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REVIEW

Managing bone defects in primary total knee arthroplasty: options and current trends

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Abstract
While tackling with bone deficiencies in the context of total knee arthroplasty, it is imperative for the arthroplasty surgeon to arm himself with an in-depth knowledge on the various management options available and to use the right option for the right type of defect in the right patient. Aim of this review paper is to focus on the various options available and discuss the evolving concepts and recent trends with regard to the implications and treatment of bone deficiencies, in primary total knee arthroplasty. Relevant literature is evaluated with specific focus on the modality used for managing a defect, their clinical and radiological outcomes and failure rates. Out of various classifications described, Anderson Orthopaedic Research Institute (AORI) system is universally employed to classify the bone defects. The currently available management options include more tibial resection, the use of bone cement to fill the defect, with or without augmentation with screws, bone grafting which may be autograft or allograft, metal augments, metaphyseal cones and sleeves. There is no single option which can be applied universally; each has its own advantages, disadvantages and specific indications with regard to application in specific types of defects, in specific patients as outlined in this article.

Keywords Total knee arthroplasty · Bone defects · Management · Current trends

Introduction

Patients with advanced osteoarthritis of knee requiring total knee arthroplasty (TKA) in our population are usually associated with moderate to severe varus deformity with bone defects in tibia involving the medial compartment as majority of them report to hospital at a late stage. Among the various challenges faced by the arthroplasty surgeon, bone defects or bone loss, especially on tibial side, is of prime importance. There may be several causes of bone defects, such as secondary to trauma, osteonecrosis, infections, previous osteotomy, neoplastic conditions etc., but the most common cause is usually an advanced stage of osteoarthritis (OA) of knee. About 29% of the people in India are estimated to be suffering from some form of OA knee [1]. Bone loss is a common occurrence especially in the posteromedial aspect of the tibial condyle in end-stage OA of the knee due to degenerative erosions and may also be seen on the femoral condyles. These defects, if not addressed properly, may lead to a compromised bone-implant interface causing malalignment of the implants and hence a postoperative deformity, increased complications and need for revision surgeries. This article aims to review the different types of bone defects encountered during primary TKA and the various logistics and techniques employed to address them with plethora of options available.

Classification

Various classification of bone defects have been reported in the literature, based on size, severity and location of the bone deficiencies which may help in accurate preoperative planning for management, predicting outcomes and providing guidelines on treatment [2, 3]. However, controversy exists among the various classification systems for bone defects. Anderson Orthopaedic Research Institute (AORI) classification, based primarily on the size of the bone defect present in tibia and femur, is the most useful and widely used system (Table 1).

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Table 1 Anderson Orthopaedic Research Institute (AORI) classification of bone defects

Type	Severity of bone defects in tibia (T) and femur (F)
1 (T1 and F1)	Minor bone defect without compromising the stability of a component
2A (T2A and F2A)	Metaphyseal bone damage and cancellous bone loss in one femoral condyle/tibial plateau requiring reconstruction to maintain implant stability
2B (T2B and F2B)	Metaphyseal bone damage and cancellous bone loss in both femoral condyles/tibial plateau
3 (T3 and F3)	Significant cancellous metaphyseal bone loss compromising a major portion of either femoral condyles or tibial plateau, occasionally associated with patellar tendon or collateral ligament detachment

Bone deficiencies are categorised into contained (central) defects, with an intact bony rim which acts as a support for the implant, most commonly seen in OA knees with valgus deformity, and uncontained (peripheral) defects, often seen in varus knees which offer no peripheral support for the implant [2].

Preoperative templating will give a rough idea about the possible need to augment a bone defect. After drawing the line of expected resection of the tibial plateau in orthogonal radiographs, any defect more than 10 mm in its largest dimension usually needs to be addressed.

Intra-operatively, a bone defect should be augmented if implant instability is observed during the trial reduction. The knee is subjected to full range of motion in order to assess the stability of the trial reduction. This manoeuvre will reveal any displacement at the bone-trial implant interface which is duly noted. This instability during trial reduction is observed if bone defect involves 40% or more of the circumference of the resected bone with trial implant lying unsupported by host bone [3].

