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Tissue regeneration in the reconstruction of lost bone and soft tissue in the lower limbs: a preliminary report

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Summary—Tissue regeneration obtained by using a limb lengthening apparatus has been used by the authors in five cases for the repair of traumatic loss of bone and soft tissue from the lower limbs.

The principles of "regenerated tissue" introduced by Ilizarov for the lengthening of limbs were modified and applied to traumatological needs. Very encouraging results have been obtained.

If bone and soft tissue are lost from the lower limbs due to injury, priority is generally given to reconstruction of the soft tissues in order to provide adequate cover for later bone grafting. There are several techniques available. In contrast the Papinau technique (1973) involves the filling in of the bony defect with cancellous graft followed by soft tissue closure. Recently, in certain specialised centres bone and soft tissue defects have been repaired simultaneously using free microvascular composite tissue grafts.

These methods have their limitations:

(i) They require the actual bony defect to be sterile, since local infection interferes with the survival of the bone grafts and of the covering flaps.
(ii) They may require several operations.
(iii) They require long periods in hospital, sometimes in awkward positions, and prolonged rehabilitation of disability.
(iv) The end result may be unsatisfactory, particularly the strength of the bone and function of the muscle.

In the early 1950s, Ilizarov of the USSR began treating the first patients using skeletal lengthening of limbs employing a novel method (Ilizarov and Soibelman, 1969; Bianci-Maiocci, 1983; Ilizarov, 1983). This entailed:

(i) Initial osteotomy of the mid-diaphysial cortical bone without interfering with the periosteal or cancellous circulation;
(ii) Progressive distraction of the bone ends using special frames.

Growth of new tissues was induced in the artificially created gap between the bone ends by continuous distraction and was defined by Ilizarov as "regenerated tissue", its characteristics being identical to those of normal bone.

In many of Ilizarov's patients and those of other authors (Krjur *et al.*, 1985) there are reports of bone being regenerated in limbs to lengths of more than 20 cm, by using single or multiple osteotomies. The successful formation of this "regenerated tissue" depends on an ideal relationship between the osteoplastic capacity of the tissue that has been stimulated and the degree of distractive stimulus that has been applied. This will only take place if the bone remains well vascularised.

Ilizarov has extended the concept of "organic regeneration" of bone to other tissues (*e.g.* muscle, tendon, blood vessels, nerve and skin), recognising in all of them a capacity to grow in response to a distractive stimulus, a principle accepted in the use of soft tissue expanders. In practice, any living tissue which is mechanically stressed responds by growing in the direction of the stress.

In 1983, on the basis of Ilizarov's research, we began to study, in selected traumatic cases, the possibility of extending the principle of "regenerated tissue" to the repair of lost bone and soft tissue in the lower limbs. Those deemed suitable for the study were fit patients, whose damaged limbs were well vascularised and innervated and who would accept a solid external fixation frame (Figs 1 and 2).

The procedure we developed involved a number of phases. The first step was to transform a traumatised limb which had lost bone and soft tissue, into a shortened limb without a bony and soft tissue gap (Fig. 3). In the subsequent phases

