

From the Nuffield Orthopaedic Centre, Oxford, England.

LEG LENGTHENING

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Since its first introduction by Codivilla in 1905 and the pioneer work of Abbott (1927) leg lengthening has been undertaken with some trepidation in view of the serious complications that can occur (Compere 1936 and Allan 1951). More recently Anderson (1967) has shown that lengthening is relatively safe if certain precautions are observed. Even so significant complications, e.g. delayed union, non-union, malunion and sepsis are still recorded in recent published series. As a consequence it is often difficult to decide which method to use for surgical correction of significant leg length discrepancy.

It was the impression that the incidence of complications in the patients treated by the method employed at the Nuffield Orthopaedic Centre over the last eight years was low and, although the measured length was often shorter than that recorded in other series, a useful gain in length was achieved in most cases. This led to the present study aimed at assessing the reliability and safety of the method with particular reference to the effect of tibial or femoral lengthening on the final length of the limb.

The alternative procedures available for equalising limb lengths are:

1. *Shortening the Longer Limb*

a. *Epiphyseal arrest and epiphyseodesis*: These are well tried procedures but they are unpredictable, are carried out on the normal limb, and lead to reduction in the total height of the patient (Phemister 1933, Blount & Clarke 1949, Poirier 1968). There is also a notable incidence of extrusion or breaking of staples, genu valgum, genu recurvatum, ligamentous instability, and late irregularity of the articular surfaces of the knee.

b. *Bony resection*: This is a relatively safe method of shortening the longer limb which can be performed at any age and the post-operative length can be judged with accuracy. However, like stapling, the operation is performed upon the normal leg and the patient loses height.

2. Lengthening the Shorter Limb

a. *Stimulation of bone growth*: Many operations have been devised for stimulating bone growth, but the gain in length is small and unpredictable (Tupman 1960). In thirty-nine cases treated by the method of intramedullary bone-block and periosteal stripping in Oxford prior to 1960 the average lengthening achieved was only 0.5 centimetres, and the greatest individual gain in length was 1.8 centimetres.

b. *Mechanical lengthening*: In view of the drawbacks in the former procedures there is a good case for using a mechanical lengthening operation on the shorter leg if this can be shown to give safe and reliable results.

THE PATIENTS

Between 1961 and 1968, thirty-five tibial and eight femoral leg lengthenings have been performed by one of the authors (J.D.M.) on forty-three patients at the Nuffield Orthopaedic Centre, Oxford.

Diagnosis

The underlying causes of the discrepancies are shown in Table 1.

Age and Sex

The average age of the patients at operation was 10.5 years for the tibial and 10.7 years for the femoral lengthenings (Figure 1). All the patients except one who had femoral lengthening at the age of twenty one, and two who had tibial lengthening performed at the age of fifteen, were skeletally immature at the time of operation. There were twenty-four female patients and nineteen males.

Table 1. Causes of Leg Length Discrepancy—Forty-three Patients

Diagnosis	Femur	Tibia
Poliomyelitis	2	29
Septic Arthritis of Hip	2	0
Birth Fracture	2	0
Old Osteomyelitis	1	0
Congenital Hip Dislocation	1	0
Congenital Short Bone	0	3
Congenital Dysplastic Fibula	0	2
Congenital Hemi-hypertrophy	0	1
Total	8	35

AGES of PATIENTS at OPERATION

Figure 1. Ages of patients at operation.

CASE SELECTION

Great stress was placed upon correct case selection which was based on the following criteria.

1. *The Length Discrepancy*

This should be at least 3.8 centimetres.

2. *Joint Mobility*

The adjacent joints to the lengthened bone must be mobile. This applies particularly to the knee and ankle joints in tibial lengthenings. If the foot cannot move at the ankle joint during a tibial lengthening there may be undue pressure resulting in damage to the articular cartilage.