Management

Available options

The various options for management of bone defects include undersizing of tibial base plate, bone cement only or with screws, autograft, structural or morselised allograft, metal augments, porous tantalum cones and metaphyseal sleeves (Fig. 1).

In shallow defects of < 10 mm AORI type 1, the strategy of more tibial resection with a thicker polyethylene insert may be employed [3]. In primary TKA, the maximum amount of bone removed from the level of the original lateral tibial subchondral plate should not exceed 10 mm or 5 mm from the original medial subchondral plate [4]. When bone deficiencies are more than 10 mm, the tibia should not be cut to the level of the deficit. It has been demonstrated that the strength of osseous support is reduced by a distal tibial resection with the resultant use of a narrower tibial component. This further reduces the area of support with increased loading [5–7].

Cement augmentation

Bone cement only may be used to primarily fill defects less than 5 mm in their largest dimension after the proximal tibial resection. In defects of 5–10 mm (AORI type 1), cancellous screws may be used to stabilise the implant while the cement is setting (Fig. 2), which help to prevent component malposition [3]. Cement should not be used as a primary modality in larger defects, i.e. more than 10 mm as the construct with excessive cement even if augmented by screws is weak and unstable mechanically. Fragmentation of cement and early implant failure may be the resultant outcome in such cases [8–10]. Moreover, thermal necrosis and shrinkage of volume of bone cement during polymerisation and lamination may occur due to release of great amount of heat from the large volume of cement used. Radiolucent lines are frequently observed at the bone-cement interface [11]. Lotke et al. [12] reported their study with mean follow-up of 7.1 years, on use of cement only in 59 knees with bone defects measuring 10–20 mm ($n = 33$) or > 20 mm ($n = 23$) in height. They observed non-progressive radiolucent lines at cement–bone interface in 43 knees. Implant loosening was seen in only one patient which was subsequently revised. Dorr et al. [13] published 7 years follow-up results of use of cement in AORI type 1 bone defects in 54 patients. They reported good outcomes in 53 cases with failure in one due to loosening. Ritter [14] reported the management of tibial defects of 9 mm in mean height with cement and screws in 57 patients. They demonstrated non-progressive radiolucency at the bone–cement interface in 25% cases after a minimum of 3 years of follow-up. No failure was observed. In femoral condyles with bone defect < 5 mm (Type 1 AORI), cement augmentation alone is preferred. In summary, cement augmentation should be preferred only for elderly, low demand patients with a relatively small defect (AORI type 1) [3].

