Dynamic foot movement in children treated for congenital talipes equinovarus

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The aim of this study was to define objectively gait function in children with treated congenital talipes equinovarus (CTEV) and a good clinical result. The study also attempted an analysis of movement within the foot during gait. We compared 20 children with treated CTEV with 15 control subjects. Clinical assessment demonstrated good results from treatment. Three-dimensional gait analysis provided kinematic and kinetic data describing movement and moments at the joints of the lower limb during gait. A new method was used to study movement within the foot during gait. The data on gait showed significantly increased internal rotation of the foot during walking which was partially compensated for by external rotation at the hip. A mild foot drop and reduced plantar flexor power were also observed. Dorsiflexion at the midfoot was significantly increased, which probably compensated for reduced mobility at the hindfoot. Patients treated for CTEV with a good clinical result should be expected to have nearly normal gait and dynamic foot movement, but there may be residual intoeing, mild foot drop, loss of plantar flexor power with compensatory increased midfoot dorsiflexion and external hip rotation.

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After early conservative or surgical treatment, children with congenital talipes equinovarus (CTEV) are periodically reviewed and reassessed. Residual and recurrent deformities or overcorrection are potential problems which may require further treatment. The evaluation of children treated for CTEV includes clinical and radiological examination as

well as assessment of function, level of pain and patient satisfaction.^{1,2} Functional assessment is usually based on questionnaires and does not include objective measurements of the performance of the foot during gait or other physical activities. As a result, the indications for further treatment in patients with recurrent or residual deformity are not clearly defined.

Several previous attempts have been made to assess objectively the function of children treated for CTEV using gait analysis. Early publications presented only limited aspects of gait analysis.^{3,4} More recent studies show consistent abnormalities in the gait of children treated for CTEV, including reduction of the range of movement at the ankle and of the power of the plantar flexors during walking.⁵⁻⁹ To our knowledge, no previous study has compared the functional performance of children with treated CTEV and a good clinical result with that of normal children. Such a study would define the function during gait of children with CTEV who score high on clinical evaluation. It would therefore set an objective standard for the optimal function in treated CTEV.

Routine methods of gait analysis consider the foot as a rigid structure with no relative movement between its anatomical structures. Most methods only use dorsiflexion and plantar flexion at the ankle as well as rotation of the foot in relation to the tibia. It is known, however, that one of the major problems with surgical treatment and, particularly, repeated treatment of CTEV is residual stiffness within the foot.¹⁰ A method of gait analysis appropriate for the study of CTEV should therefore include a satisfactory means of studying movement within the foot during gait.

In our study gait analysis was used to evaluate children with treated CTEV and a good clinical result. The latter was defined by using foot assessment in a group of children in whom no further treatment was indicated. Our aim was to assess gait function in these children and movement within the foot objectively.

Patients and Methods

Patients with previous surgical treatment of CTEV are usually followed up until skeletal maturity at our hospital in the Children's Clinic. Patients between the ages of six and 16 years who had had previous surgical treatment for CTEV

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Fig. 1a

Fig. 1b

Photograph (a) showing the preparation of the patient for obtaining gait data to study movement within the foot. The skin markers are positioned on anatomical landmarks and their trajectory during gait captured by infrared cameras. The computer model used for this purpose considers movement between the hindfoot and tibia and between the forefoot and hindfoot. The midfoot is represented by a complex joint linking the forefoot with the hindfoot as shown diagrammatically (b).

and were not awaiting further treatment, were invited to participate in the study. A total of 22 patients was recruited consecutively through the clinic and informed consent for participation in the study was obtained from their parents or carers. The local Ethics Committee granted approval for the study.

Two patients were excluded because of insufficient data from their gait analysis, leaving 20 children in the study. There were five girls and 15 boys with a mean age of 9.8 ± 2.3 years (6.9 to 14.6). Of the 12 patients with unilateral CTEV, in three it was on the left side and in nine on the right. There were eight patients with bilateral CTEV in whom we studied only the more severely affected foot.

All patients were treated early under the care of the senior author (MKDB) using a standard protocol. Treatment

included stretching and casting up to the age of three to six months. At that stage patients were assessed clinically and radiographs of their feet obtained. A decision was then made as to whether or not surgical treatment was indicated.

The operation undertaken was a stepwise release of posterior, medial and lateral structures of the foot, as required. The Cincinnati incision was used. Postoperatively, moulded plaster casts were applied for two to three months. Night splintage continued if forefoot adduction and/or supination persisted. Additional procedures were carried out in later years if clinically indicated.

All patients in the study had undergone early surgery. Ten had also undergone additional procedures which included transfer of the tendon of the tibialis anterior in six and repeat posteromedial release in four.

