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Changes in knee motion following femoral and tibial lengthening using the Ilizarov apparatus: a cohort study

Nicola Maffulli[1], Ubaldo Nele[2], and Lorenzo Matarazzo[2]

[1] Department of Trauma and Orthopaedic Surgery, School of Postgraduate Medicine, North Staffordshire Hospital, Thornburrow Drive, Hartshill, Stroke on Trent, ST4 7QB, UK
[2] Department of Orthopaedics and Traumatology, Ospedale Fatebenefratelli, Via Manzoni, Naples, Italy

Abstract We studied 46 patients undergoing tibial or femoral lengthening to correct limb-length discrepancy (LLD) to assess the effects of the procedure on the range of motion (ROM) of the knee. The ROM of the knee has decreased even before the lengthening process started, and was at its most pronounced by the end of the lengthening. Mean preoperative ROM was 125° ± 21°, and at follow-up, at an average of 41 ± 7.8 months from the beginning of the lengthening procedure, mean ROM was 117° ± 25° (P = 0.31). There was no association between the worst ROM achieved during lengthening and the final ROM. Femoral lengthening resulted in a significantly greater loss of ROM for longer periods than tibial lengthening. Patients with congenital LLD were at risk of faster, more permanent loss of ROM than patients with posttraumatic or postinfective LLD. After the removal of the tibial or femoral Ilizarov frames, the ROM of the knee tended to return to prelengthening values.

Key words Callotasis · Longitudinal study · Motion · Knee · Complications

Introduction

Distraction osteogenesis allows reliable and predictable correction of limb-length inequality, with a significant reduction in many complications associated with bone healing, such as nonunion, malunion, deep infections, and internal fixation failure.[18,21] However, persistent loss of strength[16] and decreases in the range of motion (ROM) of the joints immediately proximal and distal to the bone segment being lengthened[10] have been reported. These features may be related to the lengthening process and its effects on soft tissues and cartilage,[22] or to the adhesions created between bone and soft tissues, or to the adhesions between the various layers of soft tissues, when transfixation with wires and pins is done.[10] Finally, the increased production of stiff connective tissue surrounding the distracted muscle fibers may account for the increased joint stiffness often found in these patients.[26]

Although experimental interventional studies are lacking, recent evidence from observational studies would suggest that joint contractures and subluxations can be, at least partially, prevented by protecting the relevant joint during lengthening. In this way, lengthening does not result in marked loss of motion or joint injury.[4,7,8,24] Empirical recommendations suggest cessation of distraction if a knee extension lag develops, or if the ROM of the knee decreases to 45°.[4,10,24]

We have used the Ilizarov apparatus to correct limb-length discrepancy (LLD) since the mid 1980s, and our impression following limb lengthening was that, after a period of loss of motion, most patients regained their prelengthening ROM. Also, we thought that there was no difference between femur and tibia. We therefore set up a prospective observational cohort study to monitor the evolution of ROM of the knee during and after the lengthening process.

We hypothesized that: (1) there were no differences in ROM of the knee in the limb undergoing lengthening before lengthening, during lengthening, and after the removal of the Ilizarov apparatus; and (2) that femoral and tibial lengthening exerted the same effects on the ROM of the knee in the lengthened limb.

Patients and methods

All procedures reported in this study were approved by the Ethics Committee of the Ospedale Fatebenefratelli, Napoli. All patients had given their informed consent to

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undergo leg-lengthening by callus distraction, and to take part in the study.

Patients

Only patients in whom leg-lengthening by callotasis (using an Ilizarov apparatus) had been planned were entered in the study. We excluded: (1) patients who underwent upper limb-lengthening, because we aimed to study the ROM of the knee; (2) patients who, in addition to lengthening, required correction of an angular deformity of more than 8°, as angular correction may unduly interfere with ROM of the knee; (3) patients who underwent simultaneous femur and tibia lengthening, as the combined lengthening could have an additive effect; (4) patients who underwent bone transport procedures for posttraumatic or postinfective bone loss, because of the preoperative state of the leg and the knee, with soft-tissue adhesions that could have prevented full ROM of the knee; (5) patients in whom a full ring was used in the proximal tibia, as it would impinge on the posterior aspect of the femur, and, thus, would act as an extrinsic limiting factor to knee ROM; (6) patients who underwent lower limb-lengthening with other apparatuses; and (7) patients undergoing a second lengthening procedure on the same limb. In these patients, only the first lengthening was considered, as the ROM of the knee could have been influenced by the first lengthening.