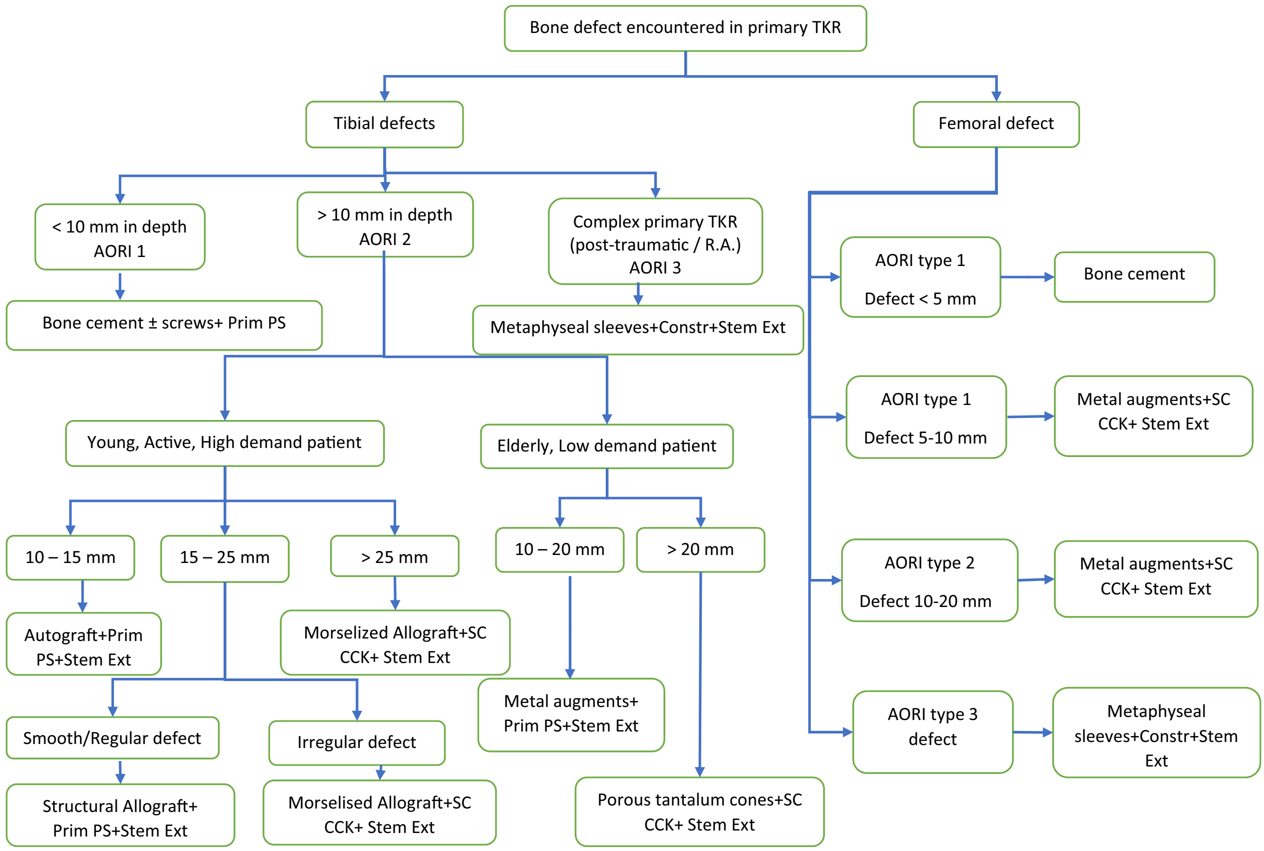

Fig. 1 Flow chart depicting the management options for various types of bone defects in primary TKA

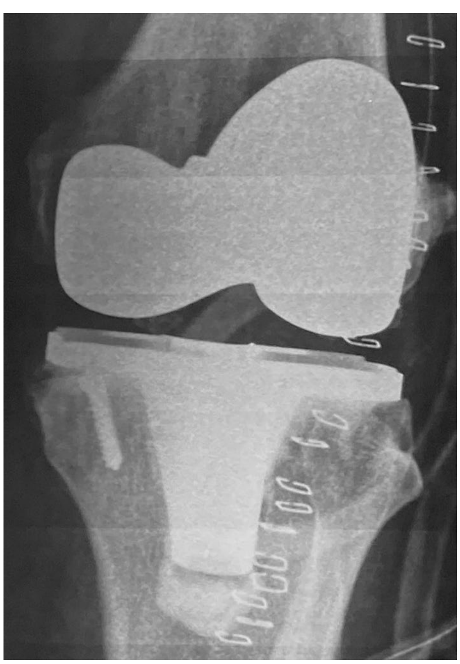

Fig. 2 Photograph showing postoperative X-ray of knee anteroposterior view showing management of AORI type 1 bone defect by using screw and cement

Small contained (central) defects AORI type1 can be managed with cement augmentation.

Bone graft

Autograft technique uses bone pieces harvested from the same individual, from the resected femoral condyles or from the iliac crest, to correct a bone defect (Figs. 3, 4, 5). This is a good technique for relatively small bone defects, as the amount of bone graft that can be obtained is limited. Liu et al. [15] reported the results of autografts used from resected distal femoral bone which was fixed with screws to manage the bone deficiency. This helped in restoration of knee stability and its mechanical axis. At 6 to 9 years of follow-up, statistically significant improvement was observed from the preoperative Knee Society Score (KSS).

