

Research Progress of the Surgical Treatment of Subtrochanteric Fractures of the Femur

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Abstract: *Subtrochanteric femur fracture (SFF) is one of the more common diseases in traumatological orthopaedics, with two types of prevalent populations: young people with high-energy injuries and elderly people with low-energy injuries. Due to the special anatomical location of the subtalar femoral region, perioperative complications, and complex underlying diseases in elderly patients, SFF has become very challenging in clinical treatment. With the gradual attention of many scholars to this disease and the continuous improvement of clinical surgical techniques, there are more and more methods for the treatment of SFF, and its results are getting better and better. In this article, we review the anatomical features, typing and progress of surgical treatment methods of SFF in order to provide more new solutions for the clinical treatment of SFF in the future.*

Keywords: Femoral trochanter, Fracture, Surgical treatment, Research progress.

1. Introduction

Subtrochanteric femoral fractures are a relatively specific class of fractures that can lead to hip deformity, dysfunction, physical disability, reduced quality of life and even death [1]. Based on the previous classification of subtrochanteric femoral fractures, clinical recommendations define them as fractures in which the fracture line passes through the femur mainly in the region of 5 cm below the inferior border of the lesser trochanter. Subtrochanteric femoral fractures account for 45.26% of all proximal femoral fractures, and the prevalent age group is 61-80 years old, accounting for 41.94% of the age group counted (16 years and older), with a slightly higher incidence in males than in females [2]. The subtrochanteric region of the femur is in the most concentrated area of stress transmission, with high pressure stresses on the medial and posterior medial cortical bones and high tensile stresses on the lateral cortex. The higher tensile and compressive forces and the limited vascular supply in this region make fracture reduction and healing more difficult. When the fracture occurs in the subxiphoid region, it is prone to fracture displacement due to unbalanced muscular tension; more specifically, the tension of the adductor muscle groups, such as the iliopsoas and hip shorteners, causes the proximal femur to flex, externally rotate, and abduct, whereas the tendons of the quadriceps tendon and adductors lead to the internalisation and shortening of the femoral stem [3]. Surgical treatment is suitable for patients who have no clear contraindications to surgery and have good tolerance for subtrochanteric femur fracture, but there are still different opinions on the type of internal fixation to be used, and inappropriate choice of internal fixation treatment can lead to postoperative internal fixation failure, ischemic osteonecrosis, fracture nonunion, hip deformity and other complications. The authors present a review of the anatomy, clinical typing, and surgical treatment of subtrochanteric femoral fractures.

2. Related Anatomical Research Progress

Subtrochanteric fracture is a fracture that occurs in the region of 5 cm below the inferior border of the lesser trochanter, which happens to be the transition zone from the cancellous

bone of the intertrochanteric region of the femur to the cortical bone of the femoral stem. It is characterised by a slightly thinner medial and lateral cortex and a wider medullary cavity, which makes it easy to fracture after direct or indirect violence. The pulling of the muscle attachments at the ends of the fracture leads to flexion and abduction and external rotation displacement of the proximal fracture end, and posterior, inward, and upward displacement of the distal fracture end. The main sources of blood supply to the thigh muscles and femur are the deep femoral artery from the femoral artery, the superficial femoral artery and the perforating artery from it, and the femoral trunk nutrient artery. The deep femoral artery originates from the posterior lateral femoral artery, starts from the anterior medial femoral artery, and then extends posteriorly towards the femoral stem and down the thigh, closer to the femur than the superficial femoral artery. Farouk et al [4] discovered the adjacency between the femoral perforating and trophoblastic arteries and the femur through cadaveric injection experiments, which divided the femur into 6 equal parts equally and then into 5 vascular segments: 1) The 1st 1/6 of the proximal femur, supplied by branches of the spinothalamic medial and lateral arteries and anastomosed to each other. 2) The first perforating artery crosses the 2nd 1/6 of the femur. 3) The 3rd 1/6 of the femur crossed by the second and third perforating arteries and the trophoblastic artery. 4) The fourth perforating artery crosses the 4th 1/6 of the femur. 5) The distal 1/3 of the femur, which is supplied by branches of the medial supra-knee artery and lateral supra-genital and descending arteries of the knee and forms an anastomotic band around the knee joint. Ixer et al. [5] found that trophoblastic arteries of the femur are always in the the region of the thick line into the bone, with one artery entering the upper 1/3 of the femur and the other entering the lower 1/3 of the femur. Grob et al. [6] Through cadaver injection research, it was found that the deep femoral artery and its penetrating in the superficial femoral artery, the lateral septal blood vessels form the external anastomosis of the femoral bone marrow through direct anastomosis, periosteal anastomosis, muscle anastomosis and the fascia, subcutaneous layer and the skin level, which is most easily damaged during the operation of proximal femoral fracture surgery (especially in revision surgery). Injure these two arteries. Sharma et al. [7]

