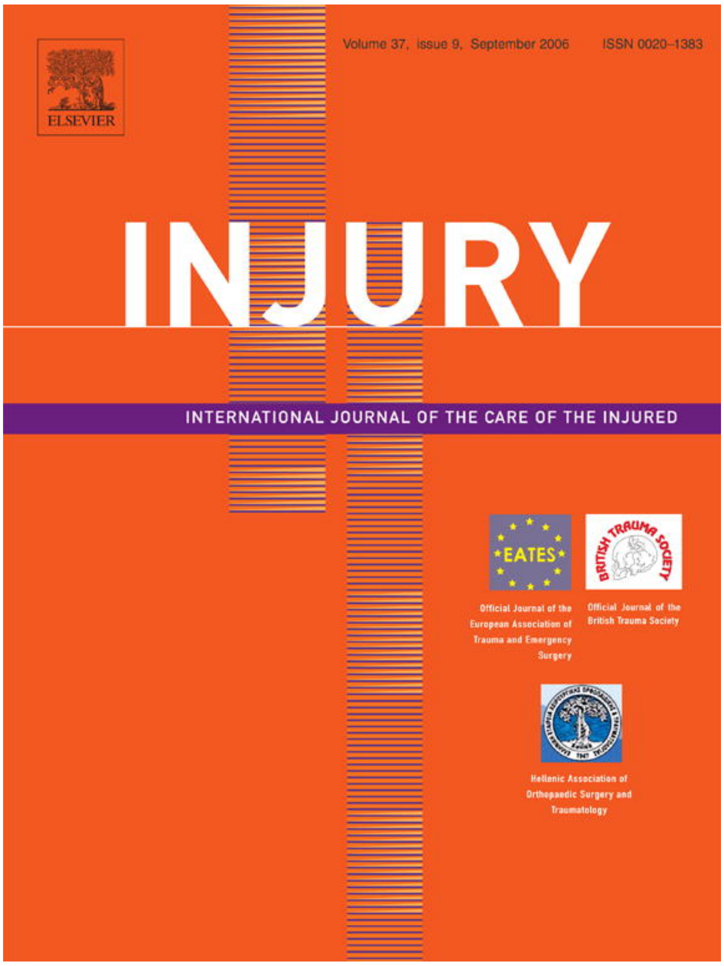
Volume 37, issue 9, September 2006
ISSN 0020-1383
ELSEVIER
INJURY
INTERNATIONAL JOURNAL OF THE CARE OF THE INJURED
EATES
BRITISH TRAUMA SOCIETY
Official Journal of the European Association of Trauma and Emergency Surgery
Official Journal of the British Trauma Society
Hellenic Association of Orthopaedic Surgery and Traumatology

Injury, Int. J. Care Injured (2006) 37, 869–876

ELSEVIER

INJURY
INTERNATIONAL JOURNAL OF THE CARE OF THE INJURED

www.elsevier.com/locate/injury

Long-term review of five leg replantations: Emergency strategy and examples of lengthening of the leg on nerve regeneration

A. Salon, P.A. Liverneaux*, T. Dubert, R. Bleton, J.Y. Alnot

Service d'Orthopédie, Hôpital Bichat, 75018 Paris, France

Accepted 5 June 2006

KEYWORDS
Amputation;
Leg lengthening;
Microsurgery;
Nerve regeneration;
Reimplantation;
Tinel's sign

Summary The success rate for leg replantation has improved with the development of shortening–lengthening protocols. We checked whether this success was maintained long term in five cases of emergency reimplantation. The significant initial shortening of 93 mm, on average, enabled direct internal osteosynthesis, secondary lengthening was initiated swiftly, in the proximal metaphyseal area, and average lengthening was 85 mm. Consolidation was achieved in all cases within normal time periods, with an average inequality in residual length of 8 mm. The speed of nerve regeneration was on average 1.926 mm/day, twice faster than usual after simple nerve suturing. At average follow-up of more than 11 years, all patients were walking. We conclude that nerve lengthening stimulates nerve regeneration, and that the results of this protocol, involving extensive initial debridement compensated by secondary lengthening, have enabled the limitations on unilateral leg replantation to be reduced.

