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Original Research

Early Femoral Insufficiency Fractures After Primary Total Knee Arthroplasty

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ABSTRACT

Background: Periprosthetic femur fracture following total knee arthroplasty (TKA) is a devastating complication. Although trauma-related periprosthetic femur fractures have been well studied, early atraumatic insufficiency periprosthetic fractures (IPFs) are gaining attention. We present the largest IPF series to date to better understand and prevent this complication.

Methods: A retrospective study of all patients who underwent a revision surgery for periprosthetic fracture within 6 months of primary TKA between 2007 and 2020 was performed. Patient demographics, preoperative radiographs, implant details, and fracture radiographs were reviewed. Alignment measurements and fracture characteristics were assessed.

Results: Sixteen patients met criteria (rate 0.05%), and 11 had posterior-stabilized TKAs. The mean age was 79 years, mean body mass index was 31 kg/m^2, and 94% (15/16) were female. Seven (47%) patients had a confirmed history of osteoporosis. IPF occurred on average 4 weeks (range, 4 days-13 weeks) after the index TKA. Overall, 12 of 16 (73%) had preoperative valgus deformities, and 11 patients (10 valgus, 1 varus) had preoperative deformities >10 degrees. A characteristic radiographic appearance of femoral condylar impaction and collapse was noted in 12 of 16 cases (75%); 11 of these 12 fractures (92%) involved the unloaded compartment based on preoperative varus/valgus deformity.

Conclusions: Patients who developed IPFs were most commonly elderly, obese women with osteoporosis and severe preoperative valgus deformities. The apparent mechanism of failure was overloading of previously unloaded osteopenic femoral condyle. In high-risk patients, the use of a cruciate-retaining femoral component or a femoral stem for a posterior-stabilized femur may be considered to help avoid this catastrophic complication.

Introduction

Periprosthetic fractures are a rare but devastating complication that can occur following total knee arthroplasty (TKA) and typically involve the distal femur [1]. The incidence of this complication has ranged from 0.3% to 2.5% [2,3] after TKA. The majority of periprosthetic knee fractures occur several years after the operation and are often associated with traumatic mechanisms [4], with both patient and surgical risk factors identified [5–7].

In addition to these late fractures, a less common yet distinct clinical entity involves the early, atraumatic insufficiency periprosthetic fracture (IPF) that occurs within the first 6 months following TKA [8]. Previous reports have noted that the unloaded condyle in patients with severe coronal plane deformity combined with a low bone density could be at elevated risk of sustaining an IPF [9,10]. Additionally, the use of posterior-stabilized (PS) knee implant designs has been linked to IPF due to the rationale that a large intercondylar box resection in smaller femoral component sizes for specific TKA designs could compromise the condylar integrity and increase the risk of fracture [11].

To date, the published literature related to IPF consists solely of case reports and case series. The incidence of IPF in a large TKA cohort remains unknown. Therefore, the purpose of the current study was to describe the incidence of IPF with our long-standing

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single institution series of primary TKAs. Furthermore, we sought to identify patient- and implant-dependent risk factors associated with IPF. Finally, in the event that a substantial number of IPFs were identified, we sought to describe our experience in treating IPFs as well as evaluating their clinical outcomes.

Material and methods

Institutional review board approval was obtained prior to the initiation of the study. A retrospective review of primary TKA procedures from 2007 to 2020 was queried to identify all patients who sustained an early periprosthetic fracture. Early was defined as 6 months to consider normal recovery time and clinical consideration for reoperation. We identified all TKA patients of our institution who subsequently underwent a revision surgery (Current Procedural Terminology codes 27486, 27487) within 6 months of the index primary TKA procedure. A revision for periprosthetic fracture was identified through diagnosis codes: 996.44 (International Classification of Diseases-9) and T84.042 & T84.043 (International Classification of Diseases-10). The charts of potentially qualifying cases were reviewed in detail, and diagnoses were verified. All patients with a reported traumatic episode preceding the periprosthetic fracture were excluded. In addition to data extracts, all attending arthroplasty surgeons within our institution were individually contacted to ensure no other additional patients were missed. Surgeons were also asked to submit cases that they were aware of that were treated nonoperatively. Intraoperative fractures and any postoperative infections were excluded.

