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# Open reduction, internal fixation of Vancouver B1, C & D type periprosthetic femoral fractures with use of an antiglide plate at fracture apex - The “Apex Plate”

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ABSTRACT

*Background:* Periprosthetic femoral fractures are associated with significant morbidity, mortality, social and economic cost. The incidence of these fractures is expected to increase with an ever-growing elderly world-population. The complex nature and varied pattern of these injuries requires a range of specialized surgical techniques and tools. Fixation alone is being increasingly regarded as the preferred method of addressing these fractures, even in cases where the femoral stem is unstable, showing favourable outcomes overall when compared to a fix-and-replace approach. Lateral plate fixation is the primary surgical method for either case, and while there is a growing offer of implants specifically for this subset of orthopaedic injuries, the problem of non-union appears to be the most common of complications encountered postoperatively. We prefer fixation alone, including for Unified Classification System (UCS) B2 and B3 type fractures. A small-fragment plate fixed at the fracture apex acts as both a reduction device, thereby simplifying the operation itself, and as a buttressing device. The lateral tension-banding plate method can exploit the latter function of this smaller plate to improve the stability of the fixed construct, and thereby encourage more reliable bone healing.

*Cases:* We have treated 6 patients between the ages of 59 and 93 with UCS B1, B2, C and D fractures in this fashion. Fragments around an unstable stem (as with a UCS B2 or B3 fracture) were first reduced anatomically and fixed using cerclages, effectively creating a UCS B1, C or D type fracture, which can then be addressed using this two-plating system. All patients were discharged from hospital, returning home to activities of daily living. All radiographic follow-up demonstrated maintenance of reduction and implant position. For patients with radiographic follow-up beyond two months, fracture consolidation or partial consolidation was noted. No surgical infections were recorded.

*Conclusions:* We present this method of fixation for these types of fractures as a “mixed principles” approach to osteosynthesis. Here, the buttressing nature of the medial femoral cortex is at least in part reconstituted so that compressive forces are generated across cortices where an oblique or spiral fracture pattern would otherwise generate shear forces. *Re*-establishing these biomechanics with a lateral tension band plate, we assume, generates a more stable construct that favours bone healing and reduces the chances of non- or mal- union.

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## Introduction

### *Epidemiology*

Periprosthetic femoral fractures (PPFF) are associated with significant morbidity, mortality and disability. The incidence of these injuries is on the rise and thereby represents an ever more significant burden on healthcare systems and society.

Postoperative periprosthetic femoral fracture (pPPFF) risk lies at around 0.8% overall when considering the data from international joint registries [1]. With a rising number of total hip arthroplasties (THA) performed in an ever-ageing population, the absolute numbers are projected to increase by 4.6% every decade until 2050 [1,2]. Periprosthetic fractures currently represent the 3rd most common indication for revision surgery documented in the UK National Joint Registry (NJR) 2023 report [3]. However, the NJR has not yet captured fixation alone for pPPFF, which may well leave this particular postoperative complication significantly underreported [3].

PPFF occur predominantly in the segment of the population aged over 60 years [4,5], and occur either intraoperatively (iPPFF) on implantation, or postoperatively (pPPFF) through low-energy falls [4,5]. pPPFF occur significantly more often in revision- than in primary hip arthroplasty [6,7], in patients with rheumatoid arthritis [7] and in patients with previous iPPFF [5]. In the segment of patients over the age of 60, risk of both iPPFF and pPPFF has been found to be significantly higher in women [4,5] and where uncemented stems were used [4,5,7].

Surgical treatment for pPPFF are associated with a 2.4 %–3.9 % 30 day, [8] 9 % 90 day mortality, a 10–21 % 12 month mortality [8,9], and 60 % 5 year mortality [9], figures which are higher than those associated with revision hip surgery for any other reason for all cohorts except for males <75 years of age with an ASA < 2 [9] and are at least on par with those described for patients with native hip fractures in the first 12 months following surgery [10–12].

### *Impact and cost*

pPPFF diverge from native hip fractures and in terms their greater complexity and the concomitant technical demand on the surgical team. That observed times-to-treatment were found to be between 1.9 and 5.7 days [10,11], may well be a reflection of the effects of this demand, both in terms of planning time and higher temporal and technical demand on theatre capacities [10,11]. This observed delay is itself correlated significantly with increased morbidity, mortality, disability, [8,10,13] reoperation rates [10] and length of hospital stay [13]. Longer operating times (as is especially the case for complex fractures) themselves probably play a role in high postoperative high dependency unit (HDU) and intensive treatment unit (ITU) admission rates [10].

Disability following pPPFF is also significant, reflected in discharge rates to skilled nursing facilities in at least 64 % of cases, and 25–39 % of all patients do not return to life at home following pPPFF [10]. The financial implications of treating PPFs is higher than that of primary arthroplasty with mean cost of treating PPFs from one major trauma centre lying at £23,469 (range: £615–223,000) [14]. US data also corroborate these high costs with both readmission, surgery and hospitalisation costs contributing to a significant financial burden [15]. As a result, there is a growing need to centralise these complex cases in order to concentrate services and expertise to optimally manage often complex patient needs [16].

