Microvascular Corticoperiosteal Flap of the Femoral Condyle in the Treatment of Recalcitrant Shaft Nonunions in the Upper limb

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Purpose. To present our experience in the treatment of recalcitrant nonunion in the upper limb using microsurgical corticoperiosteal flaps.
Materials and methods. Five adults (18-54 years of age), operated before referral to our centre on different occasions (3-7 times), were treated for upper limb shaft nonunion (2 humerus, 2 ulnas and 1 radius). After radical debridement and osteosynthesis, the bone defect was filled with cancellous bone graft and a corticoperiosteal flap from the femoral condyle, with anastomosis of local blood vessels. In all cases immediate mobilization was initiated without protection.
Results. Flap survival was 100%, there were no postoperative complications. Healing determined by X-rays was seen in less than 3 months in all cases. Three patients recovered complete joint functional range of motion (ROM).
Conclusion. Corticoperiosteal flaps can help to resolve recalcitrant nonunions in the upper limb, even in cases that have suffered infection. An obvious bone bridge can be seen in X-rays 2 months after the procedure.

Key words: *recalcitrant nonunion, vascularized bone graft, periosteal flan, microsurgery.*

Colgajo microvascular corticoperióstico de cóndilo femoral para las pseudoartrosis diafisarias recalcitrantes de extremidad superior

Objetivo. Presentar nuestra experiencia en el tratamiento de pseudoartrosis recalcitrantes en la extremidad superior mediante colgajos corticoperiósticos microquirúrgicos.
Material y método. Cinco adultos (18-54 años), intervenidos antes de su traslado a nuestro centro en varias ocasiones (entre 3 y 7 veces), fueron tratados de pseudoartrosis diafisarias de la extremidad superior (dos húmeros, dos cúbitos y un radio). Tras el desbridamiento radical y osteosíntesis, el defecto óseo se rellenó con injerto de esponjosa y un colgajo corticoperióstico del cóndilo femoral, anastomosado a los vasos locales. Todos los casos comenzaron la movilización inmediata sin protección.
Resultados. La supervivencia de los colgajos fue del 100%, sin complicaciones postoperatorias. Se consiguió la consolidación radiológica en menos de tres meses en todos los casos. Tres pacientes recuperaron el rango completo de movilidad articular y dos el rango de movilidad funcional.
Conclusión. Los colgajos corticoperiósticos pueden ayudar a solventar pseudoartrosis recalcitrantes en la extremidad superior, incluso en casos de antecedentes de infección. Puede ser apreciado un evidente puente óseo en las radiografías 2 meses después del procedimiento.

Palabras clave: *pseudoartrosis recalcitrante, injerto óseo vascularizado, colgajo periostio, microcirugía.*

New techniques in bone fixation as well as progress in the field of the biology of bone healing are enabling the achievement of positive results in the treatment of long-bone fractures. Occasionally, a small percentage of cases evolves adversely towards nonunion [1,2]. Most of these cases consolidate with conventional methods (grafting and rigid synthesis)[1,3-7], but there is one kind of nonunion which, for various reasons, cannot be corrected in spite of the implementation of this kind of treatment. We have defined it as a "recalcitrant nonunion", and it is considered to be the kind of nonunion which does not consolidate after three or more interventions, albeit the lack of consensus regarding the exact number of surgical attempts that are actually necessary to consider it a recalcitrant nonunion[8]. We have also defined a series of fac-

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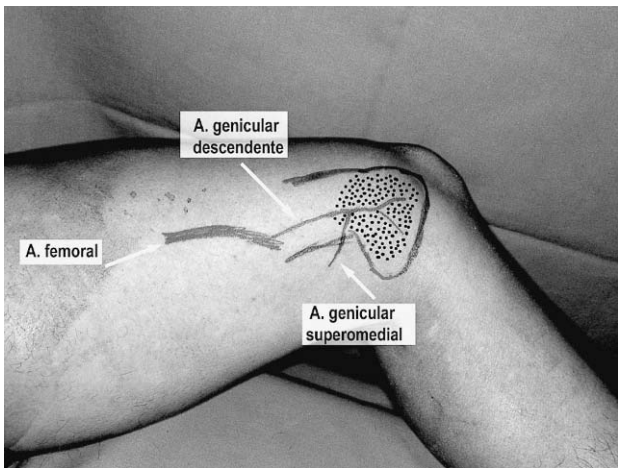

