CONTINUOUS MONITORING OF FORCES DURING TIBIAL LENGTHENING BY DISTRACTION EPIPHYSIOLYSIS

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A leg length inequality of 5 cm was compensated by lengthening of the proximal tibia by distraction epiphysiolysis. During the first 7 weeks of lengthening the distraction force was monitored continuously by strain gauges attached to the extension bars of the external distraction device. The increase in length was 1.25 mm a day. The force registration showed a visco-elastic response of the tissue to distraction. In the first week the distraction force increased up to 791 N. Then lysis occurred, followed by a sudden decrease in force to an average level of 150 N. During subsequent distraction, pain and clinical symptoms could be associated with increasing tension and inadequate stress relaxation of soft tissues. Adjusting the distraction rate decreased the build-up of force in the tissue and ameliorated the clinical symptoms. These results show that force measurements can be clinically useful for appropriately adjusting the distraction rate.

Keywords : distraction epiphysiolysis ; limb lengthening ; distraction force ; tibia.
Mots-clés : épiphysiolyse par distraction ; allongement des membres ; force de distraction ; tibia.

INTRODUCTION

Tibial lengthening by distraction epiphysiolysis has become an accepted method for correction of major lower limb-length discrepancies (7). Gradual traction on the epiphysis will produce lysis. Continued traction will cause lengthening of the limb, thereby stretching soft tissues.

Biomechanical data from distraction epiphysiolysis are limited. Jani (2) measured the force required for distraction epiphysiolysis of the rabbit tibia. Accumulation of tension was registered with a sudden release at the moment of lysis. Monticelli and Spinelli (6) measured the force required for epiphysiolysis of the proximal tibia in 7 patients and in sheep at the time of lysis only. Sprigging *et al.* (8) and Kenwright *et al.* (4) monitored axial forces across the upper tibial growth plate, both in rabbits and patients. These authors showed that the tissue response to controlled distraction was dependent upon both the level of force across the growth plate and the rate of distraction. The authors also observed a build-up of tension and release at the time of lysis. The force pattern after fracture of the growth plate depended upon the underlying pathology. Jones *et al.* (3) recorded the same phenomenon while monitoring epiphyseal distraction forces in children.

Continuous monitoring of forces during tibial lengthening after a diaphyseal osteotomy was reported by Leong *et al.* (5) in 2 patients. The authors pointed out that the magnitude and pattern of forces are greatly determined by the biomechanical properties of the tissues to be lengthened. These biomechanical properties may vary between individuals, necessitating an individual adjustment of the distraction rate to prevent excessive tensile forces. However, complications

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associated with excessive forces may occur without previous clinical symptoms, which may hamper appropriate adjustment of the distraction rate.

In this report a pilot study is presented to investigate if continuous measurement of forces during distraction epiphysiolysis can be helpful to better adjust the distraction rate in tibial lengthening and to reduce the risk of causing excessive tensile forces and associated complications.

METHODS

The patient was a 15-year-old boy with a congenital shortening of the left leg. After previous attempts to lengthen the left femur and tibia by the Wagner method (9) the leg-length discrepancy had gradually increased to 5 cm. Associated deformities of the left lower limb were dysplasia of the hipjoint, a hypoplasia of the anterior cruciate ligament of the knee resulting in a tendency of the proximal tibia to sublux posteriorly, a fixed flexion deformity of the knee of 15°, a fixed equinus position of the left foot of 30° allowing plantar flexion of 60°, and severe hypoplasia of the left fibula.

On roentgenograms the physis of the proximal tibia showed no signs of bony fusion, which according to the recommendations of Monticelli and Spinelli (6) indicated distraction epiphysiolysis to be a method of lengthening.

