Treatment Strategies for Nonunion After Intramedullary Nailing for Femoral Fracture: Experiences of Fifty Nonunion Patients

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Research article

Keywords: Femoral fractures nonunion, Intramedullary nailing, Treatment strategy, Revision

Posted Date: August 5th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-49219/v1

Abstract

Background: Femoral nonunion is mainly caused by factors such as instability of the fracture end, insufficient blood supply, or infection. However, these factors are mainly related to the different fracture types and inappropriate treatment plans. It is important to analyze the etiology of femoral nonunion and use a simple and effective treatment method to resolve it. The purpose of this study was to divide femoral nonunion into different types and give corresponding treatment strategies.

Methods: We retrospectively evaluated 50 patients with femoral nonunion. Patients were divided into six groups and each group was treated with a different strategy. All patients were followed up clinically and radiologically every month until fracture healing.

Results: All 50 patients were followed up with an average follow-up time of 17.44 ± 5.48 months. Based on the type of primary femoral fracture and the factors causing nonunion, we divided the femoral nonunion into six types. These included Type I: nonunion caused by instability of simple fracture (AO classification 32-A); Type II: nonunion caused by stress shielding at fracture ends of a simple fracture (AO/OTA classification 32-A); Type III: nonunion in femoral fracture with third fragment (AO/OTA classification 32-B); Type IV: nonunion in femoral fracture with segmental femoral fracture (AO/OTA classification 32-C2); Type V: nonunion in comminuted femoral fracture (AO/OTA classification 32-C3); and Type VI: nonunion caused by infection. Based on these classifications, the following methods are used to treat femoral nonunion. Type I femoral nonunion will achieve fracture healing by blocking screws, exchanging intramedullary nails, or adding plates. Type II femoral nonunion can be addressed through dynamitization or bone graft (possibly in combination with plate fixation) to achieve fracture healing. Type III femoral nonunion requires a treatment plan of bone graft or bone graft combined with plate fixation. The treatment plan for Type IV femoral nonunion is to add a plate, and autogenous bone graft if necessary. Type V femoral nonunion treatment is bone graft combined with plate fixation, or external fixation with subsequent bone segment transport or lengthening. Type VI requires placement of antibiotic bone cement or external fixation added to fix the fracture end.

Conclusions: There are several factors associated with failure of femoral fracture treatments by intramedullary nailing. We need to carefully analyze the causes of fracture treatment failure. Our six classifications and corresponding treatment strategies resulted in satisfactory clinical outcomes.

Introduction

Femoral fracture is one of the most common diseases in traumatic orthopedics. The incidence rate is about 10 to 26.7 per 100,000 person-years and is often caused by high-energy mechanisms such as motor vehicle crashes, high-altitude fall injuries and pedestrian accidents [1-3]. Surgical treatment is a common option for femoral fractures, and intramedullary nails, plates and external fixators are commonly used for surgical treatment. Because closed reduction and internal fixation with intramedullary nailing will preserve the hematoma at the original fracture and protect the soft tissue and periosteal blood supply, it is generally considered the gold standard for treating closed femoral fractures. However, complications such as limb length inequality, infection, malunion, and nonunion represent a serious socioeconomic problem for the patient and pose a treatment challenge for orthopedists. Nonunion is one of the most common complications (about 1.9%–11.3%) [3, 4]. It is often related to surgeons' lack of understanding of different fracture types and inappropriate treatment plans that lead to differences in the etiology of iatrogenic bone nonunion [5-7]. Therefore, it is important to analyze the etiology of femoral nonunion and use appropriate and effective methods to address the nonunion.

Biomechanical reasons, such as instability at the fracture site, stress shielding at the fracture end, and shear stress, seem to be major risk factors for nonunion. Clinically, the instability of the fractured end after intramedullary nail fixation of femoral fractures is mainly related to the surgeon's inappropriate choice of intramedullary nail or poor surgical operation. For example, the diameter of the intramedullary nail is not large enough, the length of the intramedullary nail is too short, and the distal locking screw is not inserted accurately [5]. Stress shielding is also a common cause of femoral nonunion after intramedullary nail treatment of femoral fractures that mainly caused by insufficient compressive stress due to the separation distance of the fracture end. In addition, femoral nonunion caused by shear stress is more common in wedge-shaped multi-level fractures of the medial femur and comminuted fractures of the femur, especially when there is a small amount of callus formation on medial femur but no callus formation on lateral [8]. Furthermore, biological reasons, such as poor blood supply around the fracture end, infection in the fracture area and large bone defects, are held responsible for disturbance in fracture healing [4, 9,10]. The etiology of femoral nonunion needs to be clarified to determine the treatment strategy for nonunion.

From a broad perspective, analysis of the treatment of patients with nonunion after intramedullary nailing should include improving local biological behavior and/ or strengthening mechanical stability. Bone grafting, injection of bone growth factors, and removal of infections are treatment methods to improve the local biological environment, while exchange of intramedullary nails, additional plate fixation, and increased blocking screws are ways to promote mechanical stability. However, there is currently no consistent strategy for treating nonunion after intramedullary nailing for femoral fractures. Therefore, it is necessary to evaluate the inducing factors of nonunion based on imaging characteristics to select an appropriate treatment strategy for nonunion. For this reason, fifty cases of treatment for femoral nonunion were summarized and analyzed. At the same time, we proposed a classification of femoral nonunion and developed a treatment strategy based on the type of femoral nonunion.

Basic Information

This retrospective study was approved by the Institutional Review Board (No. 2020013). All of the treatment procedures conformed to the ethical standards established in the Declaration of Helsinki, and all patients had signed informed consent. From January 2012 to January 2019, we observed 50 patients with nonunion after treatment of femoral fractures with intramedullary nails. Sixteen of these patients underwent the first surgery at our hospital, while others received initial treatment at other facilities.

