Fracture fixation versus revision arthroplasty in Vancouver type B2 and B3 periprosthetic femoral fractures: a systematic review

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Abstract

Introduction Hip arthroplasty (HA) is commonly performed to treat various hip pathologies. Its volume is expected to rise further due to the increasing age of the population. Complication rates are low; however, periprosthetic femoral fractures (PFF) are a rare, albeit serious, complication with substantial economic impact. While current guidelines propose revision with long-stemmed prostheses for all Vancouver B2 and B3 PFF, some recent research papers suggest that open reduction with internal fixation (ORIF) could lead to an equivalent outcome. Our aim was to summarize the evidence, elucidating under which circumstances ORIF leads to a favorable outcome after B2 and B3 PFF compared with revision surgery.

Materials and methods A systematic literature search was performed to identify studies on patients treated with ORIF and with stem revision after B2 and/or B3 fractures. Extracted information included initial pathology, stem fixation mechanism, bone quality and stem stability at the time of PFF, clinical outcomes, and mortality. Results of individual studies were summarized in a table in lieu of a quantitative data synthesis due to a lack of standardized information.

Results We identified 14 original research articles including both patients treated with ORIF and with stem revision after B2 and/or B3 fractures. Five studies included statistical comparisons, all were in favor of ORIF or indeterminate. The common lack of rigorous statistical analyses and significant methodological weaknesses made identification of outcome predictors impossible.

Conclusion The choice of treatment modality for PFF depends on fracture, implant, and bone characteristics. Recent data show that successful outcome can be achieved without revising loose stems. ORIF may be a viable option if bone stock is adequate around uncemented or tapered polished stems with an intact cement mantle and the fracture geometry allows stable anatomic reconstruction. Conceptional considerations support this idea, but more data are needed to identify outcome predictors.

Keywords Periprosthetic fracture · Femoral fracture · Hip arthroplasty · Review · Aged patients · Vancouver classification

Introduction

Hip arthroplasty and periprosthetic femoral fractures

Hip arthroplasty (HA) is a commonly performed successful procedure used to treat various hip pathologies. Due to the general aging of the population and increased lifestyle demands, the number of people receiving hip replacements is expected to further rise in the future. The United Nations’ 2017 report on World Population Prospects states “In Europe, 25% of the population is already aged 60 years or over and that proportion is projected to reach 35% in 2050, while in Northern America it will go from 22 to 28%” [1].

In general, complication rates for HA are low. However, periprosthetic femoral fractures (PFF) are a rare, but
serious complication, that often occurs many years after the initial surgery. In the majority of patients, they are caused by minor trauma [2–5]. The risk to undergo revision surgery due to a PFF has been shown to increase with age, which becomes more evident in geriatric patients [6, 7]. Based on age being a major risk factor for osteoporosis and osteoporosis being a major risk factor for sustaining hip fractures [8], it is not surprising that the incidence of periprosthetic fractures around hip implants has steadily increased over the past few decades. The National Joint Registry of England and Wales reported a 1.5- and 1.6-fold increase in periprosthetic fractures around hybrid and cemented hip prosthesis respectively between 2011 [9] and 2016 [10] alone, while it remained stable for uncemented HAs.

Given the continual increase in volume of hip replacements performed and the lag between primary hip surgery and fracture, the number of periprosthetic fractures is expected to increase further in the years to come. The economic impact that arises from PFF is significant: Figures from the United Kingdom generated between 1999 and 2009 suggest that the average cost generated by a PFF amounts to £23,469 per patient [11].

Treatment of PFF

Treatment of PFF is usually demanding, complication rates are high, and often the prognosis concerning outcomes and mortality is bad [5, 12]. The choice of the treatment modality depends on fracture characteristics, implant stability, the quality of the surrounding bone, and the presence of infection [13–15].

The Vancouver classification is currently the most commonly used classification for PFF after HA and provides distinct treatment recommendations. It divides PFF into three classes: A, B and C. Type A fractures are confined to the greater (A_G) or lesser (A_L) trochanter. Type B fractures are diaphyseal, around the prosthesis or immediately distal to it, and are divided into three subtypes: B1, B2 and B3, characterized by a well-fixed stem, an unstable or loose stem with good quality of the surrounding bone stock, and an unstable or loose stem with inadequate surrounding bone stock, respectively [13]. Type C fractures are well below the tip of the prosthesis. According to the authors of the Vancouver classification, “type A fractures may be treated either conservatively or surgically, depending on the stability of the fracture. Type B1 fractures are best treated using ORIF or the bicortical onlay allograft technique. Type B2 fractures are best treated using long-stem revision total HA. Type B3 fractures usually require complex reconstruction. Type C fractures are best treated using ORIF” [13].

Current treatment recommendations under debate

Recently, a debate around the necessity to strictly follow those recommendations for some fracture types has been raised. Several authors have argued that under certain conditions, B2 or B3 fractures could also be treated successfully with ORIF or ORIF combined with cement-in-cement revision [16–18].

Quah et al. have proposed a treatment algorithm where, in the presence of good bone stock, the potential to reduce the fracture anatomically as well as the integrity of the cement mantle rather than the stability of the prosthesis alone, are the major determinants for the treatment decision [18]. According to this algorithm, ORIF is an option for B2 fractures that can be reduced anatomically. Additionally, they point out that in cases where the cement is well fixed at the cement–bone interface, cement-in-cement revision could also reduce surgical time and better preserve the existing bone stock [17, 18].

