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Evaluation of fracture topography and bone quality in periprosthetic femoral fractures: A preliminary radiographic study of consecutive clinical data

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ABSTRACT

The unique configuration of periprosthetic femoral fractures (PFFs) is a major determinant of the subsequent management. The aim of this preliminary study was to investigate potential relationships between fracture angle (FA), fracture level (FL) and bone quality of Vancouver type B PFF. The FA, FL and the canal thickness ratio (CTR) were quantified for 27 patient X-rays. The CTR is an indicator of the underlying bone quality. Relationships between these factors were studied for the whole X-ray set, for a subgroup involving fracture above the tip of the stem and for subgroups with stable and unstable implants. When considering all cases, no significant correlation was found between the FA and any other measurement. Considering only cases with unstable implants, a statistically significant correlation was found between the FA and the FL ($R^2 = 0.489$, $p = 0.002$). No correlation was found between FA and any other measurement for stable implants suggesting that FA could be considered as an independent factor when classifying B1 fractures. Considering all cases, a weak correlation was found between CTR and FL ($R^2 = 0.152$, $p = 0.044$) suggesting that fractures below the tip of the stem may indicate a lower bone quality. This preliminary study suggests that the effect of FA on the optimal management of Vancouver type B1 fractures could be considered, independent of the quality of the bone or fracture position. Furthermore, fractures around or below the tip of the stem may suggest a poor bone quality. Larger number of patients is required to confirm these initial findings.

Total hip arthroplasty (THA) is frequently complicated by periprosthetic femoral fractures (PFFs) [1–3]. The incidence of intra-operative PFF reaches 1% for cemented and 5.4% for uncemented prostheses during primary surgery [1,2], increasing to 3.6% for cemented and 20.9% for uncemented prostheses during revision surgery [1,2]. Further cases occur postoperatively, with reported incidences of approximately 4% following revision THA [1,2,4]. Data extracted from the Swedish Hip Register demonstrate that PFF is the third most common reason for revision surgery, following aseptic loosening and dislocation [2].

The Vancouver classification has been widely accepted for the classification of PFFs [3,5,6]. Fractures classified as A or C are those located respectively very proximal or distal to the stem in situ. The majority of the PFFs however are located around the tip of the stem and are subdivided as B1 with the stem stable, B2 with the stem unstable and B3 with significant bone loss. Amongst B1 PFFs, the most difficult to treat are those with a short oblique or transverse configuration as they are axially and rotationally unstable and difficult to control with single plating [1,7]. On the contrary, long oblique or spiral fractures are more stable and can be more easily reduced, and due to their large fracture area may heal faster [1,7]. Early reports highlighted the increased failure rate of single plating for transverse B1 PFFs [8,9]. Parvizi et al. advocated that short oblique and transverse B1 fractures require biplanar plate fixation [10].

Fracture location and configuration, concurrently called 'topography', and bone quality are not clearly defined in the

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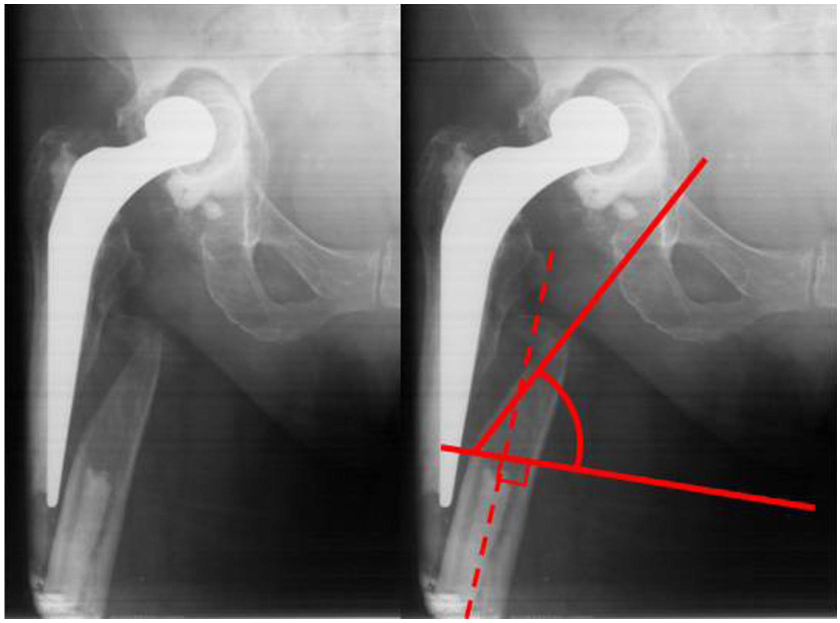

Fig. 1. Methodology of fracture angle measurement. The fracture angle is calculated based on an initial line drawn perpendicular to the long axis of the bone.

