Effects of Increased Femoral Anterversion on Gait in Children with Cerebral Palsy

Femoral Anteversiyon Artışının Serebral Palsili Çocukların Yürüyüşüne Olan Etkileri

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Summary

Objective: The aim of this study is to identify the gait deviations due to increased femoral anteversion and to distinguish these deviations from those which are commonly seen in children with spastic diplegic cerebral palsy (SD).

Materials and Methods: The gait parameters of six neurologically intact children with increased femoral anteversion (NIFA), nine spastic diplegic children with increased femoral anteversion (CPIFA), and fifteen neurologically intact typically developing children (TD) were compared. 3D Motion Analysis System was used to analyze the sagittal plane pelvis, hip, knee, and ankle kinetics and kinematics, as well as the temporo-spatial parameters.

Results: Increased dorsiflexion and knee flexion at initial contact, increased mean pelvic anterior tilt during stance, decreased peak plantar flexion moment in terminal stance, increased double support time and decreased mean velocity which are the pure effect of SD, were significantly different in CPIFA group compared to NIFA and TD groups. A strong similarity existed between CPIFA and NIFA groups regarding the increased peak knee extension moment.

Conclusion: This study supported the hypothesis of "existence of relation between IFA and crouch posture". The orthopedic surgeons may consider the priority of planning femoral de-rotational osteotomy in surgical treatment schedule for children with CP. *Turk J Phys Med Rehab 2009;55:135-40.*

Key Words: Femoral anteversion, cerebral palsy, gait analysis, gait parameters

Özet

Amaç: Bu çalışmada, femoral anteversiyon artışının neden olduğu yürüme anomalilerini belirlemek ve bu anomalileri spastik diparezik tip serebral palsili (SD) çocuklarda gözlenen yürüme deviyasyonlarından ayırmak amaçlanmıştır.

Gereç ve Yöntem: Altı femoral anteversiyonu artmış nörolojik açıdan normal olgunun (NFAA), dokuz fermoral anteversiyonu artmış SD'li olgunun (SDFAA) ve onbeş femoral anteversiyonu olmayan ve nörolojik açıdan normal olgunun (NO) yürüme parametreleri karşılaştırılmıştır. Üç boyutlu hareket analiz sistemi ile sagital plan pelvis, kalça ve diz kinematik, kinetik ve zaman-mesafe parametreleri analiz edilmiştir.

Bulgular: İlk temas fazındaki diz fleksiyon ve ayak dorsifleksiyon artışının, basma fazındaki ortalama pelvik anterior tilt artışının, basma fazı sonundaki plantar fleksiyon momentindeki azalmanın, çift destek periyodundaki artışın ve ortalama yürüme hızındaki azalmanın SDFAA grubunda, NFAA ve NO grubuna göre istatistiksel olarak anlamlı derecede farklı olduğu belirlenmiştir ki bu parametreler saf spastik diparezi etkisidir. DFAA grubundaki maksimum diz ekstansiyon momentindeki artış NFAA grubuyla kuvvetli derecede benzerdir ki bu durum saf femoral anteversiyon etkisini göstermektedir.

Sonuç: Bu sonuçlar femoral anteversiyon artışı ile çömelme postürü arasındaki ilişki varlığını savunan hipotezi desteklemektedir. Ortopedik cerrahinin, spastik diparezik serebral palsili hastalarda öncelikle artmış femoral anteversiyonu düzeltmeyi planlaması, anormal yürüme parametrelerinin normale yaklaşmasında faydalı olabilir. *Türk Fiz Tıp Rehab Derg 2009;55:135-40.*

Anahtar Kelimeler: Femoral anteversion, serebral palsi, yürüme analizi, yürüme parametreleri

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Introduction

One of the most common causes of toe-in gait pattern in children with cerebral palsy (CP) is increased femoral anteversion (1). In-toeing gait is treated surgically by soft tissue procedures and/or osteotomies (2). Because of the difficulties in identifying the exact cause of in-toeing gait pattern, the most appropriate treatment is still unclear and outcomes of the surgical procedures are unpredictable and sometimes unsatisfactory (1,2).