Patient demographics, preoperative and postoperative radiographs, and implant details were evaluated by 2 independent attending surgeons. IPF was defined as an atraumatic femoral-sided epiphyseal "impaction"-type fracture. Demographic variables and patient medical history including age, gender, body mass index, history of osteoporosis (733.0x), osteopenia (733.90), vitamin D deficiency (268.9), history of previous fragility fracture (hip: 820.0, 820.2, 733.14; spine: 805.0, 805.2, 805.4, 805.8, 806.0, 806.2, 806.4, 806.8, 733.13; wrist: 813.4, 733.12), history of falls (V15.88), history of dementia (290.xx), use of bisphosphonates (V58.68), American Society of Anesthesiologists Score, and Charlson Index Score were recorded. A review of all preoperative radiographs, including anteroposterior, lateral, and merchant views, was conducted by a fellowship-trained arthroplasty surgeon. Preoperative coronal alignment was assessed by the tibiofemoral angle, defined as the angle between the anatomical axis of the femur and the anatomical axis of the tibia on anteroposterior short-knee radiographs. Standing full-length lower-extremity radiographs were not available for the entire cohort. Postoperative implant alignment was assessed on postoperative radiographs that preceded any periprosthetic fracture. An assessment of the presence or absence of femoral notching was performed on lateral radiographs of the knee. All available immediate postoperative radiographs up to 1 year following the index procedure or the fracture radiographs were reviewed. Bone quality was assessed and compared with chart review for a formal diagnosis of osteopenia/osteoporosis.

Implant-specific variables identified included manufacturer, primary knee femoral component design, type of implant fixation, use of constrained or nonconstrained polyethylene articular insert, femoral and tibial component sizes, and the presence or absence of stemmed components. Product and specification catalogs from individual implant manufacturers were referenced to calculate the box width, box width proportion (ratio of the box width to the overall medial-lateral dimension of the femoral component), box height, and box anteroposterior proportion for each femoral component associated with an IPF.

Descriptive statistics were reported as means and standard deviations or as counts and percentages as appropriate. All analyses were conducted with SAS version 9.3 (SAS Institute, Inc., Cary, NC).

Results

The minimum estimated cumulative incidence of early IPF following primary TKA was 0.05% (26 of 51,535). Ten cases were excluded due to clear documentation of a traumatic etiology. Nine of these 10 traumatic cases were found to have a PS level of constraint, and 1 case had a constrained articular insert. Following exclusion, 16 cases of IPF with a mean time of 4 weeks (range, 4 days to 13 weeks) from the index procedure to radiographic confirmation of periprosthetic fracture were identified. The mean age of IPF patients was 79 years, mean body mass index was 31 kg/m^2, and 94% (15/16 patients) were female. The operative report and clinical chart of 1 patient was not available, nor any implant sticker confirming the size of the implants. However, the implants were identified as Smith & Nephew (London, UK) Genesis II. Because radiographs were available, this patient was still included in our radiographic review, resulting in 16 total patients that underwent a radiographic analysis but just 15 patients that underwent a clinical analysis. Seven of these 15 (47%) patients with available clinical history had a confirmed history of osteoporosis (Table 1). Of these 15 cases, 13 involved PS TKAs, and 2 involved constrained condylar knee designs. Overall, the fracture pattern involved 11 isolated condylar fractures and 5 supracondylar fractures involving both condyles.