Patients with pathological fractures, open fracture, smoking or long-term use of drugs that affect fracture healing (such as indomethacin, heparin, corticosterone, and cyclophosphamide) were excluded. All patients were followed up for at least one year.

Based on the type of primary femoral fracture and the factors causing nonunion, we divided the femoral nonunion into six types. These included Type I: nonunion caused by instability of simple fracture (Arbeitsgemeinschaft Für Osteosynthesefragen / Orthopaedic Trauma Association (AO/OTA) classification 32-A); Type II: nonunion caused by stress shielding at fracture ends of a simple fracture (AO/OTA classification 32-A); Type III: nonunion in femoral fracture with third fragment (AO/OTA classification 32-B); Type IV: nonunion in femoral fracture with segmental femoral fracture (AO/OTA classification 32-C2); Type V: nonunion in comminuted femoral fracture (AO/OTA classification 32-C3); and Type VI: nonunion caused by infection.

Therapeutic Methods

After patients were admitted to the hospital, complete laboratory tests such as white blood count, C reactive protein, erythrocyte sedimentation rate, and procalcitonin were performed. At the same time, imaging examinations of fractured ends were undertaken using X-rays and computed tomography (CT).

Depending on the type of femoral nonunion, the surgical strategy was divided into six groups. The first group was the femoral nonunion of a simple fracture (AO/OTA classification 32-A) caused by instability. Reasons for the instability of the fracture end were divided into: the selection of intramedullary nails too small; the selection of intramedullary nails too short; and, the failure of locking nails. Our treatment plan was to consider exchanging the intramedullary nail or adding a plate if the fracture end was in the stenosis and the intramedullary nail was too thin or short. If the fracture located in a non-stenotic area, we consider using blocking screws or adding a plate to increase stability. If the intramedullary nail failed, we considered exchanging the intramedullary nail or adding a plate. The second group was the femoral nonunion of the simple fracture (AO/OTA classification 32-A) caused by stress shielding at both ends of the fracture. In this case, early treatment of dynamitization was considered first. If there was still no evidence of healing, bone grafting and plate fixation was considered. The third group was the nonunion of femoral fracture with the third fragment (AO/OTA classification 32-B). The treatment for this nonunion was bone grafting or bone grafting combined with plate fixation. The fourth group was nonunion with segmental femoral fracture (AO classification: Type C2). Treatment for this nonunion was an additional plate, and if necessary, autologous bone grafting was added. The fifth group was where the nonunion occurs in a comminuted femoral fracture (AO/OTA classification 32-C3). Treatment was autologous bone grafting combined with plate fixation. If the blood supply at the fracture end was poor, an external fixator was chosen after the fracture end fibrous tissue was cleared. The sixth group was the nonunion caused by infection factors. In this case, the internal fixation of the infection was generally removed and the infected area debrided; then antibiotic bone cement was placed and the external fixator was used to fix the fracture end.

All patients were followed up clinically and radiologically every month until fracture healing. At each follow-up, the patient was instructed about appropriate functional exercise, while weight bearing and walking were evaluated based on the imaging results. The results of the imaging assessment were recorded in detail.

Experimental data were analyzed using SPSS 20.0 (IBM Corp, NY, USA). Patients' ages were expressed as means ± standard deviation (x ± s). Third fragment features of femoral shaft fractures were expressed as means and medians. Other data were expressed by description.

Results

A total of 50 patients (38 males, 12 females, mean age 42.46 ± 13.99 years, range 15–69 years) were included in this study. There were 21 cases of left femoral fractures and 29 cases of right femoral fractures. Types of femoral fractures were classified according to AO/OTA classification. Of these, ten cases were 32A1; eight were 32A2; twelve were 32A3; eight were 32B2; two were 32B3; five were 32 C2; and, five were 32 C3. According to our classification of femoral nonunion, there were 19 cases of type I, ten cases of type II, ten cases of type III, five cases of type IV, four cases of type V, and two cases of type VI.

All 50 patients were followed up for more than 12 months, with an average follow-up time of 17.44 ± 5.48 months. Among them, 46 patients with femoral nonunion achieved healing after one operation, and four patients healed after two operations. The average healing time of all patients was 25.84 ± 15.73 weeks. Thirteen cases of type I femoral nonunion were fixed with blocking screws (Fig.1), but two cases had nonunion again with healing achieved after the second surgery of bone grafting combined with plate fixation. In addition, one case of type I femoral nonunion was replaced with intramedullary nail; two cases were fixed with a plate, and three were treated with bone grafts combined with plate fixation. After treatment, these nonunions were all healed. There were ten patients with type II femoral nonunion, of which seven were treated with dynamitization for the first time (Fig.2). However, two patients had not achieved healing after motorized therapy, and healing was only achieved after bone grafting combined with plate fixation. Another three patients with type II femoral nonunion achieved healing after bone grafting combined with plate fixation on the first occasion (Fig. 3). Eight patients with type III femoral nonunion underwent bone grafting combined with plate fixation, and two underwent bone grafting alone (Fig. 4). All achieved healing after treatment. There were five cases of type IV femoral nonunion. Of this number, four achieved healing simply by additional plate fixation, and one healed after bone grafting combined with plate fixation. There were four cases of V-type femoral nonunion, of which two achieved healing after bone grafting combined with plate fixation, and another two were treated by bone resection with shortening and external fixation with subsequent bone segment transport or lengthening owing to poor stability of the fractured end and poor blood supply. In two patients with type VI femoral nonunion, we removed the femoral intramedullary nail and debrided the infected area. We then placed antibiotic bone cement, and applied external fixation to fix the fracture end. In one case, bone segment transport was performed in the second stage due to shortened deformity, and the fracture end was healed. Based on the above treatment plan, we compiled a processing flow chart shown in Figure 5.

