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Relation of Hip Anteversion, Knee Flexion Angle and Balance in Spastic Diplegic Cerebral Palsied Children

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Abstract

Background: Torsional disorders and flexed knee gait are frequently pronounced in spastic diplegic cerebral palsy (CP) children. Identification of these anomalies is essential as they affect postural control and balance reactions.

Purpose: The purpose of this study was to investigate the relation between femoral anteversion(FA) angle, knee angle and balance in spastic diplegic CP children.

Methods: Cross-sectional correlational design utilizing a sample of 40 spastic diplegic children (21 girls and 19 boys). Their ages ranged from 5 to7 years with mean±standard deviation 6.04±0.47 years. FA, knee flexion angles and balance were measured by3-D axial CT scan, two digital cameras with the resultant captured video processed using Tracker Video Analysis and Pediatric Balance Scale, respectively.

Results: Data analysis revealed that there were statistically significant moderate negative correlations between FA angles for both sides and balance scores. Strong statistically significant negative association was found between knee flexion angles and balance scores for both sides. The correlations between FA angles and knee flexion angles were found to be statistically significant strong positive association ($p<0.05$).

Conclusion: Increased femoral anteversion has positive correlation with knee flexion angle and negative correlation with balance in diplegic CP children. These results provide objective information in formulation of rehabilitation strategies to select appropriate treatments for functional abnormalities.

Keywords: Cerebral palsy, Spastic diplegia, Femoral anteversionangle, knee flexion angle, Balance

Introduction

Cerebral Palsy (CP) is an umbrella term used to describe a group of posture and movement disorders, due to non progressive lesions in the immature brain, there are many causal pathways and many types and degrees of disability [1]. The worldwide incidence of CP being 2 to 2.5 per 1000 live births [2].

Spastic cerebral palsy is the most common type and shows motor disorders, which are spasticity, deep tendon reflex exaggeration, and muscle weakness. As a result, those children show both kinetic and kinematic changes in addition to various forms of gait deviations and poor balance [3-5].

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 abnormality, disturbances in balance, and coordination [6].

Increased femoral anteversion (IFA) is one of the important deficits that are frequently seen in children with cerebral palsy. The femoral anteversion (FA)angle of the femur can be defined as a measure of the rotation of the neck of the femur around the diaphysis. The FA angle is 30° in normal development, and it decreases to 15° as the skeletal system matures. FA is increased slightly and maintained at a high level during development in children with CP [7].

Increased FA refers to a structural deformity that could affect the adjustment of foot progression angle [8], and recent studies have reported that it is a cause of gait abnormalities and lower extremity deformities [9]. Biomechanically, increased FA is thought to place the hip abductor muscles at a biomechanical disadvantage during ambulation by decreasing the functional lever arm relative to the hip joint center during the stance phase [10].

Hip anteversion angle could be measured by axial three-dimensional computed tomography (3D-CT) scan based on three-dimensional reference system depending on functional axes of the femur, this method is free from variations induced by femoral and condylar geometry.It is considered a relevant method for evaluating FA angle [11]. The axial 3D-CT method for measuring the FA showed high intra-rater and inter-rater reliabilities and is effectively used in evaluating children with intoeing gait to compare with normal young children, as well as for deciding treatment criteria for them. It may also be used for the diagnosis of patients at the risk of intoeing gait with an increased FA and for determining effect of rehabilitation programs [12].

Crouch gait is the gait pattern which is characterized by knee joint flexion during stance phase in spastic diplegic cerebral palsied children [13]. Diminished knee extension during the terminal swing phase results in a problematic flexed-knee position at initial contact and a shortened stride [14]. Short and spastic hamstrings (semimembranosus) are thought to be the primary cause of this abnormality; however, studies based on musculoskeletal modeling suggest that multiple factors are involved [15].

It had been showed that postural control and balance reactions are insufficient in children with cerebral palsy, and these children use an altered pattern of muscle coordination, which are thought to be a result of interacting the primary deficit due to early brain damage with the compensation due to postural instability. This may lead to several deformities including lower extremities [16].