No patient had previous hardware removal prior to the index arthroplasty, 2 cases were performed with computer navigation (KneeAlign; OrthAlign, Aliso Viejo, CA), and no case involved robotic assistance. Cementless fixation was utilized in 1 of 16 patients identified in this investigation. Overall, 12 of 16 patients (75%) had preoperative valgus deformities, and 11 patients (10 valgus, 1 varus) had preoperative coronal plane deformities of >10 degrees. Femoral condylar impaction and collapse was noted in 12 of 16 cases (75%); 11 of those 12 fractures (92%) involved the unloaded compartment based on preoperative coronal plane deformity. The time from the index arthroplasty to fracture, preoperative magnitude of deformity, and fracture location are depicted in Table 2.

Of the 16 femoral components involved in early IPF, only 6 contained pegs to aid in fixation. The mean anteroposterior size of the femoral component was 60.11 mm while the mean mediolateral component size was 66.74 mm, translating to femoral component sizes in the midrange of the size spectrum for the various manufactures. The corresponding box width and box proportion, as well as box height and box anteroposterior proportions, are listed in Table 3. Of the implants involved in our investigation, the Stryker (Kalamazoo, MI) Triathlon had the highest box width proportions

Table 1
Demographics of patients who sustained early insufficiency periprosthetic fracture (IPF).

Demographics	Early IPF	%
Overall number of patients	16	-
Age, mean (range) (y)	79.1 (±7.5)	-
Female gender	15/16	94
Body mass index, mean (range) (kg/m^2)	31.6 (±5.0)	-
Valgus preoperative deformity	12/16	75
Osteoporosis	7/15	47
Inflammatory arthropathy	2/15	13
Cancer	7/15	47
Diabetes	1/15	7
Recurrent falls	4/15	27

One incomplete clinical patient record was included, resulting in the denominator discrepancy.

Table 2
All patients who sustained femoral-sided fracture within 6 months of the index arthroplasty.

Patient #	Laterality	IPF from index TKA (wk)	Presence of femoral notching	Preoperative deformity	Preoperative coronal plane deformity(degrees)	Fracture condylar location
1	Right	6	No	Valgus	17	Medial condyle
2	Left	4.5	No	Varus	1	Lateral condyle
3	Left	5.25	No	Valgus	25	Medial condyle
4	Right	2	No	Valgus	11	Bicondylar
5	Left	0.5	No	Valgus	23	Supracondylar
6	Right	3	No	Varus	12	Supracondylar
7	Right	4	No	Valgus	12	Medial condyle
8	Right	1.5	No	Valgus	23	Medial condyle
9	Left	2	No	Varus	2	Lateral condyle
10	Right	2.5	No	Varus	8	Lateral condyle
11	Left	2	No	Valgus	17	Bicondylar
12	Right	2.4	Yes	Valgus	6	Medial condyle
13	Right	2.4	No	Valgus	12	Medial condyle
14	Right	13	No	Valgus	19	Medial condyle
15	Right	3	Yes	Valgus	11	Medial condyle
16	Left	4	No	Valgus	6	Lateral condyle

of 0.32 and 0.31, corresponding to femoral components of size 3 and 4, respectively. Additionally, both patients with the highest box width proportions had osteoporosis documented preoperatively. On the other end of the spectrum, the lowest box width proportion found in this series of early IPF belonged to the Smith & Nephew Journey 2 and Zimmer (Warsaw, IN) NexGen femoral components at 0.26 for each. Overall, 4 different femoral component manufacturers were implicated in this series of IPF. Four patients were implanted with components in the smallest one-third of available implant sizes, 9 in the middle one-third, and 2 in the largest one-third of sizes. Implant information was unavailable for 1 patient.

Management of IPF in this series consisted of 13 patients treated operatively and 3 patients treated nonoperatively. Operative management encompassed isolated femoral component revision, both component revision to a constrained condylar design prosthesis, both component revision to a distal femoral replacement design prosthesis, and open reduction internal fixation (Table 4). Preoperative and postoperative fracture radiographs and postrevision radiographs are demonstrated in Figures 1-3. Ten of 16 early insufficiency fractures demonstrated a vertically oriented pattern as depicted in Figure 2. Overall, after a minimum of 1-year follow-up for all patients treated operatively for an early IPF, 2 patients underwent a subsequent reoperation. These failures both were a result of periprosthetic joint infections, with both patients receiving irrigation and debridement at 1 week and 2 months postoperatively, respectively. Of the 3 patients treated nonoperatively, none required subsequent operations to address fracture healing.

