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ORIGINAL STUDY

Impaction bone grafting of segmental bone defects in femoral non-unions

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Impaction bone grafting shows encouraging early results as a method of immediately restoring leg length, while allowing weight-bearing as tolerated, in the treatment of large segmental femoral defects after femoral shaft and metaphyseal non-unions. The operative technique followed is described in three consecutive cases and the effectiveness of impaction bone grafting for femoral non-unions with associated large segmental bone defects has been demonstrated. Between 80 and 120 cm^3 of coarsely milled irradiated bone allograft was used to reconstruct the defects, which were contained in malleable metal mesh. All three patients were fully weight-bearing by three months postoperatively. At two years follow-up, plain radiographs demonstrated maintenance of reduction and healing in all three cases.

Keywords : femoral fractures ; ununited fracture ; fracture fixation ; impaction bone grafting ; leg length discrepancy.

INTRODUCTION

Impaction bone grafting has been used successfully to reconstruct bone defects at the time of revision total hip arthroplasty (*12,13,20,27*). Despite bone grafting being widely used in orthopaedic trauma we could find only one report on the use of bone grafting using the technique of impaction bone grafting in trauma patients, specifically, the treatment of acute tibial plateau fractures (*28*). We report on three patients who were successfully managed with impaction bone grafting enclosed in a malleable wire mesh to treat critical femoral defects (*23*). The results at two and three years follow-up suggest that impaction bone grafting offers an effective alternative to the established techniques of long bone segmental reconstruction.

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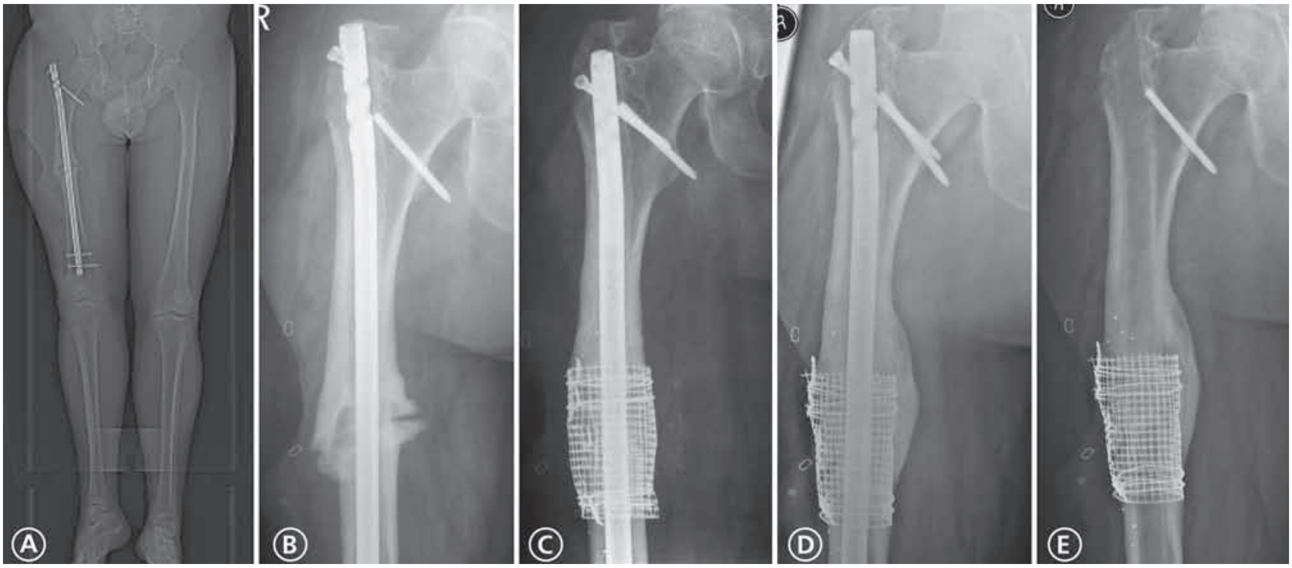

Fig. 1. — Longitudinal radiographs of the right femur of a 30-year-old male (Case 1) whose femoral non-union and 3 cm leg length discrepancy were treated with acute length restoration and impaction grafting. A) Preoperative CT scanogram illustrating the leg length discrepancy. B) Preoperative AP radiograph of the non-union. C) Immediate postoperative AP radiograph of the reconstruction. D) Two year postoperative radiograph demonstrating maintenance of reduction/lengthening and abundant new and remodeled periosteal bone formation. E) Radiograph of the reconstructed femur after nail removal, two and a half years after the reconstruction.