Figure 1. *Design of a medial femoral condyle corticoperiosteal flap. The dotted area corresponds to the bone and periostium donor area.*

tors leading to a negative prognosis-infection, high-energy trauma, compound fracture and loss of coverage, whose coexistence reduces the possibility of treating of the fracture.

When a recalcitrant nonunion is intervened, the surgeon must consider the need to exchange the osteosynthesis material and, possibly, of correcting deformities, all of which will further deteriorate the already damaged local blood supply. In these situations, treatment must include an additional step-one that is different from all previous steps and oriented fundamentally towards improving the local vascular conditions. Free flaps allow the provision of healthy tissue in devascularized areas.

The employment of vascularized bone grafting is widely accepted in the treatment of nonunions with significant bone defects. However, in the case of minor defects, the use of classical techniques (serial debridement, internal stabilization and non-vascularized bone grafting) is common practice. On the basis of the concept stated above (the need of vascularized tissue), we believe that in the case of recalcitrant nonunions with minor defects, the combination of vascularized periostium and the thin cortex of the femoral condyle, with its own vascularization, is the biologically ideal solution. The corticoperiosteal flap (CF) of the femoral condyle[9] possesses these features (Fig. 1).

In this paper we present our experience of the treatment of recalcitrant nonunions in long upper limb bones with bone defects of less than 3cm using CF flaps from the medial femoral condyle.

MATERIALS AND METHODS

We present five patients with a recalcitrant shaft nonunion in their upper limb treated during 2003 and 2004: 2 humeruses, 2 ulnas and 1 radius (table 1). The series consists of 4 males and 1 female of 18-54 years of age.

Initial trauma was an open fracture in 3 cases, a comminuted humeral fracture, and a closed, subsequently infected, fracture. Two patients had a previous clinical history of osteomyelitis, but there were no signs of active infection at the time they were referred to our unit. One of the open fractures was treated with a local plasty at another hospital. All patients were intervened on three or more occasions (3-7 range). On first examining them, we found that the hardware remained *in situ* in 4 of the cases; the fifth patient had been treated with an external fixator after the removal of the material in an attempt to control infection. The patients were undergoing pain, functional disability, inflammation and a feeling of instability. The related negative factors are shown in Table 1.

In all five cases the fracture site was approached via a previous excision. The osteosynthesis material was removed and the fibrous tissue was debrided and devitalized. After realignment of the bone, all existing bone defects were assessed. While one surgical team carried out rigid

Table 1. Demographic and pre-operative data

Case	1	2	3	4	5
Age	18	32	28	42	54
Gender	F	M	M	M	M
Occupation	Student	Truck-driver	economist	bricklayer	Engine-driver
Affected bone	Ulna	humerus	radius	humerus	ulna
Time since discharge (months)	5	14	24	19	29
Open fracture	Yes	Yes	Yes	No	No
No. of previous procedures	3	3	3	3	7
High-energy trauma	Yes	Yes	Yes	Yes	No
In-situ hardware	No	Yes	Yes	Yes	Yes
Coverage flap	No	Yes[a]	No	No	No
History of osteomyelitis[b]	Yes	No	No	No	Yes
Nonunion type[o]	Atrophic	Atrophic	Atrophic	Atrophic	Atrophic
Bone defect (c)	3	0	1	0	2

(a) Pediculated lattisimus dorsi flap used as coverage on first intervention.
(b) None of the patients presented signs of active infection at the time of the last operation
F= female; M= male

synthesis using locking compression plates (LCP) (4 cases) and one dynamic compression plate (DCP) for an ulna, 3.5mm for the forearm and 4.5mm for the humerus, the other team carried out the elevation of the flap.