Another technique of tibial flip autograft has been described by Franceschina and Swienckowski [16]. During surgery, after exposure the tibial resection is done 2 mm below the lowest points on medial and lateral plateau thus producing a flat cancellous bony surface with an intact cortical rim. An extramedullary guide is used to mark a line which is perpendicular to the long axis of tibia. The line of resection passes exactly through the middle of the wedge of

Fig. 3 Preoperative X-ray of knee anteroposterior view depicting AORI type 2 defect on medial condyle

Fig. 4 Intraoperative photograph showing use of bone graft to manage AORI type 2 defect during TKA

bone, and an oscillating saw is used to carry out this resection. The resected wedge is then flipped such that its thickest portion lies over the medial tibial plateau. This creates a surface which is exactly perpendicular to the long axis of the tibia. The autograft may be temporarily stabilised with the help of Kirschner wires during tibial preparation. The use of a central stem in the tibial component helps to

Fig. 5 Postoperative X-ray of knee anteroposterior view showing management of medial AORI type 2 defect by bone graft

reduce compressive forces and shear loading across the bone graft. Rest of the surgery is performed as usual, and the components are cemented in place. Franceschina and Swienckowski [16] managed seven patients using this technique and followed them up for 14–93 months. The varus deformity was corrected in all cases which was maintained at various follow-up. Bone grafts consolidation occurred in all the patients. No loosening of the tibial components was reported by the authors radiographically, and there was no progressive radiolucency at the graft-bone interface in any of the cases.

Allograft may be procured from bone banks which is either fresh frozen, freeze-dried or irradiated. Allograft is a viable alternative if a dedicated facility is available in the vicinity of the treating centre, although there are risks of complications such as graft failure due to resorption; fracture; non-union; the possible transmission of viral, bacterial and prion disease; and other issues related to their expense and availability [17, 18]. There are two types of allografts: structural allograft and morselised allograft.

Structural allograft allows for a stable restoration of bone in large defects. Commonly used structural allografts include femoral heads, distal femur and proximal tibial segments. The ability to shape the allograft to match the defect is a big advantage of using it. Intraoperatively, the dimensions of the defects are measured after taking a conservative proximal tibial cut. Structural allograft can be used for defects involving up to 40% of the tibial condyle cut surface and measuring up to 25 mm in depth. The purpose of using structural allograft to tackle bone defects is to provide maximum stability at graft–host bone interface and achieve a stable surface for fixation of implant. The opposing surfaces of the graft and defect are thoroughly debrided to expose bleeding bone. Conversion of the oblique peripheral defects into rectangular space with vertical and horizontal surfaces before repair has been demonstrated to improve stability for the tibial component fixation [19]. The stepped patterns have also a biological advantage since it allows improving the contact area of the host–graft construct maximising the probability of graft incorporation [20, 21]. The graft can be stabilised with 2–3 countersunk cancellous compression screws [22, 23].

Technical difficulties may be faced with fitting structural bone grafts in irregular bone defects, and often more native bone has to be sacrificed to fit the graft. The use of impacted morselised grafting in this respect appears to be a more advantageous option [24]. The aim is to address the failure mechanism, minimise further bone loss and produce a stable platform with good load transfer to the underlying bone, while relieving pain and maintaining good function. Impaction grafting can be done for defects larger than 25 mm in depth with the help of a wire mesh [25]. The defect should initially be contained with the help of a stainless steel mesh fixed with cortical screws. Morselised grafts of size ranging from 5 to 7 mm are prepared and impacted, following which the tibial base plate is cemented on top [25]. Stem extenders may be considered for larger defects to decrease proximal axial load of the reconstructed area [8, 19]. Impacted grafts can be incorporated with the host bone in response to surrounding loading pressures [26]. Studies have indicated that impacted bone graft required additional supports to achieve stable fixation. Naim and Toms [24] used impaction bone graft with a short cemented stem on 11 patients with a minimum follow-up of 2 years. The KSS improved from 27.4 to 89.2 on average, with Knee Society Function score and WOMAC increasing by 26.3 and 23.2 points, respectively. In summary, bone graft may be preferred in AORI type 2 bone defects in relatively young and active patients, who can adhere to the rehabilitation protocols, to preserve bone stock for the possibility of future revisions.

Large central defects (AORI type 2) can be managed by bone grafts: autografts or allografts with impaction grafting.

