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Vancouver B periprosthetic fractures involving the Exeter cemented stem: reducible fractures with intact bone-cement interfaces can be fixed

Abstract

Aims: The aim of this study was to determine whether fixation, as opposed to revision arthroplasty, can be safely used to treat reducible Vancouver B type fractures in association with a cemented collarless polished tapered femoral stem (the Exeter).

Patients and Methods: This retrospective cohort study assessed 152 operatively managed consecutive unilateral Vancouver B fractures involving Exeter stems; 130 were managed with open reduction and internal fixation (ORIF) and 22 with revision arthroplasty. The primary outcome measure was revision of ≥1 component. Kaplan Meier survival analysis was performed. Regression analysis was used to identify risk factors for revision following ORIF. Secondary outcomes included any reoperation, complications, blood transfusion, length of hospital stay and mortality.

Results: Fractures (B1 n=74 (49%); B2 n=50 (33%); and B3 n=28 (18%)) occurred at median of 4.2 years (IQR 1.2-9.2) after primary THA (n=143) or hemiarthroplasty (n=15). Mean follow up was 6.5 years (SD 2.6, 3.2 to 12.1). Rates of revision and reoperation were significantly higher following revision arthroplasty compared to ORIF for B2 (p=0.001) and B3 fractures (p=0.05). Five-year survival was significantly better following ORIF: 92% (86.4 to 97.4 95%CI) Vs 63% (41.7 to 83.3), p<0.001. ORIF was associated with reduced blood transfusion requirement and reoperations, but there were no differences in medical complications, hospital stay or mortality between surgical groups. No independent predictors of revision following ORIF were identified: where the bone-cement interface was intact, fixation of B2 or B3 fractures was not associated with an increased risk of revision.

Conclusion: When the bone-cement interface was intact and the fracture was anatomically reducible, all Vancouver B fractures around Exeter stems could be managed with fixation as opposed to revision arthroplasty. Fixation was associated with reduced need for blood transfusion and lower risk of revision surgery compared to revision arthroplasty.

Introduction

The number of primary total hip arthroplasty procedures (THA) is increasing annually [1] and periprosthetic femoral fractures (PFFs) are an increasing burden. The National Joint Registry for England, Wales, Northern Ireland, the Isle of Man and the States of Guernsey reports a revision rate of 0.34% for PFFs [2] with Scottish data suggesting a 0.9% five year rate of PFF after primary THA and 4.2% after revision THA [3]. However, this may be an underestimation: PFFs undergoing fixation rather than revision are not reported as revisions in arthroplasty registries.

The risk of PFF is influenced by femoral stem design [2, 4, 5]. The Exeter (Stryker, Mahwah, New Jersey, USA) femoral stem is a polished, tapered, collarless (PTC) femoral stem and is made of stainless steel. It is the most commonly implanted cemented femoral stem in the UK with excellent reported survival [6, 7]. However, PTC stems are associated with an increased risk of PFF compared to anatomic cemented stems which follow different design principles [4, 5].

PFFs are usually classified using the Vancouver system according to fracture location and construct stability. B1 fractures can be treated with open reduction and internal fixation (ORIF), whereas it is recommended that B2 and B3 fractures are managed with revision arthroplasty [8], because the stem is loose in these cases [9, 10]. While the Vancouver system has been widely validated [11], it was primarily developed using uncemented femoral stems. Evidence specific to cemented stems is sparse and there is no clear guidance as to which interface should be assessed for implant loosening: the implant-cement interface or the bone-cement interface. Subsequently there is marked variation in practice with some surgeons treating all Vancouver B fractures around PTC stems with revision arthroplasty and others adopting fixation. By definition, all cemented PTC stems are loose at the implant-cement interface with no bond between the highly polished stem and the cement. If the bone-cement interface is well fixed, and the fracture and cement mantle are anatomically reducible, fractures are potentially amenable to fixation as opposed to stem revision.

This study aims to determine whether fixation, as opposed to revision arthroplasty, can be used to treat Vancouver B type fractures in association with an Exeter stem. The primary outcome measure was revision surgery of ≥1 component. Secondary outcomes included any reoperation, perioperative morbidity, blood transfusion rates, length of hospital stay and mortality.

Methods

Ethical approval was obtained for this retrospective cohort study (Scotland (A) Research Ethics Committee 16/SS/0026). From 2008 to 2016, 211 consecutive unilateral periprosthetic femoral fractures around Exeter stems treated at the study institution were identified from a prospectively collected trauma database. Patients with intraoperative periprosthetic fractures, atypical periprosthetic femoral fractures [12] or Vancouver A and Vancouver C fractures were excluded. This gave a study population of 158 patients with unilateral Vancouver B PFFs (Figure 1).