Discussion

Overall, early IPF is a devastating complication but, fortunately, a rare event. The incidence of IPF in our single institutional series of over 50,000 primary total knee replacements was 0.05%. Patients who sustained IPFs were most commonly elderly obese women with osteoporosis and severe preoperative valgus deformities. Although only 44% of the identified cases of the IPF cohort had a preoperative diagnosis of osteoporosis, we suspect that a high number of IPF cases had undiagnosed osteoporosis given the age and gender. The apparent mechanism of failure was overloading of a previously unloaded osteopenic/osteoporotic femoral condyle. We are aware of 1 recent case report recommending caution regarding the use of robotics in TKA in the setting of osteoporosis. In their report, Skibicki et al. reported a 77-year-old women with osteoarthritis and osteoporosis who underwent robotic assisted TKA and sustained an atraumatic midshaft femur fracture at the pin site associated with the use of intraoperative robotic technology [12]. Interestingly, we found no cases of IPF that had previous hardware removal or that utilized navigation/robotically assisted surgery incorporating extra-articular pins to accommodate the use of arrays in our series.

Table 3
Femoral component characteristics for patients sustaining early insufficiency periprosthetic fracture of the femur.

Patients	MFG/femoral size	Pegs	AP size (mm)	ML size (mm)	Box width (mm)	Box width proportion	Box height (mm)	Box AP (mm)	Box AP proportion
1	Smith & Nephew 4	No	58	62	19.1	0.31	19.6	41.7	0.72
2	Stryker 3	No	59	65	20.8	0.32	20.5	42	0.71
3	Zimmer 7	Yes	61	69.5	18.1	0.26	8	33	0.54
4	Smith & Nephew 4	No	59.7	64.5	16.5	0.26	20.5	31	0.52
5	Zimmer F	No	65.5	72	18.1	0.25	20	49	0.75
6	Exactech (Gainesville, FL) 5	No	70.8	74.9	21.3	0.28	20.8	31.9	0.45
7	Unknown	No	-	-	-	-	-	-	-
8	Smith & Nephew 3	No	56.7	61.5	16.5	0.27	17	30	0.53
9	Zimmer 3	Yes	53	62.5	17	0.27	8	24	0.45
10	Zimmer 4	Yes	55	64.25	17	0.26	8	25	0.45
11	Stryker 4	No	62	68	20.8	0.31	20.5	42	0.68
12	Smith & Nephew 5	No	61	66	19.1	0.29	19.8	45	0.74
13	Smith & Nephew 5	No	61	66	19.1	0.29	19.8	45	0.74
14	Zimmer 5	Yes	57	66	17	0.26	8	29	0.51
15	Zimmer 7	Yes	61	69.5	18.1	0.27	8	33	0.54
16	Zimmer 7	Yes	61	69.5	18.1	0.27	8	33	0.54

MFG, manufacture; AP, anteroposterior; ML, mediolateral; box width proportion, box width/femoral component ML size.

Table 4
Early insufficiency periprosthetic fracture management.