We also analyzed the characteristics of the third fracture after intramedullary nails fixated for the femoral fracture, and found the following for the third fracture in the femoral nonunion group. The mean length of the third fragment was 8.33 cm (range 4.8–13.8 cm, standard deviation 2.66cm). The mean distance at proximal diaphysis fragment was 0.74 cm (range 0.2–2.0cm, standard deviation 0.57 cm), and the mean distance at the distal fragment was 1.16 cm (range 0.6–1.6 cm, standard deviation 0.32 cm). The third fragment angle was 6.60° (range 3.5–22.4°, standard deviation 5.64°). All patients with femoral fracture achieved healing after simple bone grafting or bone grafting combined with plate fixation.

We analyzed the characteristics of femoral nonunion caused by segmental femoral fracture (type IV) and found four cases of femoral fracture lines distributed in the proximal 1/3 and middle 1/3 of the femur, but the femoral nonunion occurred in the middle 1/3 of the femur. In addition, there was one case of femoral fracture lines distributed in the proximal 1/3 and distal 1/3 of the femur, and this nonunion occurred in the distal 1/3 segment of the femur. In these cases of femoral nonunion, healing was achieved after plate fixation or bone grafting combined with plate fixation.

Discussion

Femoral nonunion is mainly caused by factors such as instability of the fracture end, insufficient blood supply, or infection. However, the different factors often have special imaging characteristics. The Weber and Cech classification systems, the most popular classification systems in the past, do not fully support all clinical and radiological descriptions: some similarities have been reported in the histological analysis of hypertrophic and atrophic nonunion meaning that the factors that induce nonunion are not well explained. To develop a more effective femoral nonunion type to guide treatment, we retrospectively analyzed and summarized the characteristics of fifty cases of femoral nonunion after intramedullary nailing. We divided the femoral nonunion into six types according to the type of primary femoral fracture and the factors causing nonunion. These six types include Type I: nonunion caused by instability of simple fracture (AO/OTA classification 32-A); Type II: nonunion caused by stress shielding at fracture ends of a simple fracture (AO/OTA classification 32-A); Type III: nonunion in femoral fracture with third fragment (AO/OTA classification 32-B); Type IV: nonunion in femoral fracture with segmental femoral fracture (AO/OTA classification 32-C2); Type V: nonunion in comminuted femoral fracture (AO/OTA classification 32-C3); and, Type VI: nonunion caused by infection. At the same time, we formulated a treatment strategy based on the mechanism of these six types of nonunion, which provides an effective reference for treatment of femoral nonunion after intramedullary nailing.

When a simple type of femoral fracture (AO/OTA classification 32-A) is treated with intramedullary nail internal fixation, the nonunion is mostly caused by the instability of the fracture end. Rotational instability and pendulum are the main factors of nonunion, and mainly relate to the improper operation of the surgeon, such as incorrect selection of intramedullary nail model, and failure of distal locking nail fixation

[4, 11]. Exchange of intramedullary nails, additional plate fixation, and increased blocking screws are the main solutions for the treatment of nonunion caused by unstable factors at the fracture end. In patients with nonunion of the femoral isthmus without obvious bone defects, the exchange of intramedullary nails will increase the stability of the fracture end, and the osteogenic active substance of the reamed bone is more conducive to the healing of the fracture, making it a satisfactory treatment in many cases [12, 13]. However, when the femoral nonunion is not in the femoral isthmus section, the intramedullary nail can also not form a close fit with the medullary cavity after exchange of intramedullary nails, due to the larger medullary cavity. This makes it difficult to obtain satisfactory results by simply replacing the intramedullary nail [14]. If the intramedullary nail does not completely fit the femoral marrow cavity, when there is a certain swing during limb movement a blocking screw can be selected to limit this swing phenomenon. In addition, when the length of the intramedullary nail exceeds the fracture line, the longer part of the anti-swing force arm will be secured so that stronger anti-swing ability will be achieved. Thus the choice of intramedullary nail should be as long as possible and blocking screws can be used to limit this swing phenomenon [15]. Sometimes, however, exchange of intramedullary nails and increased blocking screws cannot prevent the torsion and pendulum of the fracture end, but the additional plate reduces rotation instability and pendulum due to its angular stability, making it a better choice. Additional plate fixation will also prevent loosening of screws and prevent loss of reduction in patients with severe osteoporosis. Further it may accelerate the formation of fibrous cartilage calcification and new blood vessel penetration calcification to achieve bone bridging and shaping, thereby promoting fracture healing [16, 17]. However, the exposure of the fracture end and the removal of cartilage tissue that may be involved in the application of the additional plate fixation may cause the destruction of local callus and blood flow, and then have an effect on healing. Therefore, the nonunion of simple type of femoral fracture caused by instability requires detailed analysis based on the location of the fracture end, the thickness and length of the intramedullary nail, and the condition of the distal locking nail. These considerations can then be linked to selection of an appropriate treatment.