Metal augmentation

Metal augmentation is one of the most commonly used techniques to tackle bone loss [3]. These augments are available in wedge and rectangular shapes. Several biomechanical studies have indicated that rectangular blocks are superior to wedges since they could directly transmit torsional load to the bone reducing cement mantle strains between the base plate and the tibial plateau [19, 27]. They can be attached using cement or screws, allowing up to 20 mm of segmental bone loss to be replaced and offer immediate support with satisfactory transfer of load [28]. After the proximal tibial cut is made at 10 mm depth from the unaffected tibial condyle, tibial surface is prepared to accept the tibial base tray. The sclerotic base of the defect is cut to expose a flat, cancellous bony surface, and the concave, irregular defect is converted to a flat one by minimal bone removal with a saw. The tibial bone defect is then assessed, and an appropriate-sized metal block is selected. A cutting guide for the block is assembled, and a matching bone resection carried out. Care must be taken not to over-resect the bone, since the tibial blocks should be inserted in a tight manner. The trial tibial component with the block and intramedullary stem is assembled and inserted and a trial reduction is done, verifying alignment, stability and patellar tracking. After lavage, the real components are assembled and cemented. The first block is attached to the tibial tray with screws. After that, the next block is cemented to the first one [29] (Figs. 6, 7a, b). Werle et al. [30] used large metal distal femur augments to compensate for AORI type 3 bone defects and observed no radiographic evidence of loosening. No implants had been revised after a mean of 37 months. Lee and Choi [31] followed 59 patients with primary TKA requiring metal blocks for a mean of 78 months. At the final review, all patients had good to excellent scores, according to OKS and WOMAC system, with mean valgus alignment of 5°. Similarly in

Fig. 6 Preoperative X-ray of knee anteroposterior view showing medial AORI type 2 bone defect (> 20 mm)

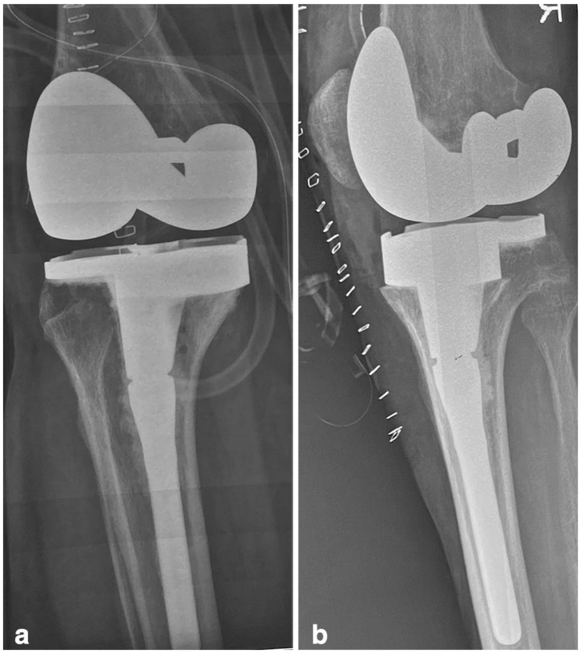

Fig. 7 **a** Postoperative X-ray of knee anteroposterior view showing management of AORI type 2 defect of > 20 mm by metal wedges medially and tibial extender. **b** Postoperative X-ray of knee lateral view showing management of AORI type 2 defect of > 20 mm by metal wedges and tibial extender

defects in femoral condyle: distal, posterior or anterior, metal augments can be attached with femoral component with screws and cement. The biggest drawback with metal augments is that they do not improve bone stock and hence are likely to complicate any future revision. Hence, they may be preferred in AORI type 2 bone defects (both tibia or femur) in elderly and low demand patients, as they can be rehabilitated early and are unlikely candidates for revision. Though augmentations provide satisfactory results in terms of stability of the implant, many patients may complain of pain and dissatisfaction after primary TKA [32].