3. *Equinus Deformity*

There must be no severe fixed equinus deformity at the ankle. There is a tendency for the foot to go into equinus during lengthening of the tibia, and any marked deformity should be corrected before lengthening. If necessary the tendo Achillis should be lengthened with the

first stage operation. If there is only a minor tendency towards equinus the foot is brought up into as much dorsiflexion as possible when it is immobilised in plaster of Paris at the end of the first stage operation.

4. The Age of the Patient

Operation before skeletal maturity is advisable to avoid delayed and non-union. The ideal age for operation is as soon as possible after the discrepancy has reached one and a half inches. Technical difficulties are encountered with the fitting of the lengthening machine in very small children. At least 15 cm of diaphysis is needed for fitting the lengthening apparatus, so that the child is usually six years or more at the time of operation.

METHOD OF LEG LENGTHENING

Pre-operatively and post-operatively the leg length was measured clinically and radiographically. The radiographs were taken using a standard method which is considered to have advantages over the scanogram films. With the patient at a fixed distance of six feet from the X-ray machine a radiograph is taken to include both legs. This gives accurate comparative measurements, and in practice the results were very close to the absolute length values. The films were of good definition so the presence or progress of any other disease or abnormality could be followed from these radiographs, e.g. old septic arthritis, absent fibula (Figures 2 and 3). The exposure to radiation is no greater than when performing scanogram radiographs.

Techniques of Operation

The operative methods were based on the principles laid down by Anderson (1967).

Tibial Lengthening

Tibial lengthening was performed in two stages. The first stage consisted of creating a tibio-fibular synostosis which prevents the fibula from lagging behind during the lengthening procedure which would result in a valgus foot. It was performed as a separate operation and the second stage was started only when a sound synostosis had occurred. This was thought to lead to more reliable results than when the synostosis was performed at the same time as the lengthening osteo-



Figure 2. Standard leg length radiograph demonstrating the discrepancy between the two legs and the presence of an old septic arthritis of the left hip joint.



Figure 3. Standard leg length radiograph demonstrating short right tibia and absent right fibula.

tomy. It also allowed the tendo Achillis to be stretched, by placing the foot in a calcaneus position in plaster at the end of the first stage, or by elongating it if necessary.

The fibula was approached through a postero-lateral incision and divided close to its lower epiphysis and also 3.8 cm above this level. The free piece of fibula was then impacted into a small hole drilled in the tibial cortex, and acted thereby as a bridge between the distal fibula and the tibia (Figure 4). A long leg plaster was used and weight bearing was allowed after two weeks to reduce osteoporosis.

The second stage was performed as soon as the first stage had consolidated. The Anderson frame was used and in order to obtain the best position of the pins for maintaining alignment they were inserted through the bone and attached to the frame before the osteotomy was performed. Osteotomy was then performed through a short anterior incision, the bone being divided transversely by a drill and osteotome in cases under ten years of age. In children over ten years the bone was divided "Z" fashion with a mechanical saw (Figure 5). It was considered that union was more rapid and callus more abundant when a "Z" osteotomy was employed (Figure 6). With the pins under tension the bone was divided and the ends sprang apart for 0.3 cm. No more length was gained at this point. Special precautions were taken to handle the periosteum and soft tissues gently. The fibula was re-divided at the level of the osteotomy as it had been seen in several cases that the bone had rejoined at the site of the first stage operation (Figure 7).

Femoral Lengthening

Femoral lengthening was undertaken in a very similar manner with osteotomy being performed under direct vision. Once more a "Z" osteotomy was used in cases over ten years of age. The method of distraction was the same as for tibial lengthenings with two Steinmann pins above and two below the osteotomy.

Post Operative Management

In order to allow the post-operative oedema to subside no lengthening was begun for five days. This delay also prevented discomfort during the first few days which was thought particularly undesirable in the sometimes apprehensive children undergoing this fairly lengthy procedure.

