Management of bone deficiency by metal augmentation in total knee arthroplasty

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Background
Inadequate bone stock is frequently encountered in total knee arthroplasty and may be found in primary and revision procedures. Different techniques and devices for their management include additional bone resection, shifting of the components, filling the defect with cement with or without reinforcing screws or mesh, bone grafting, modular metal augmentation, or custom components. The modular augmentations are particularly useful in restoring the proper anteroposterior dimension as well as distal positioning of the joint line. In this study, the authors evaluate the use of metal augmentation for the management of deficient bone stock in total knee arthroplasty.

Patients and methods
A prospective study was done through the period between June 2014 and June 2017 on 30 knee arthroplasties, both primary and revision cases in 28 patients with bone deficiency consistent with Anderson Orthopedic Research Institute type II, treated by metal augmentation using different types of tibial and femoral augments applied to a posterior-stabilized prosthesis. The mean follow-up was 19 months. Eighteen cases (60%) were primary knee arthroplasties, and 12 cases (40%) were revision knee arthroplasties. Assessment at follow-up included clinical assessment through the knee society clinical rating system and radiographic assessment through the knee society roentgengraphic evaluation system.

Results
At the last follow-up, the average clinical knee society score was 80.4 (range from 16 to 93) compared with the average preoperative knee society score of 32 (range from 6 to 51). Only tibial radiolucent lines appeared in zones 1, 2 (nine cases), zones 3, 4 (four cases), and zone 5 in one case. All were nonprogressive radiolucent lines, except for two cases that progressed to aseptic loosening, and only one of them to a varus subsidence of the tibial implant.

Conclusion
Modular metal augmentation is a successful way for reconstruction of bone defects encountered in total knee arthroplasty through preservation of joint line and bone stock.

Keywords:
bone deficiency, metal augments, total knee arthroplasty

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Introduction

Inadequate bone stock is frequently encountered in total knee replacement and may be found in both procedures whether primary or revision. In primary total knee arthroplasty, the tibial defects most commonly are associated with significant preoperative angular deformity. In varus knees, peripheral posteromedial bone loss is seen. In the valgus knees, central bone loss from the lateral tibial plateau is most common. Revision total knee arthroplasty procedures can present a spectrum of bony deficiencies involving the tibial and femoral sides of the knee [1].

The variable size of the defects and location of the bone loss have bred an assortment of techniques and devices for their management, including additional bone resection, shifting of the components, filling the defect with cement with or without reinforcing screws or mesh, bone grafting, modular metal augmentation, or custom components [2].

The goals for filling bone defects in total knee replacement differ on the femur and tibia. On the femur, the goals are to establish the distal and posterior joint lines, and place the component securely and firmly on bone. The goal on the tibial side is to provide a stable support for the implant [3].

The attractiveness of modular metal wedges and blocks is the ability to produce a "custom" implant at the time of surgery, establish correct component alignment, and avoid the potential complications associated with structural bone grafting. Wedges and blocks are available in various sizes and angles that can be attached to the tibial component undersurface to provide prosthetic support and fill bone defects [2,4,5].

Modular femoral augments are available with most revision total knee systems. Augmentations are available for the distal femoral condyle, the posterior condyle, or a combination of the two. These usually come in multiple thicknesses and can be independently applied to each condyle. The modular augmentations are particularly useful in restoring the proper anteroposterior dimension as well as distal joint line positioning [2,6,7].

In this study, the authors evaluated the use of metal augmentation for the management of deficient bone stock in total knee arthroplasty.

Patients and methods

A prospective study was done through the period between June 2014 and June 2017 in Ain Shams University Hospitals on 30 knee arthroplasties, both primary and revision cases in 28 patients with bone deficiency consistent with Anderson Orthopedic Research Institute (AORI) type II according to bone defect classification, treated by metal augmentation using different types of tibial and femoral augments applied to a posterior-stabilized prosthesis according to individual case requirement. The study was approved by the institutional ethics committee in the Orthopedic Department of Orthopaedic Surgery, Ain Shams University, Cairo, Egypt. This study has included 17 females (57%) and 13 males (43%). Age of the patients in this study ranged from 54 to 67 years with a mean age of 60.2 years. Fifteen patients (54%) had left-sided knee arthroplasty, and 11 patients (39%) had right-sided one. Two patients (7%) had bilateral knee arthroplasty, one of which was performed simultaneously.

