THE FORCES WHICH DEVELOP IN THE TISSUES DURING LEG LENGTHENING

A CLINICAL STUDY

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Axial forces were measured during limb lengthening in a series of ten patients with varying pathologies in order to assess the mechanical characteristics of the distracted tissues and the levels of axial force to which soft tissues are subjected during leg lengthening.

The pattern of force was found to vary according to the underlying pathology. For post-traumatic shortening in adults both the peak and the resting forces rose steadily during lengthening reaching maximum forces of the order of 300 N. Patients with congenitally short limbs developed very high peak forces (in some cases over 1000 N) and also showed large amounts of force relaxation (typically 400 to 500 N).

When very high levels of force were recorded, there was a higher complication rate. In particular, there was a high instance of angular deformity. This occurred because the loads encountered resulted in failure of some of the external fixation frames.

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Recent advances in the techniques of leg lengthening have allowed large increases in limb length to be achieved safely. Much is known about the response of bone to distraction, but little about that of the soft tissues, and the latter often cause clinical problems. Muscles and soft tissues react unfavourably to distraction after the initial length of a limb segment has been increased by more than 10% (Kawamura et al 1968), and it has been shown that leg lengthening in patients with poliomyelitis often leads to further weakening of the muscles (Sofield, Blair and Millar (1958). Deformities may develop insidiously during lengthening in limbs in which there is a congenital abnormality. These include progressive varus of the femur, valgus deformity of the tibia and fixed deformity of the joints adjacent to the lengthened segment. The hip or knee may even dislocate due to the inadequate response of the soft tissues.

Large forces, of over 600 N, have been recorded during the early stages of distraction epiphyseolysis (Kenwright, Spriggins and Cunningham 1990) but, until recently, the forces which are exerted on the soft tissues during callus distraction have been reported for only three patients, all of whom had had infantile poliomyelitis (Wolfson et al 1990). Subsequently, Younger, Mackenzie and Morrison (1994) have reported the forces in three patients undergoing femoral lengthening.

We measured axial forces during leg lengthening in a series of patients with varying types of pathology to assess the mechanical characteristics of the distracted tissues and the levels of axial force to which soft tissues are subjected. This information may be useful for the design of safer leg-lengthening programmes.

PATIENTS AND METHODS

In ten patients undergoing leg lengthening we measured the axial forces throughout the procedure. In eight patients we used callotasis and in two the Wagner technique with immediate distraction (Table I).

Measurement. We used two types of unilateral external fixator, the Dynabrace (Smith and Nephew Richards Ltd, Cambridge, UK) and the Orthofix lengthening fixator (Orthofix srl, Verona, Italy). A precalibrated compression load cell was incorporated within the lengthening mechanism of the fixator at the time of initial application (Fig. I).

We measured the axial distraction force from the load cell before each increment of distraction and again immediately after lengthening, and recorded the amount and frequency of distraction. The increments of lengthening were measured from the calibrated thread on the frame. Each week we measured the total amount of distraction achieved from radiographs on which there was an imposed
scale to confirm that the expected length had been achieved.

Serial radiographs were taken every two weeks during lengthening. Clinical examination of the range of joint movement was recorded and any complications were noted.

RESULTS

Overall pattern of axial tension. Continuous recordings made throughout the day showed that the axial force declined exponentially after each lengthening increment; most of the force relaxation occurred within the first hour after distraction (Fig. 2). Figure 3 shows the distraction forces (peak and resting) measured in a patient who had had poliomyelitis and was undergoing tibial lengthening. In the early stages of lengthening both the peak and resting distraction forces increased with increasing distraction. When distraction was stopped at between 24 and 36 days because of poor joint movement, the force decayed exponentially; on recommencing distraction both the peak and resting forces were below the values previously obtained, indicating that there had been an adaptation of the tissues.

The force pattern varied according to the underlying pathology. In adults with post-traumatic shortening, both the peak and resting forces rose steadily during lengthening, reaching a maximum value of about 300 N (Fig. 4). Patients with congenitally short limbs, however, developed very high peak forces which at times exceeded 1000 N and also had large amounts of force relaxation (typically 400 to 500 N). When particularly high forces developed, distraction was stopped temporarily but other than in the patient described above, this did not lead to a significant reduction in the peak forces (Fig. 4). There was a noticeable difference between the resting forces in the post-traumatic and congenital groups (Fig. 5), but the number of patients was small.