Introduction

The factors limiting replantation of large segments of amputated limbs (or macro-replantations) differ in the upper and lower limbs. In the upper limbs replantation should always be attempted,[1,9,11] in response to requirements that are aesthetic as much as functional. Shortening, even significant shortening, does not compromise the functioning of the healthy upper limb. In the lower limbs, however, inequality in length affects posture and function when standing erect and when walking. The first macro-replantations had a low success rate because initial debridement was limited in order to restrict the inequality in length between the lower limbs.[6,18] At Bichat Hospital between 1975 and 1989, of 18 lower-limb revascularisations or macro-replantations carried out according to this conventional protocol on length preservation, only two (11%) proved successful. One such success was achieved after amputation of

* Corresponding author. Tel.: +33 6 88 89 47 79; fax: +33 5 46 82 39 30.
E-mail address: p.liverneaux@wanadoo.fr (P.A. Liverneaux).

0020–1383/$ — see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.injury.2006.06.004

both legs by a train; reimplantation on one side led to significant shortening, whereas on the other side, exceptionally, there was shortening of less than 5 cm. All the other cases were failures; essentially owing to insufficient initial debridement.

Since the appearance in 1990 of shortening—lengthening protocols for leg replantations,[2,8] we have preferred a strategy of an initial debridement sufficiently radical to avert severe septic complications, followed by lengthening in the upper tibial metaphyseal area to correct the inequality in length. This strategy has improved leg replantation results in terms of survival of the limb and limb length.[12,15,16] However, properly to evaluate the functioning of these reimplanted limbs other criteria are involved, such as resumption of work, recovery of mobility, strength and sensitivity, pain levels, stability and the aesthetic aspect long term.[4,7] In this study, we report on the results of a consecutive series of five leg replantations performed at Bichat Hospital from 1990 to 1993, with follow-up of 6—15 years.

Patients and methods

We reviewed all attempts at replantation of traumatic leg amputations at Bichat Hospital between 1990 and 1993 (Table 1). Traumatic amputations regularised immediately were not included. During this period, no attempt at replantation failed.

The level of amputation varied from the lower quarter of the leg (four cases) to the tibiotarsal joint (one case). Four amputations were complete (Fig. 1); one was subtotal, preserving the posterior tibial nerve, seat of a Sunderland four lesion, and a small posterior cutaneous bridge, but with complete devascularisation. The average age of the patients was 33.8 years (average 46 years for women and 25.5 years for men), although the sample was too small to obtain statistically significant results. All the amputations were secondary to high-energy motorcycle or industrial accidents.

The technique was unifocal (Fig. 2). As soon as the patient arrived at the hospital, a team of resuscitators took charge of the vital functions. During this time the operating team, trained in microsurgery, prepared the amputated limb in the operating unit. After broad multi-tissue debridement, the osteosynthesis was inserted on the distal fragment (four plates, of which three were medial (Fig. 1c) and one posterior plus one transplant pin), and the vasculo-nervous and tendon elements to be sutured were located. As soon as the haemodynamic readings had stabilised, replantation commenced using a pneumatic tourniquet. After multi-tissue debridement of first the distal and then the proximal fragments, the total shortening amounted on average to 93 mm.