Lengthening was proceeded with at 1.5 mm per day and this was

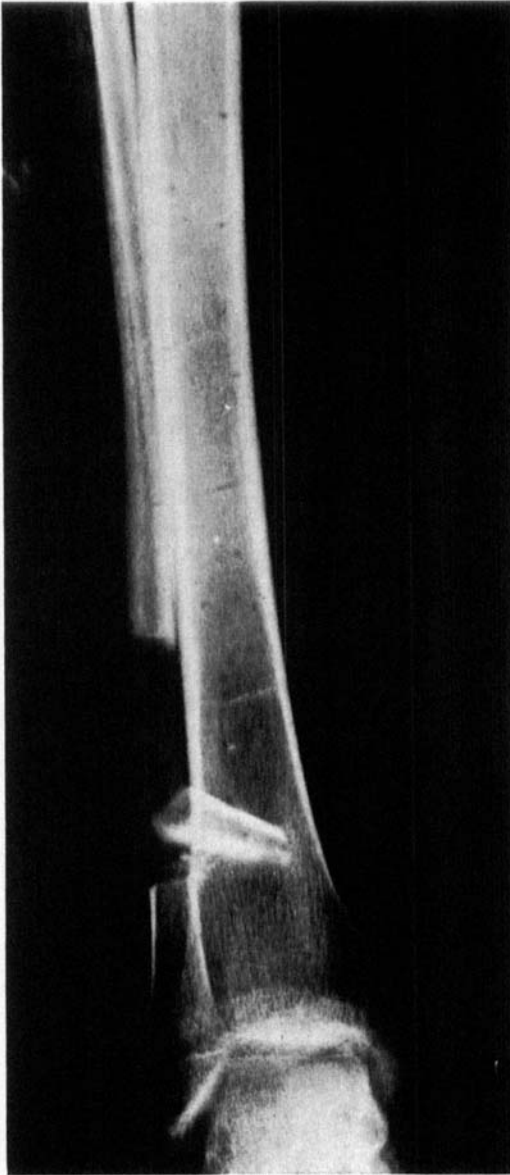


Figure 4

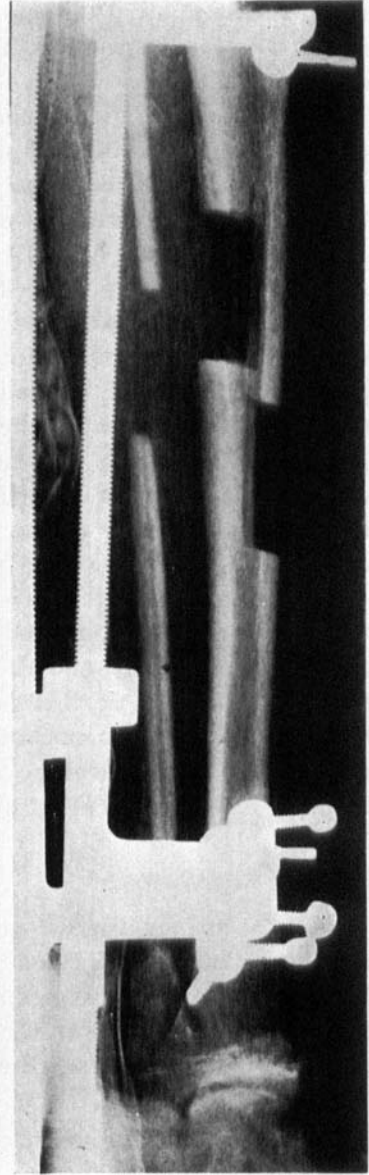


Figure 5

Figure 4. Antero-posterior radiograph of ankle showing method of producing first-stage synostosis.

Figure 5. "Z" division of tibia employed for lengthening in children over ten years of age.