OPERATIVE TECHIQUE AND ILLUSTRATIVE CASES

Three patients underwent impaction bone grafting to manage critical segmental bone loss in femoral non-unions at a tertiary referral hospital. All surgeries were performed by one surgeon (LBS).

Case 1 (Figs. 1-2) : A 30-year-old male involved in a motor vehicle accident, sustained multiple injuries including an open comminuted right femoral shaft fracture with bone loss. His initial management included debridement, open intramedullary nailing (Trigen, Smith and Nephew, Memphis, TN, USA) and skin grafting. He presented 18 months post-injury with failed fixation and a non-union with a gap of 3 cm between bone ends. He was mobilizing non-weight bearing with crutches.

Case 2 (Fig. 3) : A 74-year-old female fell at home, sustaining an osteoporotic left supracondylar femoral fracture (T score at the time -2.1) ; she underwent open reduction and internal fixation with a LISS plate (Synthes, West Chester, PA, USA). She presented 8 months post-injury with failed fixation, non-union and varus collapse of the supracondylar region of the femur and a bony gap of 3 cm. She was unable to mobilize and was wheelchair-bound.

Case 3 (Figs. 4, 5) : A 57-year-old female fell at home, sustaining a left supracondylar femoral fracture. She underwent open reduction and internal fixation with a LISS plate (Synthes, West Chester, PA, USA). She developed a multifocal *Cryptococcus* infection and *Staphylococcus Warnei* infection. Over three years she underwent five surgeries that included multiple debridements, autologous and bone substitute grafting. At three years post-injury she had non-union of the femur with a 7 cm defect and was wheelchair bound.

Operative Technique [Impaction grafting]

Surgery for all three cases involved removal of the failed implant and radical debridement of the non-union site, especially in Case 3 due to her prior recurrent infections and repeated surgery. The fibrous tissue around the non-union site was removed and the bone ends were freshened. Re-fixation was achieved with a locked antegrade Trigen nail (Smith & Nephew, Memphis, TN, USA) in one case

