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Management of Bone Loss in Revision Total Knee Arthroplasty

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Bone deficiencies around the knee can present a substantial challenge during revision total knee arthroplasty. Bone loss occurs from stress shielding, osteolysis, chronic infection, and bone removed during implant extraction. Smaller defects have traditionally been treated with cement filling or allograft bone chips. Larger defects can be reconstructed with bulk allografts or custom prostheses. A hinged prosthesis may be necessary to account for ligamentous insufficiency. In addition to traditional methods of managing bone loss, recent developments include the use of metaphyseal-filling implants made of highly porous metal. These implants can be press-fit into host bone to accommodate large metaphyseal defects. Each revision knee surgery provides unique challenges, requiring proficiency in multiple techniques of bone loss management.

Level of Evidence: Level V, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

There are multiple well-known methods for dealing with deficient bone stock during total knee revision. However, traditional methods have not always been sufficient to deal with bone defects that extend from the periarticular region into the metaphysis or the diaphysis. Smaller contained defects have been managed by filling the defect with cement or bone graft. Larger defects have been treated with modular augments, impaction grafting, or bulk structural allograft. Modular augments have commonly been used with cemented and cementless stems. Hinged, rotating platform prostheses and larger custom implants are reserved for massive bone loss with ligamentous instability for which periarticular bone replacement is indicated. More recently, the use of metaphyseal filling implants that fill the gap between the common revision and the megaprosthesis have provided an alternative solution for metaphyseal bone deficiencies (Fig 1).

Causes of bone deficiencies include mechanical bone loss from gross loosening of the prior prosthesis, stress shielding, osteolysis, and iatrogenic bone loss occurring during implant removal.[5] The loss of bone after a primary knee replacement generally is a gradual process heralded by the deficit of structural bone and qualitative changes in the remaining bone and the overall stability of the knee. Changes in the remaining bone may interfere with the ability to achieve stable fixation of a revision prosthesis because of endosteal sclerosis, osteonecrosis, osteopenia from stress shielding, and periarticular fracture. Bone loss can also be associated with chronic infection. Segmental bone defects extending into the metaphysis can compromise ligament attachments, leading to instability or fibrosis. Physical examination and planning for ligamentous instability will help determine the appropriate prosthesis for revision surgery. Lastly, the management of bone loss depends on the size and location of the deficit, in addition to the patient's age and life expectancy.[8] Allograft reconstruction is appropriate for patients in whom bone restoration is a priority, whereas prosthetic replacement of defects may be more appropriate in older or low-demand patients. Specialized instrumentation, new techniques, and the development of new prostheses are required to deal with the array of bone restoration and fixation challenges posed in bone loss.

The number of revision total knee arthroplasties (revTKAs) performed each year in the United States is increasing. From 1990 to 2002, the rate of primary total knee arthroplasties per 100,000 people in the United States nearly tripled.[18] This rate of increase in primary arthroplasty is expected to continue as the baby boomer generation enters its seventh decade of life in 2006. Since the rate of revision total knee surgery has remained fairly constant, the substantial increase in primary total knee replacements will result in more revisions in the coming years. Consid-

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Fig 1. Porous metal metaphyseal-filling cones (Zimmer, Warsaw, IN) have been designed to accommodate femoral and tibial bone loss. Tibial cones are shown.

ering the advances in technology that may be on the horizon, the combination of more primary knee arthroplasty in a younger and more active group means articular surface wear, particle generation, osteolysis, implant loosening, and bone loss. Therefore, strategy for management of bone deficiency around the knee during revTKA will play an increasingly important role in successful knee reconstruction.

This review is novel in that it covers both the past standards and current trends in management of bone loss in revTKA. It is comprised of all studies of sufficient size and experience from a review of the literature over the past twenty years. Articles which were felt to make a significant contribution to the literature were selected. In reviewing clinical studies, quality was not judged by any quantitative or statistical means. In addition, the discussion of techniques includes the author's personal experience with porous metal filling implants in the treatment of large metaphyseal bone defects.

Classification of Bone Defects

Various classification systems have been used to quantify the amount and type of bone loss present in the setting of revision knee replacement.[5,12,31] The Anderson Orthopaedic Research Institute (AORI) classification is widely used.[12] It is based on radiographic and intraoperative findings. AORI Type 1 defects are minor bone defects that do not compromise the stability of the component. The metaphyseal bone is intact. Type 2 defects involve damaged metaphyseal bone. There is loss of cancellous bone in the metaphyseal area that requires cement fill, augments, or bone graft to restore the joint line. This can occur in one (AORI Type 2A) or both (AORI Type 2B) femoral condyles or tibial plateaus. Type 3 defects are consistent with massive bone loss. This involves a deficient metaphyseal segment that comprises a substantial portion of condyle or plateau. Type 3 defects can involve the collateral ligaments or patellar tendon, often requiring bulk allografts or custom implants at revision.