Figure 6. Radiograph illustrating abundant callus formation following 'Z' division of tibia and lengthening.

continued until 3.8 cm of length had been obtained. During this period careful daily observations were made to ensure that there was no pain, no pyrexia, no loss of ankle joint movement, and no evidence of neurological or vascular embarrassment. The lengthening procedure was



Figure 7. Radiograph showing the rejoined fibula six weeks after the first-stage operation. This requires redivision of the fibula at the second-stage operation.

stopped if any of these complications developed. Minor discomfort only occurred at the time of lengthening. Some hypo- or hyperaesthesia over the dorsum of the foot occasionally developed, and this was an indication for stopping lengthening. It was usually possible to restart again after twenty-four to seventy-two hours. Increase in the equinus deformity of the foot was constant and accepted, but any rapid increase indicated immediate stopping of the lengthening. Equinus was not forcibly prevented by a plaster, thus avoiding ankle joint damage or deformation of the talus. It was prevented by placing an adhesive pad under the sole of the foot which was attached to a quarter pound weight suspended over a pulley (Figure 8). This held the foot in the maximum corrected position, but still allowed the patient to exercise the ankle easily. This had the additional advantage of keeping the muscles as active as possible.

Weekly radiographs were taken to assess callus formation and bony alignment. In the case of the tibial lengthenings there was sufficient callus for the limb to be transferred from the frame into a long leg non-weight bearing plaster six weeks after the completion of lengthening. Weight bearing began in plaster after another four weeks and the limb was left free after a further four to six weeks.

There was frequently some equinus deformity present at the time of removal of the lengthening frame. The plaster was applied without trying to correct this. When the plaster was finally removed a cork heel raise was applied to the shoe and this was gradually reduced over several months as the equinus deformity disappeared.

A longer period was required before the lengthened femurs could safely be taken off the lengthening frame, the time varying from two months to three months according to age. The patients then began mobilising in a hip spica and when the osteotomy was united were readmitted for mobilisation. Angulation at the osteotomy may occur at the time of progressing from the frame, and wedging of the plaster at this stage was necessary in two patients who had had tibial lengthening and in one who had femoral lengthening.

Assessment

The patients were reviewed at an average time of three years two months after lengthening. Twenty-one had reached skeletal maturity. Any deformity of the lower limb joints was recorded and the power of the limb compared with the pre-operative state was noted. The limb lengths were measured from the radiographs. The femur was measured



Figure 8. Photograph of patient undergoing tibial lengthening, illustrating the sole pad with attached weight used to prevent equinus deformity whilst permitting active ankle movements.

by taking the distance from the highest point of the head to the centre of the intercondylar notch and the tibia measured from the tibial spine to the centre of the distal end of the tibia. The individual bone lengths and the total length of both femur and tibia were recorded and compared with the pre-operative and the immediate post-operative measurements.

Table 2. Results of Leg Lengthening

Bone lengthened	Number of cases	Average lengthening achieved	Time of union
Tibia	35	3.6 cm	13.4 weeks
Femur	8	3.8 cm	17 weeks

RESULTS

Thirty-five tibial and eight femoral leg lengthenings had been performed since 1961 in forty-three patients. The average gain in length at the lengthening operation was 3.6 cm for tibial and 3.8 cm for femoral lengthenings (Table 2). On five patients the gain in length was less than 3.2 cm and these cases are considered later in the section on complications.

Bony Union

The average time for bony union with unsupported weight bearing was thirteen weeks for tibial lengthenings and seventeen weeks for femoral lengthenings from the time lengthening ceased (Table 2). Union was delayed beyond six months in two patients following tibial lengthening, and non-union occurred in one patient after femoral lengthening.

Maintenance of Lengthening after Operation

The gain in length at review in the lengthened bone was expressed as a percentage of the lengthening actually achieved at operation (Figure 9). These figures are thus a measure of how well the gain in length achieved by operation had been maintained. It was found that there was no significant effect on the growth rate of the femur in tibial lengthenings and on the tibia in femoral lengthenings. The maintenance of the distracted length depended upon the post-operative growth of the lengthened bone itself and not on any effect on the growth of the limb as a whole.

The patients have been subdivided into four groups on the basis of how well length was maintained in the lengthened bone.

