Review article: Bone defect classifications in revision total knee arthroplasty

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ABSTRACT

There are several classification systems for bone defects in revision total knee arthroplasty. Each has its own drawbacks, and none satisfies all the clinical demands. Therefore, a new classification system and treatment guideline based on a combination of criteria (location, side, containment, and severity of the bone defect) is necessary.

Key words: arthroplasty, replacement, knee; classification; reoperation

INTRODUCTION

Bone defects are commonly encountered in revision total knee arthroplasty (TKA) and can affect implant alignment and the bone-implant interface. Bone loss can be caused by stress shielding, osteolysis, infection, and mechanical motion generated from a loose implant.1-4 It may also be iatrogenic at the time of implant removal.5-8 In revision TKA, bone defects must be addressed to restore the joint line and provide structural support for the new implant.9 There is no consensus on the classification and management protocol. An ideal classification system should be easy to use, enable accurate evaluation of bone loss for preoperative planning, facilitate comparison of results among surgeons, predict outcomes, and provide guidelines on treatment and rehabilitation.8,10-12

CLASSIFICATION

Dorr classification

It classifies tibial defects as central or peripheral and TKAs as primary or revision.13 The size of the defects is not defined. Tibiae with peripheral defects have no peripheral support for the tibial component; Tibiae with central defects have an intact bony rim that acts as a support. In revision TKAs, most defects are peripheral and secondary to a condylar fracture (usually medial) or subsidence of the component.
without fracture. This classification does not include femoral defects and is too crude for complex bone defects. It provides little value on treatment of revision TKA.

**Rand classification**

It describes 4 types of femoral defects (minimal, moderate, extensive, and massive) based on their depth and the area of condylar involvement expressed as a percentage. Defects are defined as minimal when <5 mm deep with <50% condylar involvement, moderate when 5–10 mm deep with 50 to 70% condylar involvement, extensive when >10 mm deep with 70 to 90% condylar involvement, and massive when condylar involvement is >90%. The severe cavitary defects can be subdivided into having an intact or deficient peripheral rim. This classification is based on intra-operative observation. It does not take into account the morphology of the defect, and hence provides little guidance for treatment.

**Bargar and Gross classification**

It covers both femoral and tibial defects and classifies them into (1) segmental type (lacking both cortical and cancellous bone at the joint surface level), which is regarded as a peripheral or uncontained defect in other classification systems, (2) cavitary type (lacking cancellous bone at the joint surface level with an intact peripheral rim), which is regarded as a contained defect in other classification systems, (3) intercalary type (defect in the centre of the bone, usually below the joint surface level, with intact bone proximally and distally [i.e. a cyst in the metaphyseal area]), and (4) discontinuity type (fracture or segmental bone loss). The latter 2 types are seldom encountered and not so applicable in revision TKA.

This classification measures the depth of the bone loss based on specific anatomic landmarks on preoperative radiographs and intra-operative inspection. For the femur, the reference points are the epicondyles and 2 additional lines 1 and 2 cm proximal to them to categorise 3 grades of bone loss. For the tibia, the reference points are the top of the tibial tubercle, the top of the fibular head, and 1 cm distal to the top of the fibular head. Each type of defect is assigned a point score to enable comparison between studies.

Anatomic landmarks are objective and may increase the inter-observer error. In addition, femoral epicondyles are far from the knee joint line; their involvement indicates loss of integrity of the collateral ligaments, which is a very severe defect and not commonly encountered. The quality of radiographs is crucial to demonstrate the osseous anatomy, but reference landmarks can be obscured even in high-quality radiographs, and classification may become time-consuming and inaccurate.

**Elia and Lotke classification**

It classifies bone defects into large and small. A large bone defect was defined as >1 cm in depth and involving >50% of the surface of the osteotomised femur or tibia. This classification is too simple to guide treatment and predict clinical outcome, and unable to describe the commonly encountered defects. It was first used to appraise the results of revision TKA associated with severe bone loss and compare clinical outcomes of different treatments.