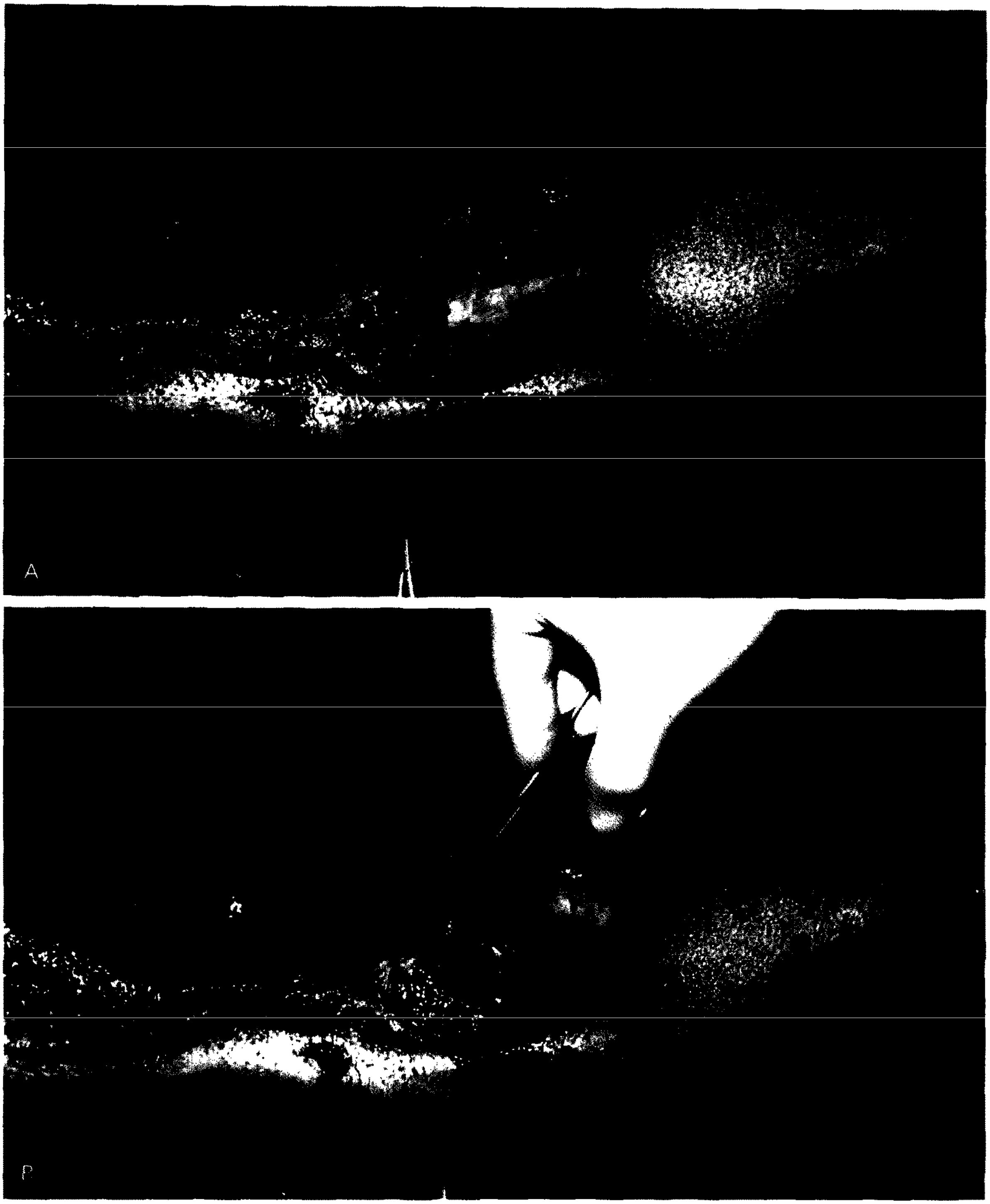

Fig. 1

Figure 1A and B—*Case 2.* Exposed diaphysial fracture of the right femur with large loss of soft tissue and sequestrum of 8 cm. The patient came under our observation 1 month after injury.