Surgical anatomy

The periostium and the cortex of the medial femoral condyle are irrigated by very thin blood vessels proceeding from an arcade formed on their surface (Fig. 1). This arcade is reached by the articulating branch of the descending genicular artery and the superomedial geniculate artery among others. These two arteries irrigate the region competitively so that when one is developed the other one is hypoplastic, and vice versa. The descending genicular artery provides an 8-10cm peduncle and a vessel with a 1.5-2mm caliber. This is the ideal kind of peduncle and it is dominant in 80% of the cases. The superomedial geniculate artery on the other hand possesses a similar caliber when dominant but its peduncle is much shorter (3-4cm), and its dissection is more difficult.

Surgical technique

The dissection technique we used is the one described by Sakai-Doi et al[9]. By means of an excision in the medial aspect of the thigh, the femur is approached through the fascial hiatus between the vastus medialis and the sartorius. Towards the anterior region of the medial intermuscular cartilage, and posterior to the vastus medialis, is the hiatus opening with the articulating branch of the descending genicular artery. In this hiatus are the perforate arteries which must be dissected if a cutaneous island is to be included (two of the five cases). After this step the whole of the vascular anatomy of the flap and the donor femoral condyle must be exposed (Fig. 2). Next, the peduncle of the descending genicular artery should be isolated. If the artery is hypoplastic, dissection must be continued towards the posterior region, up to the origin of the superomedial geniculate artery in the popliteal. A small skin flap, based on the perforating artery of the descending genicular vessels, can be included with a view to post-surgical monitoring.

The flap area that is to be used is delimited by means of a thin osteotome (preserving the vascular arcade); next, the flap, constituted by the periostium, the cortex and a thin layer of cancellous bone, is elevated. This maneuver is done mostly by hand, advancing gradually, from all sides, and avoiding a crowbar movement, lest the flap should be torn.

On releasing the ischemia cuff, bleeding in the periostium and on the surface of the cancellous bone is checked. The flap is transferred after osteosynthesis (Fig.3). The corticoperisoteal flap is molded so as to embrace the bone defect. Doi suggests simply folding it, but we have found this to be a risky maneuver due to the thinness of the periosteal vessels. We therefore recommend making a series of notches with an

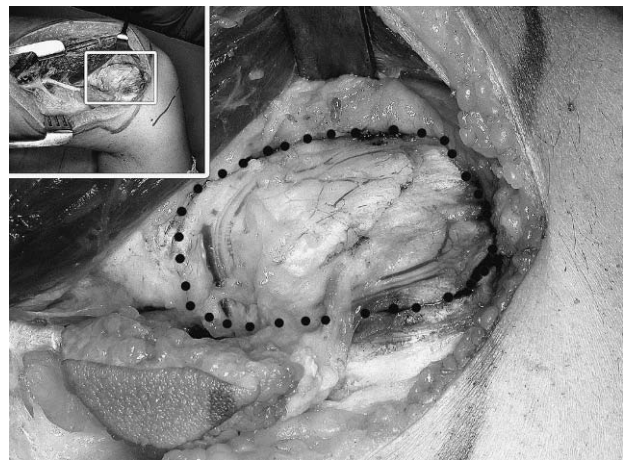

Figure 2. *Close-up view during flap elevation showing the abundance of periosteal vessels on the medial femoral condyle. The flap borders have been premarked with an osteotome (dotted line). Upper left hand corner frame: panoramic view.*

Figure 3. *Elevated corticoperiosteal flap with a long peduncle (dependent on the descending geniculate arteries and veins). Above: periosteal surface. Below: under-surface, showing exposed cancellous tissue. The flap is constituted by periostium, medial cortex and 2-3mm of cancellous tissue from the femoral condyle.*

oscillating saw, in the manner of a dotted line, on the underside of the flap (cancellous tissue), without reaching the periostium. This debilitates the cortex so that it can be folded easily (fig.4). The flap is sutured to the donor site on the opposite side of the plate and the space between the plate and the flap is filled in with cancellous bone graft taken from the femoral condyle. The arterial anastomoses are performed termino-laterally to the dominant local artery (brachial, radial, or ulnar); the vein anastomoses, on the other hand, were either termino-terminal to subcutaneous veins or concomitant.