Vancouver classification. The aims of this study were twofold. The first was to examine if there was any correlation between the fracture angle (FA) and the fracture level (FL), the bone quality or the implant stability (i.e., the three existing factors in the Vancouver classification). No statistically significant correlation could potentially highlight that the FA should be considered as an independent factor in the classification. The second was to examine if there was any correlation between bone quality and FA, FL or stability of the implant. Here, any correlation would suggest that perhaps the aforementioned factors could provide an indication of the bone quality. The results of this preliminary study could potentially enlighten the relationship between the components of PFF characteristics and provide additional information for the classification and treatment of different PFF configurations.

Materials and methods

Radiographic analysis

The radiographic images of 27 patients with Vancouver type B PFF were studied. These were antero–posterior pelvic radiographs taken during admission prior to surgery with the patient lying supine. No standardised position protocol was applied for these radiographs due to the nature of the injury and discomfort the patient experienced prior to surgery. The radiographs were analysed using an image editing software package CorelDRAW X4 (Corel Corporation, 2008, Ottawa, ON, USA). Data included FA and FL indicating fracture topography and canal thickness ratio (CTR) indicating bone quality as defined in mathematical terms below. All radiographs were rated by two individuals, blind to each other, at two different time points 2 weeks apart. The mean value of all measurements was finally accepted for the analysis. An inter-observer and intra-observer agreement of $\geq$95% was considered acceptable for the mean value calculation. When close agreement ($\geq$95%) was not achieved, a third rater acted as referee for the final assessment and the closest two ratings were taken into account for the final scoring.

To standardise the Vancouver classification, measurement criteria were introduced. Only fractures occurring between two femoral diameters, measured at the level of the ipsilateral femoral isthmus on either side of the tip of the prosthesis, were classified as type B and were included in the study.

The stem was considered unstable when, in more than 25% of Gruen zone interfaces, namely stem/bone for uncemented implants or stem/cement and cement/bone for cemented implants, a radiolucent line of >2 mm was measured. Subsidence was considered an indicator of instability for the uncemented implants, whilst for the cemented double-tapered implants, stability was accepted in up to 4 mm subsidence within the cement mantle [5].

Bone quality was evaluated by the senior author on the basis of fracture comminution and the ratio of cortical thickness to femoral canal external diameter as described in the section titled 'Canal Thickness Ratio'.

Fracture angle

To calculate FA a reference line was drawn perpendicular to the long axis of the bone, intersecting the most distal fracture line. Subsequently, the angle of the fracture was calculated from this reference line in relation to the medial side of the femur, as shown in Fig. 1. As a result, the angle could vary between 0° (exactly transverse) and 180°. Since the angle was measured in relation to the medial side of the femur, there was no need to differentiate between the right and left legs.

Fracture level

In most of the X-ray images, the magnification and the exact stem sizes were not known. In order to address this issue, the relative distance from the tip of the stem to the fracture was used to describe the position of the fracture independently of the size of the femur. The percentage distance from the tip of the stem was calculated by dividing the distance from the tip of the stem to the most proximal part of the fracture by the length of the stem covered by bone as shown in the X-ray in Fig. 2. This technique was used in order to calculate at what percentage of the stem length the fracture occurred. The length was classed as positive if the fracture was above the tip of the stem and negative if the fracture was below.

Canal thickness ratio

The CTR was used as an indicator of the underlying bone quality. A previous study by Dorr et al. found that a higher CTR was

