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Intraoperative Periprosthetic Fractures during primary Total knee arthroplasty: Experience from an Asian high-volume arthroplasty centre

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ABSTRACT

Background: Intraoperative periprosthetic fracture (IF) is an under-reported complication in primary total knee arthroplasty (TKA). This study aimed to audit the outcomes and complication rates in patients encountering IF during primary TKA and propose a new classification for its management.
Methods: A nested case–control study was performed at a tertiary referral hospital where 50 patients encountering IF during primary TKA operated by a single surgeon team between January 2016 to May 2021, were compared with 150 (3:1) age-, gender- and implant-matched patients not encountering IF. Demographic data, risk factors, outcomes and complications of both groups were compared at a minimum follow up of 1 year.
Results: The incidence of IF was 0.45%, with 44 fractures in the femur (88%), six (12%) in the tibia and none in the patella. Medial collateral ligament avulsion fracture (54.54%) in the femur and medial plateau fracture (66.66%) in the tibia were the most common fracture types. At final follow up, the fracture group had higher rates of 90-day re-admissions (8% vs. 2.66%, $P = 0.095$), deep infection (4% vs. 0.66%, $P = 0.15$) and revisions (6% vs. 1.33%, $P = 0.06$). The mean Knee Society Score was not significantly different between the two groups (152.22 ± 9.25 vs. 161.68 ± 11.22, $P = 0.642$) with union being achieved in all but one patient at a mean duration of 9.6 weeks.
Conclusions: Patients with severe and fixed deformities have a higher risk for IF. The occurrence of fracture and the complexity of surgery equally contribute to the higher complication rates. Appropriately managed fractures have comparable functional outcomes.

1. Introduction

Intraoperative periprosthetic fracture (IF) is a rare and under-reported complication in primary total knee arthroplasty (TKA), with incidence ranging from 0.4 to 2.2% [1–3]. With the rising demand for TKA, a small incidence of such a complication may add up to large numbers and correspondingly larger expenditures.

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An IF may occur during any of the stages of TKA, including exposure, preparation, trialing, final implantation of the components and insertion of the polyethylene insert. Retrospective studies have associated IF with osteoporosis, female gender, steroid abuse and implant design [1–4]. The majority of these fractures are reported from the Western world, however, their bone morphology is known to be significantly different from the Asian population. Designs of popular internationally recognized knee implants are inspired by morphometric data of the Western population, where the knees are larger and wider than their Asian counterparts [5]. The intercondylar 'box', an integral part of the posterior stabilized (PS) knee design, has been considered to be one of the important causes of intraoperative femoral fractures [1].

Intraoperative fractures are associated with increased surgical time, hospital stay, delayed mobilization, brace supplementation, delayed weight-bearing, early revision and even re-surgery [1,2,6]. From the surgeon's perspective, such fractures may necessitate an inventory of implants that may not be readily available.

To date, IFs have been solely treated based on the surgeon's discretion. There are no established guidelines to choose between internal fixation with screws, plates, tension-band wires, augments, stemmed components with or without varying degrees of constraint and conservative methods including protected weight-bearing and knee immobilization for IF [1,7]. This study aimed to analyse the incidence, predisposing factors, patho-anatomy, treatment, and outcomes of intraoperative fractures occurring at a high-volume arthroplasty centre and provide an evidence-based approach to their management.

2. Material and methods

This was a retrospective nested case–control study conducted at a single high-volume referral hospital wherein data of 12,010 consecutive primary TKAs operated between January 2016 to May 2021 were retrieved and screened. All surgeries were performed by a single surgeon team headed by the senior author. Fifty patients encountering an IF during primary TKA surgery were included in the fracture group (FG). For each case, three age-, gender- and implant-matched controls who did not encounter fracture during the surgery were recruited in the non-fracture group (NFG) (n = 150). The study was approved by the institutional review board (IRB-SIEC/2021/462).

Patients who underwent primary TKA surgery in the age group between 40 and 85 years were included in the study. Those patients with a history of trauma, previous knee surgeries, metabolic bone diseases or any developmental anomalies were excluded from the study.

To compare the determinants of periprosthetic fracture, the preoperative baseline and laboratory parameters including age, gender, height, weight, body mass index (BMI), underlying aetiology, preoperative and 24 h postoperative haemoglobin levels, deformity on weight-bearing X-rays (hip–knee–ankle angle, mHKA), implant details and preoperative Knee Society Scores (KSS) [8] of individuals of both the study groups were retrieved from the hospital repository. Intraoperative details such as the stage of surgery when the fracture occurred, tourniquet time and total surgical duration were retrieved from the surgeon's notes and photographic records.

These patients were followed up monthly for 3 months and 6-monthly subsequently for a minimum duration of one year. Fracture union was diagnosed radiologically and clinically confirmed by the absence of tenderness. Functional scoring (KSS) was performed by a trained clinical fellow preoperatively and at 6-monthly and yearly [8]. KSS at the last follow up was used for statistical analysis. Complications such as 30-day readmission, 90-day re-admission, implant failure, nonunion, implant prominence, infection or instability were monitored in both groups.

