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Intramedullary nailing of abnormally bowed atypical femoral shaft fractures: surgical technique

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Abstract
The treatment of atypical femoral shaft fractures with abnormal bowing provides a unique challenge for surgeons. Whilst intramedullary fixation of atypical femoral shaft fractures affords both mechanical and biological benefits, the mismatch between standard intramedullary devices and the abnormal femoral bowing in these patients makes this method of fixation challenging for the surgeon. The purpose of this manuscript is to illustrate the evolution of our surgical technique through a series of four patients. The critical factors we identified include lateral positioning of the patient for reduction, the use of a piriformis-start nail, and an entry point that was anterior in the sagittal profile and lateral in the coronal profile. This technique was easily replicable, facilitated more anatomical reduction and aided in avoiding complications.

Keywords Intramedullary nailing · Abnormal bow · Antegrade · Entry point · Piriformis start · Atypical femoral fracture

Introduction

Intramedullary surgical fixation of atypical femoral shaft fractures provides mechanical and biological advantages [1, 2]. Bisphosphonate therapy reduces the bone's ability for intramembranous ossification; hence, intramedullary devices are considered the first line of surgical treatment in atypical fractures.

However, a discrepancy exists between the radius of curvature of standard femoral intramedullary nails designs and lateral and anterior bows of femurs, thus leading to the potential complications of cortical perforation and fracture angulation [3–6]. This problem is aggravated by the presence of pronounced abnormal femoral bowing, in both the sagittal and coronal planes, known to be present in multiple ethnicities [7–9].

Whilst several authors have innovated techniques to avoid these complications [10, 11, 16], our center has identified a unique and replicable solution for this challenge. We describe four patients with features of atypical femoral shaft fractures and abnormal femoral bowing on bisphosphonate therapy who were surgically managed with intramedullary devices at our institution, to illustrate the evolution of our novel surgical technique.

Surgical technique

The patient is placed in a lateral decubitus position without a traction device. Bolsters are placed opposite to the apex of the natural lateral bow to aid in reduction, whilst manual traction is performed, as illustrated in Fig. 1. The use of the bolsters at this point facilitates the closure of the medial gap between the fracture fragments. Reduction maneuvers in traction devices are avoided to reduce the linear vector created by ligamentotaxis that has the propensity to over-correct and straighten the femur into a non-anatomical position.

Upon achieving anatomical reduction of the femur, the entry point of the nail is identified in both the sagittal and coronal planes. In the sagittal plane, an entry point anterior to the midline is chosen.

The mismatch of the anterior bow with current nail designs has been extensively investigated [3, 12]. Consequently, when the anterior bow is more pronounced in abnormally curved femurs, the greater the risk of fracture angulation to accommodate the intramedullary device and

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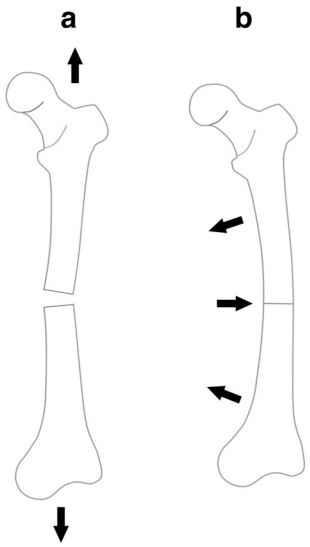

Fig. 1 **a** Depicts the resultant over-straightening of the femur when using longitudinal traction in the setting of a bowed femur. **b** Shows that with a medial bolster as a fulcrum, an anatomical reduction with closure of the medial gap may be achieved

anterior perforation. Engaging the sagittal entry point anterior to the midline facilitates a trajectory aiming posteriorly. This allows adherence of the nail to the posterior cortex of the femur, and, therefore, reduces the risks of anterior perforation and fracture angulation, as illustrated in Fig. 2.

Similar to the sagittal entry point, the aim of the coronal entry point is to avoid lateral cortical perforation. Hence, lateralization of the entry point would facilitate adherence to the medial cortex and negotiation across the lateral bow.

Finally, the effect of this entry point on reduction was enhanced by our implant choice of an antegrade femoral piriformis-start cephalomedullary device. With the use of piriformis-start implants, but with a trochanteric entry point, the straighter nail is able to adhere to the medial cortex to a greater degree. In contrast, if a trochanteric-start device is used, the medial aspect of the device may perforate the lateral cortex distally due to the proximal angulation of the nail. Alternatively, it may result in fracture angulation in the coronal plane to accommodate the intramedullary device, as illustrated in Fig. 3.

