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Periprosthetic femoral fracture type and location are influenced by the presence of an ipsilateral knee arthroplasty implant: A case-control study of 84 interprosthetic femoral fractures.

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- Chloe Scott – personal fees from Stryker and Pfizer; grants from Stryker; editorial board roles on the BJJ & BJR.

- Hemant Pandit – personal fees from Zimmer Biomet, DePuy Synthes, Invibio, Smith and Nephew and JRI Ortho; grants from Zimmer Biomet and DePuy Synthes

Abstract

Background

This multicentre case-control study compares Vancouver Classification System (VCS) grade and Arbeitsgemeinschaft fur Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA) fracture type in interprosthetic femoral fractures (IPFFs) between primary total hip arthroplasty (THA) and ipsilateral total knee arthroplasty (TKA) to periprosthetic femoral fracture (PFF) without ipsilateral TKA.

Methods

Data were collected following institutional approval. Eighty-four IPFFs were assessed for VCS grade and AO/OTA type. Each IPFF case (84) was matched to five PFF controls (360) by age, gender and stem fixation philosophy (SMD<0.1). VCS grade and AO/OTA type were compared between the IPFF and PFF groups using weighted proportions and medians.

Results

Median (IQR) age of IPFF patients was 81.75 (76.57-85.33) years and 61 (72.6%) were female. The commonest VCS grade was B1 (34, 40.5%). The commonest AO/OTA type was spiral (51.8% of VCS B fractures; 50.0% of VCS C fractures). A greater proportion of fractures occurred distal to the stem in IPFF patients versus PFF patients (33.3% versus 18.2%, p= 0.003). VCS grade was significantly different between groups (p=0.015). For VCS C fractures, twice as many AO/OTA transverse and wedge fractures occurred in the IPFF group compared to the PFF group (25.0% versus 12.6% and 7.1% versus 3.3%, respectively) although the overall difference was not statistically significant (p=0.407).

Conclusion

The presence of an ipsilateral TKA affects the location of PFF with more fractures occurring distal to the stem. A greater proportion of bending type fractures occurred when an ipsilateral TKA was present. These unstable fractures often require more complex surgery.

Key words: interprosthetic, periprosthetic, femoral fracture, ipsilateral, total hip arthroplasty, total knee arthroplasty

Introduction

Postoperative periprosthetic femoral fracture (PFF) is a potentially devastating complication of total hip arthroplasty (THA) [1] which carries a high rate of morbidity and mortality [2]. Management of these injuries often presents a challenge to orthopaedic surgeons, as they usually require complex surgery involving internal fixation and/or revision arthroplasty [3, 4]. Interprosthetic femoral fractures (IPFFs) occur between an ipsilateral THA and total knee arthroplasty (TKA). With increasing arthroplasty rates globally and an aging population [57], the number of PFFs is expected to rise. Whilst the incidence of IPFF is low at 5-7% of all periprosthetic fractures [8], the number of IPFFs is similarly likely to rise. These injuries can be extremely challenging to manage and outcomes are often poor, with high rates of fixation failure requiring further surgery (10.7-16%) and death (6.5-31.4%) [8].

Much of the literature on IPFFs has focused on management and outcomes following IPFF surgery [9-17], or observation of fracture patterns and locations in order to classify IPFFs [10, 18, 19]. Many authors present small case series [9-17], making it difficult to draw meaningful conclusions. Biomechanical studies have not demonstrated a clear stress riser effect in the implant-free femur between two prostheses and conclude that patient and implant factors remain predominantly responsible for IPFFs [20, 21]. Design features of THA stems have also been shown to modify the location and type of PFF [22]. Risk factor analysis of PFFs around THA has also shown that the presence of ipsilateral TKA increases the risk of PFF around THA, however this study did not evaluate fracture location or morphology [23].

It is possible that the presence of a TKA might also affect fracture location and type, however, there is no study to date comparing fracture location and character of IPFFs to PFFs in the absence of a TKA implant. This comparison may identify modifiable factors allowing prevention of these complex injuries and guide further research. The Vancouver Classification System (VCS) is a globally accepted classification system which describes PFFs based on location, stem stability and bone stock [24]. The Arbeitsgemeinschaft fur Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA) system is used to describe long bone fractures based on their morphology [25]. Both are often used to guide treatment algorithms.

This study aims to describe fracture location and character by VCS grade and AO/OTA type in patients with an IPFF and compare this to a matched cohort of PFFs around THA to establish the impact of an ipsilateral TKA on PFF location and morphology.

This study was approved by the institutional review board at the host organisation (MREC 19-005 Amd1).

Materials and Methods

A multicentre case-controlled study was conducted on consecutive patients from May 2006 to March 2020 with primary THA suffering postoperative VCS type B and C PFFs. Routinely recorded data were collected in eight UK centres performing high volume THA surgery.
Plain radiographs and stratified data were anonymised and collated for analysis. Patients with hemiarthroplasty or those with evidence of intraoperative PFF and patients where the presence or absence of an ipsilateral knee implant could not be established on radiographs or from clinical records were excluded from this study. The study excluded patients with VCS grade A fractures to ensure consistency with the existing literature, and any patient with a knee implant other than an unstemmed total knee arthroplasty.

