



## Effect on knee motion of gradual intramedullary femoral lengthening

Ashok ACHARYA, Jean-Marc GUICHET

From the Cardiff & Vale NHS Trust, Cardiff, United Kingdom and the Hôpital Privé Beauregard, Marseille, France

Gradual femoral lengthening causes loss of knee motion due to soft tissue tightness. Lengthening with an intramedullary device would be expected to retain good knee movements since it avoids soft tissue transfixation. To ascertain this we looked at the knee movements recorded in 27 patients before, during and after bilateral simultaneous femoral lengthening using Albizzia nails. The mean gain was 6.2 cm and the mean follow-up 28.6 months. No significant difference was noted between the mean preoperative and final knee flexions (148.3° vs. 148.4°) and the mean preoperative and final knee extensions (2.3° vs. 3.4°). By their last visit, all patients were flexing to at least 120° and only one patient had a flexion deformity over 5°. Thus maintenance of good knee motion and early return to activities is possible when an intramedullary device like the Albizzia nail is used for femoral lengthening.

**Keywords** : femoral lengthening ; intramedullary nail ; knee motion.

Herzenberg *et al* (9) published in 1994 the first study directly relating to knee motion during femoral lengthening. They reported a series of 25 femoral lengthening using external fixation with a mean gain of 6 cm. Their patients started with a mean pre-operative flexion of 127°, which fell to a minimum of 37° during lengthening, then improved to 69° by the end of consolidation and finally attained 122° at final follow-up. Although there was no statistically significant difference between the pre-operative and final flexions, 6 months after frame removal (and 17 months after initial surgery) their patients were still managing only 90° flexion (9). A subsequent report from the same centre presented a series of femoral lengthening using external fixation over nails, where normal knee motion returned two times faster due to early external fixator removal. Whilst this was a great improvement, the mean knee flexion still fell to 58° during lengthening and recovered to only 96° four weeks after frame removal (12). In addition this

### INTRODUCTION

A decrease in the range of knee motion is a constant feature of femoral lengthening. This decrease is noted mainly in flexion of the knee, owing to quadriceps tightness, and to a smaller extent in extension (1, 3, 9, 12, 14-17). While the lengthening process itself is an obvious cause, when external fixators are used for lengthening, the irritant effect of pins and screws on the soft tissues contributes substantially (1, 14, 16).

■ Ashok Acharya, MD, Specialist Registrar.  
Cardiff & Vale NHS Trust, Cardiff, Wales, United Kingdom.

■ Jean-Marc Guichet, MD, Consultant Orthopaedic Surgeon.

Hôpital Privé Beauregard, Marseilles, France.

Correspondence : Ashok Acharya, 6 Wexford Court, Pontprennau, Cardiff CF23 8PW, United Kingdom.

E-mail : acharya.ashok@gmail.com.

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technique still carried the risk of deep infection as highlighted in the paper by Simpson *et al* (13).

Barker *et al* (1) conducted a prospective study to elucidate the factors affecting knee motion during femoral lengthening using external fixators.

This study reported a significant loss of knee motion immediately following the operation, despite a surgical technique aimed at minimising soft tissue tethering and confirming full knee range of motion intra-operatively with pins and wires *in situ* (1). While the actual cause for this was uncertain, insufficient analgesia, apprehensions about moving and poor psychological acceptance of the frame were suggested as probable causes.

Against this background we posed our study question: "How would a completely intra-medullary lengthening device such as the Albizzia nail affect knee motion?" We presumed that it would allow better knee function than external fixation since it avoids soft-tissue transfixation.

## PATIENTS AND METHODS

We conducted a therapeutic retrospective cohort study of 27 consecutive patients with proportional short stature or normal stature who underwent bilateral femoral lengthening using the Albizzia system (De Puy, Villeurbanne, France) under the care of the second author. These procedures were carried out between January 1994 and September 2003. A minimum follow-up of 6 months was ensured. The mean age at operation was 26.9 years (range: 14 to 42.6) and the mean initial height 1.55 m (range: 1.33 to 1.78). There were 13 females and 14 males. No patients were lost to follow-up.