### *Classification*

Periprosthetic femoral fractures are commonly classified according to the Vancouver [17] or its modification, the Unified Classification System (UCS) [18]. We apply the UCS classification in this paper and describe B1 (fractures with a fixed stem) B2 fractures (fractures with a loosened stem) C fractures (below the tip of the stem) and D fractures (interprosthetic femoral fractures with fixed femoral knee and hip replacement component).

### *Basic principles, traditional concepts and challenges in surgery for pPPFF*

Operative treatment of B and many C and D type fracture patterns precludes use of intramedullary nailing when the fracture extends too far proximal or distal to allow for sufficient locking locking-screw fixation. In such cases, plate fixation is the mainstay of treatment.

Treatment of UCS B1, C and diaphyseal D type fractures with a stable stem are suitable for fixation alone as opposed to fixation in combination with revision arthroplasty [18–20]. Indeed, a survey of European Hip Society Members indicated a clear preference for fixation alone in addressing B1 type fractures [21]. It is worth mentioning at this point that emerging evidence indicates outcomes are at least comparable and likely better overall for fixation alone when compared to fixation and revision surgery, including for fractures with unstable stems [22].

Fixation of such fractures in osteoporotic and osteopenic bone, often found in this older segment of the population, represents a special problem. Demineralisation and generally poor quality of bone, decreases pull-out strength of screws and the stability of fixation [23,24]. This reduction in stability increases strain at the site of fracture and is thereby assumed to slow and reduce the chances of healing [25,26] in bone where healing is already biologically likely to be at the very least delayed and generally poor in quality [25,26]. In combination, these are factors which likely underlie data indicating that non-union and implant failure rates are more prevalent in osteoporotic fractures [24].

The method of plating such injuries is also generally biologically disadvantageous when compared to nailing in that any amount of soft tissue (periosteal) compression by plates leads to devascularisation and osteonecrosis. This in turn leads to porosity in cortex deep to the plate, which further decreases pull-out strength and increases infection rates by generating sequesters [27].

The development of Low Contact Dynamic Compression Plates (LC DCP) provided a more stable and biologically protective construct than conventional plates, and has been found to improve outcomes in osteoporotic bone [28].

In spite of these technological advances, non-union in periprosthetic fractures, at a rate of 18 % was found to account for the most frequent surgical complication following fixation [29], with rates significantly higher than the 2.8 % reported in native femoral fractures in all adult age-groups for both plating and nailing [30].

These biological and technical challenges where incidence of pPPFF are constantly increasing, require continuous development of surgical strategies to effectively tackle fractures encountered around hip arthroplasty stems.

*Basic principles of femoral fracture fixation*

Plates will stabilise a fracture or fractures by neutralising torsional and shear forces at the fracture site. The convex structure of the intact femur generates tensile forces through the lateral cortex which are converted to compressive forces on the medial cortex when the femur experiences axial loading [31]. Application of a lateral femoral plate across a fracture site reconstitutes these biomechanics to a greater or lesser degree depending in large part on the fracture configuration by acting as a tension band plate [31].

A simple, transverse fracture is amenable to lateral tension band plating alone as the medial cortex can buttress the effects of tension transmitted to the fracture site. A “buttress” is a construct which redirects deforming forces to 90 degrees of their axis [32]. The medial cortex in a simple transverse fracture will act as a buttress by redirecting these forces 90 degrees to the tensile forces generated by the lateral plate and thereby across the fracture site [32]. This compression in turn increases friction at the fracture site and therefore stability [27].

Comminuted, spiral and oblique fractures of the femur generate predominantly shear forces through the site of fracture on axial loading, that are mostly the result of torque [33]. Tension band plating alone is therefore suitable only for simple transverse (AO Type A3) fractures [31].

## Case report

We describe a novel surgical technique in addressing UCS B1, B2, C and D type fractures with an oblique or spiral pattern. We make use of a dual-plate construct, by which a small-fragment 4 or 5-hole locking compression plate (“Apex Plate”) is applied at the apex of a reduced, simple spiral or oblique pPPFF fracture. We employ this method for fractures with a fixed femoral stem (that is, a UCS B1, C or D type fracture) or for B2 or B3 fractures in with a fracture line that extends distal to the tip of the femoral stem, where the fragments surrounding the stem have been reduced and fixed with cerclages thereby effectively creating a B1, C or D type fracture. A long lateral locking plate (such as a Synthes® VA Condylar or Periprosthetic Femur Plate) is subsequently applied. Beyond reconstitution of the biomechanics that favour bone healing, the use of a second plate in this fashion simplifies application of the lateral plate considerably by maintaining reduction without using a clamp such as a Haygroves, which can be obstructive.

