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Use of a delayed cortical bone graft to treat diaphyseal defects in the forearm

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Abstract The technique of delayed autogenous cortical bone grafting was used in 17 patients (6 women, 11 men, with an average age of 22 years) to treat diaphyseal defects resulting mainly from closed or compound fractures complicated by infection and bone tissue loss. Bones affected were the humerus in 1 case, the radius in 7 cases, the ulna in 4 cases, the radius and ulna in 2 cases, the first metacarpal in 1 case, and the femur in 2 cases. The average length of the defect was 5.7 cm and the graft, prepared from the anteromedial aspect of the tibia, was at least 1.5 cm longer than the defect. The graft application was combined with rigid internal fixation using an AO 3.5 mm DCP plate in most cases and this permitted early active movement. Union occurred without the need for any additional grafting procedure in 14 patients and within an average of 23 weeks. In most cases there was an increase in the thickness of the graft probably as a result of osteo-induction, with consequent restoration of the original diameter of the recipient bone diaphysis. The most frequent complication was infection (4 cases), and this was controlled by means of debridement, cleaning and antibiotics. A delayed graft provides mechanical support, incorporates quickly and is therefore a reasonable alternative method for treating diaphyseal defects of long bones, particularly in the upper limb.

Résumé La technique de l'autogreffe corticale retardée a été utilisée chez 17 patients (six femmes et onze hommes à l'âge moyen de 22 ans) pour traiter les pertes de substance osseuse diaphysaires, résultant surtout des fractures fermées ou ouvertes compliquées par l'infection et la perte d'os, du radius (7), cubitus (4), radius et cubitus (2), humérus (1), premier métacarpean (1) et femur (1). La longueur moyenne des fractures était de 5,7 cm et la greffe a été préparée dans la face antéro-interne

de la tibia au moins 1,5 cm plus longue que la fracture. L'application de la greffe a été faite par la fixation interne rigide avec une plaque DCP de 3,5 mm dans la majorité de cas, ce qui a permis la mobilisation précoce. L'intégration de la greffe s'est faite, sans qu'on fasse une nouvelle greffe, sur 14 patients, dans une période moyenne de 22,9 semaines. Dans la majorité de cas, il y a eu une augmentation de l'épaisseur de la greffe peut-être comme résultat de l'ostéo-induction, avec la restauration conséquente du diamètre original de la diaphyse de l'os receveur. La complication la plus fréquente a été l'infection (4 cas) contrôlée par le débridement, le nettoyage chirurgical et l'usage des antibiotiques. L'autogreffe retardée donne un support mécanique correct et est incorporée rapidement et c'est alors une alternative raisonnable pour le traitement des fractures diaphysaires des os longs, surtout des membres supérieurs.

Introduction

Despite the good results reported with the use of autogenous cortical grafts it is well known that they take longer to integrate than cancellous grafts, and this delayed integration is often aggravated by the presence of fibrosis and a decreased blood supply within the defect.

However, it has been demonstrated that integration of a cortical graft can be improved. This, together with the greater mechanical strength of cortical bone, can make cortical grafting a very attractive treatment for diaphyseal defects. According to Moore, a delayed cortical graft is incorporated more rapidly than a conventional cortical graft, and he believed that improved healing resulted from the new osteoid which had formed around the transferred bone [8].

Virtually no other description of the clinical use of delayed cortical bone grafts was published until the early 1960s. However, a few experimental investigations were reported and these confirmed some degree of interest in this technique. Siffert and Barash (based on experimental studies in dogs and rabbits in which they tested a type of

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delayed iliac cortico-cancellous bone graft) stated that the osteoid formed around the graft undergoes necrosis a few days after transplantation and could not in any way contribute to integration [11]. However, Lima (using experimental studies in dogs) demonstrated that delayed autogenous cortical graft revascularises and reorganises earlier than a fresh cortical graft and felt that this must be due to the newly formed osteoid [6].

In an experimental study in dogs Barbieri and De Souza [1] used histology, bone labelling with tetracycline, and scintigraphy with technetium (Tc99m-pyrophosphate) to demonstrate that both delayed and fresh autogenous cortical grafts undergo the same healing process, but that a delayed graft is incorporated twice as quickly as a fresh graft. They concluded that such a difference in behaviour was due either to the fact that the delayed graft was 3 weeks older than the fresh graft, or to an intrinsic increased capability to integrate, probably linked to the osteoid formed around the grafted cortex, and this agrees with the ideas of Nelson [10].