A total of 46 patients were therefore recruited in the study. Their mean age at operation was 21.4 years (range, 5 to 46 years). The etiology of LLD was non-traumatic (congenital, developmental, or infective) in 21 patients, and trauma-related in the remaining 25 patients. Mean femoral lengthening ($n = 17$) was 6.6 cm (range, 4–16 cm), and mean tibial lengthening ($n = 29$) was 5.8 cm (range, 4–14 cm).

Operative technique

The operative technique has been described previously.[17,18] After the Ilizarov apparatus had been applied, a corticotomy/osteotomy of the structural bone of the shorter limb segment was performed. A delay of 5 days (in children) and of 7 to 10 days (in adults) to allow early callus formation was implemented. Gradual progressive distraction of the gap was then produced, at the rate of 0.25 mm four times a day, but this rate could vary according to clinical conditions and imaging results.[17,18] The process of lengthening was monitored on an in- and outpatient basis to ensure that pin sites were kept clean, that correct alignment was maintained, and that bone formation took place. The attending surgeon decided when to discontinue the distraction, and when to remove the frame, based on the length achieved and the appearance of cortico-medullary differentiation. Patients were told that the mean time planned for full bridging was approximately 1 month per centimeter, but they were told that the procedure might not be straightforward, and that additional operations might be necessary, including bone grafting, and repositioning or exchange of the apparatus.

Measurement of range of motion (ROM) of the knee

A fully trained physiatrist measured the ROM of the knee of the leg undergoing lengthening, using a commonly available portable goniometer (Ilizarov Courses Goniometer, Richards Smith and Nephew, Memphis, TN, USA). With the knee at the maximum extension possible, the goniometer was placed over the lateral aspect of the lower limb. Given the presence of the fixator, it was not possible to place the goniometer over the skin. Therefore, it was placed over the fixator, with each arm of the goniometer being visually aligned with the longitudinal axis of the leg and of the thigh, after the tip of the lateral malleolus, the middle of the knee joint, and the tip of the greater trochanter had been marked on the lateral aspect of the lower limb to be tested. After palpation of the lateral knee joint line, the center of rotation of the goniometer was visually aligned with the midpoint between the anterior and the posterior aspect of the knee over the lateral joint line. The patient was then asked to flex the knee as much as possible, taking care to maintain the centre of rotation of the goniometer co-axial with the centre of rotation of the knee. The ROM, in degrees, was thus obtained. The procedure was started on the normal knee, and then repeated on the knee of the lower limb undergoing lengthening. A preliminary study of 25 patients showed that the physiatrist achieved a result within 5° in duplicate measurements on the same knee of a limb undergoing lengthening, with a coefficient of variation (CV) of 7% ($P = 0.007$).

The preoperative angular value for each knee was regarded as 100%, and all post-operative results are expressed as a percentage of the original measurement. The knee ROM was measured immediately before the application of the external fixator, just before the distraction was started, at discharge from hospital, and at twice-weekly to monthly intervals until removal of the fixator. After the removal of the fixator, the measurements took place at 4- to 12-week intervals for the first year (average, every 6.4 ± 4.7 weeks), and at 24- to 52-week intervals thereafter (average, every 37.4 ± 11.3 weeks), for an average of 41 ± 7.8 months.

Clinical and radiographic data

The clinical and radiographic data included the patient's age at operation, the bone segment involved (femur or tibia), the amount of lengthening planned, and the lengthening achieved (mm).

