Assessment of Ilizarov correction of club-foot deformity using pedobarography

A PRELIMINARY REPORT

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Relapsed congenital talipes equinovarus is difficult to assess and treat. Pedobarography provides dynamic measurement of the pressures under the foot, and may be used in the assessment of these patients both before and after operation.

Our findings showed a statistically significant difference in the distribution of pressure across the foot after treatment by the Ilizarov technique.

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Congenital talipes equinovarus (CTEV) is a complex disease ranging from mild correctable to severe fixed deformities which may be resistant to surgical correction.

A good result after corrective surgery is a foot which is free from pain, plantigrade and fits into standard footwear.¹ Patient satisfaction and the function of the foot have also been used as indicators of outcome²⁻⁵ which may include objective assessment by static or dynamic measurements. Patient satisfaction can be assessed by the relief of pain, cosmesis, shoe wear and the use of a questionnaire. It is difficult to produce a sensitive, balanced questionnaire which can be used by children.

Static assessments of the relapsed club foot can be made by clinical examination and analysis of radiographs. Clinical examination is often poorly carried out and recorded, and it is difficult to reproduce consistency between observers. Using radiographs to measure the axis of bones in the

foot can also be difficult since these structures may be severely deformed or absent. The function of the foot can be assessed dynamically by such techniques as gait analysis and pedobarography.²⁻⁵

Patients may describe pain, stiffness and a decreased walking distance. Alterations in the distribution of pressure across the foot may cause pain and the formation of ulcers and callosities.⁶⁻¹³ Various techniques for measuring the pressures across the foot have been described^{4,9,11,12,14} and include pedobarography which allows both static and dynamic measurements. It has been used in the assessment of the outcome after such procedures as arthroplasty of the forefoot and of the knee. Measurements have also been reported on the diabetic and rheumatoid foot, and in patients with plantar fasciitis.⁶⁻⁸

An outcome measure has to be reproducible, suitable for all ages and show a change after treatment. Our study describes the changes seen in pedobarography before and after the treatment of relapsed CTEV using an Ilizarov frame.

Patients and Methods

Patients with idiopathic CTEV and with a mean age of 11 years (3 to 17) were studied prospectively. They had had an average of three (1 to 7) operations for CTEV and had been referred to the Sheffield Children's Hospital with recurrence or persistent symptoms, for consideration of treatment using the Ilizarov technique with a tibial, hindfoot and forefoot construct. The fixator allows gradual correction of all elements of the deformity with a low risk of damage to the skin or neurovascular structures.

In 18 patients (26 feet) pedobarography was undertaken before and in 21 (30 feet) after operation. The mean follow-up was for 12 months (5 to 120).

The pedobarograph which was used has been described by Betts et al.^{9,14} It consists of a glass plate illuminated at two opposing edges by strip lights and covered by a thin, white deformable film across which the patient walks. The light rays are internally reflected within the glass plate, except at points where the film touches the glass. When they are refracted out of the plate and scattered back from the film. On a microscopic scale the film surface is undulating in structure, and increasing pressure applied to the film

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causes these undulations to be deformed into intimate contact with the glass plate. Thus, the greater the pressure which is applied at a given point, the more light escapes from the glass at that site. The result is a continuous grey scale image of the sole of the foot in which intensity is related to applied pressure. The image is viewed by a camera and the resultant signal digitised and stored in a microcomputer system. Calibration is achieved by four vertical force transducers, mounted one under each corner of the glass plate. Frame-by-frame calibration is undertaken by comparing the sum of the output of the force transducer and the integrated pressure (light) output.

The measurements may be made with the patient standing or walking in order to reproduce the pressures exerted on the foot during the gait cycle. The results are produced graphically for each selected area of the foot (Fig. 1). While the patient is walking, the operator can view both the images produced and the patient's gait, and with experience can reliably identify the area of the foot producing the

Fig. 1

The pedobarograph result for a normal foot; the regions of interest including the heel, metatarsal heads and great toe are identified from 1 to 7. The pressure in each area is then plotted graphically against time from heel-strike to toe-off.

image on the plate, in both normal and pathological feet. The change in pressure in each area throughout the gait cycle is recorded against time, as shown in Figure 1. The measurements used were those in the areas corresponding to the first metatarsal head, the fifth metatarsal head and the heel. We considered these areas to be the most affected by CTEV. The peak pressure in each area during the gait cycle and the static pressure on standing were recorded. Figure 2 shows typical results before and after treatment.

A formula was derived to reflect the distribution of pressure across the whole foot in relation to these three areas. First, the distribution in the mediolateral plane was represented by considering the proportion of pressure on the first metatarsal compared with the fifth (1st/5th metatarsal pressure). Secondly, the distribution in the antero-posterior plane was represented as the proportion of the pressure on the heel to that on the front of the foot (heel pressure/ first + fifth metatarsal pressure). The two measurements were then considered together and multiplied.

This formula reflected the distribution of pressure across the whole foot, such that the smaller the value obtained, the closer the distribution is to the fifth metatarsal head and the larger the value obtained, the closer it is to the postero-medial part of the foot (Fig. 3).

Measurements were also taken for the 16 normal feet in the children with unilateral disease.

Student's *t*-test was used to compare the preoperative and postoperative group as well as the static and dynamic measurements.

Results

Peak pressure. The peak pressures exerted for each region were recorded in kPa. The pre- and postoperative peak pressures were compared. Although the standard deviations are large, a statistically significant difference was found between the two groups ($p < 0.005$) with more of the total pressure being distributed over the fifth metatarsal head, and less on the heel and first metatarsal in the preoperative group (Table I, Fig. 4). No statistically significant difference was shown between the postoperative group and the normal feet.

