Original Article

Correlation of tibial bone defect shape with patient demographics following total knee revision

Madhav Bole*, Matthew Teeter, Brent A. Lanting, James L. Howard

Division of Orthopaedic Surgery, London Health Sciences Centre, University Hospital, 339 Windermere Rd., London, Ontario N6A 5A5, Canada

ARTICLE INFO

Keywords:

Revision total knee arthroplasty
Tibial bone defect
Revision TKA
Bone loss

ABSTRACT

Background: Bone defects of the proximal tibia following revision total knee arthroplasty (TKA) are challenging to manage, but must be addressed to provide lasting stability. This paper will categorize tibial bone defects into shape groups and correlate resulting groups to patient demographic data.

Methods: Retrospective analysis of four hundred and four patients post revision TKA between January 2005 and February 2014 was conducted. One hundred and eighteen met the inclusion criteria and were subcategorized by defect shape on their post-operative lateral and anterior-posterior (AP) radiographs. The subgroups of defect shape were subsequently analyzed with Fisher's exact test and one way ANOVA.

Results: Trapezoidal shaped defects were the most common in both radiographic views, and the magnitude of the defect at the top joint line varied significantly amongst shape groups in both AP and lateral views. Trapezoid shaped defects were correlated with smaller defect top lengths in both views. There was no statistical correlation between defect shape BMI, TIV and reason for revision in lateral view. However, T-bilateral defect shapes were correlated with higher BMIs in AP view.

Conclusion: A volumetric classification system of tibial defects is necessary for preoperative planning in revision TKA. Common tibial bone defect shape groups were identified and analyzed in AP and lateral radiographs after revision TKA. Trapezoidal defects were the most common, and all other shapes followed a pattern of proximal enlargement tapering distally. Trapezoidal defects were smaller than other shapes and AP T-bilateral shaped defects were correlated with higher BMIs.

1. Introduction

With the demand for primary total knee arthroplasties (TKA) in the United States expected to increase to over 3 million procedures by 2030 and the revision burden (the ratio of primary to revision arthroplasties) remaining constant at just over 8%, there will be an exponential increase in the demand for revision TKAs which provide better outcomes than their predecessors.¹

The reasons for failure of primary TKAs are numerous: infection, instability, implant failure, periprosthetic fracture, osteolysis, dislocation, bearing surface wear, and mechanical loosening.^{2–4} Despite the many possible causes, generally the most common indication for revision TKA is aseptic loosening.^{4–6} To restore joint line and potentiate implant stability, bone defects present after removal of primary TKAs must be addressed in revision TKAs.

Although primary TKA is a successful procedure and provides good patient satisfaction,^{7,8} revision TKA is less successful in longevity and patient satisfaction.^{4,9,10} The reasons for this discrepancy in outcomes

between primary and revision arthroplasties are likely multifactorial: technical challenges, extensile exposure requirements, ligamentous laxity, bone stock deficits, stress shielding due to longer stems, and increased constraint.¹⁰

Tibial cemented intramedullary long stems have been in use for over two decades in revision and have generally been competent in the case of poor bone stock,^{11,12} but there is still a clear need for improvement. To deal with bone loss, revision knee arthroplasty augments such as sleeves and cones have been introduced, with a variety of augment geometry, porosity, and implant interfaces. However, how to plan for their use pre-operatively, understanding which system to use, and how to correlate intra-operative findings with pre-operative imaging is unclear. To that end, a better understanding of the common morphology of bone defects following revision TKA is an important first step in using augments in revision knee arthroplasty surgery.

Currently, various classification systems for tibial bone defects exist. However, each has its own drawbacks. The Dorr system does not take into account the size of the defect, the Rand assessment and the

* Corresponding author at: Madhav Bole, 23 Maureen Drive, Toronto, Ontario M2K1J7, Canada.
E-mail address: mbole@uwo.ca (M. Bole).

Anderson Orthopedic Research Institute classifications both require intraoperative assessment¹³ and the University of Pennsylvania classification system, though quantitative and reproducible, has not been adopted widely due to its complexity.¹⁴

Thus, this study aims to classify tibial bone defects in revision TKA radiographs into discrete shape groups and subsequently identify correlations between those groups and cohort demographics.