Case series

Patient 1, an 84-year-old female with osteoporosis, suffered a mechanical fall whilst climbing stairs and sustained a right femoral shaft fracture. Based on methods mentioned by Lasam and Chang et al., her contralateral femur was used as a surrogate to measure her anterior and lateral bowing [13]. Her anterior bow was calculated to be 18.9° and the lateral bow to be 20.4° that is much more pronounced than the median Asian anterior bow of 13.9° and lateral bow of 7° [8, 9]. Surgery was performed with the patient positioned in a traction table to facilitate reduction. A 380 mm length 13 mm diameter trochanteric-start intramedullary device with a standard radius of curvature was inserted utilising a midline sagittal and coronal trochanteric entry point. Anatomical restoration of the femoral bow was defined as within 5° of the contralateral limb anterior or lateral bow [14]. Postoperative radiographs showed non-anatomical reduction of the fracture with a difference of 7.2° in the lateral bow and 8.0° in the anterior bow. Thus, there was excessive straightening of her right femur, as illustrated in Fig. 4.

Patient 2, a 72-year-old female on bisphosphonates, sustained a ground-level fall at home and presented with a left atypical femoral shaft fracture after complaining of prodromal anterior thigh pain for 3 months. Preoperative radiographs taken during the prodromal period depicted a severe lateral bowing of 16.3°. She was positioned on a traction table for surgery. Due to the severe anterior and lateral bowing of the femur, a piriformis-entry point device,

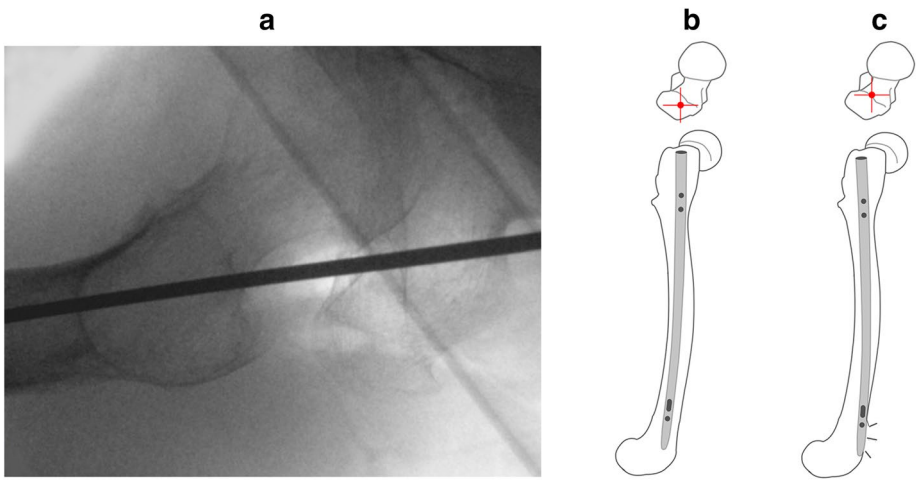

Fig. 2 **a** Image intensifier image of the anterior sagittal entry point recommended. **b** Depicts the ability of the nail to negotiate the anterior bow of the femur during insertion. **c** Shows the natural tendency for anterior perforation in the distal femur when the nail is inserted posterior to this entry point in a bowed femur

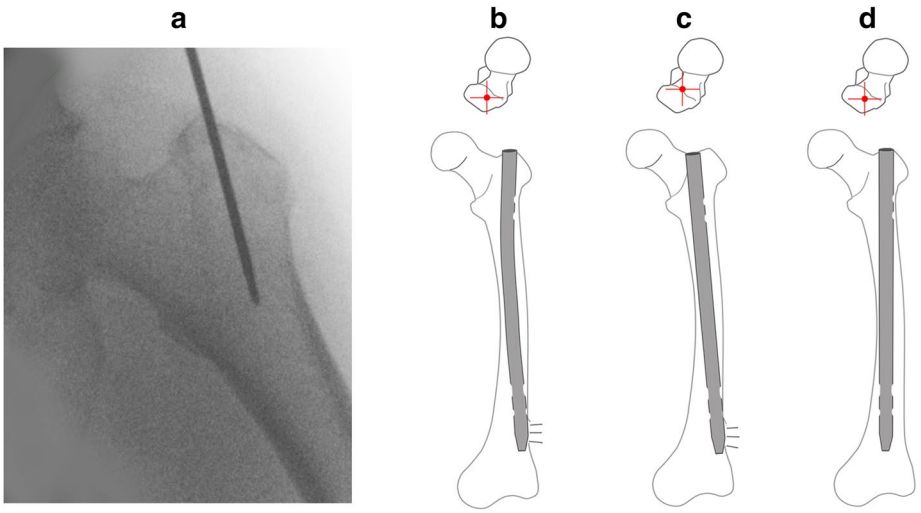

Fig. 3 **a** Image intensifier image of the lateral coronal entry point recommended. **b**, **c** Display the tendency for lateral perforation in the distal femur when a trochanteric-start device with a lateral entry point and a piriformis start with a medial entry point are used, respectively. **d** Depicts the ability of the piriformis-start device, used with a lateral entry point, to avoid lateral perforation