Eighteen cases (60%) were primary knee arthroplasties, and 12 cases (40%) were revision knee arthroplasties. The etiology of bone deficiency among the primary cases was a severe angular deformity due to varus osteoarthritis in 14 cases (50%) or due to rheumatoid arthritis in three cases (10%). Among the revision cases, the etiology was aseptic loosening with angular subsidence of the components in six cases (20%), osteolysis in four cases (13%), and infected knee arthroplasty in two cases (7%). Constrained condylar insert is used in nine cases and posterior-stabilized insert is used in 21 cases. All patients were followed up for a period ranging from 6 to 36 months, with a mean follow-up of 19 months.

Long-standing anterioposterior view for the lower limb, lateral and skyline views of the knee done for all cases. Knee and functional score of knee society scoring (KSS) system are calculated for all patients before surgery and during follow-up visits. Bone deficiency was assessed according to Anderson Orthopedic Research Institute classification.

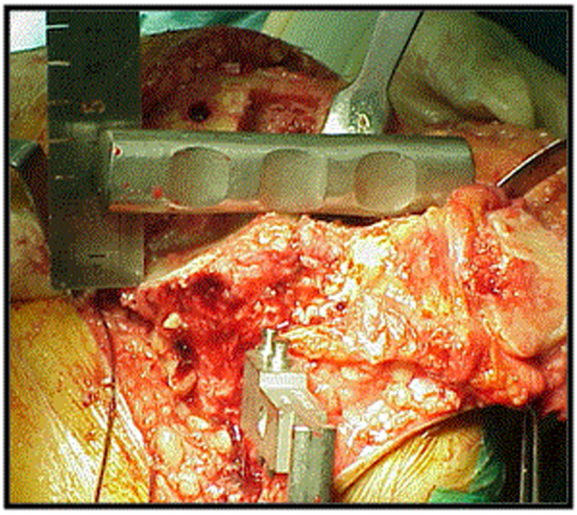
The extent of bone deficiency was provisionally estimated (Fig. 1) before the bone cuts were made on the tibial and femoral sides taking into consideration all the parameters for surface defect description such as bone defect location, depth and surface area, containment, slope, and bone quality at the floor of the defect.

Bone defects were classified after the bone cuts were made in primary knee arthroplasty and after component removal and joint debridement in revision knee arthroplasty. Bone deficiency equivalent to AORI type II defects, whether tibial or femoral/unicondylar or bicondylar, was the case in which metal augmentation was used as a method of reconstruction.

Metal augmentation of tibial bone defects

(1) After performing the tibial cut, the anteroposterior axis of proximal tibia was drawn by using cautery knife from anteriorly the medial third of tibial

Figure 1



Provisional estimation of the extent of bone deficiency on the tibial side before the bone cut.

tuberosity to the notch of the posterior cruciate ligament posteriorly (Fig. 2). This axis guides the correct rotational placement of the tibial component and consequently the augment used.
(2) Residual defect after performing the tibial cut has been measured from the base of the defect to the cut surface of the proximal tibia to determine the correct metal augment size (Fig. 3).
(3) According to defect shape and slope, a choice was made between metal wedges and blocks. The augment that best fits the defect was used, but if little bone stock was to be sacrificed in order to transform an oblique defect to a trapezoidal one, preference was given to metal block use for its mechanical advantages over wedges.
(4) Tibial augment-cutting jigs are used to prepare the bony bed for the metal augment (Fig. 4).
(5) Trial is done with the assembled trial tray and augment to ensure proper seating of the tray and the augment upon the cut surfaces.