Static measurements. Static pressure measurements were compared before and after operation. No statistically significant differences were found except in the pressure measured at the heel, which was significantly lower ($p < 0.005$) in the preoperative group (Table I, Fig. 5).

Comparison of calculated values. Using the formula described above the preoperative and postoperative values were significantly different ($p < 0.005$) for peak, but not for static pressure (Table II). We then compared the calculations for the dynamic and static state in each group. In normal feet, the results were the same for both. In the affected feet, there was a statistically significant difference ($p < 0.05$) between dynamic and static values both before and after treatment.

Fig. 2a

Fig. 2b

Pedobarograph results a) before and b) after operation. The areas of interest used were the heel (1), first metatarsal (2) and fifth metatarsal (6). The highest pressure from heel-strike to toe-off was taken as the peak pressure for each area. The results (b) show restoration of the normal foot-print when compared with (a) and Figure 1.

Fig. 3

A formula was derived to represent the distribution of load across the foot. A high value indicates that the centre of pressure is posteromedial and a low value anterolateral (illustrated by the arrow).

Table I. Measurements of mean dynamic peak pressure and static pressure in the three areas of interest before and after operation

	First metatarsal	Fifth metatarsal	Heel
Dynamic peak pressure in kPa (SD)			
Normal group	294 (214)	183 (144)	311 (244)
Preoperative group	131 (231)	665 (458)	46 (84)
Postoperative group	261 (360)	334 (402)	249 (235)
Static pressure in kPa (SD)			
Normal	47 (36)	48 (34)	106 (57)
Preoperative group	27 (45)	102 (105)	39 (47)
Postoperative group	45 (72)	66 (78)	125 (138)

Table II. The mean calculated values for peak and static pressures in kPa (SD)

	Peak pressure	Static pressure
Normal	1.43 (1.07)	1.42 (0.96)
Preoperative group	0.11 (0.55)	0.39 (0.85)
Postoperative group	0.88 (1.35)	1.74 (2.63)

Fig. 4

Scatter plot of all dynamic peak pressure values before and after operation. The horizontal line indicates the mean for each area examined.

Fig. 5

Scatter plot of all static measurements of pressure before and after operation. The horizontal line indicates the mean for each area examined.

Discussion

An adequate standardised assessment must achieve two objectives. First, it must be reproducible between observers and institutions and, secondly, give a meaningful indication of severity. A wide range of postoperative protocols has been used to analyse outcome, using clinical and radiological assessment^{1-4,15-18} and several scoring systems have also been described.^{15,19} Cumings et al²⁰ reviewed 46 articles reporting the results of surgery for club foot. They looked at the outcome measures and assessed their reproducibility between observers. Poor results were found when assessing a patient clinically. Slightly better reproducibility occurred with radiological assessment and, not surprisingly, history-taking. Simons¹⁹ suggested that radiological assessment was only reliable and reproducible if radiographs of the foot were taken in a position of maximum correction.¹⁷ Carroll²¹ suggested a simple point scoring system, but the categories were broad and no validation had been per-

formed. Flynn, Donohoe and Mackenzie²² compared two scoring systems described by Pirani and Dimeglio. They found the Pirani score to show less interobserver error than many accepted scoring systems for other disorders. Few scoring systems have been evaluated in this manner, and it was developed for the untreated club foot.

The review of our patients showed that what appeared to be a cosmetically 'good' foot did not necessarily have good function. Patients often complained of pain, stiffness, poor balance and inability to walk long distances, when the cosmetic and radiological outcome appeared to be satisfactory.

Our results show that the pressures under the areas of interest, when assessed dynamically, changed with treatment, and despite large standard deviations the changes were significant ($p < 0.005$). Our static results were less convincing; only the heel area showed a statistically significant difference between the peak preoperative and postoperative pressures. It is common in patients with CTEV to

observe hyperextension of the knee and tilting of the pelvis to allow heel contact with the ground when there is a fixed equinus deformity. This is easier when standing than when walking. Our hypothesis is that although patients can redistribute the pressure across the foot when standing by compensating at the knees, hips and pelvis this may not be possible while walking and suggests that a static examination may not be representative of the changes which occur on exercise. This is further supported when comparing the differences in static and dynamic values in these feet. In the patients with CTEV before and after surgery, the values were significantly different, whereas in the normal feet they were the same.

The calculated value was derived in order to represent the balance across the foot. Balance cannot be assessed by considering individual peak pressure measurements alone.¹⁴ These measurements show the pressure after operation in the fifth metatarsal head to be higher than that in the other areas (Table I). Figure 4, however, shows that this 'balance' is more evenly distributed. Pressure is a representation of load and area (pressure = load/area). The load across the whole foot should remain constant since it is proportional to body-weight. The lateral side of the foot has a larger weight-bearing area than the medial side. If the whole foot is considered, the larger weight-bearing area on the lateral side should be associated with lower overall pressure on this side of the foot and hence a more even balance. The calculated value was therefore used to assess this and showed that the distribution of pressure moved away from the fifth metatarsal head after surgery.

These results, although preliminary, suggest that pedobarographic assessment shows significant changes after treatment, especially with dynamic measurement. It may show subtle changes suggestive of recurrence before problems can be identified on clinical examination. In our series the number of patients was small, but we were able to show statistically significant results. Our study was also short-term. Six patients had a follow-up of less than one year, but even when their findings were excluded the results were the same, with the exception of the change in the first metatarsal peak pressure after surgery ($p = 0.09$).

Pedobarography identifies areas of high pressure under the foot, which may contribute to pain or the formation of callosities. It should be used when assessing patients with symptoms which cannot be explained on clinical examination. A further long-term study is planned to compare prospectively pressure measurements with symptoms.

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