2.1. Surgical technique

Cemented TKA was performed through a standard medial parapatellar approach under tourniquet control using multiple implants recognized internationally. However, fractures were encountered only with seven commonly used implants and thus they were included in the study cohorts. These implants were Buechel–Pappas™, PFC Sigma® PS (*DePuy Inc., Warsaw, IN, USA*), Maxx Destiknee (*Meril Life Sciences India, India*), Genesis II Posterior stabilized (*Smith and Nephew, Watford, UK*), Triathlon (*Stryker Inc, Mahwah, NJ, USA*), Advance® Medial Pivot (*Wright Medical Group, TN, USA*) and Natural Knee II (*Zimmer, Warsaw, IN, USA*).

All osteophytes tenting the medial collateral ligament (MCL) were meticulously resected and the MCL was protected during each step using a blunt Hohmann retractor. Graded releases and standard jig-based resections were performed using measured resection techniques/gap-balancing techniques specific to the implant. The trial implants were inserted in the flexed position, and the knee was gradually extended, palpating the tautness of the MCL. Utmost care was taken to avoid the occurrence of ligament or bony avulsions, which, if they occurred, were appropriately analysed and addressed.

Condylar fractures, when encountered, were provisionally stabilized using Kirschner wires and were exchanged for cannulated cancellous (CC) screws after implantation. In conditions of poor bone quality or larger fragments, a locked plate construct was preferred in place of CC screws. When the condylar fracture involving a significant proportion of the condyle was encountered prior to implantation, an extension stem was used to achieve a diaphyseal fixation. Any residual mediolateral imbalance was actively searched for in cases with a displaced MCL avulsion fracture, which was suitably addressed with releases before fracture fixation and component implantation. Such patients were mobilized full weight-bearing with a range of movement (ROM) restriction of up to 40° using a locking brace support for 6 weeks. Restricted weight bearing up to 6 weeks and ROM restriction up to 2 weeks was preferred for patients with associated condylar fractures.

2.2. Statistical analysis

Descriptive statistics such as mean, standard deviation and proportions were used for baseline demographic data. The normality of data was tested using the Shapiro–Wilk test. Continuous data such as age and BMI were tested using independent *t*-test and categorical variables were tested using the Chi-squared test. Non-parametric Mann–Whitney U-test was used to test the preoperative mHKA and functional outcomes (KSS). As the outcomes were scored between 0 and 100, they were treated as continuous data. Excel (2019, Microsoft, USA) was used for data compilation and data analysis was performed with SPSS Statistics 26.0 for Windows (IBM SPSS, Bangalore, India).

3. Results

3.1. Baseline patient information

Among the 50 IFs, 44 occurred in the femur, six in the tibia and none in the patella. The baseline characteristics of these individuals are summarized in Table 1. The mean age of patients in the FG and NFG was 63.76 ± 7.60 years and

Table 1
Baseline demographic characteristics of the study population.

	Fracture group (FG) (n = 50)	**Non-fracture group (NFG) (n = 150)**	***P***	
Mean age in years (SD, range)	63.76 (7.60, 44–76)	64.28 (4.59, 45–77)	0.5626 ‡	
Gender				
Male	11 (22%)	33 (22%)	1 †	
Female	39 (78%)	117 (78%)		
Side				
Left	28 (56%)	72 (48%)	0.955 †	
Right	22 (44%)	78 (52%)		
Mean BMI (SD, range)	29.53 (5.60, 26.6–33.6)	27.63 (3.39, 26.6–36.2)	0.005 ‡,*	
Mean mHKA in degrees (SD, range)	−18.6 (7.07, −23 to +14)	−12.8 (4.06, −14 to +15)	<0.0001 ‡,*	
Direction of Deformity				
Varus	45 (90%)	146 (97.33%)	0.0308 †	
Valgus	5 (10%)	4 (2.66%)		
Aetiology				
Primary osteoarthritis	42 (84%)	145 (96.66%)	0.0017 †,*	
Rheumatoid arthritis	8 (16%)	5 (3.33%)	0.0017 †,*	
Mean preoperative KSS (SD, lower bound, upper Bound)	79.92 (5.45)	85.62 (6.24)	$P < 0.0001$ ‡	
Implants	**FG (n = 50) No. (%)**	**NFG (n = 150) No. (%)**	**Total (n = 12010) (% fracture incidence)**	***P*** †
Buechel–Pappas™	6 (12%)	18 (12%)	1698 (0.353%)	1
PFC Sigma® PS (DePuy)	21 (42%)	63 (42%)	2372 (0.885%)	1
Maxx Destiknee (Meril)	9 (18%)	27 (18%)	2149 (0.418%)	1
Genesis II PS (Smith and Nephew)	6 (12%)	18 (12%)	686 (0.874%)	1
Triathlon (Stryker)	2 (4%)	6 (4%)	1100 (0.181%)	1
Advance® (Wright)	3 (6%)	9 (6%)	316 (0.949%)	1
Natural Knee II (Zimmer)	3 (6%)	9 (6%)	862 (0.348%)	1
Others				–
PFC Sigma CR	0	0	1479 (0%)	–
Link–Gemini	0	0	489 (0%)	–
NexGen (Zimmer)	0	0	486 (0%)	
Bioradmedisys	0	0	373 (0%)	–

BMI: body mass index; CR: cruciate retaining; FG: fracture group; KSS: Knee Society Score; mHKA: hip–knee–ankle angle; NFG: non-fracture group; PFC: press fit condylar; PS: posterior stabilized; SD: standard deviation.
* Significant at $P \leq 0.05$.
† Chi-squared test.
‡ Mann–Whitney U-test.

