



Increased femoral anteversion-related biomechanical abnormalities: lower extremity function, falling frequencies, and fatigue

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ABSTRACT

Background: Increased femoral anteversion (IFA) is defined as forwardly rotated femoral head relative to the transcondylar knee axis which may have a potential to reduce the functional quality of adolescents. Therefore, the aim of our study was to investigate the effects of IFA on lower-extremity function, falling frequency, and fatigue onset in neurologically intact children.

Research question: Does increased femoral anteversion influence lower extremity function, falling frequency and fatigue on set in healthy children?

Methods: Sixty-five participants with increased femoral anteversion (IFA) and thirty-two healthy peers as control were included into the study. For the function, the lower extremity function form (LEFF) which is adapted from Lower Extremity Function Test used. Falling frequency and fatigue onset time were assessed by a Likert-type scale. In addition, the activities which cause frequently fall for the participants were questioned. **Results:** Lower extremity function was found deteriorated ($p = 0.02$) and falling frequency was higher ($p = 0.00$) in IFA than in controls. Fatigue onset time was not different between groups, although lower extremity function was strongly correlated with fatigue onset ($\rho = -0.537$, $p < 0.001$). IFA children fall four times more during running (60%), three times more during fast walking (21.42%) than their healthy peers (14.28%, 7.14% respectively). **Significance:** IFA leads functional problems, especially in the form of high falling frequencies. According to the LEFF score, the most difficult functional parameters for these children were walking long distances, becoming tired, walking more than a mile, and standing on one spot. Also, shorter fatigue onset time may worsen the lower-extremity function secondarily. Because of the higher frequency of falling and functional problems, children with IFA may be more defenseless to injuries, especially in high-motor-skill activities such as running and soccer.

1. Introduction

Musculoskeletal deformities in the lower extremity affect the person's activities of daily living and his or her functional status. Although functional quality improves more rapidly with growth, the influences of the deformities can deteriorate the quality of function more aggressively when children grow faster [1]. Increased femoral anteversion (IFA), which is higher forward rotation of the femoral head relative to the transcondylar knee axis than the specific ranges for different ages [2], is one of the skeletal problems that may reduce the functional quality of

adolescents [3]. IFA is usually diagnosed after 3 years of age, peaks at 4–6 years (30°–40°), and then gradually resolves (10°–15°) by early adolescence [4,5]. It tends to be familial and is visible on both legs [6,7]. IFA is also related with functional problems, such as sitting in the “W” position, walking in the toe-in gait pattern, and standing with internally turned patella and knee in which, it is questionable whether “w sitting” is the cause or the result of IFA [8]. The effects of IFA on walking were clearly revealed in typically developed children as an increased knee and hip flexion in stance by decreasing the peak knee and hip extension, knee flexion moment, and peak knee power generation [3].

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Patient Name : _____

Protocol Number: _____

Test Date: _____

How often your child falls in a day?

How long does him/her get tired?

Fig. 1. Likert-type form for falling frequency and fatigue onset timing.

Some children with IFA may have symptoms such as anterior knee pain, patellar instability, femora-acetabular impingement, and labral tear. However, the majority of the unnoticed IFA population who live like their pairs are asymptomatic [9–14]. Some authors have implied that parents' complaints about their children falling, tripping, walking clumsily, and getting tired easily may be signs of asymptomatic IFA [1,15,16]. These complaints, which influence the child's functional level, may also affect the child's participation in leisure-time activities. Because IFA influences the typical loading behavior on lower-extremity joints [17], tripping, falling, and getting tired easily may cause traumatic and musculoskeletal injuries. Moreover, these injuries may occur in potential young athletes, which shortens their professional sportive lives.

Therefore, the aim of our study was to investigate the effects of IFA on lower-extremity function, falling frequency, and fatigue onset in neurologically intact children. It is hypothesized that IFA may deteriorate lower extremity function, increases falling frequency during high speed function.

2. Methods

To understand the effects of IFA on lower-extremity function, falling frequency, and fatigue onset, 65 participants with IFA (8.69 ± 3.20 years) and 32 healthy peers as control (9.50 ± 3.05 years) were included in this descriptive study. The participants had no prior neurological and/or musculoskeletal abnormalities other than IFA, which was diagnosed by the neurologist and orthopedists at Istanbul University, Faculty of Medicine. The participants had not joined in any high-level physical sportive activities in the 3 days prior to tests. The participants in this study were evaluated at Istanbul University, Faculty of Medicine, Gait Analysis Laboratory, from March 2015 through March 2017. All participants and their parents were volunteers, and the consent form to participate in this study was signed by each parent, in agreement with the requirements of the local ethics committee.