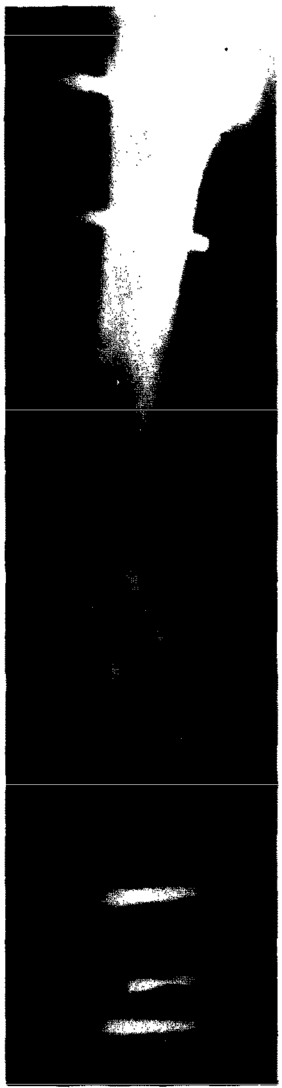
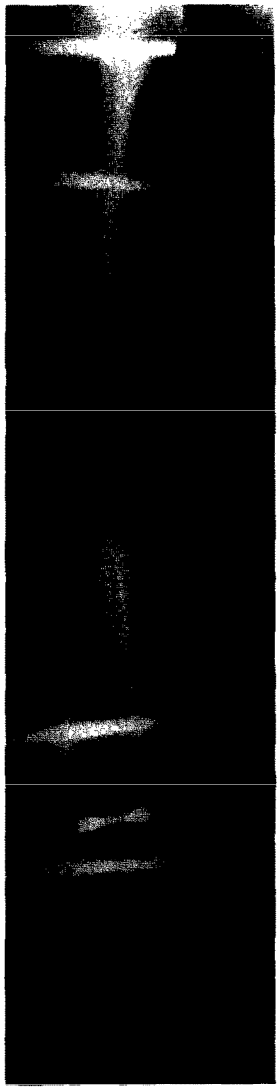
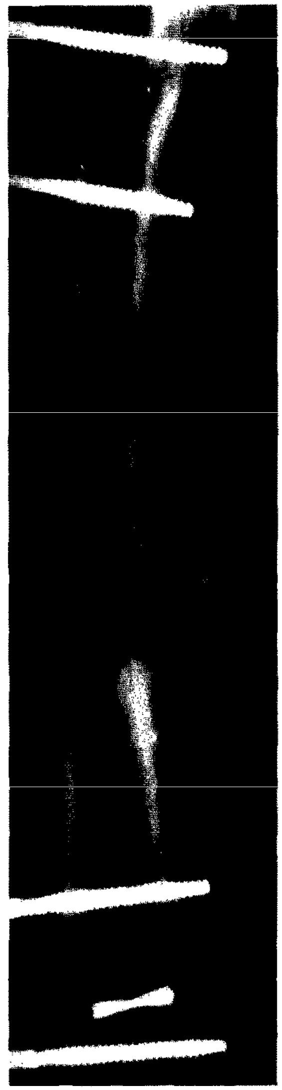
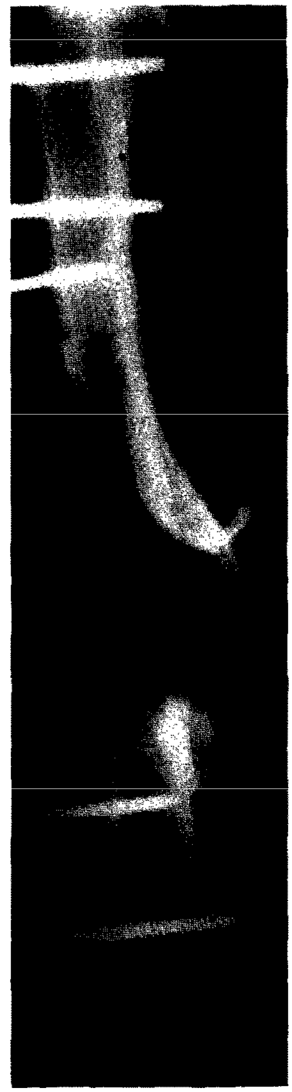

Fig. 2 Fig. 3 Fig. 4 Fig. 5

Figure 2—*Case 2.* Preoperative X-ray. Figure 3—*Case 2.* X-ray after debridement, sequestrectomy, 8 cm shortening and covering of the wound with flaps and skin grafts. Figure 4—*Case 2.* X-ray 4 weeks after starting the distraction and progressive bone regeneration. Figure 5—*Case 2.* X-ray taken in the 14th week after starting the distraction.

the shortened limb was brought back to its original length using a programme of distraction (Figs 4 and 5). This shortening process had immediate advantages:

(i) A reduction in the extent of the soft tissue deficit, making it easier to repair.
(ii) The approximation of the bone ends, which stimulated osteogenesis.