The 15 normal control children were recruited through advertisements at our hospital and local schools. They were not known to have any musculoskeletal or neurological abnormalities. There were six boys and nine girls with a mean age of 10.7 ± 1.8 years (7.7 to 13.1).

Clinical evaluation. For the clinical assessment of the patients' feet we used the protocol described by Bensahel et al.¹ This includes evaluation of passive movement of the foot, muscle strength and posture in the resting position. It also includes scoring of radiographs of the foot according to bone alignment. Radiographs obtained for clinical indications within 12 months from the study were used for this purpose. Finally, the protocol included scoring based on the subjective observation of gait.

Functional rating was carried out using the protocol of Laaveg and Ponseti.² This includes a patient and parent-based questionnaire on the level of satisfaction with the result of treatment, function and levels of pain. It also includes the observer's scoring of heel position, passive movement of the foot and observation of gait.

Gait analysis. All children walked at their self-selected walking speed along a 10 m walkway. For routine clinical gait analysis we used a Vicon Motion Capture system and processed using Plug in Gait Modelling Software (Vicon Motion Systems Ltd, Oxford, UK) based on the protocol described by Davis and DeLuca.¹¹ Temporal parameters of gait included speed, cadence, stride and step time and length as well as single and double-limb support times. Kinematic data, the position and movement of the pelvis, hip, knee and ankle in the sagittal, coronal and transverse planes were recorded in graphic representation. Kinetics, three-dimensional moments and powers around the joints of the lower limb were obtained using two force platforms (AMTI, Newton, Massachusetts). Three representative gait cycles were used for the kinematic and kinetic analysis. We compared the data collected with those obtained by the same method from the 15 normal control subjects.

In addition to the routine gait analysis, we obtained information on movement within the foot based on a method which was developed and evaluated for this purpose (Fig. 1).¹² We studied the movement of the hindfoot in rela-

Fig. 2a

Fig. 2b

Fig. 2c

Diagrams showing transverse plane kinematic graphs of hip rotation, foot adduction and foot progression. The vertical line separates stance from the swing phase of gait. The normal range is represented by the shaded area. The patient's performance is represented by the solid line. Foot adduction is increased throughout the gait cycle. Compensatory external hip rotation is observed. The resulting foot progression is internal to normal, indicating that the patient has an intoeing gait pattern.

Table I. Parameters (mean $\pm$ SD; degrees) of gait analysis showing significant differences between 22 children treated for CTEV and 15 control subjects

	CTEV	Control group	p value
Range of ankle movement	27.32 $\pm$ 5.27	34.42 $\pm$ 5.44	<0.001
Maximum hip internal rotation	2.62 $\pm$ 5.71	6.48 $\pm$ 5.93	0.027
Hip internal rotation	-4.23 $\pm$ 4.06	-1.80 $\pm$ 3.22	0.031
Foot adduction	6.33 $\pm$ 9.26	0.90 $\pm$ 6.25	0.017
Foot progression angle	-2.77 $\pm$ 7.01	-7.13 $\pm$ 5.82	0.021
Maximum ankle plantar flexion moment	1.09 $\pm$ 0.21	1.47 $\pm$ 0.20	<0.001
Range of ankle plantar flexion moment	1.17 $\pm$ 0.24	1.64 $\pm$ 0.25	<0.001
Maximum ankle power	2.42 $\pm$ 0.62	4.44 $\pm$ 1.42	<0.01

tion to the tibia in three planes. We studied the relative movement between forefoot and hindfoot and also considered the relative movement between the forefoot and the tibia. Using three representative gait cycles, we compared the kinematic data relating to movement within the foot with data from the 15 control subjects. The reliability of this method has been evaluated.¹² For routine kinematic and kinetic analysis we used data from both lower limbs of the 15 control subjects which provided a normal database. For the kinematic analysis of movement within the foot we used data from the dominant foot of the control subjects only.

Statistical analysis. We initially carried out a qualitative assessment of deviations of gait of more than one standard deviation from normal. Following this, all parameters of the gait and ranges of movement of joints during gait as well as their mean values and related moments were compared between the children with CTEV and the control subjects. We used the paired Student's *t*-test for this purpose and considered significance to be $p < 0.05$. Finally, a regression analysis identified any influence of age on dorsiflexion of the ankle or foot progression.

Results

Clinical evaluation. The mean score on clinical evaluation using the protocol of Bensahel et al¹ was 10.8 (3 to 20). The

possible scoring on this protocol is between 0 and 50 with 0 being normal and 50 the most severely affected foot. Our patients were therefore within the top 40% of this score.

The radiological score which is included in this evaluation also confirmed good objective results. Our patients scored a mean of 1.7 ± 1.2 points on a scale between 0 and 10, where 0 is normal.

The mean functional assessment score, according to the method of Laaveg and Ponseti,² was 78.5 (48 to 98). The possible score on this protocol is between 0 and 100 with 100 being normal. According to this subjective evaluation, four patients had excellent results, seven good, five fair and four poor.