Postoperative regimen

When the external fixator was in place, weight-bearing was allowed as tolerated. During the distraction and consolidation periods, patients received regular physiotherapy twice a week, under the supervision of a fully trained physiotherapist with an interest in Ilizarov frames. Patients were taught home exercises to keep the joints proximal and distal to the bone segment lengthened flexible, and were advised to exercise at least twice a day. If a child below age 12 years was treated, one parent (usually the mother) was instructed in the above exercises, and advised to administer them to their children. Given the widespread catchment area, patients lived up to 200 km away from the hospital. Therefore, most of them received physiotherapy in their home town, and we monitored them as outpatients according to planned visits and clinical needs. Patients were admitted for inpatient physiotherapy and for the slowing-down or stopping of distraction if they developed a fixed equinus of 10° or more at the ankle, or a fixed flexion of 15° or more at the knee, or a total ROM of the knee of less than 60°, or a fixed flexion of 25° or more at the hip. The decision to admit a patient or to decrease or stop distraction was left to the attending surgeon. After fixator removal, the limbs were protected for 4 to 6 weeks in a functional orthosis or cast, allowing weight-bearing as tolerated.

Data management

The time in the fixator varied from patient to patient. To standardize the time, for each patient, we considered the time from the application to the removal of the fixator to be equal to one unit, and we expressed the temporal data collected after such events as multiples of such units. Data were entered in a commercially available database, and analyzed using the inbuilt statistical program and SPSS 6.1 for Windows.[19] Descriptive statistics were calculated. The Shapiro-Wilk statistic determined that the data were normally distributed. The time course in the variation of ROM was analyzed using analysis of variance (ANOVA) for repeated measures, and post-hoc Student's t-tests were used to determine the direction of the differences detected. The different groups of patients (see below) were compared using one- or two-way ANOVA, with the underlying pathology and the age range of the patients as covariates. Cross-tabulation, breakdown, regression, and Pearson moment products were performed. A general linear regression model was used, although it is acknowledged that some of the variables may be correlated nonlinearly with time. This approximation was well tolerated by the model.

Results

The average time in the Ilizarov apparatus was 192 days (range, 126–712 days). The mean preoperative ROM was 125° ± 21°, with no significant differences between the patients with traumatic and nontraumatic LLD. At an average of 41 ± 7.8 months from the removal of the fixator, the ROM was 117° ± 25° (P = 0.31 vs preoperative value) (Fig. 1). In six patients, the final ROM achieved was 110°, and four of them had a decreased ROM (average, 108°) at the beginning of the study. One patient lost more than 15% of her preoperative ROM, which decreased from 130° to 110°. However, she stated that her activities of daily living were not affected by such a decrease in ROM, and she was delighted with the results of the lengthening procedure. One-way ANOVA did not show evidence of an association between the worst ROM achieved during lengthening and the final ROM. There was a significant trend for the patients with congenital LLD to lose ROM more quickly, and to regain the original ROM at a slower pace (χ^2-for-trend; P = 0.034) (Fig. 2). In these patients, the ROM decreased to 51% of the preoperative ROM value by the end of the lengthening, and the average preoperative ROM returned only 21 months (± 4.6 months) after removal of the fixator.

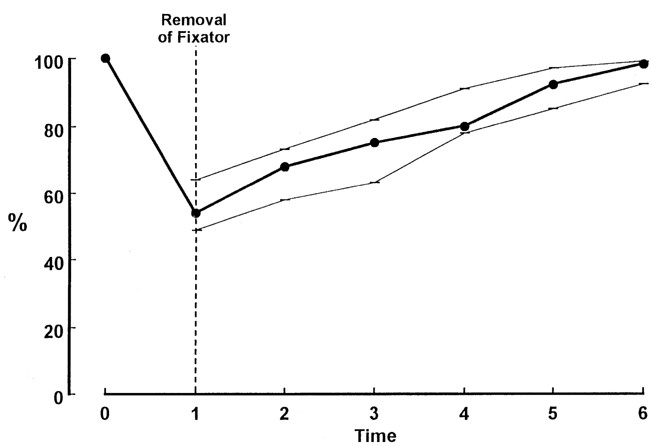

Fig. 1. Time course of the range of motion of the knee following callotasis for all patients (n = 46). The time in the fixator varied from patient to patient, and from limb to limb. To standardize the time, for each patient, we considered the time from the application to the removal of the fixator to be equal to one unit, and expressed the temporal data collected after such events as multiples of such units. The range of motion is expressed as a percentage of the immediate prelengthening value, and 95% confidence intervals are reported