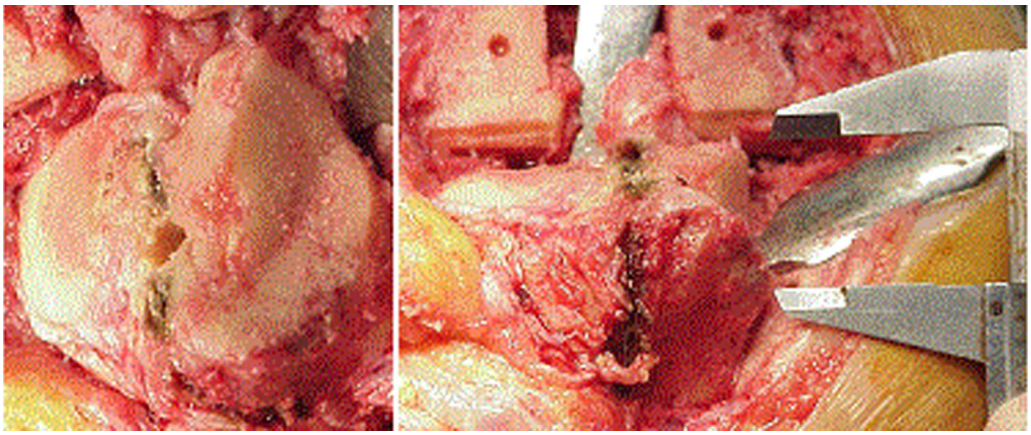
Metal augmentation of femoral bone defects

(1) Femoral bone deficiency that required reconstruction with metal augmentation was predominantly encountered in revision knee arthroplasty where bone loss involved the distal and posterior aspects of the femoral condyles to variable extents.

Rebuilding the flexion space

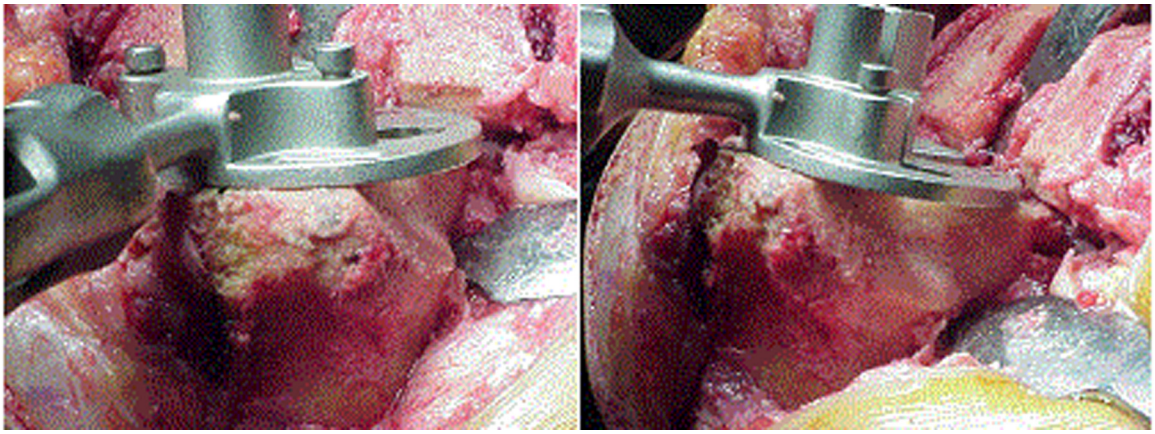
(1) Posterior femoral augments were used to compensate for bone deficiency on the posterior femoral condyles in order to restore the original anteroposterior dimensions of the femur for proper tension of the flexion space to provide stability in flexion and restoration of proper knee kinematics.
(2) Sizing the femoral component in the presence of posterior femoral bone deficiency was done