Clatworthy and Gross[5] present an alternate classification based on contained or uncontained defects. In Type I defects, the metaphyseal bone is intact. No bone grafting or augmentation is necessary to restore the joint line. Smaller defects can be filled with cement. Type II defects are contained metaphyseal deficiencies requiring cement, bone graft, or augmentation to restore the joint line. Stemmed revision prostheses are often necessary. Type III defects are uncontained and noncircumferential. Partial distal femur, partial proximal tibia, or femoral head structural allografts may be used for management. Type IV defects are uncontained and circumferential. Segmental or custom prostheses may also be used.

The Knee Society Index of Severity has been developed to quantify the many factors involved in total knee revision surgery.[30] It accounts for bone loss and exposures, contractures, alignment, complexity of implant removal, soft tissue stability, extensor mechanism stability, and the need for patellar revision. A score is given to each case based on these factors. There are possible prognostic implications based on this score, although no long-term studies have been published.

Techniques for Management of Bone Defects

Bone preservation during implant removal is crucial.[22] A fundamental corollary to bone preservation in revision total knee arthroplasty is restoration of the natural joint line.[26] Placement of the joint line is essential to maintain properly tensioned collateral ligaments, balanced flexion and extension gaps, and correct patellar height. The extension space and level of the joint line are affected by tibial and distal femoral bone loss. This bone loss must be properly managed to restore the joint line, which tends to be elevated in total knee revision surgery. The combination joint line elevation, distal femoral bone loss, and femoral prosthesis downsizing is a scenario that leads to the common pattern of flexion instability. Various techniques have been established to manage this bone loss and create a stable revision construct.

Cement Filling

For simple bone defects such as AORI Type 1, cement filling may suffice. Ritter[28] used cement filling and screw stabilization to treat tibial plateau defects in 57 primary total knee arthroplasties. The average depth of filling was 9 mm. Although nonprogressive radiolucency was common at the bone-cement interface, no components had loosened at a minimum 3 years. Dorr et al[10] recommend bone grafting when the cement column under the prosthesis will exceed 5 mm.

Modular Augments

For larger or uncontained defects, including AORI Type 2, modular augments are a treatment alternative. The development of modular augments has provided a stable, simple solution to total knee revision in many cases. The first reported use of modular metal augments to augment bone stock deficiencies was by Brand et al[3] in 1989.

Modular augments are available in most total knee revision systems.[29] They address most bony defects encountered in total knee revision and provide a simple way to reestablish the joint line. Precise cuts are required to provide proper fit of the augment and selectively manage deficient areas of bone without resecting the entire bone surface down to the level of the defect. The drawback of this approach is that there is not a modular augment for every size defect, which means some defects may require cement augmentation or bone grafting in conjunction with an augment. Conversely, some smaller defects may necessitate additional bone resection to make an off-the-shelf augment fit properly. Fixation of modular augments to compromised or sclerotic bone surfaces can be problematic. Nevertheless, the inherent stability of modular augments offers the potential for early weightbearing in the revision situation.

Although long-term results of modular augments in revTKA are relatively unknown, short-term data show satisfactory results. Pagnano et al[24] treated 28 knees in 25 patients with wedge augmentation for tibial deficiency. Good to excellent results were found in 94% of patients at a mean of 5.6 years. Although no failures were observed in this series, stable radiolucencies were observed in more than 50% of the cases at the bone-cement interface beneath the augment. The authors recommend this technique for peripheral tibial deficiencies exceeding 10 mm. Werle et al[33] reported the use of large distal femoral augments, up to 30 mm, to treat bone loss and reestablish the joint line. There were no revisions and no radiographic evidence of loosening at a mean 37 months followup.

Impaction Grafting with Particulate Allograft Bone

The technique of impaction grafting of allograft bone chips has been applied to AORI Type 1 to Type 3 tibial and femoral defects. Morselized allograft has the potential to remodel and incorporate with the host bone. It can be mixed with autograft to add osteoinductive properties. Specialized reamers and instruments may be used to impact the bone graft into place against the host bone. Cemented and noncemented techniques have been applied.