This significant debridement of the bone, on every occasion, achieved a stable primary osteosynthesis (Fig. 2a). In each case this was protected

Table 1 Series of five leg replantations

	Case number				
	1	2	3	4	5
Patient					
Age (years)	36	28	56	26	23
Gender	Female	Male	Female	Male	Male
Profession	Computers	Driver	Farmer	Police officer	Cook
Tobacco addiction	No	No	No	Yes	Yes
Lesion					
Mechanism	Motorcycle	Truck	Manure machine	Motorcycle	Motorcycle
Level	Lower 1/4	Lower 1/3	Tibio-tarsal	Lower 1/4	Lower 1/4
Side	Left	Left	Right	Right	Left
Procedures					
Tibial osteosynthesis	Medial plate	Medial plate	Transplant pin	Internal plate	Posterior plate
Ankle external fixator	Yes	Yes	Yes	Yes	Yes
Tendons repaired (*n*)	5	3	0	4	5
Nerves repaired (*n*)	4	2	1 (secondary graft)	2 (1 continuous)	1
Arteries repaired (*n*)	2	2	2	2	2
Veins repaired (*n*)	6	4	3	2	4
Duration of ischemia (h)	7	?	6	?	6
Day of cross-leg graft	8	30	16	0	10
Month lengthening started	4	4	3	3	3

Description of lesions and therapeutic techniques.

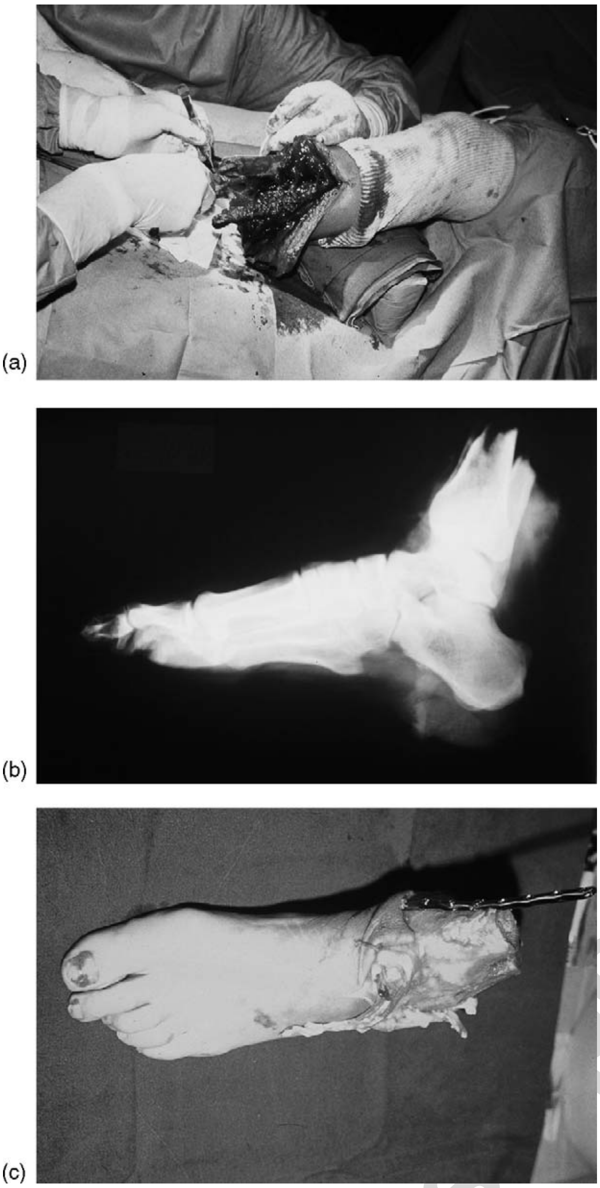

Figure 1 Traumatic amputation of the left leg of a 36-year-old woman (case 1). (a) Debridement of the multi-tissue lesions from the proximal end. (b) Preoperative radiograph of the amputated distal end. (c) Appearance of the distal end after debridement and insertion of the osteosynthetic plate.

by a Hoffmann external fixator bridging the ankle, to facilitate postoperative care and to avoid equinus deformity (Fig. 2b). Once the bone had been successfully fixed, repair of the soft tissues, tendons, nerves, arteries and veins was undertaken in that order (Table 1). On average, 34 tendons were sutured with 2/0 or 3/0 nylon thread including, on four occasions, the peroneal tendons, the tibialis anterior tendon and Achilles tendons; on three occasions, the common toe flexor; and, on two occasions, the posterior tibialis tendon.