**Insall classification**

It classifies bone defects as contained and uncontained. A contained defect has an intact cortical rim, whereas an uncontained defect has segmental bone loss with no remaining cortex. This classification is based on treatment options of cementation alone, cementation or augmentation plus a stemmed component, and block augmentation and stem extension (for massive defects). The size of the contained defect can be defined as small (<5 mm) or large (>5 mm). The size of the uncontained defect can be defined as small (<5 mm), intermediate (5–10 mm), or large (>10 mm). Femoral defects are further categorised as symmetrical or asymmetrical, central and medial/lateral peg hole, distal ice-cream cone, and asymmetrical ice-cream cone defects. Similarly, tibial defects are categorised as asymmetrical, full slope, ice-cream cone, asymmetrical ice-cream cone, and contained defects.

This classification is full of visual description and covers almost all shapes of bone defects. However, morphologies such as ice-cream cone or medial/lateral peg hole defects are uncommon and not applicable nowadays, as they were originally defined based on the design of old implants. The correlation of proposed treatment and defects is unsatisfactory.

**Slooff and de Waal Malefijt classification**

It classifies contained bone defects to be repaired by impaction bone grafting. The size of the contained defect can be defined as small (<4 cm³), moderate (4–10 cm³), or large (>10 cm³). This classification is an intra-operative description and thus not useful for preoperative planning.
Anderson Orthopaedic Research Institute classification

It classifies femoral and tibial defects separately into types I, II, and III (Fig. 1). In type-I defects, the metaphyseal bone is intact, with minor bone defects not compromising component stability. In type-II defects, there is metaphyseal bone damage and cancellous bone loss in one femoral/tibial condyle (type IIA) or both femoral/tibial condyles (type IIB); cement reinforcement, bone grafting or metal augmentation is needed. In type-III defects, the metaphyseal bone is deficient and a structural allograft or a custom-made, hinged or revision prosthesis with an extended intramedullary stem is needed.

This classification is most frequently used. It takes into consideration both the location of the defect and the stability of the implants. It provides guideline to treatment and enables preoperative planning on radiographs. Moreover, it enables statistical comparisons and retrospective categorisation of cases from intra- and post-operative inspection/radiographs.

However, this classification is a subjective assessment; there are no specific physical instruments or scale for quantification of bone loss on preoperative radiographs. Furthermore, underestimation of bone defects preoperatively is common when radiographs are obscured by the radio-opaque implants (especially the femoral component on the anteroposterior view). Further bone loss can also occur after implant removal.

Massachusetts General Hospital classification

It classifies femoral defects into major and minor types according to the epicondylar level (above vs. below), volume (>1 vs. ≤1 cm³), and containment (contained vs. uncontained). Using the femoral epicondyles as landmarks may not be appropriate, as they are way above the native knee joint line and thus very few cases are classified as major. For most minor defects, it does not guide the treatment options. There may be a paradox in that defects may be >1 cm³ but still below the epicondyles.

Clatworthy and Gross classification

It classifies bone defects into contained and uncontained (Fig. 2). Contained defects are further divided into types 1 and 2, based on the integrity of the metaphyseal bone. In type-1 defects, metaphyseal bone is intact and thus no bone grafting or augmentation is needed to restore a normal joint line. These small defects can be filled with cement, and primary prosthesis designs without stems can be used. In type-2 defects, metaphyseal bone is deficient and requires bone grafting, cementation or

![Figure 1](image-url)  Anderson Orthopaedic Research Institute classification of bone defects: (a) type 1 (intact metaphyseal bone with minor defects not compromising the stability of a revision component), (b) type IIA (damaged metaphyseal bone with defects in one femoral condyle or tibial plateau), (c) type IIB (more than one damaged metaphyseal bone), and (d) type III (deficient metaphyseal bone with bone loss compromising a major portion of the condyle or plateau). The latter defects are occasionally associated with collateral or patellar ligament detachment and usually require bone grafting or custom implants.
augmentation to repair. The uncontained defects are further divided into types 3 (non-circumferential) and 4 (circumferential). Type-3 defects require partial grafting for the distal femur, proximal tibia, or femoral head, whereas type-4 defects require segmental grafting for the distal femur or proximal tibia. This classification is based on the severity of defects and the treatments necessary. It does not enable accurate preoperative assessment, as it entails intra-operative evaluation.