Distraction device

The distraction device was designed in the Department of Orthopedics of the Utrecht University Hospital and the Department of Technology of th University of Technology of Twente. The design was based on the frames described in detail by Ilizarov and Soybelman (1) and Monticelli and Spinelli (6) (fig. 1). In this version the frame consisted of 3 horseshoe-shaped rings connected by 3 extension bars. A complete turn of the turn-buckles attached to the extension bars resulted in an elongation of 1.25 mm. Skeletal pins of the Hoffmann type were used, consisting of 2 transfixing pins and 3 half-pins.

Measurement procedure

Strain gauges (Micromeasurement, type EA-09-050 AR-120 option LE) were attached to the upper part of the three extension bars in a full Wheatstone-bridge arrangement to measure axial strain. The leads were passed to a central connector on the upper ring of the distraction device (fig. 1), which made it easier to connect and disconnect the patient from the monitoring equipment.

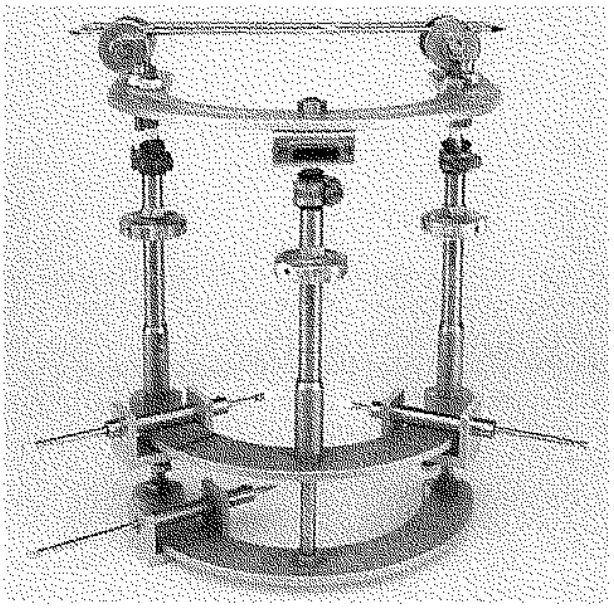

Fig. 1. — The external distraction device developed at the Utrecht University Hospital and the University of Technology of Twente. This design is based on the frames described by Ilizarov and Soybelman (1) and Monticelli and Spinelli (6). In this version, 3 horseshoe-shaped rings are connected by 3 extension bars. A complete turn of the turn-buckles attached to the extension bars results in an elongation of 1.25 mm. Skeletal pins of the Hoffmann type are used, consisting of 2 transfixing pins and 3 half-pins. Strain gauges are attached to the upper part of the outermost extension bars. The central connector can be seen on the central extension bar.

The signals from the strain gauges were transferred to three bridge amplifiers (HP 17403A). The bridge output was continuously monitored on a 4-channel HP 7404A oscillographic recorder. The strain gauge configuration had been tested and calibrated by subjecting the distraction bars to tensile loads up to 100 N.

Forces were measured directly before and after each distraction step during the first 7 weeks following surgery.

Surgical procedure

Under general anesthesia 2 transfixing pins of the Hoffmann type were drilled parallel to each other transversely through the epiphysis of the left proximal tibia,

and 3 half-pins through the tibial diaphysis. One of the half-pins was drilled through the distal fibula to stabilize the ankle mortise as well. The position of the pins was checked roentgenographically. The pins were then connected to the distraction device.

Starting the second day after surgery, distraction was performed 3 times a day, with each distraction increasing the length of the gap by 0.41 mm.

RESULTS

Forces were measured from the fourth day following surgery. Figure 2 shows the pattern of the force registered. Each distraction step resulted in an immediate increase in load followed by gradual but incomplete relaxation.