Delayed autogenous cortical grafts were successfully used clinically by Eyre-Brook, Baily and Price [5] and by Campanacci et al. [4] to treat congenital pseudarthrosis of the tibia employing the McFarland by-pass technique [7]. We have also reported our previous experience using this type of graft to treat difficult cases of diaphyseal defects of long bones in 7 patients [3]. This success stimulated us to continue to use delayed cortical autogenous bone grafts rather than other forms of bone grafting. The results of this further investigation are reported in this article.

Material and methods

Seventeen patients (6 women, 11 men) with an average age of 22 years (range 3 to 36 years) with diaphyseal defects of long bones, predominantly in the upper limb, were treated by delayed autogenous cortical grafting. The affected bones were the humerus in 1 patient (Fig. 1), the isolated radius in 7 patients (Fig. 2, Fig. 3), the ulna alone in 4 patients (Fig. 4), both radius and ulna

Fig. 1A–C Nonunion of the humerus following a GIII compound fracture. **A** The 5.2 cm long diaphyseal defect maintained on an external fixator; **B** immediate postoperative appearance, showing the delayed graft (arrows) and the internal fixation; **C** appearance at 11 weeks, showing advanced healing of the graft

Fig. 2A–C Isolated closed fracture of the radius internally fixed with a 3.5 mm DCP, evolving with infection. **A** bone resorption at the level of the fracture; **B** 6.5 cm-long diaphyseal defect resulting from débridement, maintained on an external fixator; **C** completely healed delayed graft at 24 weeks, although a slight separation remains in the proximal bone-graft junction

Fig. 3A–C Isolated fracture of the radius resulting from a gunshot wound and evolving with infection and bone necrosis.

A 6 cm-long diaphyseal defect maintained on an external fixator, after débridement; **B** immediate postoperative appearance, showing the graft slotted into both recipient stumps (arrows); **C** final appearance, showing a marked increase in thickness of the graft and reconstitution of the diaphysis, one year later

Fig. 4A–D Isolated GIII compound fracture of the ulna. **A** initial 4 cm long diaphyseal defect, after débridement; **B** appearance at 6 weeks, showing the 6.1 cm long delayed graft; **C** appearance at 16 weeks showing on-going healing; **D** appearance at 26 weeks, showing complete healing

in 2 patients, the femur in 2 patients (Fig. 5), and the first metacarpal bone in 1 patient (Fig. 6). The defects had resulted from trauma in 13 patients, from osteomyelitis in 2 and from tumour resection in 2. All patients were operated on within an average of 10.6 months (range 4 to 20 months) from trauma or from the first operation in the tumour cases.

The cases resulting from trauma included 7 compound fractures of different severity and 6 closed fractures. The closed fractures had been managed by open reduction and internal fixation, but later developed complications such as infection with pseudarthrosis, or mal-union. In one of the cases there was delayed union of the first metacarpal bone which had been previously submitted to combined external and minimal internal fixation and cancellous bone grafting but had failed to unite.

Two of the 7 compound fractures were Gustillo's type III, with severe contamination and moderate bone loss. On admission both were managed by thorough cleaning, débridement and external fixation until the soft tissues had healed. In a second operation, one of them received a free fibular graft combined with internal fixation, but went on to partial resorption and fracture of the graft, and loosening of the fixation. At a further operation a delayed cortical graft was used, again combined with internal fixation and this was followed by good union. Another case was treated immediately with a delayed cortical graft combined with internal fixation, and healed well.

Three of the compound fractures were Gustillo's type II, one of them resulting from a gunshot wound, and this was treated primarily with open reduction, extensive cleaning and débridement, and internal fixation. The other 2 cases were treated with cleaning, débridement, and external fixation until the soft tissues had healed; one of these patients then required internal fixation with cancellous bone grafting, while the other continued with external fixation. All these 3 patients developed infection and non-union which was managed by serial cleaning and débridement until the infection was controlled and a delayed bone graft could be performed.

Two compound fractures were Gustillo's type I, one of them being treated primarily with open reduction and internal fixation, and the other with a plaster cast. Both developed infection and non-union and were treated with cleaning, débridement, plate removal (where applicable) and external fixation. Delayed bone grafting combined with internal fixation was carried out as soon as the infection had subsided.

