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Quantitative gait characteristics of children who had successful unilateral clubfoot operation

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Objectives: In this study, we aimed to evaluate the functional results of patients operated for unilateral clubfoot who had good clinical outcome with gait analysis. We also investigated the deviation from the normal, and determined the compensation mechanisms by comparing this data with the unaffected feet and with the feet of healthy children.

Methods: Sixteen children [10 boys, 6 girls; mean age, 6.8 years (range 4-9 years)] with surgically treated unilateral clubfoot and 24 age-matched healthy children were included in the study. Foot length, calf circumference, ankle range of motion, and radiographic measurements were recorded. All time-distance (walking velocity, cadence, step time, step length, double support time), kinematic (joint rotation angles of pelvis, hip, knee, and ankle in sagittal, coronal and transverse planes), and kinetic (ground reaction forces, moments, and powers of hip, knee, and ankle) data were evaluated.

Results: Calf circumference and ankle range of motion of involved extremity were significantly less than the unaffected side ($p<0.05$). Quantitative gait data revealed that children with clubfoot had slower walking velocity (0.75±0.25 m/sec vs. 1.02±0.18 m/sec, $p=0.01$), shorter stride length (0.72±0.23 m vs. 0.91±0.05 m, $p=0.01$) than healthy children group. Affected foot of unilateral clubfoot patients had more toe-in than healthy children (-14.24±21.78° vs. 18.54±7.90°, $p=0.001$). Unaffected side showed increased pelvic excursions and medio-lateral ground reaction forces as well as decreased ankle and hip motion in sagittal plane.

Conclusion: Even asymptomatic well-treated children with unilateral clubfoot may have gait deviations both in the affected and unaffected sides. These alterations may also be the result of the subclinical involvement of the so called healthy foot by disease (clubfoot) as well as the compensatory mechanisms.

Key words: Clubfoot; children; gait; surgical operation; unilateral.

It is possible to evaluate the treatment results and to understand in which extend radiologically and clinically elucidated results correlate with kinematical parameters in idiopathic clubfoot via gait analysis. Some authors reported that even if treated clubfoot has good clinical and functional outcome, gait characteristics evaluated by gait analysis methods are not favorable.[1,2]

There are few reports in the literature evaluating the outcome of operated clubfoot with detailed gait

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analysis methods. Due to different treatment methods, varying age of the patients and clinical results, it is hard to compare and evaluate the results of reports. There are controversies especially concerning evaluation of unilateral cases. Davies et al.[3] showed that the unaffected sides develop important mechanisms of compensation, and proposed that unilateral and bilateral cases should be evaluated separately. In some studies the affected side has been compared with unaffected side,[4,5] and in some healthy children have been used as the control group.[6-8]

In a previous report, we have shown that gait characteristics of patients operated for bilateral clubfeet were different from the healthy children.[8] In this study, we aimed to evaluate the functional results of patients operated for unilateral clubfoot who had good clinical outcome with gait analysis. We also investigated the deviation from the normal and determined the compensation mechanisms by comparing this data with the unaffected feet and with feet of healthy children.

Patients and methods

Patients who had been operated for unilateral clubfoot were assessed at latest follow-up. Patients with no need for orthotics or any other further therapy, and who had excellent International Clubfoot Study Group Functional Rating Scale (ICSG) outcomes were included in the study. There were 17 patients with excellent scores. One patient did not want to participate in the study. Sixteen patients [10 boys, 6 girls; mean age at the time of surgery 9.8 months (range 4-38 months); mean age at last follow-up 6.8 years (range 4-9 years)] and 24 age-matched healthy children were included in the study. Informed consents were obtained from the parents of children.

Preoperatively six patients were classified as benign, three patients as moderate, seven patients as severe according to Dimeglio classification.[9] Posteromedial release described by Turco[10] was performed in 10 patients with severe and moderate deformities and achiloplasty and posterior capsulotomy (including ankle and subtalar joints) were performed in six patients with benign deformity due to under correction after cast treatment. Surgeries were performed by three different surgeons.