Electronic patient records were examined and the following data recorded: demographic data, deprivation level (Scottish Index of Multiple Deprivation-SIMD) [13], BMI, date of primary prosthesis, date of injury, femoral head size (for radiographic calibration), details of operative management and complications were recorded. Where revision arthroplasty was utilized, indications for this were recorded. Mortality was calculated at ninety-days and one year. Modes of surgical management failure were determined and revision surgery or other reoperation were recorded.

Radiographic review was performed by three orthopaedic surgeons (CEHS, MPB and EO), who had no clinical contact with the patients, using picture archiving and communication system (PACS) (Kodak Carestream, Rochester, New York, USA). Fracture pattern, bone-cement interface radiolucencies (radiographic loosening) and Vancouver classification [11, 14] were recorded. All subsequent radiographs were reviewed in the national PACS archive to identify any subsequent revision surgery which may have occurred out-with our institution, but within Scotland. Though 12 patients moved away from the region during follow-up, all remained in Scotland and thus radiographs were viewable. Final follow up was defined as the date of the most recent radiograph or clinical review.

Fixation technique

All treating surgeons followed the same indications and surgical technique which has been previously described [15]. A PFF was considered suitable for fixation in the absence of symptomatic bone-cement interface loosening, unreconstructable comminution, or stem subsidence into the cementraliser [16]. Where the operating surgeon was not a revision hip surgeon, a surgeon specializing in revision hip surgeon was available during all ORIF procedures to revise the implants if required. A lateral approach to the femur was used to expose the fracture and the bone-cement interface was inspected. Where doubt existed regarding stem stability, the surgical approach was extended proximally as a posterior approach, the hip was dislocated and stem stability confirmed. Where anatomic reduction was achieved fixation was with a non-locked 4.5mm plate with or without cerclage cabling (Figure 1). Strut allografts were not used in any case. Conversion to revision arthroplasty was undertaken if the bone-cement interface was loose prior to reduction; if the stem was loose after reduction; or if the fracture was irreducible.

Revision technique

Femoral reconstruction was directed by fracture comminution, reducibility and bone stock. Indications for revision arthroplasty are shown in Table 1 [16]. Where bone stock and existing cement mantle were sufficient, but reduction was not possible with the original stem in-situ a long-stem cement-in-cement revision was performed after reduction and cabling of the femur (Figure 2a). Where bone stock or cement mantle were insufficient, an uncemented tapered fluted modular stem was used (Figure 2b). Where proximal bone stock was inadequate, most frequently due to fracture comminution, a proximal femoral endoprosthesis was used retaining an intact vastogluteal sling.

No postoperative weightbearing restrictions were applied to either surgical cohort.

Statistical Analysis

Data were analysed using SPSS version 25.0. Interobserver correlation for the Vancouver classification was assessed using Cohen's Kappa statistic (values 0.41–0.60 moderate correlation, 0.61–0.80 substantial, and 0.81–1 almost perfect reliability). Differences in patient characteristics between fracture types were compared using ANOVA, Chi squared and Fisher's exact. Univariate analysis was performed using parametric (Student's T-test: paired and unpaired) and non-parametric (Mann-Whitney U-test) tests as appropriate to assess continuous variables for significant differences between ORIF and revision groups. Nominal categorical variables, such as revision and reoperation, were assessed using Chi squared or Fisher's exact test. A p value of ≤ 0.05 was considered statistically significant.

Survival analysis was undertaken with Kaplan Meier analysis using the endpoints revision of ≥1 component and reoperation for any reason. Log rank statistic was used to compare treatment strategies. Cox multivariable regression analysis was performed to identify risk factors for revision surgery for those treated with ORIF using the covariates: sex, BMI, age at primary implant, age at fracture, time from primary to fracture, Vancouver B2/3 fractures, osteoporosis, Dorr classification, radiographic bone-cement interface loosening, and transverse or short oblique fracture patterns.