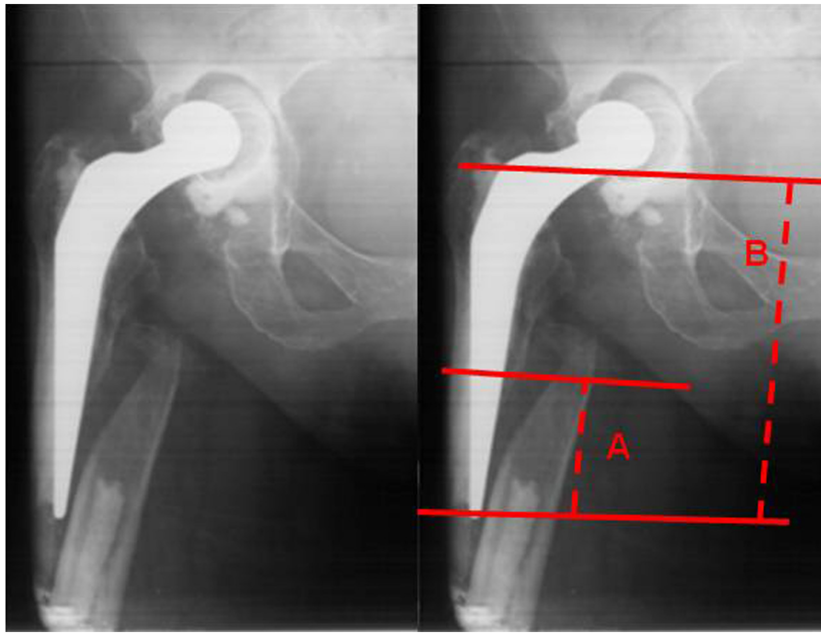

Fig. 2. Methodology of calculating the fracture level as percentage distance of the fracture from the tip of the stem. The fracture level is calculated by dividing the distance from the tip of the stem to the most proximal part of the fracture (A) by the length of the stem covered by bone.

related to better bone quality when the index was compared to results from biopsy and biochemical analysis [11]. The CTR was measured at the visibly narrowest part of the femoral canal around the stem and was calculated as being the ratio of the total cortical width to the outside diameter of the bone as shown in Fig. 3.

Statistical analysis

The relationships between the parameters of interest were investigated using the linear regression analysis using a statistical software tool (SPSS v. 17, IBM SPSS, Armonk, NY, USA). The significance level was set at 0.05.

Results

When the intra-observer error was calculated, the FL as well as the CTR both varied by up to 5%. The angle of the fracture varied by up to 5°.

Out of the 27 type B cases analysed, 11 were classified as B1, eight as B2 and eight as B3. A full set of the measurements is presented in Table 1. The FA ranged from 0 to 146° (mean = 75.4°, standard deviation (SD) = 33.3°). The CTR was recorded between 31% and 59% (mean = 45.3%, SD = 8). The FL in relation to the tip of the stem ranged between 22% and 84% with an average of 37.8% and an SD of 34.1%.

The correlation between the measurement parameters and the relevant *p* values is presented in Table 2. No significant correlation was found between the FA and FL, FA or CTR considering all cases or just considering the stable implant cases. However, there was a relatively strong correlation between the FA and FL for only the unstable implants (16 cases, $R^2 = 0.489$, $p = 0.002$; Fig. 4). Considering just the fractures within the stem length (22 cases), a weak but statistically significant correlation was found between the FA and FL.

A weak but statistically significant correlation was found between the FL and CTR across all 27 cases. More specifically, lower bone quality correlated with fractures near the tip of the stem (Fig. 4). This correlation remained statistically significant only when the fractures within the stem length were considered (22 cases). However, no significant correlation was found between the FL and CTR when the cases were subgrouped to stable and unstable implants.

Discussion

The management of PFFs and particularly that of the Vancouver B1 subtype has been shown to be both debatable and controversial, with varying clinical and biomechanical results [1,12,13]. Here we analysed a series of Vancouver type B cases to examine the relationship between the FA and the existing factors in the Vancouver classification, that is, FL, bone quality and implant

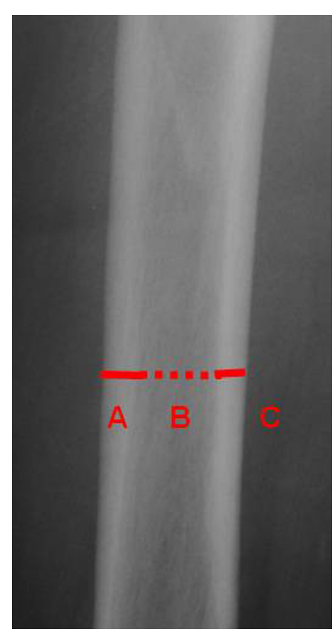

Fig. 3. Methodology of cortex (A, C) to canal (B) ratio measurement. The CTR is measured at the visibly narrowest part of the femoral canal around the stem and is calculated as being the ratio of the cortical width to the whole diameter of the bone.

Table 1
A summary of all cases.