64.28 ± 4.59 years, respectively. Ninety percent of the patients in FG and 97.33% of those in NFG had varus coronal alignment. The mean preoperative mHKA in the FG was a varus of 18.6° (standard deviation (SD) = 7.07) with 77.77% of them having a fixed deformity and 91.11% having lateral tibial subluxation. Primary osteoarthritis (OA) was the most common underlying aetiology (84%), followed by rheumatoid arthritis (16%). On the contrary, the mean preoperative mHKA in the NFG was a varus of 12.8 ± 4.06° and primary osteoarthritis was the most common underlying aetiology (96.66%).

3.2. Fracture occurrence and assessment

Eighty-eight percent of the fractures occurred in the femur and 12% in the tibia. Among the 44 femur fractures, 32 (72.72%) occurred during trialing, nine (20.45%) during implantation and one during exposure. Among the six tibial fractures, two occurred during implantation and one each during exposure, tibial preparation and trialing. One tibial and two femoral fractures were missed during the index surgery (Figure 1). The surgeon preliminarily classified these fractures based on their site, mechanism and configuration. As repeated cases of similar fracture patterns were encountered, a classification system was proposed and put to use.

3.3. Fracture patho-anatomy and treatment

The patho-anatomy of femoral and tibial periprosthetic fractures is summarized in Table 2. Forty-five (90%) of the total fractures were associated with varus tibiofemoral alignment. Among the femur fractures, MCL avulsion fracture was the most common type seen in 24 (54.54%) cases. Nineteen patients had large-fragment MCL avulsion fractures and seven had partial small-fragment avulsions. Displaced small-fragment avulsion (involving less than 2 cm × 2 cm with partial MCL attachment) were treated with CC screws and an undisplaced fracture was treated conservatively. Large-fragment avulsions (greater than 2 cm × 2 cm or with complete MCL attachment) needed fixation using a plate (n = 7), screws (n = 11) or both (n = 1).

Among the non-avulsion fractures, isolated medial condyle fracture was most common (n=13, 65%) followed by bi-condylar fracture seen in four (20%). Five of the isolated medial condylar group extended proximally above the level of the adductor tubercle, all of which were treated with locked plating. The remaining eight which ended short of the adductor tubercle were managed with a CC screw (n = 5) or locking plate (n = 3). One of the three patients having a bi-condylar type of fracture, mandated the use of dual plates whereas the remaining two obligated the use of a rotating hinge distal femur replacement prosthesis due to extensive comminution and collateral compromise. Further analysis revealed that 63.63% of these patients had smaller femoral components (the first- or second-smallest available size) implanted (Table 3) and 84.09% of them had PS femoral design (Figure 2). Subgroup size-fracture frequency analysis of DePuy PFC Sigma implant revealed a higher incidence of femoral IF with size 1.5 and 2 femoral components (risk ratio = 2.71, P = 0.077) (Table 4).

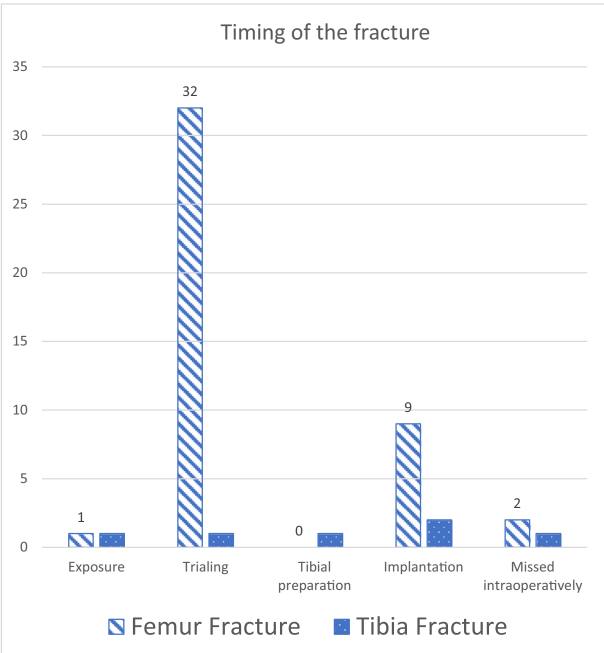

Figure 1. Fractured bone and its relation to the timing of fracture during surgery.

Table 2
Patho-anatomy of the femoral and tibial fractures, their frequency and implants used for fixation.

Fracture pattern (femur)	Number (%)	VAR	VAL	P	S	S + P	STEM	HINGE	C
MCL avulsion – small	7 (15.90%)	7	0	0	6	0	0	0	1
MCL avulsion – large	17 (38.63%)	17	0	5	11	1	1	0	0
Medial condyle- distal to adductor tubercle without metaphyseal compromise	8 (18.18%)	6	2	3	5	0	0	0	0
Medial condyle – extending proximal to adductor tubercle	5 (11.36%)	4	1	5	0	0	3	0	0
Lateral condyle	1 (2.27%)	1	0	1	0	0	0	0	0
Both condyle fracture with intact metaphysis	1 (2.27%)	0	1	0	0	0	1	0	1
Both condyle fracture with metaphyseal comminution	3 (6.81%)	2	1	1	0	0	0	2	0
Anteromedial condyle fracture	1 (2.27%)	1	0	0	1	0	0	0	0
Posteromedial condyle fracture	1 (2.27%)	1	0	0	1	0	0	0	0
Total	44	39	5	15	24	1	5	2	2
Fracture pattern (tibia)	**Number (%)**	**VAR**	**VAL**	**P**	**S**	**S+P**	**STEM**	**Sleeve/ Cone**	**C**
Medial condyle fracture	4 (71.42%)	4	0	2	2	0	2	0	0
Tibial tuberosity fracture	1 (14.28%)	1	0	0	0	0	0	0	1
Posterolateral plateau fracture	1 (14.28%)	1	0	0	0	0	1	0	1
Total	6	6	0	2	2	0	3	0	2

C: conservative; HINGE: rotating hinge distal femur replacement prosthesis; MCL: medial collateral ligament; P: plate; S: cannulated cancellous screws; S + P: cannulated cancellous screws with plate; VAL: valgus coronal alignment; VAR: varus coronal alignment.