All vasculo-nervous suturing was carried out under an operating microscope. On average two nerves were repaired in each case, including on two occasions the anterior tibial, superficial deep peroneal and sural nerves and, on four occasions, the posterior tibial nerve. It should be noted that in one instance (case 4), the posterior tibial nerve was continuous and was not repaired and, in another instance (case 3), there was no urgent repair but two 17-cm strands were grafted 8 months later. The posterior tibial nerve was the only continuous nerve in all cases. The emergency repairs to the nerves all consisted of resection of the ends in a healthy area, facilitated by shortening epiperineural sutures at separate points using 9/0 or 10/0 nylon under physiological tension, on two occasions with the addition of biological glue.

The number of veins repaired (average 3.8) was almost double the number of arteries repaired (average 2). The only instance in which two veins and two arteries were repaired (case 4) was where the posterior tibial nerve and a small cutaneous dorsal bridge remained continuous. In all cases, the anterior and posterior tibial arteries were repaired with a direct nylon 9/0 anastamosis. No bridging was required because the significant amount of shortening enabled vascular recutting in healthy areas. Among the 19 repaired were 10 anterior tibial veins, six posterior tibial veins, two sural veins and one saphenous vein. The technique for repairing the veins was identical to that for the arteries.

The time of total ischaemia from accident to revascularisation was on average 6.5 h. The one subtotal amputation benefited, in emergency treatment, from a cross-leg type of pedicled graft to cover a circumferential loss of epidermis at the ankle. The four other cases all developed quasi-circumferential cutaneous necrosis of the ankle, exposing the repaired nerves and vessels. The cutaneous necrosis was excised with secondary cover by means of a cross-leg graft, on average in the second postoperative week. In one instance (case 5), partial necrosis of the pedicled graft required the cross-leg graft to be advanced.

Lengthening was begun as soon as the cutaneous problems were controlled (Fig. 2c), at the same time as removal of the external fixator on the ankle, while the foot was still insensitive. Weight bearing was resumed partially during lengthening and then completely once lengthening had ceased, with the external fixator still in place. This involved progressive proximal tibial metaphyseal lengthening with a Garches T (Orthofix®), at the rate of 1 mm/day, under regular radiological monitoring of the callus and clinical neurological monitoring of the peroneal nerve. Lengthening was stopped if there was pain or

Figure 2 Replantation of the left leg of a 36-year-old woman (case 1). (a) Immediate postoperative radiograph showing fixing of the tibia by an internal plate and of the fibula by a pin. (b) Immediate postoperative appearance of the replanted leg. Note the advantage of suspending the limb with the external fixator bridging the ankle. (c) Radiograph of the replanted limb at the start of lengthening on the left and at the end of lengthening on the right. Note that lengthening began while the distal tibial osteosynthesis fracture site was still not consolidated.

when the inequality in length was deemed acceptable (85 mm on average). After temporary dynamisation, the external fixator was removed when the radiological appearance of the callus was considered satisfactory.

The results were evaluated according to radiological, neurological and functional criteria. Radiologically, the quality of the two bone calluses (for the fracture and for the lengthening) was evaluated, as well as any axial defects by pangonometry. Recovery

Table 2 Clinical and radiological results (except for sensitivity) of series of five leg replantations

	Case number				
	1	2	3	4	5
Follow-up (years)	15	15	6	11.5	11
Clinical					
Leg pain (VAS/10)	1 (lumbar pains)	1	0 (sciatica)	0	0
Monopodal weight bearing	Stable	Unstable	Unstable	Stable	Stable
Walking perimeter (h)	1	3/4	1	Unlimited	Unlimited
Radiological					
Shortening (mm)	85	115	85	90	90
Lengthening (mm)	80	120	55	85	85
Inequality in length (mm)	5	5	30	5	5
Femorotibial angle (°)	+2	+6	0	+5	+14
Socio-professional					
Interventions (*n*)	7	6	8	7	5
Time off work (years)	4	4	No resumption	?	3
Resumption of work	Reclassification	Special arrangements	No	Reclassification	Reclassification
Resumption of sports	Cycling	No	No	Yes	Yes
Permanent impairment (%)	70	55	?	?	?
Family	Divorced	Divorced, remarried	*Idem* married	*Idem* single	Same partner