Seventeen of the 27 patients were short statured (the lower limit of normal is 1.66 m for Caucasian males and 1.53 m for Caucasian females). The short stature was constitutional in 14 patients, due to Turner's syndrome in two and due to irradiation of the pituitary for Von Recklinghausen's Disease in one. The 10 patients (all males), who were normal statured desired to be taller for personal reasons.

### Pre-operative protocol

All patients underwent full physical and psychological evaluation. The physical evaluation included among other things measurement of joint range of motion and

muscle power testing (MRC Grading 0-5). The psychological assessment was carried out by a trained psychologist who ensured that each patient was adequately motivated and mentally prepared for the programme. This step is especially important in patients undergoing cosmetic lengthening.

The pre-operative physiotherapy protocol has evolved with our growing experience. For the initial four patients, pre-operative muscle strengthening was recommended but not enforced. When this did not produce the desired results, we shifted to custom-made muscle training programmes supervised by trained physiotherapists where possible. The programme presently consists of daily exercises for an hour for up to 6 months prior to the surgery. Patients without access to physiotherapists are given personal training goals and advised to get help at local gymnasiums.

### Surgical Technique

The surgical technique also underwent modifications over time, to minimise soft tissue trauma and optimise recovery of function. The first four patients had a 6 to 12 cm incision in the gluteal/upper thigh region to expose the greater trochanter followed by the conventional femoral intramedullary nailing technique. In later patients this was refined to a percutaneous insertion of the nail with the help of a 6 cm extension tube surmounting the modified sighting device and nail (7). Trauma to the gluteal muscles was thus minimised, which in turn allowed for early commencement of post-operative physiotherapy.

### Post-operative Care and Rehabilitation

Post-operative analgesia was dictated by patient preference (Morphine pump or epidural catheter or oral) and in all cases anti-inflammatory medication (ketoprofen) was given along with pain-killers (paracetamol). Ice packs, leg elevation, compressive stockinet and continuous passive motion (CPM) were also prescribed.

The knee mobilisation strategy was modified over time to achieve the best possible results. Our present approach consists of fitting patients in the recovery room with CPM machines set at 110° and going for knee flexion above 120° on the evening of surgery, which is then maintained with the help of the physiotherapist.

The attitude has also changed with reference to weight bearing. At the beginning, patients were advised to refrain from weight-bearing until the end of distraction. At the moment however our patients are allowed to

partially weight bear on the first post-operative day, to cycle (up to 1 hour per day) from the second or third postoperative day and to swim or participate in other non-contact and non-impact sports from the second week. Cycling is especially helpful for rehabilitation since an hour of cycling puts the knee through many more cycles of flexion and extension than a physiotherapist ever could.

### Follow-up

Once the patient was felt to be making good progress with the exercises and the lengthening, he/she was discharged with arrangements made for regular follow-up clinic appointments. During each clinic visit, flexion and extension of the knee was measured using a goniometer in the standard fashion (12) and the length gain from radiographs. The gain obtained would be cross-checked against the gain expected from the ratcheting manoeuvres.

### Statistical analysis

All analyses were performed using the SPSS statistical package version 12.0.1 (SPSS Inc., Chicago, Illinois). Descriptive data was used to summarise the information on the sample along with correlation to test for associations. For comparisons between the pre-operative and final flexions and extensions of the subjects, paired t-test was employed. Using the independent t-test, least flexion and extension measurements were compared between patients aged 16 years or younger ( $n = 6$  knees) and those older than 16 ( $n = 48$ ). Finally the least flexion and extension values were correlated against the gain using Spearman's Rank Correlation test.

## RESULTS

The mean femoral gain (measured from radiographs) was 6.2 cm with a range of 3.7 cm to 10 cm. The mean percentage gain was 14.7% of the initial length (range 8.9% to 23.6%). The mean number of movement measurements was 13 (range : 8 to 19) and the mean duration of post-surgery follow-up was 28.6 months (range : 7.9 to 80.7).

