STIFFNESS MEASUREMENTS TO ASSESS HEALING DURING LEG LENGTHENING

A PRELIMINARY REPORT

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We describe a technique for measuring the stiffness of regenerate bone after leg lengthening. This allows early identification of slow healing by reference to normal patterns. We determined the time of removal of the fixator from clinical and radiological information independent of the stiffness result.

In a series of 30 leg lengthenings there were no refractures when the tibial stiffness had reached 15 Nm/° or the femoral stiffness 20 Nm/°. Three refractures occurred at lower stiffness values. The technique is simple to perform, will allow a reduction in plain radiography and is recommended for routine postoperative management.

Plain radiography and clinical examination are the usual methods of assessing healing, but ultrasonography and bone densitometry have also been used to develop objective measures of healing, particularly during the early stages (Eyres, Bell and Kanis 1993a,b). Quantified CT is also useful for estimating regenerate stiffness (Harp, Aronson and Hollis 1994).

Direct measurements of stiffness are now used routinely at some centres to aid the management of tibial fractures treated by unilateral external fixation by monitoring healing. It is now accepted that the stiffness required for safe removal of an external fixator on the tibia is 15 Nm/° (Richardson et al 1994).

We aimed to measure the normal pattern of increasing stiffness during leg lengthening by callotasis and to determine objective standards for timing the removal of the fixator.

PATIENTS AND METHODS

We made a prospective study of 24 patients undergoing limb lengthening by callotasis. There were 15 women and 9 men with a mean age of 18 years (13 to 29). Two patients were short in stature and the remaining 22 had leg-length inequality due to various causes (congenital hypoplasia, injury, congenital dislocation of the hip, slipped upper femoral epiphysis, poliomyelitis and sepsis). We performed 30 leg lengthenings, 15 femoral and 15 tibial.

Technique. The technique for the measurement of stiffness involves the temporary removal of the fixator. Clamps are applied separately to each set of pins to attach a goniometer (Penny and Giles, Gwent, UK) for the measurement of angular displacement. The use of spirit levels in each clamp ensures consistency in the plane for both the goniometer and the displacement force.

A force plate is placed at a fixed distance from the distal margin of the regenerate segment. For the tibia, the limb is suspended with the heel on the force plate and a bolster behind the knee (Fig. 1). For femoral fractures, the limb is suspended with the plate behind the knee and a bolster under the buttocks. A displacement force is then applied manually to the regenerate segment while both the displacement angle and force are measured. The displacement angle is kept between 0.5° and 1° for each
assessment. The mathematical product of the force and its moment arm is the applied moment in Newton metres. The stiffness value is the moment divided by the angular displacement in degrees in Newton metres per degree (Nm/°). A series of five measurements is made in the sagittal plane. A hand-held microcomputer is being developed for the calculations.

One month after the fixator had been dynamised, stiffness measurements were made at monthly outpatient follow-up clinics until the removal of the fixator. These measurements were performed by an independent operator, blinded to the clinical and radiological assessments made by the operating surgeon. The surgeon responsible for the patient’s clinical management was not informed of the stiffness reading.

After the removal of the fixator most of the patients who had had tibial lengthening were mobilised weight-bearing in protective gaiter splints and those with femoral lengthening were allowed to walk weight-bearing with crutches until their next review appointment. This was in accordance with the surgeon’s usual clinical practice.

RESULTS
Bone lengthenings were between 30 and 85 mm (mean 48), giving increases of 7% to 36%. The healing index ranged from 31 to 109 days/cm (mean 52.4).

The increase in stiffness was approximately exponential.
and lines of best fit applied to each patient’s data gave the distribution of stiffness curves for femoral and tibial lengthenings (Figs 3 and 4). There were three failures. One patient with Turner’s syndrome had synchronous tibial lengthenings; stiffness values were less than 1 Nm/° after 31 weeks and the bones collapsed when the fixator was removed. After hormone correction and relengthening, healing was satisfactory, the fixators being removed when stiffness reached 15 and 16 Nm/°. In this case, the decision on removal was made as a result of stiffness measurements; the patient had recognised their value and refused to allow removal until the presumed safe level had been reached.