MAINTENANCE OF LENGTH GAINED AT OPERATION

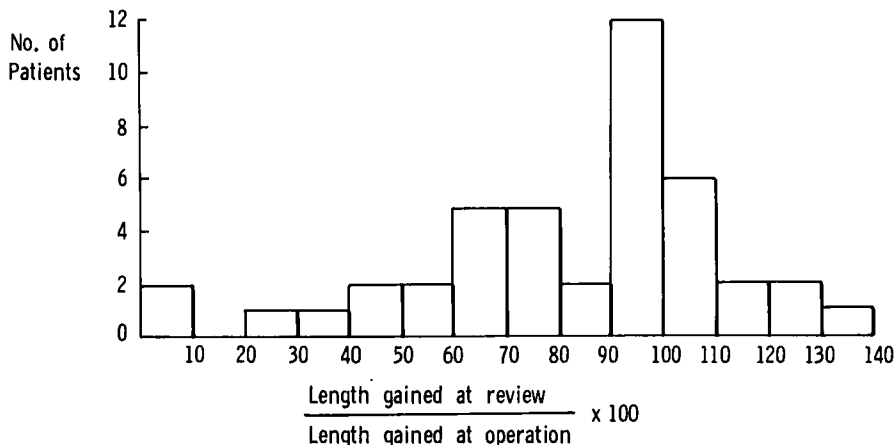


Figure 9. Maintenance of length gained at operation.

- Group I.* Gain on pre-operative length greater than that achieved at lengthening operation (i.e. more than 100 per cent maintenance of distracted length) 11 cases (26 %)
- Group II.* Good maintenance of gained length (i.e. 60-100 per cent maintenance of distracted length) 24 cases (56 %)
- Group III.* Fair maintenance only (i.e. 40-60 per cent maintenance of distracted length) 4 cases (9 %)
- Group IV.* Poor maintenance (i.e. below 40 per cent maintenance of distracted length) 4 cases (9 %)

It can be seen that thirty-five (82 per cent) fell into Groups I and II with satisfactory maintenance of gain in length in the bone lengthened. Analysis of the other eight patients (18 per cent) with fair or poor maintenance showed that five of these were operated on before the age of seven and a half years. These were patients with large and increasing discrepancies requiring operation early in life. The other three patients with only fair or poor results were all associated with complications resulting in only a small gain in length at operation.

It is also of interest that the eleven patients in Group I (26 per cent) have not only maintained the length achieved at operation, but have shown a further decrease in discrepancy in the bone lengthened at the time of review. The average follow-up time for review of these patients was two and a half years and all had an increasing discrepancy pre-

operatively. It can be said that the lengthening process had favourably affected the growth rate of the lengthened bone in these eleven patients, six of whom had been followed to maturity. Ten of these eleven patients in Group I had old poliomyelitis and one neonatal septic arthritis.

COMPLICATIONS OF TIBIAL AND FEMORAL
LENGTHENING (TABLE 3)

I. *Joint Complications*

1. *Loss of Joint Movement*

Some temporary equinus deformity occurred in almost every case during the tibial lengthening procedure. This was severe enough to cause termination of the lengthening prematurely in four patients. No patients, however, were ultimately left with any permanent increase in equinus deformity or loss of motion of the ankle joint, and the post-operative lengthening of the tendo Achillis was not required. Loss of the last five degrees of extension of the knee was present at follow-up in two tibial lengthenings. Following femoral lengthening one patient was left with five degrees fixed flexion deformity of the knee and another with a reduction of knee flexion to seventy-five degrees. The latter was the patient who was aged twenty one at the time of operation and whose convalescence was complicated by a refracture.

Table 3. Complications of Leg Lengthening

Bone lengthened	Joint complications	Bony complications	Soft tissue complications
Tibia (35 patients)	Temporary equinus deformity - 4	Delayed union - 2	Minor pin track infection - 3
	(Necessitating premature termination of lengthening process)	(1 deep infection)	Superficial wound infection - 1
	5 degrees fixed flexion of knee - 2	Slight malunion - 3	Temporary numbness of dorsum of foot - 3
		Stress refracture - 3	
Femur (8 patients)	5 degrees fixed flexion of knee - 1	Non-union - 1	Torn branch of profunda femoris - 1
	Flexion reduced to 75 degrees - 1	Stress refracture - 1	
		Malunion - 1	

2. *Valgus Deformity*

Valgus deformity was thought to have increased slightly after three tibial lengthenings. These patients all had old poliomyelitis with some valgus pre-operatively. There were no instances in which the fibula failed to come down during the lengthening procedure, and all first stage operations led to sound synostosis.