Figure 2



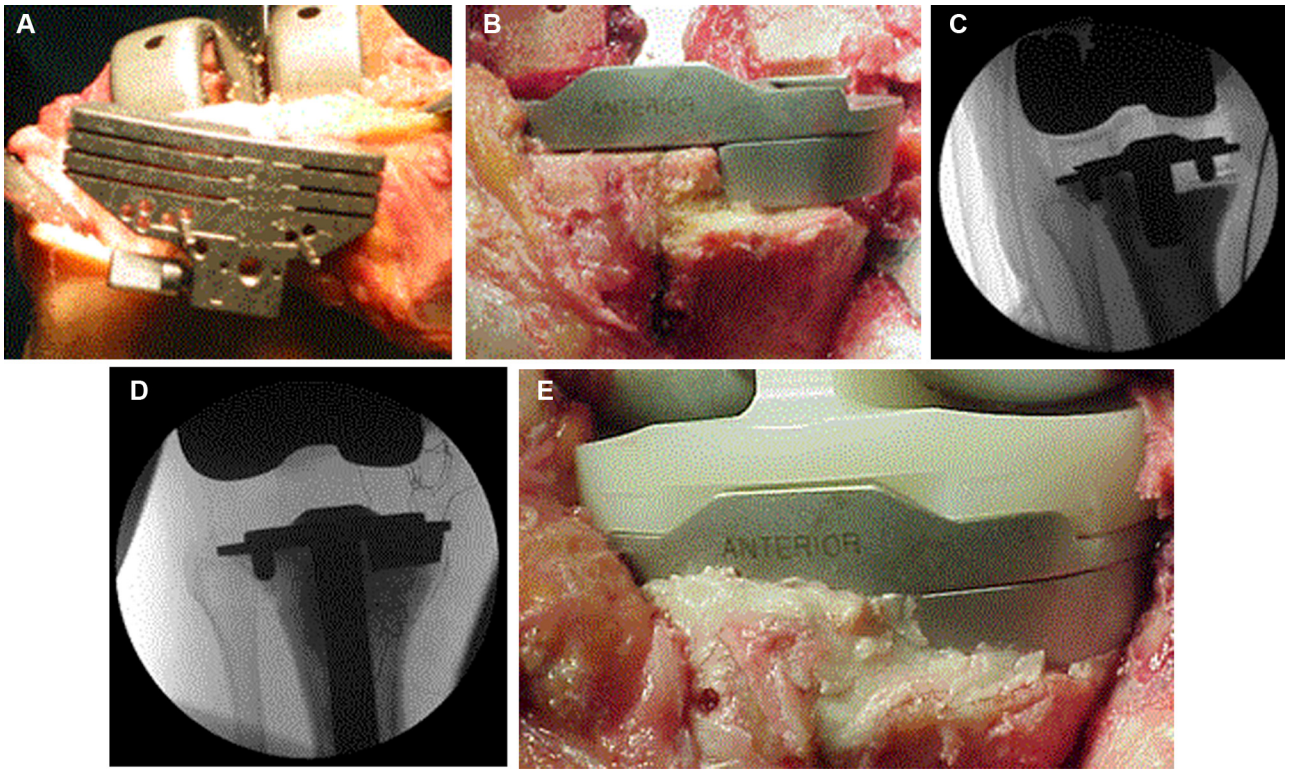
The anteroposterior axis of proximal tibia drawn by cautery knife.

Figure 3



Assessment of the residual defect after performing the tibial cut.

Figure 4



(a) Tibial augment-cutting jig. (b) Trial. (c,d) Intraoperative imaging. (e) Cementation.

by matching the component size used for the original primary arthroplasty, unless the original component was already undersized, or by templating the radiographs of the opposite femur.

(3) The trans-epicondylar axis was determined to ensure correct rotatory position of the femoral component before making the intercondylar box osteotomy for posterior-stabilized prosthesis.

(4) Provisional estimation of posterior femoral augment size was done for each condyle by trial posterior augments (Fig. 5) with the trial femoral component applied in a correct rotation.

(5) The femoral trial construct was applied after determining the posterior and distal augment size and stem extension to ensure correct relation to the epicondylar axis and joint line position. The need to change an augment size to adjust femoral component position can be determined at that time.

(6) The posterior femoral augments were fixed with screws to the interior aspect of the posterior flanges of the femoral component.

Rebuilding the extension space

(1) The extent of bone deficiency on the distal femur was estimated separately for each condyle measuring from the base of the defect to the original joint line.

(2) The aim of distal femoral augmentation was to restore a normal joint line position that is located at a distance of 30 mm from the medial epicondyle and 25 mm from the lateral epicondyle.