Table 3
Fracture group: femoral component sizes and frequency of fractures.

Fractured femur vs. femoral component size (n = 44)	Size	Frequency	Size	Frequency	Size	Frequency	Size	Frequency	Size	Frequency	Size	Frequency
BP	**1**	0	**2**	3	**3**	2	**4**	1				
PFC	**1.5**	4	**2**	10	**2.5**	3	**3**	1	**4**	0	**5**	0
DESTIKNEE	**A**	0	**B**	3	**C**	2	**D**	2	**E**	1		
GENESIS II	**1**	0	**2**	2	**3**	4						
TRIATHLON	**1**	1										
ADVANCE	**1**	2	**2**	1								
NATURAL KNEE II	**0**	2										
Total		**9**		**19**		**11**		**4**		**1**		**0**

The second-smallest available femoral component size was associated with the highest number of fractures. n: Number; BP: Buechel–Pappas™.

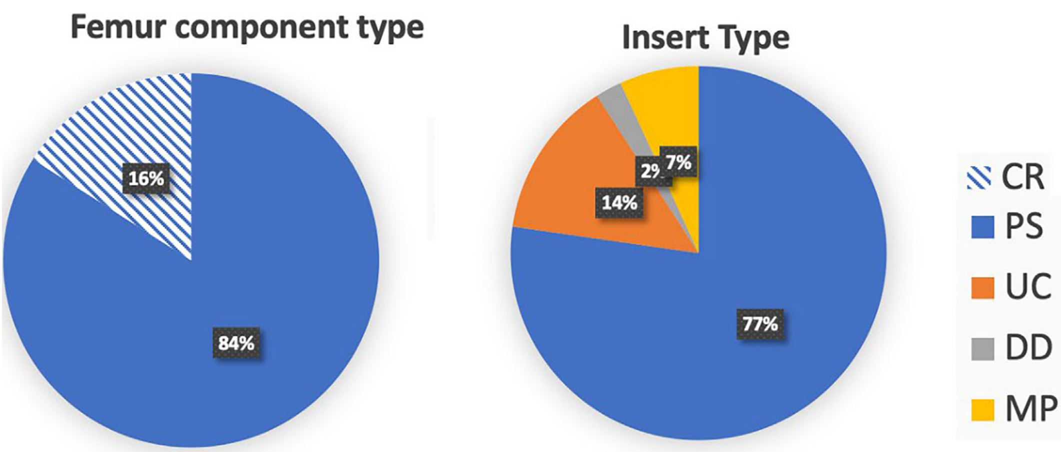

Figure 2. Fractured femur and its relation to the type of femoral component and insert. CR: cruciate retaining; DD: fixed-bearing deep-dished insert with tall anterior lip; MP: ball and socket type medial pivot insert; PS: posterior stabilized; UC: highly conforming ultra-congruent rotating platform insert.

Table 4
Femoral component size femur fracture frequency for DePuy PFC sigma.

Femur component size	Fracture incidence (n = 18)	Total no. of cases	%
1.5	4	437	0.915%
2	10	899	1.112%
2.5	3	523	0.574%
3	1	274	0.365%
4	0	186	0
5	0	53	0
Total	18	2372	0.759%

Among the five valgus IF, medial condylar fracture and bi-condylar fractures were the only encountered patterns. Avulsion fractures were not seen in the valgus knees.

Of the six tibial fractures, four were coronal splitting medial tibial plateau fractures (66.66%), whereas the other two were sagittally oriented, one extending from the anterior tibial plateau to the tuberosity and the other involving the posterolateral tibial plateau. The tibial extension stem was used to offload the baseplate when the medial plateau fracture extended beyond the metaphysis, compromising the stability of the keel. The fracture was stabilized with screws in two cases and a buttress plate in the other two.

3.4. Outcomes and complications

In the FG, the average tourniquet time and total surgical duration were 92.62 ± 26.84 min and 143.1 ± 52.10 min, respectively. The same in the NFG were 48.32 ± 16.22 min and 71.6 ± 13.5 min, respectively, which was almost half as compared with the fracture group. The average postoperative fall in haemoglobin in both cohorts was 2.18 (range = 0.5–5.4) and 1.89 (range = 0.8–3.2), respectively. Forty-seven of the 48 patients achieved radiological union at a mean duration of 9.6 weeks (range 8–16 weeks). At their last follow up, the mean KSS of the FG improved from 79.92 ± 5.45 preoperatively to 152.22 ± 9.25, whereas the same for the NFG improved from 85.62 ± 6.24 to 161.68 ± 11.22 (P = 0.642, Mann–Whitney U-test) (Table 5).