3. *Traumatic Arthritis*

Traumatic arthritis and flattening or deformation of the talus did not occur in this series of patients.

II. *Bony Complications*

1. *Delayed Union and Non-Union*

Non-union did not occur amongst the tibial lengthenings, but two patients showed delayed union. One was a girl aged fifteen who was skeletally mature at the time of operation who also developed a deep wound infection requiring drainage. The infection then settled and union, although slow, was eventually sound after ten and a half months. The other patient was again a skeletally mature girl aged fifteen whose osteotomy did not show sound union until seven months.

There was only one case of non-union, occurring in a femoral leg lengthening, for which bone grafting was needed. This child was ten years old at operation and was unusual in that union was progressing well with callus formation when a pin tract infection became evident (Figure 10). Despite prolonged immobilisation the osteotomy failed to unite. The gained length was lost and bone grafting was required. This led to satisfactory union (Figure 11). It was thought that the non-union was due to low grade infection spreading to the osteotomy site from the pin tract and causing thrombosis of the nutrient artery.

2. *Mal-Union*

Angulation at the site of osteotomy occurred in four cases, but was above ten degrees in only two. One of these was accepted in a tibia and the other required correction by osteotomy at the site of the lengthened femur.



Figure 10

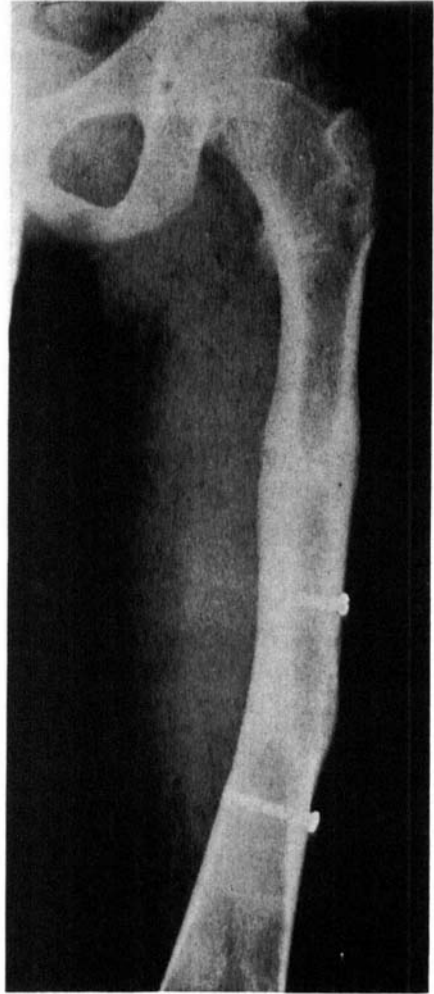


Figure 11

Figure 10. Antero-posterior radiograph of the femur showing loosening of the upper distraction pins and periosteal reaction caused by pin track infection.

Figure 11. Same patient as in Figure 10. Radiograph showing eventual union of the femur with incorporation of the bone graft.

3. *Refracture*

Refracture occurred on three occasions associated with tibial lengthenings. These were all stress-type fractures with minimal displacement and occurred between four and a half and eight months after lengthening. In each of these a transverse osteotomy had been performed. Two united well and did not result in any loss of length. In one case of femoral leg lengthening in a man of twenty-one, refracture occurred at five months and resulted in the length gained being only one inch.

III. *Soft Tissue Complications*

1. *Neurological Complications*

None of a severe nature occurred, but three of the tibial lengthening patients showed minor hypo-aesthesia over the dorsum of the foot. This was a temporary phenomenon in each case and full recovery occurred.

