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Impact of femoral anteversion and tibial torsion on balance in children with spastic diplegic cerebral palsy

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Abstract---Purpose: To investigate the relation between femoral anteversion angle, tibial torsion and balance abilities in children with spastic diplegic cerebral palsy. Methods: A cross-sectional correlational research design study utilizing a sample of 50 spastic diplegic children (22 girls and 28 boys), with gross motor functional classification system levels I, II were recruited and their ages ranged from 7 to 13 years. Femoral anteversion and tibial torsion angles were measured by computed tomography scan, while balance abilities were assessed by Biodex balance system. Results: Data analysis revealed that there was a statistically significant moderate positive correlation between right femoral anteversion angle and the overall stability index and the antero posterior stability index, while a weak positive non-significant correlation with the medio-lateral stability index was found. There was a weak negative non-significant correlation between left femoral anteversion angle and stability indices. There was a weak non-significant correlation between tibial torsion angle and stability indices. Conclusion: It can be concluded that the relation between femoral anteversion angle, tibial torsion angle and balance in spastic diplegic children can provide quantitative and objective information that could be used in the clinical assessment and rehabilitation strategies. It also will assist in detection of functional abnormalities and to determine the appropriate treatment that would result in improved management with earlier intervention.

Keywords---Biodex balance system, Cerebral palsy, Computed tomography, Femoral anteversion angle, Spastic diplegia, Tibial torsion angle.

Introduction

Cerebral palsy (CP) is a collection of motor disorders resulting from damage to brain that occurs before, during, or after birth. The damage to the child's brain affects motor system, and as a result the child has poor coordination, poor balance, or abnormal movement patterns or a combination of these characteristics [1].

Spastic diplegic cerebral palsy (CP) accounts for 22% of all types of cerebral palsy [2]. Children with spastic diplegia usually walk independently but most have an increased lumbar spine lordosis, anterior pelvic tilt, bilateral hip internal rotation, bilateral knee flexion, intoeing, and equinus foot position that result in gait abnormalities including; a short stride, increased stride frequency to maintain speed, increased swing, and poor stability due to center of-gravity fluctuations, they have disturbances in balance, and poor motor coordination [3].

In children with CP, the likelihood of having rotational malalignment of the lower limb tends to increase with age. Skeletal deformities, including malalignment, excessive femoral internal rotation, external tibial torsion and pes planovalgus with midfoot break, causing lever arm dysfunction, may also contribute to flexed knee gait [4].

Femoral anteversion (FA) is the angle between the neck of the femur and the condylar axis (axis between the two femoral condyles). The range of femoral anteversion is 30°–40° at birth, which progressively decreases throughout growth to 15° by 16 years of age. Children with spastic CP often show excessive femoral anteversion, however, the etiology is not clear. Some previous studies reported that at the functional level, fetal alignment and hip adductor spasticity could affect femoral anteversion in children with CP [5].

The tibial torsion describes a twist of the tibia along its long axis so that the leg is rotated internally or externally. The torsion angle at the age of 4 years was on average 28° with an individual variation of 20°–37°. From this age, it increased by about 1° each year until the age of 10 years, when the lateral torsion of the leg was 34°. From the age of 10 years until skeletal maturity, it increased from an average of 34° to 38° [6]. In children with abnormal motor control, this abnormal torsion can progress with age (8 to 10 years of age). These children may be clumsy, but function well. However, there is a major difference in children with CP in that tibial torsional deformities do not resolve spontaneously with growth and there is often substantial disability from the tibial torsion [7].

Children at Gross Motor Function Classification System (GMFCS) levels I and II have deficits in postural control that may interfere with speed, stability, or agility when walking or running, or cause challenges to safety and attention in complex

environments or on uneven surfaces. Children with this level of severity gain independent ambulation before 6 years of age [8].

Postural control is the ability to control the position of the body in space to maintain stability and postural orientation [9]. It is a complex process that results from the interaction of different systems (e.g. peripheral, visual and vestibular) and neuromuscular response [10]. One of the most important problems in CP children is postural control problem. These children use an altered patterns of muscle coordination, which are taught to be a result of two interacting mechanisms, the primary deficit due to early brain damage and compensation due to postural instability [11]. Of note, principles of the therapeutic approaches in CP mostly rely on achieving normal postural control, improving motor functions, and reaching the maximum level of potential independence [12].