Even though there have been several studies focused on the importance of postural control and balance in children with CP, the relationship between FA angle, knee angle and balance is still a question. It was reported that the effect of IFA on gait pattern have a complex relationship with other orthopedic and neurological abnormalities of cerebral palsy [9]. Gait pattern of spastic diplegic CP had been studied by Lin et al., who showed that gait is altered based on the characteristics of the knee joint [13]. Also , it is believed that several factors in addition to tight hamstrings may contribute to crouch gait, and determining whether an individual's gait abnormality is due to short or spastic hamstrings, spastic hip flexors, weak knee extensors, weak ankle plantarflexors, torsional deformities of the tibia, problems with balance or another source is not straight forward [15]. Therefore, the main aim of this study was to investigate the relationships of FA with knee flexion angle and balance in spastic diplegic children.

Materials and methods

Research design

Cross-sectional correlational design.

Subjects

This study used a sample of spastic diplegic CP children from both sexes. Their ages ranged from 5 to 7 years. Participants were recruited from the Out-patient clinic of Faculty of Physical Therapy, Cairo University and from the National Institute of Neuromotor System. Initially, sample size was estimated based on effect size from previous studies, a sample size of total 80 would be required (GPower 3.0.9.2 program).

Fifty-two patients were initially enrolled. However, 12 patients were excluded (5, owing to having lower limb surgeries, 3 children' parents refused to participate in the study and 4 their FA exceeded 50 degrees). A flow chart describing the distribution of participants is shown in Figure 1.

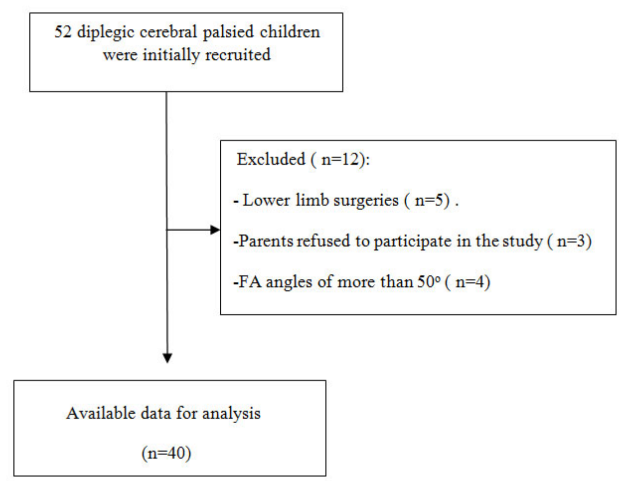

Figure 1. Flow chart of the participants.

The study included a total of 40 children (both sides were assessed by 3D- axial CT for FA and 2-D video based motion for knee angles; 80 readings were included in the final data analysis).

The parents of the children were informed about the research study and signing a written consent form. The study was approved by the Ethics Committee of the Faculty of Physical Therapy, Cairo University.

Criteria for inclusion were as follows(1) the degree of spasticity ranged from 1 to 1+ according to the Modified Ashworth scale [17]. (2) Gross Motor Function Classification System (GMCFS) of levels I and II [18]. (3) Femoral anteversion angle from 30° to 50° measured by 3-D axial CT scan. (4) The ability to understand and follow orders. While exclusion criteria included (1) Visual or auditory problems (2) Fixed deformities in lower limbs (3) History of surgical interference in the lower limbs.

Instrumentation

Assessment instruments

Physical examination was conducted as part of baseline assessment for patients' selection. Spasticity assessments were referred to the extent of the resistance against passive movement of each muscle group; it was evaluated according to Modified Ashworth scale. Spasticity was tested for the hip adductors, knee flexors, and ankle plantarflexors [19]. Diplegic CP children were selected if the degree of spasticity ranged from 1 to 1+ according to the scale [17].

Gross Motor Function Classification System is best considered as a tool to stratify patients with cerebral palsy according to broad functional levels. It is considered to be stable over time, and is not usually used as an outcome measure [20]. The participants were independent ambulators with a relatively equal distribution between Gross Motor Function Classification System levels I and level II. Persons with GMFCS level I can ambulate independently without limitations, but may have limitations in more advanced gross motor skills whil participants with level II ambulate independently but have limitations in walking outdoors and in the community [18].

Femoral anteversion angle was measured by axial 3-D CT scan. It is the formed angle to the transverse axis by a line running through the center of the femoral head through the mid point of the narrowest segment of the femoral neck [11]. It has a high accuracy and reliability. In addition, improvements in processing software and 3D-CT technology have resulted in high intra-observer and inter-observer reliability of this method for FA angle measurement of patients with cerebral palsy regardless of femoral neck-shaft angle or postural deformity [12]. Children were referred if they had FA from 30° to 50°.