conducted a questionnaire survey of members of the British Hip Society. It founded that 14 of the 26 vascular injuries occurred during revision surgery, which made it clear that hip revision is prone to vascular damage. Aleto et al. [8] reported a patient with superficial femoral artery injury caused by peripheral hip prosthesis, suggesting that great care must be taken when placing ringed steel wire to avoid damage to blood vessels. The closed-porous nerve, sciatic nerve and femoral nerve travel along the thigh and control the movement of the thigh. Because these three nerves are distributed in muscles, and far away from the bone surface and have more branches, subtrochant fractures of the femur are rare and direct nerve damage during surgical treatment.

3. Type of Subtrochanteral Fractures of the Femur

Seinsheimer typing, Russell-Taylor typing and AO typing are more common in many clinical classification systems for subtrochanteric femoral fractures [9]. Seinsheimer type I is a subtrochanteral fracture of the femur without obvious displacement or displacement of < 2 cm. Seinsheimer II includes 3 subtypes, type IIa is a transverse fracture, Type IIb is a small proximal spiral fracture of the femur, and type IIc is a small rough proximal spiral fracture of the femur. Seinsheimer type III is a three-part fracture, including two subtypes. Type IIIa is a three-part fracture with a butterfly bone mass located on the inside, and type IIIB is a three-part fracture with a butterfly bone mass located on the outside. Seinsheimer IV is a fracture of internal and external cortical compulsion. Seinsheimer type V is a bilateral cortical fracture involving the rough part. Seinsheimer typing shows that the integrity of the medial cortex of the femur is directly related to the prognosis. Russell-Taylor classifies femur fractures into types A and B, each of which includes 2 subtypes. Type I fracture does not involve the piriform fossa, of which type IA fracture extends from the femur roughness to the isthmus (this area includes bilateral crushing), and the IB fracture line involves the small troughness of the femur to the isthmus. Type II fractures involve large femur roughness and pear-shaped fossa, of which type IIA fractures involve small roughness of the femur, pear-like fossa and isthmus, but small roughness of the femur is non-main and crushed bone mass. Type IIB fracture extends to the large protomy of the femur, the medial cortex of the femur is crushed and the small tropory of the femur is separated. Russell-Taylor typing determines the use of intramedullary or extramedullary fixation based on the completeness of the pear fossa and the femoral coarse along. As the fracture classification of other parts, AO classification divides subtrochanteral femoral fractures into A, B and C, of which type A1.1 is a spiral fracture, A2.1 is an oblique fracture, and A3.1 is a transverse fracture. Type B1.1 is a fracture with an lateral butterfly block, Type B2.1 is a fracture with an inner and lateral butterfly block, and Type B3.1 is a fracture with an internal and lateral bone mass. In type C, except for the two transverse fracture lines and relatively complete three-part fractures of type C1.1, the rest are comminuted fractures, and type C3.2 is also accompanied by intertrochanteric femoral fractures. With the progress of AO typing of subtrochanter femoral fractures, the treatment of fractures becomes more and more difficult, and the worse the prognosis is.