Demographic data included patient age at time of PFF (years), gender, side of surgery, stem manufacturer and brand and hip stem fixation philosophy (cemented polished tapered stem [PTS] versus cemented composite beam [CB] versus cementless). VCS grade and AO/OTA fracture type (oblique, transverse, wedge and spiral) were assessed from plain radiographs. Although there are several classification systems used in the context of IPFF [11, 13, 15, 18], the VCS and AO/OTA classification systems were used due to their familiarity and consistent use in the literature. The VCS is based on fracture location (A, B or C), stem stability of the THA femoral implant (B1 vs B2/B3), and bone quality (B2 vs B3). We further assessed fracture pattern using the AO/OTA system based on fracture morphology [25]. In addition to the existing AO/OTA fracture types, an additional fracture type of ‘metaphyseal split’ fractures was included where the metaphysis has fractured from the diaphysis and splits in multiple parts around the stem [26]. Radiographs were independently assessed by two arthroplasty trained investigators (XX, XX) and in any cases where there was uncertainty in classification, the final decision was settled through discussion. Neither assessor was involved in the surgical management of any of the patients included in this series. Details ofsurgical treatment were also collected. Fixation was defined as fracture stabilisation without THA or TKA implant removal, exchange, or modification. Revision surgery was defined as removal, exchange, or modification of any component of either of the THA or TKA constructs with or without an additional fixation device.

Statistical analysis

Patients were separated into two groups: those with an ipsilateral TKA (IPFF group) and those without ipsilateral TKA (PFF group). Data were tested for normality using a Shapiro-Wilks test. Normally distributed continuous variables were summarised as mean values with standard deviations (SD) and non-normally distributed variables as medians with interquartile ranges (IQR). Comparisons between non-normally distributed continuous variables were performed with a Mann-Whitney U test. Comparison of ordinal and nominal variables were performed with Chi-squared tests.

The IPFF cohort was analysed to characterise the demographic data for this group. Each case in the IPFF group was then matched with a target matching ratio of five controls from the PFF group without TKA. Matching for stem fixation philosophy and gender was exact and age was matched using propensity score, as these factors are thought to influence fracture location and morphology. Acceptable balance of covariates in the resulting dataset was assessed using standardised mean difference (SMD) cut off of less than 0.1 for each variable, indicating good balance between the groups. Following matching, comparisons of fracture position, VCS grade and AO/OTA type using weighted proportions and medians were made between the IPFF group and the matched PFF control group. Statistical significance was set to $p<0.05$.

Results

769 cases of PFF following primary THA were included in the analysis, of which 84 had an ipsilateral TKA (IPFF group) and 685 had only the primary THA (PFF group). All TKAs were primary unstemmed cemented TKAs. The IPFF cohort was first analysed, followed by a propensity score matched cohort analysis comparing the IPFF group to the matched PFF

cohort.

IPFF cohort analysis

Median (IQR) age for the 84 IPFF patients was 81.75 (76.57 to 85.33) years (**Table 1**). IPFF patient included a greater proportion of female patients than male patients (72.6% female), with a wide variety of femoral implant brands. The commonest stem brands implanted were Exeter (Stryker, Kalamazoo, Michigan), Charnley (Depuy Synthes, Warsaw, Indiana) and CPT (Zimmer Biomet, Warsaw, Indiana) at 29.8%, 31.0% and 20.2% respectively. Forty-nine patients (58.3%) had cemented PTS stems implanted, 29 (34.5%) had cemented composite beam stems and six (7.1%) had uncemented stems.

The most frequent fracture location was around the THA stem (56/84 VCS B, 66.7%). Within the VCS grade B fractures, B1 fractures were most common (34/84, 40.5%, **Figure 1**). The femoral stem was stable in 62 of 84 patients (73.8% were VCS B1 and C grades). AO/OTA fracture morphology analysis of both VCS B and C groups showed spiral fractures to be the most frequent type (51.8% of VCS B fractures and 50.0 % of VCS C fractures, **Figure 2**).

Matched cohort analysis

84 patients in the IPFF group were matched to 360 in the PFF group and balance between IPFF group and matched PFF controls was acceptable, with SMD less than 0.1 for all matching variables (**Table 2**).

VCS grade

There was a significantly greater proportion of fractures occurring distal to the stem for patients in the IPFF versus PFF group (33.3% versus 18.2%, p=0.003). The distribution of VCS grades was also significantly different between groups, with the IPFF group experiencing fewer B2 fractures (20.2% versus 29.2%) and more C fractures (33.3% versus 18.2%) than the PFF group (p=0.015, **Table 2; Figure 1**).

AO/OTA type

The most common fracture pattern around the femoral stem was spiral and there was no substantial difference between AO/OTA type between groups for VCS B fractures (p=0.977). There was almost double the proportion of bending type fractures (transverse and wedge types) and fewer spiral fractures for VCS C fractures in the IPFF group compared with the PFF group, but the overall difference between the groups was not statistically significant (p=0.407, **Table 2; Figure 2**).

Treatment

In the IPFF group, fixation (**Figures 3a, 3b, 4a & 4b)** was performed in 54.8% of cases and revision was performed in 42.9% of cases. In the PFF group, revision (**Figures 5a, 5b, 6a & 6b)** was performed in 49.1% of cases and fixation was performed in 43.7% of cases. Differences in treatment between these groups were not statistically significance (p=0.167) (**Table 2**).