Femoral anteversion is 30-40° at birth and gradually decreases to 10-15° by early adolescence. The essential part of this improvement occurs before 8 years of age. Children with excessive femoral anteversion comfortably sit in "W" position, commonly walk with toe-in gait pattern, and stand with internally turned patella and knee. It is familial, symmetrical and common in females, unless there is a neurological problem (3). In CP children with hip flexor muscle spasticity, the normal extension and concomitant external rotation of the hip are prevented by tight hip flexors, so that the natural remodeling of the femoral torsion cannot develop and the decreasing of femoral anteversion by age cannot be seen (4).

Femoral anteversion is identified clinically by examining the child in prone position with 90° flexion at the knee. The hips are allowed to fall into maximum internal and external rotation without using any force. The amount of rotations should be similar and the range should be 90°. The excessive femoral anteversion is diagnosed when internal rotation is greater than 70° and external rotation is less than 20° (3).

The definitions of gait deviations related with femoral anteversion are highly questionable (5). Some previous studies have found correlations between them (6,7), while, some others have not (8,9). The main reason for this disagreement may be hidden under the complexity of the nature of the CP, which combines multiple muscle spasticities, selective motor control difficulties, coping responses, sensory-motor problems. Due to these multi-factorial involvements, it is very difficult to distinguish the primary reflections of increased femoral anteversion (IFA) and the reasons for in-toeing gait pattern (8).

It would be very useful information for clinicians and surgeons, if any relationship could be defined between the femoral anteversion and the gait deviations, taking into consideration only the bony deformity and its compensatory responses, and excluding the muscle spasticity, selective motor control and sensory-motor problems. It would also contribute to achieving the correct level of treatment, developing new treatment strategies and preventing new deformities (5).

The aim of the study is to identify the gait deviations clearly due to the increased femoral anteversion and to distinguish these deviations from the other causes, which are commonly seen in children with spastic diplegic CP. The hypothesis was that the increasing flexion motion and extensor moment at the hip and knee during stance phase, which are commonly seen in children with crouch gait, have a strong relationship with IFA.

Materials and Methods

Participants

Thirty children, 21 girls and 9 boys, participated in this study. Of these children, 9 were with spastic diplegia with increased femoral anteversion (CPIFA) (mean age 7.8±1.7), 6 were neurologically intact children with increased femoral anteversion (NIFA) (8.6±1.3) and 15 were neurologically intact typically developing children (TD) with no IFA (9.5±0.4). All the participants were able to walk independently 12 meters walkway and the groups were comparable with respect to age.

Femoral anteversion was measured geometrically (Figure 1) as described previously (3). The hip internal rotation angles of all the children in IFA groups (NIFA, CPIFA) were ≥70° and external rotations were ≤20° bilaterally. No tibial torsion was detected in any of the participants.

Gait Analysis

Each subject underwent gait analysis at self-selected walking speed in Istanbul Faculty of Medicine, Motion Analysis Laboratory. A six-camera motion analysis system (Elite Eliclinic, BTS, Milan, Italy) was used to compute the three-dimensional pelvis, hip, knee and ankle kinematics in the sagittal plane, the ankle, knee and hip kinetics and the temporal-spatial parameters. For each subject, the mean value of 3 trials was analyzed by considering the specific points of gait cycle. The specific points for sagittal plane pelvis, hip, knee and ankle kinematics were: range of motion (ROM) (excursion), peak values for flexion and extension, and angles at initial contact (Ic), maximum dorsiflexion moment in 0-30% of gait cycle (GC) and maximum plantar flexor moment in 30-60% of GC for the ankle, peak extension moment in 0-30% of GC and peak flexor moment in 30-60% of GC for the knee, maximum flexor and extensor moments in stance for the hip. The peak power absorption and generation were also of concern in stance phase for the hip, knee and ankle.