Balance was assessed by The Pediatric Balance Scale (PBS), it is a modified version of the Berg Balance Scale (BBS), it includes 14 items which were contained within Berg's scale, and they were modified to create a pediatric version of this tool. The modifications were minor and included: 1) reordering of test items; 2) reducing time standards for maintenance of static postures; and 3) clarifying directions. Test items within the BBS are organized by increasing difficulty of task. In the pediatric version, items were reordered into functional sequences with novel tasks placed at the end of the scale. it is a valid and reliable assessment method for balance in school- age children with mild to moderate motor impairment [21].

Knee flexion angle was measured using digital cameras and a 2D video–based motion was captured from sagittal view. Then the model was used to connect the reflected dots and compute the angles of both knee joints during the mid stance frame of the gait cycle [22].

Outcome measures

Knee flexion angle measurment

Knee flexion angle was measured from the lateral view using two digital cameras for video recording of the participants' lower limb movements. The camera encodes digital images and videos digitally. It stores them for later reproduction. A flash memory card was used for storing digital information. Each digital camera was mounted on a tripodfor maintaining its stability [23]. It was placed perpendicular to the side of the walk way one meter above the floor and 1.5 meter away from the center of the child body to provide full view. The child's movement was recorded by digital video camera from sagittal view to capture the movements of the lower limbs [24]. Each child was allowed to walk over the walkway several times to be familiar with the procedure. Walking was tested barefoot using the usual gait pattern, 25-mm diameter round reflective markers were attached to each child, based on the Helen-Hays marker set. The locations of the markers included greater trochanter, lateral femoral epicondyle, and lateral malleolus. The child walked until at least three strides were recorded on each side [25].

The resultant captured video was processed using the Tracker Video Analysis and Modeling Tool. It allows to model and analyze the motion of objects in videos. By overlaying simple dynamical models directly on to videos. knee angle was measured at the midstance frame,this angle is formed by the intersection of two lines; the fist line connecting greater trochanter and lateral femoral epicondyle and the second line connecting lateral femoral epicondyle and lateral malleolus [22].

Balance measurement

Balance was measured using the Pediatric Balance Scale (PBS). The PBS examines functional balance using 14 tasks, with score ranging from 0 to 56, higher scores indicating better postural control. The evaluated tasks in the PBS are as follows: (1) sit to standing, (2) standing to sitting, (3) transfers, (4) standing unsupported, (5) sitting unsupported, (6) standing with eyes closed, (7) standing with feet together, (8) standing with one foot in front, (9) standing on one foot; (10) turning 360 degrees, (11) turning to look behind, (12) retrieving object from floor, (13) placing alternate foot on stool, and (14) reaching forward with outstretched arm.

Equipments needed to administer the test items were; adjustable height bench (items 1,2,3,5), chair with back and arm rests (item 3), stopwatch (items 4,5,6,7,8,9,10,13), a masking tape (items 4,6,7,8,9,11,14), a step stool (item 13), chalkboard eraser (item 12), ruler (item 14), and a small level wooden step (item 14) [21].

First, general instructions were given to each child before participation, then demonstrations of each task was also given separately and the child received one or two practice trials on each item before recording. Verbal, visual and physical cues were given when needed.

Each item was scored in a scale from 0 to 4. The best of the three trials was recorded. The child's performance was scored based upon the lowest criteria which describes the child's best performance. Score 0 referred to "need moderate to maximal assistance" while score 4 referred to "ability to do the task independently as described in the tested item". It took approximately 15 minutes to administer and score the PBS [26].

Data analysis

To minimize bias produced by similarities and differences between the right and left sides; anteversion and knee angles of the same child, both sides measurements per patient were analyzed.

Results

In this study, 52 diplegic children were initially recruited. However, 12 children were excluded (5 children due to surgeries of lower limbs, 3 children' parents refused to participate, 4 children after revising their CT scan reports of FA angles were more than 50°). In the final analysis, a total of 40 participants met the inclusion criteria for this study as shown in the flow chart (**Figure 1**). Minimum, maximum, mean and standard deviation (SD) of anteversion angle, balance scores and knee flexion angles were calculated. Statistical analyses were computed with IBM SPSS statistics, version 22.0 (IBM Corporation, Armonk, NY).

Descriptive statistics were used to summarize children' demographics and values of measured variables as shown in **Table 1**.

