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Surgical strategy of the treatment of atypical femoral fractures

INTRODUCTION

The atypical femoral fracture (AFF) has attracted significant attention since Odvina *et al*[1] first reported non-traumatic subtrochanteric fractures in the femur in nine patients with the prolonged use of bisphosphonate therapy (BP). The treatment of AFFs is challenging, even for skilled orthopedic surgeons. Biologically, long-term use of anti-resorptive agents is associated with reduction of bone turnover and altered biomechanics[2]. The inhibition of the bone remodeling process by reducing the activity of osteoclasts causes changes in the mineral and matrix properties of the bone, consequently increasing the thickness of the bone cortex. As a result, bone strength and stiffness increase, making the bone more brittle and susceptible to fragility fractures. Also, biomechanical analyses indicate that tensile stresses are high in the lateral femoral cortex and these can predispose the AFFs[3]. In addition, it affects primary and secondary bone healing[2-4], resulting in delayed union or non-union[5]. In addition, AFFs are often encountered in unfavorable mechanical environments, such as anterolateral bowing of the femur[6], and intramedullary nailing (IMN) may not fit the femur[7-9]. As the incidence of AFF is rising owing to an increase in the aging population[4] and is often associated with the potential risk of poor bone healing, the treatment of AFF has become a major issue in the medical community, leading to convening a task force by the American Society of Bone and Mineral Research[10,11].

In general, AFF often requires surgical treatment depending on the fracture pattern (complete or incomplete), location (subtrochanter or diaphysis), and presence of symptoms (thigh pain), which is considered the standard treatment for both complete

and incomplete fractures. However, as there has been a lack of randomized controlled trials demonstrating the optimal treatment of AFFs, clear guidelines for surgical treatment are currently scarce[12,13], and treatment for AFF is being performed according to a lack of consensus based on expert opinions.

In the current study, we reviewed the current surgical treatment methods for complete and incomplete AFF and highlighted the specific considerations to be observed in unique situations, such as concurrent severe bowing and surveillance of the contralateral femur. Finally, we summarized the context by providing a management algorithm for AFFs based on contemporary evidence in the literature.

SURGICAL TREATMENT OF COMPLETE FRACTURES

AFFs can be classified into complete and incomplete fractures, and surgical treatment is inevitable for complete fractures[14]. Randomized clinical trials have not yet been conducted to determine the optimal surgical method for complete fractures; however, long cephalomedullary IMN spanning the full length of the femur has been recommended[6,10].

Biomechanical aspect should be considered for the surgical treatment of AFFs. Previous reports have suggested several reasons why IMN is preferred for plate fixation in AFFs. First, from a mechanical aspect, IMN has advantages, including a better load-sharing capacity and less bending moment owing to its more medial location compared to plate fixation[15,16]. Thus, devices with greater load sharing have an advantage in AFFs in terms of early ambulation in elderly patients. Second, because of decreased bone remodeling and the subsequent poor bone quality, the stress concentration around the end of implants may induce peri-implant stress fractures[17]. While it is difficult to span the full length of the femur with open plating, IMN has the advantage of spanning the whole femur, and therefore, stabile fixation can be achieved without imbalance between tensile force and compressive force of the fracture site and it may be better than plating in reducing subsequent fatigue fractures[18]. Biologically, osteoclastic activity is suppressed by previous anti-resorptive medication in AFF patients, thereby

rendering bone remodeling and subsequent direct bone healing difficult[1-4]. Although direct bone healing is important in plate fixation, IMN may induce indirect bone healing by endochondral ossification, and decreased osteoclastic function may affect the fracture healing process lesser compared to other methods[19]. Also, Basically, biological damage can be minimized by avoiding incision and direct manipulation of the fracture site. In addition, Although intramedullary nailing can have detrimental effect on the cortical and the endosteal blood flow, it has important effect for bone healing with increased extraosseous circulation and the bone grafting effect from marrow reaming during IMN may enhance osteosynthesis in AFF patients with reduced fracture healing potential[20,21]. Finally, AFFs often accompany anterolateral bowing of the femur; however, contouring the plate to fit the three-dimensional (3D) curvature of the bowed femur during surgery requires additional time and a large incision for open plating itself in elderly patients[9]. Therefore, IMN has theoretical advantages over plating in terms of mechanical, biological, and practical aspects.