2. Materials and methods

The study protocol was approved by institutional ethics review board. Prospectively collected data on 404 patients requiring primary and knee revision surgery was identified using an institutional joint database as well as the retrieved implant database. Patients who underwent revision total knee arthroplasty from January 1, 2005 to February 28, 2014 were considered for inclusion within the study. Reasons for exclusion included amputations, fusions, lack of a suitable radiograph, previous revisions on the same knee and polyethylene exchange revisions. Patients were included if they had undergone revision surgery for aseptic loosening, polyethylene wear, osteolysis, instability, periprosthetic fracture, implant fracture, infection, malpositioning, pain, stiffness, and arthrofibrosis.

Surgeries were conducted by one of six fellowship trained, high volume surgeons and both fully cemented and metaphyseal cemented techniques were used.

Patient charts were retrospectively analyzed to record age at time of surgery, body mass index (BMI), gender, specific knee, weight, height, indications for revision and complications.

For each revision TKA, tibial defect size was assessed based on the radiographs taken six weeks after surgery. Measurements of defects in the radiographs were taken using ImageJ (National Institutes of Health, Bethesda, MD) in anteroposterior (AP) and lateral views by two experienced, fellowship trained, high volume arthroplasty orthopedic surgeons. All defect shape measurements were independently calibrated using the known tibial component implant size. These shapes were then categorized into shape groups in both lateral and AP views for each patient. Observers were blinded to all patient information and analyzed the presence of bone defects independently. The tibial components used were Smith & Nephew® (Andover, MA) Genesis 2™ and Legion Revision™; DePuy® (Warsaw, IN) Sigma®; Zimmer® (Warsaw, IN) NexGen® and Stryker® (Kalamazoo, MI) Triathlon® Total Knee Universal.

2.1. Statistical analysis

The cohort was subdivided by defect shape to analyze for a correlation between defect shape in AP and lateral views and TIV, BMI and indication for surgery. Statistical analysis was completed using SPSS Statistics version 23 (Armok, NY). Categorical data were analyzed using chi square or Fisher's exact test. One-way ANOVA analysis was utilized for examining variance of demographical factors within categorized groups. P values less than 0.05 were considered significant.

3. Results

One hundred and eighteen patients were included, 76 females (average BMI: 33.1st d. dev.: 7.1) and 42 males (average BMI: 34.1st d. dev. 12.6). Sixty-one operations were done on the right knee (51.7%) and 57 on the left (49.3%). Average demographics included a height of 163.7 cm, a weight of 89.7 kg and a BMI of 33.4 kg/m² (Table 1). Aseptic loosening was the most common reason for revision, followed by polyethylene wear (Table 2).

On analysis, six distinct shape groups were found for both AP and lateral views (Fig. 1).

On analysis of anterior-posterior and lateral radiographs, trapezoidal shaped defects were the most common, 55.1% and 45.8%

Table 1

Demographics of study cohort, range in parentheses.

Demographic Variable	Average (Range)
Gender (F/M)	76/42
Knees	118 (118 patients)
(Right/Left)	61/57
Height (cm)	163.7 (140.2–186)
Weight (kg)	89.7 (50–173)
BMI (kg/m ²)	34.3 (17.9–54.4)
Time in vivo (years)	8.5 (0.8–27.2)

Table 2

Reason for revision. Percent of patients experiencing each in parentheses.

Reason for Revision	Counts
Aseptic Loosening	55 (46.6%)
Polyethylene Wear	27 (22.9%)
Osteolysis	11 (9.3%)
Instability	32 (27.1%)
Periprosthetic Fracture	1 (.01%)
Pain/Stiffness	34 (28.8%)

respectively, while t-bilateral, flashlight and cone made up significant portions as well (Table 3).

Secondly, defect size along prescribed measurements in both lateral and AP fell within the range of tibial implant sizes (see Appendix Table A in Supplementary material) used for the patients in this sample (Tables 4 and 5). ANOVA of defect top length showed significance ($p = 0.00001$) between shape groups in AP view. Subsequent Tukey's test showed trapezoid top length to be significantly smaller than that of flashlight ($p = 0.0004$) and T-bilateral ($p = 0.00001$). In lateral view, ANOVA of top length showed significance as well ($p = 0.0004$). Subsequent Tukey's showed T-bilateral top length to be significantly larger than cone ($p = 0.048$) and trapezoid ($p = 0.003$) and trapezoid to be significantly smaller than trapezoid-anterior t-posterior ($p = 0.04$).