Table 1. Demographic characteristics of participants.

Variable	N	Min	Max	Mean	SD
Age (years)	40	5.2	6.9	6.04	0.47
Gender (no. and %)	40	Female (21,52.5%) , male (19, 47.5%)			
Weight (kg)	40	15.9	19.5	17.44	1.122
Height (cm)	40	107	119	113.2	3.473
GMFC	40	I =18, II = 22			
Rt femoral anteversion angle (degrees)	40	30	49	39.42	4.914
Lt femoral anteversion angle (degrees)	40	30	50	39.60	5.324
Balance score	40	22	50	35.70	9.685
Rt knee flexion angle (degrees)	40	22	44	34.05	8.635
Lt knee flexion angle (degrees)	40	23	44	33.83	8.067

N=number , Min=minimum , Max=maximum , SD= standard deviation

Data was assessed for normality using one-Sample Kolmogorov-Smirnov test and linearity was assessed as well. Based on testing of the data, Pearson correlation coefficients were computed to estimate the relation between all testing pairs of parameters; femoral anteversion angles with balance scores, femoral anteversion angles with knee flexion angles, knee flexion angles and balance scores for both sides in diplegic children aged from 5 to 7 years. The 2-tailed significance level was set at $p<0.05$.

First, relation between both sides was tested regarding anteversion angles and knee flexion angles using Pearson correlation coefficient, results showed strong statistically significant positive association ($r>0.7$) between both sides as shown in **Table 2**.

Second, testing relationship between measured variables (FA angle, knee flexion angle and balance) revealed that there is a statistically significant moderate negative correlation ($-0.5 < r < -0.7$) between femoral anteversion angles of both sides and balance scores. Strong statistically significant negative association ($r>-0.7$) was found between knee flexion angles of both sides and balance scores. The correlations between results of hip anteversion and knee flexion angles of both sides were found to be significant strong positive association ($r>0.7$) ($p<0.05$). As shown in **Table 3** and **Figures 2-7**.

Table 2. Correlation between angles of the Rt and Lt sides.

	Pearson coefficient (r)	P value
Rt and Lt femoral anteversion angles	0.997	0.000**
Rt and Lt knee flexion angles	0.987	0.000**

r=correlation coefficient , Rt = right , Lt= left

Table 3. Relation between FA, balance scores and knee flexion angles.

	Pearson coefficient (r)	P value
Rt femoral anteversion angle and balance score	-0.625	0.000**
Lt femoral anteversion angle and balance score	-0.630	0.000**
Rt knee flexion angle and balance score	-0.846	0.000**
Lt knee flexion angle and balance score	-0.838	0.000**
Rt anteversion angle and Rt knee flexion angle	0.813	0.000**
Lt anteversion angle and Lt knee flexion angle	0.789	0.000**

r=correlation coefficient , Rt = right , Lt= left
**correlation is significant at the 0.05 level (2-tailed)

Discussion

The purpose of this study was to examine the relationship of femoral anteversion, knee flexion angles and balance in spastic diplegic CP children. Increased femoral anteversion and flexed-knee gait are common disorders in children with CP with limited researches in the area of finding out correlations between joint angles and balance in CP.

Results of this study revealed that spastic diplegic children from five to seven years experience excessive anteversion angle, restrictions of knee movement during the stance phase

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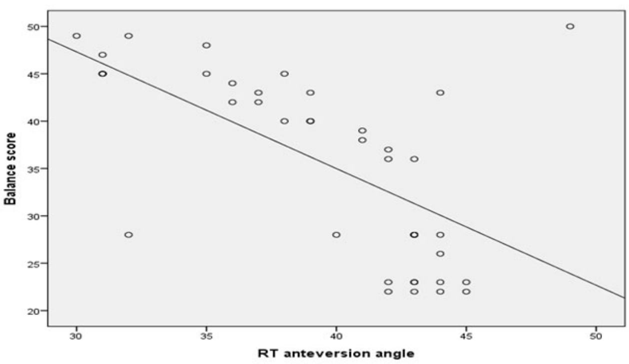

Figure 2. Relation between Rt anteversion angle and balance scores.