This procedure changes a complicated problem of bone and soft tissue loss into that of a closed fracture in a shortened limb.

Technique

First phase: Preparation of the wound

This involves several stages:

1. *Application of external fixation apparatus.* This

enables the position of the bone ends to be mechanically manoeuvred from the outside in order to regulate compression or distraction.

The original method used a three-dimensional fixation apparatus consisting of double pairs of concentric rings. We now consider these to be excessively bulky and complicated and prefer to use a well tested type of unilateral or bilateral support (Castaman, 1983) which requires less expertise, creates fewer risks and has a distractive capacity equal to the original models.

2. *Debridement of the defect.* This involves removal of dead soft tissue, removal of bone fragments, and clearing out all septic foci. The bone ends are then prepared. This last manoeuvre is very important as it permits better end-to-end contact, resulting in increased osteogenic activity.

In cases where there is an extensive soft tissue deficit, bone can be trimmed by 2 to 3 cm both proximally and distally. In this way the soft tissue deficit is also reduced and it becomes easier to repair with whatever plastic techniques are appropriate.

3. *Osteotomy to shorten the fibula (if necessary).* When the bone deficit involves the tibia, it is necessary to shorten the fibula by a length equivalent to the loss of the tibial segment. In cases requiring considerable shortening it is necessary to remove an adequate length of the fibular diaphysis, but minor shortening can be obtained by a simple section of the bone.

4. *End-to-end bone contact.* For minor shortening (3–5 cm) contact is obtained during the operation. The bones are kept in a stable position by an external fixation apparatus.

If more than 5 cm of shortening is required, the bone ends must be brought gradually together in order to avoid deformation of the vessels and nerves. This is achieved by daily adjustment of the external fixation apparatus (shortening of 0.5–1.0 cm per day).

5. *Bone filling (if necessary).* The Papineau technique may be useful when it is not possible to bring the bone ends into complete contact or when there are defects in the bone ends. Cancellous bone is placed to bridge the gap and acts as an osteogenic primer.

6. *Repair of lost soft tissue.* Excess of soft tissue created by shortening makes immediate repair much easier. In ideal cases the wound edges can be directly sutured together. If this is not possible, local skin flaps, fasciocutaneous or musculocutaneous flaps are generally sufficient.

Second phase: Organisation of the wound

1. *Healing of the soft tissue.*

2. *Initial bone consolidation through the formation of islands of osteogenic activity.* The time necessary for this to take place varies according to the viability of the tissues in the area traumatised. It is possible to speed this up with repeated cycles of alternating compression and distraction calibrated so as bioelectrically to "rouse" the healing bone (Yasuda *et al.*, 1955; McKibbin, 1978).

The period between the shortening operation and the appearance of a sufficient proliferative matrix has varied in our cases, from a minimum of 21 to a maximum of 75 days.

Assessment of the progress of "organisation" is based on clinical evaluation of the state of healing and on X-ray examination of the quantity of inner callus which should fill at least two-thirds of the space between the bone ends.

Third phase: Regeneration through progressive distraction

This consists of imposing a distractive force between the apposed bone ends. This force must be adequate to activate regeneration but not be so marked as to go beyond this breaking threshold.

The tolerance limits of the distraction force vary with age, constitution, physical activity and mental state of the patient, and the site and vitality of the segment under treatment.