Buttress plates are otherwise used traditionally for the reduction and stabilisation of oblique fractures at the metaphysis [32] through the conversion of shear force to compressive force as described above [34]. The application of this Apex Plate restores buttressing in oblique and spiral diaphyseal fractures where the biomechanics of lateral tension band plating would otherwise be disrupted by shear forces. This method represents a “mixed principles approach” for the treatment of diaphyseal femoral fractures in which nailing is not an option. Additionally, an apex plate augments the fixation provided by the lateral plate, which we assume increases stability and pull-out strength as shown in in vitro biomechanical studies [35].

This technique is indicated only for the aforementioned fracture-patterns that are simple in nature, or in fractures which can be reduced to two stable fragments such as with cerclages as described above. This method is not suitable for fractures with more extensive comminution where the fracture cannot be stably reduced to a simple, two-part pattern. The collapse of the zone of comminution under loading would therefore eliminate the buttressing effect of a construct otherwise intended as an antiglide plate. For such injuries, orthogonal dual plating – as described in the *Discussions* section of this paper – using a larger secondary plate as a bridging fixation, with or without revision arthroplasty might be considered as one that would confer better stability and therefore be more conducive to bone healing [36].

We have treated six patients, three female and three male, between the ages of 59 and 93, with periprosthetic femoral fractures in this fashion. American Society for Anaesthetics (ASA) grade for these patients lay between II and III. A Consultant Trauma and Orthopaedic surgeon with subspecialisation in orthopaedic trauma, hip and revision-hip arthroplasty carried out all operations. Fracture patterns included two B1, one C, one D and two B2 fractures. Injuries were incurred and treated between April 2019 and March 2024. Five patients suffered their injuries secondary to low-energy falls, one patient from a high-energy road traffic crash. One patient was transfused with a single unit of blood preoperatively, two patients required one and four units of blood postoperatively, respectively. Postoperatively, one patient developed AKI, another pneumonia. No surgical site infections were noted. There were no HDU or ITU admissions. All patients were either discharged home or transferred to in-patient rehabilitation. Clinical follow-up could be carried out for four patients after discharge. These patients returned to their activities of daily living, two still required walking aids at the time of follow-up. One patient represented five years later with clinical and radiographic signs of contralateral hip osteoarthritis and requesting consultation for a THA.

Radiographic follow-up could be obtained for five patients and ranged widely from 6 days to 5 years. Imaging verified maintenance of reduction of the fracture and implant position. Anatomical reduction could not be achieved in one case, leaving a fracture gap of approximately 2 mm as measured on postoperative X ray. In this case, some small callus formation was noted in 6-week follow-up x-rays. In the three remaining cases with radiographic follow-up at 6 weeks or more, signs of consolidation were noted without callus formation. Reduction and implant position was consistently maintained in all cases. The longest period of radiographic follow-up was at just over 5 years. In this case of a UCS B2 fracture, fragments around the stem had first been reduced en bloc with wire-cerclages, effectively leaving a simple fracture which was reduced and then fixed first with a Synthes® Small-Fragment Locking Compression Plate™ (LCP) plate at the fracture apex. A Synthes® Large-Fragment Locking Compression Plate™ was then applied as a lateral tension-band plate.

Fig. 1 below shows a plain-film radiograph of periprosthetic UCS B2 fracture with a loose stem and spiral fracture extending distally to the tip of the femoral stem. Fig. 2 shows detailed relief of the reduced fracture with a Haygroves proximally and small fragment plate fixed distally across the fracture apex and Fig. 3 the completed fixation-intraoperatively. Figs. 4 & 5 show followup plain-film radiographs at 6 days and 5 years, respectively.

## Discussion

Beyond the intraoperative practicality of utilizing a low-profile implant to maintain reduction, we assume that this construct increases stability in favour of direct bone healing, by increasing compression and rigidity, thereby reducing strain sufficiently to encourage primary bone healing [34,37,38].


**Fig. 1.** Plain radiographs showing a periprosthetic femoral fracture around a loosened stem.

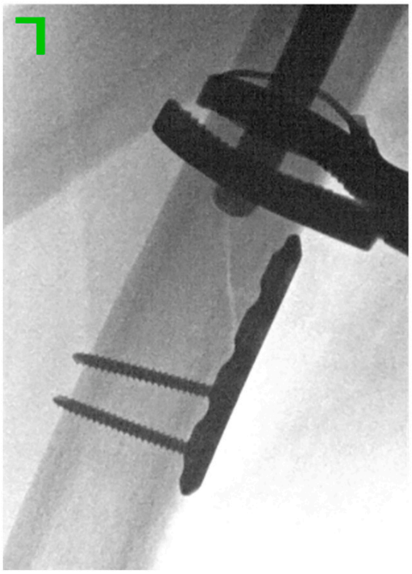

**Fig. 2.** Intraoperative imaging showing application of a small fragment plate at the apex of a reduced, periprosthetic femoral fracture extending distal to the indwelling stem.

Fracture gap strain is defined as $\frac{\Delta L}{L}$ where $L$ is the magnitude of fracture gap and $\Delta L$ is the change in fracture gap magnitude [33,39]. Direct healing (laminar bone) tolerates a strain of 2 %, whereas indirect healing (woven bone in callus) tolerates strain of up to 10 % [27,38,39].