The conception that ORIF could be advantageous in PFF around certain loose stems is supported by several reports where ORIF was compared to stem revision in B2 and/or B3 fractures and resulted in equivalent, if not better, outcomes [5, 16, 19–27].

To date, there is no publication that summarizes the factors determining the outcome after ORIF or revision arthroplasty in the treatment of B2 or B3 fractures based on clinical evidence. Therefore, we performed a systematic literature search with the aim to identify articles that provide sufficient information on potential prognostic factors for favorable or unfavorable outcome in the treatment of Vancouver B2 and B3 fractures.

Materials and methods

Search strategy

Systematic literature searches were conducted in Web of Science (WoS), Medline and the Cochrane databases in April 2017 and updated in February 2018 (Table 1).

Study selection

Publications were deemed eligible if they were original research articles that included both patients treated with ORIF and patients treated with stem revision after a Vancouver B2 or B3 fractures and were published 1999 or later. In the case of mixed study populations (including Vancouver classifications other than B2 and B3 fractures), information on B2/B3 fractures had to be reported separately for both
treatment groups to allow data extraction. Abstracts were only included if they presented sufficient numerical information to extract relevant data.

Additionally, the references of relevant review articles [12, 14, 18, 28, 29] were screened for further eligible studies.

Data extraction and analysis

Information was collected on a standardized data extraction form and included the initial diagnosis for hip replacement, fixation parameters of the originally implanted stem (primary/revision, uncemented/cemented incl. fixation mechanism, e.g., cemented collarless polished tapered [CCPT]/composite beam [CB]), information on bone quality and stem stability at the time of PFF, and outcome parameters (e.g., union rate, functional outcome, complications, re-operations, mortality). Bearing in mind that our research question concerned explicitly B2 and B3 type fractures, relevant data were extracted specifically for B2 and B3 fractures, but not for other types of PFF.

Data analysis

Depending on the type of information presented in the eligible publications, outcome data were collated stratified for treatment, i.e., ORIF and revision arthroplasty, as well as for the fracture types B2 and B3 separately. If needed, data from the publications were recalculated to facilitate presenting the desired stratifications. However, since the data presented in the eligible publications were scarce concerning prognostic factors and diverse concerning outcomes, it was not possible to quantitatively analyze summary data beyond the descriptive information in Table 2.

Results

Our systematic search identified 14 original studies that included patients treated with ORIF and patients treated with revision arthroplasty in the treatment of B2 and B3 PFF [5, 16, 19–27, 30–32]. The publications were mainly retrospective cohort studies which did not describe the treatment allocation, provided little information about potential predictive factors and presented diverse outcome parameters. Additionally, in most studies, the group sizes were small so that no statistical tests were performed. Table 2 provides an overview about the eligible studies including relevant outcomes and potential predictors.

Prognostic factors

Only a handful of publications provided information about the most likely prognostic factors such as type of the original stem, initial indication for THA, or implants used to treat the PFF, which have been shown to be important outcome predictors [29]. Therefore, it was not possible to quantitatively analyze these potential prognostic factors.

Eight studies presented information on whether the PFF occurred around primary or around revision hip stems [5, 16, 22–25, 27, 31], eight presented the information whether the stem was cemented or uncemented [5, 16, 22, 24, 25, 27, 30, 31], three provided information about the fixation mechanism of the cemented stem (CCPT or CB) or the stem’s brand name for the respective treatment group [16, 22, 27], three informed about the diagnosis that had led to the initial hip replacement [22, 27, 31] and 7 provided details about the implants used for ORIF [16, 20, 22–25, 30]. One study presented some of the aforementioned parameters for some of the PFF types but did not follow a consistent pattern in doing so [26].

In addition to the assessment of bone quality and stem stability inherent to the Vancouver classification (B2: unstable or loose stem with good quality of the surrounding bone stock, B3: unstable or loose stem with inadequate surrounding bone stock), one study classified the bone quality around B3 fractures according to Paprosky [5]. In this study no ORIF was used to treat B3 fractures.

Outcome parameters

Since the reported outcome measures were diverse, it was not possible to summarize them quantitatively. Some studies
| Pub year | Authors                  | Vancouver classification | Initial diagnosis | Fixation type | Implant information for complete cohort | Outcomes: hospital and surgery parameters | Complications and reoperations (for B2B3) | Survival | In favor of |
|----------|--------------------------|--------------------------|------------------|---------------|----------------------------------------|-----------------------------------------|------------------------------------------|----------|------------|
| 2006     | Lindahl et al.           | B2: 90 B3: 34 C: 31     | Not available    | Cemented Composite Beam (CCPT) or polished taper (CCP) | No available                           | Not available                           | Not available                            | 0        |            |
|          |                          |                          | 76% of the cohort | Unreamed proximal or distal fixation Both: primary or revision implant |                     |                                      |                                         |          |            |
|          |                          |                          |                  |               |                                       |                                        |                                         |          |            |
| 2010     | Zuurmond et al.          | A: 3 B1: 14 B2: 26 B3: 7 C: 21 | Total 71 patients | Primary osteoarthritis (71%) Fracture (15%) | 70% of the cohort used CB and CCPT stems | Not available                           | Not available                            | 0        |            |
|          |                          |                          |                  |               |                                       |                                        | Complications not provided separately for treatment groups | 0        |            |
|          |                          |                          |                  |               |                                       |                                        | Reoperations in B2 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | ORIF: 6/19 (32%) Revision + ORIF: 20/86 (25%) | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | Revision: 5/4 (10%) Reoperations in B3 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | ORIF: 0/0 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | Revision: 3/2 (13%) | 0/0 | 0/0 |