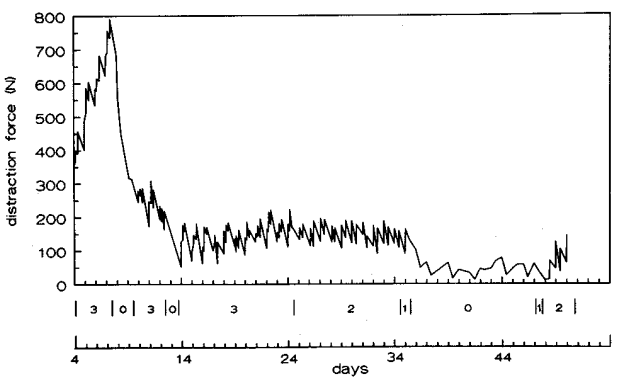

Fig. 2. — Diagram of the force measured from the fourth day following surgery. The numbers directly under the diagram indicate the number of times the turnbuckles were turned each day.

On the fifth day the patient noticed increased resistance when turning the turn-buckles. The next day increasing pain was felt in the left knee region.

On the seventh day the pain became intense and distraction was discontinued. Roentgenograms showed a slight increase in the width of the lateral part of the growth plate of the proximal tibia. On the morning of the eighth day the force required for further distraction was 791 N. In the afternoon the force decreased rapidly and roentgenograms showed complete lysis. The rate of force reduction in the first days after lysis was the most rapid reduction in force observed during the elongation period.

The following two days no further distraction was performed and a continuing decrease in force was measured.

On the ninth day the pain subsided and distraction was resumed. However, the pain increased rapidly and distraction was discontinued again. From the 13th to the 22nd day distraction was continued and some pain was felt on tightening the turn-buckles. Intensive physiotherapy was started. The forces measured subsequently showed a cycle of instantaneous load increase after each distraction followed by a varying degree of stress relaxation.

On the 22nd day movement in the left knee became restricted and some pain was felt. One day later pain and restriction of motion increased significantly. Roentgenograms showed a posterior subluxation of the proximal tibia (fig. 3 left). At that time, the gain in length was 2 cm (fig. 3 right). Under sedation the knee joint was realigned by manipulation with radiographic guidance. The pain disappeared. A removable posterior plaster splint extending beyond the ankle and knee joints was applied to keep the knee in maximal extension and to reduce the risk of recurrent subluxation. The distraction rate was reduced to 0.41 mm twice a day, and training of the quadriceps muscle was intensified.

From then on a regular pattern of increase in force with subsequent relaxation was seen. The mean force remained at a steady level.

In spite of intensive physiotherapy the ankle joint became fixed in a maximum equinus position. Distraction was discontinued on the 34th day and one day later a surgical lengthening of the calcaneal tendon was performed. For the next 2 weeks the wound was allowed to heal and no further lengthening techniques were used ; only forces from spontaneous muscle activity were registered.

After the 2-week period, distraction was resumed at a rate of 2 times 0.41 mm a day, until the desired lengthening of 5 cm was achieved. Again a cycle of instantaneous load increase and relaxation was seen, although at a lower level than before. The force measurement was stopped on the 49th day. The patient was allowed to walk with two crutches.