Among the complications, the patients in the FG showed higher 30-day (4% vs. 2%, P = 0.6005) and 90-day re-admission rates (8% vs. 2.66%, P = 0.0958) when compared with the NFG. Dyselectrolytaemia and urinary tract infections were the most common causes of re-admissions. Among the major complications, two patients from the FG and one from the NFG had a deep prosthetic joint infection (PJI) necessitating a two-staged revision (P = 0.15). The mean duration to the diagnosis of PJI was 9 months. Both patients in the FG showed prolonged persistent wound drainage >7 days which was treated conservatively. One patient in the fracture group (Type 1B femur – large-fragment avulsion) had persistent coronal plane instability which was subsequently revised using a hinged prosthesis; on the contrary, one patient in the NFG developed flexion instability at 1.5 years, revised using a constrained condylar knee (CCK) prosthesis. One patient with large-fragment MCL avulsion

Table 5
Preoperative and postoperative function, operative details and complication rates in both fracture and non-fracture groups.

	Fracture group (n = 50)	**Non-fracture group (n = 150)**	***P*** †
Mean preoperative KSS (SD, 95% CI)	79.92 (5.45, 65–84)	85.62 (6.24, 64–88)	0.54
Mean postoperative KSS (SD, 95% CI)	152.22 (9.25, 142–175)	161.68 (11.22, 144–182)	0.64
Mean tourniquet time in min (SD, 95% CI)	92.62 (26.84, 52–132)	48.32 (16.22, 26–55)	<0.0001*
Mean total surgical duration in min (SD, 95% CI)	143.1 (52.10, 78–174)	71.6 (13.5, 95% CI 55–92)	<0.0001*
Postoperative fall in haemoglobin in gram% (SD, 95% CI)	2.18 (1.66, 0.9–3.5)	1.89 (0.6, 0.8–2.5)	0.0060*
Complications	**Fracture group**	**Non-fracture group**	***P*** ‡
30-day readmission (non-arthroplasty causes)	2 (4%)	3 (2%)	0.6005
90-day readmission (non-arthroplasty causes)	4 (8%)	4 (2.66%)	0.0958
Infection	2 (4%)	1 (0.66%)	0.1548
Non-union	1 (2%)	–	0.2500
Implant prominence	2 (4%)	–	0.0616
Instability	1 (2%)	1 (0.66%)	0.4384
Wound dehiscence and secondary closure	1 (2%)	3 (2%)	1
All cause revision	3 (6%)	2 (1.33%)	0.0675

CI: confidence interval; KSS: Knee Society Score; SD: standard deviation.
† Mann–Whitney U-test.
‡ Fisher's exact test.

fracture and another with medial tibial plateau fracture, treated using plate and screws, presented with painful implant prominence. Non-union and implant failure was seen at 6 months in one patient with a bi-condylar femur fracture treated with dual plating (Figure 3).

4. Discussion

Although rare, IF is a preventable and manageable surgical complication associated with TKA [1]. Various implant-, surgeon- and patient-related factors have been explored to find associations with this complication. Berry et al. [9] reported the lowest incidence of IF (0.2%), with femur fractures occurring twice as commonly as tibial. The incidence of IF in our study was 0.45%, with the femur seven times more commonly fractured than the tibia.

Among the risk factors for fracture, rheumatoid arthritis had a relative risk of 2.73 ($P = 0.0001$) in predicting IF compared with primary osteoarthritis. Osteopenia associated with prostaglandin-induced bone resorption, disuse, steroid use, rigid deformities and regional bony cysts were the contributing factors for higher fracture risk [10,11]. Overzealous hammering of the prosthesis in the presence of clinical osteopenia should be avoided to prevent the occurrence of fractures.

Though Alden *et al.* reported a 4.74-times higher risk of femoral fracture with PS TKA than with cruciate retaining (CR) TKA [1], a causal relationship could not be established in our study due to implant matching in the control group. Although different industry implant designs differ concerning the volume of box-bone resected, there is a trend for a single-sized box across the range of femur sizes, in their respective designs [12–15]. Resection of a uniform volume of bone in a smaller-sized femur leaves a narrow segment of bone bridging the condyles with the diaphysis, thus predisposing for a fracture [13]. This was seen in our study where a subgroup size-fracture frequency analysis of a single implant manufacturer revealed a higher relative risk of fracture (risk ratio = 2.71, $P = 0.077$) seen in patients requiring smaller sizes (first or second smallest) of the femoral component. The ratio of the resected box volume to the femur size is a better predictor of fracture than the volume or the size independently [16,17]. Thus, our study supports the use of a non-cam-post-implant design in patients with smaller sizes to avoid fractures similar to the recommendation by Sherman et al. [17].

In our study, MCL bony avulsion fractures were the most common type of femoral fractures. The magnitude of the deformity and the complexity of the surgery could be the plausible contributing factors. The magnitude of varus (mean mHKA) in the FG was significantly higher in the FG in comparison with the NFG (18.6° vs. 12.8°). The association of fracture, particularly MCL avulsion type with severe and fixed varus deformities was also supported by the study done by Rajkumar et al. (odds ratio = 1.462, $P = 0.05$) [18]. An extensive medial and posteromedial soft tissue release is usually warranted to balance an uncorrectable varus knee. This mediolateral balancing is even more challenging when an extra-articular deformity such as proximal tibia vara is corrected intra-articularly. Femoral preparation using a measured resection technique with a standard 3° of external rotation may leave residual medial flexion tightness in such knees. Forcing a trial tibial component into a tight flexion gap could cause bony avulsion fractures in osteoporotic bones. We would emphasize the use of gap-balancing or hybrid resection techniques along with adequate tissue releases in such tight knees. Robotic technology should be used in such moderate to severe deformities whenever available [19].