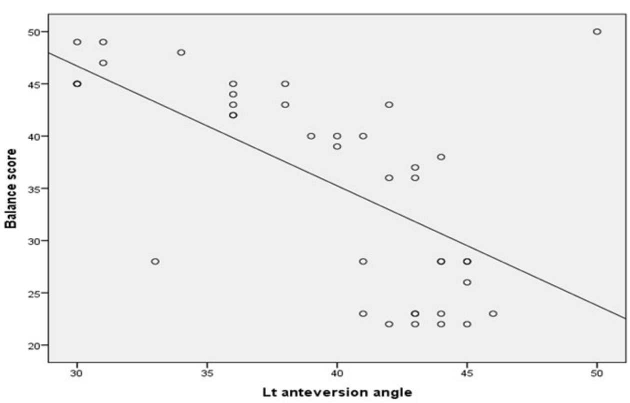

Figure 3. Relation between Lt anteversion angle and balance scores.

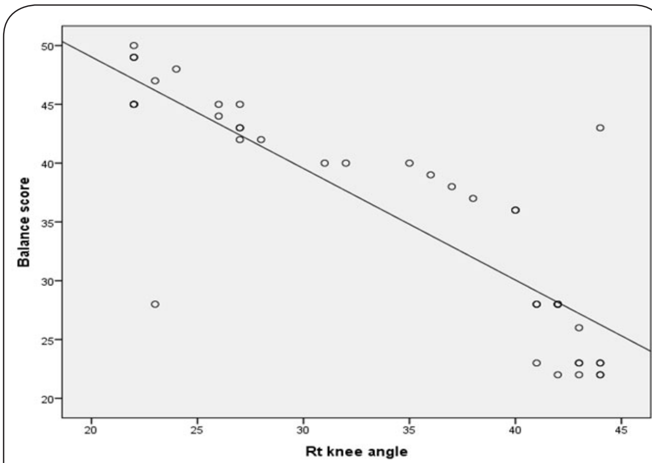

Figure 4. Relation between Rt knee angle and balance scores.

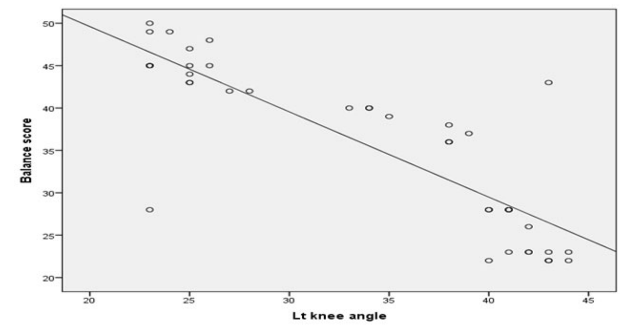

Figure 5. Relation between Lt knee angle and balance scores.

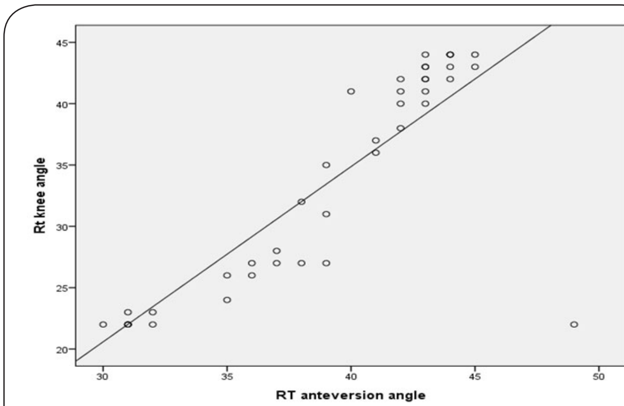

Figure 6. Relation between Rt anteversion angle and Rt knee angle.

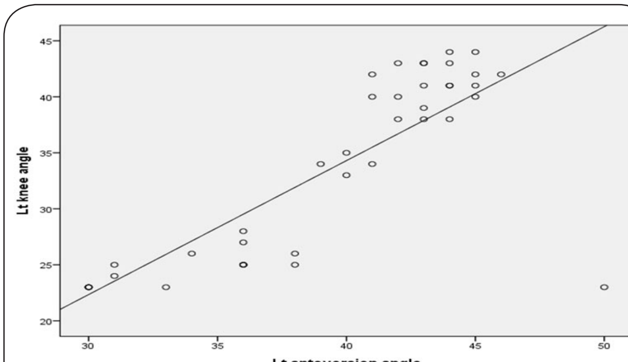

Figure 7. Relation between Lt anteversion angle and Lt knee angle.

and impaired postural control and physical balance. This 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 [27].