Results

From 2008-2016 158 Vancouver B level fractures involving Exeter stems occurred in 158 patients (Figures 3 & 4): B1 77/158 (49%); B2 53/158 (34%); and B3 28/158 (18%). Fracture patterns are provided in Figure 5. The mean age was 77.9 years (SD 11.3, range 44 to 103), mean body weight was 76.6kg (SD16.6, range 36 to 115), mean BMI 27kg/m^2 (SD4.8, range 17 to 39) and 95 (60.0%) were male. Periprosthetic fractures occurred at a median of 4.2 years (IQR 1.2-9.2) after the primary procedure (Figure 6) which was THA in 143 cases (91%) and hemiarthroplasty in 15 cases (9%). Three were interprosthetic. The mean length of follow-up in patients still alive was 6.5 ±2.6 years (3.2 to 12.1 years) and 87 patients (55.1%) had died (90 day mortality 12/158 (7.6%); 1 year mortality 25/158 (15.8%)). Initial management was ORIF in 130 patients (82.3%), revision arthroplasty in 22 (13.9%) and non-operative management in 6 (3.8%). Non-operative management was attempted for undisplaced fractures that were considered stable and included 6 weeks of non-weightbearing. Fracture displacement requiring revision arthroplasty occurred in 1/6 non-operatively managed patients. Femoral reconstruction methods at revision arthroplasty included: cement-in-cement stem revision with ORIF (n=4, Figure 2a); fluted tapered stems with cabling (n=12, Figure 2b); or proximal femoral endoprostheses (n=6).

Vancouver Classification

Interobserver agreement for the Vancouver classification was excellent (κ = 0.809 p<0.001) between two pre-expert observers (TPB, EO); and was moderate κ = 0.411 (p<0.001) between expert and pre-expert observers (CEHS and TPB). Where differences were found, radiographs were re-examined, discussed and a final classification agreed. The greatest disparities existed between Vancouver B1 and B2 fractures. There were no significant differences in patient characteristics between different Vancouver B classifications (Table 2). Patients with B3 fractures had a longer time between primary THA/hemiarthroplasty and fracture, although not statistically significant (p=0.799, Kruskall Wallace). Radiolucent lines at the bone-cement interface (radiographic loosening) were evident in 22 patients (14%): 12/53 B2 fractures and 10/28 B3 fractures.

Complications

Complication rates in operatively managed patients (n=152) are compared in Tables 3 (all B and B1 fractures) and 4 (B2 and B3 fractures). Medical complications were frequent following operative management (66/152, 43%), but did not differ in nature or frequency between ORIF and revision arthroplasty. Though length of hospital stay and postoperative blood transfusion requirement were lower following ORIF, this was not statistically significant (Table 4). One-year mortality was 28/158 (18%) and did not differ by fracture type (Table 2) or operative strategy (Tables 3 and 4).

Revisions

Revision surgery (exchange of ≥1 arthroplasty component) was required more often following revision arthroplasty (10/22) (figure 2b) compared to ORIF (10/130, p<0.001 Chi squared). With revision as an endpoint, 5-year Kaplan Meier analysis demonstrated significantly better survival following ORIF compared to revision arthroplasty (Log rank p<0.001, Table 5, Figure 6a). This was the case for each Vancouver B subtype (Figure 7). There were two cases of symptomatic femoral stem loosening requiring revision arthroplasty following ORIF (Table 6). Modes of failure requiring revision of ≥1 component are given in tables 6 and 7. The relative risk (RR) of revision for all Vancouver B fractures following revision arthroplasty was 5.45 (2.7 to 10.9, 95% confidence intervals) that of ORIF. B2 fractures had significantly lower rates of revision surgery (0/40 vs 4/10, p<0.001 Fisher's exact test) and of any reoperation (4/42 vs 6/10, p=0.002, Fisher's exact test) when managed with ORIF compared to revision arthroplasty.

Cox multivariable logistic regression analysis did not identify any independent predictors of revision following ORIF of Vancouver B fractures (Table 9). Fixation of B2 or B3 fractures was not associated with an increased risk of revision.

Reoperations

Modes of failure requiring reoperation differed according to surgery types: non-union or additional fracture predominated after ORIF (table 5) and dislocation after revision arthroplasty (table 6). With reoperation as an endpoint, 5-year Kaplan Meier analysis demonstrated significantly greater survival following ORIF compared to revision arthroplasty (Log rank p<0.001, Table 5, Figure 6b). Multiple reoperations were required in 3 patients following ORIF and 4 following revision arthroplasty (p=0.665, Table 3).

In patients treated with ORIF, there was no significant difference in reoperation rate between Vancouver B1 fractures (7/69, 10%) and Vancouver B2/3 fractures (8/61, 13%

p=0.597, Chi squared). Considering B2 fractures alone, the RR of reoperation was 2.26 (1.05 to 4.86, 95% CI) for revision arthroplasty compared to ORIF. For B3 fractures, the reoperation RR was 1.78 (0.73 to 4.32, 95% CI) following revision arthroplasty compared to ORIF.