The 8 fractures which went on to an infected pseudarthrosis were treated first with bone and soft tissue débridement, external fixation and systemic antibiotics. It was only after the infection had been cured, and soft tissue healing had occurred, that delayed bone grafting was performed. The 4 fractures which developed non-infected pseudarthrosis or mal-union were managed first by resection

Fig. 5A–D Closed fracture of the femur initially treated with an intramedullary nail, which evolved with infection and incomplete healing, maintained on an external fixator. **A** initial appearance; **B** immediate postoperative appearance, showing the delayed graft fixed onto both stumps of the femur with two screws and the external fixator maintained; **C** complete healing of the graft at 16 weeks; **D** complete remodelling of the femur diaphysis 2 years and 8 months later

of the pseudarthrosis or by osteotomy which was then followed by the application of a lengthening device to recover the original bone length. A delayed graft was done at a second operation.

The defect had been caused by osteomyelitis complicated by fracture in 2 patients. Primary treatment had been drainage, debridement of the infected and necrotic soft tissues, installation of a continuous irrigation-suction wash-out system combined with systemic antibiotics, and external fixation. One patient was treated with a delayed graft and internal fixation as soon as the infection had completely subsided, and external fixation was maintained in the other patient until a sterile atrophic non-union developed. Resection of the entire non-union site and application of a lengthening device to recover the original bone length was followed by delayed grafting. The graft was fixed to the recipient bone with a 3.5 mm DCP plate.

The patient with Ewing's sarcoma had already received a vascularised fibular graft following serial chemotherapy and resection

Fig. 6A–D Non-union of the first metacarpal bone following a closed intraarticular fracture, unsuccessfully treated by arthrodesis with cancellous graft from the radius. **A** initial appearance on a lengthening device; **B** appearance at 10 weeks, showing the on-going healing of the delayed graft (arrows); **C** appearance at 22 weeks, showing complete healing; **D** remodelling just over one year later

of the entire ulnar shaft. She developed non-union at the junction of the vascularised graft with the proximal ulnar stump. This was treated with a delayed cortical graft which unfortunately failed to unite the defect. Two further conventional grafting procedures were then necessary to produce union.

The patient with a giant cell tumour at the distal end of the radius (the defect resulting from wide resection of the tumour) was treated primarily with a free graft of the proximal end of the fibula. This went on to partial necrosis, with infection and fracture of the graft, and destroyed the anatomy of the wrist joint. The free fibula graft was removed and replaced 4 weeks later with a delayed cortical graft. This was fixed to the proximal radial stump and to carpal bones with a 10-hole 3.5 mm DCP plate. An external fixator was used during the delay period of 4 weeks in order to maintain length and to allow soft tissue healing and cure of the infection.

Fig. 7A, B Immediate postoperative radiographic appearance of the donor tibia (**A**) and after removal of the graft, 4 weeks later (**B**)

Operative technique

The delayed cortical graft was taken from a tibia 3 to 4 weeks prior to its implantation into the recipient site. The tibia was approached through a straight longitudinal incision of appropriate length on the antero-medial aspect of the leg. The periosteum was also incised longitudinally and carefully detached so as to permit exposure of the bone. The graft was always rectangular in shape, never wider than half the width of the antero-medial tibial cortex and about 1.5 to 2.0 cm longer than the estimated defect to be corrected. The 4 corner points of the graft were marked with a dermatographic pencil and lines linking them were marked with a delicate Lambotte osteotome. An air-driven oscillating saw was then used to cut into the medullary cavity. The rectangle of bone was then entirely detached and immediately returned to its bed. The periosteum was sutured over the bone and the wound was closed in layers (Fig. 7). A suction drain was left in the subcutaneous space for 24 h. The entire procedure lasted just over 1 h. Prophylactic antibiotics were started the day before the operation and maintained for 3 days. The leg was protected with a dorsal plaster slab for 10 days, followed, after removal of the stitches, by a weight-bearing below-knee PTB type plaster cast.