4. Progress in Surgical Treatment of Femur Fractures

Surgical treatment is mainly divided into intramedullary fixation system and extramedullary nail fixation system. Intramedullary fixation system includes Gamma nail, proximal femur intramedullary nail, proximal femoral anti-rotation intramedullary nail, femoral reconstruction intramedullary nail and reinforced proximal femoral intramedullary nail, and proximal femoral bionic intramedullary nail. The extramedullary fixation device mainly includes a locking steel plate at the aximal end of the femur, a minimally invasive internal fixation system, a power condylar screw and a power hip screw, and an external fixation frame.

4.1 Intramedullary Fixation System

(1) Gamma nails: Gamma nails were developed in the mid-1980s for the treatment of femoral roughness fractures, and were first put into clinical use in 1988. In 1992, they were used to treat femoral roughness fractures. The original Gamma nail requires injection in the pear-shaped nest because of the straight nail design, so the pear-shaped socket fracture is a surgical taboo and is not suitable for obese patients. AO tissue improved the Gamma nail for the above defects, designed the proximal 10° external angle, and moved the needle point to the large rough apex, which is the first generation of Gamma nail. However, the diameter and external angle of the Gamma nail are large, which increases the pressure of the medullary wall of the femoral shaft, and it has a risk of iathrogenic fracture. Luo Xianzheng and others [10] designed the second-generation Asia-Pacific Gamma nail, which is more in line with the test of the Chinese femur backbone, but there are complications such as tension screw cutting and prolapse, and the fracture of the femoral shaft at the end of the main nail. In view of the shortcomings of Gamma nails, scholars have developed the third generation of Gamma nails (referred to as Gamma3) through continuous improvement. Its advantages are that the fracture ends are firmly fixed, effective anti-rotation and shortening, easy to learn, minimally invasive surgery, etc. Wang et al. [11] found through comparative research that Gamma3 can provide a good pressurization effect and is not easy to cause the displacement of the rough section fracture, and the clinical effect of the treatment of the elderly femur fracture is satisfactory.

(2) Intramedullary nail of the proximal femur: PFN is an intramedullary fixation system for proximal femur fractures improved by the AO Association according to the principle of Gamma nail. It is suitable for all fractures 31-A fractures and coronic fractures of the femur in the AO classification. There are 2 screws in the head and neck of PFN. The lower part is the main tensile screw, and the upper part is the anti-spin screw. The advantage is that it can effectively prevent the rotation of the broken end of the fracture and reduce the removal of the tensile screw. However, the main complication is that the upper anti-spin screw is cut out or exiting outward, which is called the "Z effect". Simermacher et al. [12] used PFN to treat 191 cases of apximal femur fractures and conducted a 4-month follow-up survey. It was found that 4.6% of patients had poor reduction, poor rotation or wrong

screw selection, and 0.6% of patients had head and neck screw incision. They believed that PFN was more effective in treating coarse femoral fractures. Wang et al. [13,14] adopted the femoral hypotrophic fracture model of proximal femoral intramedullary nail, proximal femoral locking steel plate, dynamic condylar screw, and dynamic hip screw to fix the medial cortical defect. It was found that in the case of incomplete medial cortex, the biomechanical performance of the proximal intramedullary nail of the femur was better than the other three fixation methods.

(3) Anti-rotating intramedullary nails at the proximal femur: due to the aging of the population, the number of patients with osteoporosis is increasing, and the bone conditions of patients with osteoporosis fractures are poor, which can easily lead to failure of internal fixation and other related complications. The proximal end of the femur is placed into the spiral blade through rotation and extrusion, which directly impacts the bone around the spiral blade, improves the anchor force of the spiral blade, prevents its rotation and collapse, and also improves the ability to resist cutting out, which can bring additional benefits to patients with osteoporosis. Guan et al. [15] Retrospective analysis of 59 patients with femoral hypoplasia fractures with hypomyasia admitted to the orthopedics of Jiangning Hospital affiliated to Nanjing Medical University believed that PFNA is the first choice for the treatment of hypoplasia fractures of femur due to its small surgical incision, low intraoperative bleeding, rapid postoperative recovery and low incidence of complications. Huang et al. [13] conducted a finite element analysis of PFNA combined with steel wire ring ligation for the treatment of subtropasty fractures of the femur. The results showed that the biomechanical fixation strength of the fracture end increased after the addition of ring wire was added, and the probability of anatomical reduction was higher, which could increase the stability of fracture and reduce the failure rate of internal fixation, but it also existed the risk of bone damage in local stress concentration.