Table 2: Potential predictors and outcomes in the treatment of B2 and B3 periprosthetic fractures with osteosynthesis or a revision stem

| Pub year | Authors                  | Vancouver classification | Initial diagnosis | Fixation type | Implant information for complete cohort | Outcomes: hospital and surgery parameters | Complications and reoperations (for B2B3) | Survival | In favor of |
|----------|--------------------------|--------------------------|------------------|---------------|----------------------------------------|-----------------------------------------|------------------------------------------|----------|------------|
| 2006     | Lindahl et al.           | B2: 90 B3: 34 C: 31     | Not available    | Cemented Composite Beam (CCPT) or polished taper (CCP) | No available                           | Not available                           | Not available                            | 0        |            |
|          |                          |                          | 76% of the cohort | Unreamed proximal or distal fixation Both: primary or revision implant |                     |                                      |                                         |          |            |
|          |                          |                          |                  |               |                                       |                                        |                                         |          |            |
| 2010     | Zuurmond et al.          | A: 3 B1: 14 B2: 26 B3: 7 C: 21 | Total 71 patients | Primary osteoarthritis (71%) Fracture (15%) | 70% of the cohort used CB and CCPT stems | Not available                           | Not available                            | 0        |            |
|          |                          |                          |                  |               |                                       |                                        | Complications not provided separately for treatment groups | 0        |            |
|          |                          |                          |                  |               |                                       |                                        | Reoperations in B2 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | ORIF: 6/19 (32%) Revision + ORIF: 20/86 (25%) | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | Revision: 5/4 (10%) Reoperations in B3 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | ORIF: 0/0 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | Revision: 3/2 (13%) | 0/0 | 0/0 |

Table 2: Potential predictors and outcomes in the treatment of B2 and B3 periprosthetic fractures with osteosynthesis or a revision stem

| Pub year | Authors                  | Vancouver classification | Initial diagnosis | Fixation type | Implant information for complete cohort | Outcomes: hospital and surgery parameters | Complications and reoperations (for B2B3) | Survival | In favor of |
|----------|--------------------------|--------------------------|------------------|---------------|----------------------------------------|-----------------------------------------|------------------------------------------|----------|------------|
| 2006     | Lindahl et al.           | B2: 90 B3: 34 C: 31     | Not available    | Cemented Composite Beam (CCPT) or polished taper (CCP) | No available                           | Not available                           | Not available                            | 0        |            |
|          |                          |                          | 76% of the cohort | Unreamed proximal or distal fixation Both: primary or revision implant |                     |                                      |                                         |          |            |
|          |                          |                          |                  |               |                                       |                                        |                                         |          |            |
| 2010     | Zuurmond et al.          | A: 3 B1: 14 B2: 26 B3: 7 C: 21 | Total 71 patients | Primary osteoarthritis (71%) Fracture (15%) | 70% of the cohort used CB and CCPT stems | Not available                           | Not available                            | 0        |            |
|          |                          |                          |                  |               |                                       |                                        | Complications not provided separately for treatment groups | 0        |            |
|          |                          |                          |                  |               |                                       |                                        | Reoperations in B2 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | ORIF: 6/19 (32%) Revision + ORIF: 20/86 (25%) | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | Revision: 5/4 (10%) Reoperations in B3 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | ORIF: 0/0 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | Revision: 3/2 (13%) | 0/0 | 0/0 |

Table 2: Potential predictors and outcomes in the treatment of B2 and B3 periprosthetic fractures with osteosynthesis or a revision stem

| Pub year | Authors                  | Vancouver classification | Initial diagnosis | Fixation type | Implant information for complete cohort | Outcomes: hospital and surgery parameters | Complications and reoperations (for B2B3) | Survival | In favor of |
|----------|--------------------------|--------------------------|------------------|---------------|----------------------------------------|-----------------------------------------|------------------------------------------|----------|------------|
| 2006     | Lindahl et al.           | B2: 90 B3: 34 C: 31     | Not available    | Cemented Composite Beam (CCPT) or polished taper (CCP) | No available                           | Not available                           | Not available                            | 0        |            |
|          |                          |                          | 76% of the cohort | Unreamed proximal or distal fixation Both: primary or revision implant |                     |                                      |                                         |          |            |
|          |                          |                          |                  |               |                                       |                                        |                                         |          |            |
| 2010     | Zuurmond et al.          | A: 3 B1: 14 B2: 26 B3: 7 C: 21 | Total 71 patients | Primary osteoarthritis (71%) Fracture (15%) | 70% of the cohort used CB and CCPT stems | Not available                           | Not available                            | 0        |            |
|          |                          |                          |                  |               |                                       |                                        | Complications not provided separately for treatment groups | 0        |            |
|          |                          |                          |                  |               |                                       |                                        | Reoperations in B2 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | ORIF: 6/19 (32%) Revision + ORIF: 20/86 (25%) | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | Revision: 5/4 (10%) Reoperations in B3 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | ORIF: 0/0 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | Revision: 3/2 (13%) | 0/0 | 0/0 |