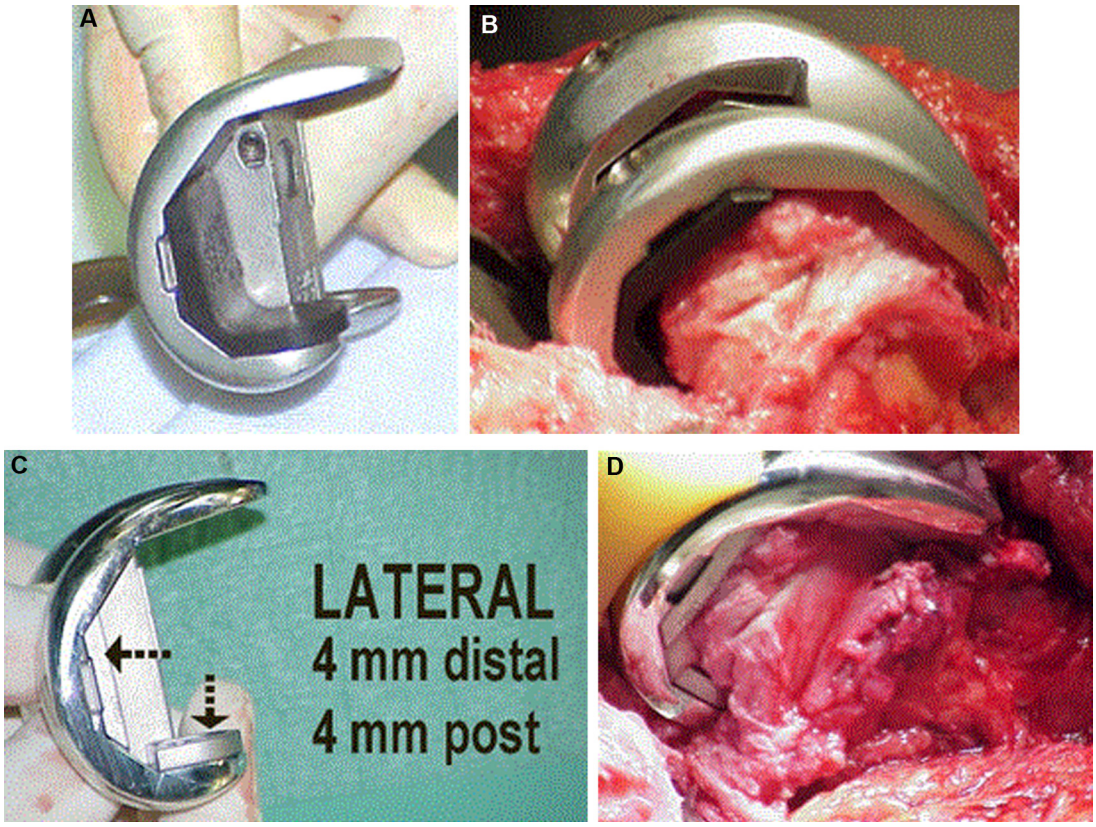
(3) The size of distal femoral augments required was calculated by subtracting the remaining bone stock from the epicondyles to the base of the defect and the thickness of the prosthesis from the above-mentioned values done separately for each condyle.

(4) The femoral trial construct was then applied, and the relationship to the joint line and the epicondylar axis was confirmed (Fig. 6).

(5) Posterior-stabilized prosthesis was used in all cases and was inserted with the routine cementation technique (Fig. 7).