The internal and external rotation of the hip were evaluated by a goniometer while the participants were lying prone with 0° hip extension and the knees were at 90° flexion [5,15]. Children who had a greater than 60° hip internal rotation angle (IR) and lower than 20° hip external rotation angle (ER) were defined as having IFA [6,10]. The trochanteric prominence angle test (TPAT) was also used for measuring femoral anteversion in the same position as goniometric hip rotation measurement when the great trochanter of the femur was palpated most prominently [10,18]. Also, midpoint of the hip internal and external rotations was calculated by measuring arithmetic combination of passive internal and external hip rotations [19]. The clinical examination data was considered as it was measured in 1° goniometric values. To investigate the pure effects of IFA, children with increased tibial external torsion (thigh-foot angle $> 15^\circ$) were not included in the study.

To investigate how the IFA affects lower-extremity function, the lower-extremity function form (LEFF), which was adapted from the

Lower Extremity Function Test and used for children with toe-in gait pattern at Wake Forest University Baptist Medical Center hospital, was used [20,21]. The scale consists of 20 items, and each item can be scored between 0 and 4. High scores (maximum score of 80) indicate worse functional status. The scale contains items that evaluate ascending and descending stairs, running heel-toe, skipping, keeping balance while walking, kicking a ball, walking long distances without becoming tired, walking without falling, climbing 3 and 1 flights of stairs, walking more than 1 mile, walking 3 and 1 blocks, riding a bicycle/tricycle, being able to heel walk, ability to wear orthotics, walking with heels down, ability to put on shoes, standing in one spot, and standing with feet together. The form was scored by the parents or the caregivers considering the children's general functional status.

To investigate the association of the falling frequency and IFA, daily falling frequency was evaluated using a Likert-type scale. The scale was scored by the family or caregiver, with scores ranging between 1 and 4 points. Lower scores indicate more frequent falling status (Fig. 1). In addition to the falling frequency, the activity during which the child falls at the highest frequency in 6 different activities (standing, walking, walking faster, running, climbing stairs, walking on uneven ground) was also questioned. For all participants, each response was ranked separately by using the falling percentage.

To understand whether IFA causes fatigue or not, the fatigue onset time was also questioned by Likert-type scale. The scale, which was completed by the family member or caregiver, was equally fragmented into four parts and numbered from 1 to 4. The lower scores indicate quicker fatigues (1 = fatigue in less than 5 min, 4 = fatigue after 30 min; Fig. 1).

The inclusion of 95 participants was above the minimum sample size needed to ensure a power of 95% confidence level and to detect statistical significance at a two-sided significance level of 0.05 ($b = 0.20$) by considering the effects of size 18.90% in average between the two groups, IFA and controls, using the calculation method for the basis of descriptive studies [22].

Statistical analysis was performed with SPSS 21.0 (licensed by ... University). For comparison, according to the analysis of normality test (Shapiro-Wilk test), statistical analysis was done by Mann Whitney *U* test, and for correlation between parameters, Spearman rho's correlation test was used. The strength level of the correlation was determined as Cohen's coefficient [23]. Parameters of interest were compared between these groups using the Kruskal-Wallis test ($p < 0.05$). The demographics of the participants were not significantly different between the groups ($p > 0.05$).

3. Results

The measured hip internal rotation was found as strongly correlated with the external rotation ($\rho = 0.779$, $p < 0.001$), midpoint hip rotations ($\rho = 0.626$, $p < 0.001$) and TPAT values ($\rho = 0.738$, $p < 0.001$) (Table 1) [23].

Table 1
Demographics of participants.

	IFA (n = 65)	Control (n = 32)
Age (years)	8.69 ± 3.20	9.50 ± 3.05
Height (cm)	135.77 ± 15.63	137.48 ± 16.35
Weight (kg)	33.39 ± 13.99	35.34 ± 13.84
Mean hip internal rotation (°)	71.57 ± 5.99	44.83 ± 12.64*
Mean hip external rotation (°)	14.26 ± 0.84	31.59 ± 1.39
Midpoint of the hip internal and external rotations (°)	42.91 ± 0.41	38.21 ± 1.04
Tibial torsion angle (°)	13.08 ± 4.22	11.33 ± 2.64
TPAT (°)	45.62 ± 7.07	22.23 ± 11.38*

Abbreviations: IFA increased femoral anteversion; TPAT trochanteric prominence angle test; cm centimeter; kg kilogram.