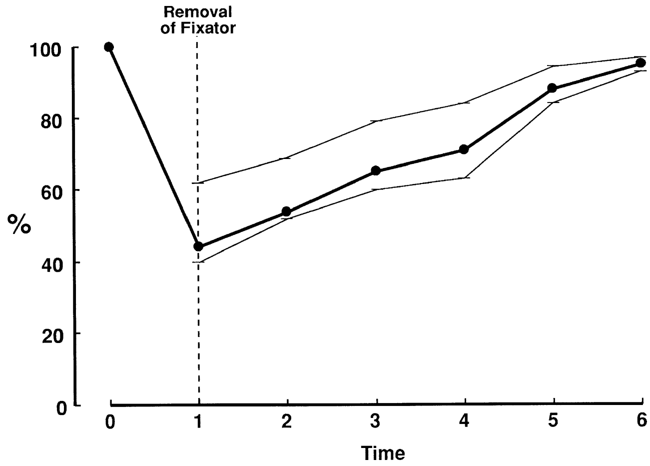

Fig. 2. Time course of the range of motion of the knee following callotasis for all patients undergoing lengthening for congenital pathologies (n = 11). The time in the fixator varied from patient to patient, and from limb to limb. To standardize the time, for each patient, we considered the time from the application to the removal of the fixator to be equal to one unit, and expressed the temporal data collected after such events as multiples of such units. The range of motion is expressed as a percentage of the immediate prelengthening value, and 95% confidence intervals are reported

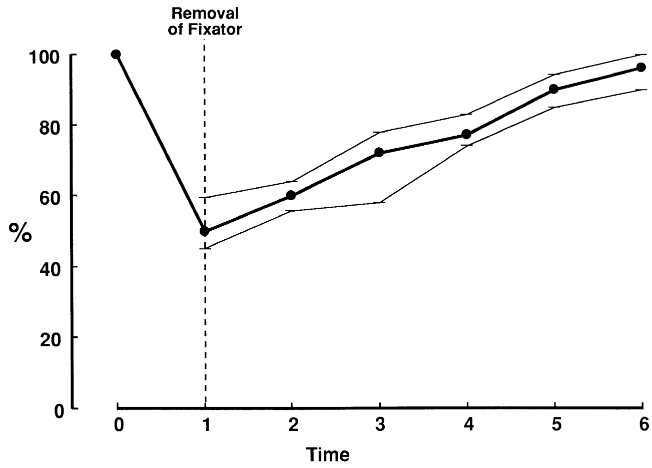

Fig. 3. Time course of the range of motion of the knee following callotasis for patients undergoing lengthening of the tibia (n = 29). The time in the fixator varied from patient to patient, and from limb to limb. To standardize the time, for each patient, we considered the time from the application to the removal of the fixator to be equal to one unit, and expressed the temporal data collected after such events as multiples of such units. The range of motion is expressed as a percentage of the immediate prelengthening value, and 95% confidence intervals are reported

We did not detect differences in the decrease in ROM for limb-lengthening in patients with LLD of traumatic and nontraumatic etiology, and we therefore grouped these patients together for further analysis. The ROM of the knee decreased significantly in the immediate postoperative period in both tibial (Fig. 3) and femoral (Fig. 4) lengthening ($0.01 < P < 0.05$, one-way ANOVA), regardless of the underlying pathology. However, femoral lengthening produced a significantly greater loss in ROM ($P = 0.012$; one-way ANOVA), and these patients took longer to recover the original ROM ($P = 0.04$, one-way ANOVA) than those with tibial lengthening, returning to their average preoperative ROM only 19 months (± 3.8 months) after the removal of the fixator, versus 15.4 months (± 4.5 months) after removal of the fixator in the tibia.