Systematic reviews have shown that a greater proportion of complete AFFs treated with plate fixation required reoperation compared to those individuals treated with IMN[11,22]. Egol *et al*[23] reported favorable functional outcomes with IMN in the treatment of AFFs. Shkolnikova *et al*[24] demonstrated that extramedullary fixation, such as plate fixation, resulted in a functional decline in the majority of patients with AFFs. Thus far, studies have shown that IMN provides better radiographic and functional outcomes when compared to plate fixation[11,22].

The selection of an IMN implant design is important for AFFs. The largest possible nail should be used to avoid distal perforation and iatrogenic fractures caused by IMN[25]. If accompanied by femoral bowing, it is recommended to use a nail with a small radius of curvature (ROC)[7,25]. The conventional standard IMN involves the oblique transverse orientation of the proximal interlocking screws across the proximal femur. However, because these interlocking screws do not cover the femoral neck, there is a potential risk of stress fractures around this unprotected area[26]. As cephalomedullary IMN incorporates one or two large proximal locking screws into the

nail and places them in the direction of the femoral head, this method may protect the femoral neck from subsequent fragility fractures. A recent study showed that cephalomedullary IMN reduces the incidence of delayed peri-implant fragility fractures, newly developed AFFs, and non-unions in patients with AFF[27].

AFFs have been reported to have high complication rates with operative fixation because of their unique properties, including anterolateral bowing of the femur[4,28,29]. Although IMN follows the standard surgical technique for subtrochanteric or shaft fractures, meticulous surgical techniques may be necessary to treat complete AFFs. In AFFs, the lateral cortex of the femur at the fracture site is often thickened, which makes nail passage difficult. To overcome this, the medullary canal can be over-reamed by 2.5 mm to ensure good nail passage, stimulate fracture site healing, and reduce iatrogenic fractures[30]. The quality of fracture reduction is important for determining the healing of AFFs, and mal-alignment is strongly correlated with the healing time and failure rate[31,32]. Moreover, if the IMN straightens the curved femur, this not only affects the healing time but also induces limb length discrepancy (LLD)[9]. A previous study analyzed the factors affecting healing in complete AFFs and reported that IMN without cortical breakage around the fracture site and reduction of the fracture gaps anteriorly and laterally affected the healing of AFFs[33]. Since non-union may occur if there are residual fracture gaps anteriorly and laterally more than 2 mm, it is recommended to attempt narrowing of the gaps using the back-slapping method by applying the angular stable locking system (ASLS®, Synthes GmbH, Oberdorf, Switzerland) for distal interlocking. Another study reported that the quality of fracture reduction was the most important factor for achieving bone union; additionally, the cutoff points for the neck-shaft angle, differences in the neck-shaft angle, and sagittal angulation were 125.6, 4.4, and 5.5°, respectively[34]. If adequate alignment cannot be achieved with traction, particularly in subtrochanteric AFFs associated with strong muscle forces, percutaneous wiring or preliminary plating may be necessary[32,33]. The possible causes of failure include the position of the nail as well as the quality of reduction, and it is important to

consider the respective starting points[35]. If loss of reduction occurs during nail passage, repositioning of the starting point should be considered.