All patients had same cast immobilization and orthosis protocol following surgery. A circular above knee cast has been applied for 12 weeks postoperatively. K-wires were removed at 6 weeks postoperatively in cases who had Turco's posteromedial release and the cast was renewed. After the removal of the cast a reverse pronator vitraten mold brace was applied and after the walking age, a shoe having the same properties with the mold was used during day time, and mold was given for nightly use. Parents were trained for the exercise program, which has been performed after the removal of the cast. Compliance to the exercise program was assessed at every follow-up visit. Mean follow-up time was 5 years 6 months (range 3-8 years).

Clinical and radiological evaluation at latest follow-up

In addition to ICSG evaluation by Bensahel et al.[11] bilateral length of the feet, calf circumferences, and ankle range of motion were measured in all children. Foot length was determined on the footprints by labeling the most anterior and posterior points, and measuring the distance between these points. The reference point for the calf circumference was the midpoint between the tibial tuberocity and medial malleolus. Antero-posterior and lateral talocalcaneal angles were measured bilaterally. Kite angles (antero-posterior and lateral talocalcaneal angles) were measured bilaterally.

Quantitative gait analysis

Anthropometrical data including height, weight, leg length, and joint width of the knee and ankle were documented. Fifteen passively reflective markers were placed on standard and specific anatomical landmarks: sacrum, bilateral anterior superior iliac spine, middle thigh, lateral knee (directly lateral to axis of rotation), middle shank (the middle point between the knee and the lateral malleolous), lateral malleolous, heel and forefoot between the second and third metatarsal head. After retro-reflective markers were applied to the subjects, they were instructed to walk barefoot, at a self-selected speed over a 10 m walkway; data capture was completed at this time. The best of data of 3 trials was used for analysis. The trial, in which all the markers were clearly and automatically identified by the system, was determined as best data.

Three dimensional gait data was collected with the Vicon 370 Motion Analysis System (Oxford Metrics, Oxford, United Kingdom).[8] Two force plates (Bertec, Colombus, OH, USA) were used for kinetic analysis. Concomitant videotape recordings of the subjects' gait were also performed. Five cameras recorded (at 60 Hz) the three-dimensional spatial location of each marker as the subject walks. All time-distance (walking velocity, cadence, step time, step length), kinematic (joint rotation angles of pelvis, hip, knee and ankle in sagital, coronal and transverse planes) and kinetic (ground reaction forces, moments and powers of hip, knee and ankle) data were processed using Vicon Clinical Manager software package. Calibration of the motion analysis system was performed daily.

The affected sides of operated patients with clubfoot were grouped as Group CF and contralateral normal sides were named as Group CL. Quantitative gait data of Group CF and Group CL were compared with the age-matched normal database of the laboratory (Group C).

Statistical analysis

Statistical analysis was performed using SPSS for Windows version 11.5. We used independent samples t-test for the comparison of age, height, weight, and time-distance characteristics of Group P and Group C; and chi-square test for the comparison of gender. Paired t-test was used for comparisons of Group CF and Group CL. Statistically significance was set at $p<0.05$.

Results

There were no significant differences in terms of age, sex, height, and weight parameters between clubfoot and control groups ($p>0.05$) (Table 1).

Clinical and radiological evaluation

Mean values of the clinical and radiological measurements (foot length, calf circumference, and ankle range of motion) are presented in Table 2. Foot length in Group CF was shorter than the Group CL, but the difference was not statistically significant ($p>0.05$). On the other hand, calf circumferences and

Table 1

Comparison of the groups in terms of age, gender, weight, and height (mean±SD or n)

	Group CF (clubfoot, n=16)	Group C (control, n=24)	p value
Age (years)	6.8±1.8	8.2±0.9	0.061
Gender (male/female)	10/6	15/9	1.000
Weight (kg)	20.7±2.8	21.5±2.7	0.575
Height (cm)	108±18.4	116.1±5.9	0.146

Table 2

Clinical and radiological measurements of the affected and contralateral sides of operated patients (mean±SD)

	Group CF (clubfoot, n=16)	Group CL (contralateral side, n=16)	p value
Foot length (cm)	16.27±1.95	17.63±1.85	0.109
Calf circumference (cm)	17.91±1.31	20.27±1.55	0.001
Ankle range of motion (°)	41.4±8.4	57.34±7.3	0.023
Antero-posterior talocalcaneal angle (°)	32.63±6.68	35.72±7.87	0.330
Lateral talocalcaneal angle (°)	28.72±11.42	37.18±7.06	0.050

ankle range of motion were significantly lower in Group CF when compared to Group CL (p<0.05). Lateral and antero-posterior talocalcaneal angle values were lower at the affected site, although this difference was not statistically significant (p>0.05).