Although the mechanical alignment in the FG was predominantly varus, we had five patients encountering IF with valgus alignment. All five valgus knees were secondary to rheumatoid arthritis, three of which encountered a medial condylar fracture and two suffered from a bi-condylar fracture during surgery. In spite of the soft tissue tightness, none of these patients had lateral bony avulsion.

The patho-mechanism of tibial fractures was different from femoral fractures. Agarwala *et al.* [2], in their study of 15 intraoperative tibial fractures, postulated excessive cement stuffing and overzealous hammering as the cause of fracture in an osteoporotic bone. Pinaroli *et al.* and Pun *et al.* attributed keel preparation and impaction as the causative reason [3,20]. Two of the six fractures in our study occurred during tibial preparation and trialing. We postulate that the fracture occurs through a stress riser between the line joining the tibial resection guide pinhole and the posteromedial vertical pinhole during keel preparation in osteoporotic bones with sclerotic surfaces. This occurs especially in cases where the tibial

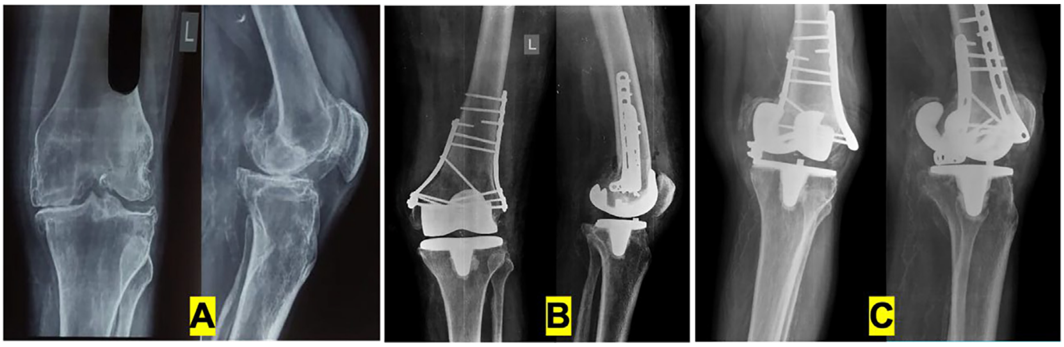

Figure 3. Type 4b fracture treated with both column plating non-union and implant failure. (a) Preoperative radiograph; (b) immediate postoperative radiograph; (c) 1-year follow up radiograph.