Using one- or two-way ANOVA, we were not able to detect a significant relationship between knee ROM at final follow-up and lengthening obtained, age, or worst knee ROM during the lengthening process, with approximately half of the patients regaining their preoperative knee ROM. The overall average ROM at the latest follow-up was 94% of the preoperative ROM. However, 3 patients had a fixed flexion deformity of 10° or more at the latest follow-up. All 3 undergone had lengthening for congenital LLD. Only 6 of the 46 patients in this study had lost more than 15° of knee flexion at final follow-up.

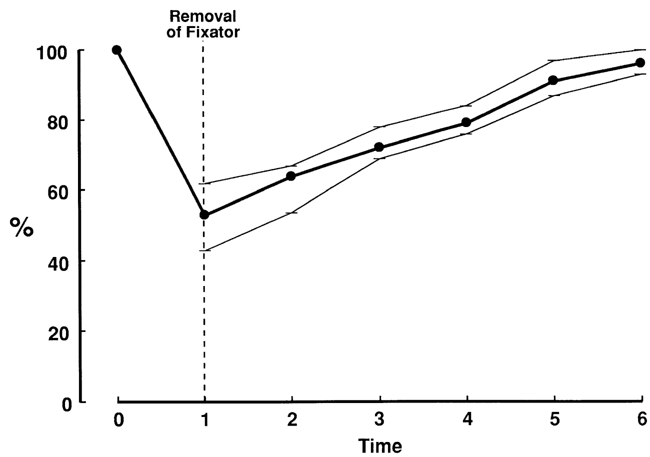

Fig. 4. Time course of the range of motion of the knee following callotasis for all patients undergoing lengthening of the femur (n = 17). The time in the fixator varied from patient to patient, and from limb to limb. To standardize the time, for each patient, we considered the time from the application to the removal of the fixator to be equal to one unit, and expressed the temporal data collected after such events as multiples of such units. The range of motion is expressed as a percentage of the immediate prelengthening value, and 95% confidence intervals are reported

Lengthening greater than 18% of the original length of the affected bone produced a significantly greater loss of knee ROM (58% vs 69% at removal of fixator; $P = 0.01$; one-way ANOVA), and took an average 11.4

weeks (SD, 4.2 weeks) longer to return to 90% of the original ROM than shorter lengthenings ($P = 0.02$; one-way ANOVA).

Discussion

Muscle contractures and joint stiffness remain significant problems during limb lengthening.[27] It should be expected that higher degrees of loss of motion occur with longer lengthenings, with longer external fixation times, and with pins or wires transfixing muscles or tendons.[10] If we detect significant, abrupt loss of knee motion that does not respond to physiotherapy, we may elect to abandon the lengthening. However, before reaching this point, we slow down or temporarily stop the distraction while undertaking in-patient physiotherapy.

Previous research hypothesized that the loss of knee ROM could be caused by the pattern of wire transfixion used in the distal femur.[10] In the present study, we have shown that tibial lengthening also produces a significant decrease in the ROM of the knee. Our external fixation technique broadly reflects the use of trans-osseous tensioned Kirschner wires, as recommended in the original studies by Ilizarov; however, in some patients, we used half pins instead of wires, although the small number of patients in whom we used half pins precluded statistical analysis. In our practice, we have noted that patients undergoing angular correction without lengthening experience significant loss of ROM of the knee until removal of the fixator, although the loss of ROM is not of the same magnitude as that in patients undergoing lengthening. This would confirm the hypothesis that impalement of muscles and soft tissues is a major cause of decrease in ROM, and would favor the use of half pins to prevent this decrease.

Recently, long-bone lengthening has been performed over interlocked intramedullary nails, using either unilateral or circular fixators,[9] with a significantly faster treatment time.[20] With this technique, the pins and the wires offend the soft tissues for shorter periods, with less scarring and arthrofibrosis. In the present and other studies, a rapid gain in knee motion follows removal of the fixator. Therefore, lengthening over an intramedullary nail, although technically demanding,[13] would allow earlier recovery of joint motion by decreasing the time during which the fixator would be in situ.