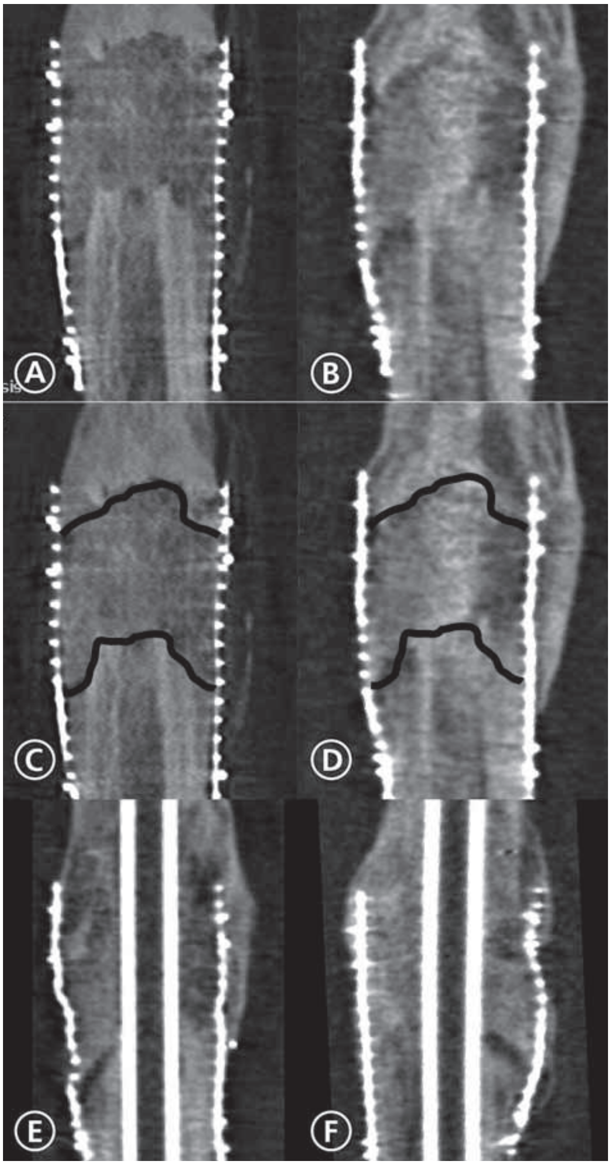

Fig. 2. — Coronal and sagittal CT images through the reconstructed defect (Case 1). A) and C) Coronal CT scan, just posterior to the femoral nail, illustrating the 3 cm long femoral defect filled with homogeneously impacted allograft six months after re-construction. B) and D) The images illustrated in A) and C) two years after reconstruction. In images C) and D) the contour of the original defect is delineated with a continuous black line. Note the graft remodeling and integration as well as the new bone formation outside the wire mesh. E) Coronal and F) Sagittal CT reconstructions though the nail two years after reconstruction. Note the graft remodeling and integration. Note that this process, as expected, is not uniform throughout the grafted area.

(Case 1) and a locked retrograde Austofix nail (Austofix, Adelaide, Australia) in the other two cases. In two cases (Cases 1 and 2) the re-fixation was performed at the corrected leg length. In the third case (Case 3) a residual 2 cm leg length discrepancy was accepted due to an inability to completely restore the patient's leg length as a result of soft tissue shortening and scarring from the previous infections, multiple operations and being wheelchair bound for 3 years. The size of the femoral defect requiring impaction grafting varied from 3 cm (Cases 1 and 2) to 5 cm (Case 3). A malleable wire mesh (Stryker, Mahway, NJ, USA) was fashioned to contain the segmental defect and secured to the two free ends of the femur with cerclage wires while leaving a window in the mesh to allow impaction bone grafting. The bone graft was prepared as per techniques for impaction bone grafting in hip revision surgery (*13*). The graft was impacted with a mallet and femoral packers from the revision hip system until the defect was filled with impacted bone and no more graft could be inserted. In each case, the femoral defect was impacted with coarsely milled, irradiated (25 kGy) femoral head allograft, with the amount of allograft required being 80 cm^3 (Case 1), 100 cm^3 (Case 2) and 120 cm^3 (Case 3), contained within the wire mesh.

Postoperative management included immediate range of motion exercises, weight bearing as tolerated and standard medical and nursing care. Clinical and radiographic follow-up was performed over the two years following the impaction bone grafting surgery. Patient's data were analyzed descriptively.

RESULTS

The postoperative recovery of all three cases was uneventful and there were no intraoperative or postoperative complications. All patients were able to commence knee range of motion exercises and weight bearing as tolerated (without imposed restrictions) immediately after surgery. Time to full weight bearing ranged from six weeks (Cases 1 and 3) to three months (Case 2). Sequential postoperative radiographs demonstrated healing of the nonunion at the restored (Cases 1 and 2) or partially