Fracture management	Number (%)
Nonoperative	3/16 (19)
Open reduction internal fixation	1/16 (7)
Revision of both components	2/16 (13)
Revision of femoral component only	6/16 (38)
Revision to a distal femoral replacement	4/16 (25)

Previous reports have suggested the unloaded condyle with a decreased bone mineral density (BMD) in a patient with preoperative coronal plane deformity is at risk of early insufficiency fractures [9,10]. The medial femoral condyle has been reported to have 30% greater density than the lateral femoral condyle [13], yet in our series, the majority of patients sustained a medial femoral condylar impaction and collapse following TKA and correction of the preoperative valgus deformity. Previous studies found that correction of the coronal deformity after TKA equalizes the mediolateral BMD ratio through decreasing the density of the preoperatively loaded femoral condyle [14,15]. While pharmacologic agents, such as bisphosphonates, can improve BMD, the authors are not aware of any study to date investigating their use preoperatively or postoperatively to increase femoral condylar BMD that could potentially provide additional support to the unloaded condyle once mechanical realignment is achieved. One randomized controlled study of weekly administration of risedronate for 6 months following total hip arthroplasty found an effective reduction of periprosthetic bone resorption around uncemented femoral stems at 1 year [16], while another randomized controlled study noted that a decrease in periprosthetic BMD accelerates when therapy is discontinued and no effect is seen at 4 years postoperatively following total hip arthroplasty [17]. Bisphosphonates have been reported to be effective in improving BMD in the proximal tibia for the first 6 months after TKA [18]. However, the diminishing effect identified after THA following the discontinuation of bisphosphonates could be suspected following TKA as well. One recent randomized controlled trial suggested that monitoring bone turnover markers can accurately reflect bone metabolism to monitor the treatment of osteoporosis in postmenopausal women undergoing TKA to enhance bone density [19]. Additional research is warranted to better understand the long-term outcomes of improving efficacy with the use of medical therapy to help prevent periprosthetic fracture.

Preoperative deformity was also found to be a trend among patients who sustained early IPF. We found, overall, 12 of 16 patients (75%) had preoperative valgus deformities, and 11 patients (10 valgus, 1 varus) had severe preoperative deformities >10 degrees. A characteristic radiographic appearance of femoral condylar impaction and collapse was noted in 75% of cases, and almost all those fractures involved the unloaded compartment based on the preoperative varus/valgus deformity (Figs. 1-3). Our results are similar to a recent report in the literature noting that in a series of 24 patients who sustained early periprosthetic fracture within 3 months, all lateral condylar fractures were associated with preoperative varus deformity, and 55% of medial condylar fractures had preoperative valgus deformity [20].

All femoral components identified in this series incorporated a box, requiring host distal intercondylar femoral bone resection to accommodate the implant geometry. Various box preparation techniques were implemented at the time of surgery depending on the implant manufacture recommendations. For example, Smith & Nephew Journey II BCS box preparation features a guide requiring reaming on power anteriorly and posteriorly, followed by a finishing chisel impacted through the guide designed to prevent undermining of the condyles. Other implant manufactures identified in this series, such as the Zimmer Persona, feature a PS box cut guide that requires the use of an oscillating or reciprocating saw blade parallel on the front surface of the PS box cut guide for the anterior-to-posterior box cut, as well as for preparing the vertical wall cuts. There is a potential for undercutting the medial and lateral condyles in certain designs and is best avoided to minimize the risk of IPF. We suspected that cruciate-substituting implant designs, as well as those containing pegs, would be at a higher likelihood of experiencing an early insufficiency fracture given the volume of bone removed prior to implantation. However, we noted that only 6 of 16 (38%) fractures had pegs associated with the femoral component design. Box preparation was theorized to contribute to early fracture with a specific concern that a fixed amount of resection across different