The graft site was again approached through the same incision 3 to 4 weeks later. The periosteum was incised longitudinally and delicately detached from the bone by sharp dissection so as not to damage the osteoid which had formed around the cortical window. The graft was then removed from its bed by cutting through the osteotomy lines with a scalpel, and taken immediately to the recipient site which had been prepared to receive it. The periosteum was sutured over the donor site and the wound was closed in layers, a suction drain being used for 24 h.

At the recipient site, tissue of doubtful viability was removed from the bone surfaces and the medullary canal was opened. The graft was carefully shaped to fit exactly into the defect and to produce good contact with the bone ends. This was done by preparing either a step-cut in both surfaces to slot the graft into, or as a peg on each end of the graft which could then be slotted into the medullary canal.

The average defect was 5.7 cm (range 2 to 11 cm) and the average length of the graft was 8 cm (range 3.5 to 13 cm). Its average width was 1.2 cm (range 0.8 cm to 1.7 cm). The graft was slotted under compression into the recipient site and covered when possible by a plate.

Patients were reviewed at monthly intervals for clinical and radiographic assessment. Particular attention was paid to trophic conditions of the skin and the presence of any infection, stability

of the segment operated on, and mobility of the neighbouring joints. Radiography was used to demonstrate signs of integration and fusion of the graft with the recipient bone, relations between the recipient bone and the plate and screws, and eventual reconstitution of the diaphysis.

Results

Union of the graft occurred in all but 2 of the 17 cases without complications over a period of an average of 22.9 weeks (range 11 to 32 weeks). However, in the 2 patients with complications the healing period greatly exceeded the 32 weeks upper limit considered acceptable for this type of graft, and therefore they were not included in the calculation of the average time to heal.

Further grafting was necessary in only 3 patients. In one case the graft fractured and a new internal fixation with chip cancellous bone grafting was performed; in another the plate fractured and had to be replaced and a chip of cancellous bone graft was added; and in the third case infection resulted in partial resorption of the graft and this required serial surgical debridement and cleaning followed by new internal fixation with additional chip cancellous bone grafting. The grafts eventually healed in all 3 patients, but the healing times were 32, 72 and 80 weeks, all well above the average.

Infection occurred in 4 patients, 3 of whom had deep infections and 1 had a superficial infection. All but one of these patients were successfully treated with serial surgical debridement, cleaning and systemic antibiotics. The exception was the patient in whom both radius and ulna grafting had been performed: the ulna united, but recurrent infection of the radius required long-term systemic antibiotics to control the infection and permit an additional grafting procedure. The radius united after 80 weeks.

Radiography demonstrated slow but progressive fading of the original shape and margins of the graft. However, it fused with the recipient bone, and increased in thickness, apparently gaining mass, until complete integration occurred. This included the formation of a new medullary canal, indicating regeneration of the recipient bone diaphysis (Figs. 3, 5, 6).

Except for moderate pain during the first post-operation days there were no complications from the donor sites. No problems arose from allowing all patients to walk after the first week using a long leg plaster cast for protection.

As a late complication one of our patients developed a radio-ulnar synostosis 7 months after the delayed grafting procedure and this required an operation to remove the bone bridge.

A satisfactory range of motion was found in the relevant joints of most patients, with an overall limitation of not more than 20%. One patient, whose graft did not increase much in thickness and who had both bone fragility and limitation of neighbouring joint motion (elbow flexion-extension $90^{\circ}/-10^{\circ}$, pronosupination $50^{\circ}/70^{\circ}$) was warned that there was a potential risk of fracture.

Discussion

Since first described 50 years ago delayed autogenous cortical bone grafting has been carefully studied, and this has demonstrated its quick and complete healing [1, 6, 10]. Clinical trials have shown its efficacy and value in the treatment of difficult cases of diaphyseal bone defects which have occurred for various reasons [3, 4, 5, 8].

In our study a delayed graft was employed to replace diaphyseal bone loss following severe trauma, tumour resection, osteomyelitis and, in most of our cases, multiple previous operations, which had resulted in wide whole-thickness bone defects. The defects were too wide for correction by more conventional procedures and were surrounded by a thick layer of poorly vascularized fibrosis which is a very unfavourable situation for any type of graft. Nevertheless, the delayed grafts healed uneventfully and resulted in full correction and re-modelling of the defect in most cases, including the non-union of a femur.

