at midswing. The gained results showed that there was a great arc of hip angular displacements, that move from flexion to extension then to flexion that may be due to hip flexors were stronger than antagonist muscles and increase lumber lordosis during terminal stance that children with CNS damage display difficulties in motor unit recruitment, abnormal co-contraction of two joint muscles and grading of muscle contractions. Thus, the presence of abnormal muscle tone coupled with motor planning and force generation difficulties may delay or prevent the development of antigravity control and limit the acquisition of other patterns of movements [9].

The arc of angular displacement of knee joint in uninvolved side (Table I) starts with more flexion at 20.96±9.60 to 22.07±8.44degrees while the involved knee (Table II) starts with 6.48±3.58 to 22.59±8.35degrees, During normal walking, the knee is rapidly accelerated toward flexion during preswing, reaching its peak flexion velocity near toe-of .During the remainder of the swing phase, the knee is accelerated toward extension then toward flexion as the knee's extension motion is slowed prior to contacting the ground. The knee reaches its peak flexion between 25% and 40% of the swing phase [10]

The children with cerebral palsy often walk with diminished knee extension during the terminal-swing phase, resulting in an abnormally short stride. Tight hamstrings, resulting from an exaggerated reflex response or from excessive passive forces, are thought to cause the diminished knee extension in most cases [11].

The ankle joint in uninvolved side (Table I) starts at initial contact with dorsiflexion at9.00±5.54 degrees and at initial swing with planter flexion -13.17±8.15degrees while the involved side (Table II) starts with planter flexion at -12.87±5.33degrees and reach to maximum planter flexion at -21.59±12.11 degrees. The increased planter flexion is due to extensor spasticity [12], diminished knee extension [11], increased hip flexion and also increased lumber lordosis [9].

There is no correlation between shoulder and elbow in the involved side except at terminal stance with strong correlation 0.460** (Table III) which may be explained as the terminal stance is the second part of single limb support with maximum shoulder flexion. While in uninvolved side there is a negative correlation at initial contact -0.291* and at terminal stance0.286*(Table III) that can be explained as that during normal walking, humans use shoulder muscles to help drive backward arm swing in-phase with the backward swing of the contralateral leg while elbow is in flexionat initial contact [13]**.**

Hip joint in uninvolved side has no correlation to shoulder joint (Table III), while the involved side has a correlation at initial contact, midstance, and preswing(0,352*, 0.352*, and0.334* respectively) as in the initial contact the presence of pathological tonic reflex may increase tone all over the body , while in midstance(which is the point of single limb support) there is increase intrinsic muscular reaction force, and at preswing there is over protection from falling by forceful shoulder flexion and short step due to decrease postural support.

The shoulder joint has a correlation to knee joint at involved side (Table III) at terminal stance, initial swing, midswing, and terminal swing(.353*, .305*, .341*, and 383** respectively) while in uninvolved side there is no relation. That a limited selection of primary neuronal networks is the main deficit in children with CP, that lead to abnormal postures of arms with retraction of the shoulder and may accompany retraction of the pelvis and the persistence of abnormal primitive reflexes or their reemergence after brain injury has been associated with delayed postural reflex development (i.e. righting, equilibrium and protective reactions and disrupted neuromotor control) [14].

The ankle joint positive correlation to the shoulder of the uninvolved side (Table III) at loading response, terminal stance, initial swing, midswing, and terminal swing (.371**, .295*, .332*, .404**, and.492** respectively) may explained by the work of[15]who concluded that a child with hemiplgic cp always has associated movement due to inadequate weight acceptance by the involved lower limb during the stance phase, and the affected arm moves less than the other side [15].

At the initial contact the elbow and hip Positively correlated (Table IV) (.352* and .363* at involved and uninvolved sides respectively), and between elbow and knee joint (Table IV) (.420** and.491** at involved and uninvolved sides respectively) while the elbow shoulder (Table IV) at the uninvolved side (-.291*). At mid stance, the elbow and hip positively correlated (.352* and .290* at involved and uninvolved sides respectively) and the elbow and knee (Table IV) were positively correlated (.396** and .446** at involved and uninvolved sides respectively).

At terminal stance the elbow only correlated to shoulder joint (Table IV) (.460** and .286* at involved and uninvolved sides respectively), at preswing, the elbow on uninvolved side positively correlated with shoulder joint (0.334*). At initial swing elbow is correlated to knee joint (0.316* and0 .467**at involved and uninvolved side respectively). At terminal swing elbow at uninvolved side is correlated to hip and knee joint (Table IV) (0.533** and .401**). In spastic hemiplegic CP with prevailing gait pathology on the involved side, the contra lateral limb often elicits kinematics deviations that can be described as compensatory motions [7]. Gait pattern in a growing cerebral palsied child caused by the complex interplay of abnormal muscle timing and force generation, secondary limitations in joint range of motion, and altered muscle force lever arms caused by skeletal adaptation [16].

V. Conclusion

From the obtained results of this study, it can be concluded that the upper limbs used in gait of spastic hemiplegic children but not smoothly. That the upper limbs in those cases are used in substitution to increase postural reaction, which is decreased in involved lower limb; so we recommend to use upper limb in rehabilitation program of hemiplegic children.

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