Table 2: Potential predictors and outcomes in the treatment of B2 and B3 periprosthetic fractures with osteosynthesis or a revision stem

| Pub year | Authors                  | Vancouver classification | Initial diagnosis | Fixation type | Implant information for complete cohort | Outcomes: hospital and surgery parameters | Complications and reoperations (for B2B3) | Survival | In favor of |
|----------|--------------------------|--------------------------|------------------|---------------|----------------------------------------|-----------------------------------------|------------------------------------------|----------|------------|
| 2006     | Lindahl et al.           | B2: 90 B3: 34 C: 31     | Not available    | Cemented Composite Beam (CCPT) or polished taper (CCP) | No available                           | Not available                           | Not available                            | 0        |            |
|          |                          |                          | 76% of the cohort | Unreamed proximal or distal fixation Both: primary or revision implant |                     |                                      |                                         |          |            |
|          |                          |                          |                  |               |                                       |                                        |                                         |          |            |
| 2010     | Zuurmond et al.          | A: 3 B1: 14 B2: 26 B3: 7 C: 21 | Total 71 patients | Primary osteoarthritis (71%) Fracture (15%) | 70% of the cohort used CB and CCPT stems | Not available                           | Not available                            | 0        |            |
|          |                          |                          |                  |               |                                       |                                        | Complications not provided separately for treatment groups | 0        |            |
|          |                          |                          |                  |               |                                       |                                        | Reoperations in B2 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | ORIF: 6/19 (32%) Revision + ORIF: 20/86 (25%) | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | Revision: 5/4 (10%) Reoperations in B3 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | ORIF: 0/0 | 0/0 | 0/0 |
|          |                          |                          |                  |               |                                       |                                        | Revision: 3/2 (13%) | 0/0 | 0/0 |
| Pub year | Authors | Arthroplasty type, bone quality/Vancouver classification | Treatment group (whole group: B2 and B3 fractures), implant details | Outcomes: hospital and surgery parameters | Outcomes: union rate and radiological outcome | Outcomes: functional outcome, mobility, disability | Complications and reoperations (for B2/B3) | Survival | In favor of |
|----------|---------|-------------------------------------------------------|-----------------------------------------------------------------|----------------------------------|---------------------------------------|-----------------------------------------------|---------------------------------------------|-----------|----------|
| 2011     | Pavlou et al. | A: 4 B1: 15 B2: 66 B3: 106 C: 11 All THA | Not available | No further information available | No further outcomes stratified for treatment (ORIF/revision) available | No further outcomes stratified for treatment (ORIF/revision) available | ORIF B2 grafting 1.0 B2 no grafting 4.6 B3 no grafting 1.5 Stem revision 1.6 ORIF B2 grafting 2.2 B3 grafting 6.1 B3 no grafting 1.9 ORIF vs B2 stem revision and graft. OR 17.3, 95% CI 1.63-184.4, p=0.018 | No available | Union rate and complications (infections and dislocations) small n.s. randomization, however patient numbers are very small |
| 2013     | Montalti et al. | A1: 3 PPFx Ag: 2 B1: 10 B2: 13 B3: 16 C: 3 PPFx after primary THA: 3 patients Cemented THA: 2 Cemented THA: 26 Hybrid THA: 64 Hybrid THA: 3 (Note: unclear why the total isn't 111) | Osteoarthritis: 31 Femoral neck fracture: 6 Osteoarthritis secondary to developmental hip dysplasia: 4 Post-traumatic osteoarthritis: 4 Femoral head osteonecrosis: 2 | No further information on the fixation mechanism available | No available | No available | No available | B3 Dislocation: 1 (?) Stem breakage: 1 (?) Aseptic loosening: 1 PPF: 1 B2 Dislocation: 1 Stem breakage: 0 Aseptic loosening: 1 PPF: 1 C Aseptic loosening: 1 Inter-op PPF: 1 | No available | Union rate and complications (infections and dislocations) small n.s. trend in favor of revision, however patient numbers are very small |
| Pub year | Authors | Arthroplasty type: bone quality/Vancouver classification | Initial diagnosis | Fixation type: Cemented: Composite Beam (CB) or polished taper (CCPT) Un cemented: proximal or distal fixation Both: primary or revision implant | Number of patients per treatment group (whole group, B2 and B3 fractures), implant details | Outcomes: hospital and surgery parameters | Outcomes: union rate and radiological outcome | Outcomes: functional outcome, mobility, disability | Complications and complications (for B2/B3) | Survival | In favor of |
|----------|---------|-----------------------------------------------------|------------------|---------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-----------------------------------------------|-----------------|----------------|
| 2014     | Niikura et al | Ag: 1  B1: 6  B2: 6 (1 of these treated conservatively) C: 6  THA or HA, not known for which pts Not known whether first HA or already revision | Not available | No information on fixation mechanism available | **Total group:** ORIF: 13  Stem revision: 2  Conservative: 3  B2 and B3 fractures: B2 fractures in 6 patients: ORIF: 3  Non on LCP: 2  Reversed LCP-DF: 1  Stem revision: 2  Cementless longer stem: 1  Conservative treatment: 1  **Surgery time for B2:** ORIF: mean 152.6 min 245 min: 1  77 min: 1  182 min: 1  Stem revision: mean 144 min 138 min: 1  130 min: 1  **Intraoperative bleeding:** ORIF: mean 300 g 615 g: 1 (4 units blood transf) 135 g: 1  405 g: 1  Stem revision: mean 1923 g 535 g: 1 (2 units autol. blood transf) 2470 g: 1 (12 units blood transf) | Bony union in all patients | **Halo Mobility Score for B2 only:** ORIF 1 pt: Before fx 5, latest fu 5 1 pt: Before fx 1, latest fu 1 1 pt: Before fx 0, latest fu 0  **Stem revision:** 1 pt: Before fx 9, latest fu 9 1 pt: Before fx 3, latest fx 3  **Ambulatory status:** ORIF 1 pt: Before fx crutch, latest fu crutch 2 pts: Before fx non-ambulatory, latest fu non-ambulatory  **Stem revision:** 1 pt: Before fx no aids, latest fu no aids 1 pt: Before fx walker, latest fx walker  **Social status:** ORIF 1 pt: Before fx independent, latest fu independent 1 pt: Before fx with support, latest fx with support 1 pt: Before fx nursing home, latest living at home  **Stem revision:** 2 pts: Before fx independent, latest fx independent | No infection (no further information given) | All patients with B2 and B3 survived (2 cases of “early postoperative mortality”) 3 m and 5 m post-op, both type C | N.s. trend that blood loss was less in ORIF |
### Table 2 (continued)