For the statistical analysis, according to the analysis of normality test (Shapiro-Wilk test), ANOVA and post-hoc tests (Bonferroni test: $p < 0.0167$ was assumed as significant) were performed to analyze parametric data. Kruskal-Wallis and Dunnett's tests (post-hoc) were also used for non-parametric data. The significance level was set at $p<0.05$. The gait deviations, which show no differences between NIFA and CPIFA groups and significant differences between these groups when compared to the TD children, can be interpreted as possible cause of IFA. On the other hand, non-significant differences between TD and NIFA groups, as well as the difference found when comparing them to the CPIFA group, demonstrate the effect, which excludes the IFA (possible cause of CP).

Results

The mean anterior pelvic tilt and knee flexion at Ic increased in NIFA and CPIFA groups compared to TD group (Figure 2),

Figure 1. Testing femoral anteversion in clinic by measuring the angle of maximum internal rotation (A), and external rotation (B) without applying any force.

however, these results showed no difference in NIFA and CPIFA groups (Table 1). On the other hand, the decrease in maximum plantar flexion in terminal stance was not found significantly different in NIFA and CPIFA groups, but it was also not different in TD and NIFA groups.

Increased dorsiflexion and knee flexion at Ic, and enhanced mean pelvic tilt motion during stance phase were significantly different in CPIFA group compared to NIFA and TD groups (Table 1).

The increase in peak knee extension moment between 30-60% of GC (Figure 3) was not found significantly different in CPIFA and NIFA groups, but it was significantly different in TD group (Table 2), which may correspond with IFA. The decrease in peak plantar flexion moment in CPIFA group, when compared to TD and NIFA groups, was significantly different, which demonstrates that the possible cause was CP. Although the knee power absorption in 30-60% of GC increased, the difference was not significant in NIFA and CPIFA groups compared to TD children (Table 2).

The increase in percentage of double support in GC and the decrease in mean velocity were significantly different in CPIFA group compared to TD and NIFA groups (Table 3).

Discussion

The purpose of this study was to distinguish the specific gait deviations related to the IFA from the other gait deviations, which occur as a result of muscle spasticities, selective motor control difficulties, coping responses, sensory-motor problems that are in nature of cerebral palsy.

According to our results, increased knee flexion, ankle dorsiflexion at Ic and increased mean value of pelvic anterior tilt were the kinematic parameters which seemed to be mainly influenced by the nature of the cerebral palsy itself. These parameters were significantly similar in NIFA and TD groups and significantly different in CPIFA and NIFA groups (Table 1).

The most significant difference was knee flexion angle at Ic ($p<0.0001$) in CPIFA group. The hip flexion angle at Ic was not investigated in this study, but the sagittal plan hip kinematic graphs showed increased hip flexion at Ic in CPIFA group compared to other groups (Figure 2). These parameters are commonly seen in children with CP because of the hip flexor, hamstring muscle tightness and soleus weakness (4,10,11). Because of the tightness of the knee flexors in CP, hamstrings do not elongate smoothly and cannot eccentrically contract to control the knee extension (motor control problem and the spasticity) at Ic, and hence, knees remain at flexion in stance phase (11). Because the only interest was the relationship between IFA and gait parameters in this study, the physical examinations such as ROM, muscle testing and spasticity measurements were not included. Therefore, the relationship between gait deviations and clinical examinations were not considered.