2. *Vascular Complications*

One femoral lengthening was complicated by a haemorrhage from a branch of the profunda femoris artery at three weeks. This was due to the avulsion and rupture of the artery by one of the Steinmann pins during distraction, and surgical ligation was required.

3. *Post-operative Muscle Weakness*

Slight muscle weakness following operation was seen in both tibial and femoral lengthenings. However, this improved and one year after operation the muscles had returned approximately to their pre-operative strengths. This applied to cases of polio with muscle weakness and to patients with normal muscle power.

4. *Wound Infection*

Deep wound infection occurred in two cases. One of these was low grade and due to spread of pin tract infection. It settled following antibiotic therapy, but appeared to be a factor in causing non-union of the osteotomy. The other infection resolved after surgical drainage, but was also associated with delay in union.

One superficial osteotomy wound infection occurred which healed rapidly, and there were three cases of minor pin tract infections, but these likewise resolved.

DISCUSSION

The incidence of complications and the possibility that some of them may lead to severe disability to a patient are features which dominate the literature and the surgeon's mind when considering mechanical lengthening of the femur or tibia. It is considered that there is an established place for this operation and that it is safe and reliable if patients are selected carefully and a modest increase in length of 3.8 cm is aimed for.

The development of foot deformities or the increase of those already present have been described as frequent complications of leg lengthening by Sofield, Blair & Millar (1958). A temporary increase in equinus deformity was almost universal in this series during lengthening, but always reverted to the pre-operative level after a few months' walking. It is considered that permanent equinus deformity is avoided by: (1) excluding cases with severe deformity which cannot be corrected by a preliminary elongation of tendo Achillis, (2) stopping the lengthening prematurely if there is rapid onset of equinus, (3) lengthening the limb by no more than 3.8 cm.

Valgus deformity of the foot was a common complication before the use of the preliminary tibio-fibular synostosis. Nowadays, the worsening of a valgus deformity should be preventable. It is more reliable to perform the synostosis as a separate operation and to await union of that before beginning the definitive lengthening procedure.

Stiffness of joints has also been described as a frequent complication by Sofield, Blair & Millar (1958). However, experience with this series has shown that permanent foot stiffness and reduced ankle movements are rare with moderate lengthenings. When stiffness has been seen to be developing, lengthening has been stopped immediately and the movement has recovered. Reduced knee movement occurs with femoral lengthenings, but this almost invariably recovers during mobilisation.

Severe vascular and neurological lesions did not occur in this series. Minor loss of sensation over the dorsum of the foot occurred in several patients, but there was rapid recovery after stopping the lengthening for a few days. In one patient a branch of the profunda femoris artery was penetrated and this bled during lengthening, but following ligation of the vessel there was no further difficulty. Reports of more severe lesions have always been associated with greater and more rapid rates of length increase.

Most published series describe an incidence of non-union following

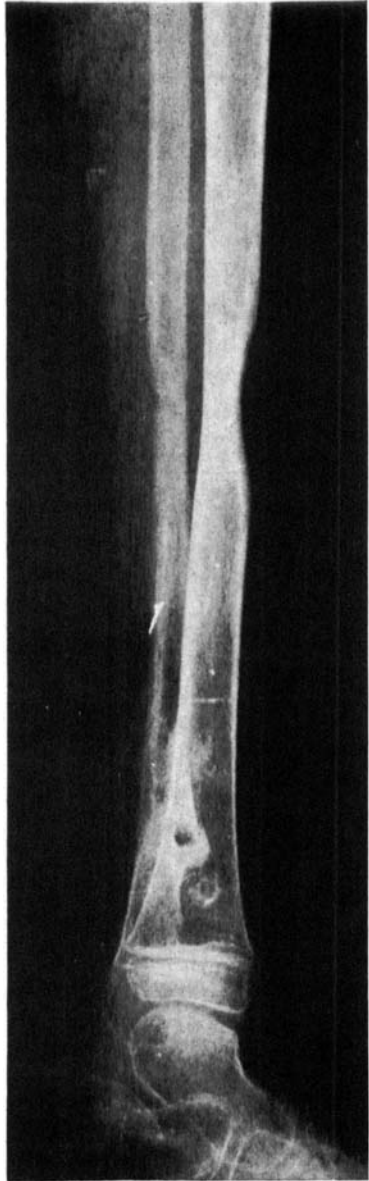
leg lengthening of approximately ten per cent (Coleman & Noonan 1967, Kawamura et al. 1968). It is noticeable that union problems are frequently in patients who are skeletally mature or nearly so at operation. Anderson (1967) has also pointed out that delayed union may result from too rapid a lengthening process. Only two cases of delayed union occurred and these were in patients aged fifteen and skeletally mature at operation. One of these was associated with deep wound infection as was the solitary case of non-union.