| Pub year | Authors | Arthroplasty type, bone quality/Vancouver classification | Initial diagnosis | Fixation type | Cemented: Composite Beam (CB) or polished taper (CCPT) | Uncemented: proximal or distal fixation | Both: primary or revision implant | Number of patients per treatment group (whole group, B2 and B3 fractures), implant details | Outcomes: hospital and surgery parameters | Outcomes: union rate and radiological outcome | Outcomes: functional outcome, mobility, disability | Complications and reoperations (for B2B3) | Survival | In favor of |
|----------|---------|--------------------------------------------------------|-------------------|--------------|------------------------------------------------|------------------------------------------|---------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|-----------|-----------|
| 2014     | Spina et al. | Ag: 1 | B1: 30 | R2: 7 | B3: 11 | C: 12 | B2: Straight stem: 4 (+ 1 excluded) | B2: Anatomic stem: 2 | Not known for B3 | Not known whether first HA or already revision | Not available | No information on fixation mechanism available | Complete group: ORIF: 54 | Revision: 7 | B2 and B3 fractures: ORIF: 10 (+ 2 not included because of short FU): B2: 7 (+ 1) | B3: 3 (+ 1) | Revision: B3: 7 | Not available | Fracture consolidation and implant stability at the end of treatment | ORIF: B2/straight stemplate: 4 | B2/anatomic stemplate: 1 | B2/anatomic/cables: 0 | B3/NA/plate: 0 | Stem revision: B3: 7 | Functional outcomes | ORIF: Walker:2, crutches:3, sick:1, walking free | B2/anatomic stemplate: 0 | B2/anatomic/cables: 0 | B3/NA/plate: 0 | Stem revision: B3: 3 (2) | Complications (pts) | ORIF: B2/straight stemplate: 1 (1) | B2/anatomic stemplate: 3 (2) | B2/anatomic/cables: 0 (0) | B3/NA/plate: 0 (0) | Stem revision: B3: 2 (2) | Information only available for the complete cohort: 1-year survival: 96.7% | 2-year survival: 88.5% | No information in favor of ORIF or revision in B2 or B3 fractures available since treatment groups are too small (B3) or no comparison group (B2) is available |
| 2015     | Inngul and Enokson | B1: 23 | R2: 25 | B3: 1 | C: 14 | Number of HA/THA not provided for B2 and B3 PPF | Non-pathological femoral neck fracture | Number of primary-revision not provided for PPF | CCPT only | Complete group: ORIF: 44 | Single lateral plate with screws: 25 | Screws in combination with cerclage wires: 19 | Revision: B9 | Longer cemented stem: 10 | Longer cemented stem and lateral plate: 2 | Distally thinned uncemented revision stem: 7 | B2: ORIF: 9 | Revision: 16 | B1 | ORIF: 0 | Revision: 1 | No outcome for B2 B3 provided | Not available | Complications other than those re-operated upon not provided | Reoperations in B2: ORIF: 29 (1 re-fracture, 1 non-union) | Revision: 1/16 (1 re-fracture) | Reoperations in B3: 0 | Survival not provided separately for B2 and B3 | No reliable information in favor of ORIF or revision in B2 or B3 fractures available due to missing information and small sample. Possibly a trend for less reoperations in stem revision |
Significantly in favor of ORIF for OR time, skin-to-skin time, blood transfusions.

N.s. trend in favor of ORIF for Harris pain score and for mobility in favor of revision (but mean pt age 9 years less and 1 pt evaluated directly after knee replacement).

N.s. trend for complications in favor of ORIF.

7/9 All 5 deaths occurred:

- Stems revision: 9/12
- ORIF: 1

However patient numbers within the first 3 months, before fx healing:

3 pts had an ASA score of 4 and 2 pts had an ASA score of 3 (ORIF n = 12).