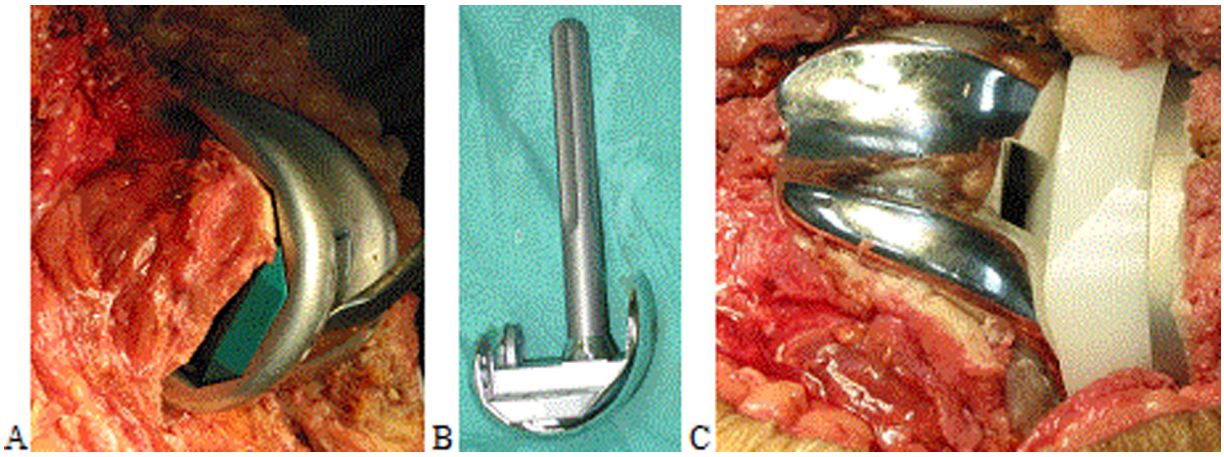
The patients were followed up at 6 weeks, 3 months, and 6 months than yearly. Assessment at follow-up included both clinical assessment through the knee society clinical rating system and radiographic assessment through the knee society roentgenographic evaluation system to detect any change in component position, progressive limb malalignment, or progression of radiolucent lines.

Figure 5



(a,b) Trial posterior and distal augments. (c,d) Definite femoral augments.

Figure 6



(a) Trial distal femoral augment. (b) Assembled femoral component. (c) Definite prosthesis after cementation.

Analysis of data was performed by using SPSS (Statistical Program of Social Sciences) (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.) for analysis of these data as follows:

(1) Description of quantitative parameters was performed in the form of mean, SD, and range.

(2) Paired *t*-test was used for comparison of quantitative parameters in the same group before and after the surgical procedure.

Results

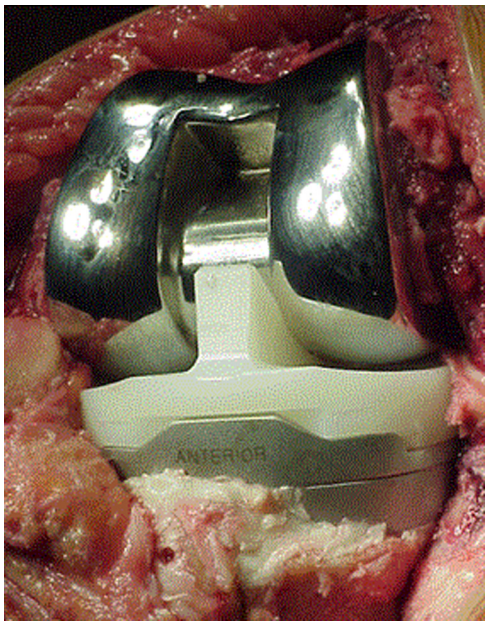
Combined tibial and femoral bone deficiency was encountered in six cases, all were revision surgeries.

Isolated femoral bone deficiency was encountered in two revision cases. Isolated tibial bone deficiency was encountered in 22 cases, of which 18 were primary cases and four were revisions. Out of the 18 primary cases, there were 16 cases with medial tibial plateau deficiency and two cases with lateral plateau deficiency. Distal femoral augments were used medially in four cases and laterally in three cases. Posterior femoral augments were used laterally in four cases and medially in two cases. All femoral augments were fixed with screws to the inner aspect of the femoral component.

(1) The tibial component had a mild varus inclination in one case postoperatively, β-tibial angle of 84°. The latter developed progressive radiolucent lines and varus loosening of the tibial tray at the latest follow-up.
(2) The femoral component had a mild valgus inclination in one case postoperatively, α-femoral angle of 100°.
(3) Only tibial radiolucent lines appeared in zones 1, 2 (nine cases), zones 3, 4 (four cases), and zone 5 in one case. All were nonprogressive radiolucent lines, except for two cases that progressed to aseptic loosening, and only one of them to a varus subsidence of the tibial implant.

At the last follow-up, the mean clinical knee score (KSS) was 80.4 (range from 16 to 93), while the mean preoperative KSS was 32 (range from 6 to 51).

Figure 7



The posterior-stabilized prosthesis with medial tibial metal augment.