In 1993, Whiteside reported on the use of impaction grafting to restore massive femoral and tibial defects in revision total knee arthroplasty in 56 patients.[34] Long, uncemented stems were used. All grafted areas showed increasing radiodensity at 1 and 2 years after surgery. All but two achieved stable fixation to host bone. Other authors[2,14,16] have produced favorable short-term results with impaction grafting using long stems with uncemented and cemented techniques. In all cases, weightbearing must be delayed to allow incorporation of the allograft. Several authors[14,20] have reported on the use of wire mesh to convert an uncontained to a contained defect, allowing the technique of impaction grafting to be applied to more substantial bony defects. Although promising as a salvage option, long-term data are not available on this technique.

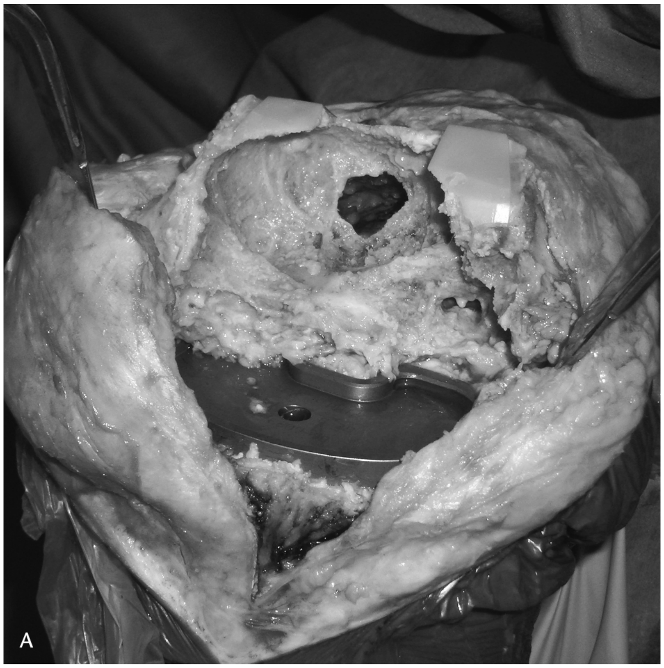
Structural Allograft

Bulk or structural allograft is reserved for larger AORI Type 2 and Type 3 bone defects. Options include the femoral head, partial distal femur, or partial proximal tibia. Structural grafts can potentially provide bone stock for future surgery and are less expensive than custom prostheses.[29] Initial stability is crucial if the graft is to eventually unite with the host bone.

The femoral head can often be used to fill large cavitary defects (Fig 2) or fashioned to fit a large noncircumferential defect such as an isolated femoral condyle. Massive bone defects may require replacement of the entire distal femur or proximal tibia. In this case, the point of union between the structural allograft and the host bone is made at a cortical step cut in an area where the host bone is structurally sound. The allograft is fashioned to unite with the step cut and the union site is bypassed with a cemented or uncemented long stem to provide stability.

Dorr et al[10] treated 24 knees using structural bone graft in areas of tibial deficiency at the time of primary and revision knee arthroplasty. Twenty-two of 24 cases showed union without collapse at 3 to 6 year followup. The authors recommend the use of structural grafts for bone defects involving 50% or more of either tibial plateau, and prefer bulk to morselized bone graft because it provides greater initial structural support.

Using bulk allograft for the treatment of massive femoral and tibial bone loss, Dennis[9] reported 86% good to excellent results in 30 patients at an average of 50 months. Engh et al[11] reported similar results, with 87% good to excellent results for 35 allografts in 30 patients at an average of 50 months. The femoral head was used for 29 of the 35 allografts. Ghazavi et al[13] reported a 77% success rate at 4 years based on knee scores. Common among these studies is the use of a stemmed component to bypass the allograft, diverting stress away from deficient metaph-



