



Novel Classification System for Bone Loss in the Setting of Revision Total Knee Arthroplasty

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Introduction

Management of bone loss is important in achieving long-term implant survivorship during revision total knee arthroplasty (TKA). With an incidence approaching 80%, bone loss is exceedingly common in this setting.¹ A quantitative bone loss classification system and associated algorithm would be helpful to guide surgeons regarding strategies to manage of bone loss during revision TKA. Currently, the two most popular classification systems in use, the Anderson Orthopaedic Research Institute classification^{2,3} and the University of Pennsylvania classification,⁴ have been identified as being deficient in guiding treatment and have failed to be universally accepted.^{5,6} A quantitative classification system is needed that is objective, reproducible, user-friendly, and able to accurately guide surgical strategy as well as allow for valid comparisons between various bone loss management options.^{1,6} The aims of our study were to evaluate the intra- and inter-observer reliability of a newly developed quantitative radiographic classification system and to assess whether the radiographic classification of bone loss could be combined with a treatment algorithm to predict the revision prostheses and strategy utilized to manage the bone loss.

Materials & Methods

We gathered anteroposterior (AP) and lateral preoperative radiographs from all patients

who had a revision TKA performed by the senior author (CLN) between April 2006 and December 2009. From this cohort, 54 knees were eligible for inclusion in the inter- and intra-observer reliability portion of this study, with 17 procedures excluded. Exclusion criteria were as follows: (1) prior total femur or proximal tibia replacement, and (2) lack of appropriate preoperative radiographs. The radiographs were then evaluated, using our classification system, by three attending surgeons and one PGY-3 orthopaedic resident. The evaluators were each provided with a description of the classification system (Table 1). All 54 radiographs were de-identified and evaluated by each physician on two separate occasions, at least three weeks apart, using a secure online survey distributed and managed with REDCap, an electronic data capturing tool.⁷

On the femoral side, our classification is based upon anatomic principles. The goal of femoral component revision is to achieve long-term fixation of an axially, rotationally, coronally and sagittally stable femoral implant of appropriate size and at an appropriate joint line in proper rotation, alignment and position. The normal femoral joint line is approximately 2.5–2.8cm below the medial femoral epicondyle, and the normal length of the posterior flange of the femoral component is approximately 2cm8. Therefore, uncontained condylar bone loss of up to 1.5cm would allow near joint-line restoration with distal metal augments of

TABLE 1. Classification of Femoral and Tibial Bone Loss

Rating	Parameters
M0 or L0	Compartment never violated by prosthesis
M1 or L1	Femur: < 1.5 cm Tibia: Above tip of the fibular head
M2 or L2	Femur: 1.5 – 2.5 cm Tibia: Between fibular head and tibial tubercle
M3 or L3	Femur: Compromised collateral ligament insertion (>2.5cm) Tibia: Distal to tibial tubercle
C0	Canal never violated
C1	Stemmed implant with intact cortical tube
C2	Stemmed component with cortical thinning of the canal
C3	Stemmed implant with significant remodeling or canal ectasia

approximately 10-12mm and still provide sufficient posterior condylar bone to establish prosthetic rotational stability with the posterior flange or posterior metal augments of appropriate thickness. Bone loss of more than 1.5cm results in a decreased ability to establish rotational stability at the normal joint line against metaphyseal bone with distal and posterior augments. Therefore, consideration for use of bulk allografts or metaphyseal porous metal sleeves or cones may be necessary to ensure stability. Bone loss that does not compromise the femoral epicondyles allows maintenance of the collateral ligament attachments, and therefore allows use of non-constrained or non-linked varus-valgus constrained knee designs. Bone loss proximal to the femoral epicondyles is associated with loss of collateral ligament stabilizers and typically requires use of a rotating hinge or segmental megaprosthesis device.

On the tibial side, our classification system is based on the anatomic relationship of the joint line to the fibular head and tibial tubercle. The relationship between the tip of the fibular head and the normal joint line varies. Nevertheless, the normal joint line has been estimated to be about 1.5cm proximal to the tip of the fibular head.^{8,9} Additionally, tibial size and metaphyseal strength diminish as tibial bone loss extends further distally.¹⁰ The insertion of the lateral collateral ligament is into the fibular head, while the superficial medial collateral ligament inserts further distally along the medial tibia, well below the level of the fibular head. Moreover, when tibial bone loss extends below the tibial tuberosity, there is normally a loss of extensor mechanism function requiring repair or reconstruction at the time of the revision procedure.

When evaluating bone loss on either the femur or tibia one must also consider the canal. The presence of a prior stem, particularly with loosening, cortical thinning and femoral ectasia may lead to greater bone loss after removal and may

compromise metaphyseal or diaphyseal fixation with standard stem implants.

The associated treatment algorithm (Tables 2 and 3) we developed is largely based on these same principles. In order to assess the validity of the classification system and the associated algorithm, we compared the treatment predicted by the first survey attempt of the senior author with the actual management strategy utilized for each case, based on operative notes and a record of implanted devices. There was sufficient information from 48 femurs and 47 tibias for this assessment.