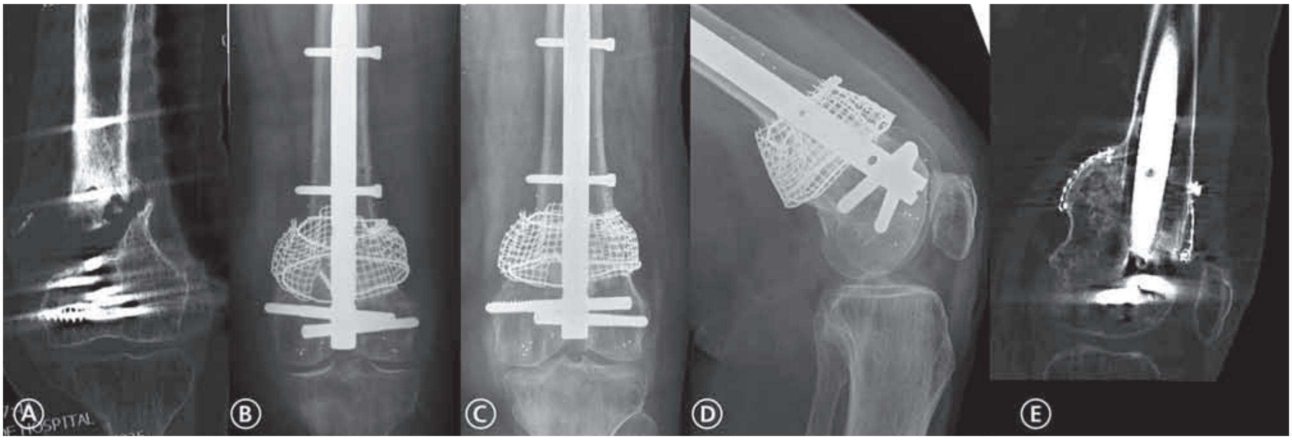

Fig. 3. — Sequential radiographs and CT scans of the left distal femur of a 74-year-old female whose femoral non-union and 3 cm metaphyseal distal femoral defect were treated with impaction grafting (Case 2). A) Coronal CT reconstruction through the non-union. B) Immediate post-reconstruction AP radiograph. C) and D) Two year post-reconstruction AP and lateral radiographs demonstrating maintenance of reduction/lengthening. E) Sagittal CT reconstruction through the nail two years after reconstruction. Note the graft remodeling and integration. Note that this process, as expected, is not uniform throughout the grafted area.

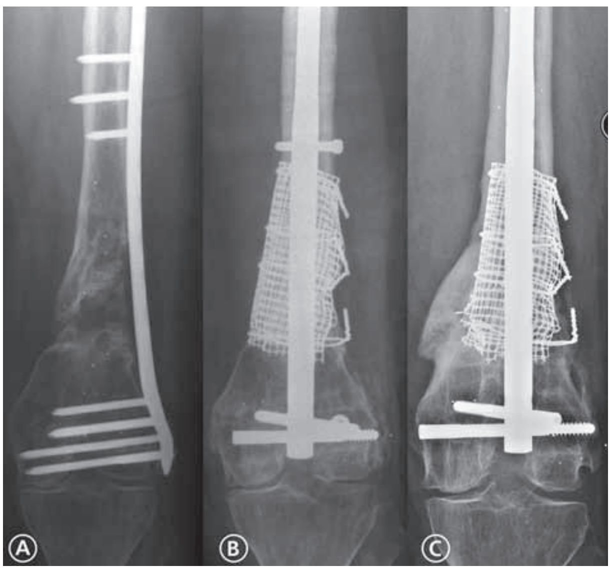

Fig. 4. — Sequential radiographs of the left distal femur of a 60-year-old female whose femoral non-union and defect were treated with acute lengthening and impaction grafting (Case 3). A) Preoperative AP radiograph of the non-union. B) Immediate postoperative AP radiograph of the reconstruction. C) Two year post-reconstruction AP radiograph demonstrating maintenance of reduction/lengthening and abundant new and remodeled periosteal bone formation.

restored (Case 3) leg length. In all three cases, postoperative CT scans at two years post-impaction bone grafting demonstrated new bone formation, graft remodeling and replacement by host bone (Figs. 2, 3, 5).

DISCUSSION

Femoral non-unions with a residual gap are difficult to treat. Non-critical defects can be managed with autologous bone grafting in young patients, however the treatment options for large segmental defects vary. The established surgical techniques for the management of diaphyseal segmental defects include distraction osteogenesis, vascularized and nonvascularized fibula grafts, and the use of allografts for reconstruction (*7,25,26,29*). To date, no surgical technique has been established for the management of juxta-articular segmental defects.