Discussion

This is the largest published series of PFFs involving the Exeter cemented polished tapered stem. It demonstrates that provided the bone-cement interface is intact and the fracture is anatomically reducible, PFFs around this stem can be managed with fixation. The risk of both reoperation and revision was significantly less following ORIF, with significantly better 5-year Kaplan Meier survival following ORIF for both endpoints. Fixation of B2 or B3 fractures was not associated with an increased risk of revision. The high rates of reoperation and revision following revision arthroplasty reflect the complexity of the cases selected for this treatment: irreducible, comminuted fractures with bone loss ± pre-existing symptomatic stem loosening. When revision arthroplasty is required to treat PFFs, additional constraint should be used to mitigate against instability which was the commonest mode of failure in the revision arthroplasty group.

Understanding fractures around the Exeter stem is important for numerous reasons. It is the most commonly implanted cemented femoral stem in the UK (69% of 467,510 cemented stems in the National Joint Registry [6]) and is associated with an increased risk of PFF compared to anatomic cemented stems: twice that of the Charnley in a linked NJR study of 257,202 primary THAs [4]; and ten times the risk of the Lubinus in a Swedish registry study of 65,910 primary THAs [5]. Though the absolute risk of fracture remains small (0.66% of 22,271 Exeter stems) [5] the effect of stem design is more marked in patients >80 years of age [17]. PFFs are increasing in incidence [10] and are associated with high 1 year mortality of 13-17% [18, 19]. Minimising surgical morbidity and mortality in the management of these complex fractures is paramount.

The Vancouver classification can be difficult to apply to fractures involving PTC stems, particularly in distinguishing between B1 and B2 fractures. The subjective nature of identifying radiographic femoral loosening has been identified previously [9, 10]. The Vancouver classification achieves classification system ideals (reliable, repeatable, aids communication and guides treatment) for uncemented femoral stems [11]. Clarification is required regarding which interface to assess for loosening and whether the entire cement mantle is considered part of the implant. By definition, all taper slip stems are loose within the cement mantle. As most B fractures involve cement mantle fracture, the majority of PTC associated PFFs are technically loose (B2). However, if the classification is applied only to the bone-cement interface, few are defined as loose. The majority of PFFs occur early following primary implantation: 44% within 90 days of primary surgery after cementless implants [2] and 50% within four years after cemented implants here. Few cemented Exeter stems display evidence of bone-cement interface loosening within the first decade [20].

The proportion of B2 fractures in the current study is less than in previous studies, e.g., 53% of 1055 PFFs in Lindahl et al [21], but the proportion of B1 is higher reflecting the difficulty in distinguishing B1 and B2 fractures involving this stem. The results for each fracture type have therefore been presented both together and separately. This distinction between subtypes is less important if it does not dictate management: B1 and B2 were both best treated with ORIF. In a recent systematic review of B2 (n=343) and B3 (n=167) fractures from 22 studies, only 13% of B2 and 5% of B3 fractures were managed with fixation [10]. Though reoperation rates for B2 fractures were similar following ORIF (13.3%) and revision arthroplasty (12.4%), B3 fracture management strongly favoured revision arthroplasty in terms of reoperation risk (14% vs 29%) [10]. A variety of cemented and uncemented stem designs were included in this review. Adopting a policy of fixation when possible for Vancouver B2 fractures involving the Exeter stem in the current study was not associated with an increased rate of revision surgery or reoperation compared to that that reported for ORIF of B1 fractures in the literature [19, 21].

Fixation of B2 fractures involving PTC stems has been reported previously. In a small series of 12 B2 fractures involving PTC stems all united with stable stems within their original cement mantles at a median of 5 years following ORIF [22]. In a larger study of 52 B2 fractures around PTC stems treated with ORIF Smitham et al [23] reported no revision surgery or stem loosening, though similar to the present study 7/52 (13%) required reoperation for non-union or refracture. Goudie et al [15] reported that Vancouver B fractures involving Exeter stems can be fixed with non-locking plates with or without cables provided anatomic reduction is achieved without bone loss: failure to anatomically reduce predisposes to stem loosening and subsidence [15]. Where anatomic reduction is possible, ORIF has potential advantages over revision arthroplasty: reduced operative time [22]; reduced transfusion requirement [22]; bone stock preservation and lower complication rates. Though no mortality benefit has been demonstrated [18], the current study suggests an implant survival benefit following ORIF and this is novel.