(4) Femoral reconstruction intramedullary nail: Femoral reconstruction intramedullary nail is a second-generation femoral intramedullary nail designed and developed in the 1980s on the basis of locking intramedullary nail. There are 2 tension screws to firmly fix the femur roughness and femoral trunk, and there are 2 locking screws at the distal end, which not only prevents the rotation of the femoral head, but also ensures the axial stability of the femoral shaft. Yang Jun et al. [14] used reconstructed intramedullary nails to treat 18 cases of femur rough and lower proterty fractures. The follow-up found that all fractures were bone-heal, and there were no complications such as hip inversion deformity, cut-out phenomenon, loose internal fixation, fracture deformity healing, etc., with a total excellent rate of 88.89%. However, the femoral reconstruction intramedullary nail surgery has high technical requirements for the surgeon. Only by accurately and correctly placing the intramedullary nail and the proximal 2 tensile screws, and the length of the screw needs to be appropriate, can the failure rate of internal fixation be reduced and the fracture can be well healed.

(5) Proximal femoral bionic intramedullary nail: PFBN is a new generation of intramedullary fixation in the proximal femur based on the "Zhang's N Triangle Theory" put forward

by Academician Zhang Yingze's group, compared with the traditional proximal intramedullary nail system, PFBN is a transverse support screw that crosses the fixation screw instead of a screw that is parallel to the fixation screw. Compared with the traditional proximal intramedullary nail system, PFBN is a new generation of proximal femoral intramedullary fixation system, in which the transverse support screw, the fixation screw, and the main intramedullary nail form a three-dimensional intersection in the proximal femur, forming a triangular stabilising structure, which can significantly increase the strength of the internal fixation and play the role of anti-rotation, and reduce the occurrence of postoperative internal fixation failures [16]. Chen et al. [17] found that PFBN showed better biodynamic stability in proximal pelvis revision surgery compared to PFNA and DHS. Since PFBN is the latest technology emerging in recent years, there is currently less literature on PFBN for the treatment of subcrotal fractures, and more clinical research is needed.

(6) Reinforced proximal femur intramedullary nail: Reinforced proximal femoral intramedullary nail was first used in Australia and has now been used internationally. Its 15.66mm main nail gradually cuts the outer side of the proximal end of the intramedullary nail from the distal end to make it flat instead of round to reduce the damage of surrounding bone [18]. The hollow design of the head nail is connected to the terminal hole structure, which can make patients with osteoporosis more controll in the femoral head by injecting bone cement. Yang et al. [19] successfully treated a patient with a patient with a thickening femoral neck fracture with a hollow nail after internal fixation of the femoral neck. Six months after the operation, X-rays showed that the fracture had completely healed. In addition, compared with the proximal anti-circular intramedullary nail of the femur, the curvature radius of the reinforced proximal intramedullary nail of the reinforced femoral is smaller, which is conducive to preventing anterior wall fracture caused by the back of the needle point in patients with normal femoral arch. From the perspective of biomechanicals, some studies have found that reinforced proximal intramedullary nails of the femur may be more suitable for the treatment of comminuted femur undertrochantic fractures [20].