Complications:

- Episode of 2 dislocations, to hip surgery 4 yrs post-op: 1 pt
- Delayed wound healing:
  - Stem revision (n = 2 pts)

Reoperations:

- None mentioned
- Reoperations in B2: 21
  - ORIF: 12 (all primary THA)
  - Stems revision: 9 (7 primary, 2 revision THA)
- B3: 209 min (41)
- ORIF: 122 min (26)
- Stems revision: 183 min (SD): 143-239

Surgery time:

- ORIF: B2 (n = 16): mean (SD): 122 min (SD), range 80-165
- B3 (n = 1): 90 min
- ORIF and stem revision: B2 (n = 7): mean (SD): 209 min (41), range 165-274
- B3 (n = 1): 185 min

Blood loss:

- ORIF: B2 (n = 16): mean (SD): 454 mL (159)
- B3 (n = 1): 250 mL
- ORIF and stem revision: B2 (n = 7): mean (SD): 667 mL (377)
- B3 (n = 1): 750 mL

Opening bone time (p = 0.052)

- ORIF: Median (range): 180 min (143-239)
- Stem revision: Median (range): 270 min (206-352)
- Site-sel. approach time (p = 0.012): Median (range): 122 min (81-165)

Union achieved in all patients.

Surgery time and blood loss in seemingly in favor of ORIF; however patient numbers are small.
Table 2 (continued)

| Pub year | Authors | Arthroplasty type, bone quality/Vancouver classification | Initial diagnosis | Fixation type | Cemented Composite Beam (CCB) or polished taper (CCPT) | Number of patients per treatment group (whole group, B2 and B3 fractures), implant details | Outcomes: hospital and surgery parameters | Outcomes: union rate and radiological outcome | Outcomes: functional outcome, mobility, disability | Complications and reoperations (for B2B3) | Survival | In favor of |
|----------|---------|--------------------------------------------------------|-------------------|---------------|------------------------------------------------------|------------------------------------------------------------------------------------------|---------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|---------|----------|
| 2016     | Joestl et al. | B2: 36 (Revision THA: 2  Primary THA: 3 4) | Not available | No information on fixation mechanism available | ORIF: 8 4.5 mm LC | 28 Screw revision (non-concurrent) | Not available | Parker Mobility Score | Not available | Complication rate: ORIF vs. ORIF | Not available | N.s. trends in favor of ORIF for surgery time, blood units needed and number of patients returning to pre-injury activity level, however patient numbers are small |
| 2017     | Antoniadis et al. | B2 | Not available | No information on fixation mechanism available | Revision: 26 ORIF: 27 | Surgical time | Not available | Odds ratio for having a complication, revision group: 2.489 (95% CI 0.6705–10.02) | Not available | Trends in favor of ORIF for complications and mortality |
| 2017     | Baum et al. | B2: 57 (THA: 53  HHA: 4) | Not available | No information on fixation mechanism available | Revision: 36 ORIF (LCP): 21 | Length of hospital stay | Non-union ORIF (n = 21): 1  Revision (n = 30): 8 | Odds ratio of dying within first 12 months: 6.350–57.15 after stem revision | Not available | Surgical time and blood loss significantly in favor of ORIF |
|          |          | | | | | | | | | | N.s. trend in favor of ORIF for complications and mortality |
| Pub year | Authors | Arthroplasty type, bone quality/Vancouver classification | Initial diagnosis | Fixation type | Cemented: Composite Beam (CB) or polished taper (CCPT) | Uncemented: proximal or distal fixation | Both: primary or revision implant | Number of patients per treatment group (whole group, B2 and B3 fractures), implant details | Outcomes: hospital and surgery parameters | Outcomes: union rate and radiological outcome | Outcomes: functional outcome, mobility, disability | Complications and reoperations (for B2B3) | Survival | In favor of |
|----------|---------|------------------------------------------------------|------------------|--------------|----------------|----------------|----------------|--------------------------------|----------------|--------------------------------|----------------|----------------|-------------------------|-----------------|----------------|----------------|
| 2017     | Bulatovic et al. | B1: 10 cemented: 8 uncemented: 2 | B2: 10 cemented: 7 uncemented: 3 | B3: cemented: 3 | Not available | No information on fixation mechanism available | R1 LCP: 6 DCP: 3 wire cerclage: 1 (Complication: Atrapico) B2 LCP: 3 DCP: 2 Long stem: 1 cerclage: 2 B3 LCP: 2 Long stem: 1 | Not available | Not available | Modified Merle d'Aubigné score: B2: 10.6 (bad) B3: 12.0 (fair) | Broken plate/re-op: 1 Pressure ulcers on skin: 1 Broken LCP/re-op: 1 Deep vein thrombosis: 1 | B2 DCP Broken plate/re-op: 1 Superficial wound infection: 1 B2 cerclage Wound infection and ulcer on the skin: 1 Death: 1 (after 1 yr) B3 LCP Broken plate/re-op: 1 (at 3 mo) Superficial wound infection: 1 | Not available | No reliable information in favor of ORIF or revision in B2 or B3 fractures available due to missing information and small sample (revision only in 1 patient each in B2 and B3) |
| 2017     | Gitajn et al. | B1: 82 | B2: 96 | B3: 25 | Not available | No information on fixation mechanism available | Complete group: ORIF: 110 Revision arthroplasty: 93 B2 and B3 combined: ORIF: 42 Revision: 79 Implants not known | R2 and R3 combined ORIF: estimated blood loss (EBL): 595 cc (499) No blood units transfused: 2 R2 and R3 combined Revision THA: EBL: 146 cc (90) No blood units transfused: 5.0 (3.5) | Not available | Weight bearing instructions (B2 and R3 combined): ORIF: NWB (no): 2 TDWB (touch down): 24 PWB (partial): 24 WBAT (as tolerated): 24 Revision THA: NWB: 1 TDWB: 14 PWB: 16 WBAT: 48 | No information provided for complications of R3B3 | B2 and R3 combined: Survival in patients treated with surgical fixation compared to revision arthroplasty: No difference at 1 year (80% vs. 85%, p=0.36) or 5 years (41% vs. 58%, p=0.11) | Blood loss and blood transfusions in favor of ORIF. Postoperative weight bearing instructions in favor of revision | No difference in survival |