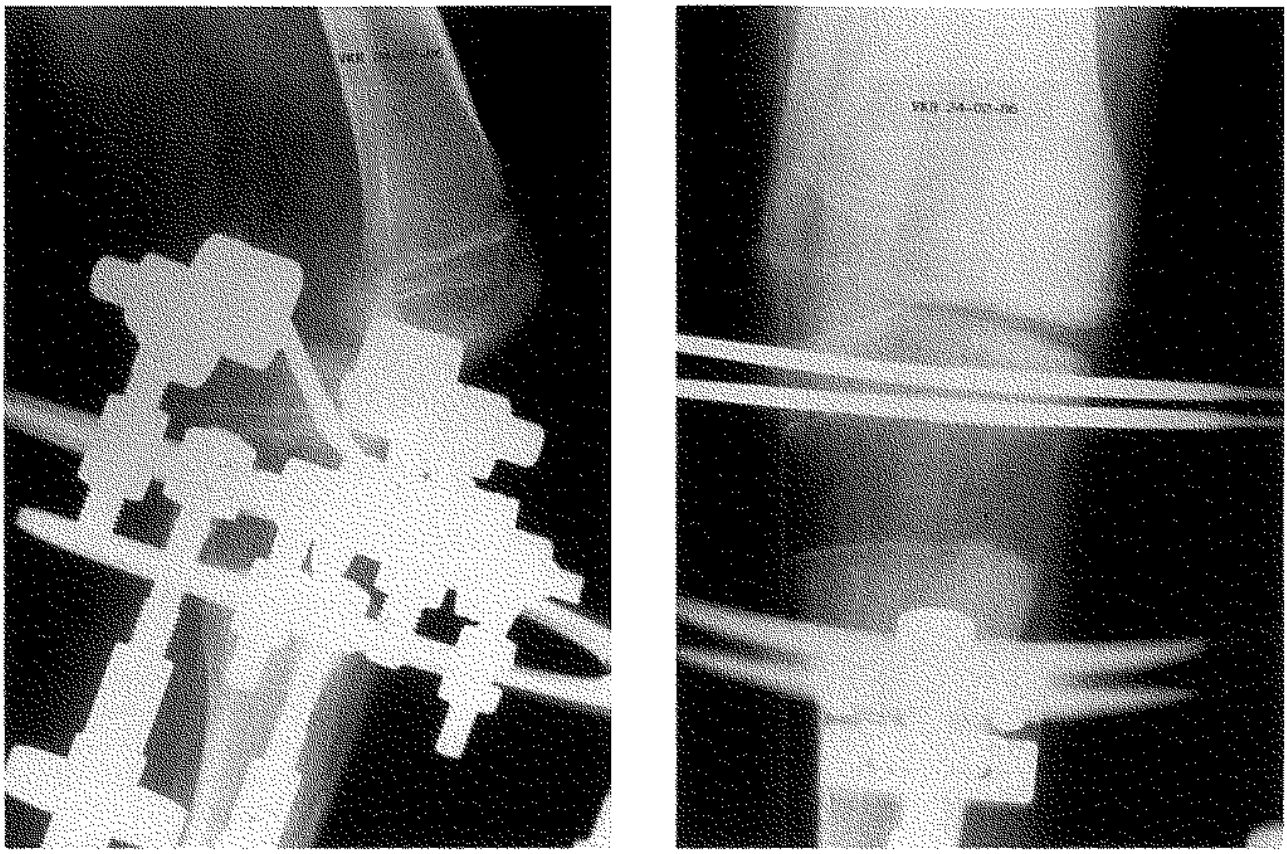

Fig. 3. — Roentgenograms of (left) a lateral view and (right) the anterior view of the knee showing a posterior subluxation of the proximal tibia.

After 11 months the external device was removed, and the patient could walk without any support. Function, alignment, and stability of the knee and ankle joints were equivalent to the preoperative status.

No complications occurred except for removal of one of the distal skeletal pins because of loosening without signs of infection.

DISCUSSION

The force diagram was available only at the end of the distraction period to prevent the data from influencing clinical decisions. This permitted proper assessment of the clinical value of such force measurements.

The pattern of the registered force before lysis showed an instantaneous increase in load after each distraction followed by a varying degree of stress relaxation. This release of tension after load increase has been described by others (2-4, 8), and reflects a visco-elastic response of tissues to distraction forces.

In the present study the force required for complete lysis was about 800 N. Monticelli and Spinelli (6) reported similar values. Kenwright *et al.* (4) recorded a force of about 600 N, and Jones *et al.* (3) a load of 400 N. Forces exceeding 1500 N at the time of lysis were measured by Monticelli and Spinelli (6) in two patients. In both cases complications occurred involving delayed union and an anomalous separation of the epiphysis.