Once the wound has been closed layer by layer, a bandage with an opening is placed over it so as to control the perfusion of the cutaneous island, and also to control the flap with a Doppler probe if necessary. A suction drainage

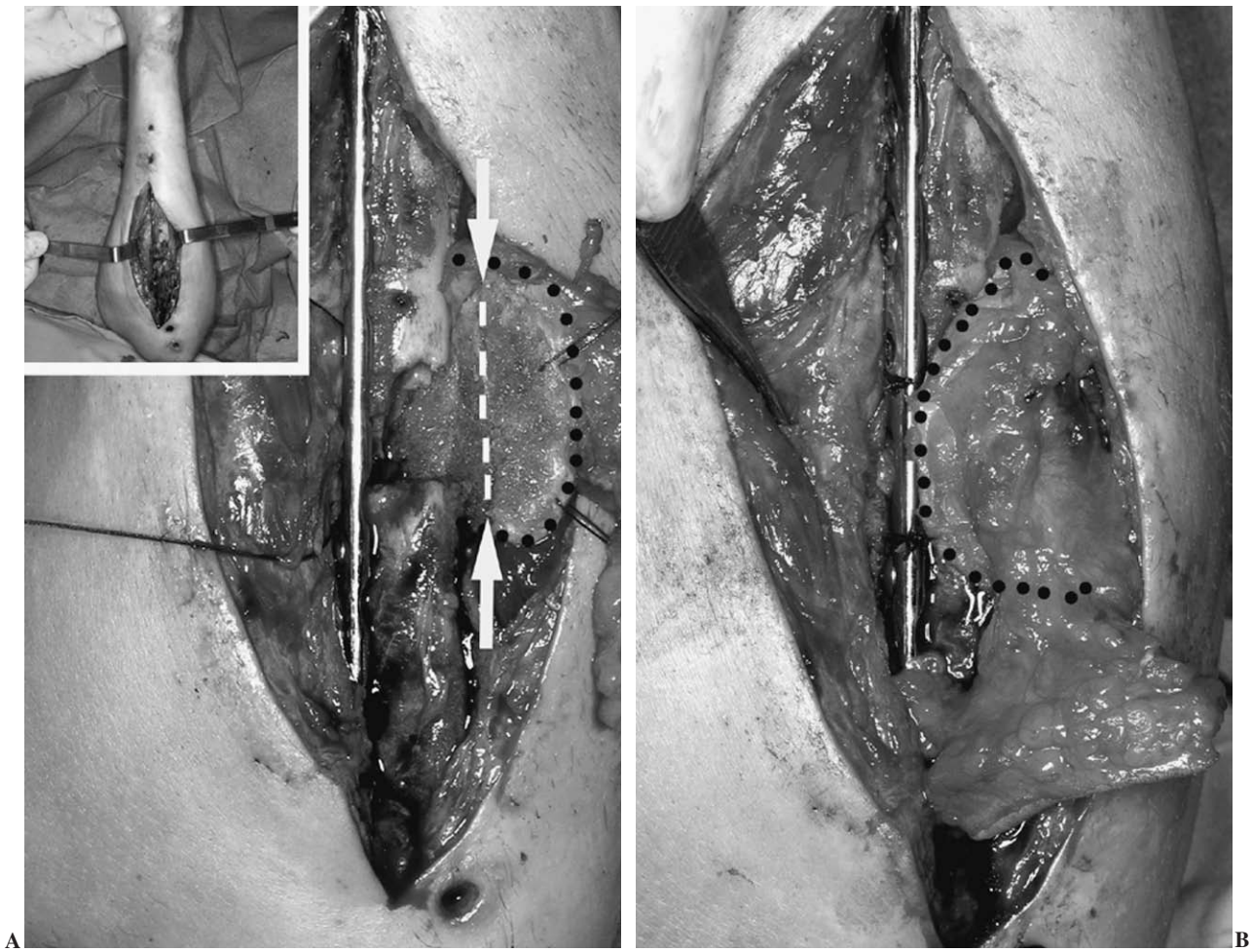

Figure 4. *Corticoperiosteal flap technique for adaptation to an ulna (case 1). Left (A): the flap (marked with a dotted line) is already fixed and adapted to the anterior and medial aspects of the ulna and elevated with a thread before being applied to the posterior aspect of the ulna. The white arrows and the dotted line delineate the osteotomy in the corticocancellous section of the flap where it is folded to form a 90° angle to cover the posterior aspect of the ulna (right). Right (B): the flap covers the defect in the ulna and is sutured to the plate (cancellous bone graft introduced beneath the flap). Upper left-hand corner frame: panoramic view.*

was left in the donor site and a soft bandage was applied. This enabled unrestricted weight-bearing to take place 24 hours later. The medication used was hemorrheologic and intravenous up to the moment of discharge from hospital 5 days later, and antithrombotic prophylaxis was used until unrestricted mobilization was possible (2-3 weeks).

Mobilization of the limb without a splint was begun during immediate post-surgical treatment. Monthly X-ray controls were carried out. The supervision period varied between 8 and 24 months (average: 14 months).

RESULTS

Flap dissection time varied (45-90 minutes), depending on anatomic variations and on the inclusion of the cutaneous island. Synthesis was performed simultaneously by another team of surgeons. In 3 of the cases in this series the peduncle was short. In 2 cases which had a 3cm peduncle –the dominant was the superomedial geniculate artery— it was necessary to resort to venous grafting in one case and to a change of the recipient bed for anastomosis in the other. In another case, although there was sufficient descending genicular artery, there was also an anatomic variation of the femoral artery at the abductor hiatus, which resulted in an abnormally short peduncle of the descending genicular artery (an approximately 4cm long artery). Artery caliber was approximately between 1-1.5mm in the cases with a short peduncle and between 1.5-2.5mm when a long peduncle was used with the descending genicular artery.

All the flaps survived and in all the cases radiological consolidation, which was obtained in the second and third months after surgery, showed a juxtacortical bone bridge (figs. 5 and 6).