a Known as loose beforehand, scheduled for revision
b Recognition of loose at presentation
focused on mobility [16, 23–27, 30] as measured with various instruments, whereas other studies focused on union rates [16, 20, 23, 24, 26, 27, 32], reoperation rates [5, 19, 21–23, 30, 32], mortality [21, 22, 25, 26], or on perioperative parameters [16, 19–21, 23–25], including various combinations of these outcomes.

**Success of treatment modality**

Only five studies used statistical tests to compare the results of ORIF vs. stem revision in B2 or B3 fractures. Solomon et al. compared ORIF to stem revision in 21 patients whose initial stem was a CCPT stem and who had sustained B2 fractures. The results were significantly in favor of ORIF for surgical time and the need for blood transfusions. There were also non-significant (n.s.) trends in favor of ORIF for the Harris pain score and complications as well as n.s. trends in favor of revision surgery for mobility. However, the authors pointed out that the mean age in the revision group was 9 years higher and that one of the nine patients in the revision group had been evaluated for mobility directly after having received a knee replacement to explain the latter trend [16]. Antoniadis et al. compared results of ORIF to stem revision in 53 patients who had sustained B2 fractures with an unknown fixation type of the initial stem. They found results significantly in favor of ORIF for surgical time and blood loss along with n.s. trends in favor of ORIF concerning complications and mortality [19]. Joestl et al. compared the results of 3 treatment modalities to treat B2 PFF, one being ORIF, with a graft size of only 8, and two different revision stem designs with group sizes of 14 each. They found n.s. trends in favor of ORIF for surgery time, blood units needed and the number of patients returning back to their pre-injury mobility level [23]. Gitajn et al. analyzed the outcomes of patients with B1, B2 and B3 fractures. The results of the patients who had sustained B2 or B3 fractures were in favor of ORIF concerning blood loss and blood transfusions, showed no difference concerning mortality, and were in favor of revision surgery concerning the postoperative weight bearing instructions given by the treating physician [21]. Pavlou et al. compared ORIF with and without grafting with stem revision with and without grafting, amongst other PFF types also between B2 and B3 fractures. The main outcome of the paper was that in the treatment of PFF, using a graft in addition to ORIF or a revision stem is beneficial. A comparison of all possible treatment combinations (ORIF/revision/with graft/without graft) demonstrated that in B2 fractures, treatment with a revision stem with or without graft resulted in higher union rates than treatment with ORIF without graft. No significant differences were seen in any of the other combinations, including ORIF with graft compared to revision with a stem with or without graft [32].

In several other publications, which had not used statistical tests to compare the results of ORIF vs. stem revision in B2 or B3 fractures, there were trends which appeared to favor ORIF for various parameters [20, 24, 25]. Other publications also showed trends for better outcomes of revision arthroplasty [22, 24]. However, the lack of appropriate statistics and the small group sizes do not allow drawing reliable conclusions.

**Discussion**

In summary, the majority of recent studies suggest equivalence of ORIF compared to revision arthroplasty in the treatment of selected B2 and B3 fractures. Notwithstanding, most of these studies have significant methodological weaknesses, especially concerning the choice of treatment allocation, which bears a high risk of producing biased results. Additionally, the scarcity of information concerning prognostic factors and the diversity of outcome instruments did not allow to identify outcome predictors or to quantitatively summarize the results.

This is well in line with the findings of Mont and Maar, who published a quantitative analysis of the outcomes after PFF reported in the literature in 1994 [33]. They found that the lack of relevant information provided in the respective publications rendered them unable to stratify the results for important predictors.

Only few studies provided a rigorous statistical analysis [16, 19, 21, 23, 32]. Whereas some of these studies could show significant advantages of ORIF for various in-hospital parameters [16, 19, 21], this was not the case for postoperative clinical outcomes: Only one study found a significant difference, namely the postoperative weight bearing instructions as given by the treating physician, which allowed more weight bearing after revision arthroplasty than after ORIF, and thus was in favor of revision surgery [21]. Various studies found n.s. trends in postoperative outcome parameters either in favor of ORIF [19, 23], in favor of revision [32] or balanced [16], i.e. some parameters were in favor of ORIF; others in favor of stem revision. These findings challenge the recommendations given in the Vancouver classification, which defines that B2 and B3 PFF are associated with an unstable prosthesis and thus should be replaced with a long-stemmed prosthesis [13].

In line with the findings of the aforementioned studies, several authors postulate that B2 or B3 fractures could also be treated successfully with ORIF [16, 18]. This would not need to be restricted to palliative care in patients with low lifestyle demands. A fixation of PFF with ORIF alone could be generally beneficial due to the reduced surgical time and complexity and reduced implant costs. Moreover, preserving bone stock by avoiding a long-stemmed implant...
could benefit especially younger patients who are likely to require further revisions in the future [16].