No	Vancouver Classification	Prosthesis	Cemented	Stability	% Fracture level (FL)	Fracture angle (FA)	% Bone quality (CTR)
1	B1	Austin Moore	No	No	−22.2	111.3	40
2	B1	Exeter	Yes	No	−10.8	116	50
3	B1	Mackie	Yes	No	−9.0	29	38
4	B1	Exeter	Yes	No	−8.5	146.5	45
5	B1	Exeter	Yes	No	15.5	0	42
6	B1	Exeter	Yes	No	24.5	30	35
7	B1	Not known	No	No	39.9	50	42
8	B1	Exeter	Yes	No	42.1	114.9	50
9	B1	Osteonics	No	No	71.9	51	34
10	B1	Exeter	Yes	No	22.9	72	48
11	B1	Austin Moore	No	No	67.3	52	54
12	B2	Exeter	Yes	Yes	7.2	61	44
13	B2	Exeter	Yes	Yes	13.0	61	50
14	B2	Exeter	Yes	Yes	15.4	73	43
15	B2	Charnley	Yes	Yes	34.1	51.8	31
16	B2	Exeter	Yes	Yes	47.3	63.8	48
17	B2	Exeter	Yes	Yes	70.0	75	42
18	B2	Exeter	Yes	Yes	72.7	75	57
19	B2	Exeter	Yes	Yes	84.0	97.7	59
20	B3	Exeter	Yes	Yes	−15.0	46	42
21	B3	Exeter	Yes	Yes	23.2	75	31
22	B3	Charnley	Yes	Yes	66.0	65.4	59
23	B3	Exeter	Yes	Yes	66.6	115	38
24	B3	Not known	Yes	Yes	72.0	110	47
25	B3	Not known	Yes	Yes	74.9	110	48
26	B3	Exeter	Yes	Yes	77.0	108.1	58
27	B3	Charnley	Yes	Yes	79.0	75	47

stability. We also investigated the potential relationship between the bone quality and these factors.

The wide range of FA and FL (fracture topography) that was found within the Vancouver type B1 cases illustrates the variation that can occur within this classification subgroup. The fact that no correlation was found between the FA and FL, neither the FA and bone quality considering all cases is suggesting that the FA may need to be considered as an independent parameter when classifying these fractures. This lack of correlation remained when considering only the stable implants (B1 fractures), providing an even stronger case for consideration of FA for classifying B1 fractures. However, considering the unstable implants (B2 and B3 fractures) a statistically significant correlation ($R^2 = 0.489$, $p = 0.002$) was found between the FA and FL.

On the other hand, considering the fractures within the stem length (positive FL) a weak correlation was found between the FA and FL. This suggests that unstable fractures (transverse and short oblique) tend to occur around the tip of the stem. This correlation became stronger, considering only loose stems, which further suggests that, in the loose stems, the fractures around the tip of the stem become more transverse and hence unstable.

The importance of each of the parameters that constitute the fracture topography has also been described in the literature. Parvizi et al. advised that short oblique and transverse fractures are unstable and require stronger and more secure fixation in all planes [10]. Furthermore, the importance of the level of the fracture was identified by Bryant et al., as they claimed that the B1 fractures around the tip of the stem are the most challenging to treat [14]. They further advocated the use of long locking plates spanning the whole femur with multiple screws for the management of this type of fracture [14]. Choi et al. suggested that comminuted B1 PFF occurring at or near the tip of the stem might not benefit by fixation with a locking plate alone [15]. They suggested supplementation of the locking plate fixation either with an allograft or with an anterior plate [15]. Furthermore, our ongoing biomechanical study shows that FA can considerably alter the pattern of the mechanical stress on the fixation device and single locking plate fixation can be detrimental to healing (particularly under full postoperative weight bearing).

A weak correlation ($R^2 = 0.152$ for all cases and $R^2 = 0.188$ for fractures within the stem, $p = 0.044$) was found between the FL and bone quality. This suggests that fractures below the tip of the stem may indicate poor bone quality and that caution may need to be taken in the treatment of these fractures. Our results did not support any statistically significant correlation between the bone quality and FA. Nevertheless, the recorded trend was that worse bone quality correlated with unstable patterns of fracture. This is in agreement with the study of Anakwe et al., where all the B1 fractures in osteoporotic bones were shown to be unstable (transverse or short oblique [16]).

Table 2
A summary of the statistical analysis. Note N.S. highlights cases that there was no statistical significance.