* Significantly different parameters between the two groups ($p < 0.05$).

Table 2

Comparison of lower-extremity function score, falling frequency, and fatigue onset time between IFA and control groups.

	u	z	p
Lower-extremity function	1321	2.312	0.02*
Falling frequency	583.5	-3.511	0.00*
Fatigue onset	1043	0.030	0.97

U: Mann-Whitney U variable, * $p < 0.05$.

3.1. Lower-extremity function

The mean lower-extremity function form score was significantly higher in IFA (10.66 ± 8.43) than in controls (5.91 ± 7.44; $p = 0.02$, median of IFA: 9.0, median of controls: 4.5; [Table 2](#)).

LEFF scores were moderately correlated with IR ($\rho = 0.396$, $p < 0.001$) and falling frequency ($\rho = -0.475$, $p < 0.001$).

Walking long distances without becoming tired was the hardest parameter for IFA children (mean score: 1.48 ± 1.20). In addition, walking more than a mile and standing on one spot were the second and the third other most difficult parameters, respectively (mean scores: 1.17 ± 0.99 and 0.72 ± 0.83, respectively.)

3.2. Falling frequency and the activities that cause falling

Falling frequency score was significantly lower in the IFA (3.20 ± 0.78) than in the control group (3.56 ± 0.60; [Table 2](#)) (Lower scores indicate more frequent falling status). Falling frequency was found as a weakly correlated parameter with hip internal rotation angle ($\rho = -0.248$, $p < 0.005$).

It was found that IFA children fall most frequently during running (60.00%). Falling frequencies decrease during fast walking and walking on an uneven surface (21.42%), walking at a comfortable speed (14.28%), climbing stairs (12.85%), and standing (2.80%). On the other hand, for controls, the most frequently fall was seen during walking on an uneven surface (35.71%), and the fall frequency reduced during running (14.28%), climbing stairs (10.71%), and walking faster (7.14%; [Table 3](#)).

Table 3

Falling frequency during activities (%).

	IFA (n = 65)	Control (n = 32)
Standing	2.80	0.00
Walking	14.28	7.14
Walking faster	21.42	7.14
Running	60.00	14.28
Climbing stairs	12.85	10.71
Walking on uneven ground	21.42	35.71

Abbreviation: IFA, increased femoral anteversion.

3.3. Fatigue onset

Fatigue onset score was not found to be significantly different between the IFA group (3.41 ± 0.73) and the control group (3.42 ± 0.75; $p = 0.97$, median for IFA: 4, median for controls: 4; [Table 2](#)). There was a strong correlation between fatigue onset (3.41 ± 0.74) and LEFF ($\rho = -0.537$, $p < 0.001$) [[23](#)]. However, there was no correlation between fatigue onset and TPAT and hip internal rotation ($\rho = 0.06$, $p = 0.51$; $\rho = 0.07$, $p = 0.45$, respectively).

4. Discussion

The present study investigated the effects of IFA on lower-extremity function, falling frequency, and fatigue onset, and the results demonstrated that the lower-extremity function was reduced and falling frequency increased in IFA children.

To our knowledge, this was the first study to investigate the relationship between asymptomatic IFA and function. In addition, we found that lower-extremity function gets worse as the internal hip rotation angle increases. Contributing to the literature, these findings suggest that IFA negatively affects children's activity of daily living, even though they have no musculoskeletal symptoms [[9–14](#)]. As agreed with Arnold et al.'s (1997) work using mathematical modeling, 30–40° hip anteversion reduces the abduction moment arm of the gluteus medius about 40–50 % of the moment arm, which may contribute primarily on functional deterioration [[24](#)]. Furthermore, children with IFA may have different movement strategies, if they are divided in to sub-groups based on sagittal knee kinematics as it is revealed in Alexander et al.'s study (2019) which demonstrated not all patients with IFA have a decreased knee extension in terminal stance [[25](#)]. We found that the most difficult parameter for those with IFA was becoming tired after walking a short distance, which was in agreement with the literature [[16](#)]. Developing fatigue in a short period of time may increase the child's biomechanical disadvantage during playtime and increase the risk of injury during recreational activities or sports competitions [[26,27](#)].