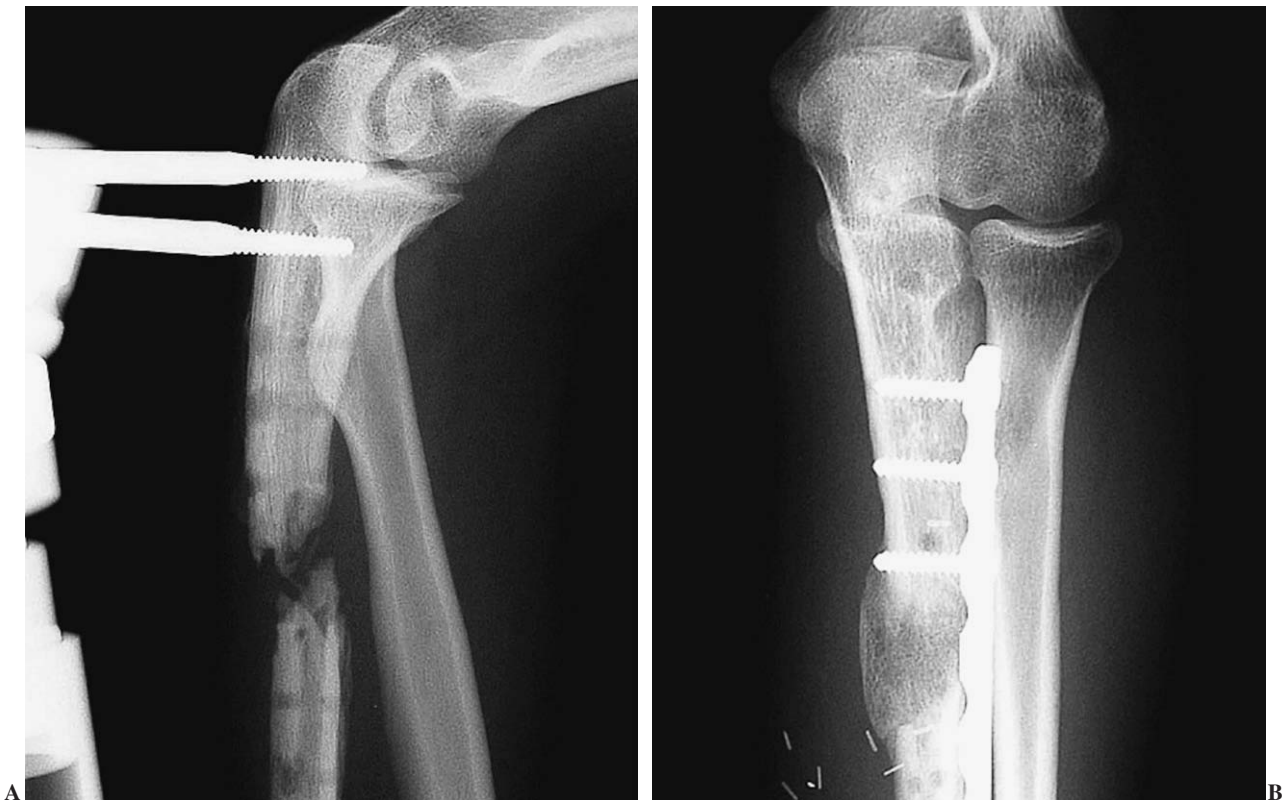

Figure 5. *Case 1. Recalcitrant ulnar nonunion. Pre-surgical X-ray (A); post-surgical X-ray (B), 2 months after intervention. The result after applying the microvascular flap was satisfactory.*