Unexpectedly, the increase in mean pelvic anterior tilt in stance was found to be significantly different in CPIFA and NIFA groups in our study. However, the decrease in maximum hip extension and the increase in hip flexion in stance were not significantly different among these groups. Therefore the increase in anterior pelvic tilt with double bump pattern seems to be a possible CP effect, which is related with inability to dissociate pelvic from hip motion because of spastic hip flexors and/or weak hip extensors (11). However, both groups have decreased hip extension and increased hip flexion, even though NIFA group has no hip flexor tightness, which seems to be a possible cause of IFA. The same effect can be seen in the decreased knee extension in stance phase, which was not significantly different in CPIFA and NIFA, although, due to no significant difference with the TD group, it is very hard to conclude the solid relationship with IFA. To reach to a substantial conclusion, the number of subjects should be increased. However, it is rare to see these children in clinic. Therefore, the number of subjects in NIFA group was not large in this study. Because of the difficulty in finding subjects of similar age range as NIFA group in clinics, the number of subjects for the CPIFA and TD groups is limited. Additional gait parameters such as time of peak values in gait cycle, coronal plane moti-

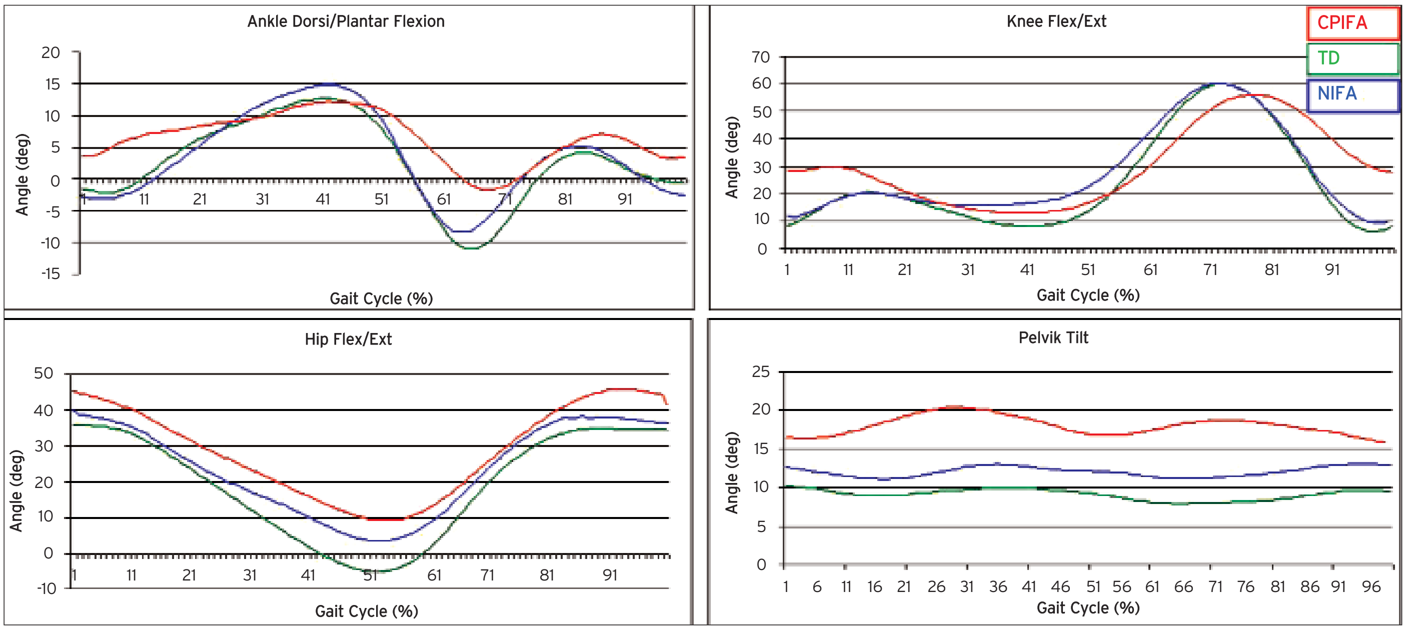

Figure 2. Kinematics of TD group which is represented as green line, CPIFA (spastic diplegia with increased femoral anterversion) is red line and NIFA (neurologically intact children with increased femoral anterversion) is blue line.

ons can be included for future studies. In order to find new solid relationships between IFA and gait deviations, spastic diplegic group with no IFA and physical examination results could be also added into the study. These parameters may be considered as the limitations of the study.