VAS, pain assessment on an visual analogue scale.

of sensitivity was assessed by monitoring the progression of the distal Tinel's sign, and of motor function by observing the flexion of the toes and intrinsic muscles of the foot. The recovery of sensitivity in the sole of the foot was assessed during the operating programme at the last follow-up, using the British Medical Research Council's international classification. A treadmill was used to study case 1. Walking perimeter, mobility of ankle, knee and toes, quality of monopodal weight bearing and aesthetic aspect were also noted. Pain was evaluated at the level of the replanted limb and the spinal column by the need for analgesia and a visual pain scale. Lastly, number of days in hospital, time to resuming work, number of anaesthetics and interventions, and the resumption of sporting and/or leisure activities were recorded.

Results

No general or serious septic complications were observed. The average stay in the postanaesthesia care unit was 24 h, and on average 10 units of blood compensated for perioperative blood loss, with removal of perfusions after 24—72 h. Postoperative hepatitis in the oldest patient resolved. After an average follow-up of more than 11 years, no patient regretted replantation.

On the clinical level (Table 2), the replanted limb was not painful, or only slightly painful, but two patients complained of lumbago or sciatica. The average residual shortening was 8 mm, compensated for by a heel-piece (four cases) or an orthopaedic shoe (one case). Unilateral weight bearing on the replanted limb for longer than 30 s was possible (Fig. 3) in each case with compensation, but was unstable in two cases. All the patients could walk without crutches for more than 1 km and two patients could run. The mobility of the knee was normal in all cases, but mobility of the ankle was limited on average to 20° plantar flexion with zero dorsal flexion. In all cases there was anaesthesia of the dorsum of the foot, but plantar sensitivity was on average S3+. All the patients exhibited toe grips, but none had any trophic cutaneous disorder. In case 1, where walking had been studied on a treadmill, the result was hyperlateral varus-related weight bearing and a predominant lateral attack on weight bearing on the heel.

Radiologically, all the lengthening and fracture sites had consolidated at the latest follow-up (Fig. 3). In two cases, surgical retreatment was required during the lengthening process to correct a rotational fault (case 5), and also after lengthening (case 4) for a fracture of the lengthening callus. Tiny axial defects were noted in the frontal plane (except in case 5 with 14° of valgus) without lateral femoro-tibial arthrosis.

The operating programme was long and painful, with an average of 6.6 interventions. The period off work was more than 3 years in all cases. One patient, 56 years old at the time of the accident, ceased to work altogether; another went back to work in the previous job with some adaptations; and the last three patients were reclassified. Only two

Figure 3 Result, after 15 years, of a left leg replantation in a 36-year-old woman (case 1). (a) Radiograph of the front of both legs. Note the consolidation of the fracture sites and the lengthening of the replanted limb. (b) Stable bipodal weight bearing. Note the aesthetic effect after cross-leg pedicled grafting of the right leg. (c) Stable monopodal weight bearing on the replanted limb. Note the absence of ankle equinus or knee flessum.

Table 3 Recovery of sensitivity in series of five leg replantations

	Case number				
	1	2	3	4	5
V_T distal (mm/day)	?	0.952	?	1	1.11
V_T total (mm/day)	?	1.904	?	1.875	2
Sole of foot at last follow up (BMRC)	S3+	S2	S3+	S4	S4

V_T distal = $D/(t_1 - t_2)$, where V_T is the velocity of advance of Tinel's sign after repair of the posterior tibial nerve during, and D is the distance travelled, by Tinel's sign between the times t_1 and t_2. V_T total = $D + A/(t_1 - t_2)$, where A is the lengthening between times t_1 and t_2. BMRC, 1954 international classification of sensitivity of the British Medical Research Council.

patients resumed sporting activities (cases 4 and 5). The marital status of three patients remained stable (cases 3, 4 and 5), but the remaining two divorced (cases 1 and 2); one of these remarried (case 2).