The mechanisms of integration of a delayed graft are probably the same as with any free bone graft, and include so-called 'creeping substitution' with characteristic bone resorption by osteoclastic activity, followed by revascularization and replacement with new bone. Restoration is then completed by remodelling [1]. This mechanism of integration starts in the donor bed during the graft's delay period so that once transplanted it is already in a state of on-going integration. In this respect a delayed graft may be considered simply older than a freshly obtained cortical graft. While these should integrate satisfactorily under the same circumstances, they would certainly take a longer time. However, we believe that the speed of integration of a bone graft is just as important as the final outcome and the cases that our report support this. On the other hand a vascularised fibula graft certainly integrates faster than any other type of bone graft, but the biological phenomena involved in its integration are entirely different and its use is best reserved for filling larger defects.

We have already shown that delayed cortical grafts integrate twice as quickly as fresh cortical grafts [1]. In the present study delayed grafts were not compared to any other type of graft, but the period required for their complete integration (23 weeks) was longer than that taken by cortico-cancellous bone block grafts taken from the iliac crest and also used to correct diaphyseal defects of the radius and ulna. In a previous study this average period of integration was 17.2 weeks. However, variation in the period of integration was greater for cortico-cancellous grafts (4 to 40 weeks) than for delayed grafts (11 to 32 weeks). We believe that such a difference may be irrelevant as the radiological criteria for integration are different for each type of graft, and the diagnosis of complete integration is probably more difficult for a cortical graft as these take longer to remodel than a cortico-cancellous graft [2].

Another interesting observation concerning integration of the delayed graft was its increase in thickness. In

fact the graft's original thickness was that of the tibial cortex. Although this was slightly increased during the delay period by the apposition of newly-formed bone, or osteoid, this never exceeded 5 mm. However, in almost all cases of complete diaphyseal defect particularly of the radius and ulna, the graft's final thickness was that of the recipient bone, around 18 mm, and was accompanied in most cases by the formation of a new medullary canal and this is considered to be the real landmark of the complete integration of any type of bone graft. This probably means that a delayed cortical graft retains at least in part the 3 properties of the ideal bone graft, namely osteogenesis, osteo-induction and osteo-conduction, apart from its mechanical resistance [9].

The surgical technique of delayed cortical grafting is simple and requires only extra care during the graft removal from the donor bed so as to avoid damaging the osteoid tissue formed around it. Another important point is the careful resection of any devitalised tissue from the recipient site as this contributes to preventing infection and facilitates revascularisation and integration of the graft. Furthermore, correct application of the dynamic compression plate is important as a very stable bone-graft-plate assembly is necessary for complete integration of the graft.

The delayed graft technique, although simple, requires an extra operation to prepare the graft and this has all the inherent risks involved in this kind of procedure, particularly in a superficial bone like the tibia. This may be a disadvantage of the method. However, in the present investigation there were no complications relating either to the preparation or the removal of the graft from the donor bed so that the potential disadvantage was fully compensated by good final results. The infection rate was relatively high but this was expected considering the patients' previous histories. However, all but one case responded very well with surgical debridement and cleaning, and systemic antibiotics. Despite our good results infection may have contributed to delayed healing in at least one case, although curiously it was in the case with superficial infection. The most severe complications were delayed union or non-union. These were eventually overcome by further grafting procedures, although it took longer than the average to achieve a satisfactory final result.

Despite considerable loss of muscle mass and power at the beginning of treatment in almost all cases (resulting from the combination of fibrosis and disuse) the final functional results were good. These were certainly not related to the delayed graft but rather to the rigid fixation provided by the plate combined with the graft and which allowed early mobilisation.

More sophisticated techniques are available to reconstruct diaphyseal defects. A vascularised transplant from the fibula certainly produces excellent results, but only in the hands of experienced surgeons trained in microsurgical procedures. These may only be available at major medical centres, whereas the delayed grafting technique is within armamentarium of any conventionally

trained orthopaedic surgeon. We have considerable experience with vascularised fibular transplants and believe that the final results of the two techniques are comparable.

We conclude that the delayed autogenous cortical graft that we describe provides adequate mechanical support, is integrated within a reasonable period of time and restores the anatomy of the bones by means of osteogenesis, osteo-induction and osteo-conduction. It should therefore be considered for the treatment of diaphyseal bone defects similar to those that we have reported in this article, and this applies particularly to defects of the radius and ulna.

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