Compared with traditional intramedullary nails, interlocking intramedullary nails have the advantages of firmer fixation and better anti-rotation performance, so they can be used for comminuted femoral fractures, fractures with bone defects and femoral fractures outside the narrow section that are not suitable for traditional intramedullary nails. Interlocking intramedullary nails have two fixing methods: static and dynamic fixation. Dynamic interlocking only fixes the main fracture end of one side, but does not fix the fracture end of the other side. The advantage is that early muscle contraction and weight bearing can provide axial compressive stress to the fracture end, which is beneficial for healing, but fracture displacement may occur. Static interlocking is where both ends of the fracture are fixed with interlocking intramedullary nails, which have a better axial and rotational fixation to prevent fracture displacement that expands with the use of intramedullary nails. However, axial stress will be concentrated on the locking nail on both sides after the static fixation, and the fracture end will lack compressive stress stimulation. This will not only affect the fracture healing, but also make the bone become a ‘disused’ segment between the locking nail, with the fracture gap gradually enlarging and osteoporosis occurring through disuse, eventually leading to delayed healing and nonunion. Therefore, the delayed healing or nonunion of femoral fractures caused by the stress shielding at the two ends of the fracture can be considered to change static interlocking to dynamic interlocking or what is called 'dynamitization.' Dynamitization reduces the stress shielding effect and increases the stress stimulation at the fracture end, thereby promoting the later callus formation [18, 19]. This kind of dynamitization is not suitable for fractures with rotational deformity. At the same time, it should be noted that dynamitization can only occur after the fracture end is sufficiently stable to prevent the loss of reduction. The best timing for dynamitization remains unclear, but it can be considered after 3–4 weeks, and 10–24 weeks is optimal [20-23]. At the same time, it is necessary to carefully read the X-ray before removing the locking nail, and decide which side of the locking nail should be removed based on the height of the fracture site, the position of the nail head, and the nail tail position. In general, the distal locking nail is removed in upper femoral fractures; and the proximal locking nail is removed in middle and lower fractures. In addition, the patient's load should be gradually increased under protection due to the decreased stability of the fracture end after removal of the locking nail, and regular X-rays should be reviewed to make sure that the load is gradually increased without fracture displacement [20, 23]. In some cases, femoral nonunion is not caused by a single factor, so motorization cannot achieve healing. Two patients in our study did not heal after dynamitization, and additional plate fixation was used to achieve healing. However, being a quickly performed, cost saving minor surgery, dynamitization can be recommended as a first line surgical therapy when there is a stress shielding phenomenon on a simple type of femoral fracture (AO/OTA classification 32-A).

Femoral fracture with a third fragment belongs to Type 32-B in the AO/OTA classification system, which accounts for about 10–34% of femoral fractures [18, 24]. The presence of a third fragment of femur makes it difficult to receive the anatomic reduction. However, the reduction quality of the third fragment determines the healing rate. Lin et al. [25] reported that the nonunion rate was 79.9% when the third segment gap was greater than 1 cm, and the nonunion rate was only 24.1% when the single gap was less than or equal to 1 cm. Lee et al. [26] reported that nonunion developed significantly more frequently with fragments 8 cm or longer or when the displacement was 20 mm or more in the proximal area and 10 mm or more in the distal area. Statistical analysis of X-ray data of femoral fracture patients with nonunion, indicated the average length of third fragment fractures was 8.33 cm, the proximal length was 0.74 cm, the distal length was 1.16 cm and the rotation angle was 6.60°. It is generally believed that larger displacement of the fragment could indicate a worse environment resulting from potential soft tissue interposition and poor axial load-bearing ability [27]. In addition, the fractured segment is sometimes necrotic due to poor blood flow after overturning that results in nonunion [28]. This would require removal of fibrous tissue and bone grafting at the fracture end to treat this type of nonunion, and an auxiliary fixation scheme such as an additional plate or steel wire needs to be applied based on the stability evaluation of the fracture end.

Segmental femoral fracture is a unique fracture type characterized by a completely isolated intermediate fragment separated by distinct fractures at two or more levels, assigned AO/OTA classification 32-C2. At present, intramedullary nailing is considered the first choice for treating segmental femoral fractures, but reaming will easily cause the middle segment of segmental fractures to rotate and shift. If the middle bone of the multi-segment fracture is not fixed, it can easily cause local torsion and rotation micro-motion, which will affect the formation of the epiphysis and cause bone nonunion [29]. Therefore, the focus of treating this type of femoral nonunion lies in stable fixation, especially rotational stability. In clinical practice, after intramedullary nail fixation of segmental femoral fractures with only one nonunion, application of an additional plate to control rotational instability can be considered to achieve fracture healing. If nonunion of two or more bones occurs, anatomical reduction of the fracture end is required, with the position near the middle end then fixed by an additional plate [30]. Bone grafting also needs to be evaluated based on the fracture end space and stability when treating the nonunion of segmental femoral fractures.

Femoral comminuted fractures (AO/OTA classification 32-C3) are mostly caused by high-energy injuries; soft tissue damage is severe and fracture end stability is poor, so nonunion is prone to occur. When the inner cortex of the femur fails to provide a strong adduction against the adductor muscles of the femur, the interface between the internal fixation and the bone is prone to loosen. Shear force and rotational stress generated during limb movement acting on the fracture end will easily cause nonunion, loosening of internal fixation, or internal fixation rupture. Bone defects and incomplete cortex of the medial femur are usually present at the nonunion site of a comminuted femoral fracture. Although bone grafting will improve the local biological environment, it will not provide sufficient stability, making healing difficult to achieve. Although additional plate fixation will increase the stability of the fracture end, poor local blood circulation will also make it difficult to achieve healing. Therefore, nonunion of comminuted femoral fracture requires autogenous bone grafting combined with plate fixation. If the blood supply is insufficient due to severe soft tissue and periosteal damage during the initial surgical treatment, or the blood supply is poor when the femoral nonunion is repeatedly treated, then the autologous bone grafting combined with plate fixation may also result in nonunion again. At this point, resecting of the nonunion site could be considered to allow for radical removal of fibrous and scar tissue. This approach could, however, result in segmental defects larger than 5 cm that would need to be restored by corticotomy at the remaining proximal or distal bone segment with daily gradual distraction of this bone segment through an external fixator apparatus. In our study, one patient who still experienced nonunion after multiple operations was cured with this approach.