Both distraction osteogenesis and fibula grafts can result in numerous complications and are not ideal in the juxta-articular regions. These complications include inadequate bone regeneration after bone transport, non-union of the docking site, persistent pain, joint stiffness and pin track infections after bone transport (*6,29*), and stress fracture and donor site morbidity after vascularized fibular reconstructions (*8,11,14,16,17,19*). Rehabilitation after these techniques, involving months of non- and partial-weight bearing, requires considerable patient

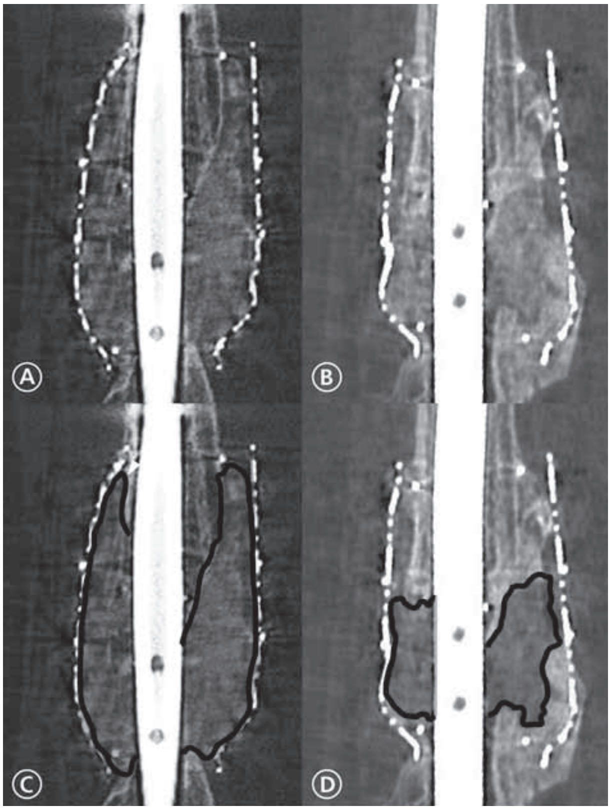

Fig. 5. — Sagittal CT images through the reconstructed defect (Case 3). A) and C) The same sagittal CT reconstruction through the nail used for internal fixation illustrating the femoral defect filled with homogeneously impacted allograft six months after surgery. In image C) the grafted area is delineated with a continuous black line. B) and D) The images illustrated in A) and C) two years after reconstruction. Note the graft remodeling and integration. Note that this process, as expected, is not uniform throughout the grafted area. Note, again as expected, the centripetal direction of graft remodeling and integration. The continuous black line in image D) delineates the part of the grafted defect that is showing less remodeling.

compliance, which is difficult, particularly in the elderly.

There have been a number of case reports and small case series that have reported on the treatment of large post-traumatic bone defects using massive structural allograft (*3,5,9,10,15,18,20,21,24-26*). Structural allografts have the advantage of providing immediate stability and the potential for early unrestricted weight-bearing. However, the disadvantages of structural allografts are their high rates of early (< 3 years) and mid-term (4-12 years) graft fracture (*21*), limited host bone ingrowth and limited remodeling of the graft even up to 15 years after implantation (*9*). In addition, structural allografts are costly and not readily available in all bone banks.

Another more recent option for the treatment of segmental long bone defects in the diaphyseal region is the use of titanium cages filled with bone graft. The results of this technique have been reported in several case series involving patients younger than 24 years of age with promising results demonstrated up to one year (*1,2,4,22*). In all these cases the titanium cages provided enough construct stability to allow the patients to safely mobilize immediately and in an unrestricted fashion. In all cases the host bone united to the graft in the cage at the cage-host bone junction. None of these case reports provide good evidence of bone remodeling of the graft used, with only 5 to 12 months follow-up reported after reconstruction (*1,2,4,22*).