The mean pre-op flexion was 148.3° (range : 135 to 160) and this fell to 124.3° (range : 70 to 155) by the lock-off date (end of active lengthening). By the last visit however the mean knee

Table I. — Knee flexion measurements at various stages

Period	Mean flexion (degrees)	Standard Deviation/Range (degrees)
Pre-operative	148.3	r6.9/135-160
Lock-off	124.3	r18.8/70-155
Final	148.4	r8.6/125-160

flexion came back up to 148.4° (range : 125 to 160) (table I). The mean least knee flexion recorded was 111.7° (range : 60 to 155) and 83% of the knees demonstrated least flexion during active lengthening. In 8 knees the flexion fell below 90° but rose back to 140° or more by the last follow-up. Figure 1 shows how the knee flexion values changed during the lengthening process. The extent to which patients were able to maintain good flexion can be judged from figure 2, which shows a patient with full flexion of the knee on the 52<sup>nd</sup> day following 5.6 cm lengthening.

The mean pre-operative extension was 2.3° i.e. a hyperextension of 2° (range : -5 to 10). By the end of active lengthening, the mean extension had changed to -6.2° (range : -55 to 10) and once again to 3.4° (range : -10 to 10) by the last follow-up (table II). The mean least extension value was -9.3° (range : -55 to 2) and the least extension values were encountered in 91% of knees during active lengthening. Figure 3 shows the variation of knee extension during the lengthening process. Note that the average knee extension approached 0° i.e. full extension by the 13<sup>th</sup> post-operative week.

Nineteen knees in 11 patients developed fixed flexion deformities (FFD) equal to or higher than 10° during the lengthening phase. At last follow-up, only one patient had a persistent FFD of 10° in one knee. She was 44 months post-op and had regained full extension in one knee but not in the other. Since she was not significantly disabled by the lack of extension, no specific treatment was offered. None of the other patients needed tenotomies or joint manipulations to improve movements.

Anterior pelvic tilt was another common manifestation of tissue tension but we made no attempt to measure it since in our experience it always improves with time and physiotherapy.

### Knee Flexion During Femoral Lengthening with the Albizzia Nail

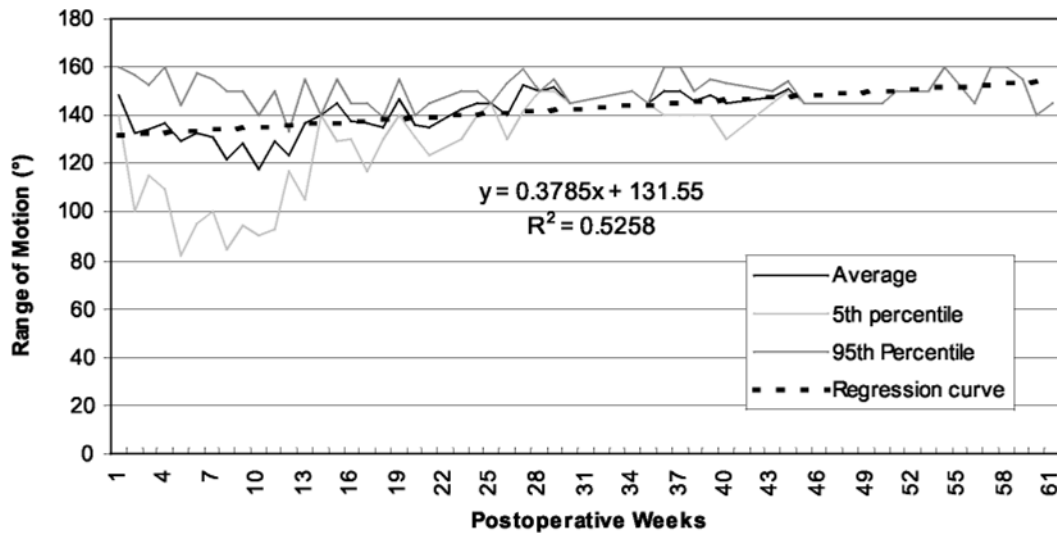


Fig. 1. — Variation of knee flexion during femoral lengthening



Fig. 2. — Normal knee flexion on the 52<sup>nd</sup> day following a 5.6 cm bilateral femoral lengthening.