Our kinetic results showed that in CPIFA group, the decreased plantar flexion moment in terminal stance was significantly different from that in TD and NIFA groups (Table 2). There was no significant difference between NIFA and TD groups with regard to this parameter, therefore it may be considered as a possible

Table 1. Means, standard deviations, median, minimum and maximum values are shown for kinematic parameters (angles).

	TD mean°±SD min-max median	NIFA mean°±SD min-max median	CPIFA mean°±SD min-max median
Ankle			
ROM	24.67°±5.46 16.11-32.63 26.22	24.17°±3.25 19.86-27.87 24.62	17.60°±7.22 £ 8.58-30.14 18.04
Pk PF	-11.57°±5.32 -19.12-(-0.78) -13.46	-8.96°±5.02 -17.07-(-4.72) -7.49	-3.82°±9.19 £ -20.74-12.54 -4.03
Pk DF	24.67°±5.46 16.11-32.63 26.22	15.20°±4.41 10.20-21.49 15.19	13.77°±7.52 5.18-31.30 13.08
DF at IC	-1.47°±4.73 -9.86-7.61 -2.23	-2.85°±3.20 † -5.26-3.09 -4.42	3.46°±5.90 £ -4.80-12.75 1.38
Knee			
ROM	56.01°±4.55 50.75-66.86 56.56	53.10°±2.09 50.11-56.10 52.81	46.54°±11.05 £ 32.67-67.42 45.99
Pk Flex	60.22°±8.21 41.33-70.33 62.08	60.81°±3.51 55.21-64.68 61.48	57.17°±7.86 46.32-67.66 56.23
Pk Ext	4.21°±7.29 -9.44-18.24 5.64	7.714°±1.77 5.09-10.24 7.94	10.63°±9.60 -2.05-23.55 7.47
Knee Flex at IC	8.77°±5.50 -3.47-19.20 10.05	11.03°±5.23 † 5.09-19.70 9.38	28.31°±5.38 £ 18.81-36.85 29.18
Hip			
ROM	43.02°±7.84 30.63-61.60 43.12	39.15°±7.21 2.83-48.18 32.42	40.34°±9.37 24.41-53.19 38.77
Max Flex	37.81°±8.65 12.78-49.42 37.50	42.21°±5.11 34.69-50.02 41.88	48.35°±6.91 £ 32.16-57.00 49.70
Max Ext	-5.20°±10.21 -24.50-13.42 -5.99	3.05°±4.71 -5.08-9.58 3.55	8.13°±8.75 £ -3.58-25.16 8.55
Pelvic tilt			
ROM	3.95°±2.86 1.67-12.23 2.83	3.68°±0.82 2.77-4.87 3.64	6.358°±4.97 2.48-18.99 4.66
Mean in St	9.38°±5.18 -1.42-17.06 10.12	12.02°±2.57 † 8.12-15.76 12.21	17.79°±5.73 £ 11.48-28.094 18.10

*Was used for significant difference between TD and NIFA, † for significant difference between NIFA/CPIFA, £ for significant difference between TD/CPIFA groups. ROM: Range of Motion, IC: Initial contact, Pk: Peak, Max: Maximum, DF: Dorsi flexion, PF: Plantar flexion, Flex: Flexion, Ext: Extension, St: Stance

Table 2. Means, standard deviations, median, minimum and maximum values are shown for kinematic parameters (angles).