Gait analysis. Temporal parameters of gait in the CTEV group were not significantly affected.

Most kinematic data were within normal limits. There were only few deviations from the normal controls in the range and pattern of movement of the joints of the lower limb. As measured by conventional gait analysis, 12 of the patients had increased adduction (internal rotation) of the foot during gait. Nine of these had compensatory external hip rotation, but 11 had a measurable internal foot progression angle during walking (Fig. 2). Furthermore, seven had mildly increased plantar flexion of the ankle during the swing phase of gait, i.e. a mild foot drop. Statistical analysis showed that the CTEV group had significantly increased

Fig. 3a

Fig. 3b

Kinetic graphs showing ankle plantar flexion moments and power. The plantar flexion moment is reduced, indicating reduced strength of the plantar flexors. The ankle power is markedly reduced in terminal stance, indicating reduced push-off.

Table II. Details of the gait parameters (mean $\pm$ SD; degrees) showing movement within the foot. Several forefoot parameters showed significant differences between the 20 children treated for CTEV and the 15 control subjects. The hindfoot data showed trends towards reduced movement but no significant differences

	CTEV	Control group	p value
Mean forefoot dorsiflexion (relative to hindfoot)	3.53 $\pm$ 4.66	-1.50 $\pm$ 5.51	0.008
Mean forefoot dorsiflexion (relative to tibia)	3.62 $\pm$ 4.67	-1.46 $\pm$ 5.55	0.008
Minimum forefoot adduction (relative to tibia)	12.47 $\pm$ 11.30	1.44 $\pm$ 5.90	0.001
Mean forefoot adduction (relative to tibia)	16.55 $\pm$ 11.26	6.25 $\pm$ 5.95	0.002
Range of hindfoot dorsiflexion	14.57 $\pm$ 5.28	16.93 $\pm$ 4.04	0.144
Mean hindfoot inversion	2.70 $\pm$ 5.36	1.28 $\pm$ 4.13	0.382

external hip rotation, internal foot progression and foot adduction during gait (Table I).

Kinetic data showed reduced plantar flexion moment at the ankle in 17 patients. Ankle power at terminal stance (during push-off) was reduced in five patients (Fig. 3). The statistical analysis showed that these differences between the two groups were significant (Table I).

Data indicating movement within the foot showed a reduced range of movement of the hindfoot in relation to the tibia in seven patients. Only six had a reduced range of movement between the forefoot and the hindfoot, i.e. a stiff midfoot. The remainder had normal or increased mobility at the midfoot. Nine feet had adduction of the forefoot and another eight internal rotation of the hindfoot, both producing internal rotation of the forefoot in relation to the tibia.

Statistical analysis of the foot kinematic data showed a significantly increased range of movement of the forefoot in relation to both the hindfoot and the tibia. Forefoot internal rotation in relation to the tibia was also significantly increased. There was a trend towards a reduced range of movement of the hindfoot and increased hindfoot inversion, but this was not statistically significant (Table II).

Regression analysis showed no significant influence of the age of the patient on dorsiflexion of the ankle. There was a trend towards improvement, i.e. more external foot progression with age ($p = 0.052$).

Discussion

It has been suggested that revision CTEV surgery should address a specific problem or deformity "that has become unacceptably symptomatic producing functional problems and pain".¹⁰ It has also been widely accepted that the decision for repeated surgery should be balanced against the additional stiffness within the foot and the further loss of muscle power which surgery produces.¹⁰ Indications for the treatment of recurrent or residual CTEV deformity are therefore not clearly defined. The lack of any objective method for the assessment of function in treated CTEV adds to this problem. Early studies of treated CTEV using gait analysis were limited because of the technology available at the time. Brand et al³ found little useful information in studying the centre of pressure path in treated CTEV during walking. Yngve⁴ found internal foot progression during gait in more than half of the patients with treated CTEV whom they studied, which is in agreement with the findings of our study.

Asperheim et al⁵ used gait analysis to study indications for treatment and planning in patients with residual/recurrent CTEV deformity referred for further management. In their patient population, they found increased intoeing because of foot adduction, tibial torsion or femoral anteversion. In some patients, pelvic rotation was used to compensate for unilateral intoeing.

Aronson and Puskarich⁶ used testing of treadmill performance and isokinetic power measurements to assess the results of treatment in CTEV. They found diminished isokinetic strength of the plantar flexors but normal endurance performance. No kinematic data were provided in this study.