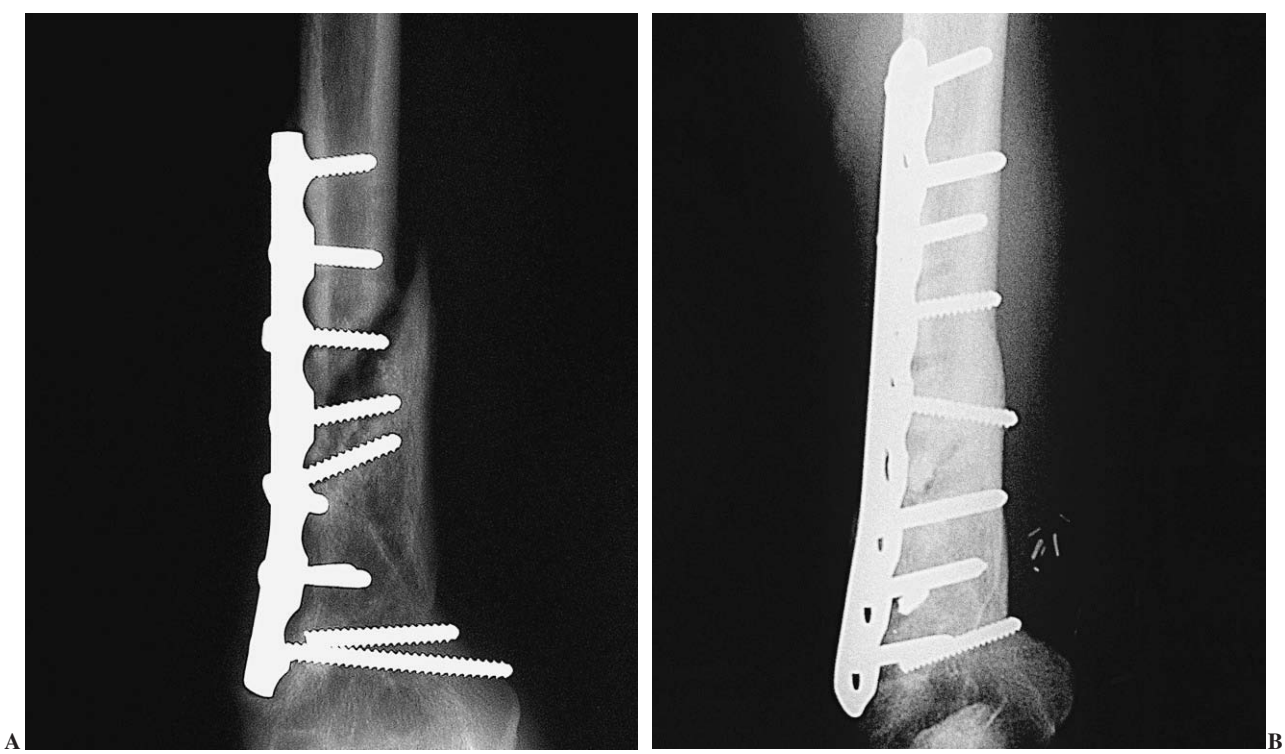

Figure 6. *Case 4. Pre-surgical X-ray of a recalcitrant nonunion in the distal humerus (A). A butterfly-shaped fragment has consolidated in the distal region, but the proximal region has not consolidated after two attempts to change the hardware and bone grafting. X-ray taken 3 months after microvascular flap placement (B). The result was satisfactory.*

All patients reported the improvement of their clinical condition and the disappearance of discomfort. There were no cases of bone infection recurrence. The range of mobility of neighboring joints was 100% in three cases. One patient (case 1) had a limitation of supination for a period of time, which ended when the material was removed one year later. In the last examination the pronation and flexo-extension of the elbow were complete, while there remained a 60% limitation of supination (active).

Patient 4, who had suffered the loss of a 12cm section of the radial nerve, underwent a palliative tendinous transfer six months after bone reconstruction. In the case of patient 2, an economist who is keen on sports, we have suggested the extraction of the osteosynthesis material, which at the moment he prefers to postpone. Additional surgery is not foreseeable in any other of the patients.

In the donor areas, local discomfort in the knee was frequent at the initial stage of ambulation. In all cases it diminished in less than two months. At the last examination the patients did not report any problem in the donor site.

DISCUSSION

The usual therapeutic response for cases of nonunion is to attempt a stable osteosynthesis with autologous bone grafting. High rates of consolidation are attained using this method 3, 4, 7. Nevertheless, the problem is quite different in the case of recalcitrant (or potentially recalcitrant) nonunions. González del