Discussion

This is the first study comparing IPFF fracture patterns to PFF fracture patterns around primary THA. It is also the largest cohort of IPFFs analysed in the literature, and in considering only primary THA patients is one of the most homogeneous datasets. This study demonstrated that the presence of an ipsilateral TKA is associated with a significantly greater proportion of PFFs distal to the THA stem without a significant change in overall fracture morphology. However, for VCS C fractures in the presence of a TKA, there are fewer spiral fractures and more bending type (transverse and wedge) fractures, indicating a bending mechanism of injury rather than a rotational one. There was no statistical difference in the proportion of patients undergoing fixation compared to revision surgery between the IPFF and PFF groups. These are important findings given the increasing prevalence of IPFFs, and the challenges faced by surgeons in successfully managing these injuries.

The IPFF group had a statistically significant increase in the proportion of VCS grade C fractures compared with the PFF group, even when cohort matched to control for confounders such as age, gender and stem brand which are known to increase the risk of VCS grade C fractures. This suggests that the presence of an ipsilateral TKA may alter the biomechanics of the femur resulting in fractures occurring in a different location to a femur with a THA only. In a cadaveric study, Weiser et al found the application of a bending force to a femur with both hip and knee arthroplasties in-situ to consistently result in fractures occurring between the prostheses, which they attributed to the relative weakness of the implant-free femur compared with the implant-containing segments [27]. In this study, however, all implants remained well fixed following IPFF, which is at clear odds with our findings that 26.2% of IPFFs result in unstable THA implants (VCS B2 or B3). Biomechanical testing using finite-element models has not identified a stress riser effect between models with differing lengths of implant-free femur [20, 21]. However, neither of these studies looked at how or where the femur fractured in the presence of different proximal and distal implants, and only analysed the effect of the implants on forces tolerated by the bone. Furthermore, neither study reported a stress riser effect from well-fixed implants, though there was a stress riser effect in the presence of loose implants (both hip and knee). Iesaka et al did find an increase in stress with decreased cortical thickness [20]. It should also be noted that existing biomechanical studies have studied the effect of bending forces only, and thus fail to reflect the real-world forces experienced by the femur in elderly patients experiencing low-energy trauma [20, 27, 28].

There was no statistically significant overall effect on AO/OTA fracture type between the IPFF and PFF groups, when analysed by VCS grade. Comparison of AO/OTA fracture type in VCS B fractures revealed similar proportions of the different fracture types ($p = 0.977$). However, examination of the data for VCS C fractures shows a reduction in spiral fractures (torsional injuries) and more than twice as many transverse and wedge fractures (bending injuries), although it did not reach statistical significance ($p = 0.407$ for comparison of all AO/OTA types in VCS C fractures). Although not statistically significant, this is a key finding of clinical significance, since bending fractures are inherently unstable and may therefore require more complex fixation with dual plating or plating with strut grafting to provide compensatory additional stability [29, 30].

Since our study shows that the location of the fracture on the femur is influenced by the presence of an ipsilateral TKA, which suggests possible modification of the transmission of force through the femur due to TKA presence, it is possible that this also influences fracture morphology. For example, the presence of a TKA could reduce the torsional force on the femur in low energy falls, with the result that the femur fractures due to blunt, bending trauma from impact against the floor, rather than sustaining a spiral fracture from the torsional element of the fall itself. Further work with larger cohorts may reveal whether this is significant. Current biomechanical studies on IPFFs predominantly assess the impact of dual implants on bending force required to fracture the femur, and do not consider the altered biomechanics of TKA vs native knees on force transmission through the femur. Future biomechanical studies should assess differential torsional force transmission through the femur between TKA and native knees to evaluate the impact of TKA on force required to fracture.

This paper is the first to assess fracture location and morphology in patients with IPFF between primary THA and TKA and compare them directly with PFFs occurring around primary THA alone. It is also the largest IPFF cohort analysed in the literature. There are several strengths of this study, including the large sample size of the IPFF cohort, which makes our findings more generalisable. We performed a comparison to a PFF cohort using matched cohort analysis to control for major confounding factors (age, gender and THA stem fixation philosophy). Since distal femoral fractures are effectively fragility fractures and are more common in females than males [22, 31], controlling for age and gender allows us to make valid conclusions on the impact of an ipsilateral TKA on IPFFs. We excluded revision THA and TKA cases to limit the potential confounding effect of these long-stemmed devices on fracture pattern. Careful analysis of immediate post-arthroplasty radiographs ensured significant intraoperative periprosthetic fractures were excluded from this analysis although it is possible that occult fractures may not have been identified. Furthermore, this study presents in vivo clinical data, as opposed to biomechanical studies performed in a non- clinical setting, which allows the findings to be applied directly to patients with ipsilateral THA and TKA implants with fewer caveats. Finally, matching the IPFF cohort with a target ratio of five PFF controls to each IPFF resulted in greater power and more reliable conclusions. We acknowledge that there are limitations to this study. With the IPFFs, we considered the fracture location in the context of the THA (VCS), without differentiating distal fractures according to their relationship to the TKA, as some studies on IPFFs have done. We did not consider stability of the TKA resulting from the fracture, as we were primarily concerned with fracture type and location rather than management. Finally, VCS grade was assessed using plain radiographs only. Although the VCS is a well validated, reliable classification system [32-34], we acknowledge that stem stability can sometimes only be established intraoperatively, especially for polished taper-slip stems [35]. However, in this retrospective series, intraoperative stability was frequently not recorded. For consistency across the dataset, we have therefore relied on the independent assessment of the radiographs by two arthroplasty trained assessors.