As expected, falling frequencies increased in the IFA group compared with controls [[1,16](#)]. As the participants' lower-extremity function worsens, the frequency of falling increases. Logically, there was a moderate relationship between reduced lower-extremity function and falling frequency, which may be a good indication of predisposing sport injuries [[10](#)]. Children with IFA fall frequently during running, which is a high-level activity that requires more coordination and motor skills than walking or standing. Falling frequency increased as the activities became faster and required more skill. Rapid walking and walking on uneven ground were the other activities, after running, that had a higher falling frequency for IFA, respectively. In addition, because of the high velocity, falling during running can lead to more serious injuries than other activities, such as walking or standing, which

therefore increases the risk of injury and reduces sport performances [14]. In the literature, IFA was reported to be associated with anterior knee pain, patellar instability, femoroacetabular impingement, and labral tear [11–14]. In Stambough et al.'s (2016) study, the authors treated the patients with symptomatic (knee pain) IFA performed by derotational osteotomy [9]. According to our results, lower-extremity function was reduced long before the symptoms (knee pain, etc.) developed in daily living, recreational activities, and sportive activities such as running [9]. Therefore, children with IFA may have a great potential for injuries in sportive activities, which dominates lower-body parts such as sprinting, triple jump, long jump, and soccer. Therefore, biomechanical influences of IFA should be carefully evaluated in different sport branches.

There was no difference between the two groups in terms of fatigue onset time. It might be related to the parent's poor determination of fatigue for their child in the Likert test. The Likert scale may not be as sensitive as using objective assessment tools for measuring the differences in fatigue onset time in children with IFA [28]. Because fatigue onset time has not been measured for children previously in the literature, the Likert scale was used in this study. However, the strong correlation between fatigue and reduced lower-extremity function may demonstrate that fatigue's influence on lower-extremity function is higher in children with IFA than in controls. For this reason, biomechanical disadvantages of IFA should be investigated and compared before and after fatigue.

In this study, LEFF which was utilized earlier in the only one study for the individuals with IFA, was used in order to evaluate functional status of the lower extremity [20,21]. At the Jacks et al.'s study, the LEFF originally was adapted from LEFS which is, we believe, well understood by the parents. Although, different from LEFS, the validation and Turkish adaptation of LEFF was not investigated, which should be worked in future studies.

Even though IFA was found moderately correlated with functional deteriorating in the present study, toe in gait, which is expected to see with IFA may not be the responsible parameter. Because not all of the participants agreed to sign the consent form for 3D gait analysis, foot progression data were insufficient for statistical analysis. Besides, some studies revealed that IFA children do not necessarily have a noticeable in-toeing gait [29–31]. Different than IFA, compensatory movements for toe-in gait may have other relation to functional problems which should be investigated in future.

Because of the lack of studies on evaluation of falling frequencies and fatigue onset, the Likert-type scale was utilized in the present study. The present study focused only that effects of IFA on these parameters in activity of daily living, which should be investigated in detail by more sophisticated tools in the future studies. Therefore, the validity and reliability of our results were not investigated. In the present study, hip rotation angles were measured by goniometer [6,10]. Sophisticated tools such as magnetic resonance imaging or computed tomography are more reliable and objective methods for measuring IFA [32]. However, these tools are expensive, and radiation exposure is difficult for parents to approve for their asymptomatic in-toed children. In addition, although, goniometric measures of hip internal rotation and TPAT have high reliability and validity for clinical usage [10,18], the midpoint of hip internal and external rotation is another frequently used parameter for hyper flexible children, which may have also increased value in both directions [19]. Therefore, the correlations of the external, the internal, the midpoint of the internal and external rotations of the hip and TPAT values were analyzed and the measured hip internal rotation was found as strongly correlated with the external rotation, midpoint rotation and TPAT values [23].

According to the literature and our clinical observations, joint hypermobility is also commonly seen with IFA [33]. Hypermobility may be an exacerbating genetic factor for these children that interferes with the biomechanical alterations of IFA in function. Therefore, in future studies, investigation of the pure influences of femoral anteversion and hypermobility is needed.

5. Conclusion

IFA leads to functional problems, especially in the form of falling frequencies. The most difficult functional parameters for these children were walking long distances, becoming tired, walking more than a mile, and standing on one spot. Also, shorter fatigue onset time may worsen the lower-extremity function secondarily. To reveal the direct effects of fatigue on IFA, future studies measuring the effect of fatigue with objective methods are needed. Because of the higher frequency of falling and functional problems, children with IFA may be more defenseless to injuries, especially in high-motor-skill activities such as running and soccer.

Conflict of interest statement

The authors have no conflicts of interest to declare.

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