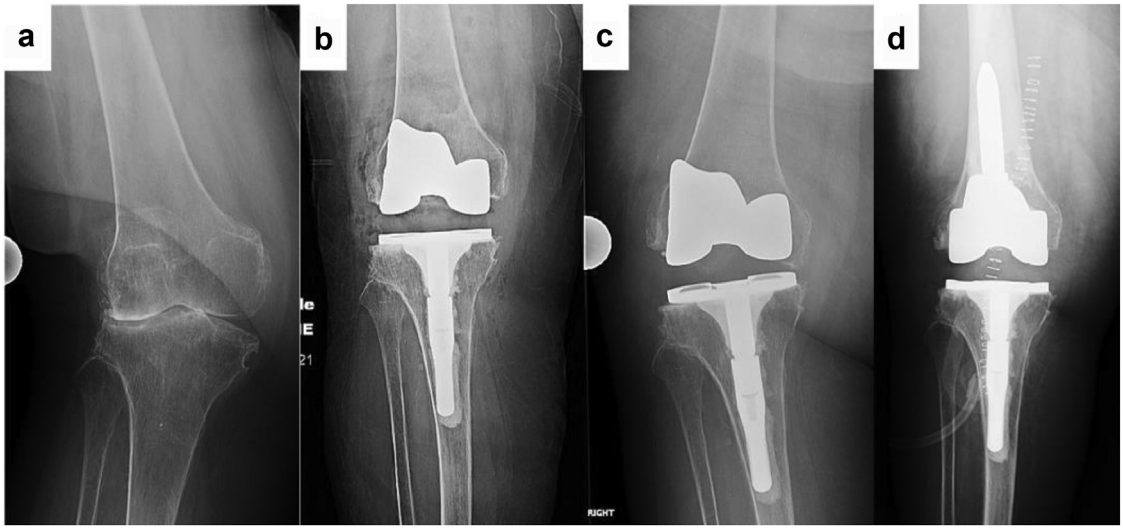

Figure 1. An 81-year-old female patient with severe preoperative valgus deformity seen on anteroposterior (AP) view (a) who received a bicruciate-stabilized primary total knee replacement as demonstrated on the AP view (b). The patient reported progressively worsening lower-extremity pain and decreased lower-extremity function at the 2-week postoperative visit and was found to have a varus deformity with collapse of the medial femoral condyle as demonstrated on the AP view (c). The fracture was treated with revision of the femoral component only as demonstrated on the AP view (d).

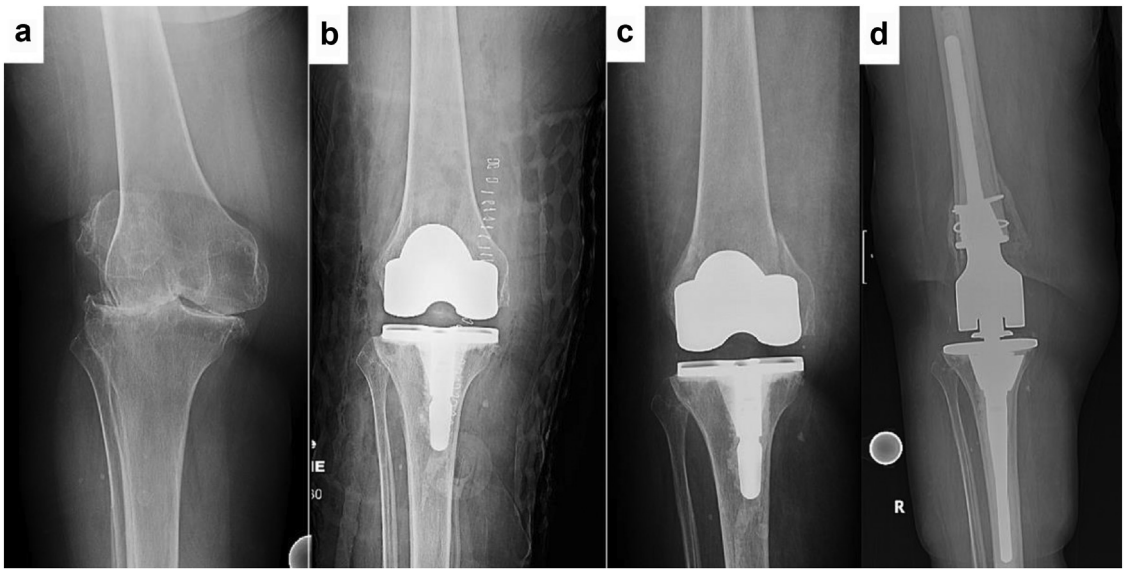

Figure 2. A 68-year-old female patient with severe preoperative valgus deformity demonstrated on the AP view (a). The patient received a posterior-stabilized primary total knee replacement demonstrated on the AP view (b). At 3 weeks postoperatively, the patient reported increasing knee pain and was found to have a vertical medial condylar fracture demonstrated on the AP view (c). The fracture was treated with a distal femoral replacement demonstrated on the AP view (d).