Ideal circumstances for the induction of direct bone-healing require anatomical reduction with stable compression that reduces strain to below 2 %. Indirect bone healing would require a greater fracture-gap and a fixation sufficiently stable enough to mitigate strains beyond 10 % [27]. By the mechanisms of bone resorption and implant loosening described above, these fixations may develop strain in excess of 2 % and therefore what direct bone healing is able to tolerate. Bone resorption at points of high strain, that is at the fracture margins, will increase $L$ and therefore decrease strain [27]. Osteoporotic bone complicates this situation for the reasons of reduced screw tear-out strength and compromised healing described above, which is in turn likely to lead to increase strain soon after fixation in bone with poor and slow healing tendencies, possibly even beyond 10 % and therefore the tolerances of woven bone altogether [24]. Comminuted fractures would in theory be easier to address in this respect as they may tolerate more movement as it relates to healing since movement and strain is shared among fragments within a zone of comminution [27,39].

Presumably, the method of fixation as we have described them here, are at least initially absolutely stable, compressed constructs if they can be reduced anatomically or nearly so. We assume that, in this situation of significant shear forces acting on bone of poor mechanical quality with slow healing tendencies, that ensuring a high degree of stability as can be achieved through anatomical reduction and the reconstitution of buttress/tension-band biomechanics at the time of fixation, creates a more advantageous biological situation for healing to take place than a lateral plate alone. This method appears to favour direct bone healing as follow-up radiographs showed no callus formation, with the one exception described above.

Single-plate constructs probably yield initial higher strain that is likely to later progress through a bone resorption and implant loosening as weight bearing progresses. We postulate strain in in these situations is more likely to exceed the tolerance of woven bone, thereby leading to mal or even non-union.

This assumption is reflected in the findings of in vitro studies showing that orthogonal dual plating of B1 fractures is shown to improve load and cycles-to-failure when compared to single plates augmented with locking attachment plates in cadaveric [40] and synthetic bone [35]. This method has been shown to improve union rates in Vancouver B1 type fractures to 92 % in a prospective trial [36] and to 98 % of cases for all types of diaphyseal fractures- in both native and periprosthetic femurs [41]. This method was not found to cost more surgical time, indeed surgical time was found to be reduced to single plating methods and even intramedullary nailing [36]. Orthogonal plating does not necessarily describe the technique we employ described here, however. Depending on the fracture pattern, an orthogonal plate may or may not play a role in buttressing the fracture so much as making the construct more rigid overall, whereas a plate placed at the fracture apex specifically would convey stability through buttressing.

## *Limitations*

The retrospective nature of the study and paucity of cases represent the main limitations of this study. A significantly greater number of subjects with a standardized information profile to encompass factors such as: patient age, fracture patterns, indwelling implants (e.g. cemented vs. uncemented stems), degree of mobility pre- and postoperatively and comorbidities would serve to acquire a cohort more representative of the general population. Adding to this, standardized follow up periods to describe the short- mid- and

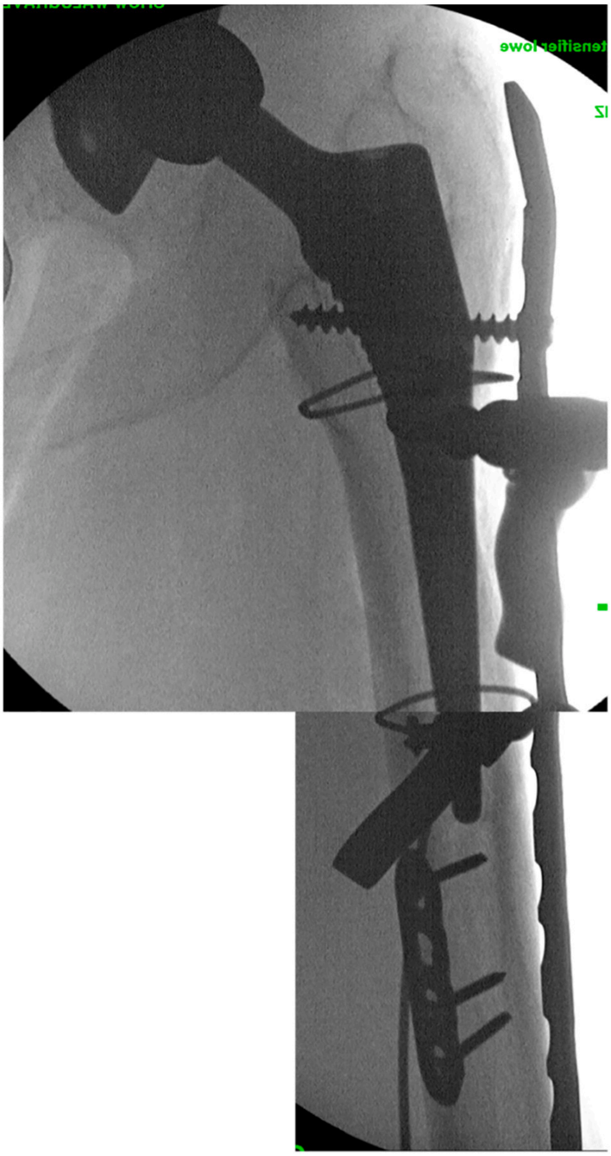

**Fig. 3.** Intraoperative imaging showing final fixation of this UCS B2 fracture with a buttressing plate at the apex of fracture extending distal to the implant stem.