There are several clinical implications of this paper. Given the findings, there should be greater clinical and patient awareness of the consequences of an ipsilateral THA and TKA. Patients with ipsilateral THA and TKA implants are at greater risk of a VCS C fracture than a VCS B fracture. Most commonly, VCS C fractures can be treated with fixation surgery which, from a trauma perspective, may be easier to manage than VCS B fractures which mayrequire revision surgery, especially in the presence of a loose stem and/or severe bone loss. However, surgeons must also be aware of the increased risk of unstable bending type (transverse and wedge) VCS C fracture patterns. These are at higher risk of nonunion compared to simple spiral fractures and may benefit from more complex fixations constructs such as double plating and/or the use of cortical strut grafts. Of course, if the TKA femoral component stability is also compromised then alternative revision TKA strategies should be utilised. It is important that surgeons implanting a second prosthesis are aware of these risks in order to adequately inform their patients of the potential consequences, especially given the potential for poor outcomes experienced with IPFF management. Given the well-established IPFF patient demographics, corroborated by this large study, and resultant presence of osteoporosis, it is essential that assessment and management of osteoporosis is undertaken prior to implantation of a second prosthesis. Furthermore, given the IPFF patient demographics consistently reported in the literature and corroborated by this paper, prospective falls risk assessment should be conducted to optimise recipients of a second prosthesis, and reduce the probability of these individuals suffering the sort of low energy trauma known to cause such high consequence injuries.

Conclusions

The presence of an ipsilateral TKA increases the probability that a PFF will be distal to the THA stem (VCS C) after controlling for age, gender and stem brand. Unstable bending type fractures may be more common in VCS C fractures when a TKA is present. These findings should also inform classification systems and treatment algorithms. Both patients and surgeons need to consider this when evaluating options for a second ipsilateral arthroplasty. Further biomechanical studies are required to establish the underlying reasons for this in order to better understand the transmission of force through the doubly implanted femur, and direct preventative implantation techniques.

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Disclosure of Potential Conflicts of Interest

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Oliver Townsend - none

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Jonathan Lamb - none

Douglas Dunlop - none

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Figure legends

Figure 1. Relative proportions of VCS grades between IPFF and matched PFF groups
Figure 2. Relative proportions of AO fracture types by VCS grade (B and C) between IPFF and matched PFF groups
Figure 3a. Vancouver C fracture between THA and unstemmed cemented TKA
Figure 3b. Vancouver C fracture between THA and unstemmed cemented TKA
Figure 4a. Vancouver C fracture from Figure 3 treated with ORIF **Figure 4b.** Vancouver C fracture from Figure 3 treated with ORIF
Figure 5a. Metaphyseal split PFF around PTS stem
Figure 5b. Metaphyseal split PFF around PTS stem
Figure 6a. Metaphyseal split PFF treated with modular tapered fluted cementless revision stem and cerclage cables
Figure 6b. Metaphyseal split PFF treated with modular tapered fluted cementless revision stem and cerclage cables