	TD mean±SD min-max median	NIFA mean±SD min-max median	CPIFA mean±SD min-max median
Ankle			
Pk PF M 0–30% GC	0.56±0.24 -0.45-(-0.002) -0.13	0.43±0.21 -0.33-0.38 -0.09	0.68±0.22 -0.12-0.12 -0.02
Pk PF M 30–60% GC	1.20±0.28 0.36-1.60 1.25	1.13±0.26 † 0.74-1.62 1.16	0.84±0.24 £ 0.42-1.18 0.86
Pk PW abs. 0-30% GC	-0.39±0.22 -0.86-(-0.08) -0.33	-0.40±0.22 -0.94-(-0.16) -0.35	-0.85±1.30 -4.03-(-0.11) -0.42
Pk PW gen 30-60% GC	2.24±0.65 0.90-3.29 2.23	2.62±0.77 † 1.43-4.03 2.91	1.37±1.26 0.36-4.13 0.84
Knee			
Pk KE M 0–30% GC	0.25±0.21 0.009-0.93 0.23	0.27±0.20 0.34-0.50 0.14	0.22±0.14 -0.01-0.45 0.20
Pk KF M 30–60% GC	-0.27±0.21 -0.59-0.01 -0.29	-0.08±0.09 -0.24-0(-0.05) -0.12	-0.18±0.29 -0.77-0.12 -0.10
Pk KE M 30–60% GC	0.12±0.11* 0.005-0.34 0.08	0.27±0.19 0.01-0.49 0.25	0.26±0.38 -0.09-1.17 0.20
Pk PW abs. 0-30% GC	-0.40±0.40 -1.49-(0.03) -0.24	-0.26±0.20 -0.32-(0.01) -0.23	-0.59±0.45 -1.39-(-0.16) -0.59
Pk PW gen. 30-60% GC	0.29±0.28 0.02-0.81 0.19	0.06±0.08 0.006-0.28 0.05	0.16±0.16 -0.02-0.45 0.16
Hip			
Pk HE M stance	0.85±0.39 0.21-1.63 0.91	0.93±0.37 0.66-1.61 1.03	0.88±0.57 0.27-1.77 0.72
Pk HF M stance	-0.28±0.17 -0.68-(-0.04) -0.26	-0.27±0.16 -0.59-(-0.08) -0.28	-0.47±0.54 -1.73-0.004 -0.38
Pk PW abs. stance	-0.34±0.29 -1.38-(-0.09) -0.25	-0.28±0.29 -0.28-(-0.05) -0.21	-0.17±0.11 -0.31-0.04 -0.18
Pk PW gen. stance	0.89±0.66 0.16-3.20 0.70	0.84±0.46 0.36-1.11 0.78	0.90±0.85 0.18-2.34 0.53

*Was used for significant difference between TD and NIFA, † for significant difference between NIFA/CPIFA, £ for significant difference between TD/CPIFA groups. P<0.05 was considered as significantly different. PF: Plantar Flexion, DF: Dorsiflexion, KE: Knee Extension, KF: Knee Flexion, HE: Hip Extension, HF: Hip Flexion, GC: Gait cycle, abs: Absorbsion, gen: Generation, M: Moment, PW: Power, Pk: Peak

Table 3. Means, standard deviations, median, minimum and maximum values are shown for kinematic parameters (angles).

	TD mean±SD min-max median	NIFA mean±SD min-max median	CPIFA mean±SD min-max median
Stance time (sec)	669.82±73.21 566.66-805 645	621.14±48.18 545-1197.5 624.28	726.75±140.1 575-925 775
Stance (%)	59.69±1.60 * 57.25-61.83 59.66	72.2±8.83 † 39.23-72.08 56.68	63.02±3.23 £ 59.83-70 63.75
Cadance (steps/min)	107.95±9.83 91.5-124.66 107.33	114.54±6.92 111.8-235 114.50	107.2±17.23 86-132 102.66
Double support (%)	9.48±1.52 7.62-11.83 9.00	9±1.41 † 7.5-16.5 9.05	12.7±3.70 £ 8-19 15.00
Mean Velocity (m/sec)	1.01±0.17 0.74-1.27 1.05	0.99±0.14 † 0.87-2.15 1.05	0.65±0.22 £ 0.39-0.94 0.55

Was used for significant difference between TD and NIFA, † for significant difference between NIFA/CPIFA, £ for significant difference between TD/CPIFA groups. P<0.05 was considered as significantly different. min: minute, m: meter, sec: second.

cause of CP. The weak soleus and prolonged knee extensor activity might be the reason for the diminished plantar flexor moment and the increased knee extension moment at the late stance in children with crouch gait (2).

