Use of Intraoperative Multidimensional Fluoroscopy to Assess Femoral Neck Reduction Quality in a Patient with Displaced Femoral Neck Fracture: A Case Report

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Abstract
We present a case of displaced femoral neck fracture (FNF) in a patient treated with closed reduction and surgical fixation. An anatomic reduction was confirmed using intraoperative multidimensional fluoroscopy following reduction and surgical fixation. At the 1-year follow-up, the patient had returned to all activities and there were no signs of avascular necrosis. The quality of FNF reduction is an important modifiable treatment variable to reduce the risk of post-operative complications. Intraoperative multidimensional fluoroscopy enables the surgeon to utilize closed reduction techniques, limiting the risk of damage to vascular structures, while allowing for critical assessment of FNF reduction.

Introduction
Displaced femoral neck fractures (FNF) in patients 60 years of age or younger are challenging injuries to surgically manage with approximately 20% of patients requiring reoperation for complications such as avascular necrosis (AVN), non-union, malunion, and implant failure [1–3]. Although quality of fracture reduction has been shown to be the most consistent predictor
of treatment success, controversy remains however on when a closed reduction is adequate or an open reduction is necessary to obtain a superior clinical outcome [4]. We report 1 case of surgical fixation in a patient with a displaced intracapsular FNF using intraoperative multidimensional fluoroscopy to assess quality of reduction prior to and after surgical fixation.

The patient was informed that data concerning the case would be submitted for publication, and he provided informed written consent. Ethics approval was not required in accordance with the conjoint health research ethics board.

Case Report

A 50-year-old healthy man sustained a closed, displaced FNF in a mountain biking crash. The patient was neurovasculally intact, and the injury was isolated. He was transferred by emergency medical services from a peripheral hospital to the Level 1 trauma centre. On arrival, pre-operative imaging including orthogonal radiographs and computed tomography (CT) scan demonstrated a Pauwels type II displaced FNF with posterior neck comminution (Fig. 1). The patient provided informed consent for closed, possible open reduction internal fixation of his FNF after discussion with the surgical team.

In the operating room, a surgical time-out was performed. The patient received a general anaesthetic and was positioned supine on the fracture table. The right foot was placed in the traction boot, and the ipsilateral arm was secured over the chest. The right lower extremity was prepped and draped in a sterile fashion. Initial orthogonal intraoperative fluoroscopic images were taken demonstrating the valgus displacement and apex anterior deformity of the FNF. A closed reduction was performed using a variation of the Leadbetter technique, with gentle hip flexion to 75°, followed by internal rotation and longitudinal traction until the deformities were reversed.

Anatomic reduction of the femoral neck was confirmed using intraoperative multidimensional fluoroscopy (Ziehm Vision RFD 3D, Ziehm, Nuremberg, Germany). To prepare for the scan, approximately 2 min was required to use the C-arm’s workflow wizard to determine the ideal radiation dose setting for the pelvis (standard setting = 19.59 mG) and to perform a collision check to ensure the C-arm did not come in contact with the patient or fracture table during rotation. The

Fig. 1. Pre-operative AP radiograph of right hip demonstrating valgus displaced subcapital FNF and (a); axial CT slice demonstrating posterior comminution of femoral neck with apex anterior deformity (b). AP, anteroposterior.
C-arm then performed a 48-s, 180° rotation to scan the pelvis followed by an 8 s time interval to allow for reconstruction of the images into coronal, sagittal, and axial image sets (Fig. 2).

A lateral subvastus approach was then performed to expose the proximal femoral shaft distal to the vastus ridge. The 135° dynamic hip screw (DHS) (Depuy Synthes, West Chester, PA, USA) guide was used to insert a 2.5 mm threaded guidewire slightly inferior to the centre of the femoral head on the anteroposterior intraoperative fluoroscopic image. The DHS triple reamer and tap were used followed by insertion of the DHS lag screw. Two 2.8 mm threaded Kirschner wires were drilled into the femoral head along the superior-anterior femoral neck and superior-posterior femoral neck. A 7.3 mm, 32-mm partially threaded cannulated screw was inserted along the superior-anterior femoral neck to compress the anterior column of the femoral neck. This was followed by a 7.3 mm fully threaded cannulated screw along the superior-posterior femoral neck due to the significant posterior neck comminution. A two-hole, 38-mm barrel DHS plate was impacted over the lag screw onto the lateral femoral cortex and secured with two 4.5 mm cortex screws. Final reduction of the FNF and implant position was confirmed by orthogonal intraoperative fluoroscopic images followed by a repeat multidimensional fluoroscopic reconstruction using the settings from the prefixation scan (Fig. 3). After irrigation, the iliotibial band was closed followed by a layered closure of the wound.

Post-operatively, the patient was non-weightbearing for 6 weeks after which he was progressed to full weightbearing. The patient returned to gentle cycling activities 6 weeks post-operatively and was weightbearing as tolerated without gait aids by 3 months. By 9 months post-operatively, the patient described his function as 85% of his pre-injury state. At 1-year post-operative, there were no signs of AVN, and the patient had a Harris Hip Score of 88/100, interpreted as good function (Fig. 4).