4.2 Extramedullary Fixation System

(1) Proximal femoral locking plate: The main structure of the proximal femoral locking plate consists of a proximal fixation plate, a distal fixation plate and locking screws. The proximal fixation plate has multiple holes which can be used to fix the proximal part of the fracture, while the distal fixation plate has multiple screw holes perpendicular to the bone to fix the distal part of the fracture. Locking screws promote fracture healing by working with the plate to fix the fracture site in the correct position. Due to the bionic and locking design of the Proximal Femoral Locking Plate, it has the advantage of biomechanical and angular stability of the plate and screw. In addition, as the proximal femoral plate has multiple holes, multiple locking screws can be inserted at different angles, which improves the stability of proximal femoral fixation and is more suitable for osteoporotic fractures and fractures in elderly patients. Hiyama et al. [21] treated subtrochant femoral fractures with osteoporosis, it was recommended to use a locking plate for

internal fixation in the lateral lying position. Anatomical reduction and steel plate fixation can minimize the potential damage to the abductor mechanism, and the therapeutic effect is better. Latifi et al. [18] found through finite element analysis that when the locked steel plate treats subtrochanical fractures of the femur, it has always been better than the dynamic condylar screw and 130° angled steel plate in terms of stability and durability. Sain et al. [19] used proximal femur locking plate to treat 35 cases of Seinsheimer III and V-type femoral subtrochanical fractures. Postoperative fracture healing is better and the incidence of postoperative complications is low, indicating that the proximal femur locking plate has certain advantages in the treatment of unstable subtrochanical femoral fractures.

(2) Minimally invasive fixation system: Minimally invasive fixation system is a pre-formed steel plate, which combines minimally invasive internal fixation and fixed screws, and can place muscles between the backbone to reduce bone exposure. Chen Liang et al. [20] found that although there is no obvious difference in the operation time between the minimally invasive fixation system and the intramedullary nail fixation, the intramedullary nail fixation has more advantages in the treatment of femur rough subtropic fracture.

(3) Dynamic condylar screws and dynamic hip screws: Dynamic condylar screws were first used to treat distal intercondylar fractures of the femur in the 1870s. Because its steel plate shape is also suitable for the anatomical structure and biomechanical characteristics of the proximal femur, the treatment effect is accurate in the case of good transverse stable fracture reduction under the femoral bulge. The core structure of the dynamic hip screw includes a sliding screw with a hook and a pressurized screw, as well as an anti-rotary screw. These components are designed to provide more stable and reliable fixation, allow pressure between bone masses to move and promote fracture healing, but sliding will also cause the possibility for the screw to cut out of the femoral head, leading to the failure of internal fixation. Sowmianarayanan et al. [22] Through the finite element analysis of dynamic condylar screw, dynamic hip screw and proximal femur intramedullary nail, the results show that the dynamic condylar screw and dynamic hip screw will have more contact area at the fracture end, which can better promote fracture healing.

(4) 95° angle steel plate and 135° angle steel plate: Angle steel plate is a whole material, which avoids the problem of deformation or fracture of the mechanical strength of the part connected by Maxwell's goose head nail under stress, and also avoids the displacement after the internal fixation of low-level three-edged nail and V-shaped nail. It is an effective internal fixation. The main difficulty during the operation is to grasp the effective position of the angle steel plate on the three planes. Zhang Gonglin et al. [23] believe that compared with the 135° angle steel plate, the 95° angle steel plate is more stable and suitable for the fracture of the femur with complete pear-shaped fossa. Research by Kinast et al. [24] shows that indirect reduction and minimal soft tissue peeling can obtain better results in fractures accompanied by medial comminution. The disadvantage is that it is difficult to insert the steel plate, and the fracture reduction needs to be completed before insertion. Biomechanical studies such as

Forward et al. [25] show that the failure efficiency of 95° angle steel plate in cyclic pressure is higher than that of intramedullary nails.

4.3 Artificial Hip Replacement for the Treatment of Subtrochanteric Fractures of the Femur

For elderly patients, due to the declining physical function and bone mass, coupled with the large shear force in the subtrochanteric area of the femur, neither extramedullary fixation nor intramedullary fixation can guarantee the stability of the fracture [26]. Artificial hip replacement to treat subtrochanteric femoral fractures can cause early activity and reduce the risk of postoperative bone atrophy and long-term bedridden complications. However, clinical artificial hip replacement has strict indications for femoral subtrochanteric fractures, which is generally suitable for patients with severe osteoporosis, older age, and severe smashing of fractures.