Huff and Sculco classification
It is based on the Anderson Orthopedic Research Institute classification. The basic patterns of bone loss are cystic, epiphyseal, cavitary, and segmental. Cystic defects are small pockets of trabecular bone loss in the bone-and-implant interface, or subchondral cysts in the primary setting. Epiphyseal defects entail cortical bone loss in the epiphyseal/metaphyseal area. Cavitary defects are massive, intracortical, metaphyseal bone loss. Segmental defects are a combination of epiphyseal and cavitary defects, with large extent of bone loss in the distal femur or proximal tibia, and may involve collateral ligament attachments. This classification is based on the morphology and appearance of the defect and thus may guide treatment. Nonetheless, the epiphysis is usually cut off during most of TKAs and the existence of epiphyseal defects is questionable.

University of Pennsylvania classification
It uses grids to quantify bone loss in the distal femur and proximal tibia on anteroposterior and lateral radiographs. The number of grids with bone defects is counted. This valid and reliable classification enables preoperative planning and outcome comparison between different series and treatment protocols. Nonetheless, it is complex and not commonly used by other joint replacement centres.

DISCUSSION
Different classification systems for bone defects in revision TKA focus on different aspects (Table). No single system can perfectly predict intra-operative bone defects from preoperative radiographs. Some systems are complicated to use or ambiguous. Intra- and inter-observer errors should be assessed to reveal accuracy and reproducibility of the classification systems. A simple, user-friendly classification system that indicates location, severity, and size of the
defects and enables accurate preoperative planning and management as well as outcome comparison between different surgeons is desirable.

Different defect types in different classifications have the same meaning. The minimal type in the Rand classification, the small type in the Slooff and Malefijt classification, the type-I defect in the Anderson Orthopaedic Research Institute classification, the uncontained minor type in the Massachusetts General Hospital classification, the type 1 in the Clatworthey and Gross classification, the cystic type in the Huff and Sculco classification, and the cavitary type in the Bargar and Gross classification—all describe a defect that is small and contained, not requiring complex reconstruction. The massive type in the Rand classification, the discontinuity type in the Bargar and Gross classification, the type-III defect in the Anderson Orthopaedic Research Institute classification, the peripheral type in the Dorr classification, the segmental type in the Huff and Sculco classification, the ice-cream type in the Insall classification—all describe severe defects that invade into the condyles and may or may not affect the integrity of collateral ligaments.

An ideal classification system should enable accurate preoperative planning for management. However, many systems are based on intra-operative observations. Even though a few systems enable preoperative planning, the intra- and inter-observer errors may be quite significant.8,22–25 The presence of metal implants may mask the bone defects on radiographs and underestimate the size and severity of defects.

Patellar defects are common in revision TKAs; poor reconstruction may lead to patellofemoral instability or even dislocation.26–29 The management of the patella with severe bony deficiency remains controversial.30–37 Studies on classification of patellar bone defects are limited. In revision TKAs, the patella should not be replaced when the patella is not resurfaced in the primary TKA, when the defect is minimal and patellar tracking is satisfactory, and when the remaining bone quantity is good. The patella should not be revised when it was resurfaced in primary TKA but not loosened during the revision. This also applies when revision is not secondary to infection and the geometry of the patellar implant conforms with the trochlea of the femoral prosthesis. Patellar revision is indicated when there is infection or patellar mal-tracking. The decision should be based on adequacy of bone stock and prostheses designs. Even tantalum patellar prosthesis can be considered depending on the integrity of the cortical rim and central bone thickness.

### References