The reoperation and revision rates following revision arthroplasty in the current study were comparatively high [10, 24]. This likely reflects selection bias: only the most complex fractures were managed with revision arthroplasty. All revision arthroplasty procedures were performed by hip revision specialists using appropriate reconstruction techniques: cement-in-cement long-stem revision [25]; uncemented fluted tapered modular stems [26, 27]; or proximal femoral endoprosthetic arthroplasty (PFR) [28-30]. PFR for non-neoplastic salvage is valid, but carries a complication rate of 22-30% [28-30]. The requirement for PFR in 6/22 revision cases may have contributed to the high complication rate. Achieving stability in multiply operated elderly hips with complex femoral reconstructions is difficult: increased constraint is indicated in these patients. Better outcomes of revision arthroplasty may be possible in absence of a selection bias favouring ORIF: cases managed with revision arthroplasty would reduce in complexity and would be performed in higher volume. Though better outcomes of revision arthroplasty would reduce the difference found between ORIF and revision in the current study, it would not change the fact that treating B2, and some B3 fractures, with ORIF provided similar rates of complication and reoperation as of ORIF of B1 fractures reported previously [19, 21].

Limitations of this study include its retrospective nature, a lack of long-term radiographic follow up and of patient reported outcome measures and frailty scores. Low numbers in subgroup analyses may have resulted in type 2 errors. Minimum follow up of 3 years was adequate but we cannot comment on longer term stem loosening in patients managed with ORIF or any long-term consequences of screws through the cement mantle. However, other failures following ORIF (non-union, infection etc) would be expected to occur early and be detected within the time period covered [19]. Cases of stem loosening that were asymptomatic may have been missed. Significant selection bias has inflated both complication and reoperation rates in the revision arthroplasty group. However the rate of both reoperation and component revision was low following ORIF of B2/3 fractures comparing favourably to the published literature. Ambulatory status was not assessed or compared. Twelve patients moved away from the region during follow-up, but all remained resident in Scotland and any further radiographs for loosening or reoperation would have been visible in the National PACS archive. If any patients been treated for difficulties outwith Scotland and had not subsequently undergone radiographs in Scotland these complications could have been missed. The current study adheres to recommendations for periprosthetic fracture dataset reporting as determined by a recent systematic review [10] and constitutes the largest cohort of Exeter stem related PFFs in the literature.

Where the bone-cement interface is intact and the fracture is anatomically reducible without excessive comminution, fixation of Vancouver B fractures (including B2 and B3 fractures) involving the Exeter stem was associated with significantly lower rates of reoperation (11%) and revision (8%) compared to revision arthroplasty. Five-year survival was significantly better following ORIF. In contrast, revision arthroplasty was associated with a significant risk of complications including revision, frequently due to dislocation. Where revision arthroplasty is required, constraint should be increased. Using a strategy of fixation when possible was not associated with inferior outcomes in terms of revision surgery or reoperation when managing Vancouver B level fractures around the Exeter stem: fixation of reducible B2 or B3 fractures was not associated with an increased risk of revision.

Table 1. Indications for revision arthroplasty. Where the stem had subsided into the cementraliser, 2 of 3 were identitifed preoperatively, and 1 was identified intraoperatively when the fracture was irreducible.

Indication	**n**
Symptomatic/progressive bone cement interface loosening	8
Unreconstructible secondary to comminution	10
Stem subsided into centraliser (likely irreducible)	3
Irreducible intraoperatively	3

Table 2. Patient characteristics by Vancouver fracture classification.

Mean (SD), Median (IQR), number [%]

* One way ANOVA, ** Kruskall Wallace, ^ Chi squared

	Vancouver Classification			
	B1 (n=75)	**B2 (n=53)**	**B3 (n=30)**	**P value**
Age at fracture (yrs)	77.8 (10.2)	78.9 (12.5)	76.6 (11.6)	0.667*
Female Sex	28 [37]	21 [40]	14 [47]	0.256^
Weight (kg)	77.6 (15.3)	77.9 (18.2)	71.1 (15.9)	0.208*
BMI (kg/m^2)	27.4 (4.9)	27.1 (5.0)	25.8 (4.4)	0.367*
Primary surgery				
Age at primary surgery (yrs)	70.9 (9.4)	70.5 (10.7)	69.5 (13.4)	0.989**
Primary implant to fracture (yrs)	3.9 (1.2-8.6)	4.9 (1.1-7.5)	6.6 (1.3-10.9)	0.799**
Primary construct was THA	69 [92]	48 [91]	26 [87]	0.701^
Scottish Index of Multiple Deprivation				
1	11 [15]	7 [13]	5 [17]	0.620^
2	10 [13]	14 [26]	5 [17]	
3	11 [15]	8 [15]	3 [10]	
4	9 [12]	8 [15]	6 [20]	
5	25 [33]	14 [26]	5 [17]	
Comorbidities				
Osteoporosis	15 [20]	14 [26]	6 [20]	0.674^
Diabetes	13 [17]	6 [11]	3 [10]	0.515^
Dementia	14 [19]	16 [30]	3 [10]	0.085^
Steroids	6 [8]	5 [9]	6 [20]	0.161^
Bisphosphonates	11 [15]	7 [13]	5 [17]	0.885^

Table 3. Complications of B2 and B3 fractures by initial operative management strategy.