There is no difference between CPIFA and NIFA groups with regard to the increase in peak knee extension moment, which is the possible cause of IFA. Even though NIFA group had no neurological deficit, the knee extensor moment increased as well as the knee power absorption (Figure 3) in terminal stance, as commonly seen in children with crouch gait (2). Eccentric contraction of knee extensors (three vasti group) without soleus weakness may produce normal ankle plantar flexion moment, but increased knee extension moment. In addition, eccentric contraction of knee extensors may be a part of the coping response mechanism of IFA, which generates an advantage in favor of knee flexors. According to literature femoral anteversion does not change or negligibly changes the rotational lever arm of the hamstrings and adductors (12,13). However, these studies used a deformable model to represent the hip by assuming normal musculoskeletal geometry, while acetabular anteversion, subluxation or dislocation, coxa vara/valga were not taken into account (13). These factors may give some advantages to knee flexors (hip extensors) and cause a compensatory eccentric contraction of knee extensors.

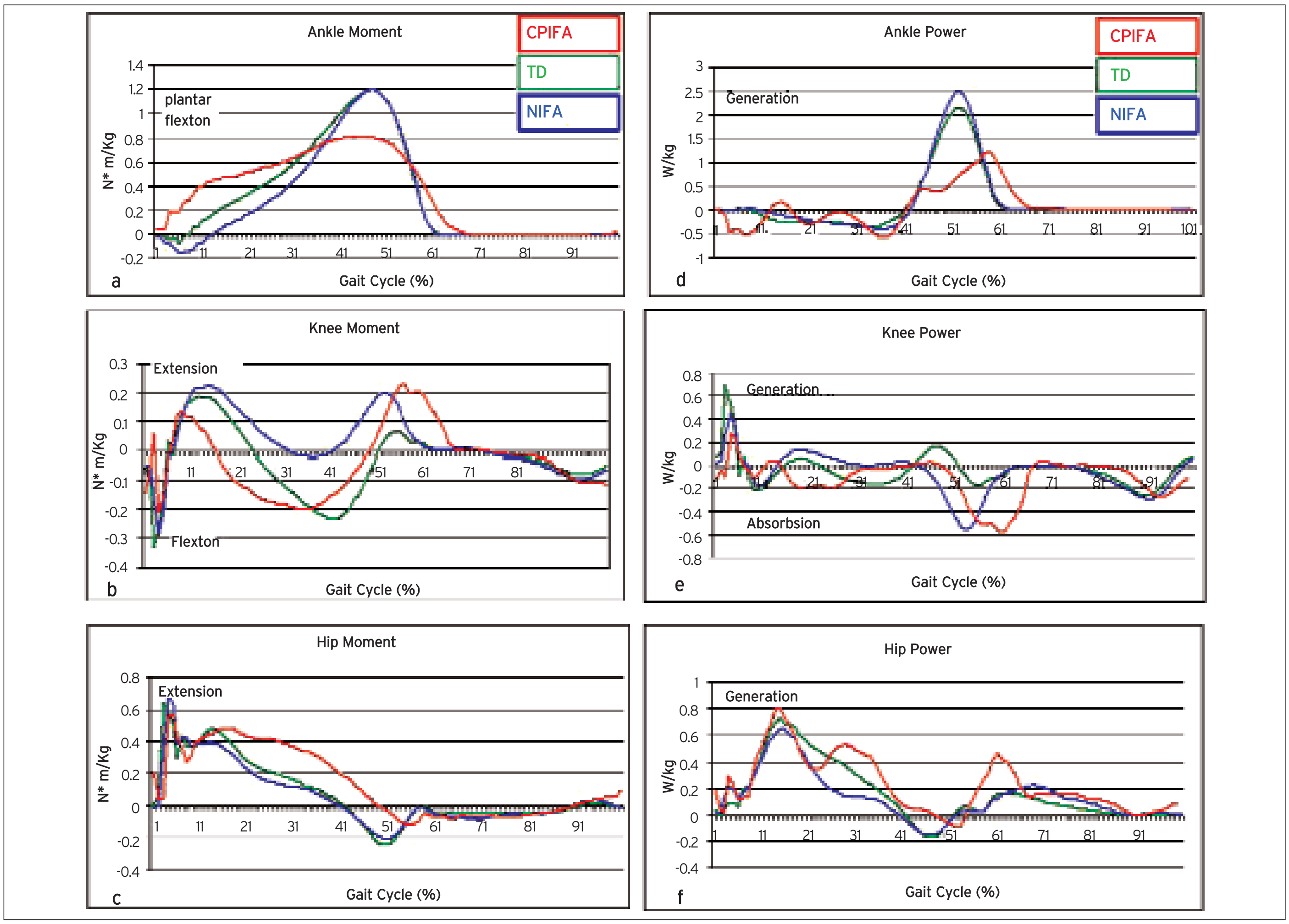

Figure 3. Joint moments (a, b, c) and powers (d, e, f) of TD group which is represented as green line, CPIFA is red line and NIFA is blue line.

The decrease in peak plantar flexion moment in 30–60% of GC seems to be a possible CP effect and it is significantly not related with IFA (Table 2). Because of absence of soleus weakness in NIFA group in contrast with CPIFA, peak plantar flexion moment was normal in this group (Figure 3).

The increased percentage of double support in GC and the decreased mean velocity were found to be significantly different in CPIFA compared to TD and NIFA groups. These parameters may be related purely to CP. These parameters are common in children with CP who have a difficulty maintaining stability during stance and selective motor control (8,2,14).

If only the similar gait deviations between CPIFA and NIFA groups were considered and if the differences with TD group were not considered, the conditioned parameters would be: the decrease in ROM of the knee, hip and ankle, peak plantar flexion, peak plantar flexion moment in early stance, peak knee extension moment in mid-stance, hip flexor moment in late stance and the increase