implant sizes could place more strain on smaller femoral condyles, leading to fracture as noted by Lombardi et al. [11]. However, the narrow range of box width proportions found here in the setting of a wide range of implant sizes, with the majority falling in the middle one-third of available sizes, suggests that disproportionate box resections in smaller femurs are not as significant of a concern as originally thought. Nonetheless, the presence of a box in every implant in this series lends credence to the notion that the process of resecting intercondylar femoral bone could predispose this specific patient population to developing early IPF, regardless of femur size. Overall, however, these findings seem to indicate that an interaction of patient demographics (age, gender), preoperative deformity, and implant selection contribute to the development of IPF.

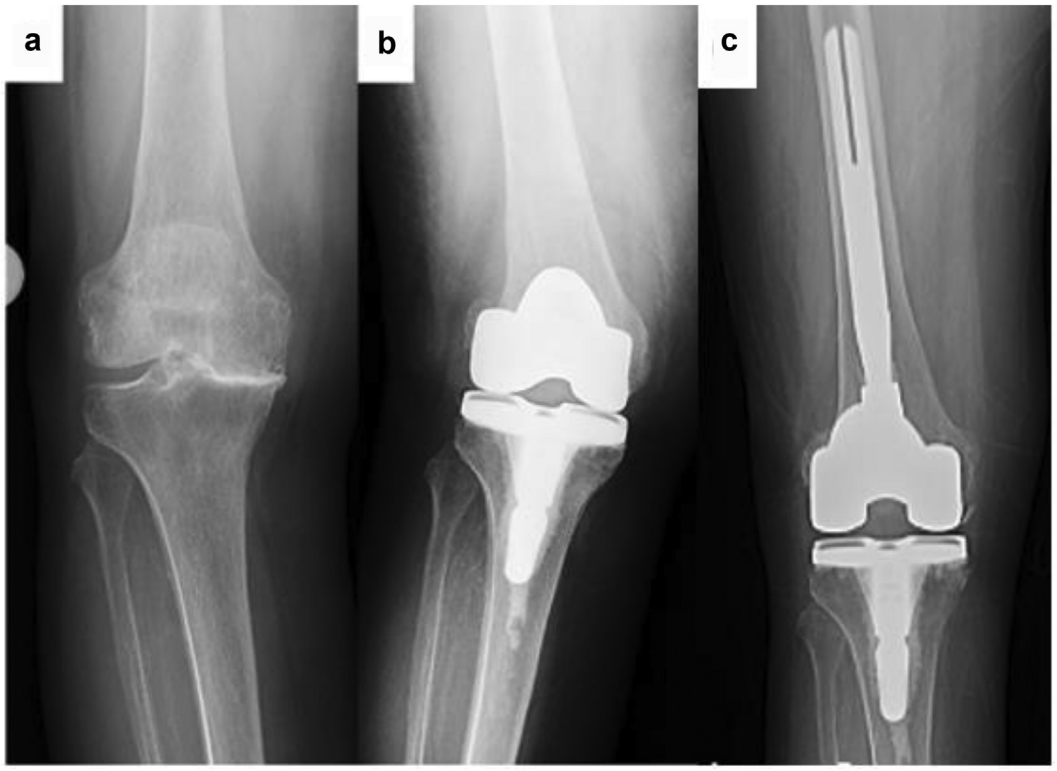

Figure 3. A patient with a preoperative varus deformity demonstrated on the AP view (a) subsequently experienced collapse of the lateral femoral condyle and failure into valgus as seen on the AP view (b) following primary total knee replacement. (c) Immediate postoperative AP view.