Defect shape in each patient was also compared to the reason for revision TKA in both AP and ML views (Tables 6 and 7). No significance was found between the reasons for revision and subsequent defect shape (Tables 6 and 7).

Mean time in vivo (TIV) and BMI were also compared to the various shapes in AP and lateral views, with ANOVA showing significance in AP BMI ($p = 0.034$) between shape groups (Table 8). Subsequent Tukey's analysis showed the BMI for the AP T-bilateral shape group to be significantly larger than that of the flashlight group ($p = 0.048$).

4. Discussion

The factors affecting bone loss are varied and the method of reconstruction depends on defect size and location, presence of a cortical rim of bone around the defect and the etiology of the bone loss.¹⁵ Current techniques used to cope with massive bone loss in revision TKA include autografts, allografts and metal augments.^{16,17} Metal augments are increasingly being utilized, and can be broadly categorized into sleeve and cone designs. Fully cemented to highly porous augments, differences in symmetry, specific reamers or other preparation techniques and other features are all reflected in the fact that each industry partner has unique metal augment features and philosophies. Going forward, the increasing demand for revision TKAs will multiply the complexity of available techniques and materials. However, despite the many surgical methods of addressing bone loss, there isn't a systemized volumetric approach to classifying tibial bone defects themselves. This makes pre-operative decision making challenging and understanding the presentation of these bone defects an asset.

In this study's analysis of defect shape, we have found trapezoidal

Fig. 1. Example Shape groups for proximal tibial bone defects.

Table 3
Breakdown of defect shape in AP and lateral views post revision TKA.

AP View			Lateral View		
Type of Defect	Count	% of Total	Type of Defect	Count	% of Total
Cone	5	4.2%	Flashlight	17	14.4%
Flashlight	21	17.8%	Trapezoid-Anterior	8	6.8%
			Flashlight-Posterior		
Trapezoid-Medial T-Lateral	2	1.6%	T-Bilateral	14	11.9%
T-Bilateral	20	16.9%	Cone	16	13.6%
T-medial	2	1.6%	Trapezoid	54	45.8%
Flashlight-Lateral					
Trapezoid	68	57.6%	Trapezoid-Anterior T-Posterior	9	6.5%

defects to be the most prevalent by a wide margin in postoperative revision TKA radiographs. Additionally, we have described “flashlight” shaped deformities, which to the best of our knowledge have not been described before. Additionally, we have found that shape groups do not carry the same size profiles. While the top lengths of the various groups do fall within the range of implant sizes used in this study (Appendix A in Supplementary material), trapezoidal defects were generally smaller than their counterparts. This would suggest trapezoidal defects are the most common and the most stable defect shape, while other groups

have a greater probability of increased defect size.

Regarding preoperative diagnosis, as in other studies, aseptic loosening was the most common indication for revision.^{4,5} However, in asymmetrical defect shapes, instability was the leading cause for surgery. Instability accounted for roughly 20% of total preoperative diagnosis, however, in asymmetrical defects it accounted for 30% of cases in ML view and 50% in AP. This might suggest that an unstable knee joint creates tibial bone loss in an uneven manner and the resulting defect persists following revision TKA. Understanding a patient with instability could have asymmetric biplanar bone loss prior to revision could therefore help long term outcomes.

A potential drawback of using instability as a marker of defect shape and as a guide for revision TKA management is that the clinical presentation of instability following primary TKA, despite having telltale subjective features, is varied in terms of onset and severity,^{18–20} leading to a potentially late diagnosis. However, we have shown that defect shape is not statistically correlated to time in vivo, essentially indicating defect shapes do not change over the life of an implant. This in turn may increase the reliability of shape groups in preoperative planning.

Additionally, we have found BMI to be correlated with defect shape in the sagittal plane. Specifically, a higher BMI is correlated with a T-bilateral shape. This could potentially be due to an increased proportion of stress directed downwards and parallel into the tibia, as opposed to forces tangential to the line of the tibia which might cause a more conical shape.