The low incidence of delayed and non-union in this present series was thought to be due to the majority of patients being skeletally immature at the time of operation, to the slow rate of lengthening and to the conservative increase in length. The manner of bone division may have been important in this respect. The older child is more likely to have a tendency to delayed or non-union, and therefore a "Z" osteotomy was performed on all children over ten years of age. This appeared to result in the formation of more abundant callus and thereby a sounder union. It also prevented the narrowing or tubulation of callus seen at the osteotomy site with some of the cases in which the bone was divided by transverse osteotomy (Figure 12).

The slow rate of lengthening and the conservative increase in length may have also been responsible for the good maintenance of muscle power following leg lengthening. The method used avoided overstretching and allowed gradual adaptation in the muscles to the new length of the bone. An additional factor was that activity of the limb was maintained during and after lengthening by siting the distraction pins so that the splintage did not prevent movement of the knee or ankle.

It is said that leg lengthening does not affect the growth rate of the limb (Coleman & Noonan 1967). Thirty-six patients (84 per cent) operated on in this series had a proven increasing discrepancy at the time of operation. At review thirty-five patients (82 per cent) were seen to have maintained at least 60 per cent of the lengthening achieved at operation. Eleven patients (26 per cent) even had a further decrease in discrepancy in the bone lengthened in addition to that gained by the lengthening procedure. It is concluded, therefore, that there is usually good maintenance of the length gained at operation, and that in some cases the lengthening does appear to be followed by an increase in the rate of growth of the bone lengthened. There seemed to be no significant effect of the lengthening procedure on the growth of the femur in tibial lengthenings and on that of the tibia in femoral lengthenings. The mechanism for the increase in growth rate of the lengthened bone is

Figure 12. Radiograph five months after tibial lengthening showing the narrow tube of callus formed following transverse bony division.



thought to be due to increased blood supply to the epiphysis of the limb associated with the division of the nutrient artery. (Trueta & Cavadias 1955). If the operation has to be performed on patients with a marked discrepancy early in life, then some relative loss of length can be ex-

pected. Though not performed in this series, it may be advisable in dealing with these patients to repeat the lengthening procedure at a later date, aiming at a modest length increase and thus avoiding the complications associated with greater lengthenings.

SUMMARY

1. A review of thirty-five tibial and eight femoral lengthenings performed on forty-three patients at the Nuffield Orthopaedic Centre, Oxford, since 1961 has been made to assess the value, reliability and safety of the method employed.

2. Emphasis has been laid upon the prevention of complications by the careful selection of patients, maintenance of joint mobility during the lengthening procedure, and by aiming at a modest increase in bone length.

3. Thirty-five patients out of forty-three (i.e. 82 per cent) maintained more than 60 per cent of the length achieved at operation in the bone lengthened. These included eleven patients (26 per cent) with a reduced discrepancy at the time of review compared with the immediate post-operative discrepancy, suggesting that the operation had a stimulating effect on the growth of the lengthened bone.

4. The findings in this series support the view that a useful gain in leg length can be achieved with small risk provided an increase of no more than 3.8 cm is gained by lengthening. In patients with rapidly increasing leg length discrepancy repeated lengthening may be preferable to overly ambitious single procedures.

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