During both femoral and tibial lengthening, a decrease in ROM could result from the action of the biarticular muscles crossing the knee joint. In addition, in tibial lengthening, loss of motion may result from the failure of the tibialis anterior muscle fibers to adapt to the length imposed by callus distraction at the commonly used rate of 1 mm per day by failing to add sufficient new contractile material to maintain optimum sarcomere length along the muscle fibers.[27] It is unclear why femoral lengthening produces greater losses of ROM. One could hypothesize that, as the femur is a deep bone, surrounded by muscles for most of its length, there is a greater chance of transfixing the muscles in a deleterious way. On the other hand, a whole third of the tibia is subcutaneous, with no muscle cover.

We are fully aware of the limitations of the present study. Several techniques have been used to measure the ROM of the knee.[3] For example, we could have used radiographic techniques that displayed the proximal and distal shafts of the femur and of the tibia, using the posterior cortices of the tibia and of the femur as reference lines.[11] External goniometers fixed to the lower extremity have been used by other authors,[3] and Townsend and Izak[23] developed an electromechanical goniometer for this purpose. However, most of these techniques were developed after we started the present investigation, and are time-, personnel- and cost-intensive, as well as being difficult to employ in a clinical setting. Also, we were not given ethical permission to take more, or more extensive, radiographs than what we would have taken for routine clinical follow-up. This investigation was performed in a large inner-city hospital, one of the first in the Western world to embrace Ilizarov techniques. However, the Orthopaedic Department has a major service commitment. Therefore, we had to use a technique that, while being accurate, valid, and reproducible, was also easy to administer both for the patient and for the staff, and was fast enough not to interfere with the smooth running of the clinic.

A major strength of the present study is that all measurements of ROM were taken by a dedicated medically qualified tester. Intraobserver reliability of knee ROM measurements has a high reproducibility,[25] indicating that the technique used in the present study is valid and reliable. Indeed, there is some recent evidence, reported by Jagodzinski et al.[12] that shows that radiographic measurements of knee ROM deviate systematically from measurements of the total axis of the bone.[12] However, the same authors[12] have demonstrated that the use of bony landmarks on the tibia and femur allows high accuracy. As we used a similar technique, which was validated by ourselves in patients undergoing lower-limb lengthening, we believe that the changes in ROM of the knee that we observed during and after lengthening are true and real, and reflect the normal physiological response to the process of lower limb-lengthening.

Although the lengthening process may be stopped if a patient's knee ROM is significantly decreased, each patient must be managed individually,[15] and some motion of the knee should always be maintained during lengthening, because complete and prolonged immobilization affects joint function.[1,2,5,6,29]

The hamstring, the quadriceps, and the gastro-soleus complexes span across the knee, and tendon and muscle lengthening and releases may play a role in decreasing the load across the joint. We now perform prophylactic tendon releases in patients with congenital LLD, in patients with preexisting joint stiffness, and in lengthenings greater than 15% of the original length of the bone to be lengthened. Also, in congenital LLD patients, we may elect to extend the frame proximally to the distal femur (for tibial lengthening) or distally to the upper tibia (for femoral lengthening) for 4 to 6 weeks to prevent chondrolysis and subluxation.

During the whole process of correction of LLD, all patients were encouraged to bear weight as much as possible, and as soon as possible, and to undertake active and passive stretching and ROM exercises,[4,7,8,14,28] both at home and on a supervised outpatient basis. It is likely that inpatient treatment would result in better and faster rehabilitation. However, this would be prohibitively expensive in the Western world, and would not be popular with the patients and their families.

In conclusion, although modern limb-lengthening techniques have a low rate of bone-union problems, loss of motion in the knee joint takes place in both femoral and tibial lengthening. If this loss of motion is persistent or sudden, consideration should be given to stopping the distraction to regain the loss of ROM. In the long run, however, the ROM of the knee tends to return to prelengthening values.

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