Fifteen knees (50%) had excellent results, 11 knees (36.6%) had good results, one knee (3.3%) had fair result, and poor results were encountered in three knees (10%) (Table 1). There was a highly statistically significant difference between pre- and postoperative analysis regarding clinical knee score (Table 2).

The mean function knee score at the last follow-up was 78.3 (range from 5 to 95), compared with mean preoperative knee functional score of 31.7 (range from 3 to 54).

Thirteen knees (43.3%) had excellent results, 14 knees (46.6%) had good results, and three knees (10%) had poor results (Table 3). There was a highly statistically significant difference between pre- and postoperative analysis regarding fictional knee score (Table 4).

Six of the patients in the study developed different complications. They are summarized in Table 5.

Table 1 Clinical knee score before and after surgery

Clinical knee score	Pre [*n* (%)]	Post [*n* (%)]
Excellent 85–100 points	0	15 (50)
Good 70–84 points	0	11 (36.7)
Fair 60–69 points	0	1 (3.3)
Poor <60 points	30 (100)	3 (10)

Table 2 Pre- and postoperative statistical analysis for clinical knee score

	Preoperative	Postoperative
Range	6–51	16–93
Mean score	32	80.4
±SD	13.4	15.7
Median score	37	84.5
Mean difference	48.4	
P value	*P*<0.0001 (highly significant)	

Table 3 Functional knee score before and after surgery

Functional knee score	Pre [*n* (%)]	Post [*n* (%)]
Excellent 85–100 points	0	13 (43.3)
Good 70–84 points	0	14 (46.7)
Fair 60–69 points	0	0
Poor <60 points	30 (100)	3 (10)

Table 4 Pre- and postoperative statistical analysis for knee functional score

	Preoperative	Postoperative
Range	3–54	5–95
Mean score	31.7	78.3
±SD	13.8	18.1
Median score	32.5	80
Mean difference	46.6	
P value	*P*<0.0001 (highly significant)	

Table 5 Complications encountered in the study

Complication	No. of patients
Aseptic loosening*	2 patients
Varus subsidence*	1 patient
Deep infection	1 patient
Rupture MCL*	1 patient
Partial patellar tendon stripping	1 patient

MCL, medial collateral ligament. *Complications taken place in the same patient.

Discussion

Bone stock deficiency significant enough to require an alteration in total knee arthroplasty technique is frequently encountered. Various treatment options have been proposed for dealing with these bone defects. The alternatives include increasing the resection depth, reconstitution of the defect with bone cement with or without reinforcing screws, reconstitution of the defect with autograft or allograft bone, custom implants, and the use of metal augmentation [2].

The use of metal augments in managing bone defects in both primary and revision knees having a lot of advantages renders them an appropriate solution. Metal augments provide multiple customization intraoperatively. Tibial and femoral asymmetrical defects do not need further bone resection to make a symmetrical bed to place the components. This allows preservation of bone stock and avoids damage to collaterals and attachments of soft tissue. By using metal tibial augments, less bone is resected from the tibial surface increasing the strength of tibial cancellous bone that supports the component. If defects are not reconstructed by metal augments, an undersized tibial tray will be used, which may result in mismatch between the femoral and tibial components. In addition, using of femoral augments to reconstruct bone defects will restore the normal joint line and kinematics of the knee joint, which allows balancing of the collaterals and correction of component rotation. In comparison with bone grafts, no healing is required to the sclerotic bone when metal augments are used [2–5].

Inspite of the widespread usage and advantages of metal augments, there were many concerns regarding their use in total knee replacement. Fretting, loosening, and modular implant disassociation may occur between the tibial or femoral interface and the augments. In-vitro wedge-shaped augments are less stable than metal blocks [8].

Bone strength in the subchondral region of the tibial has been shown to diminish markedly just several millimeters underneath the subchondral plate. Dorr and colleagues, 1985, evaluated that resection of tibial bone must not exceed 1 cm underneath the lateral subchondral plate or 5 mm underneath the medial subchondral plate. Based on the above data, bone defect reconstruction is recommended than additional bone resection [9].

Tsukada *et al*. [10] revealed that the survival of block-shape metal augments in TKA was not inferior to that of standard TKA without bone defects requiring augments.