Fracture healing depends on good reduction, stable fixation and adequate blood supply at the fracture site. However, the infection will not only destroy the blood supply at the fracture end, reducing the rate of healing, but the inflammatory response may also induce bone destruction, leading to a decrease in bone quality and tendency for internal fixation loosening and even nonunion [31]. As the initial catalyst of infectious nonunion is infection, effective treatment of infection is the key to treating this type of nonunion. The infection is difficult to control after fracture internal fixation because bacteria adhere to the inner plant surface to form a bacterial biofilm, and antibiotics in the blood cannot penetrate the biofilm to kill bacteria. Therefore, when deep infection cannot be controlled, the original internal fixation must be removed to further treat the infection [32]. In addition, if the infection range is wide, a large range of bone defects will be left after the dead bones are cleared. Cancellous bone grafting will be prone to bone graft resorption, failure of internal fixation and even fracture again. At this time, bone transport, masquelet technology, free fibula transplantation with blood vessels, and long allogeneic bone grafting can be applied to treat the infectious nonunion with bone defects [31, 32].

There are many factors that can cause nonunion after intramedullary nail fixation of femoral fractures. These different factors often cause radiological differences in femoral nonunion. Weber and Cech et al. summarized these as hypertrophic and atrophic nonunion. Hypertrophic nonunion was divided into ‘elephant foot’ nonunion, ‘horse hoof’ nonunion and nonunion of nutrition. Atrophic nonunion was divided into four subtypes: twisted wedge nonunion, comminuted nonunion, defect type nonunion and atrophic nonunion. There are many epiphyses at the fracture end of hypertrophic nonunion which have a certain level of osteogenic activity. Thus increasing the stability of the fracture end is the focus for promoting healing. However, atrophic nonunion is characterized by poor blood circulation and poor callus, and the improvement of the physicochemical environment is the focus of treatment. Because autologous bone grafting will improve the biological environment around the fracture site, it can be used to fill nonunion sites with insufficient blood supply and non-living bone fragments [33, 34]. However, the stability of the fracture end requires additional plate fixation to achieve fracture healing [16, 17]. Therefore, it is generally believed that there are more bone defects and poor osteogenesis activity at the fracture end of malnourished or atrophic nonunions, and autologous bone grafting is particularly required. Large segmental bone defects can also be treated with vascularized bone flaps and periosteal flaps. In this retrospective analysis of the treatment of nonunion, we also found that some patients with type III nonunion can achieve healing by bone grafting alone, while other type III, IV, and V nonunions require additional plate fixation during bone grafting. At the same time, it is necessary to remove the fibrous tissue before the bone grafting to facilitate blood supply recovery, and ensure embedding 360° around the fracture end to make close contact. There are current reports in the literature that bio-factors and PRP technology can be used to promote the healing of atrophic nonunion fractures [35, 36]. Whether bone grafting is required for femoral nonunion depends on the relationship between the imaging features and etiology of nonunion.

In summary, exchange of intramedullary nails, additional plate fixation, motorization, placement of blocking screws and external fixation, are the treatment options for femoral nonunion after femoral intramedullary nailing. However, these treatments have certain indications. It is necessary to analyze the etiology of nonunion based on the type of fracture and results of the operation, to develop a suitable treatment plan based on the factors of nonunion.

Abbreviations

Arbeitsgemeinschaft Für Osteosynthesefragen: AO

Orthopaedic Trauma Association: OTA

computed tomography: CT

Declarations

Ethics approval and consent to participate: Not applicable

Consent for publication: Not applicable

Availability of data and material: We state that all data generated during the present study are included in this article.

Competing interests: The authors declare no competing interests.

Funding: Our team was funded by the provincial key clinical special construction project in Fujian Province. Our team has received funding from provincial-level clinical key specialist construction projects (2018 NO: 145).

Authors' contributions: Guang-Shu Yu participated in the design of the study and performed the statistical analysis. Yan-Bin Lin conceived of the study, and participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript. Guo-Sheng Xiong participated in literature search and data integration. Yang-Kai Xu, Yan Zhuang, Sheng-Ren Xiong participated in statistical analysis of data.