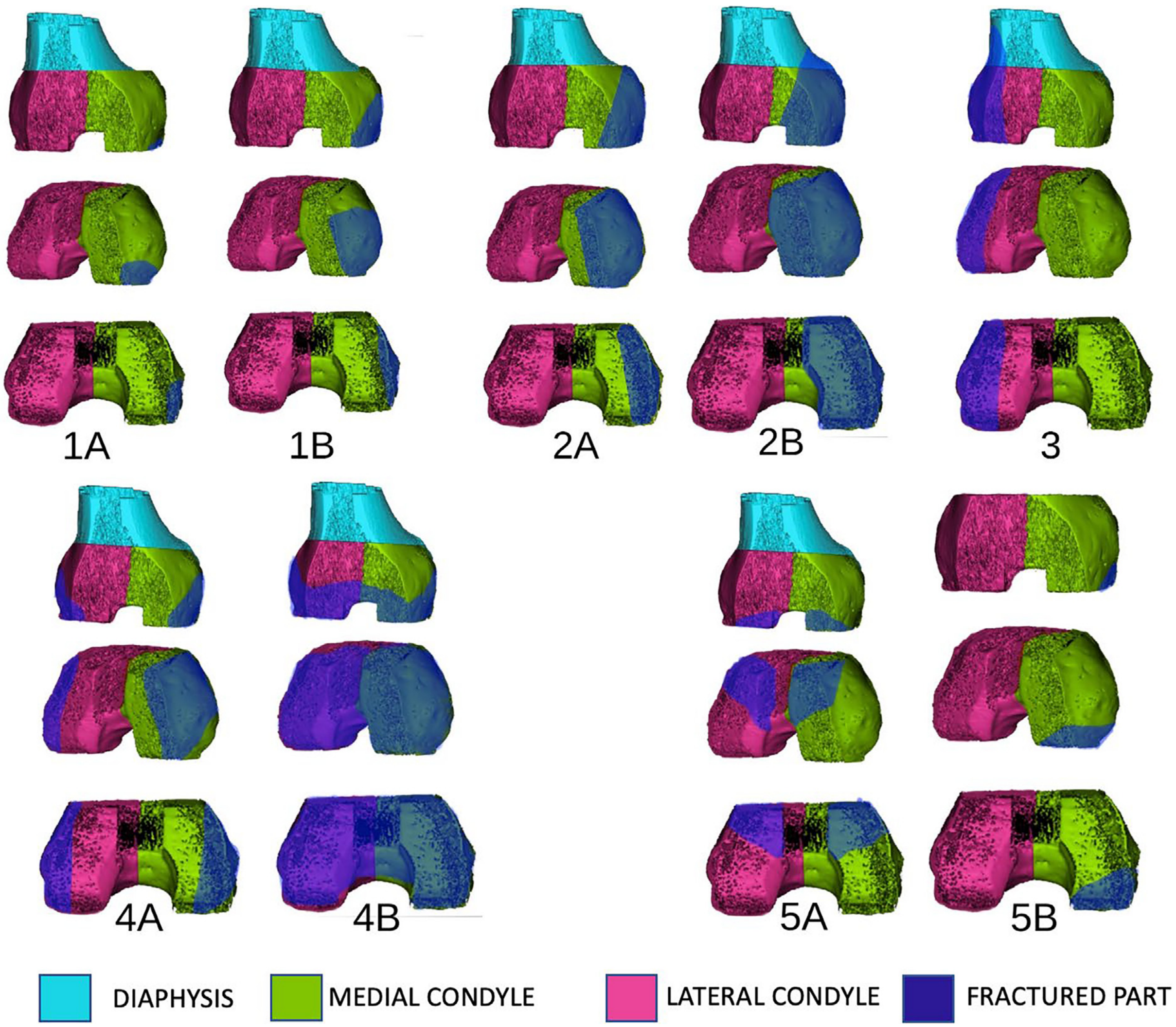

Figure 4. Proposed classification for intraoperative femur fractures.

cut is shallow and the sclerotic surface of the bone is exposed. Similar to the recommendation by Damsgaard et al. [7], we recommend using drills, osteotomes, or a reciprocating saw to cut a preliminary path for the keel punch before impaction, especially when the tibia is cut shallow and sclerotic.

There was a difference of 9.46 between the mean KSS scores of the fracture and the non-fracture groups. However, this difference between the two groups was not statistically significant ($P = 0.64$) as it was a result of the outliers (Mann–Whitney U-test). The rates of secondary complications such as infection (4%), re-admission (12%) and revision (6%) were higher in patients with IF, however, the statistical significance could not be commented upon due to the inadequate power of the study. Although the risk factors such as age, gender and implant designs were matched in our study, other factors such as severity of the deformity, nature of the deformity (fixed vs. correctable), underlying aetiology (OA/rheumatoid arthritis) and regional bone quality, which determine the complexity of the surgical procedure and indirectly influence the complication and revision rates were not matched. The higher complication rate could not be explained by the occurrence of fracture alone but could be partly attributed to the complexity of the surgical procedure.

Felix et al. recommended conservative protected weight bearing and brace for the management of small undisplaced fractures [21]. Rajkumar et al. recommended the use of a screw washer construct without an additional constraint for the management of moderate- to large-fragment MCL avulsions [18]. Multiple authors have recommended fixing condylar fractures using plate and screw constructs with additional extension stem supplementation when the fracture extended proximally to the metaphysis [1,2]. Kim et al. [22] recommended fixation for every bi-condylar fracture irrespective of the bone stock in younger individuals, keeping distal femur replacement prosthesis as a standby for elderly patients having low and comminuted fractures with poor bone stock [23]. Several authors recommend tibial fracture management using a buttress plate with