Scott and colleagues have been the pioneer in the use of metal augmentation for tibial defects. He initially designed "wedgies" that could be used on the undersurface of the tibial tray to fill peripheral defects. This concept has become popular and available on almost all total knee replacement systems [11].

Several studies have addressed the use of modular metal augments in total knee arthroplasty. The study of Pagnano and colleagues addressed modular tibial augments in primary total knee replacement and reviewed 25 knees in 21 patients. At an average follow-up of 4.8 years, excellent and good results were achieved in 96% of the patients. Although radiolucent lines were seen beneath the tibial component in 13 knees, none of these lucencies were progressive [1].

In the present study, in comparison with the study of Pagnano and colleagues, tibial radiolucent lines were observed in 14 cases, all were nonprogressive radiolucent lines, except for two cases that developed progression to aseptic loosening. In the present series, no failures of the augment–prosthesis interface were observed, a result that is comparable to the study of Pagnano and colleagues, suggesting the safety of screw fixation of the metal augments to the prosthesis with a stable and durable interface.

In the present series, the statistically significant improvement in the postoperative range of motion, pain scores, stability, and limb alignment with scores comparable to other studies was attributed in part to the relative success of the metal augmentation technique in achieving the goals of bone defect reconstruction on the tibial and femoral sides, and in the other part to considering the general principles and goals of total knee arthroplasty as regards

(1) Restoration of the lower-extremity mechanical axis
(2) Stable fixation of the prosthesis

(3) Restoration of the normal joint line
(4) Maintaining the balance of soft tissue in flexion and extension
(5) Providing a functional range of motion for daily living activities

Achievement of such goals required primarily a careful positioning of the arthroplasty components with the metal augments attached according to the preoperative and intraoperative surgical plan, and secondarily a careful balancing of the collateral ligaments and equalization of the flexion and extension gaps in such cases with a severe preoperative angular deformity that contributed to the etiology of the bone deficiency.

Rand, 1996, has studied 41 revision knees in which modular augmentation was used. At a mean follow-up of 3 years, excellent and good results were found in 98% of the 41 revisions. There were no cases of loosening [7].

Werle and colleagues reported that large distal femoral augments might be useful for management of severe metaphyseal femoral bone loss due to fracture nonunion, severe osteolysis, or infection, and that future studies comparing the use of large metal augments with allograft, as useful adjuncts to the revision knee surgeon's armamentarium, are necessary [3].

Patel and colleagues reviewed 79 revision knee replacements containing treatment of type II bone defects by modular metal augments. The survival of the components was 92% at the latest follow-up. Rerevision was done in six knees of them. Aseptic loosening of tibial tray was found in three knees. One knee was rerevised for coronal instability. Deep infection occurred in two knees. Radiolucent lines or loosening of the augments were not documented in any of the knees [8].

In the present series, three knees required revision after 1 year and two for aseptic loosening after 3 years. Deep infection requiring a two-stage revision surgery occurred in one knee. However, failure of the metal augment–prosthesis interface due to theoretical concerns of fretting or disassociation of the augment was not encountered in this series.

Aseptic loosening in one case was attributed to a mild varus positioning of the tibial component with mechanical axis deviation that led to transfer of the resultant forces acting on the knee in the coronal plane medially. Medial stress concentration together with a weaker metaphyseal bone quality present at a higher depth of resection medially, to form the bed for the block tibial augment, resulted in progressive loosening and varus subsidence of the tibial component. Aseptic loosening in the second case was attributed to component fixation in a poor bone quality, avascular necrosis (AVN) with collapsing the subchondral bone of the medial tibial plateau, and failure of the standard bony cuts for the tibial component and metal augment to take beyond all the avascular bone. Revision surgeries were performed using hinged components due to medial collateral ligament insufficiency and a more severe segmental tibial bone deficiency present at the time of revision.

Conclusion

Modular metal augmentation is a successful way for reconstruction of bone defects encountered in total knee arthroplasty when special attention has been paid for

(1) Achieving a perfect component position and limb alignment
(2) Considering stem extensions and varus–valgus-constrained inserts when indicated
(3) Careful balancing of the collateral ligaments in such cases with severe angular deformities

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Conflicts of interest

There are no conflicts of interest.

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