Limitations of this study include a lack of lifestyle data on patients to control for activity levels or other potential confounders. Use of

Table 4
Average measurements in Mm of each defect shape group in lateral view. Range in parentheses, all measurements in Mm.

	Trapezoid-Anterior Flashlight-Posterior	Flashlight	T-Bilateral	Trapezoid	Trapezoid-Anterior T-Posterior	Cone
Top Width	37.9 (29.0–44)	42.8 (33.2– 62.9)	45.9 (42.2– 51.3)	36.3 (24.7– 55.3)	45.2 (39.2–5)	37 (23.2–57.4)
Base Width	17.9 (12.6–25)	16.3 (8.4–22.3)	19.7 (16.4 –30.2)	16.7 (10.2– 29.1)	16.5 (10.3– 20.4)	
Height	38.8 (27.5– 55.2)	34.3 (17.4–43.3)	42.9 (29.9–55.8)	34.7 (19.9– 55.7)	44.4 (34.2– 51.8)	39.2 (26.6–57.2)
Anterior Width	38.5 (26.3– 57.4)	17.1 (9.4–32.2)		34.8 (17.8– 56.3)	46.3 (36.4–53.7)	41.6 (29– 56)
Inferior Anterior Width		18.4 (5.9–29.3)				
Posterior Width	18.5 (13.6–27.8)	17.8 (8 – 28.8)		36.4 (19–56)		44.4 (32.9–59.4)
Inferior Posterior Width	24.2 (15.2–38)	22.1 (6.3–30.2)				
ANTERIOR T-Height			12.0 (4.4– 19.7)			
ANTERIOR T-Width			7.4(2.1–11.3)			
POSTERIOR T-Height			11.6 (4.4–23.4)		9.5 (8–15)	
POSTERIOR T-Width			15.38 (10.2–24.6)		15.1 (9.5–26.7)	

Table 5

Average measurements of each defect shape group in AP view. Range in parentheses, all measurements in Mm.

	Cone	T-Bilateral	Trapezoid- Medial T- Lateral	T-Medial Flashlight-Lateral	Flashlight	Trapezoid
Top Length	52.5 (37.5–62.2)	70.3 (61.6–87.7)	69.7 (67.3–72.2)	64.5 (61.3–67.6)	61.6 (40.7–86.8)	46.2 (27.8–76.2)
Base Length		19.8 (14.5–31.2)	16.3 (14.3–18.3)	26.3 (18.6–33.9)	19.7 (23.6–11.1)	18.7 (10.5–33.4)
Height	36.9 (25.9–53.6)	39.6 (55.9–28)	35.5 (31.4–39.6)	45.2 (38.3–52)	39.1 (21.1–56.1)	31.68 (21.9–54.1)
Inferior Lateral Length				15.5 (5.2–25.7)	24 (11.6–37.5)	
Lateral Length	45.4 (28.9–66.7)			27.5 (18.6–36.4)	25.1 (11.9–32.0)	35.5 (22.8–57.6)
Inferior Medial Length					24.5 (10.8–41.5)	
Medial Length	46.2(29.9 - 64.6)		47.8 (42–53.6)		21.8 (11.8–38.8)	34.8 (53.9–21.3)
LATERAL T-Height		11.6 (2.9–21.2)	17 (7.5–9.6)			
LATERAL T-Length		17.4 (11.8–25.6)	20.3 (17.2–23.4)			
MEDIAL T-Height		12.4 (6.8–22.3)		11.4 (8.8–13.9)		
MEDIAL T-Length		19.3 (12.6– 27.3)		15.5 (14.2–16.8)		

Table 6

A comparison of defect shapes and reason for revision TKA in Anterior-Posterior view. P value represents Fisher's exact test between each reason for revision and defect shape distribution.