Discussion

Internal osteosynthesis carries a high risk of sepsis and pseudarthrosis in open leg fractures and, *a fortiori*, in the major multi-tissue intervention involved in leg replantation. However, provided there is rigorous debridement back to healthy tissue and cutaneous cover is adapted to the requirements of a systematic cross-leg pedicled graft, internal osteosynthesis is, in our view, the method of choice for leg replantations. In our series, no deep sepsis or osteitis was encountered, despite secondary cutaneous union failure. The internal osteosynthesis, whether by screwed plate as in four cases, or by transplant pin as in one case, should temporarily be systematically protected by an external fixator bridging the ankle. After the operation, the paralysed, oedematous and insensitive replanted foot represents a dead weight, generating not only mechanical stresses on the osteosynthesis but also the risk of cutaneous eschar. Installing an external fixator bridging the ankle neutralises the mechanical stresses on the fracture site and enables the limb to be suspended, facilitating nursing and resistance to oedema.

Thus, shortening does limit septic complications, but the inequality in length is not acceptable in the lower limbs. Lengthening is therefore essential, representing on average in our series a quarter of the overall length of the leg, to enable a return to walking without cumbersome equipment. This, however, involves uncertainty in terms of bone consolidation and recovery of sensitivity.

A tibial metaphyseal osteotomy over a potentially septic distal tibial osteosynthesis may seem risky. Lengthening the tibia, apart from any replantation, presents known complications, in particular slow mineralisation of the callus or even of the fractures.[17] However, despite surgical retreatment to correct the angle in two cases, consolidation was achieved in all cases at both the fracture site and the osteotomy.

Lengthening was started before any consolidation at the fracture site. It could therefore be concluded that the osteotomy had a positive effect on consolidation of the distal osteosynthesis site, as in studies in which osteotomies have been performed for stubborn pseudarthrosis, with surprising results.[3] The hypothesis advanced proposes the salting out of bone growth factors[1,10]; but, whatever the reason, the lengthening bone is of good quality, with normal tibial calibre and good cortico-medullary differentiation.

It might be expected that nerve regeneration would have slowed or deteriorated during lengthening in the tibial metaphyseal area. Palsies of the peroneal nerve are indeed not uncommon in conventional leg lengthening.[5,14] However, in our series (cases 2, 4 and 5), where progression of Tinel's sign was carefully studied, nerve regeneration was estimated as 1.926 mm/day, instead of the usual rate of 1 mm/day. Furthermore, tibial lengthening was evidently responsible for nerve lengthening (Table 3); in case 3, where a nerve graft was performed after 85 mm of lengthening at 1 mm/day, the proximal nerve resection margin was found to be full, suggesting nerve regeneration across the nerve-lengthening area. Does scarring of the distal nerve suture stimulate nerve lengthening? Probably yes, through the release of nerve growth factors, as shown in some recent studies.[13] In our series, the absence of neurological complications after lengthening can be explained by the fact that, because of the large amount of initial debridement (apart from the neck of the fibula), the peroneal nerve was not retained by rigid anatomical fixings and could therefore lengthen with fewer constraints.

Conclusions

The requirement for considerable debridement in traumatic distal leg amputations is no longer a limitation on the indications for unilateral replantation. Distal amputations are considered more favourable than proximal amputations because they spare the proximal muscle masses. With the help of a rigorous strategy right from the start (based on initial shortening of always more than 8 cm), a stable osteosynthesis and suitably adapted cutaneous cover, there were no setbacks in these five cases of leg replantation or revascularisation. In four instances, after secondary lengthening, walking, antalgia, return to work and even sporting activities could be resumed. In one case, where there was insufficient lengthening, painful sciatica persisted but the results are still a broad improvement on those of amputation with conventional orthopaedic apparatus. Although fitting a prosthesis to a distal amputation stump is traditionally easy and ensures quick comfort, the recovery of a sensitive and sometimes mobile foot, at the cost of very low morbidity, justifies a more complex strategy.