Impaction bone grafting is an established technique that is used to restore bone stock while providing immediate stability in revision total hip arthroplasty (*13,20,30*). We used impaction bone grafting in the three cases reported, to restore bone length while providing immediate stability to allow unrestricted mobilization. Our study showed that impaction bone grafting contained in a compliant wire mesh is a viable alternative treatment option for post-traumatic segmental long bone defects that are not amenable to shortening. Impaction bone grafting has several advantages over other reported techniques : it involves one surgical procedure, allows immediate weight bearing, restores bone stock without affecting future reconstructions and has minimal short and long term complications (*13,20,30*).

The only other surgical techniques that allow unrestricted mobilization after segmental long bone loss reconstruction are when the defect is managed with structural allograft or titanium cages packed with bone grafts. As opposed to structural allograft, impacted bone allograft is revascularized with gradual ingrowth of the host bone, which replaces the allograft, and has shown excellent long-term survival (*12,13,27*). The technique described in this paper is somewhat similar to the one that uses titanium cages but several differences and possible advantages are worth noting. First, with one technique the structural stability is provided by the titanium cage in combination with intramedullary nailing (*1,2,4,22*), while in our technique the structural stability is provided by the impaction bone grafting and intramedullary nailing. The wire mesh that is used to contain the defects in the cases presented in the current study is malleable and has a minimal role in providing structural support. The amount of bone graft used in the cases treated in this study with impaction bone grafting was greater than the volume of bone graft packed into the titanium cages (between 80-120 cm^3 for 3-5 cm defects in the current cases compared with 60-150 cm^3 for 8-12 cm defects) (*1,2,4,22*). Two advantages of the wire mesh over the titanium cages are the reduced cost and, even more importantly, the fact that the wire mesh can be moulded to suit the local bone anatomy and therefore is more suitable for use in periarticular applications as illustrated in two of the cases presented (Cases 2 and 3). Indeed, Ostermann *et al* recognized the inability of the cylindrical titanium cage to match the size difference between the metaphyseal and diaphyseal diameters of the tibia (*22*). This difference is likely to be more important in elderly patients with osteoporosis where the epiphyseal and metaphyseal bone could be penetrated rather than supported by the cage, as opposed to the young patients reported on (*1,2,4,22*) who had good quality cancellous bone that was able to support a titanium cage as an ‘inlay’ construct. In contrast to potential problems that could occur with titanium cages, the case series reported here shows that the technique of impaction bone grafting in a wire mesh can be successfully used to reconstruct post-traumatic diaphyseal (Fig. 1 & 2), juxta-articular (Fig. 3) or metaphyseal (Fig. 4 & 5) segmental femoral defects.

In our series, one patient (Case 3) with pre-existing knee arthritis and another (Case 2) with an intra-articular distal femoral fracture were both at higher risk of developing knee arthritis. Using the technique of impaction bone grafting, we were able to recreate the anatomy of the metaphyseal region of the distal femur. The bone stock thus created may allow a simple unstemmed and unconstrained knee replacement, should the need arise in the future. The leg length discrepancy could be corrected with sufficient strength to enable immediate weight bearing while maintaining the reduction achieved in surgery. Knee range of movement exercises were also commenced immediately after surgery. Radiographic signs of new bone formation surrounding the wire mesh used to contain the graft and the remodeling seen on CT at two years provided evidence of graft revascularization, host bone ingrowth and replacement of the allograft by host bone.

The main limitation of the current study is clearly the small sample size. Further studies and additional experience of treating patients with this technique are required to refine the surgical technique, including the amount of allograft required for a certain defect size. Although the size of the critical defects reported in this case series was relatively small, reconstruction of these defects was further complicated by either a pathological fracture secondary to infection or an osteoporotic supra-condylar fracture or an open fracture which required staged surgeries losing periosteum and good vascular soft tissue.

In conclusion, this study shows that impaction bone grafting contained within a malleable wire mesh can be a successful method to treat critical segmental defects in human femurs of any age and is a useful treatment option for segmental bone defects.

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