Ilizarov has indicated the advantages of an average daily progression of 1 mm for lengthening of non-traumatised limbs. A forced increase of even 2 mm per day may go beyond the growing capacity of the growing tissue in tension, leading to delays and discontinuity of the regeneration and giving poor results. Limits also exist for nerve, muscle, vessels and skin subjected to over-rapid distraction which may lead to nerve damage, tendon-muscular retraction, reactive vasospasm and dystrophic wounds. We have managed to avoid these problems and with experience we have found that an increase in length of 0.8 to 1.0 mm per day seems to be the most effective.

It is advantageous to divide the daily increase into 3 to 5 tugs of fractions of a millimetre distributed over 24 hours. This is an operation which the patient, with the right instructions, can carry out at home.

Fourth phase: Organisation and consolidation of the "regenerated tissue"

Once the limb has been brought to the required length it is necessary to continue the external fixation until the regenerated tissue has stabilised. A programme of active exercises is instituted and the patient is advised to be as active as possible. Another useful manoeuvre is to subject the regenerated tissue at brief intervals (4–8 days) to very slight variations in distraction and compression.

On average, the time needed for the regenerated tissue to stabilise and for the bone to be ready, to allow full weight bearing, has been found to be about a month-and-a-half per centimetre of axially regenerated tissue from the end of the period of distraction.

Clinical experience

We have treated five patients in the way we have described; their details are given in the Table. Figures 1–6 illustrate the progress of patient No. 2.

Discussion

The conclusions which can be drawn from this series are based on patients who have completed treatment and on those still undergoing treatment.

With the method described, the repair of both lost bone and soft tissue can be achieved simultaneously. The repair should be carried out as early as possible since closure of the wound is the most important surgical act of the entire reconstructive process. However, the technique may be used successfully to repair chronic defects of bone and soft tissue where traditional methods of covering and bone grafting have failed.

Once shortening has been achieved and the wound closed, the patient does not usually need to stay in hospital and the need for further, often complicated, surgical operations is removed.

The maturation of the regenerated tissue is related to the functional activity of the limb and it occurs only in the presence of motor stimuli. This is why the patient is required to try his best to maintain normal use of the limb despite the limitations created by the presence of the fixation apparatus and the initial, temporary, shortening of the limb. This motor activity is useful psychologically and is also extremely important for muscular, vascular and proprioceptive rehabilitation. It is the failure of this which is the most frequent cause of permanent disability following reconstruction by traditional surgical methods which require a large number of operations. With early active mobilisation the reconstruction and re-education of the limb proceed hand in hand, improving the chance of successful rehabilitation.

This technique produces new tissues—bone, blood vessels, muscle, nerves and skin—which are anatomically, physiologically and functionally indistinguishable from the original, with all the advantages this may bring (Fig. 6).

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Table Case reports

No.	*Name*	*Age*	*Site of trauma*	*Regional shortening*	*Final lengthening*	*External supports: Application time*	*Comments*
1	O.M.	18	lower third of left leg	4 cm	4 cm	255 days	The Papineau technique was used to encourage optimum contact of the bone-ends
2*	C.G.D.	19	right femoral region	8 cm	7 cm	385 days	No problems with bone or soft tissue.
3	V.F.	51	middle third of right leg	8 cm	6 cm	420 days	Rather slow consolidation due to patient's age. Myocutaneous flaps were used.
4	F.S.	46	middle third of right leg	4 cm	3.5 cm	260 days	Delayed cutaneous scarring and bone regeneration due to a slight vascular deficit.
5	D.M.	30	left femoral region	5 cm	3.5 cm	240 days	No problems.

*Patient illustrated in the photographs.