AP Shape	Aseptic Loosening	Polyethylene Wear	Osteolysis	Instability	Periprosthetic Fracture	Stiffness/Pain
Cone	4	1	–	–	–	2
Flashlight	5	5	2	7	1	7
Trapezoid-Medial T-Lateral	1	–	–	1	–	–
T-Bilateral	12	2	3	6	–	5
T-Medial Flashlight-Lateral	1	–	–	–	–	1
Trapezoid	32	19	6	16	–	19
Total	55	27	11	32	1	34
p Value	0.092	0.142	0.125	0.114	0.333	0.167

Table 7

A comparison of defect shapes and reason for revision TKA in Medial-Lateral view. P value represents Fisher's exact test between each reason for revision and defect shape distribution.

Lateral Shape	Aseptic Loosening	Polyethylene Wear	Osteolysis	Instability	Periprosthetic Fracture	Stiffness/Pain
Flashlight	6	4	2	3	–	6
Trapezoid-Anterior Flashlight-Posterior	3	1	–	3	–	3
T-Bilateral	9	1	2	5	–	7
Cone	6	4	1	2	–	3
Trapezoid	26	16	4	16	1	15
Trapezoid-Anterior T-Posterior	4	1	2	3	–	–
Total	55	27	11	32	1	34
p Value	0.269	0.317	0.217	0.267	0.333	0.497

Table 8

Defect shape in AP and Lateral views and average BMI and time in vivo, standard deviation in parentheses. P Value represents ANOVA of defect shape means with respect to BMI or TIV in AP and lateral views.

AP Shape	BMI (Kg/m ²)	TIV (Years)
Cone	31.8 (3.9)	4.5 (3.4)
Flashlight	31.7 (6.2)	10.7 (5.9)
Trapezoid Medial T Lateral	27.4 (4.1)	9.9 (9.2)
T-Bilateral	38.5 (8.6)	9.9 (4.9)
T-Medial Flashlight Lateral	29.2 (3.4)	16.4 (11.2)
Trapezoid	33.2 (7.7)	8.7 (5.6)
p Value	0.03	0.11
Lateral Shape		
Flashlight	32 (5.8)	9.26 (5)
Trapezoid-Anterior Flashlight-Posterior	31.8 (5.5)	8.7 (5.2)
T-Bilateral	36.4 (9.4)	11.6 (6.1)
Cone	33.4 (8.8)	8.8 (6)
Trapezoid	32.1 (7.2)	8.4 (6.1)
Trapezoid-Anterior T-Posterior	32.9 (6.3)	9.8 (4.1)
p Value	0.52	0.6

orthogonal views alone and solely examining tibial defects are also limitations. However, despite this we believe the findings to be substantial in understanding bone defects following revision TKA.

Our biplanar analysis of bone defects following revision TKA is a

first and has yielded several interesting findings. Currently, revision bone loss in the tibial region is managed through the use of a longer stem in combination with metal augments, allograft bone and cement.¹³ However, we have shown that defects persist. These defects typically occur with larger proximal bone loss tapering down to the base of the implant distally. While the use of modular components and bone grafts could be advantageous in such cases, an understanding of the prevalent defect shapes will be necessary to guide application.²¹ Current defect classification systems do not address this need as they suffer from complexity, a lack of information or are mainly concerned with surface defects rather than a biplanar volumetric representation of bone loss.¹⁴

Revision total knee arthroplasty can be challenging, and it requires careful preparation. Although augments are increasingly being used, differences in design exist. To guide their application, an understanding of volumetric defect shapes is necessary. This paper described common revision defect shapes and their prevalence. Trapezoidal shaped defects were by far the most common in both AP and lateral views, followed by T- bilateral and flashlight shaped defects. The size of these defects was also determined. Shape groups have differing size profiles and are correlated with BMI in the sagittal plane. Certainly, understanding the shape, size and demographic correlates of common revision TKA bone defects is important for pre-operative planning.

Conflict of interest

None.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.jor.2018.03.025>.