long-term clinical and radiographic outcomes would improve the quality and resolution of the data which, even in our small sample, lacks in those respects. We continue to gather experience with this method and follow patients prospectively with the intent of building a greater cohort and therefore be able to better assess these techniques.

## Conclusions

In conclusion, we find this method to be a useful addition to our armament in addressing UCS B1, C and D type fractures. The biomechanics of this construct, to us, represent a "mixed principles approach" to the problem of addressing diaphyseal fractures of the femur that are otherwise not amenable to intramedullary nailing. The main advantage of this approach is assumed to lie in increasing stability in a situation where a high degree of shear forces would otherwise generate strain in excess of what both direct and indirect bone healing are likely to tolerate in a population that is disproportionately affected by osteoporosis. Longitudinal examination of a greater number of cases would help shed light on these ideas and help improve our understanding of how to manage a growing incidence of such debilitating injuries.

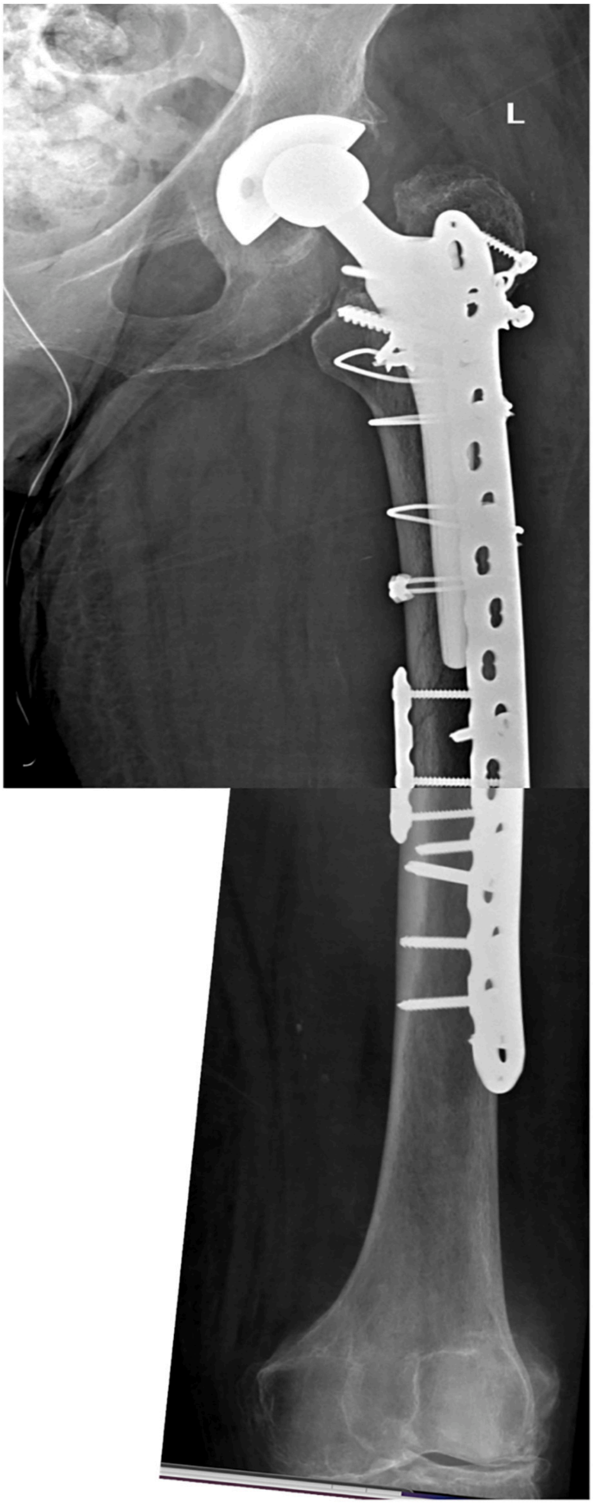


**Fig. 4.** Postoperative X rays on day six following fixation.

## CRediT authorship contribution statement

**Roland Bell:** Writing – original draft. **Mohammed Remtulla:** Writing – review & editing. **Bryan Riemer:** Validation, Supervision, Project administration.