Even though there have been several studies focused on the importance of postural control and balance in children with CP, the relationship between femoral anteversion angle and tibial torsion angle with postural control is still a question. Therefore, the main aim of this study was to investigate the effect of femoral anteversion and tibial torsion on balance in children with spastic diplegic CP. Also helping physiotherapists to understand that rotational abnormalities need to be corrected by improving muscles function that are responsible for rotated the lower extremity internally.

I. Patients, Instrumentation & Procedures

Research design

Cross-sectional correlational design.

i. Patients

Fifty spastic diplegic CP children from both sexes. Their ages ranged from 7 to 13 years. Participants were recruited from the Out-patient clinic of Faculty of Physical Therapy, Cairo University and from Abu Al-Reesh Children's University Hospital.

Criteria for **inclusion** were as follows (1) the degree of spasticity ranged from 1 to 1+ grade were according to Modified Ashworth scale [13]. (2) Gross Motor Function Classification System (GMFCS) of levels I and II [8]. (3) All children assume an in-toeing gait pattern. (4) The ability to understand and follow orders. While **exclusion** criteria included (1) Severe visual or auditory problems (2) Convulsions. (3) Fixed contractures of lower extremities. (4) Surgical interventions in the lower extremities. (5) Botox injection in the last 6 months.

ii. Instrumentation

For selection of participants:

- 1) Modified Ashworth scale were used to quantify the degree of spasticity to select CP children having 1 to +1 grade [13].

- 2) Gross Motor Function Classification System (GMFCS) was used to determine the functional level to select CP children having level I and II [8].

For evaluation:

- 1) A computed tomography (CT) is a valid and reliable method for measuring bony torsion of the femur and tibia. It is a useful adjunct to clinical measures of torsion. The model is light speed. The device is composed of two separate units. One of them contains a computer unit (software) as the radiologist control the number of images per slide as this model can give 16 images per slide. The other unit contains a tube and a sliding table. The table is of adjustable sizes to suit different body sizes [14] **figure 1.**



Figure 1. Computed Tomography device

- 2) Biodex Balance System that was introduced as a commercially available postural stability assessment and training system designed to stimulate joint mechanoreceptors and to promote reflex muscular activation necessary for joint stability. The Biodex Balance System consists of a movable balance platform, which provides up to 20 degrees of surface tilt in 360 degrees range. The system provides various degrees of surface instability which ranges from a completely firm surface; stability level (8) to a very unstable surface stability level (1) [15] **figure 2.**



Figure 2. Biodex Balance System equipment

iii. Procedures

a) Assessment of spasticity for selection

Modified Ashworth scale was used to quantify the degree of spasticity that was evaluated by passive movement for limbs, all children were assessed while lying supine on a mat with head in mid position, the upper limbs parallel to the trunk in a neutral position and with the lower limbs parallel to one another. Except the assessment of knee extensors was conducted from prone position. The test was repeated 3 times and the mean was taken to refer accurately to the degree of spasticity.

b) Assessment of Functional level

Gross Motor Function Classification System (GMFCS) was used to determine the functional level to select CP children having level I and II (as they walk indoors and outdoors with/without limitation).

c) Measurement of femoral anteversion angle and tibial torsion by CT, the child was asked to lie in supine position on the sliding board then he/she was covered with a blanket. Lower extremities were extended in relaxed position while the head and upper extremities slightly raised over a soft wedge. The child was instructed about the procedure as he was asked to hold his/her breath for few seconds while the board was automatically slide into the cylinder then resume normal breathing pattern after capturing an axial cut.