Pino et al[8] define as recalcitrant those nonunions which have been operated at least three times. They list a series of factors which lead to an adverse prognostic and result in a high rate of nonunion: previous infection, compound fracture, high energy trauma, *in situ* osteosynthesis material, and loss of substance with subsequent need of coverage. Confronted with a previously operated nonunion in which all these adverse factors are present, and suspecting the high possibility of having consolidation problems, the surgeon should add a different procedure from those used previously (osteosynthesis plus bone grafting).

It is widely known that any part of the body can be isolated by a given peduncle (artery and vein) and can be transplanted from one place in the body to another without losing its biological properties, as long as its nutrition is reestablished by means of vascular anastomosis. Taylor et al[10, 11] have shown that both the fibula and the iliac bone could be transplanted maintaining the biological and mechanical properties of the bone. Moreover, the transplanted bone becomes hypertrophied and adapts to the functional needs of the recipient bed 10. Vascularized bone transplant is a procedure that has been widely accepted for the reconstruction of serious bone defects. When defects are very small or irregular, classical bone flaps are not recommended because it is too complicated to isolate the arteries that vascularize the segment in question and there is a risk that the transplanted section might be rendered avascular. Also, they bulk in areas with scanty soft tissue. Nonunion in the upper limbs generally has the following characteristics: small defects in zones that do not accept a significant increase in volume satisfactorily[12]. It is in these situations that the CF flap is most extensively indicated[9,12-18].