When calculating intra-observer agreement, inter-observer agreement and validity, each of the 6 sub-classifications (compartments) for each knee was used as a point of potential agreement or disagreement. Observed agreement (%) and Fleiss' kappa^{11,12} were used to quantify the level of agreement.

Results

The average kappa value for intra-observer agreement was 0.78, which qualifies as substantial agreement according to the Kappa Interpretation Scale developed by Landis and Koch.¹³ The intra-observer agreement and observed agreement for each physician ranged from 0.69–0.89 and 79%–93%, respectively.

The inter-observer kappa score comparing all four raters' evaluations were 0.70 (95% CI 0.67-0.73) and 0.71 (95% CI 0.68-0.73), for the first and second attempts respectively. The observed agreement among all four evaluators was 64% for both the first and second attempts.

The predictive algorithm had near perfect agreement with the ultimate treatment utilized, with a kappa value of 0.94 (95% CI 0.86-1.02) and an observed agreement of 96%. There were six procedures, including eleven compartments, that were managed differently than would have been predicted by the treatment algorithm and the preoperative bone loss

TABLE 2. Treatment Options for Femoral Bone Loss

Rating	Recommended Treatment
M0 or L0	Metal augments generally not needed
M1 or L1	Distal and/or posterior metal augments
M2 or L2	1) - Porous metal sleeve or cone - Or bulk allograft 2) Impaction grafting with wire mesh 3) May add metal augments as necessary
M3 or L3	1) Rotating hinge or distal femoral replacement 2) Allograft prosthesis composite with fixation of host epicondyles
C0	Short cemented or diaphyseal engaging press-fit stem
C1	Short cemented or longer press-fit stem
C2	Longer cemented or press-fit stem
C3	1) Cemented stem favored over press-fit 2) Megaprosthesis or distal femoral replacement 3) Femoral osteotomy, in cases of marked deformity

TABLE 3. Treatment Options for Tibial Bone Loss

Rating	Recommended Treatment
M0 or L0	1) Standard stemmed implant 2) Short cemented stem with metal augmentin opposite compartment
M1 or L1	1) - Short cemented or diaphyseal engaging press-fit stem - May also require cement or particulate bone graft 2) Porous metal cone or sleeve
M2 or L2	1) Metal augments 2) Porous metal cones or sleeve 3) Impaction grafting with wire mesh
M3 or L3	*First, confirm whether or not extensor mechanism is intact *Intact extensor mechanism 1) Porous metal cone/sleeve or bulk allograft 2) Addition of metal augments to the above as needed 3) Also, CCK or rotating hinge required *Intact, but tenuous 1) Porous metal cone to support biologic fixation to tubercle 2) Proximal tibial allograft with fixation of host tubercle to cancellous allograft bone *Disrupted extensor mechanism 1) Proximal tibial allograft with attached extensor mechanism 2) Porous metal cone with extensor mechanism repair or reconstruction with tendon autograft/allograft or Marlex mesh
C0	Short cemented or diaphyseal engaging press-fit stem
C1	Short cemented or longer press-fit stem
C2	Longer cemented or press-fit stem
C3	1) Cemented stem favored over press-fit 2) Megaprosthesis or proximal tibial replacment 3) Tibial osteotomy, in cases of marked deformity

classification. Three of the compartments were managed more aggressively than predicted and eight were managed less aggressively.

Discussion

Comparing different strategies for management of bone loss during revision TKA requires a rational, valid and reliable classification system to quantify the degree of bone loss. We have proposed such a system that quantifies and classifies bone loss using important anatomical landmarks that are relevant when considering management.

We designed this study to evaluate the inter- and intra-observer reliability of this new classification system as well as demonstrate its ability to predict the intraoperative management when paired with the treatment recommendations we presented.

Certain limitations were identified when reviewing the cases where our system failed at predicting actual treatment. The importance of assessing every compartment for bone loss regardless of whether it has been violated by an implant

was highlighted by one case that featured significant central osteolysis in the setting of an appropriately oriented stemless component. In another case, the knee was flexed for the AP radiograph, causing many of our evaluators to interpret what was an isolated posterior femoral defect as extending across the condyles more proximally. When evaluating radiographs preoperatively, it is important to evaluate their quality, and repeat radiographs as necessary.

We recognize that two-dimensional radiographs may under- or over-predict the degree of bone loss encountered during revision TKA, and believe in the future this study will be supplemented with prospective intraoperative evaluations of bone loss in order to better assess its preoperative accuracy and also its utility as an intraoperative classification system. Nevertheless, we believe this is a good initial step which will be useful during preoperative planning and determination of management strategies. The future direction of this classification system will be to demonstrate the validity of the radiographic classification and treatment algorithm in other surgeons' hands to demonstrate its utility among surgeons with a variety of training backgrounds and practice settings.

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