Karol et al⁷ presented a study of 23 children at a mean follow-up of ten years after surgical treatment of unilateral CTEV. All were asymptomatic with a good result from treatment. Clinical examination was undertaken, but no clinical or functional scoring was available. Using gait analysis to study the functional outcome, they found disturbed ankle movement and reduced strength of the plantar flexors during gait. They also commonly found quadriceps weakness in the normal limb and genu valgum and/or hyperextension on the affected side among their patients. Another interesting finding of the study was that of abnormal electromyographic activity of tibialis anterior in children referred for intoeing. The authors stipulated that this abnormal activity could be responsible for the observed internal rotation of the foot. A weak point of the study was the comparison of their CTEV gait analysis with that of the contralateral leg, which was presumed to be normal. It is widely accepted that unilateral leg abnormality can induce bilateral leg deviations during gait because of the compensation mechanism observed in our study in which distinct abnormalities on the 'normal' side of the unilateral CTEV patients were seen.

Alkjaer et al⁸ studied nine adult patients with previously treated CTEV using video and force plates. No three-dimensional kinematic data were available. They found weakness of the plantar flexors and increased moments around the hips and knees which they interpreted as compensations.

Davies et al,⁹ studying children with treated CTEV (both unilateral and bilateral) compared them with normal and age-matched children. They found weak ankle plantar flexors and a reduced range of movement of the ankle. Furthermore, they detected abnormal moments around the knees and hips which they attributed to the abnormalities of the ankle and foot.

Patients with a good clinical result evaluated by an established protocol were not included in any of these studies. Neither did they study movement within the foot, i.e. relative movement between the different anatomical structures.

In our study, clinical scoring based on the protocol of Bensahel et al¹ demonstrated satisfactory results after treatment. None of the patients included in the study was awaiting further treatment. Our patients scored lower on the protocol of Laaveg and Ponseti.² This could be explained by the strong subjective element of this scoring system in

which the patients' and families' expectations from treatment are expressed. The functional scoring of our patients compares favourably with that of Davies et al⁹ who found fair and poor results in 41% and 53%, respectively, in their patients using the same scoring system. Finally, pain scoring on the Laaveg and Ponseti scale was invariably high for our patients, indicating that pain was not a significant problem.

A formal preoperative classification of the severity of the deformity of the foot was not used in our study. It was therefore not possible to compare the preoperative severity of the deformities.

Our study showed no abnormalities in patterns of movement or moments and powers around the hips and knees during gait. This was the case with patients treated for both unilateral and bilateral CTEV and disagrees with some previous studies which identified abnormal kinematics and kinetics around proximal joints.^{8,9} This could be explained by the fact that all our patients had a good clinical result and a milder residual deformity of the foot which did not influence the movement and biomechanics of more proximal joints.

Residual internal foot progression (intoeing gait) is a recognised clinical problem identified by previous studies and confirmed by ours. Gait analysis can be useful in clarifying whether the rotation occurs at the level of the hip, knee or foot. It can therefore show if any femoral anteversion and/or tibial torsion contribute to the rotational malalignment. Furthermore, our study of movement within the foot demonstrated that internal rotation can occur at two separate levels. It can involve hindfoot internal rotation in relation to the tibia or adduction of the forefoot in relation to the hindfoot. Finally, our study showed that many patients use external rotation at the hip to compensate for the intoeing. Despite that partial compensation, intoeing persisted in approximately half of the patients.

The most consistent abnormal finding in our study, as in previous ones, was the reduced plantar flexion moment at the affected ankle. This implies that the normal force exerted at the heel by the plantar flexors is reduced. The power generated at the ankle during push-off was significantly reduced in the CTEV group.

This is the first CTEV study to apply a method of gait analysis which could measure movement within the foot which has been previously evaluated for its repeatability.¹² It showed a trend towards reduced movement at the hindfoot, which was not statistically significant. This tendency to reduced dorsiflexion of the foot was also confirmed by routine gait-analysis kinematics and could be interpreted as a mild deviation from normal. Alternatively, it could be argued that the relatively high variation in the measurements of the movements of the foot in children or the limited number of subjects in our study led to this result. Movement between hindfoot and forefoot (i.e. mobility at the midfoot) was significantly increased in our patients. This finding may represent increased dorsiflexion at the joints of the midfoot to compensate for a relatively stiff hindfoot with limited dorsiflexion. This is an important finding since it contradicts

the current clinical impression that surgery invariably produces generalised stiffness in CTEV. Our gait-analysis methodology for studying movement within the foot also showed significant internal foot rotation in the CTEV group because of either forefoot adduction or internal rotation of the hindfoot in relation to the tibia. There was a trend towards increased inversion of the hindfoot which was not statistically significant.

We have shown that patients with treated CTEV and an optimal clinical result should be expected to have a gait with a normal or nearly normal movement in the joints of the lower limb and those of the foot in particular. Despite good clinical results and overall function, residual intoeing, a mild foot drop, loss of plantar flexor power and compensatory external rotation of the hip were the main characteristics of the gait of children with treated CTEV.

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