IMN in AFF with severe anterolateral bowing is challenging, and various methods have been suggested to overcome this difficulty[8]. First, as mentioned above, if the bowing of the femur is severe, it is recommended to use a nail with as small ROC as possible[7,27]. Second, the entry point lateral to the greater trochanter or piriformis fossa can be used as a site of insertion (Figure 1)[36]. Third, an alternative method is to use the opposite side of the nail (Figure 2)[37]. Some femoral nails have an anterior curve as well as proximal lateral bending, and thus can be aligned with the anatomical axis of the femur with anterolateral bowing by rotating the zig 180° to the opposite side of the nail. The fourth method involves adjusting the alignment by externally rotating the nail. In this method, the anterior curvature of the nail is externally rotated to fit the anterolateral bowing of the femur, and the proximal lateral bending of the nail is matched to the anterior curvature of the femur[6]. However, this method requires the use of a standard nail with proximal screws in the transverse direction instead of the cephalomedullary nail in AFFs and demonstrates concerns related to femoral neck stress fractures. Finally, with the introduction of the minimally invasive plate osteosynthesis (MIPO) technique, which can facilitate indirect bone healing, plate fixation can be considered as an alternative to IMN in AFF with an extremely narrow canal, no nail match with severe femoral bowing, or pre-existing metal implants (Figure 3)[38]. When plate fixation is considered for AFF treatment, spanning the full length of the femur is recommended, and prophylactic screw fixation toward the femoral neck may be necessary to prevent peri-implant or femoral neck fractures (Figure 4)[18,39].

Delayed union, non-union, or implant failure has been a common complication reported after the surgical treatment of AFFs[11,22,40]. Among them, non-union is the most frequent complication, followed by implant failure. According to a recent systemic review including 348 complete AFFs, reoperation was required in 6 out of 38 (15.7%) extramedullary fixation devices used for treating AFF, whereas revision was required in 20 out of 310 (6.45%) IMNs[22]. This finding is consistent with the results reported by

Koh *et al*[11]; a greater proportion of complete AFFs treated with plate fixation (31.3%) required reoperation than those treated with IMN (12.9%) (P<0.01). With regard to the clinical outcomes, the patients who underwent IMN demonstrated better functional scores[40]. A previous study reported that IMN returned to the baseline function in 64% and pain-free status in 66% of patients at postoperative 12 mo[23], while another study with a follow-up duration of up to 46 mo demonstrated a functional decline in 64% of the patients, the majority of whom had extramedullary fixation devices[24]. Unlike the increased mortality associated with typical osteoporotic fractures of the femur, a previous study reported that the mortality rate after treating AFFs was lower than that after treating ordinary femoral fractures[41]. Therefore, although the treatment of AFFs is often challenging, orthopedic surgeons may obtain promising outcomes if they choose a proper treatment option according to the individual and pay attention to meticulous surgical techniques.

SURGICAL TREATMENT OF INCOMPLETE FRACTURES

The natural history of incomplete AFFs has not yet been determined; therefore, taking decisions regarding whether or when to perform surgery is difficult[42]. Incomplete AFFs are easily misdiagnosed or undiagnosed before the fracture becomes complete (Figure 1)[43]. Meanwhile, a previous study reported that 10 of 14 (71.4%) incomplete AFFs were eventually treated surgically because of their progression to complete fractures or intractable pain[14]. The purpose of prophylactic surgery in incomplete AFFs is not only to reduce pain, but also to prevent progression to complete fractures, thereby avoiding commonly developed complications after complete AFFs, such as delayed union, non-union, implant failure, and LLD, as described above[11,44]. Therefore, it is important to assess whether the optimal option for treating incomplete AFFs is to perform prophylactic surgery or close observation. Recently, a scoring system was introduced to identify impending fractures among incomplete AFFs according to the fracture location, nature of pain, the extent of the radiolucent line, and condition of the contralateral femur (Table 1)[12]. If the score is equal to or greater than eight points,

prophylactic fixation is recommended. Contrastingly, patients with a score of seven or less may be treated conservatively, and the responsible physician should carefully evaluate the patient's symptoms and radiographic findings to identify the changes during follow-up. In addition, some authors have recommended prophylactic fixation for incomplete AFFs in cases with the "dreaded black line" on radiographs, varus femoral bowing, a history of contralateral AFF, or failure to improve after two or three months of conservative management[38,45].

The same surgical principles as those for complete AFFs can be applied; thus, cephalomedullary IMN has been proposed as a standard prophylactic fixation for incomplete AFFs[46]. However, for those with severe femoral bowing, which is common in incomplete AFFs, care should be taken because IMN may lead to iatrogenic complete fractures and result in LLD, delayed- or non-union[11,46]. Recently, a report demonstrated that the use of a 3D printing technique could facilitate the reconstruction of severely bowed femurs with incomplete AFF, which were then fixed with a pre-contoured plate using an MIPO technique to match the shape of the femur (Figure 3 and Figure 4)[9]. In this case, additional prophylactic screw fixation toward the femoral neck was required to prevent stress concentration and potential femoral neck fractures.