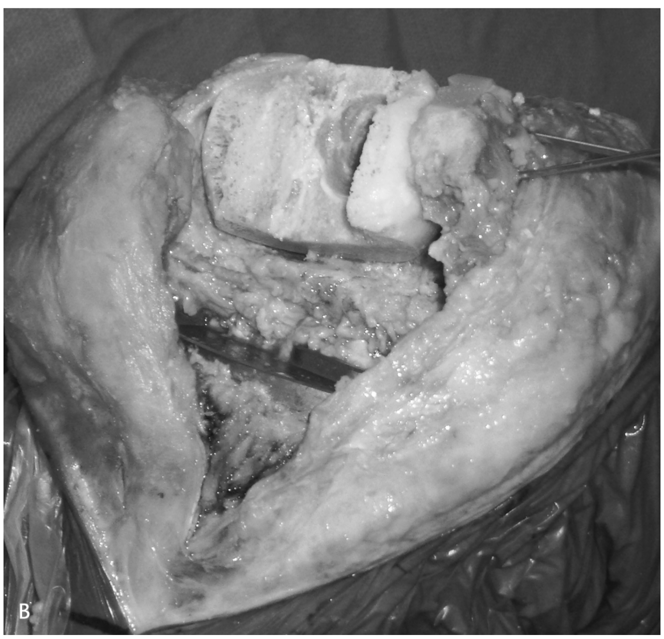


Fig 2A–B. (A) Cavitary femoral metaphyseal bone loss, AORI Type 2B, is shown in this intraoperative photograph. (B) The distal femur is now ready for cementation of the femoral component. The epicondyles and collateral ligaments have been preserved.

yseal areas and passing it to the more structurally sound cortical host bone.

The largest series of total knee revisions using structural allografts is by Clatworthy et al.[6] Fifty-two revision knee replacements implementing structural allograft were performed. Twenty-nine of these were evaluated at a mean of 97 months. The success rate at 5 years was 92%. This dropped to 72% at 10 years. Twenty-three percent of this group underwent repeat revision at a mean of 71 months. The infection rate was 8%, and 8% of the revisions failed as a result of graft resorption. This study raises legitimate concerns about the long-term success of structural allografts.

In a histologic retrieval study, Parks and Engh[25] evaluated nine bulk allografts used in revTKA after an average 41 months in situ. Seven were retrieved postmortem and two were obtained at repeat revision. All allografts were intact, but none had revascularized. New bone was being laid on dead bone at the periphery of the allograft. Despite the lack of revascularization, no collapse or loosening was observed. The use of stemmed components likely increased the durability of the construct and protected the grafts from fatigue failure, at least in the short term. Longer-term failures in other studies are likely attributable to fatigue failure of the dead allograft bone.

If structural allograft is to be used in revision surgery, it is crucial to maintain as much viable host bone and soft tissue attachments as possible and to meticulously prepare the host surface. When possible, the epicondyles can be saved and attached to the bone graft. Attachment of collateral ligaments directly to allograft bone is likely to lead to ligamentous insufficiency. The allograft-prosthesis interface must be cemented because there is no potential for bone ingrowth in this area. Another consideration with the use of allograft in revision total knee surgery is that it often requires a prolonged period of restricted weightbearing to allow the bone graft to unite with the host. This may not be a realistic option some patients. Contraindications to the use of allograft include chronic infection, neuropathic arthropathy, metabolic bone disorders, severe immunosuppression, and local radiation necrosis.[9]

Metaphyseal Filling Implants

For the patient with massive bone loss along with ligamentous insufficiency, a metaphyseal filling implant or a bone-replacing megaprosthesis using a rotating hinge may be necessary in combination with one or more of the above-mentioned techniques. Jones et al[17] reported satisfactory results on 15 patients at a minimum of 2 years using an S-ROM mobile-bearing hinge prosthesis (DePuy, Warsaw, IN). This is a salvage-type procedure and it should be recognized a hinged prosthesis is likely to fail in a younger patient.

Highly porous tantalum metal[1,4,7,32] has been fabricated for use as modular augments and structural metaphyseal-filling cones in revision total knee arthroplasty. Tantalum is biocompatible and corrosion resistant. When processed into the porous metal form, it possesses a high strength and low stiffness, similar to that of bone, making it a suitable replacement for areas of deficient bone. Porous tantalum metal has high porosity, which allows bone ingrowth. It also has a rough surface, creating a high coefficient of friction against bone and providing initial stability in press-fit applications.

Porous metal metaphyseal and segmental augments offer an alternative to structural allograft in several areas. Allograft bone can have unknown or varying degrees of structural strength. Allograft tissue also carries the risk of late failure, and infrequently the possibility of viral or bacterial disease transmission. A porous metal can be manufactured in a more uniform fashion and its structural properties will not degrade with time. To date, porous tantalum has been used in primary and revision acetabular cups, inserts for avascular necrosis of the femoral head, primary total knee tibial components, spinal implants, and revision total knee surgery.