In B2 fractures, provided there was sufficient bone stock and the possibility to anatomically reconstruct the fracture, a construct with sufficient stability to allow fracture healing could be created by means of ORIF [16, 18]. In particular straight polished tapered stems could regain stability after anatomic fracture reduction within an intact cement mantle [16]. The principle of the “loaded taper” design of cemented stems is also referred to as “force-closed” fixation where the polished stem does not bond with the surrounding cement and during axial loading becomes lodged as a wedge in the cement mantle. These stems are polished and do not bond with the surrounding cement. Thus, they allow the taper to subside within the cement mantle until it stabilizes, even in case of anatomically reduced periprosthetic fractures. In primary THA, these stems usually stabilize after the first year [34–36]. From the literature it is unknown how long it takes the stem to stabilize once the fracture has healed in an anatomical way.

In the other kind of cemented stem, the “composite beam” type (also referred to as “shape-closed” fixation), a firm cement–metal bond is mandatory. These implants are not intended to subside, and may either be collared or uncollared, anatomical or straight, undersized or canal-filling. All these designs have in common that the strong bond between the interfaces of stem and cement as well as the interface of cement and bone creates a stable construct from three different materials with different elasticities. Because the stem possesses the highest stiffness, it transmits the axial load to its tip and to the cement and bone below it [37]. Once the interface between the stem and the cement is disrupted, a loose stem can by definition never become stable again. In uncemented stems, long term clinical success depends on stem stability, which in turn depends on the area of primary fixation. According to the Mont group, the uncemented stems can be categorized in 6 major design types, primarily defined by the location of fixation (metaphyseal, diaphyseal or a combination of both) as well as their design geometry [38]. If the periprosthetic fracture does not involve the primary location of fixation, the stem remains stable and the fracture can be internally fixed. However, if the primary area of the implant stabilizing zone is involved in the fracture, the stem is loose and it will depend on the type of fracture and implants used whether sufficient stabilization can be achieved or not. According to Pilliar et al., micromotion of <20 μm results in predominantly bone formation, more than 150 μm leads to fibrous tissue formation and between 40 and 150 μm results a combination of bone and fibrous tissue formation [39]. In an unstable fracture fixation, the excessive micromotion will inhibit osseointegration of uncemented components and the stem will remain unstable, causing thigh pain associated with possibly reduced range of motion and a limp [40].

Considering the multitude of anchoring philosophies, understanding the underlying biomechanics of the fixation is essential to determine whether ORIF may be a suitable treatment. These technical considerations on stem fixation philosophies provide insights in potential success or failure mechanisms for PFF fixation.

The main limitation of our work lies in the low quality of publications. None of the eligible publications was clearly prospective and only few studies used statistical tests to identify differences in outcomes of B2 and B3 fractures treated with ORIF or stem revision. Moreover, not a single study applied transparent decision algorithms for treatment allocation that would have resulted in balanced groups, hence the risk of biased results is high. Beyond this, the lack of uniform outcome reporting did not allow to synthesize any outcome results and the lack of documentation of potential outcome predictors made it impossible to analyze those.

Notwithstanding, the currently available best evidence implicates there may be a benefit of ORIF vs. stem revision. However, the scarcity of information about prognostic factors makes it clear that further research to determine the relevant predictors is badly needed. Therefore, a registry that will document relevant predictors as well as outcomes after treatment of PFF along with other periprosthetic fractures is being funded by the AO Foundation via the AO TK Trauma and AOTrauma Network and set up by AOCID (registration: ClinicalTrials.gov: NCT03378557).

The documentation will include information about initial implant and pathology, fracture classification, clinical, radiological and intraoperative stem stability, patient data (comorbidities, joint function, pain, quality of life), adverse events, implants used to treat the PFF, quality of fracture reduction, fracture healing and postoperative clinical and prosthetic loosening. In the first phase a limited number of sites from different regions will participate. Once launched successfully, it is envisioned to open the registry for further sites.

**Conclusion**

PFF are a rare but important complication of hip arthroplasty. The choice of the treatment modality depends on fracture, implant, and bone characteristics. Recent data challenge the present treatment recommendation as they show that successful outcomes can be achieved without revising loose stems. ORIF may be a viable option in fractures around uncemented stems as well as around polished tapered stem designs with an intact cement mantle if a stable anatomic reconstruction is deemed possible. Conceptional considerations form the basis of this idea, which is further
supported by results from the recent literature. Notwithstanding, due to methodological weaknesses of the available studies, the rising evidence confirming the benefits of ORIF is still weak and more data are needed to identify relevant outcome predictors.

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Compliance with ethical standards

Conflict of interest Karl Stoffel has received research grants from the AO TK Trauma, Mathys and DePuy Synthes and is a consultant for Zimmer, Mathys and DePuy Synthes. Karl Stoffel is a board member of the AO TK Trauma. Michael Blauth is employee of DePuy Synthes. Alexander Joeris, Andrea Blumenthal and Elke Rometsch are employees of the AO Documentation and Publishing Foundation.

Research involving human participants and/or animals For this type of study formal consent is not required. This article does not contain any studies with animals performed by any of the authors.

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