References

1. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. *J Bone Jt Surg Am*. 2007;89:780–785. <http://dx.doi.org/10.2106/JBJS.F.00222>.
2. Saleh KJ, Santos ER, Ghomrawi HM, Parvizi J, Mulholland KJ. Socioeconomic issues and demographics of total knee arthroplasty revision. *Clin Orthop*. 2006;446:15–21. <http://dx.doi.org/10.1097/01.blo.0000214416.91216.77>.
3. Bozic KJ, Kurtz SM, Lau E, et al. The epidemiology of revision total knee arthroplasty in the United States. *Clin Orthop Relat Res*. 2009;468:45–51. <http://dx.doi.org/10.1007/s11999-009-0945-0>.
4. Gioe TJ, Killeen KK, Grimm K, Mehle S, Scheltzema K. Why are total knee replacements revised? Analysis of early revision in a community knee implant registry. *Clin Orthop*. 2004;428:100–106. <http://dx.doi.org/10.1097/01.blo.0000147136.98303.9d>.
5. Schroer WC, Berend KR, Lombardi AV, et al. Why are total knees failing today? Etiology of total knee revision in 2010 and 2011. *J Arthroplasty*. 2013;28:116–119. <http://dx.doi.org/10.1016/j.arth.2013.04.056>.
6. Tay KS, Lo NN, Yeo SJ, Chia SL, Tay DKJ, Chin PL. Revision total knee arthroplasty: causes and outcomes. *Ann Acad Med Singap*. 2013;42:178–183.
7. Ethgen O, Bruyère O, Richy F, Dardennes C, Reginster J-Y. Health-related quality of life in total hip and total knee arthroplasty. *J Bone Jt Surg Am*. 2004;86:963–974.
8. Binazzi J, Soudry M, Mestriner LA. Total knee arthroplasty. *Clin. Orthop. Relat. Res*. 1985;192:13–22.
9. Kurtz SM, Ong KL, Schmier J, et al. Future clinical and economic impact of revision total hip and knee arthroplasty. *J Bone Jt Surg Am*. 2007;89:144–151. <http://dx.doi.org/10.2106/JBJS.G.00587>.
10. Hartley RC, Barton-Hanson NG, Finley R, Parkinson RW. Early patient outcomes after primary and revision total knee arthroplasty. A prospective study. *J Bone Jt Surg Br*. 2002;84:994–999.
11. Murray PB, Rand JA, Hanssen AD. Cemented long-stem revision total knee arthroplasty. *Clin Orthop*. 1994;116–123.
12. Whaley AL, Trousdale RT, Rand JA, Hanssen AD. Cemented long-stem revision total knee arthroplasty 1. *J Arthroplasty*. 2003;18:592–599. [http://dx.doi.org/10.1016/S0883-5403\(03\)00200-6](http://dx.doi.org/10.1016/S0883-5403(03)00200-6).
13. Ga E, Dj A. Bone loss with revision total knee arthroplasty: defect classification and alternatives for reconstruction. *Instr Course Lect*. 1998;48:167–175.
14. Qiu YY, Yan CH, Chiu KY, Ng FY. Review article: bone defect classifications in revision total knee arthroplasty. *J Orthop Surg Hong Kong*. 2011;19:238–243.
15. Backstein D, Safir O, Gross A. Management of bone loss: structural grafts in revision total knee arthroplasty. *Clin Orthop*. 2006;446:104–112. <http://dx.doi.org/10.1097/01.blo.0000214426.52206.2c>.
16. Cuckler JM. Bone loss in total knee arthroplasty: graft augment and options. *J Arthroplasty*. 2004;19:56–58.
17. Ghazavi MT, Stockley I, Yee G, Davis A, Gross AE. Reconstruction of massive bone defects with allograft in revision total knee arthroplasty. *J Bone Jt Surg Am*. 1997;79:17–25.
18. Fehring TK, Valadie AL. Knee instability after total knee arthroplasty. *Clin. Orthop. Relat. Res*. 1994;299:157–162.
19. Pagnano MW, Hanssen AD, Lewallen DG, Stuart MJ. Flexion instability after primary posterior cruciate retaining total knee arthroplasty. *Clin. Orthop. Relat. Res*. 1998;356:39–46.
20. Waslowski GL, Marson BM, Benjamin JB. Early, incapacitating instability of posterior cruciate ligament-retaining total knee arthroplasty. *J Arthroplasty*. 1998;13:763–767. [http://dx.doi.org/10.1016/S0883-5403\(98\)90027-4](http://dx.doi.org/10.1016/S0883-5403(98)90027-4).
21. Elia EA, Lotke PA. Results of revision total knee arthroplasty associated with significant bone loss. *Clin Orthop*. 1991;114–121.