Recent early experience has been gained with the use of porous tantalum metaphyseal filling cones to compensate for femoral and tibial metaphyseal bone loss in revision total knee arthroplasty (Fig 3). These cones can be manufactured in various sizes and shapes to fit standard defect patterns. Metal augments produced in this fashion are press-fit into the host bone in the area of deficiency by fashioning the defect to accept a standard implant shape using a high-speed cutting tool. The porous metal augment provides a platform to attach a prosthetic joint to the bone, which is in turn cemented to the prosthesis. Such a construct generally is bypassed with a cemented or uncemented stem. The porous metal-host bone interface is kept free of cement to allow for bone ingrowth. This type of strategy for bone reconstruction contrasts a more traditional approach of cutting the bone from intramedullary guides. Success of this approach will depend on the ability to restore the joint line, reconstruct normal alignment, and achieve durable fixation.

Management of the Patella

Compared with the femur and tibia, less is written about patellar management during total knee revision. In the setting of sepsis, the component must be removed. Otherwise, a well-fixed and minimally worn patellar implant may be left in place. Because of the high failure rate of some older metal-backed patellar designs, it is wise to remove such components.[19]

Deficient patellar bone can be a challenging problem. If sufficient bone stock is available, the patella can be revised with minimal bone resection using a standard device. Laskin[19] reports only one postoperative fracture in more than 85 patellar revisions with a domed, inset patellar component, removing only 1 to 2 mm of bone. For severe bone deficiency, revision of the patellar component may not be possible. Patellar component excision or patellectomy may be among the only viable options.

Recently, a patellar bone grafting procedure has been described to provide patellar bone for possible future revisions.[15] A porous tantalum metal patella has also been developed for treatment of substantial patellar bone loss during revision surgery.[23] The shell is press fit and sutured to the remaining bone. This has been successful in 17 of 20 patients at 2 years. Three patients had polar fractures, two of which underwent repeat surgery. A recent report found

Fig 3A–B. (A) This radiograph shows substantial metaphyseal bone loss in a patient who had resection of hardware for a chronic knee infection. (B) The postoperative radiograph shows the revision knee prosthesis in place, bypassing the metaphyseal filling cones with cemented stems.

that suturing a porous tantalum patellar component into soft tissue can result in early implant migration and extensor mechanism damage.[27] It seems some patellar bone must be available for this type of reconstructive strategy to work effectively.

DISCUSSION

The current literature on revTKA has several limitations. Due to the complexity of the patients and the varying nature of bone loss, it is difficult to produce controlled or randomized trials. This leaves the literature with mostly small, retrospective studies, many of which are written by surgeon-designers. In addition, the studies have a limited number of centers and minimal long term follow-up. The only study mentioned above with 10-year followup is the work on structural allografts by Clatworthy et al.[6] It is worrisome the failure rate in this study showed a substantial increase between 5 and 10 years. This illustrates the need for more long-term data and new techniques in revision knee surgery. One such technique is the use of porous metal implants. Their structural likeness to bone and potential biologic fixation may provide an acceptable solution to massive bone loss, but porous metal implants have yet to be sufficiently studied and reported in the literature.

When dealing with bone loss in revision total knee surgery, there are many potential challenges and pitfalls. Management of bone loss depends on the size and location of the deficit and the patient's age, activity, and life expectancy. Generally, it is appropriate to treat smaller, contained defects (AORI Type 1, < 5 mm) with cement filling.[10,21,28] Larger defects (AORI Type 2) can be treated with bone graft or modular augments. Contained defects are ideal for impaction grafting with morselized allograft or autograft, whereas peripheral defects may be more suited to the use of augments. For massive bone loss (AORI Type 3), multiple options exist. Structural allograft can effectively replace missing bone, but there are concerns about infection rates and long-term survival. Structural porous metal augments add another option to the management of massive bone loss. These augments can provide structural support in patients for whom a custom prosthesis or large structural allograft would have been necessary.

For every technique in the management of bone loss during revTKA, certain fundamentals must be applied. Extreme care must be used during implant removal to preserve as much host bone as possible. The remaining bone structure will guide treatment. If a stable, well-balanced knee is to be achieved, restoration of the joint line is crucial. Distal femoral augments provide a simple solution to this problem in most cases. For more substantial bone deficiency, structural allograft, metaphyseal filling implants, or custom prostheses may be used. For treatment of any periarticular defect requiring more than a minimal prosthetic augment, it is imperative to use stemmed components to transfer stress away from the joint line. In the setting of revision total knee arthroplasty, there are various methods of dealing with bone loss. Each case provides a unique challenge requiring proficiency in multiple techniques.

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