The difference between pre-operative and final flexion was not statistically significant (t-value = -0.059, p = 0.953). The same applied to pre-

Table II. — Knee extension measurements at various stages

Period	Mean extension (degrees)	Standard Deviation/ Range (degrees)
Pre-operative	2.3	r3.6/-5 to10
Lock-off	-6.2	r13.8/-55 to10
Final	3.4	r3.8/-10 to 10

operative and final extension (t-value = -1.907, p = 0.062).

Comparing the least knee flexion values for patients aged 16 years or younger (n = 6 knees) and those older than 16 (n = 48 knees) there was a statistically significant difference (t-value = 6.303, p < 0.0001). While this indicates that patients younger than 16, i.e. paediatric patients have more difficulties maintaining their flexion than those over 16, i.e. adults, this conclusion should be arrived at with caution due to the small number in the former group. Difference in least extension values between these two groups was however statistically non-significant (t-value = -0.131, p = 0.897).

Weak correlation was noted between total gain and least flexion measurements (-0.29, p = 0.033)

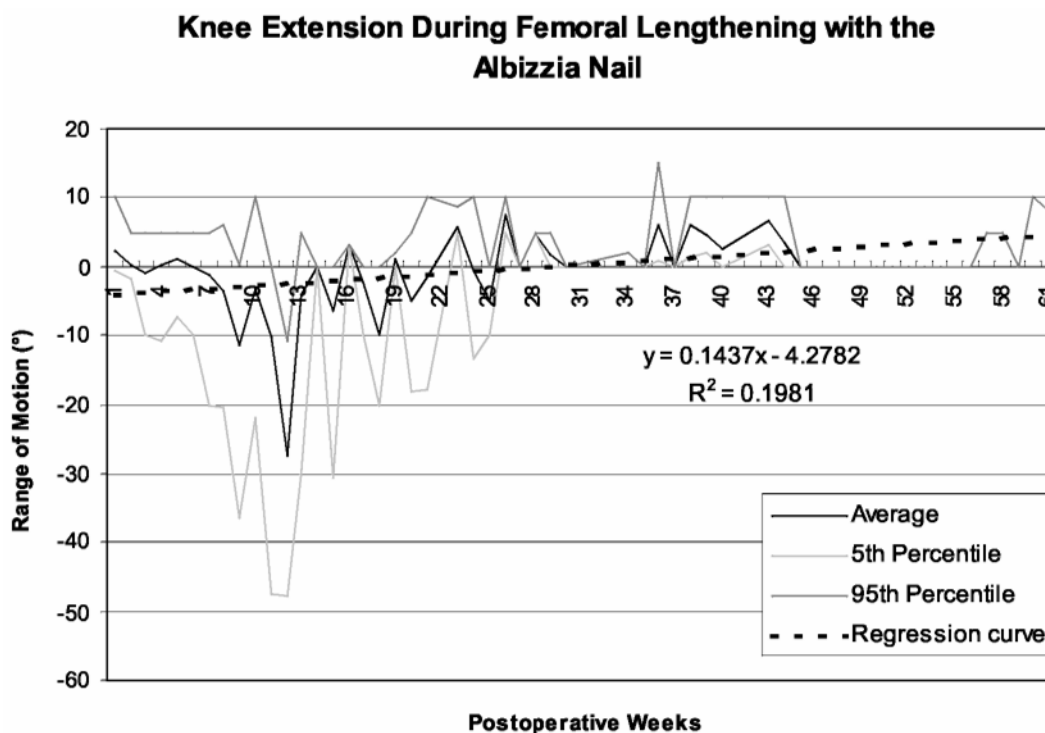


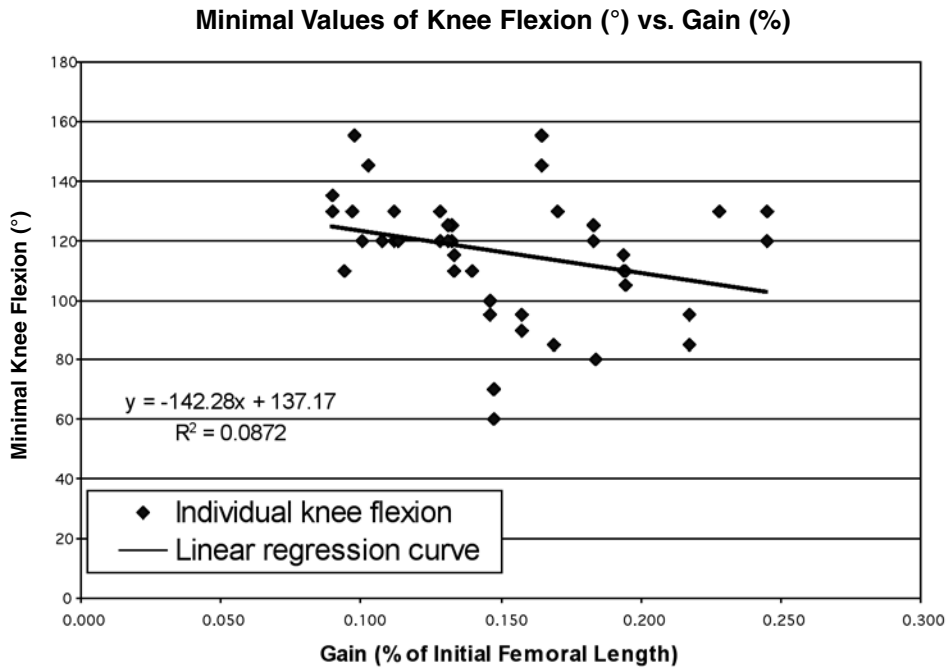
Fig. 3. — Variation of knee extension during femoral lengthening

(fig 4) and total gain and least extension measurements ( $-0.38$ ,  $p = 0.005$ ) (fig 5). In other words it is not possible to predict that patients going for higher gains using the Albizzia nail will have greater restriction of movements during lengthening.