Although the indications or methods of prophylactic fixation for incomplete AFFs are still controversial, this approach has generally been associated with excellent results[23,47]. A previous study reported that incomplete AFFs treated with surgery showed radiographic healing in 100% and pain-free status in 81% of patients at a mean of 7.1 mo postoperatively[23]. In a systematic review of 109 incomplete AFFs treated with prophylactic fixation (78 fractures with IMN, 12 fractures with plate fixation, and the remaining by unspecified means), 106 fractures (97%) healed radiologically without any revision surgery at an average of 7 mo (range, 1.5–20 mo)[11].

SURVEILLANCE OF CONTRALATERAL FEMUR

Although the pathogenesis of AFFs remains unclear, patients with unilateral AFF have an increased risk of subsequent contralateral fractures[10]. Previous studies have

reported that up to 62.9% of patients with AFFs had bilateral fractures or radiographic abnormalities in the contralateral femur[10,48]. However, as most patients with complete AFFs may have an asymptomatic contralateral femur at initial presentation, it is easy to underestimate the potential AFF in the contralateral femur until the fracture becomes complete (Figure 3)[49]. Several authors have investigated the natural course of the contralateral femur in patients with AFF and reported that up to 88.5% of contralateral femurs eventually progressed to an incomplete or complete fracture within a period of three years[50-52]. This is because reduced weight bearing in the fractured femur may propagate incipient stress fractures in the contralateral femur[9]. A recent report highlighted that the postoperative use of BP might influence the development of contralateral AFF[50]. Therefore, once AFF is diagnosed, a contralateral femur should be evaluated and appropriate medical treatment, including the discontinuation of BPs and initiation of calcium and vitamin D supplementation, must be initiated in addition to endocrine assessments, such as bone turnover markers[53]. When diagnosing a contralateral incomplete AFF, clinicians should decide whether to perform prophylactic surgery or conduct a close observation. As described in the surgical treatment of incomplete fractures, a history of contralateral AFF is a potential risk for an impending complete fracture; thus, the current consensus is that contralateral incomplete AFF may be considered an impending complete fracture[12,23,54].

In summary, orthopedic surgeons should be aware of the potential risk of contralateral AFF in patients with unilateral AFF and must evaluate the contralateral side. Although the validated guidelines to support the subsequent decision-making processes remain unclear, prophylactic fixation for contralateral incomplete AFF may be recommended in cases where the risk of impending complete AFF is increased (Figure 5)[55]. In the absence of such signs of incomplete AFF, close surveillance of the contralateral femur for at least two years may be required[50]. Once AFF is diagnosed, clinicians should discontinue BPs and provide calcium and vitamin D supplements. The use of bone-forming agents may promote healing and reduce the potential risk of complete AFF on the contralateral side[10].

CONCLUSION

The incidence of AFFs is increasing, and their treatment is challenging in terms of the biological and mechanical aspects. For complete AFFs, the cephalomedullary IMN spanning the entire length of the femur can be primarily used. The various surgical techniques for IMN to overcome the femoral bowing common in AFFs include over-reaming, use of a lateral entry point, external rotation of the nail, and the use of a nail with a small ROC or contralateral nail. In cases of narrow canals, severe femoral bowing, or pre-existing metal implants, plate fixation may be considered as an alternative. For incomplete AFFs, prophylactic fixation depends on potential risk factors such as subtrochanteric location, the presence of a radiolucent line, functional pain, and condition of the contralateral femur, and the same surgical principles as those in complete AFFs can be applied. Finally, once AFF is diagnosed, the clinicians should recognize the increased risk of contralateral AFF, and close surveillance of the contralateral femur is recommended.