Quantitative gait analysis

Quantitative gait data of the groups were presented in Tables 3-5. Groups were similar in terms of cadence and stride time whereas Group P was walking significantly slower and with short steps than Group C. Children with unilateral operated clubfeet revealed more anterior tilt than healthy children during stance phase. Hip excursion at terminal stance in the sagittal plane was restricted in Group P for both affected and unaffected sides. Knee valgus values of affected side all over the gait cycle were significantly higher than both unaffected side and healthy children (Fig. 1). Group CF had more toe-in than Group C (-14.24±21.78° vs. 18.54±7.90°, p=0.001). Groups were comparable in terms of kinetic parameters.

Ground reaction forces revealed that second peak of vertical GRF and medio-lateral forces of the affected side were significantly lower than the healthy children (p<0.05) (Table 6).

Discussion

The findings of this study revealed that even well-treated children with excellent clinical outcomes may have gait deviations not only at the affected, but also at the unaffected side. Moreover, operated feet of these children were shorter, calves were atrophic, and ankle range of motion was restricted compared to unaffected sides. In clubfoot patients, feet are

Table 3
Time distance parameters of clubfoot and control groups (mean±SD)

	Group CF (clubfoot, n=16)	Group C (control, n=24)	p value
Walking velocity (m/sec)	0.75±0.25	1.02±0.18	0.01
Cadence (steps/min)	123.45±10.00	136.36±32.38	0.05
Stride time (sec)	0.97±0.07	0.92±0.20	0.05
Stride length (m)	0.72±0.23	0.91±0.05	0.01

Table 4
Total excursion (°) of pelvis, hip, knee and ankle in sagittal, coronal, and transvers planes (mean±SD)

	Group CF (clubfoot, n=16)	Group CL (contralateral side, n=16)	Group C (control, n=24)	p value*	p value†
Pelvic tilt	4.04±2.33	4.98±2.82	2.95±0.91	0.225	0.017
Pelvic obliquity	4.30±1.36	4.58±1.46	5.31±1.99	0.331	0.202
Pelvic rotation	12.64±4.72	13.83±4.72	13.84±5.39	0.425	0.512
Hip flexion-extension	38.82±8.37	38.03±6.89	45.36±4.34	0.633	0.019
Hip abduction-adduction	11.81±3.74	12.54±2.41	9.58±2.47	0.745	0.541
Knee flexion-extension	56.60±7.86	51.15±6.92	52.13±6.93	0.168	0.281
Knee valgus-varus	18.06±8.00	11.36±6.81	13.27±6.45	0.021	0.038
Ankle dorsi-plantar flexion	27.34±11.95	29.07±11.79	28.36±4.40	0.591	0.265
Foot rotation	56.57±17.63	42.59±18.82	35.18±15.19	0.118	0.001
Foot alignment	-14.24±21.78	-8.55±7.76	18.54±7.90	0.193	0.001

*Paired sample t-test for affected side versus contralateral side, †Independent t-test for affected side versus control group.