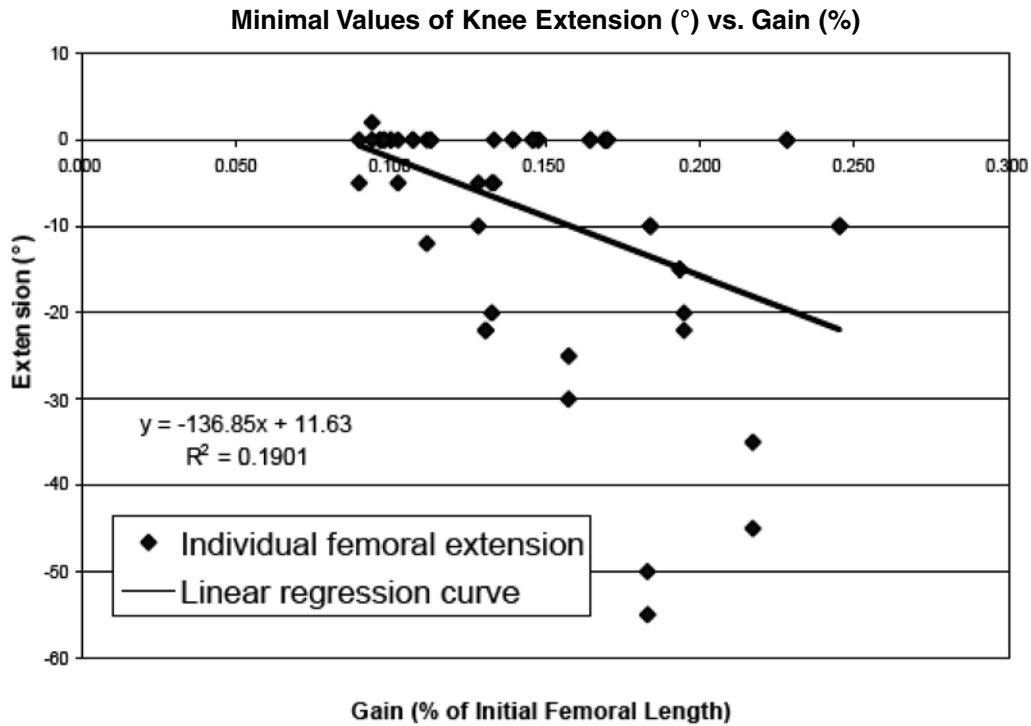
## DISCUSSION

There are several advantages to maintaining knee function as close to normal as possible during femoral lengthening. Good knee motion prevents atrophy of muscles and avoids articular cartilage damage due to excessive contact pressures from tight soft tissues. It also decreases muscle spasm and pain and prevents adhesions of the muscles to the underlying bone regenerate (9, 12). All these help to keep the patient's optimism high. Physiologically too, joint motion and muscle activity are beneficial since they increase the blood supply to bone and strengthen the bone by inducing new bone formation (3).

To our knowledge, this is the first series of bilateral femoral lengthening using any fixation technique where all patients had normal knees with normal range of motion pre-operatively. Hence comparison was not possible with other series of femoral lengthening which included patients with normal and abnormal knees (9, 12, 14). Nevertheless the speedy postoperative recovery of knee motion in our series is quite apparent. We believe this was possible due to the intra-medullary lengthening device we used. It allowed us to keep the soft tissues intact and supple, while the bone was being lengthened. As our experience with rehabilitation methods grew, we noted that a pre-operative muscle training program and full mobilisation from the recovery room helps to recover and maintain a near normal range of motion of the knee throughout the lengthening period. Bone lengthening, whether by external fixation or internal fixation, is non-physiological, and places great demands on the soft tissues. At the peak of the pubertal growth spurt,



*Fig. 4.* — Correlation between minimal knee flexion and gain



*Fig. 5.* — Correlation between minimal knee extension and gain

the femur grows at a maximal rate of three centimetres per year. This by itself can occasionally cause thigh and knee pain. In surgical lengthening, a 3 cm gain is obtained in a month and in some cases up to 18cm in 6 months. The muscles and tendons are evidently not able to keep up with the rapidly growing bone and present problems such as spasm, tightness and adjacent joint stiffness.