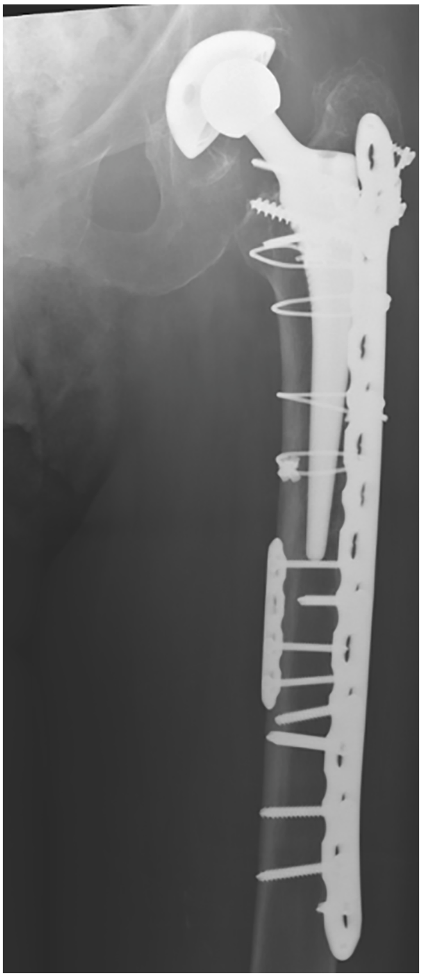

**Fig. 5.** Postoperative X rays 5 years after fixation.


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## Declaration of competing interest

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

## References


[1] R. Pivec, K. Issa, B.H. Kapadia, J.J. Cherian, A.V. Maheshwari, P.M. Bonutti, M.A. Mont, Incidence and future projections of periprosthetic femoral fracture following primary total hip arthroplasty: an analysis of international registry data, J. Long-Term Eff. Med. Implants 25 (2015), https://doi.org/10.1615/JLongTermEffMedImplants.2015012625.

[2] E. Shields, C. Behrend, J. Bair, P. Cram, S. Kates, Mortality and financial burden of periprosthetic fractures of the femur, Geriatr. Orthop. Surg. Rehabil. 5 (2014) 147–153, https://doi.org/10.1177/2151458514542281.

[3] H. Achakri, J. Bridgens, R. Brittain, P. Howard, M. Wilkinson, T. Wilton, S. Dawson-Bowling, C. Esler, A. Goldberg, Z. Hamoodi, S. Jameson, A. Toms, A. Watts, E. Young, C. Boulton, D. Taylor, O. Espinoza, V. Mccormack, C. Newell, M. Royall, M. Swanson, Y. Ben-Shlomo, A. Blom, E. Clark, K. Deere, J. Evans, C. Gregson, T. Jones, A. Judge, E. Lenguerrand, E. Marques, M. Porter, A. Price, J. Rees, A. Sayers, M. Whitehouse, National Joint Registry 20th Annual Report - 2023. www.njrcentre.org.uk, 2023.

[4] T. Konow, J. Baetz, O. Melsheimer, A. Grimberg, M. Morlock, Factors influencing periprosthetic femoral fracture risk: a German registry study, Bone Joint J. 103 B (2021), https://doi.org/10.1302/0301-620X.103B4.BJJ-2020-1046.R2.

[5] M.P. Abdel, C.D. Watts, M.T. Houdek, D.G. Lewallen, D.J. Berry, Epidemiology of periprosthetic fracture of the femur in 32 644 primary total hip arthroplasties, Bone Joint J. 98-B (2016) 576, https://doi.org/10.1302/0301-620X.98B4.

[6] Y. Deng, D. Kieser, M. Wyatt, M. Stringer, C. Frampton, G. Hooper, Risk factors for periprosthetic femoral fractures around total hip arthroplasty: a systematic review and meta-analysis, ANZ J. Surg. 90 (2020), https://doi.org/10.1111/ans.15473.