Gait of spastic diplegic CP children is characterized by knee flexion in stance phase, this is supported by the study of Rodda et al., who showed that children with spastic diplegia usually walk independently but most have an easily recognized disorder of gait which include deviations in the sagittal plane motions such as toe walking, flexed-stiff knees, flexed hips and an anteriorly tilted pelvis with lumbar lordosis. When compared to their peers, many of them also walk at a reduced speed, with increased energy expenditure and impaired functional capability [28].

Results of the present study regarding anteversion angles and knee flexion angles showed that there was a strong significant positive correlation between both right and left sides. Li and Leong 1999 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].

Flexed-knee gait in spastic diplegic CP is multi-factorial and is mainly caused by abnormal motor control, muscle weakness and imbalance, progressive muscle shortening, spasticity, femoral anteversion, torsional malalignments, and foot deformities [30,31,32] and this is support the findings of the present study that there is significant strong positive correlations identified between measurements of anteversion and knee flexion.

Our results agree with previous studies of Chang et al., and Kay et al., [33,34] who have examined the etiology of knee flexion of crouch gait which is a common gait pattern in spastic diplegia. This type of gait has been considered as increased knee flexion throughout stance phase. Most authors in the past recognized that the knee flexion could arise from spastic or contracted hamstrings or psoas muscles or both; weak hip or knee extensors or plantarflexors; or lever arm dysfunction from bony torsion such as femoral anteversion.

The results revealed that there is a moderate negative correlation between anteversion angles and balance scores, this suggests thatthe more anteversion angles, the more impairment of balancein diplegic CP children. A study of Arnold et al., reported that rotational abnormalities of the hip are often accompanied by excessive anteversion of the femur, a torsionalde formity which may alter the lines of action and moment arms of muscles about the hip, which frequently manifested as exaggerated flexion of the hips and knees in addition to increased internal rotation of the hip and troublesome gait abnormality among spastic diplegic cerebral palsy [35].

The present study reports a strong statistically significant negative correlation between knee flexion angles of both sides and balance scores. This is supported by the work of Rose et al., [36] who reported that walking with flexed-knee gait is one cause of gradual decline and loss of walking function and balance ability. In addition, the literature reports the main musculoskeletal prerequisites for maintenance of standing and walking balance include the adequate range of motion and muscle force, the size and quality of the base of support. As the base of support increases with supported standing, the stability is also increased [37]. But in crouch posture, the posterior location of the line of gravity creates an external flexion moment at knees and alters the body alignment which is one of the prerequisite for standing and walking balance. This knee flexion is accompanied by hip flexion for maintenance of stability [38].

In another study by Hicks et al., the relative orientation of the body segments and crouched posture changes was found to alter the dynamic coupling between joints which leads to major reductions in the hip and knee extension. This finding suggested that the tendency towards crouched posture in spastic cerebral palsy increased the work load of muscles to maintain balance [32].

The results of the study is supported by the work of Lowes et al., who reported that the crouched standing posture could potentially affect the pattern of postural muscle coordination which is essentially used in maintaining balance. Weakness in hip and knee extensors, ankle plantar flexors, and hip abductor muscles may adversely influence standing balance as well [39].

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 [35]. Hamstrings over-activity causes the excess knee flexion associated with crouch posture. Also spasticity tends to adduct, internally rotate and flex the hips during standing position and walking [40]. 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. Our study found that with an increase in hip anteversion angle, there is a significant increase in the knee flexion angle and impairment in balance [41].

This study has several limitations. First, a significant correlation does not imply causation, and further investigation is needed to clarify the likelihood of a true causal relationship. Second, skeletal deformities which are commonly seen in children with CP are not fully examined; future studies are needed for coxa valga, genu valgum and tibial torsion. Third, this study included knee range of motion (ROM) and further researches should be conducted to examine the association between ROM of hip and ankle joints.

Conclusions

The results of this study indicated that the existence of a relation between hip anteversion angle and altered knee alignment with impaired balance 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 limitation in range of motion of knee joint and functional problems. The child must be examined carefully and an accurate diagnos is must be established.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

Authors' contributions	NAZ	NST	MBB
Research concept and design	✓	✓	✓
Collection and/or assembly of data	✓	✓	--
Data analysis and interpretation	✓	✓	✓
Writing the article	✓	✓	--
Critical revision of the article	✓	✓	✓
Final approval of article	✓	✓	✓
Statistical analysis	✓	✓	✓

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