- Calculation of femoral anteversion is performed by measuring the level of the distal femur to define the posterior femoral condyles or the centers of the femoral condyles to define the knee joint axis plane, and then transverse cuts are made across the proximal femur to define the anterior projection of the femoral neck shaft angle. The angle between these two planes on the image is then measured as the anteversion angle [16].
- To measure tibial torsion, the examiner determines the proximal reference line by taking the axis through the widest transverse condylar diameter and draws this on the tomographic picture. The distal reference line is the transverse axis through the lower end of the tibia which bisects the anteroposterior diameter and also passes through the anterior half of the lateral malleolus. The angle between the two axes corresponds to the tibiofibular torsion [17].

d) Assessment of balance

Biodex Balance System was used to investigate the child's ability to stabilize the angle of the tilting platform. The following test parameters were introduced to the device: Child's weight in (Kg), height in (Cm), age in (years) and platform firmness level.

(1) All children were given an explanatory session before the evaluation procedures. **(2)** Each child was asked to stand on the center of the "locked" platform with both legs in the stance phase. **(3)** Support rails and biofeedback

display were adjusted for each child according to his height to ensure comfort and safety. **(4)** Platform firmness (Stability levels start with level 8 which is the most stable and end with level 1 which is the least stable). All children were tested on the same level of stability (level 8) **[18]** **(5)** The aim of centering process is to position the center of gravity over the point of the vertical ground reaction force. **(6)** Centering was achieved by asking the child to stand on both feet while grasping the handrails. The child was instructed to achieve a centered position on a slightly unstable platform by shifting his feet position until it was easy to keep the cursor (which represents the center of the platform) centered on the screen grid while standing in a comfortable, upright position. **(7)** Once centering achieved and the cursor was in the center of the display target, instructions were given to the child to maintain his feet position till stabilizing the platform. **(8)** Introducing feet angles into the device system, then test was begun. When the platform was moving, the child was asked to look on the screen with his arms were free at the side of the body not grasping handrails and keep the cursor in the middle. **(9)** Overall stability index, anteroposterior stability index and mediolateral stability index were assessed and recorded. **(10)** All children were tested for 20 seconds. The test was repeated 3 times and the mean was taken to refer accurately to the degree of balance. At the end of each child test trial, the report was printed, which includes the measured variables of stability indices.

- Interpretation of test results whatever it is high or low; high values of stability indices represent that child had difficulty in maintaining balance.

Data analysis

Descriptive statistics were utilized in presenting the subjects demographic and clinical data. Pearson Correlation Coefficient was conducted to investigate the correlation between femoral anteversion angle, tibial torsion angle and stability indices. The level of significance for all statistical tests was set at $p < 0.05$. All statistical tests were performed through the statistical package for social studies (SPSS) version 25 for windows. (IBM SPSS, Chicago, IL, USA).

II. Results

Subjects' characteristics:

Fifty children (22 girls and 28 boys) with spastic diplegic cerebral palsy participated in this study group. Their mean value \pm SD of age, weight, height and BMI were 9.88 ± 1.96 years, 30.24 ± 9.26 kg, 130.16 ± 14.74 cm and 17.41 ± 1.91 . Characteristics of participants are presented as shown in table (1).

Table 1.
Characteristics of participants.

	Mean ± SD	Maximum	Minimum
Age (years)	9.88 ± 1.96	13	7
Weight (kg)	30.24 ± 9.26	54	20
Height (cm)	130.16 ± 14.74	164	106
BMI (kg/m²)	17.41 ± 1.91	21.91	13.82

SD: Standard deviation

Stability indices, femoral anteversion angle and tibial torsion:

The mean ± SD of OASI, APSI and MLSI were 2.07 ± 0.81, 1.56 ± 0.71 and 1.51 ± 0.56. The mean ± SD of right and left femoral anteversion angle were 26.32 ± 8.9 and 26.84 ± 6.68 degrees respectively. The mean ± SD of right and left tibial torsion angle were 38.66 ± 10.56 and 35 ± 8.53 degrees respectively (Table 2).

Table 2.
Descriptive statistics of stability indices, femoral anteversion angle and tibial torsion:

	Mean ± SD	Minimum	Maximum
OASI	2.07 ± 0.81	1	4.2
APSI	1.56 ± 0.71	0.7	3.3
MLSI	1.51 ± 0.56	0.8	3.3
Right femoral anteversion angle (degrees)	26.32 ± 8.9	10	44
Left femoral anteversion angle (degrees)	26.84 ± 6.68	17	44
Right tibial torsion angle (degrees)	38.66 ± 10.56	22	65
Left tibial torsion angle (degrees)	35 ± 8.53	20	50

SD: Standard deviation; **OASI:** Overall stability index; **APSI:** Antero posterior stability index; **MLSI:** Medio lateral stability index.