Mean (SD), Median (IQR), number [%]

*Students T test, **Mann Whitney U test, ^ Chi squared, ^^ Fisher's exact

	All Vancouver Bs (n=152)			Vancouver B1 (n=74)		
	ORIF (n=130)	**Revision (n=22)**	**P value**	**ORIF (n=69)**	**Revision (n=5)**	**P value**
Age at fracture (yrs)	78.1 (10.5)	74.8 (13.6)	0.199*	78.3 (9.9)	75.2 (11.9)	0.504*
Female Sex	54 [42]	7 [32]	0.603^	27 [39]	1 [20]	0.644^^
Weight (kg)	75.4 (16.7)	81.9 (14.4)	0.105*	77.2 (15.5)	82.8 (14.8)	0.444*
BMI (kg/m^2)	26.8 (5.0)	27.9 (4.5)	0.364*	27.3 (4.9)	28.9 (5.8)	0.524*
Primary surgery						
Age at primary surgery (yrs)	71.5 (70.8-85.2)	70 (62.6-85.7)	0.540**	71.5 (70.2-85.2)	71.0 (70.9-84.9)	0.810**
Primary implant to fracture (yrs)	4.4 (1.3-9.2)	1.8 (0.2-7.3)	0.149**	3.9 (1.5-8.6)	1.8 (0.7-5.9)	0.509**
Primary construct was THA	117 [90]	20 [91]	0.975^	63 [91]	5 [100]	0.492^
Time to surgery (days)	3.0 (2.8)	3.0 (2.3)	0.953*	3.0 (2.1)	1.8 (0.8)	0.223*
Length of hospital stay (days)	16 (11-30)	21 (11-29)	0.523**	16.0 (10-29)	27.0 (15-29)	0.719**
Surgical complications						
Blood transfusion	25 [19]	8 [36]	0.043^	13 [19]	2 [4]	0.271^^
Reoperation (any cause)	14 [11]	12 [55]	<0.001^	7 [10]	2 [40]	0.109^^
Multiple reoperations	3 [2]	4 [18]	0.665^^	2 [3]	0	1.0^^
Revision (either component)	10 [8]	10 [45]	<0.001^	6 [9]	2 [40]	0.087^^
Mortality						
1 year	23 [18]	2 [9]	0.768^^	12 [17]	1 [20]	1.0^^
90 day	11 [8]	1 [5]	1.0^^	6 [9]	1 [20]	0.400^^
Medical complications						
VTE	8 [6]	0	0.605^	4 [6]	0	1.0^^
AKI	29 [22]	3 [14]	0.568^^	16 [23]	2 [40]	0.591^^
Delirium	19 [15]	2 [9]	0.739^^	8 [12]	0	1.0^^
Non-orthopaedic sepsis	35 [27]	3 [14]	0.282^^	19 [28]	0	0.318^
Myocardial infarction	3 [2]	0	1.0^^	2 [3]	0	1.0^^
Stroke	1 [1]	0	1.0^^	1 [1]	0	1.0^^
Any	59 [45]	7 [32]	0.224^	30 [43]	2 [40]	1.0^^

Table 4. Complications of B2 and B3 fractures by initial operative management strategy.

Mean (SD), Median (IQR), number [%]