[7] C. Bissias, A. Kaspiris, A. Kalogeropoulos, K. Papoutsis, N. Natsioulas, K. Barbagiannis, P.J. Papagelopoulos, O.D. Savvidou, Factors affecting the incidence of postoperative periprosthetic fractures following primary and revision hip arthroplasty: a systematic review and meta-analysis, J. Orthop. Surg. Res. 16 (2021), https://doi.org/10.1186/s13018-020-02152-0.
[8] M.R. Boylan, A.M. Riesgo, C.B. Paulino, J.D. Slover, J.D. Zuckerman, K.A. Egol, Mortality following periprosthetic proximal femoral fractures versus native hip fractures, J. Bone Joint Surg. Am. 100 (2018), https://doi.org/10.2106/JBJS.17.00539.
[9] T. Khan, R. Middleton, A. Alvand, A.R.J. Manktelow, B.E. Scammell, B.J. Ollivere, High mortality following revision hip arthroplasty for periprosthetic femoral fracture, Bone Joint J. 102 (2020), https://doi.org/10.1302/0301-620X.102B12.BJJ-2020-0367.R1.
[10] P. Baker, L. Kottam, R. Walker, K. Dwyer, S. Jameson, A. Scrimshire, A. Farrier, A.C. Panagiotopoulos, A. Hilley, H. Ingoe, M. McMullan, I. Mahmood, A. Mitchell, C. Hewitt, C. McDaid, S. Irvine, J. Hardie, A. Brunt, T. Baldock, R. Hillier-Smith, T. Lloyd, H. Gacaferi, C. Bretherton, C.J. Marusza, S. Lakpriya, R. Thumbadoo, L. Hughes, B. Sephton, L. Dupley, A. Chikate, A. Barrie, M.S. Azhar, G. Rogers, L. Hoggett, S. Rogers, S. Ashford-Wilson, T. Collins, H. Goodier, T. Heycock, S. Talha, W. Fishley, R. Strain, M.A. Khan, T. Barwick, S. Sturridge, M.A.A.S. Borland, A. Elmorsy, R. Kucheria, N. Cooke, S. Gwilym, R. Kincaid, R. Yarlagadda, O. Pearce, D. Mackay, D. Johnson, R. Boden, A. Awad, P. Bobak, A. Bonshahi, P. Maguire, T. Petheram, C. Peach, K. Gallagher, S. Shah, S. Jain, G. Pavlou, Management and outcomes of femoral periprosthetic fractures at the hip, Bone Joint J. 104B (2022), https://doi.org/10.1302/0301-620X.104B8.BJJ-2021-1682.R1.
[11] M.L. Thom, R.J. Burkhart, R.A. Arza, M.C. Brown, G.D. Wera, Are periprosthetic hip fractures more severe than native hip fractures? A systematic review of outcomes and resource utilization, Arch. Orthop. Trauma Surg. (2023), https://doi.org/10.1007/s00402-023-05116-1.
[12] S. Haleem, M.J. Choudri, G.S. Kainth, M.J. Parker, Mortality following hip fracture: trends and geographical variations over the last SIXTY years, Injury 54 (2023), https://doi.org/10.1016/j.injury.2022.12.008.
[13] L. Farrow, A.D. Ablett, H.W. Sargeant, T.O. Smith, A.T. Johnston, Does early surgery improve outcomes for periprosthetic fractures of the hip and knee? A systematic review and meta-analysis, Arch. Orthop. Trauma Surg. 141 (2021) 1393–1400, https://doi.org/10.1007/s00402-020-03739-2.
[14] S. Jain, H. Divecha, A. Rajpura, N. Shah, T. Board, J. Wynn, The financial impact of treating periprosthetic fractures at a specialist tertiary referral centre, British Hip Society Meeting, Derby, 2018.
[15] M. Hevesi, C.C. Wyles, J.J. Yao, H. Maradit-Kremers, E.B. Habermann, A.E. Glasgow, K.A. Bews, J.E. Ransom, S.L. Visscher, D.G. Lewallen, D.J. Berry, Revision Total hip arthroplasty for the treatment of fracture: more expensive, more complications, same diagnosis-related groups: a local and National Cohort Study, J. Bone Joint Surg. Am. 101 (2019), https://doi.org/10.2106/JBJS.18.00523.
[16] H. Barratt, S. Turner, A. Hutchings, E. Pizzo, E. Hudson, T. Briggs, R. Hurd, J. Day, R. Yates, P. Gikas, S. Morris, N.J. Fulop, R. Raine, Mixed methods evaluation of the Getting it Right First Time programme - improvements to NHS orthopaedic care in England: study protocol, BMC Health Serv. Res. 17 (2017), https://doi.org/10.1186/s12913-017-2012-y.
[17] C.P. Duncan, B.A. Masri, Fractures of the femur after hip replacement, Instr. Course Lect. 44 (1995), https://doi.org/10.1016/s0030-5898(05)70078-x.
[18] C.P. Duncan, F.S. Haddad, The Unified Classification System (UCS): improving our understanding of periprosthetic fractures, Bone Joint J. 96 B (2014), https://doi.org/10.1302/0301-620X.96B6.34040.
[19] J.F. Huang, X.J. Jiang, J.J. Shen, Y. Zhong, P.J. Tong, X.H. Fan, Modification of the Unified Classification System for periprosthetic femoral fractures after hip arthroplasty, J. Orthop. Sci. 23 (2018), https://doi.org/10.1016/j.jos.2018.07.014.
[20] British Hip Society, BHS Surgical Standards for the Management of Total Hip Arthroplasty Peri-prosthetic Fractures, 2022.
[21] M. Thaler, C. Weiss, R. Lechner, J.A. Epinette, T.S. Karachalios, L. Zagra, Treatment of periprosthetic femoral fractures following total hip arthroplasty: results of an online survey of the European Hip Society, Hip Int. 33 (2023), https://doi.org/10.1177/11207000211017115.