Relationship between femoral anteversion angle and stability indices:

The correlation between right femoral anteversion angle and stability indices was moderate positive significant correlation with OASI ($r = 0.36$, $p = 0.01$) and with APSI ($r = 0.368$, $p = 0.009$) while was weak positive non-significant correlation with MLSI ($r = 0.245$, $p = 0.08$).

The correlation between left femoral anteversion angle and stability indices was weak negative non-significant correlation with OASI ($r = -0.01$, $p = 0.94$), APSI ($r = -0.029$, $p = 0.84$) and with MLSI ($r = -0.032$, $p = 0.82$). (Table 3).

Relationship between tibial torsion angle and stability indices:

The correlation between right tibial torsion angle and stability indices was weak negative non-significant correlation with OASI ($r = -0.051$, $p = 0.72$) and with APSI ($r = -0.128$, $p = 0.37$) while was weak positive non-significant correlation with MLSI ($r = 0.067$, $p = 0.64$).

The correlation between left tibial torsion angle and stability indices was weak positive non-significant correlation with OASI ($r = 0.066$, $p = 0.64$) and with MLSI ($r = 0.138$, $p = 0.34$) while was weak negative non-significant correlation with APSI ($r = -0.017$, $p = 0.91$). (Table 3).

Table 3.
Correlation between femoral anteversion angle, tibial torsion angle and stability indices:

	OASI		APSI		MLSI	
	r value	p-value	r value	p-value	r value	p-value
Right femoral anteversion angle	0.36	0.01	0.368	0.009	0.245	0.08
Left femoral anteversion angle	-0.01	0.94	-0.029	0.84	-0.032	0.82
Right tibial torsion angle	-0.051	0.72	-0.128	0.37	0.067	0.64
Left tibial torsion angle	0.066	0.64	-0.017	0.91	0.138	0.34

r value: Pearson correlation coefficient; **p value:** Probability value; **OASI:** Overall stability index; **APSI:** Antero posterior stability index; **MLSI:** Medio lateral stability index.

Discussion

The current study was conducted to investigate the relation between femoral anteversion angle, tibial torsion and balance in children with spastic diaplegic cerebral palsy. Femoral anteversion and tibial torsion are common disorders in children with CP. Therefore, research is limited in the area of finding out correlations between FA, tibial torsion angles and balance in CP.

The selection of age in this study was ranged from seven to thirteen years comes in agreement with [Chester et al., \[19\]](#) who stated that pediatric gait data is considered to be adult like by age three and half to four years but the mature sagittal kinetic patterns occurred by approximately nine years of age. And [Schmid, et al., \[20\]](#) reported that by the age of seven years, the development of the structures responsible for motor control is complete, and studies agree that

seven-year-old children have generally achieved mature postural control as evaluated by displacements of the center of pressure (COP).

The most common causes of in-toeing gait in patients with diplegic CP are internal rotation of hip and internal tibial torsion. However, degree of femoral anteversion and tibial torsion do not necessarily reflect the severity of the rotational gait problem which implies that in-toeing might not be sufficiently explained by torsional bony deformities of the femur and tibia [21].

For children with bilateral spastic cerebral palsy in-toeing walk could result from metatarsal varus, weak muscles in the lower limbs, tibial medial torsion, or femoral anteversion to excess [22]. Spasticity of the muscles of the lower extremities may result in both crouching and in-toeing during walking, reducing balance and leading individuals to fall while learning to walk and walking [23].

The significance of our study can be explained by the fact that one of the most common complaints in children with CP who have the ability to walk independently is frequent falls. Consequently, impaired balance is an important subject in the rehabilitation of these children and has been the focal point of many therapeutic evaluations [24]. There is a lack of evidence to suggest that children with in-toeing lose their balance more often than their peers while first developing the ability to walk [25].