*Students T test, **Mann Whitney U test, ^ Chi squared, ^^ Fisher's exact

	Vancouver B2 (n=50)			Vancouver B3 (n=28)		
	ORIF (n=40)	**Revision (n=10)**	**P value**	**ORIF (n=21)**	**Revision (n=7)**	**P value**
Age at fracture (yrs)	79.1 (11.8)	74.3 (14.4)	0.277*	75.7 (10.1)	75.4 (15.5)	0.950*
Female Sex	18 [45]	2 [20]	0.279^^	9 [43]	4 [57]	0.754^
Weight (kg)	75.7 (18.8)	89.1 (12.7)	0.052*	68.2 (14.6)	70.4 (10.3)	0.745*
BMI (kg/m^2)	26.6 (5.3)	29.6 (3.8)	0.122*	25.5 (4.6)	24.8 (3.6)	0.709*
Primary surgery						
Age at primary surgery (yrs)	75 (73.4-87.3)	62 (60.0-83.2)	0.086**	71 (68.7-82.8)	82 (65.2-85.7)	0.219**
Primary implant to fracture (yrs)	5.2 (1.6-7.5)	0.9 (0.2-12.0)	0.116**	6.6 (1.2-11.1)	3.5 (0.3-10.3)	0.735**
Primary construct was THA	37 [93]	9 [90]	0.794^	17 [81]	6 [86]	0.963^
Time to surgery (days)	3.4 (4.1)	4.0 (3.0)	0.681*	2.4 (1.0)	2.6 (1.4)	0.651*
Length of hospital stay (days)	15 (10-28)	20 (10-29)	0.938**	17 (11-26)	25 (12-36)	0.533**
Surgical complications						
Blood transfusion	8 [19]	4 [40]	0.191^^	4 [19]	2 [28]	0.588^^
Superficial not requiring reop	0	0	-	1 [5]	0	1.0^^
Reoperation (any cause)	4 [10]	6 [60]	0.002^^	4 [19]	4 [57]	0.165^^
Multiple reoperations	1 [2]	3 [30]	0.571^^	1 [5]	1 [14]	1.0^^
Revision	0	4 [40[	0.001^^	3 [14]	4 [57]	0.050^^
Mortality						
1 year	7 [17]	1 [10]	1.0^^	4 [19]	1 [14]	1.0^^
90 day	4 [10]	0	0.576^^	1 [5]	0	1.0^^
Medical complications						
VTE	2 [5]	0	1.0^^	3 [14]	0	0.551^^
AKI	8 [19]	1 [10]	1.0^^	5 [24]	0	0.290^^
Delirium	6 [14]	0	0.576^^	5 [24]	2 [28]	0.633^^
Non-orthopaedic sepsis	13 [31]	2 [20]	0.705^^	3 [14]	1 [14]	1.0^^
Myocardial infarction	1 [2]	0	1.0^^	0	0	-
Stroke	0	0	-	0	0	-
Any	18 [43]	3 [30]	0.721^^	12 [57]	2 [28]	0.385^^

Table 5.
Five year Kaplan Meier survival analysis for ORIF and revision arthroplasty stratified by Vancouver classification.

		ORIF	**Revision Arthroplasty**
Endpoint = reoperation	Any B	91.0 (85.7 to 96.3)	64.3 (42.3 to 86.3)
Endpoint = revision	Any B	91.9 (86.4 to 97.4)	62.5 (41.7 to 83.3)
	B1	90.0 (82.4 to 97.6)	60.0 (17.1 to 100)
	B2	100	66.7 (25.9 to 100)
	B3	76.6 (56.0 to 97.2)	57.1 (20.4 to 93.8)

Table 6. Patients requiring reoperation after initial surgical management with open reduction and internal fixation (ORIF).

Bone cement interface	**Fracture pattern**	**Age**	**Sex**	**Primary implant**	**Fracture surgery**	**MoF**	**Ultimate outcome**
Vancouver B1 fractures							
Fixed	Transverse at stem tip	46	M	THA	ORIF	Non-union	Rev-ORIF
Fixed	Transverse at stem tip	66	F	THA	ORIF	Non-union	PFR
Fixed	Short spiral stem tip	67	F	THA	ORIF	Non-union	Rev-ORIF
Fixed	Short spiral stem tip	75	F			Non-union	PFR
Fixed	Short spiral proximal	80	F	THA	ORIF	Stem loosening	Revision stem (Cemented)
Fixed	Long spiral	87	F	THA	ORIF	Infection	DAIR
Fixed	Transverse at stem tip	88	F	THA	ORIF	Refracture, then non-union	Rev-ORIF
Vancouver B2 fractures							
Fixed	Axe	77	F	THA	ORIF	Infection	DAIR
Fixed	Axe	82	M	THA	ORIF	Dislocation	MUA
Fixed	Short spiral	91	F	Hemi	ORIF	Refracture	Re-ORIF
Vancouver B3 fractures							
Fixed	Short oblique stem tip	58	M	THA	ORIF	Non-union	Re-ORIF
Fixed	Axe	68	M	THA	ORIF	Stem loosening	Revision (fluted tapered stem)
Loose	Short oblique stem tip	73	M	THA	ORIF	Non-union	Revision (fluted tapered stem)
Loose	Short oblique stem tip	93	F	THA	ORIF	Dislocation	Revision (Captive cup)

MoF = mode of failure; Hemi = hemiarthroplasty; THA = total hip arthroplasty; MUA – manipulation under anaesthetic; DAIR – debridement and implant retention; PFR – proximal femoral replacement.