On the ninth day the distraction caused pain, probably because the tension of the soft tissues was still high, as demonstrated by the relatively high level of the forces measured. From the 13th

to the 23rd day the patient showed no clinical symptoms, but the force diagram showed a gradual increase of tension in the soft tissues. Eventually, the increased tensile load resulted in a subluxation of the proximal tibia and complete loss of motion in the ankle joint.

The decision to reduce the distraction rate on the 22nd day was based on clinical symptoms. In retrospect, the increase of tension between the 13th and the 22nd day, indicative of inadequate relaxation of stress, might have served as a warning signal.

Measurement of the distraction forces may help the physician to decide whether to reduce the distraction rate to prevent stress-related clinical symptoms. The pattern of force build-up and subsequent release at the time of lysis in fig. 2 is not different from that reported by other authors. The force recordings reported by Jones *et al.* (3) and Kenwright *et al.* (4) show a similar gradual increase in load later in the distraction phase. It is tempting to speculate that, although not mentioned by these authors, their recordings are also from patients in whom clinical symptoms were actually developing. This may be especially true in Kenwright's study, where the increase in load led to the decision periodically to discontinue distraction.

It should be emphasized that the value of the present study is to show that measurement of forces could alert the treating physician to forthcoming clinical problems. Measurement of forces during distraction epiphysiolysis has passed beyond academic interest. Force measurement can be helpful to increase the safety of tibial lengthening by distraction epiphysiolysis, especially for patients with an enhanced risk of complications from high tensile forces because of concomitant congenital abnormalities.

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SAMENVATTING

P. M. VAN ROERMUND, R. A. J. WIJLENS en W. RENOOIJ. Continuë krachtenmeting bij verlenging van de tibia door distractie epifysiolysis.

Een verschil in beenlengte van 5 cm werd gecompenseerd door verlenging van de proximale tibia met behulp van distractie-epifysiolysis. Gedurende de eerste zeven weken van de verlenging werd de distractiekracht continu afgeleid van rekstrookjes bevestigd aan de verlengingsstaven van het uitwendig distractie-apparaat. Er werd 1,25 mm per dag verlengd. De weefsels vertoonden een visco-elastische respons op de aangelegde kracht. In de eerste week nam de distractiekracht tot tot 791 N. Hierna trad lysis op, waarop de kracht snel afnam tot gemiddeld 150 N. Gedurende de daarop volgende verlenging konden pijn en klinische symptomen gerelateerd worden aan de toenemende spanning en inadekwate relaxering van zachte weefsels. Door de distractie-snelheid te verlagen verminderde de opbouw van krachten en verbeterden de klinische symptomen. Deze resultaten tonen aan, dat het meten van krachten van klinisch nut kan zijn voor het juist beoordelen van de distractie-snelheid.

RÉSUMÉ

P. M. VAN ROERMUND, R. A. J. WIJLENS et W. RENOOIJ. Mesure continue des forces pendant l'allongement du tibia par distraction épiphysaire.

Une inégalité de longueur des membres inférieurs de 5 cm fut compensée par une allongement de l'extré-

mité supérieure du tibia par distraction du cartilage de conjugaison. Pendant les 7 premières semaines de l'allongement, la force de distraction fut mesurée de manière continue à l'aide de jauges de contrainte, fixées aux broches du système externe de distraction. L'allongement a été fait de 1,25 mm par jour. Les tissus ont présenté une réaction visco-élastique à la force appliquée. Pendant la première semaine, la force de distraction a augmenté jusqu'à 791 N. La lyse s'installa ensuite avec, comme conséquence, une réduction de la force jusqu'à une moyenne de 150 N. Pendant l'allongement qui suivit, la douleur et les signes cliniques étaient secondaires à une augmentation de la force de traction et à un relâchement inadéquat des parties molles. En réduisant la vitesse de distraction on nota une diminution des forces et une atténuation des signes cliniques. Les résultats montrent que la mesure de la force de distraction a des applications cliniques pratiques, notamment pour déterminer la vitesse de l'allongement.