Table 1. Baseline demographics of IPFF patients

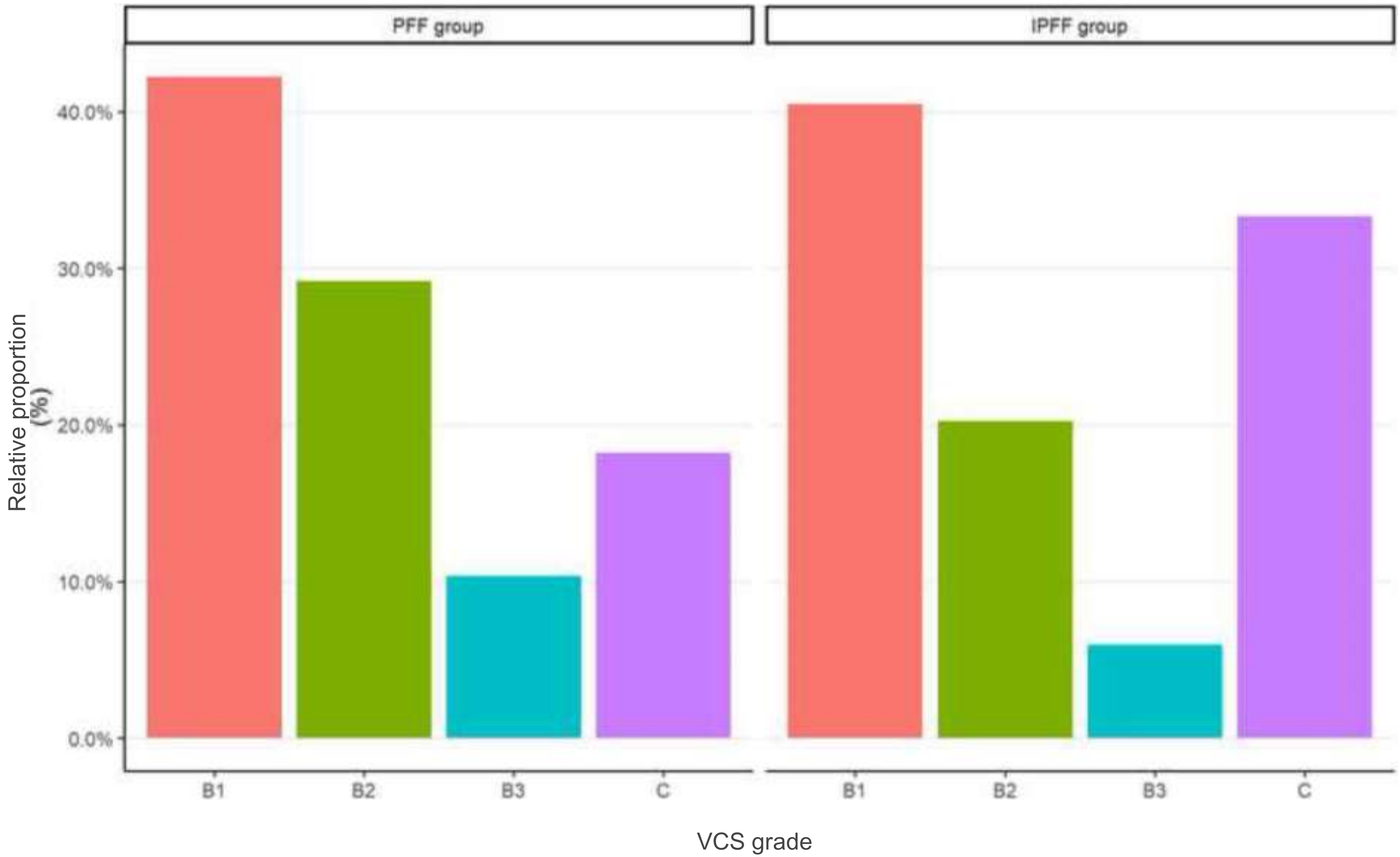
Variable		**IPFF** n = 84
Age (median [IQR])		81.75 [76.57, 85.33]
Gender(%)	*Female*	61 (72.6)
	Male	23 (27.4)
Stem fixation philosophy (%)	*Cementless*	6 (7.1)
	Cemented composite beam	29 (34.5)
	Cemented PTS	49 (58.3)
Hip stem brand (%)	*C stem AMT*	3 (3.6)
	C stem classic	4 (4.8)
	Charnley	26 (31.0)
	Corail	4 (4.8)
	CPT	17 (20.2)
	Exeter	25 (29.8)
	Furlong HAC	1 (1.2)
	Omnifit	2 (2.4)
	Spectron	1 (1.2)
	Stanmore	1 (1.2)
VCS (%)	*B1*	34 (40.5)
	B2	17 (20.2)
	B3	5 (6.0)
	C	28 (33.3)
Implant stability (%)	*Implant stable*	62 (73.8)
	Implant unstable	22 (26.2)
AO/OTA type for VCS B IPFF (%)	*Metaphyseal split*	4 (7.1)
	Oblique	11 (19.6)