Management of IPF was varied in this study, with promising results seen for both operative and nonoperative treatments at midterm follow-up. However, due to heterogeneity in treatment options left to the discretion of several different surgeons, as well as in fracture characteristics (especially displaced vs nondisplaced), a rigorous evaluation of optimal early IPF management falls outside the scope of this study. That being said, periprosthetic TKA fractures in general have received abundant attention in the literature, with multiple studies reporting on treatment algorithms taking patient and fracture characteristics into account [21–23]. Future studies could focus on whether the unique femoral condylar collapse and impaction fracture pattern seen in the majority of insufficiency IPFs in this study behave similarly to these previous findings.

This study has several limitations. First, the index procedures for these patients were performed by multiple different attending surgeons at our institution. Although we excluded any patient with a grossly evident case of iatrogenic intraoperative fractures, variation in surgeon technique and experience, such as that during component impaction or performing femoral box bone cuts, may have influenced the development of these early IPFs. With that in mind, however, one of the strengths of this study includes the variability of manufactured components. Multiple different designs, each with different technique guides, are represented here, decreasing the likelihood that an implant-specific step contributes to the development of an early IPF. We also report how these early IPFs were managed and submit that no standard treatment algorithm has been established to our knowledge. It is possible that some of the patients treated operatively after IPF could have been managed nonoperatively in select cases with acceptable outcomes. Next, although we theorize that the incorporation of a box contributes to an early IPF given their prevalence in this study and the proposed mechanisms discussed earlier, these implants are also traditionally used at our institution. Thus, the possibility of a selection bias cannot be ignored when interpreting these findings. Furthermore, the methodology used to identify our series (all TKA patients of our institution who subsequently underwent a revision surgery [Current Procedural Terminology codes 27486 and 27487] within 6 months of the index primary TKA procedure) may have missed a group of patients who were treated nonoperatively. We attempted to mitigate any missed cases of IPF by surveying attending surgeons; however, this does introduce a potential for recall bias and should be considered in light of our findings. Finally, this was an observational descriptive study. Because the incidence of these early IPFs is low, we can present demographic and implant characteristics, but associations and causation cannot be employed. Nonetheless, this study provides more extensive data than any previously reported and highlights several notable themes in these early IPF cases.

Conclusions

Our report, while the largest reported series to date, indicates a need for a broader investigation utilizing a national registry to better understand the true incidence of the devastating early complication known as IPF. The apparent mechanism of failure was overloading of a previously unloaded osteopenic/osteoporotic femoral condyle. The use of cruciate-retaining femoral component designs or the intraoperative addition of a femoral stem for a PS femur (revision type design) could prevent this catastrophic complication from occurring but would require future studies.

Conflicts of interest

Dr. F. Boettner receives royalties from OrthoDevelopment and Smith & Nephew; is in the speakers' bureau of or gave paid presentations for OrthoDevelopment; is a paid consultant for OrthoDevelopment and Smith & Nephew; and has stock or stock options in AccuJoint. Dr. A. V. Carli is a paid consultant for Heraeus Medical. Dr. E. B. Gausden receives royalties from DePuy, a Johnson & Johnson company and is a paid consultant for DePuy, a Johnson & Johnson company, and Zimmer Biomet. Dr. P. K. Sculco receives royalties from Lima Corporate; is in the speakers' bureau of or gave paid presentations for Zimmer Biomet, Lima Corporatem, and Intellijoint; is a paid consultant for Zimmer Biomet, Lima Corporatem, DePuy, and ATEC (Eos Imaging); has stock or stock options in Parvizi Surgical Innovation; receives research support as a principal investigator from Zimmer Biomet and Intellijoint; and is a member of American Association of Hip and Knee Surgeons (AAHKS) Outreach Committee and AAHKS publications committee. The other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2023.101110.

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