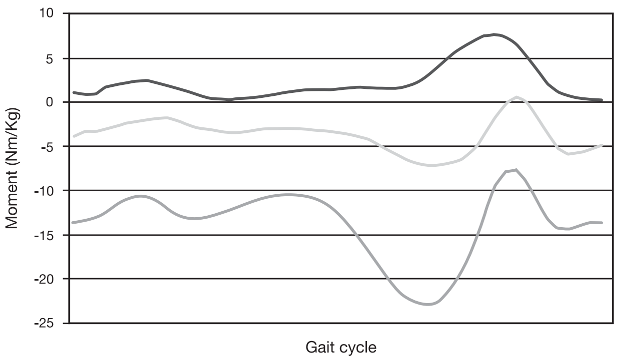

Fig. 1. The negative valgus moment of knee on the affected side. Dark grey line represents normal, light grey represents unaffected side, and grey line represents affected side.

smaller due to congenital hypoplasia of the bones and the calf musculature is also congenitally hypoplasic. These pathologies are mainly caused by congenital reasons.[12,13] The role of casting or other therapies on these pathologies are controversial. Restricted ankle range of motion may be due to the congenital bone and joint pathologies as well as long time casting and operative treatment. One may expect better motion with conservative treatment, but it has been shown that it is almost impossible to have more than 10° of dorsiflexion whichever treatment modality is used.[14,15] The reason for statistically insignificant difference between the Kite angles of the affected and unaffected sides may be the small sample size. In addition, in late evaluations Kite angles are not recommended because these angles are not well correlated with clinical evaluations.[14,16]

In our study we have found that our patient group walked slower than the control group with short steps. Previous studies did not report significant differences in these parameters.[1,3] In these studies gait

Table 5

Peak moments (Nm/kg) of the hip, knee and ankle in sagittal and coronal planes (mean±SD)

	Group CF (clubfoot, n=16)	Group CL (contralateral side, n=16)	Group C (control, n=24)	p value*	p value†
Hip flexion moment	0.90±0.18	0.83±0.19	1.66±1.30	0.768	0.098
Hip abduction moment	0.79±0.27	0.71±0.15	0.67±0.18	0.542	0.076
Knee extensor moment	0.51±0.22	0.67±0.26	0.48±0.18	0.058	0.087
Knee valgus moment	0.38±0.16	0.33±0.15	0.31±0.11	0.112	0.398
Ankle plantar flexor moment	0.71±0.26	0.69±0.35	0.89±0.07	0.823	0.051
Ankle power (watt/kg)	1.19±0.84	1.25±1.17	1.63±0.41	0.498	0.114

*Paired sample t-test for affected side versus contralateral side, †Independent t-test for affected side versus control group.

Table 6

Ground reaction forces (Newton) of the groups in sagittal, coronal, and transverse planes (mean±SD)

	Group CF (clubfoot, n=16)	Group CL (contralateral side, n=16)	Control group (n=24)
Vertical 1st peak	95.6±6.89	97.5±4.5	96±2.88
Vertical 2nd peak	92.2±6.5	96.6±6.59*	98.5±1.69
Lateral GRF	-3.2±4.28	-2.3±6.79*	5.7±1.51*
Anteroposterior GRF	22.8±5.3	22.5±5.30	21.2±4.4

*$p<0.05$ vs. affected side, GRF: Ground reaction forces.

analysis was performed at an older age group. It might be possible that with advancing age compensating mechanisms develop more to obtain a more normal speed and stride length. Hee et al.[2] reported a slower walking velocity in unilateral cases both above and below 5 years of age, but found no significant difference between two groups. In the same study, walking velocity has increased with age in unilateral cases, however it decreased in bilateral cases. This may signify inefficiency of compensation mechanisms in bilateral cases.

Kinematic parameters of both affected and unaffected side showed deviations from healthy children. The data obtained from the healthy side is not comparable to the data from the feet of healthy children. In unilateral clubfoot patients to compensate the affected side, unaffected side showed changes in range of motion. In unilateral clubfoot patient, unaffected extremity showed some changes to compensate the changes on affected site. At the same time, problems of the foot with clubfoot on the stance phase could affect the swing phase of the normal side. It has been found that although pelvic tilt was increased on the unaffected side, tilt was more in clubfoot patients than healthy children for both sides. We may explain excessive pelvic motion on this plane by the upper displacement of the same side pelvis in order to help the weak gastro-soleus muscles for the movement of the foot upwards. This may also cause hypermobility of the knee on the sagittal plane. The foot that could not be thrown out is transferred and raised from the ground by the over flexion of the knee. Foot performs heel strike also with more knee flexion. It has been found that this pelvic rise causes hip to make more passive abduction in frontal plane (Fig. 2). Although it was not statistically significant, extension component of movement of the hip in sagittal plane was less in the patient group (Fig. 3). In their study on 23 unilateral clubfoot patients Karol et al.[1] has reported limited extension on 12 patients. We think that inadequate hip extension may be one of the causes of decreased stride length in our patient group.