	Spiral	29 (51.8)
	Transverse	9 (16.1)
	Wedge	3 (5.4)
AO/OTA type for VCS C IPFF (%)	*Oblique*	5 (17.9)
	Spiral	14 (50.0)
	Transverse	7 (25.0)
	Wedge	2 (7.1)
Treatment	*Hip revision*	36 (42.9)
	Fixation	46 (54.8)
	Non-operative	2 (2.4)
	Other	0 (0.0)

Note: IPFF indicates interprosthetic fracture with ipsilateral TKA, PTS is polished taper slip stem, TKA is total knee replacement, VCS is Vancouver Classification System and AO/OTA is Arbeitsgemeinschaft fur Osteosynthesefragen/Orthopaedic Trauma Association.

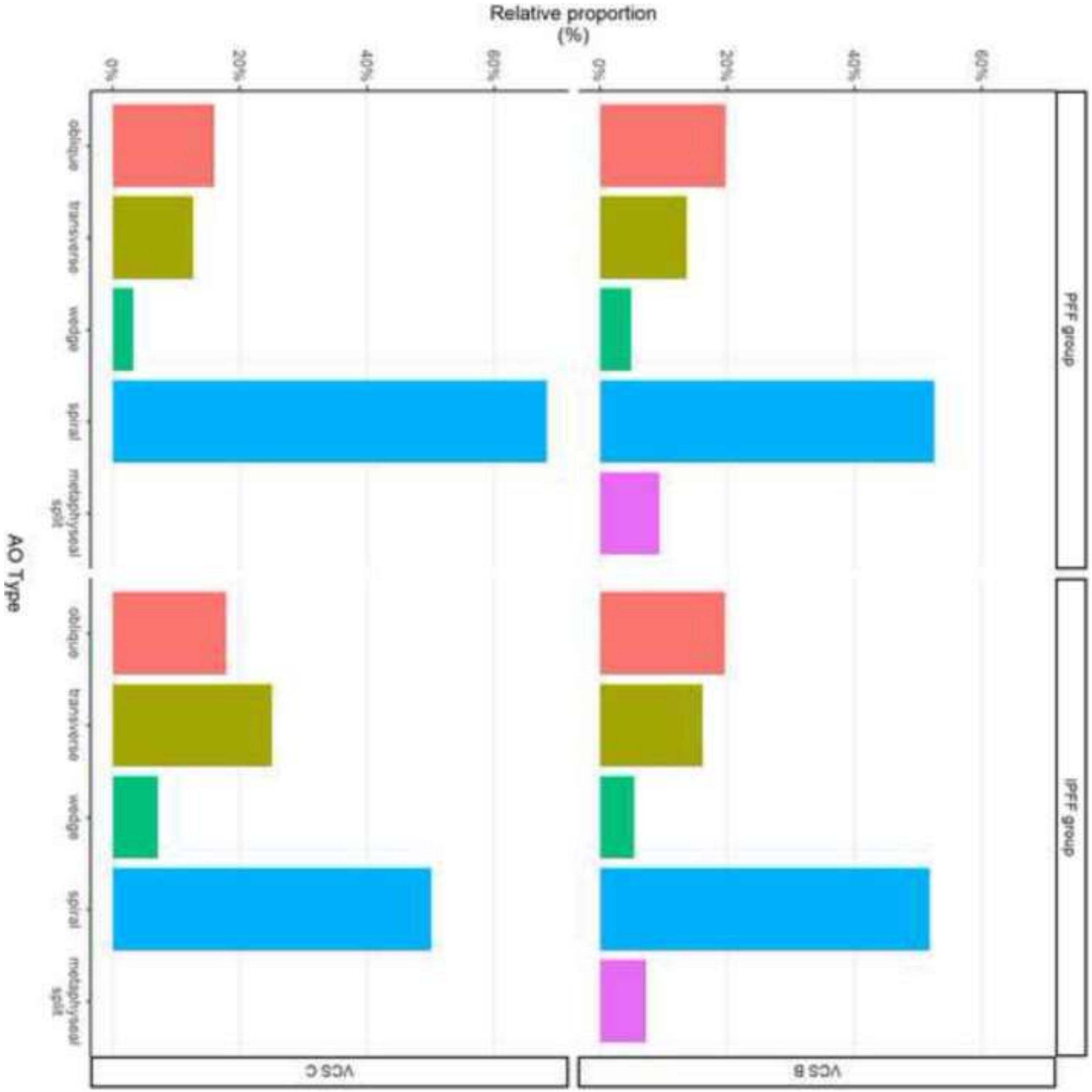
Table 2. Comparison of matched covariates, fracture position, VCS grade and AO/OTA type for patients with knee replacements (IPFF group) and matched PFF controls.