in dorsiflexion angle at the ankle, knee extension moment in late stance, knee power absorption during stance, cadence and stance time. Nevertheless, the primary purpose of this study was to distinguish the gait parameters, which are significantly different in NIFA compared to TD group, as well as the parameters showing no difference in NIFA group compared to CPIFA group. Therefore, only the parameters showing no difference were not taken into account.

There is no study that includes neurologically intact children with increased femoral anteversion in the literature. Therefore, the comparison of our results with the previous works is highly difficult. Carriero et al. (5) investigated the correlations between gait parameters and bone morphologies such as femoral anteversion in typically developing and CP children. However, they found no correlation between femoral anteversion and gait parameters which is not in agreement with our work as well as some previous studies (1,2,14).

For the children with IFA, the rehabilitation team makes a great effort to prevent crouch gait by strengthening quadriceps, plantar flexors and hip extensors. Awareness of the related effects of IFA on gait parameters may help CP children save some time and energy as well as the rehabilitation team by referring the patients to the orthopedists at earlier ages.

This study demonstrated that the increased knee flexion, ankle dorsiflexion at Ic and the increased mean value of pelvic anterior tilt, the decreased plantar flexion moment in terminal stance, the increased double support percentage of GC and the decreased mean velocity have significant relationships with the nature of the cerebral palsy and are not related with the increased femoral anteversion. However, the peak knee extension moment in terminal stance has a significant relationship with IFA, but no association with the nature of CP. Increase in peak dorsiflexion in stance, increase in knee extension moment in late stance are the only parameters which are significantly similar in NIFA and CPIFA groups within our hypothesis. These results support the hypothesis of existence of relationship between IFA and crouch posture. The orthopedic surgeons may consider the priority of planning femoral de-rotational osteotomy in surgical treatment schedule for children with crouch gait due to CP.

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