The protocol of upper metaphyseal lengthening over a distal reimplantation seems to conflict with generally accepted ideas on nerve recovery. The most notable results of this series, where four patients had direct nerve repairs, were the rate of nerve regeneration, the quality of sensation finally achieved and the significant relative lengthening of the nerve trunks even during nerve regeneration. It is as if, far from slowing down reinnervation, lengthening accelerated it.

References

[1] Bail HJ, Raschke MJ, Kolbeck S, et al. Recombinant species-specific growth hormone increases hard callus formation in distraction osteogenesis. Bone 2002;30:11724.

[2] Battiston B, Tos P, Pontini I, Ferrero S. Lower limb replantation: indications and a new scoring system. Microsurgery 2002;22:187—92.

[3] Burghele N, Troianescu O, Serban N, et al. The Paltrinieri operation in treatment of pseudarthroses of the leg. Rev Chir Oncol Radiol ORL Oftalmol Stomatol 1979;28:443—8.

[4] Chen ZW, Zeng BF. Replantation of the lower extremity. Clin Plast Surg 1983;10:103—13.

[5] Chuang TY, Chan RC, Chin LS, Hsu TC. Neuromuscular injury during limb lengthening. A longitudinal follow-up by rabbit tibial model. Arch Phys Med Rehabil 1995;76: 467—70.

[6] Fukui A, Tamai S. Present status of replantation in Japan. Microsurgery 1995;15:15842—7.

[7] Gayle LB, Lineaweaver WC, Buncke GM, et al. Lower extremity replantation. Clin Plast Surg 1991;18:437—47.

[8] Guelmi K, Maladry D, Mitz V, Lemerle JP. Replantation de jambe suivie d'allongement du tibia. A propos d'un cas. Rev Chir Orthop Reparatrice Appar Mot 1991;77:53—6.

[9] Leung PC. Hand replantation in a 83-year-old woman: the oldest replantation? Plast Reconstr Surg 1979;64:416—8.

[10] Li G, Ryaby JT, Carney DH, Wang H. Bone formation is enhanced by thrombin-related peptide TP508 during distraction osteogenesis. J Orthop Res 2005;23:196—202.

[11] Liverneaux P. Hand replantation in an 88-year-old man: replanted senior? Chirur Main 2002;21:355—8.

[12] Muneuchi G, Susuki S, Ito O, Kurokawa M. Successful replantation of an amputated leg with severe crush ans avulsion injury in an ederly patient: case report. J Reconstr Microsurg 2003;19:87—92.

[13] Osamura N, Ikeda K, Ito T, et al. Induction of interleukin-6 in dorsal root ganglion neurons after gradual elongation of rat sciatic nerve. Exp Neurol 2005;195:61—70.

[14] Paley D. Problems, obstacles and complications of limb lengthening by the Ilizarov technique. Clin Orthop 1990;250:81—104.

[15] Parmaksizoglu F, Beyzadeoglu T. Lengthening of replanted or revascularized lower limbs: is length discrepancy a contraindication for limb salvage? J Reconstr Microsurg 2002;18:471—80.

[16] Usui M, Kimura T, Yamazaki J. Replantation of the distal part of the leg. J Bone Joint Surg Am 1990;72:1370—3.

[17] Wise DI, Shaw DL, Lawton JO, Wang H. Femoral neck fracture following leg lengthening by callotasis. Injury 1994;25: 403—4.

[18] Zhang J, Chen ZW. Retrospective of the replantation of severed limbs in the People's Republic of China: current status and prospects. Microsurgery 2002;22:39—43.