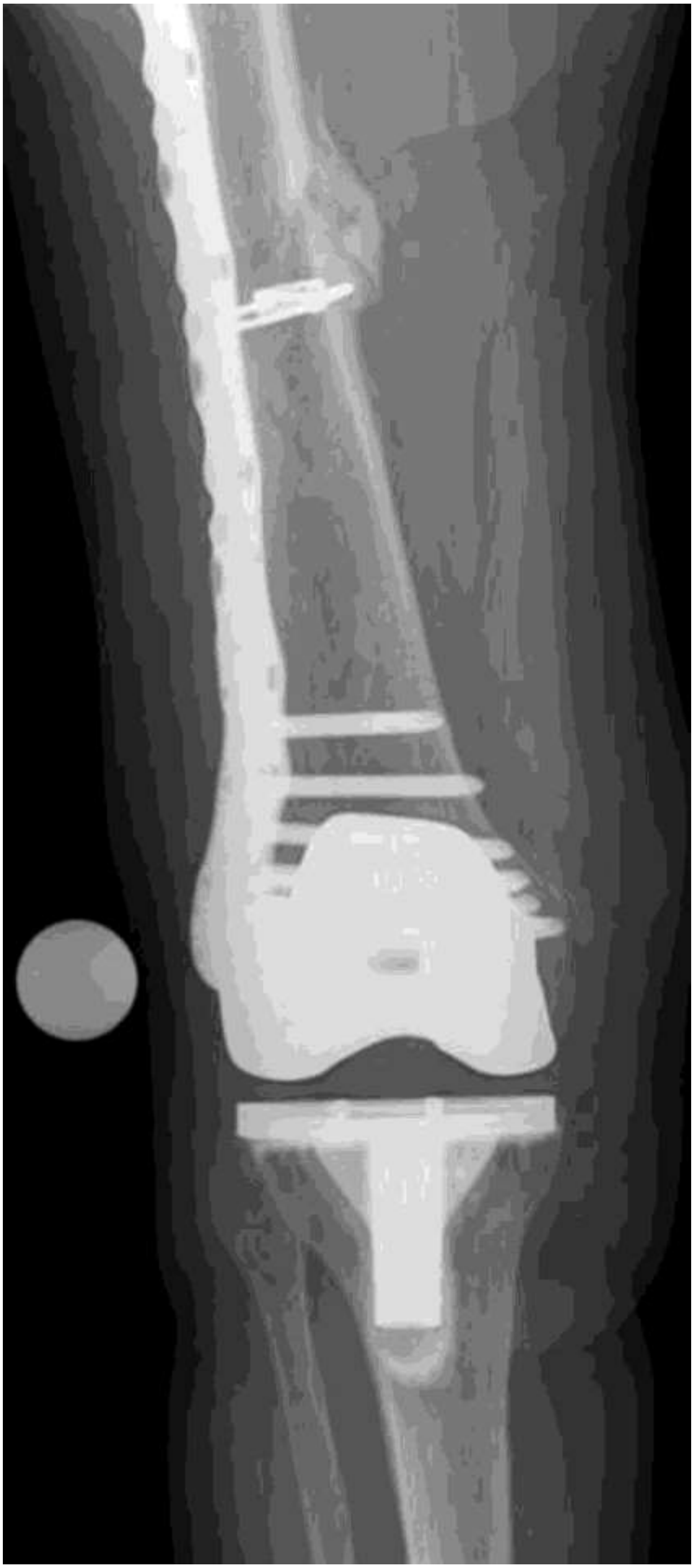
Variable		**IPFF group** n = 84	**Matched PFF controls** n = 360	p	SMD
Age (median [IQR])		81.75 [76.57, 85.33]	82.00 [76.00, 85.60]		0.087
Gender (%)	*Female*	61.0 (72.6)	261.4 (72.6)		<0.001
	Male	23.0 (27.4)	98.6 (27.4)		
Stem fixation philosophy (%)					
	Cementless	6.0 (7.1)	25.7 (7.1)		<0.001
	Cemented composite beam	29.0 (34.5)	124.3 (34.5)		
	Cemented PTS	49.0 (58.3)	210.0 (58.3)		
Fracture position (%)					
	Stem	56.0 (66.7)	294.4 (81.8)	0.003	
	Distal to stem	28.0 (33.3)	65.6 (18.2)		
VCS (%)	*B1*	34.0 (40.5)	152.0 (42.2)	0.015	
	B2	17.0 (20.2)	105.1 (29.2)		
	B3	5.0 (6.0)	37.3 (10.4)		
	C	28.0 (33.3)	65.6 (18.2)		
Stem stable	*Yes*	62.0 (73.8)	217.6 (60.4)	0.025	
	No	22.0 (26.2)	142.4 (39.6)		
AO/OTA type for VCS B (%)					
	Metaphyseal split	4.0 (7.1)	27.4 (9.3)	0.977	
	Oblique	11.0 (19.6)	58.0 (19.7)		
	Spiral	29.0 (51.8)	154.6 (52.5)		
	Transverse	9.0 (16.1)	40.1 (13.6)		
	Wedge	3.0 (5.4)	14.3 (4.9)		
AO/OTA type for VCS C (%)					
	Oblique	5.0 (17.9)	10.4 (15.9)	0.407	
	Spiral	14.0 (50.0)	44.7 (68.2)		
	Transverse	7.0 (25.0)	8.3 (12.6)		
	Wedge	2.0 (7.1)	2.1 (3.3)		
Treatment (%)					
	Hip revision	36.0 (42.9)	176.9 (49.1)	0.167	
	Fixation	46.0 (54.8)	157.4 (43.7)		
	Non-operative	2.0 (2.4)	20.9 (5.8)		
	Other	0.0 (0.0)	4.9 (1.3)		