In one hypochondroplastic patient with short stature, there was fracture at the femoral lengthening due to a fall two weeks after removal of the fixator. The stiffness at removal was 19.2 Nm/°. Stiffness measurements at the time of removal of the fixator ranged from 1 Nm/° to 38.9 Nm/° (median 15.4 Nm/° for the tibia and 19.8 Nm/° for the femur). Figure 5 shows that there were no failures when tibial stiffness had exceeded 2 Nm/° and femoral stiffness 20 Nm/°. The 16 end-points for femoral lengthenings include the case of refracture. There were only 14 end-points in the tibial group because one patient was unable to attend for removal of the fixator because of illness, but healing was uncomplicated.

Best-fit plots of the increase in femoral stiffness (Nm/°) with time in 13 patients (15 lengthenings). The upper and lower quartiles are shown.

Best-fit plots of the increase in tibial stiffness (Nm/°) with time in 13 patients (15 lengthenings). The upper and lower quartiles are shown.

Stiffness measurements at fixator removal on clinical and radiological evidence after 30 femoral and tibial lengthenings.
DISCUSSION

Our results show that the stiffness of the regenerate segment rises exponentially with time, and is similar to the pattern of healing seen in tibial fractures (Richardson et al. 1994).

‘Callotasis stiffness’ is defined as the applied moment required to produce an angular deflection of 1°. Stiffness measurements enabled us to produce an end-point for healing of the regenerate segment. This allows the definition of a new variable, ‘healing time’, which is the time from the end of lengthening to the end-point for healing as defined by callotasis stiffness. When stiffness values fall below these end-points at the time of removal of the frame, the healing time can be calculated by extrapolation.

The end-point for healing in the fractured tibia has been accepted as 15 Nm/° (Richardson et al. 1994). For femoral lengthening we would define the end-point as 20 Nm/°, based on one failure at 19.2 Nm/°. Further study of these levels is required for their validation, but their use is supported by the observation that when fixator removal is determined by standard clinical means the median stiffness values are 15.4 Nm/° for the tibia and 19.8 Nm/° for the femur. The higher value for the femur is consistent with its larger diameter and greater loading.

The average healing time in our study for femoral lengthening was 20.6 weeks (SD 7.6) and for tibial lengthening 20.3 weeks (SD 5.0). These healing times are similar despite different stiffness end-points and are independent of the increase in length (r = 0.17). This suggests that healing time may be a better variable than healing index for comparison of different methods of limb lengthening.

In our study the end-points of 15 Nm/° for the tibia and 20 Nm/° for the femur allowed the safe removal of the fixator. These values need not be considered to be prescriptive in all cases, provided that the regenerate segment is protected in some other way if the fixator is removed prematurely.

The healing index of 52.4 days/cm was higher than in most other studies, but the inclusion of patients of short stature and their complications has skewed the result. Our study group was also older than that reported in other series. Green (1991) reported a healing index for adults of 52 days/cm.

From a few stiffness measurements, it is possible to predict a healing time from the plot of stiffness against the logarithm of time. The construction of quartile plots provides easy recognition of deviation from the normal pattern of healing; patients enjoy following their own progress in an easily understandable form (Figs 3 and 4).

The technique is simple and measurement takes from five to ten minutes. It requires little training, is non-invasive and has no adverse effects. It is obvious that some judgement is needed to decide when it is safe to start stiffness measurement, but we have experienced no loss of length or alignment as a result of using the technique. It is more sensitive than plain radiography for the assessment of healing and can reduce the dose of radiation. The apparatus is relatively inexpensive and is reusable, and the method is therefore more cost-effective.

Pin-site loosening did not affect our results because the technique puts very little force through the pin sites, unlike indirect methods of measuring stiffness (Richardson and O’Connor 1993). When loose pins caused concern, the pretensioning of the pins against each other by an elastic band effectively eliminated artefactual movements produced by soft-tissue deformation.

Conclusion. Callotasis stiffness is a direct measure of the ability of bone to function mechanically. The technique can be used to monitor the progress of a patient against the normal patterns of healing for a lengthened femur or tibia and gives a quantifiable end-point. Deviation from the normal pattern allows the early recognition of problems and appropriate intervention, reducing the incidence of complications. We have defined a new variable, healing time, which can be used to compare different studies of limb lengthening.

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REFERENCES