When one looks at the strength-strain curve of muscles during stretching, the elastic limit is found to be 10-15% of the resting length. Beyond this what takes place is plastic deformation until the final rupture. Muscles which have surpassed their elastic limit are plastically deformed and develop what are commonly called "contractures". Contractures are more obvious in muscles spanning two joints (viz. rectus femoris, hamstrings, etc.) than those spanning only one joint (viz. vastus medialis and lateralis). Contractures can be corrected surgically but this carries the risk of weakening the muscle.

All the above complications can be avoided to some extent by keeping the joint supple and fully mobile, so that the muscles spanning it are well stretched. Stretching is an important stimulus for the production of more actin and myosin filaments and for the addition of sarcomeres in series and in parallel (1, 6, 14). In other words active muscle building and stretching help muscles adapt and lengthen in parallel with the lengthening bone.

Increased soft tissue tension and stiffness during lengthening causes the neighbouring joints to become relatively immobile as well as increases joint reaction forces, which puts the joints at increased risk of damage. Animal experiments have demonstrated that lengthy immobilisation of joints of up to 11 weeks (even without lengthening) can cause alterations in the concentration of articular cartilage proteoglycan, which are not reversed for long by remobilisation (8). Since proteoglycans exert a strong influence on the biomechanical properties of cartilage, these alterations could jeopardise the welfare of the articular cartilage and hence of the joint. The increase in joint reaction force also poses a threat. With femoral lengthening, the reaction force at the knee has been shown to rise as high as 14 times normal (11). Stanitski (16) most convincingly demonstrated the adverse effect of this

on articular cartilage. In her canine model, a 30% increase over initial femoral length at a rate of 0.75 mm daily produced articular cartilage changes in the knee ranging from fissuring and loss of proteoglycan staining to frank necrosis and loss of cartilage down almost to the subchondral bone. Others have also reported this phenomenon and stressed the need to avoid it (13). Keeping the soft tissues supple with activity and stretching is clearly the best way of preventing and suppressing the ill effects of increased tension.