5. Assisted Reduction Technology for Femur Fractures

5.1 Minimally Invasive Pliers Auxiliary Reset

Minimally invasive pliers assisted reduction is by using large bone-holding pliers at the incision until the bone comes into contact with the bone-holding pliers, and then tightening the large-holding bone-holding pliers around the fracture fragments. The fracture of the affected limb traction combined with the reduction pliers, tighten the reduction pliers after anatomical reduction, and maintain the reduction. Afsari et al. [27] used pliers-assisted reduction and intramedullary nail fixation to treat 55 cases of displaced femur rough lower proterum fractures. It was found that minimally invasive pliers-assisted reduction helped to achieve good fracture reduction effect and improve fracture healing rate. However, there are certain limitations in the assisted reset of minimally invasive clamps, which are suitable for simple transverse shapes. Fractures and short oblique fractures can maintain the stability of the medial and lateral cortex of the proximal end of the femur after reduction. For long spiral or long oblique fractures, the fracture end may be displaced after loosening the pliers, so it is not suitable for simple minimally invasive pliers assisted reduction [28].

5.2 Locking Steel Plate Auxiliary Reset

The auxiliary reduction of the locking steel plate is to dispose of the appropriate length of the locking steel plate in the surgical incision. After the traction of the affected limb is reset well at the fracture end, 2 or 3 screws are placed at the far and proximal end of the fracture to fix and maintain the reduction. Huang Xiaochuan et al. [29] compared the clinical effect of auxiliary locking steel plate combined with intramedullary nail fixation and simple intramedullary nail in the treatment of subtrochanteric fracture of the femur. It was found that the effect of auxiliary locking steel plate combined with intramedullary nail fixation, postoperative function recovery and fracture healing time were better than simple intramedullary nail fixation. Wang et al. [30] found that although the auxiliary locking steel plate combined with intramedullary nails, although the operation time and treatment cost increased, it has more advantages in improving

the quality of fracture reduction, shortening the full load and fracture healing time, and improving the function of the hip joint.

5.3 Metal Wire Auxiliary Reset

Ring ligation is a way to fix fractures through various forms of ring ligation. Because the rough lower femur fractures are mostly unstable fractures, ring ligation can be used to effectively reset complex fractures by ring ligation wire (steel wire or titanium cable). In most cases, 1 or 2 ring strands are used. The research of Hong Shengkun et al. [31] shows that the method of limited incision combined with wire-assisted reduction can effectively fix the medial structure of the proximal end of the femur, make its mechanical support more stable, avoid proximal abial abduction and abnormal deformity of fractures, thus promoting fracture healing and reducing the risk of complications. The retrospective controlled study of Rehme et al. [32] shows that the combined application of ring ligation can improve the stability of fracture reduction and intramedullary nail placement. Compared with patients without ring ligation, the long-term function results are significantly better. Kilinc et al. [33] confirmed that incision reduction and the use of ring ligation have no negative impact on fracture healing. Anatomical reduction fracture formation of medial support can prevent the failure of internal fixation and provide a basis for fracture healing.

6. Summary

In summary, clinical therapists should fully understand the anatomical characteristics of the fracture area of the femur and the characteristics of each type, clarify the fracture classification, carefully study the characteristics of various internal fixation instruments and reduction techniques, and improve the preoperative evaluation and preparation to ensure the smooth operation. According to the biomechanics and anatomical characteristics of the fracture under the femur, attention should be paid to protecting the soft tissue in the fracture area during the operation, avoid excessive dissection of the periosteum, and the proximal end of the femur is rich in blood supply and complex blood vessels. The surgeon should have a clear understanding and judgment to prevent iatrogenic vascular injury.

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