Acknowledgements: Not applicable

Authors' information (optional): Not applicable

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Figures

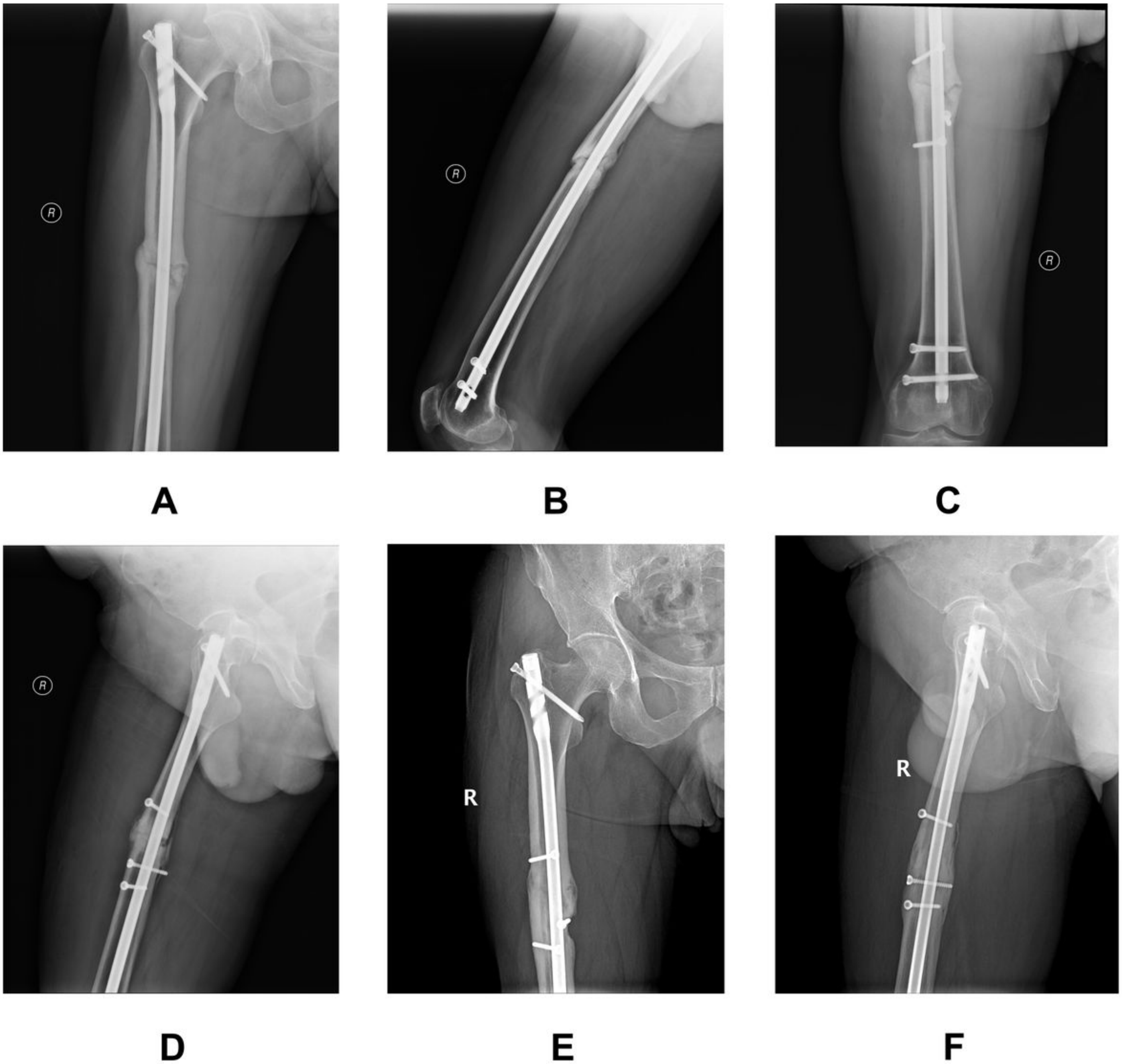

Figure 1

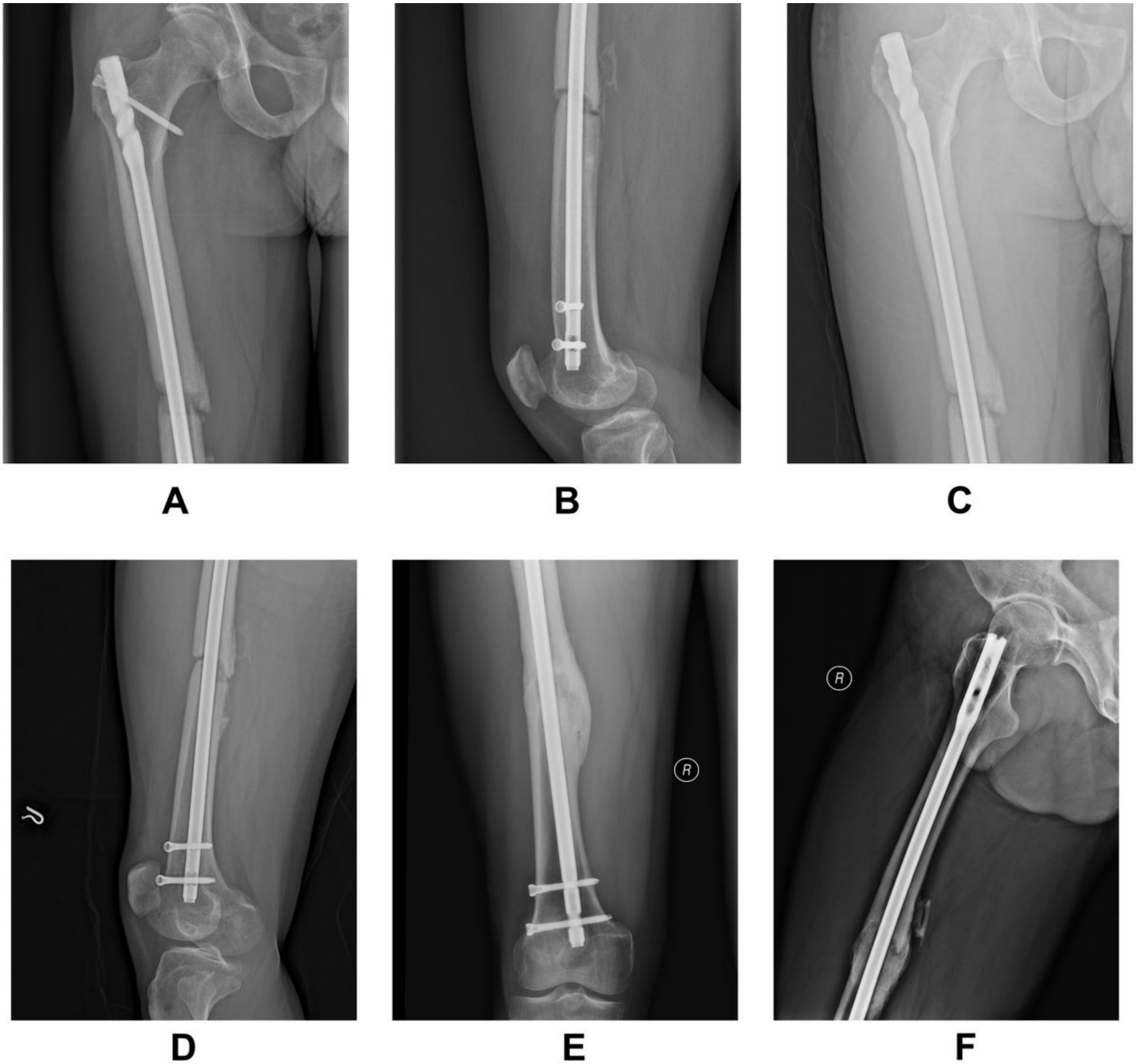

Figure 2