The CF flap has been used in cases of avascular necrosis of the ankle bone[12], but its best indication is for recalcitrant shaft nonunion with small bone defects in the upper limbs[9,12]. The advantage of using the CF flap resides in the slightly concave shape of the medial cortex of the femoral condyle, in the absence of muscle coverage, which reduces the risk of damaging the periosteal vessels, and in the possibility of including a cutaneous island.

Notwithstanding how long the nonunion has existed, its cure can be achieved by using the classical methods: stable osteosynthesis in well-vascularized zones, and autologous bone grafting[1,5,7]. Although we argue that all the cases we treated were complex nonunions that required *exceptional* action, we must admit that our work might be criticized on the grounds that "the cases could have been solved using conventional methods". Indeed, the answer cannot be categorical in the case of either of the two views, but even the most optimistic researchers advise against using conventional methods when the bed where the graft will be inserted is inelastic-scarred and/or it has lost its muscle lining[4]. We have settled for the use of CF flaps with this group of patients, because the traditional alternatives had already been used before, and we considered it was important not to repeat them without modifying the biological medium for consolidation. Furthermore, we not only took into account the fact that three or more adverse prognosis factors were present in all the cases but we also considered the socioeconomic factor (late discharge of patients in a working age), all of which led us to procure the necessary means to attain consolidation.

The CF flap has been proved to be efficacious in all the cases presented in this work. The evident presence of a bone bridge in X-rays taken only two months after the procedure must be emphasized (fig. 6). This hypertrophy of the bone callus can be explained in reference to the high osteogenic, osteoinductive and osteoblastic capacity of the flap[19]. Due to its elasticity it enables the covering of part of the nonunion focus easily. Moreover, abundant cancellous bone graft can be obtained from the femoral condyle without additional morbidity.

As far as the disadvantages are concerned, we must mention longer surgical time on a non-vascularized graft, the need of microsurgery techniques and of rigorous post-surgical controls. The elevation of the flap takes between 45 and 90 minutes, but this does not add more time to the procedure due to the possibility of working on two surgical

fields. The time required for anastomosis can be esteemed at 40 minutes with a maximum extent of two hours. Naturally, any microsurgical flap procedure requires a well-trained team of surgeons and competent post-surgical hospital controls. The vessels that are used in the CF flap are quite smaller than those used in the "more frequently used" free flaps (from the radius, the lattisimus dorsi, and the fibula). Also, the possibility of anatomic variations must be considered[20], since they may transform a relatively simple operation (when the peduncle depends on the descending genicular artery) into a complex one (when the artery used is the superomedial geniculate, or there are variations of the femoral, as in three of our cases). In these contexts it might be necessary to use venous grafting, or other recourses which may be unknown to the acting surgeon. Nevertheless, we believe that the CF flap has a key role to play in the recalcitrant shaft nonunions in the upper limbs because of its very low morbidity rate and very high rate of success.

Finally, the procedure does not cause the patient any damage or injury; neither does it preclude other alternatives, since removal of a large section of potentially healthy bone is not necessary to interpose the vascularized graft (fibula or iliac bone). Quite on the contrary, this procedure combines a classical intervention (rigid synthesis plus autologous cancellous bone grafting) with one that makes the recipient bed healthier (by adding vascularized tissue) and generates more bone (the vascularized CF flap). In case of failure, all the advantages of the classical intervention will be present and no defect for the interposition of a conventional vascularized bone graft will have been created.

In conclusion, the CF vascularized flap is an attractive therapeutic option for the treatment of recalcitrant nonunions with minor bone defects in the upper limbs, including cases with recorded infection. The existence of an obvious bone bridge in X-rays taken two months after treatment must be highlighted.

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