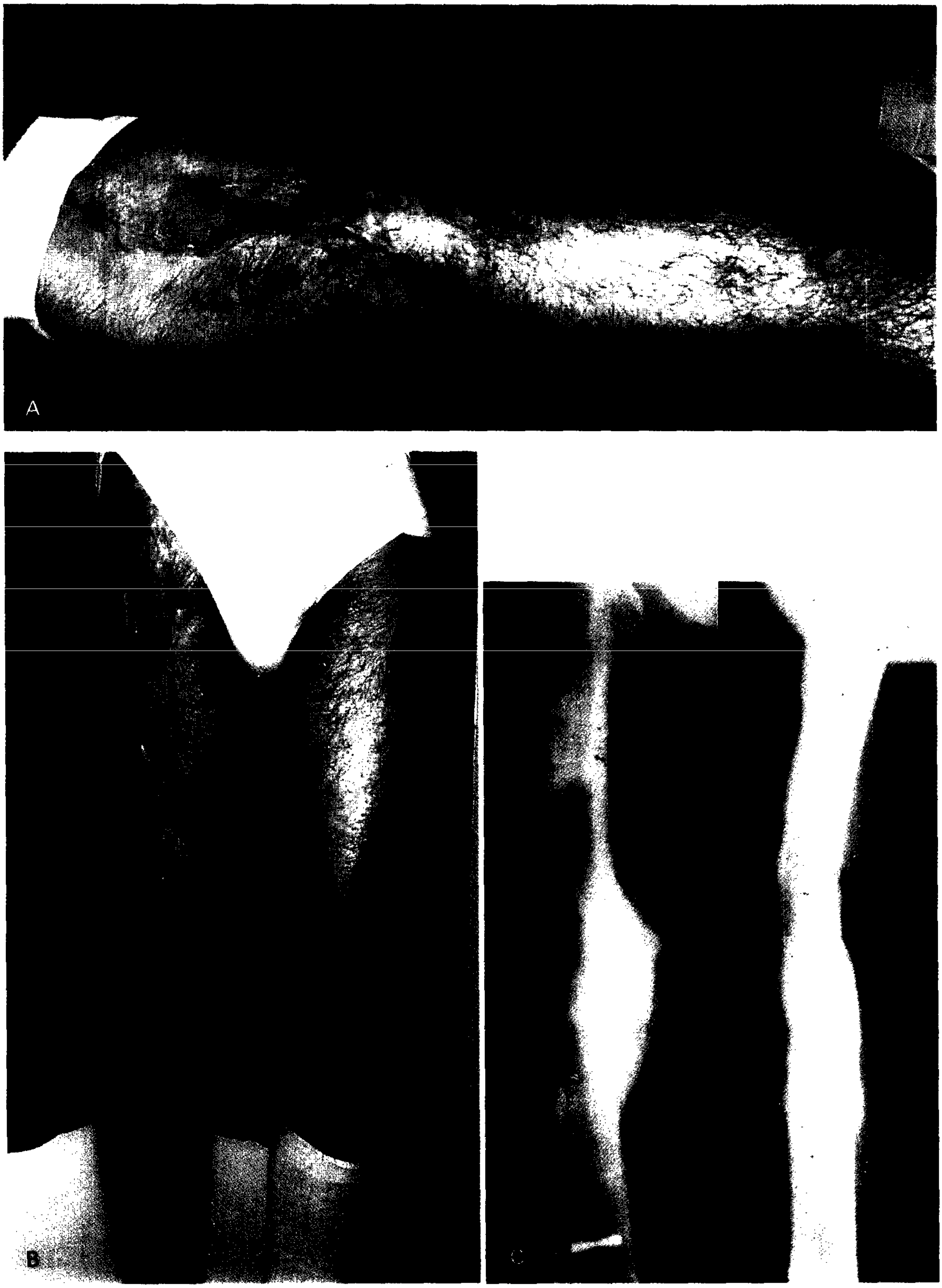

Fig. 6

Figure 6—*Case 2*. Final clinical and X-ray results at 14 months from the start of treatment. The fixation apparatus has been removed and the limb is capable of full weight-bearing. The final lengthening was 7 cm.

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