Porous tantalum cones offer mechanical and osteoconductive properties that allow it to provide structural stability for bone defects, at the same time facilitating osseointegration. Tantalum metal acts as a modular scaffold for osteoblast-mediated bone in-growth and provides a porous surface for graft and cement incorporation. Additionally, it provides significant axial compression support for implants [33]. Although usually used in revision of total knee arthroplasties, there have been reports of use of tantalum cones in primary TKA, with large defects (> 20 mm) AORI type 2 with good results [34–36]. After making the proximal tibial cut and once tibial preparation is done, a porous tantalum cone is chosen according to the size needed to reconstruct the defect, with the cone being large enough to support the tibial implant overlying the defect. An outline of the planned position of the cone can be drawn on the proximal tibia with a surgical marker pen. A high-speed burr is then used to fashion a groove in which the porous tantalum cone will be impacted. The cone is then cut to the size and configuration desired, after which it is impacted into place such that it fits snugly within the bone. Bone grafting is optional prior to cementing the area between the cone and the central portion of the tibia. Primary tibial implant is then cemented in place, after trial [35]. You et al. [35] followed 15 patients (17 knees) for a mean 3.5 years, in which porous tantalum cones were used to address large tibial bony defects. At final follow-up, all knees had stable, functioning implants with cones demonstrating radiographic evidence of osseointegration with no signs of osteolysis, instability, infection or any systemic complications and had an average KSS of 94.6. Brown et al. [36] followed 83 TKAs utilising cones for average 40 months. Ten patients required revision surgery (8 infections, one periprosthetic fracture, one aseptic loosening). The main drawback with cones is that because of its solid osteointegration, it is very difficult to extract in case of a revision and hence should not be preferred in young patients with bone loss.

Porous titanium metaphyseal sleeves are typically used in revision arthroplasties with large bone defects [34]. However, in primary arthroplasty also, larger (AORI type 3) defects such as in the setting of post-traumatic arthritis or rheumatoid arthritis with severe osteopenia offering very little epiphyseal support can be managed with metaphyseal sleeves. Metaphyseal sleeves allow filling of bone defects and direct fixation in a single step, with a single bone–implant interface. They also provide axial transmission of the load thus preventing stress shielding, reduce metaphyseal bone resorption and promote osseointegration. Martín-Hernández et al. [37] used sleeves in primary TKA for post-traumatic arthritis in 25 patients followed up for a mean of 79 months. The mean KSS increased from 29 to 78, with radiological osseointegration of implants in all cases with a survival of 100%.

Choice of constraint in management of bone defects in primary TKA

In primary TKA with bone defects, selection of the implant constraint is based on the integrity of collateral ligaments and on the severity of bone deficiency around the knee. A simple algorithm of choice of the constraint of the implant is proposed in primary TKA with bone loss (Fig. 1). AORI type 1 defects with intact collateral ligaments can be managed with primary posterior stabilised (PS) TKA implants. In these circumstances, it is possible to perform standard tibial bone resections, with bone cement or/and screws. In type T2A AORI bone defects with intact collateral ligaments, primary PS implant with stem extender can be used along with either bone grafts or metallic wedge augmentation. However, augments may not be possible with tibial trays of primary TKA systems of some of the designs. Type F2A AORI bone defects with intact collateral ligaments should be managed with metal augments with semiconstrained CCK with stem extender and constrained insert. In type 2A/2B AORI bone defects with insufficient collateral ligaments, semiconstrained CCK implant with stem extender and constrained insert should be used along with metallic wedge augmentation or porous tantalum cones. CCK are semiconstrained implants, which provide an excellent alternative to the hinged prostheses in cases of insufficient ligaments and moderate severity bone loss (AORI type 2). In CCK prostheses, constrained inserts can be used which are characterised by a large and long tibial post which engages in the large, deep intercondylar cam of the femoral component, thus ensuring medio-lateral and rotational stability. In moderate (type 2) or severe (type 3 AORI) bone defects with complete disruption or absence of the collateral ligaments, constrained or modern hinged implants with fixed or mobile insert should be used.

Conclusion

Bone defects less than 10 mm or AORI type 1 can be addressed using bone cement alone (< 5–6 mm) or (6–10 mm) with screws. AORI type 2 (10–25 mm) defects should be managed by structural bone grafts (auto- or allograft) in the young, active patient and metal block augmentation in elderly, low demand individuals along with stem extender. AORI type 2 (> 25 mm) are better managed with impaction bone grafting and a metal mesh or with porous tantalum cones in elderly along with semiconstrained CCK implants, stem extender and constrained insert. AORI type 3 defects may be addressed using porous metaphyseal sleeves and constrained or hinged implants.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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