Relationship of force measurements to clinical problems. The force measurements could be related directly to clinical problems. In one patient in whom the osteotomy was tethered, high postoperative levels of force developed which decreased dramatically after further surgery on the osteotomy (Fig. 6). In other patients, as the measured distraction force levels rose, the range of joint movement decreased.

Relationship of force measurements to callus formation. We studied the contribution of ossification of the osteotomy gap to the force readings. The rate of lengthening was taken into account by dividing the increase in force produced with each distraction by the lengthening increment to give a measure of axial stiffness of the limb. High values of
axial stiffness were not always associated with proliferative callus formation. Figure 7a shows the results in a patient undergoing lengthening for congenital shortening using the Wagner technique. There was minimal callus formation at eight weeks after distraction. This radiological interpretation was confirmed at the time of bone grafting when only a thin strand of fibrous tissue was found in the osteotomy gap. This result is compared with that in a patient who had lengthening for post-traumatic shortening and in whom proliferative callus was observed radiologically after lengthening for eight weeks (Fig. 7b). The force readings and stiffness levels recorded for this patient were lower than those from the patient with a poor callus response at the same stages of lengthening (Fig. 8).

**DISCUSSION**

Our study has shown that the axial force of distraction can easily be measured in patients, and the results recorded daily by the patients, both in hospital and at home. The method is repeatable, but some loss of accuracy is likely to occur because of the friction which develops between the sliding components of the fixator.
The disadvantage of the method is its inability to differentiate between the separate resistances of the individual soft-tissue components of the leg which contribute to the overall resistance to lengthening. Wolfson et al (1990) observed an increase in stiffness with time and attributed this to the mechanical properties of collagenous tissue and also to ossification of the osteotomy gap. Our results, however, showed no correlation between the maturity of the callus as seen on radiographs and the force readings of the external fixator. A similar observation has been made by Simpson and Kenwright.

Fig. 7a – Radiograph showing poor callus formation at the osteotomy site eight weeks after distraction had began in a patient undergoing femoral lengthening by the Wagner technique for congenital shortening. Figure 7b – Radiograph showing the formation of external callus at the osteotomy site eight weeks after distraction had began in a patient undergoing lengthening by callotasis for post-traumatic shortening.

Fig. 8
Resistance to distraction or stiffness determined from the force and distraction measurements for the patients undergoing lengthening as described in Figure 7.

Fig. 9
Radiograph showing angular deformity resulting from frame slippage due to a high distraction load. The relationship of the distraction force time is shown in Figure 4.
wright (1993) in a rabbit experimental model.

Aronson and Harp (1994) came to a different conclusion after carrying out an animal study in which the remaining force on the fixator was measured as the various tissues were sequentially divided. They did not, however, measure the gap between the bone ends. If these separated slightly as each structure was divided then the force measured for each tissue would not be the same as that exerted in vivo.

The resistance of the soft tissues reaches a high level in limbs with congenital abnormalities and these levels are found at an early stage of lengthening. Wolfson et al (1990) described the adaptation of the soft tissues to lengthening in their patient with poliomyelitis. This was also seen in our patient undergoing lengthening for poliomyelitis but not in patients with congenitally short limbs although in such patients it may be occurring at a slower pace.

The axial force level which external fixators will tolerate before frame failure, that is the point at which irreversible displacement of the frame occurs, has been measured in laboratory experiments (Chao and Hein 1988; Moroz et al 1988; Simpson et al 1995). If high distraction force levels occur during lengthening, the safe levels for many unilateral frames may be exceeded. Distraction force levels therefore need to be restricted so that there is less risk of failure.

We suggest that axial force levels should be measured during leg lengthening so that the programme of lengthening may be modified to maintain low resting and peak levels. Very high levels of force should be avoided; they may result in frame failure, or cause high compressive forces at joint surfaces which may damage the articular cartilage (Stanitski 1994).

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REFERENCES


Table I. Details of the ten patients undergoing leg lengthening

<table>
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<tr>
<th>Case</th>
<th>Age (yr)</th>
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