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Figure Legends

Figure 1 Images of an 80-year-old woman. A: An 80-year-old woman was transferred from a spine clinic because of intractable right thigh pain for three months. Radiographs revealed a transverse radiolucent line (white arrows and insets) on the lateral and anterior cortex of the right femur with 10° of varus. The patient refused prophylactic surgery for incomplete atypical femoral fracture (AFF); however, medical treatment including a switch from bisphosphonate to teriparatide was initiated. According to a scoring system,[11] the risk for impending complete AFF was scored as 10 points; B: Two months later, she visited the emergency department due to progression to a complete AFF; C: She underwent fixation with a long cephalomedullary nail (Trochanteric Fixation Nail-Advanced®, DePuy Synthes, Winterthur, Switzerland) spanning the whole length of the femur. It is to be noted that the entry point of the nail is lateral and anterior to the greater trochanter tip (arrowheads); D: Radiographs taken at 18 mo postoperatively showed healing of the fracture site.

Figure 2 Images of an 81-year-old woman who had taken bisphosphonate for two years. A: An 81-year-old woman who had taken bisphosphonate for two years visited the outpatient clinic complaining of left thigh pain for two months. Radiographs revealed a transverse beak and radiolucent line (white arrows) on the lateral and anterior cortex of the right femur with 10° of varus and 7° of anterior angulation. According to a scoring system[11], the risk for impending complete atypical femoral fracture was scored as 11 points; B: She underwent fixation with an opposite-side (right side) standard nail (Sirus Femoral Nail®, Zimmer, Warsaw, IN, USA). Prophylactic screw fixation toward the femoral neck on her left femur was performed to prevent potential femoral neck fracture around the nail.

Figure 3 Images of a 75-year-old woman underwent a fixation with a long standard nail. A: A 75-year-old woman underwent a fixation with a long standard nail due to a complete atypical femoral fracture (AFF) on her right femur two years ago at another hospital and kept taking bisphosphonate (BP) until she visited our clinic; B: She reported left groin and thigh pain for six months. Radiographs revealed arthritis on her left hip joint (arrowheads) and transverse beaks with radiolucent lines ("dreaded black line") on the lateral and anterior cortex of the left femur (white arrows and insets). According to a scoring system[11], the risk for impending complete AFF was scored as 8 points and BP medication was discontinued; C: Before total hip arthroplasty (THA) to treat hip arthritis, a locking compression plate was pre-contoured along the shape of the bone model with 3D printing rapid prototyping; D: During THA, the sterile 3D-printed model was placed in the same position as that of the femur and used as a surgical navigation. Fixation with the pre-contoured plate *via* minimally invasive plate osteosynthesis was performed to treat incomplete AFF; E: Radiographs taken three years postoperatively showed complete healing of the AFF without progression of femoral bowing or implant-related complications.

Figure 4 Images of a 75-year-old woman who had taken bisphosphonate. A: A 75-year-old woman who had taken bisphosphonate for a period of four years visited our clinic with right thigh pain for three months. Radiographs showed a transverse radiolucent line (white arrow and inset) on the apex of the lateral cortex of the right femur with 7° of varus. According to a scoring system[11], the risk for impending complete atypical femoral fracture (AFF) was scored as 9 points; B: Before the surgery, a locking compression plate was pre-contoured along the shape of the bone model with 3D printing rapid prototyping; C: During the surgery, the sterile 3D-printed bone model was placed in the same position as that of the femur and used as a surgical navigation; D: Fixation with pre-contoured plate fixation for incomplete AFF (white

arrow and inset) with severe bowing was performed *via* minimally invasive plate osteosynthesis. It is to be noted that additional prophylactic screw fixation toward the femoral neck was performed to prevent potential femoral neck fractures.

Figure 5 A proposed treatment algorithm for suspected atypical femoral fracture.

Table 1 A scoring system for the surveillance of impending complete atypical femoral fracture in an incomplete state[11]

Variables	Score		
	1	2	3
Pain	None	Mild	Functional
Site	Others	Diaphyseal area	Subtrochanteric area
Contralateral femur	Complete fracture	Incomplete fracture	Intact
Radiolucent line	Focal changes	Less than 1/2	More than 1/2

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