Regular stretching and maintenance of good joint motion also decreases the pain and muscle spasm frequently encountered during lengthening. If a patient undergoing femoral lengthening is able to move the knee well with minimal pain and discomfort, he or she will more easily cope with activities of daily living. The knee flexion of our patients fell to a mean least value of 112°, which is only 5° adrift of the 117° required for normal activities (10). We feel this kept our patients in a positive state of mind vis-à-vis the lengthening and ensured compliance.

An active muscle remodels more efficiently and maintains better range of excursion for larger gains. Interestingly, figures 4 and 5 show that some patients going for higher gains maintained better range of motion (flexion and extension) than others going for smaller gains. When the gains were higher, the dispersion of values was large pointing to the influence of factors other than gain in causing motion restriction. Identification of these factors will help obtain equally good results for all patients regardless of the magnitude of gain.

Good joint motion and good muscle function obtained by regular stretching and strengthening is beneficial for the bone and the neuromuscular junctions. Exercise strengthens bone by inducing new bone formation (4) and produces structural adaptations in the neuromuscular junction, which enhances neuromuscular transmission and thus, muscle performance (5).

It is clear that good joint and muscle function are vital to the short and long-term success of a lengthening programme and that active exercise is the best way of achieving them. Once the optimal exercise programme has been devised, the only

variable that can affect the outcome is the kind of fixation used. Presently, one can choose between external, internal and combined external- internal fixation techniques.

External fixation of the femur necessitates impaling the soft tissues of the thigh especially the muscles with half-screws and/or wires. This is unavoidable even with the least invasive techniques and has obvious adverse affects on muscle mobility and function (1, 3, 9, 12, 14-17). A muscle which cannot glide freely, is prone to getting stuck down to the bone at the regenerate site (2). Secondly, pin-tract infections are very common in femoral lengthening using external fixators. The associated pain often causes muscle spasm and inhibition of function. Further these tracts tend to heal with much scarring, tethering the soft tissues to bone and causing longer-term knee stiffness (2, 3). Stiffness can be further complicated by fractures if the knee is forced in order to improve its range of motion.

The combined technique entails lengthening over an intra-medullary nail using an external fixator and locking the nail once the desired length has been achieved and the external fixator removed. Using this technique, Paley *et al* (12) were able to regain normal knee range of motion two times faster, compared to external fixation alone. Yet their figures of 98.5° of knee flexion 5 months after the index operation and 118° at 2.8 years are not optimal, even if patients had a shorter period of transfixation of soft tissues by wires and pins.

In our patients lengthened using the "Albizzia" nail, we were able to combat directly the effects of the lengthening on the soft tissues since the nail does not interfere with the rehabilitation in any way. Thus, we were able to maintain a satisfactory range of knee motion during lengthening and regain near normal motion soon afterwards. We believe that our protocol, which consists of pre-operative muscle building and stretching, immediate post-op mobilisation and intensive training thereafter till near normal knee motion is regained, can reproducibly achieve these results. Freeing the muscle from any surgical device may allow to improve the final outcome and to return to normal activities within 3 to 5 months following the initial surgery, with gains up to 9.6 cm.

An important argument for choosing external fixation over internal fixation for femoral lengthening is the potential for genu valgum deformity due to lengthening along the anatomical axis. Surprisingly this was not the case in the senior author's reported series of 41 intramedullary femoral lengthening (7) or Paley's series of 32 lengthening over nails (12). Neither study showed a significant relationship between the change in the lateral distal femoral angle and the amount of lengthening. While we have no straightforward explanation for this phenomenon, one possibility could be that the over-reaming required to accommodate the nail introduces some femoral varus which is then corrected by the lengthening process. Whatever the reason, it further strengthens the case for intramedullary femoral lengthening.

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