Table 7. Patients requiring reoperation after initial surgical management with revision arthroplasty

Bone cement interface	Fracture pattern	Age	Sex	Primary implant	Fracture surgery	MoF	Ultimate outcome
Vancouver B1 fractures							
Fixed	Long spiral	70	M	THA	Rev PFR and bipolar head	Dislocation	Revision (captive cup)
Fixed	Short spiral	86	M	THA	Revision Fluted tapered stem	Dislocation	Revision (both components)
Vancouver B2 fractures							
Fixed	Long spiral	76	F	THA	Rev CIC Stem & ORIF	Dislocation and then refracture	MUA then ORIF
Fixed	Axe	62	M	THA	Revision Fluted tapered stem	Refracture	ORIF
Fixed	Axe	72	F	THA	Revision Fluted tapered stem	Dislocation	Revision (Captive cup)
Fixed	Axe	62	M	THA	Revision Fluted tapered stem	Infection	Revision (2 stage)
Loose	Short spiral	75	M	THA	Revision Fluted tapered stem	Dislocation	Revision (Captive cup)
Loose	Axe	58	M	THA	Revision Fluted tapered stem	Stem fracture	Revision (fluted tapered stem)
Vancouver B3 fractures							
Loose	Short oblique stem tip	83	M	Hemi	Rev CIC Stem & ORIF	Non-union	Revision PFR
Fixed	Axe	82	M	THA	Revision PFR	Dislocation	Revision (Captive cup)
Loose	Short oblique stem tip	88	F	THA	Revision PFR	Dislocation	Revision (Captive cup)
Loose	Short oblique stem tip	44	F	THA	Revision Fluted tapered stem; cemented cup	Infection	Revision (2 stage)

THA – total hip arthroplasty; Hemi – hemiarthroplasty; ORIF – open reduction and internal fixation; CIC = cement in cement stem revision; MUA – manipulation under anaesthetic; DAIR – debridement and implant retention; PFR – proximal femoral replacement.

Table 8.
Cox logistic regression analysis to identify risk factors for revision following ORIF of Vancouver B type periprosthetic femoral fractures,

Covariate	**Hazard Ratio (95% CI)**	**p value**
Female sex	0.26 (0.02 to 3.19)	0.307
BMI	0.85 (0.67 to 1.09)	0.200
Age at primary implant	0.43 (0.11 to 1.72)	0.231
Age at fracture	2.2 (0.57 to 8.73)	0.251
Time between primary and fracture	0.34 (0.06 to 1.79)	0.201
Vancouver B2 (n=30)	0.080 (0.06 to 10.97)	0.865
Vancouver B3 (n=14)	0.00	0.924
Osteoporosis	0.39 (0.02 to 6.62)	0.517
Dorr type B	0.00	0.961
Dorr type C	0.00	0.982
Radiographic bone cement interface loosening	0.00	0.939
Transverse/short oblique fracture	0.19 (0.005 to 6.44)	0.353

Figure Legends

Figure 1. Fixation of a Vancouver B2 periprosthetic fracture using cerclage cables and a non-locked 4.5mm plate. Proximally screws are directed anterior and posterior to the stem through the cement mantle. The fracture has united.

Figure 2. Revision arthroplasty
a) Employing cement in cement long stem revision with cerclage cables to treat a Vancouver B2 fracture. A captive was used as this THA had dislocated once prior to fracture.

b) Employing an uncemented tapered fluted stem to treat a Vancouver B2 fracture. This was complicated by subsequent stem fracture from cantilever bending. Previous cement in the proximal fragments may affect proximal osteointegration of uncemented implants.

Figure 3. Study cohort.

Figure 4. Trends in Vancouver B periprosthetic femoral fractures over the study period 2008-2016.

Figure 5. Fracture patterns of Vancouver B type fractures involving the Exeter stem (n=158). Proximal spiral fractures were not comminuted or had medial or lateral proximal cortices in continuity with the diaphysis. In comminuted proximal fractures medial and lateral fragments were discontinuous with each other and with the diaphysis.

Figure 6. Kaplan Meier survival plots for all Vancouver B type fractures operatively managed with initial ORIF or revision arthroplasty with the endpoints a) revision of ≥1 component (Log rank p<0.001) and b) any reoperation (Log rank p<0.001).

Figure 7. Kaplan Meier survival plots (endpoint revision of ≥1 component) for each Vancouver B fracture type according to operative management strategy. Survival was significantly greater (Log rank p<0.001) following ORIF for types B1, B2 and B3.

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