Note: Fracture position according to the VCS grade B - adjacent to the hip prosthesis in the femur and C - distal to the hip prosthesis in the femur. PFF indicates periprosthetic fracture of the femur, IPFF indicates interprosthetic fracture with ipsilateral TKA, SMD is standardised mean difference (<0.1 indicates acceptable balance), VCS is Vancouver Classification System and AO/OTA is Arbeitsgemeinschaft fur Osteosynthesefragen/Orthopaedic Trauma Association. p indicates the probability of no difference between patients with interprosthetic fracture group and matched controls.



PFF group
IPFF group
40.0%
30.0%
20.0%
10.0%
0.0%
Relative proportion (%)
B1
B2
B3
C
VCS grade


Relative proportion
(%)
0%
20%
40%
60%
oblique
transverse
wedge
spiral
metaphyseal
split
AO Type
PFF group
IPFF group
VCS C
VCS B

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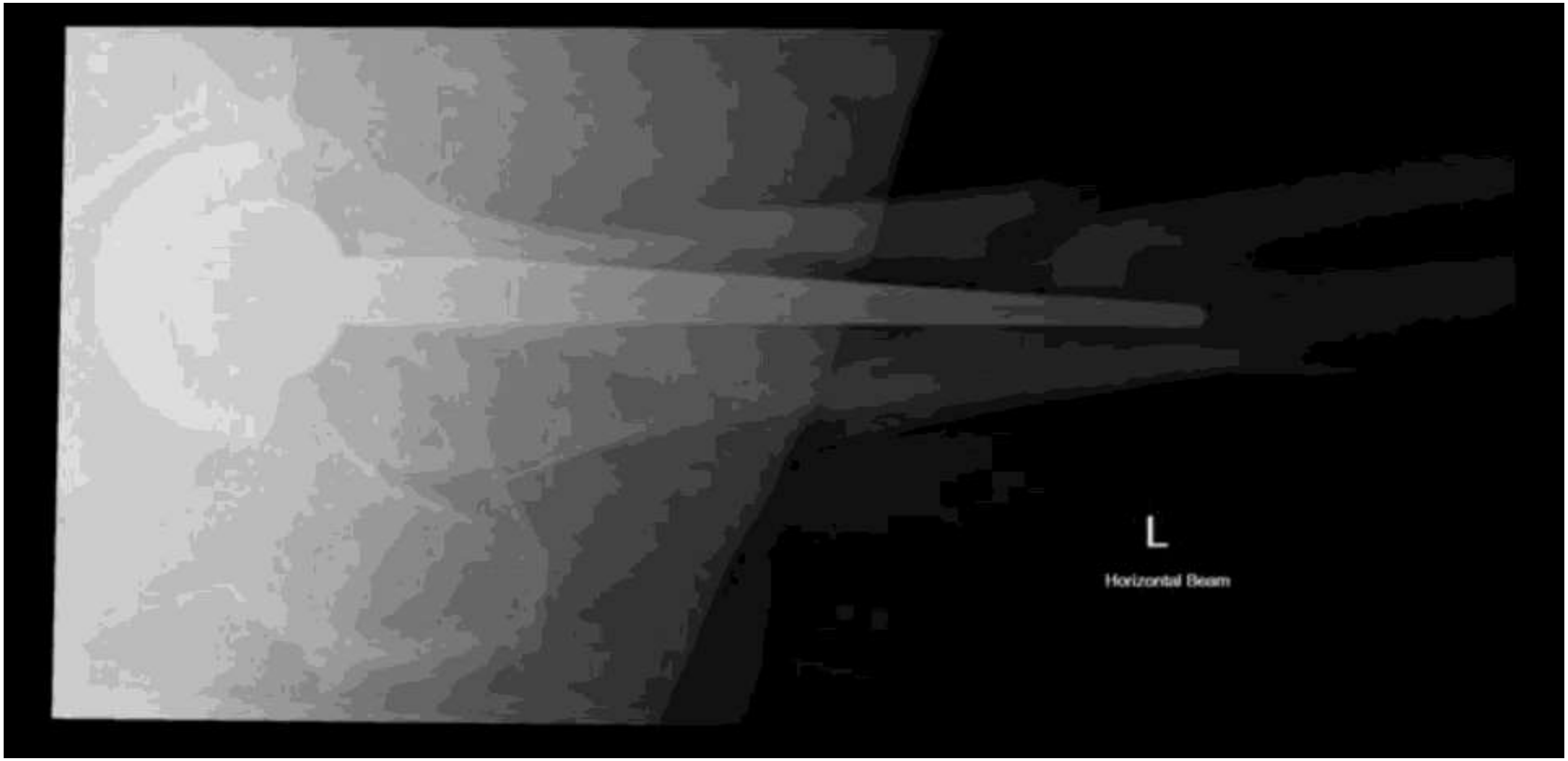
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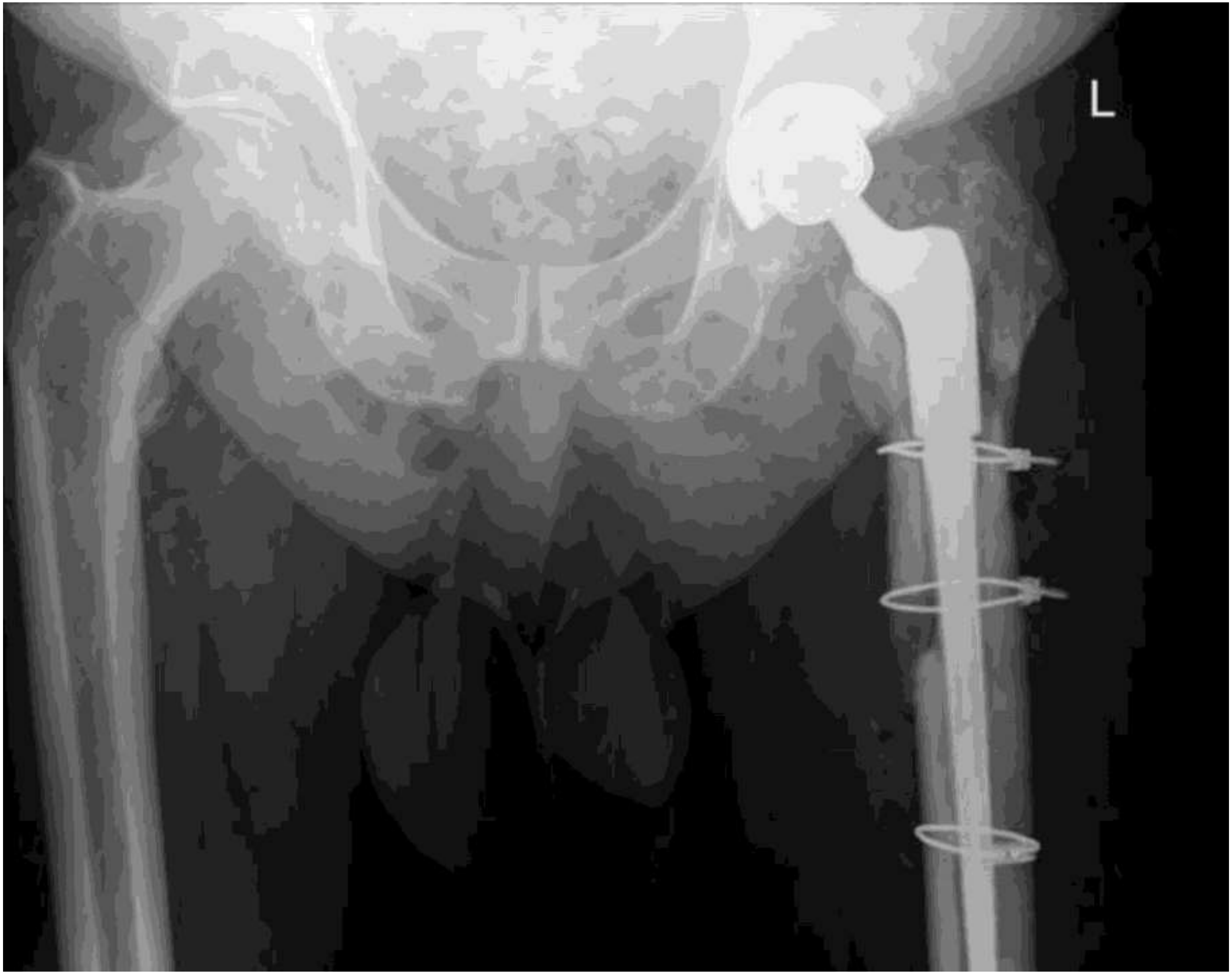
Horizontal Beam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