[22] K. Stoffel, M. Blauth, A. Joeris, A. Blumenthal, E. Rometsch, Fracture fixation versus revision arthroplasty in Vancouver type B2 and B3 periprosthetic femoral fractures: a systematic review, Arch. Orthop. Trauma Surg. 140 (2020) 1381–1394, https://doi.org/10.1007/s00402-020-03332-7.
[23] C.N. Cornell, Internal fracture fixation in patients with osteoporosis, J. Am. Acad. Orthop. Surg. 11 (2003) 109–119.
[24] E.A. Gorter, C.R. Reinders, P. Krijnen, N.M. Appelman-Dijkstra, I.B. Schipper, The effect of osteoporosis and its treatment on fracture healing a systematic review of animal and clinical studies, Bone Rep. 15 (2021), https://doi.org/10.1016/j.bonr.2021.101117.
[25] E.F. Rybicki, F.A. Simonen, Mechanics of oblique fracture fixation using a finite-element model, J. Biomech. 10 (1977) 141–148.
[26] S. Miramini, L. Zhang, M. Richardson, P. Mendis, P.R. Ebeling, Influence of fracture geometry on bone healing under locking plate fixations: a comparison between oblique and transverse tibial fractures, Med. Eng. Phys. 38 (2016), https://doi.org/10.1016/j.medengphy.2016.07.007.
[27] S.M. Perren, Evolution of the Internal Fixation of Long Bone Fractures. The Scientific Basis of Biological Internal Fixation: Choosing a New Balance Between Stability and Biology, 2002.
[28] G.J. DeKeyser, P.J. Kellam, J.M. Haller, Locked plating and advanced augmentation techniques in osteoporotic fractures, Orthop. Clin. N. Am. (2019) 156–169.
[29] S.T. Campbell, P.K. Lim, A.H. Kantor, E.B. Gausden, L.H. Goodnough, A.Y. Park, J.A. Bishop, T.S. Achor, J.A. Scolaro, M.J. Gardner, Complication rates after lateral plate fixation of periprosthetic distal femur fractures: a multicenter study, Injury 51 (2020), https://doi.org/10.1016/j.injury.2020.05.009.
[30] R.E. Koso, C. Terhoeve, R.G. Steen, R. Zura, Healing, nonunion, and re-operation after internal fixation of diaphyseal and distal femoral fractures: a systematic review and meta-analysis, Int. Orthop. 42 (2018), https://doi.org/10.1007/s00264-018-3864-4.
[31] D.J. Hak, R.L. Stewart, Tension band principle, in: T.P. Ruedi, R.E. Buckley, C.G. Moran (Eds.), AO Principles of Fracture Management, 2nd ed., Thieme, Davos, Swizerland, 2007, pp. 249–254.
[32] T. Ruedi, R. Buckley, C. Moran, Buttress/antiglide plate, in: AO Principles of Fracture Management, 2nd ed., Thieme, Davos, Swizerland, 2007, pp. 165–189.
[33] S.M. Perren, Physical and biological aspects of fracture healing with special reference to internal fixation, Clin. Orthop. Relat. Res. 138 (1979).
[34] K.A. Egol, E.N. Kubiak, E. Fulkerson, F.J. Kummer, K.J. Koval, Biomechanics of Locked Plates and Screws, 2004.
[35] D. Wähnert, N. Grüneweller, D. Gehweiler, B. Brunn, M.J. Raschke, R. Stange, Double plating in Vancouver type B1 periprosthetic proximal femur fractures: a biomechanical study, J. Orthop. Res. 35 (2017), https://doi.org/10.1002/jor.23259.
[36] J.F. Kubik, T.D. Bornes, E.B. Gausden, C.E. Klinger, D.S. Wellman, D.L. Helfet, Surgical outcomes of dual-plate fixation for periprosthetic femur fractures around a stable hip arthroplasty stem, Arch. Orthop. Trauma Surg. 142 (2022), https://doi.org/10.1007/s00402-021-03950-9.
[37] D.S. Elliott, K.J.H. Newman, D.P. Forward, D.M. Hahn, B. Ollivere, K. Kojima, R. Handley, N.D. Rossiter, J.J. Wixted, R.M. Smith, C.G. Moran, A unified theory of bone healing and nonunion, Bone Joint J. 98B (2016), https://doi.org/10.1302/0301-620X.98B7.36061.
[38] S.M. Perren, Physical and Biological Aspects of Fracture Healing with Special Reference to Internal Fixation, Davos, 1979. http://journals.lww.com/clinorthop.
[39] D.J. Hak, S. Toker, C. Yi, J. Toreson, The influence of fracture fixation biomechanics on fracture healing, Orthopedics 33 (2010), https://doi.org/10.3928/01477447-20100826-20.
[40] M. Lenz, K. Stoffel, B. Gueorguiev, K. Klos, H. Kielstein, G.O. Hofmann, Enhancing fixation strength in periprosthetic femur fractures by orthogonal plating - a biomechanical study, J. Orthop. Res. 34 (2016), https://doi.org/10.1002/jor.23065.
[41] M.F. Lodde, M.J. Raschke, J. Stolberg-Stolberg, J. Everding, S. Rosslenbroich, J.C. Katthagen, Union rates and functional outcome of double plating of the femur: systematic review of the literature, Arch. Orthop. Trauma Surg. 142 (2022) 1009–1030, https://doi.org/10.1007/s00402-021-03767-6.