	No	Fracture angle (FA) vs. fracture level (FL)		Fracture angle (FA) vs. bone quality (CTR)		Fracture level (FL) vs. bone quality (CTR)	
		R^2	p value	R^2	p value	R^2	p value
All cases	27	N.S.	N.S.	N.S.	N.S.	0.152	0.044
Stable implant	11	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Unstable implant	16	0.489	0.002	N.S.	N.S.	N.S.	N.S.
Within the stem length	22	0.269	0.013	N.S.	N.S.	0.188	0.044
Stable implant	7	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Unstable implant	15	0.395	0.012	N.S.	N.S.	N.S.	N.S.

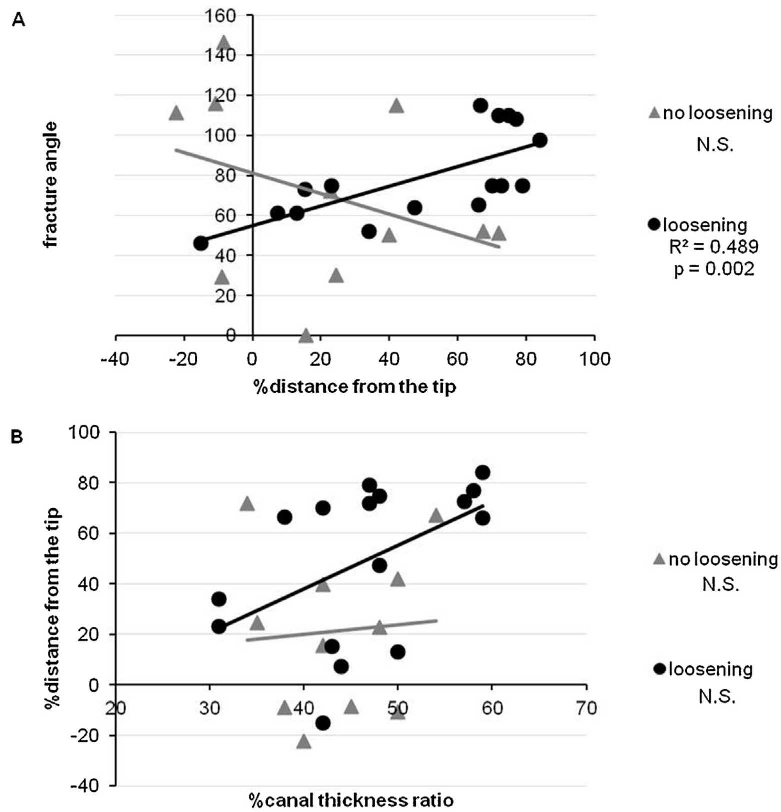

Fig. 4. Fracture angle versus %distance from the tip and %distance from the tip versus %canal thickness ratio ploted for the stable and unstable stems. (A, B) Note N.S. highlights cases that there was no statistical significance.

The current study is to the authors' knowledge the first to investigate the variation and the potential correlation between the fracture topography and bone quality in PFFs. There are a number of limitations in this preliminary study. The key limitation is the small number of cases that were studied. This could be of even more concern when all cases were subgrouped according to stem stability and FL (Table 2) that led to even smaller number of cases in each subgroup. However, such subgroups were considered to understand the effect of aforementioned parameters on the trends that were obtained. Clearly, larger patient data are required in order to confirm the findings of this study. Nevertheless, valuable tendencies were noted. Also it should be noted that in quantifying the FA the largest angle would be measured when an oblique fracture is imaged at 90° to the fracture line, and the angle would decrease as the fracture is rotated from this position. However, in this study caution was taken to ensure that fractures were imaged perpendicularly and only inter- and intra-observer agreement of ≥95% was considered acceptable. Yet the approach described in this preliminary study can be further refined in future studies.

In conclusion, this preliminary study suggests that the effect of FA on the optimal management of Vancouver type B1 fractures could be considered, independent of the quality of the bone or exact position of the fracture. Furthermore, fractures around or below the tip of the stem may suggest a poor bone quality. Therefore, the surgeon could be alerted by the fracture topography and consider adding more stability to the construct during the operative management of this injury. Larger patient data are required in order to confirm the aforementioned findings and elicit stronger statistical correlations which can subsequently provide improved information for the classification and treatment of different PFF configurations.

Conflicts of interest

We herein confirm that the authors do not have any financial and personal relationships with other people or organisations that could inappropriately influence (bias) their work.

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