Discussion

Currently, there is a lack of strong evidence in support of superiority for either open or closed reduction of displaced FNF in younger patients [4]. Some surgeons believe intraoperative two-dimensional imaging can erroneously lead a surgeon to believe that the reduction
is anatomic when in fact, rotational displacement exists and in turn, suggest that all displaced FNF require an open reduction. To our knowledge, this is the first description in the literature of the use of intraoperative multidimensional fluoroscopy to ensure an anatomic reduction of a displaced FNF prior to surgical fixation. As the majority of young FNFs are significantly displaced due to high energy trauma [1], intraoperative multidimensional fluoroscopy is a novel adjunct to achieving an anatomic reduction utilizing closed reduction techniques.
The young FNF remains a dilemma for the orthopaedic surgeon. Outcomes in this population are poor, patients experience long-term disability secondary to complications, and frequently require early conversion to total hip arthroplasty [3]. Significant controversy remains on the optimal reduction strategy for this patient population. Proponents of open reduction highlight the ability to directly visualize the FNF reduction and decompress the intracapsular tamponade [4]. However, opponents of open reduction argue that opening the capsule increases the risk of AVN by potentially damaging the anterior vessels [4]. A recent retrospective cohort study of 274 patients under 65 years of age with displaced FNF demonstrated a 2.4-fold greater hazard of reoperation following open reduction due to a complication such as AVN or non-union [3]. In contrast, a recent meta-analysis including 21 studies comparing open versus closed reduction found no difference in the rates of AVN, non-union or total complications [4]. The controversy is largely unresolved in the literature, and novel techniques are warranted.

Intraoperative multidimensional fluoroscopy generates CT-like multidimensional cross-sectional images with standard C-arm fluoroscopy units by isometrically focusing on a fixed point and rotating in a 180° arc of motion. This technique has been advanced by the Ziehm Vision RFD 3D unit (Ziehm, Nuremberg, Germany) and provides surgeons with reliable information on reductions and hardware placement, without the need for a postoperative CT scan [5]. Previous literature has demonstrated the safe use of intraoperative multidimensional fluoroscopic scans in pelvic fracture fixation [5, 6]. A case series of 52 patients with unstable posterior pelvic ring injuries treated with percutaneous iliosacral screw fixation utilized intraoperative multidimensional fluoroscopy to confirm screw placement in real time [5]. The authors demonstrate safe use of this technology, with no screws placed intraforaminal [5]. Similar techniques have also been demonstrated for evaluating the quality of reductions intra-operatively in the syndesmosis, calcaneus, distal humerus, and distal radius [7–11]. In young FNF, the single most important modifiable treatment variable in predicting positive clinical outcomes and reducing the risk of post-operative complication is the quality of FNF reduction [3]. The application of this imaging technology to evaluating FNF reduction intra-operatively enables the surgeon to utilize closed reduction techniques, limiting the risk of damage to vascular structures, while allowing for critical assessment of FNF reduction.

The goal for surgical treatment of a FNF in a young patient is an anatomic reduction and stable fixation to achieve union while avoiding osteonecrosis [12]. In our institution, pre-operative work-up includes orthogonal radiographs and CT scan of the affected hip to determine the degree of shearing stress, varus displacement, apex deformity, and posterior comminution. The patient is taken to the operating theatre within 24-h of injury. Intra-operatively, closed reduction is attempted on a fracture table to reverse the deformities, and quality of reduction is critiqued using intraoperative multidimensional fluoroscopy. If an anatomic reduction is achieved, we proceed with surgical fixation. If an anatomic reduction cannot be achieved by closed means, we proceed with an open reduction through an anterior (Hueter or Smith-Petersen) or anterolateral (Watson-Jones) approach. Finally, we confirm our final reduction and implant positioning with a multiplanar reconstruction.

In summary, FNFs in young patients are challenging injuries to treat and associated with high complication rates requiring reoperation. Given the risks associated with open reduction, intraoperative multidimensional fluoroscopy is a valuable adjunct to determine if an anatomic reduction can be achieved by closed methods. Further research using multidimensional fluoroscopy is required to confirm if anatomic reduction of FNF determined by this technique can decrease complication rates, evaluate long-term clinical outcomes, and assess the effect on operative time.
Statement of Ethics

Ethics approval was not required for this study in accordance with local/national guidelines. Written informed consent was obtained from the patient for publication of this case report and any accompanying images.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Drs. Daniel You, Annalise Abbott, Steven Boyd, and Paul Duffy provided substantial contributions to: conception of the work, acquisition and analysis of data for the work, drafting the work or revising it critically for important intellectual content, final approval of the version to be published. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Data Availability Statement

All data generated or analyzed from this study are included in the article. Further enquiries can be directed to the corresponding author.

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