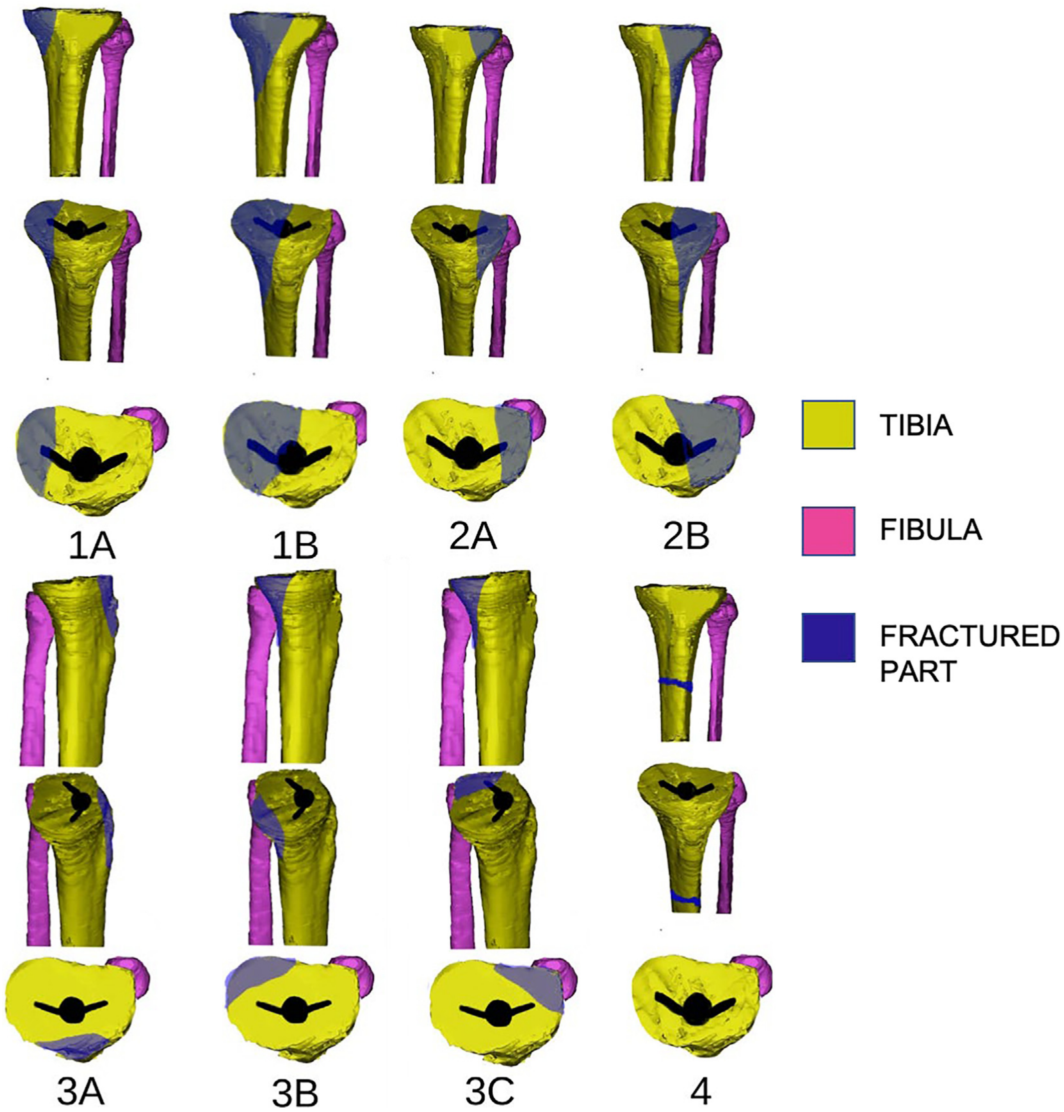

Figure 5. Proposed classification for intraoperative tibial fractures.

or without a bypassing long stem [1,2]. Undisplaced and stable fractures can tolerate protected weight-bearing and guarded ROM exercises as per the recommendations of Lombardi et al [24].

To date, there is no classification described, particularly for IF in primary TKA. The lack of guidelines leaves the surgeon's acumen and experience to guide fracture management. Through this study, we attempt to provide a working classification compiling the frequently occurring fracture patterns with their current management recommendations (Figures 4, 5; Table 6). In this classification, the femur fractures were broadly divided into avulsion, condylar, bi-condylar and sagittal plane fractures, whereas the tibial fractures were classified into medial, lateral, sagittal and diaphyseal fractures. Although the classification was derived from the institutional protocols, it was based upon the recommendations of contemporary literature. A prospective study validating the recommendations of this classification would be difficult but is highly encouraged considering the rare occurrence of such a fracture.

Our study had a few limitations. Confounding factors influencing the complications and revision rates such as severity of the deformity, underlying aetiology of arthritis and severity of osteoporosis were not matched in this study. The lack of long-term follow up and survival analysis of the implants was also a limitation of our study. Although the use of multiple implants from multiple manufacturers was a limiting factor, its design and implantation technique-related confounder was neutralized by the adoption of a nested case–control type of study design. Providing an in-depth comparative analysis with a significantly large number of this rare intraoperative complication was our study's strength. Besides, proposing a working classification for such fractures added considerable value to this study.

Table 6
Proposed fracture classification and treatment algorithm.

Femur type	Fracture description	Treatment recommendation
1A	Small-fragment MCL avulsion fracture (<2 cm × 2 cm or partial MCL insertion)	Undisplaced stable: conservative Displaced: 3.5 mm/4 mm cancellous screw with washer, screw with spiked washer
1B	Large-fragment MCL avulsion fracture (>2 cm × 2 cm or complete MCL insertion	Multiple cancellous screws with washer 3.5 mm/2.7 mm buttress plate
2A	Non-avulsion-medial femur condyle fracture extending distal to adductor tubercle	3.5-mm buttress plate with multiple screws
2B	Non-avulsion medial femur condyle fracture extending proximal to adductor tubercle	3.5-mm buttress plate with multiple screws + extension stem
3	Lateral femur condyle fracture	3.5-mm buttress plate with multiple screws ± extension stem
4A	Both-condyle femur fracture with preserved metaphyseal bone stock	Dual plating + extension stem
4B	Both-condyle femur fracture with significant metaphyseal bone loss	Metaphyseal augmentation (cones/sleeves) + Extension stem Constraint to be decided depending upon the integrity of the collateral ligaments
5A/5B	Fractures involving anterior/posterior part of the femoral condyles	Small-fragment defects can be filled with cement Large-fragment defects need fragment specific fixation using screws
Tibia type	**Fracture description**	**Treatment recommendation**
1A	Medial tibial plateau fracture not extending up to the keel (small fragment)	Buttress plating, screw fixation
1B	Medial tibial plateau fracture extending beyond the metaphysis or involving the region of the keel	Extension stem + buttress plating/screw fixation
2A	Lateral tibial plateau not extending to the keel (small fragment)	Buttress plating, screw fixation
2B	Lateral tibial plateau extending beyond the metaphysis or involving the region of the keel	Extension stem + buttress plating/screw fixation
3A	Anterior tibial cortex	Undisplaced/incomplete/stable: conservative with knee immobilizer for 3 weeks Displaced: screw, stainless-steel wire augmentation
3B	Posteromedial plateau fracture	Screw fixation If large fragment: extension stem
3C	Posterolateral plateau fracture	Screw fixation + extension stem
4	Diaphyseal fracture	Extension stem with/without plating depending upon the rotational stability

MCL, medial collateral ligament.

5. Conclusion

IFs are rare and under-reported complications. Patients with severe and fixed deformities are at higher risk for intraoperative fractures. The higher complication rates in the fracture group could be partly attributed to the occurrence of fracture and partly to the complexity of the surgery. When appropriately managed, the majority of these fractures unite and their functional outcomes are not significantly different from the non-fracture group.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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