In the present study, groups were comparable in terms of kinetic parameters. Although statistically not significant, ankle plantar flexion moment and power values were lower in children with clubfoot

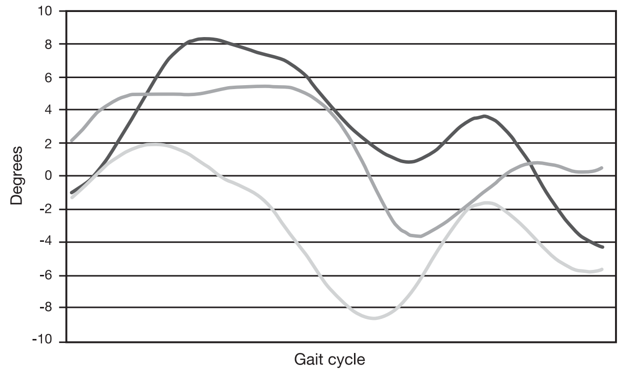

Fig. 2. The hip abduction and adduction movement on the affected and unaffected side of clubfoot and healthy subjects. Light grey line represents affected side, dark grey represents unaffected side, grey represents normal subject. Positive values are for adduction; negative values are for abduction movement.

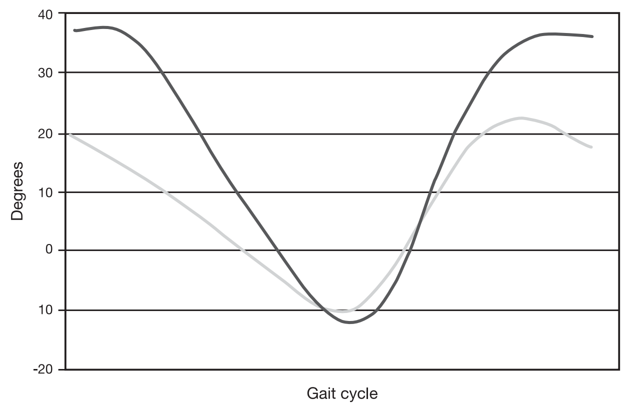

Fig. 3. The hip flexion and extension movement. Dark grey represents control group and light grey represents patient group.

than healthy children. This decreased in force production may be the result of slow walking, weak plantar flexor muscle or the shortened lever arm due to short and inverted foot. The second peak of vertical ground reaction forces, corresponding to push-off phase, was decreased significantly, possibly because of the weakness of triceps surae muscle on the affected side. The same finding has also reported by Hee et al.[2]

We found an increased knee valgus on the affected side of the children with unilateral operated clubfoot patients. We assume this excessive valgus motion was developed for the compensation of the toe-in deformity. By this way, the gravity center that is relocated laterally due to toe-in deformity is replaced to the middle of the foot with valgus movement of the knee. We attributed the mild toe-in on the unaffected side to compensatory mechanisms as well. Walking seems not to be possible without this compensation. Karol et al.[1] has also found knee valgus deformity in 11 children (47%). On the contrary Davies et al.[3] has found increased varus motion in both bilateral and unilateral cases, but did not bring any explanation for this finding.

As a conclusion, though clinical and radiological assessments showed successful results and were accepted as well-treated regarding conventional assessment methods, the quantitative gait parameters of the children with operated unilateral clubfoot revealed abnormal patterns. These children tend to compensate the abnormalities of foot and ankle by gait changes in more proximal segments. Additionally, in unilateral clubfoot patients the gait parameters obtained from contralateral foot are also different from normal child. These alterations may be the result of the subclinical involvement of the so-called healthy foot by disease (clubfoot) as well as the compensatory mechanisms. Future studies with broader series, longer follow-up, and repeated gait analyses may reveal future functional limitations caused by these abnormalities present throughout the lower extremity.

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