The findings of our study could be explained by that tightness of medial hamstrings and adductors are often considered to be one of the factors that contribute to the excessive internal rotation of hip joint in spastic diplegic CP during upright standing [26]. This muscle imbalance due to spasticity in hip adductor severely impairs the biomechanics of hip joint in children with CP, impairing stability while standing and walking. There is a significant increase in hip anteversion angle and impairment in balance [27].

Results of this study revealed that spastic diplegic children from seven to thirteen years experience excessive femoral anteversion angle, and impaired postural control and physical balance. These were supported by the work of **Kim et al.**, who studied the relations of kinematic variables in children with spastic diplegia and their normal peers, they concluded that spastic diplegic children have gait strategies and movement patterns that are different from those of normal children. This is attributed to abnormal bone, muscle growth with abnormal phasic muscle activity of the paretic lower extremity and reduction in the range of motion of both lower extremity joints which result in balance abnormalities [28].

Results of the present study regarding anteversion angles and tibial torsion angles showed that there was a strong significant positive correlation between both right and left sides. Li and Leong, showed that patients with cerebral palsy have excessive femoral anteversion and more often increases up to age of 5 to 6 years, then start to decrease gradually and sometimes seldom improves with time. It is more common in females, and is often symmetrical. When the child is standing, both patellae and knees are turned inward and this give rise to torsional malalignment with joint instability [29].

Our findings revealed that there was weak negative non-significant difference between left FA angle and OASI, APSI as well as MLSI. These results supported by **DeLuca et al., [30]** who demonstrated that femoral anteversion has a relationship with dynamic reaching movements of the trunk that require pelvic girdle muscle activation. The standing posture is controlled by the ankle, knee, and hip joints. This condition also explains why femoral anteversion had no correlation with the balance but was correlated with dynamic functions of the trunk.

Results of left FA angle with balance in the present study were supported by **Zaky, et al., [31]** who reported that increased femoral anteversion has negative correlation with balance in diplegic CP children. But this was disagreed with our findings of right FA angle that revealed was moderate positive significant correlation with overall stability index, and antero posterior stability index.

Our results were confirmed by a study of **Arnold et al.,** who reported that rotational abnormalities of the hip are often accompanied by excessive anteversion of the femur, a torsional deformity which may alter the lines of action and moment arms of muscles about the hip, in addition to increased internal rotation of the hip and troublesome gait abnormality among spastic diplegic cerebral palsy **[26]**.

Our results of left FA angle were supported by the study conducted by **Karabicak, et al., [32]** who evaluated the relation of balance and postural control with femoral anteversion (FA) in children with CP. They found a relation between FA and dynamic trunk activities but there was no relation between FA with balance, static sitting, and control of the trunk.

In the present study, tibial torsion angle was higher on right side. **Arban, et al., [33]** reported that angle of tibial torsion at distal end was more on right side. Earlier study by **Eckhoff et al., [34]** using goniometer also found it to be more on right side and **Clementz and Larsson et al, [35]** also found tibial torsion angle higher on right side using C-arm, all of these studies are in consistent with our study.

Our results showed there was non-significant correlation between tibial torsion angle and stability indices, this was disagreed with **Rethlefsen, and Kay, [36]** who reported that excessive internal tibial torsion also leads to an in-toeing gait pattern and which increases the risk of falls and balance disturbance. Also disagreed with **Carriero, et al., [37]** who said that for the children with cerebral palsy, the correlation was significant among measures of tibial torsion, pelvic and waist rotation, peak flexation of the knee upon first contact and hyperextension in balance.

Conclusion

The results of this study confirmed the existence of a relation between right femoral anteversion angle with impaired balance that would be helpful to understand the pathogenesis of altered posture observed in spastic diplegic children. These findings may have implications both for clinical judgment and for research studies related to rotational abnormalities as increased femoral neck

anteversion is common problem in spastic diplegic children. It is associated with functional problems. The child must be examined carefully and an accurate diagnosis must be established.

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Conflict of interest

The author didn't have any conflict of interest.

Ethical approval

This study was approved and conducted in accordance to the guidelines of the Ethics committee of the Faculty of Physical Therapy, Cairo University, Egypt by reference no: P.T.REC/012/003056.

Consent

The parents of the children were informed about the research study and signing a written consent form.

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