Fig. 4 Shows the anterior–posterior long limb radiograph with over-straightening of the femur in the coronal profile when a traction table was used in conjunction with a trochanteric-start device and lateral coronal entry point

Fig. 5 Displays the over-straightening of the femur obtained when longitudinal traction is used. This is despite an anterior sagittal and lateral coronal entry point with a piriformis-start intramedullary nail

320 mm length and 11 mm diameter, was utilized. The entry point used in the coronal plane was that of the greater trochanter to hinge upon the lateral cortex of the femur, and a more anterior entry point was used to prevent anterior cortex perforation. Postoperative radiographs showed that the anterior bow of the femur was anatomically reduced with a change of only 1.8° when an anterior to midline sagittal entry point was used, as compared to the previous case study. However, there was once again a non-anatomical reduction with excessive straightening of the previously bowed femur in the coronal plane (refer to Fig. 5) that we postulate is due to the traction utilized during the procedure.

Patient 3 was a 73-year-old female with a past medical history of an atypical femur fracture of her right femur, who presented with increasing pain over her left anterior thigh. Given her background of prolonged bisphosphonate use and evidence of lateral femoral mid-shaft cortical thickening, a plan for prophylactic intramedullary fixation of her

left femur was made. For this operation, the patient was positioned in a lateral position. A piriformis-start device of 380 mm length and 12 mm diameter was used. The coronal entry point utilized was the greater trochanter, and the sagittal entry point was anterior to the midline. Through the use of this method, we were able avoid cortical perforation, as shown in Fig. 6.

Patient 4, a 76-year-old female, with a past medical history of hypertension, hyperlipidemia, and osteoporosis on prolonged alendronate treatment, slipped and fell in the toilet, and sustained a left femoral shaft fracture. The patient underwent surgical fixation the day after her fall. In an attempt to achieve anatomical reduction, the patient was surgically managed in a lateral position and not on a traction table. A piriformis-start device 320 mm length 9 mm diameter was utilized. The coronal entry point was the tip of the greater trochanter, and the sagittal entry point for the intramedullary nail was anterior to the midline.

With the combination of factors, we found that we were able to achieve near anatomical reduction of the fractures. In addition, the entry points allowed us to avoid cortical perforation, as demonstrated in Fig. 7.

Discussion

Current designs of intramedullary fixation devices for femur fractures have an angle of curvature disproportionate to the geometry of the physiologically bowed femur [3–6]. This issue is especially evident in the Asian population, which is known to have markedly bowed femurs [15]. Whilst nails with a shorter radius of curvature are being developed, these options are not universally available. This has served as the premise for the development of this technique to circumvent possible complications such as cortical perforation and fracture angulation in these abnormal femurs.

Nirav et al. [11] described his technique of using the starting guide pin as a blocking screw for the insertion of the guide wire. In our surgical experience, we found that whilst this was indeed successful for avoiding anterior cortical perforations, attempts to centralize the nail in the distal fragment often led to straightening of the femur and a non-anatomical reduction. Similar to our technique, Kim et al. [16] showed in their study that the use of a straight nail with a modified entry point through the tip of the greater trochanter resulted in less deformity and improved healing.

Fig. 6 **a**, **b** Show the ability to avoid cortical perforation during prophylactic insertion of the intramedullary device in an abnormally bowed femur with adherence to the following factors: (1) lateral position without traction; (2) piriformis-start device; (3) anterior sagittal entry point; and (4) lateral coronal entry point

Fig. 7 **a**, **b** Show the ability to achieve near anatomical reduction during insertion of the intramedullary device in a fracture of an abnormally bowed femur with adherence to the following factors: (1) lateral position without traction; (2) piriformis-start device; (3) anterior sagittal entry point; and (4) lateral coronal entry point

Using three-dimensional printed models, Park et al. recommended the nail with the smallest radius of curvature, smallest diameter, or the opposite side of the laterally bended nail [10]. Whilst this may prove effective, we are concerned that the use of a smaller nail may in fact compromise the rigidity of the nail. The paper also mentions the possibility of using a straight nail with a greater trochanteric entry point to overcome the lateral bowing that is in line with our experience.

Through the combination of a piriformis-start intramedullary device with a lateral position for reduction, anterior sagittal and lateral coronal entry points, we were better able to achieve an anatomical reduction with the avoidance of cortical perforation. Thus, we suggest this novel and easily replicable technique to aid in the intramedullary nailing of patients with abnormally bowed femurs.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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