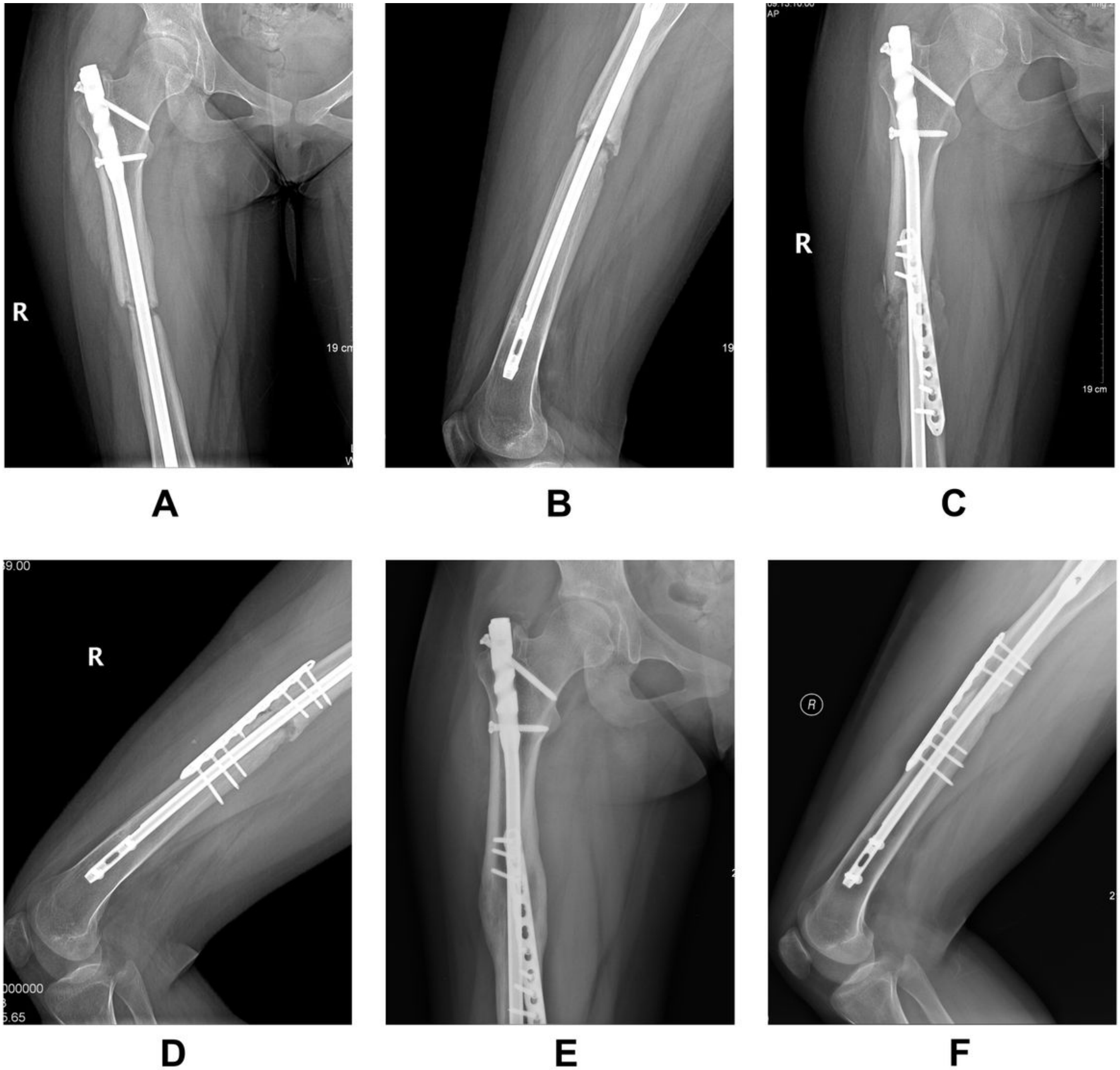

Figure 3

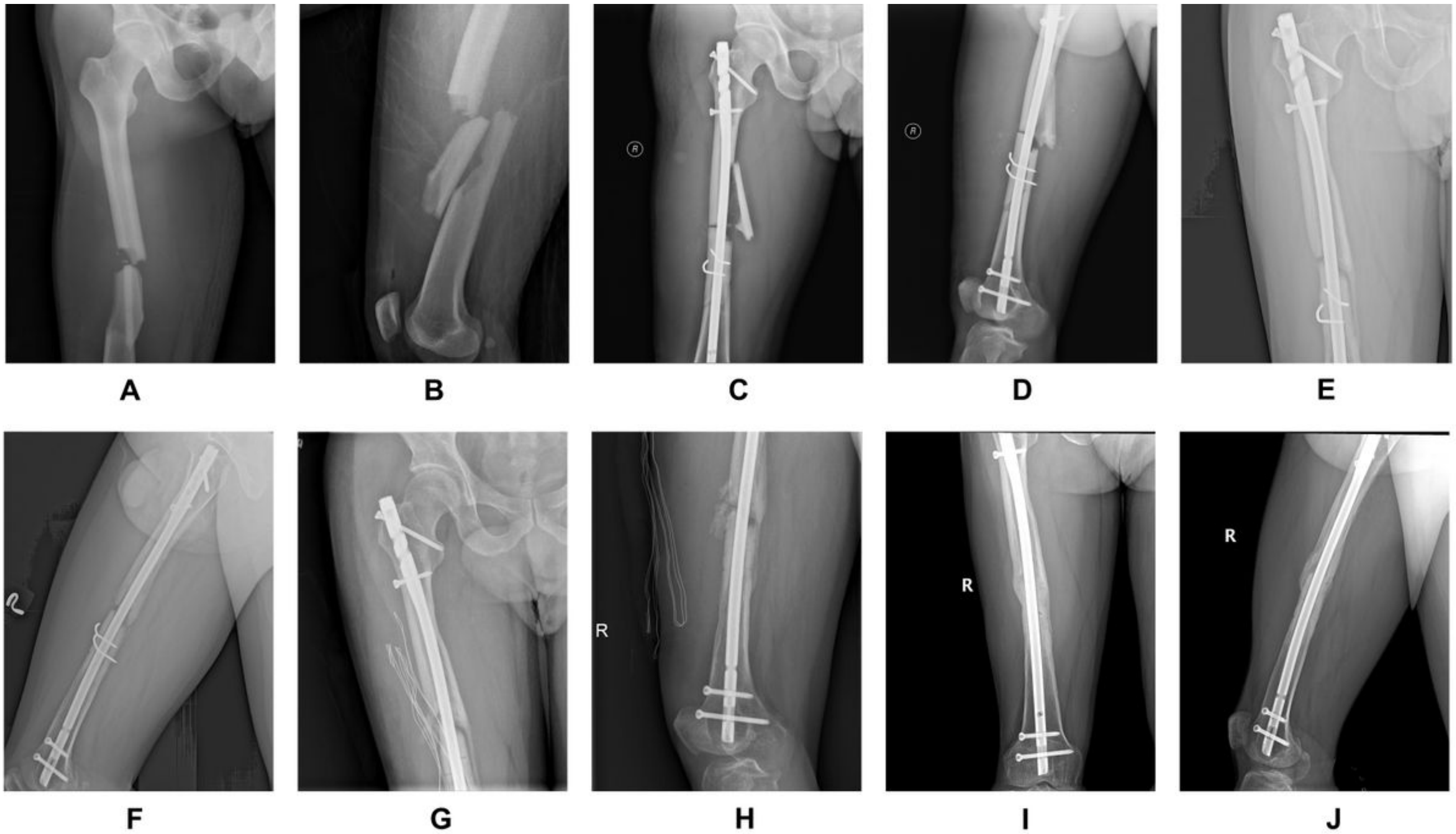

Figure 4

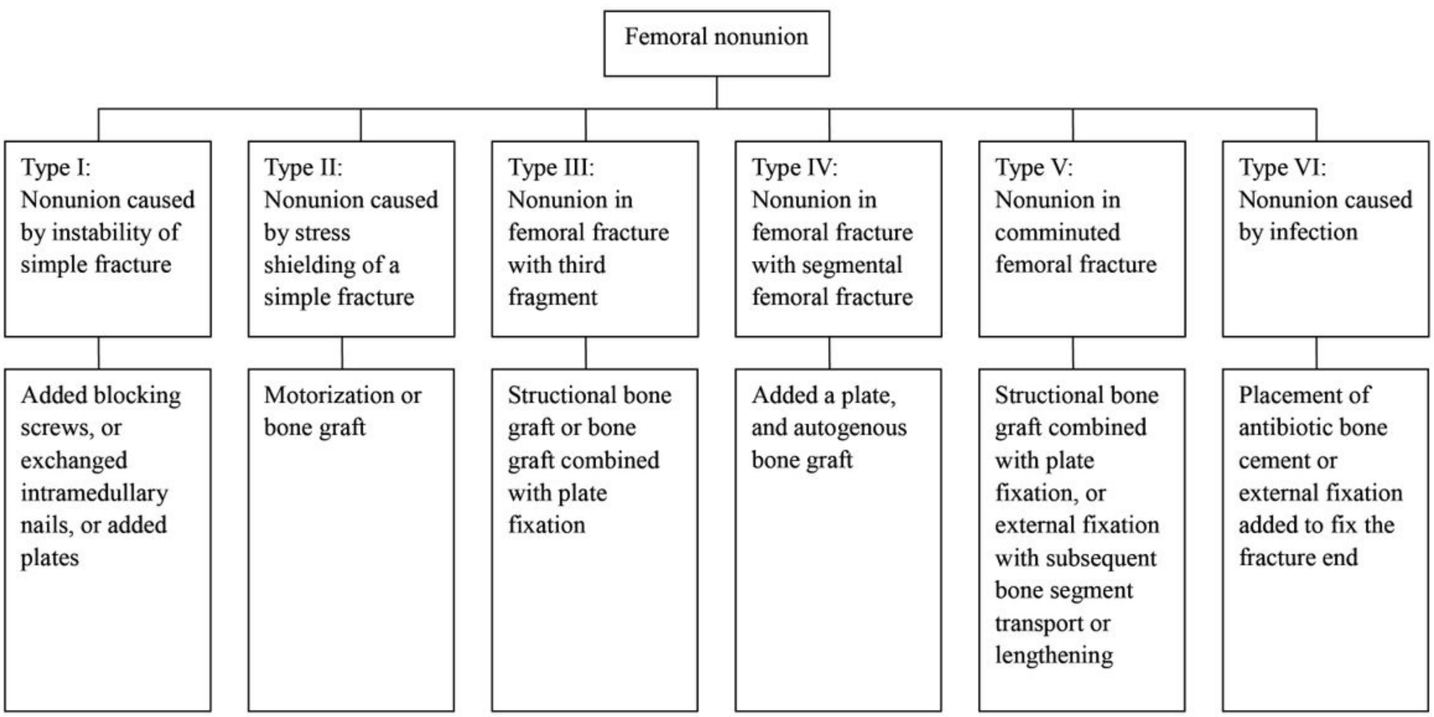

Figure 5