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Advances in the Treatment of Anterior Cruciate Ligament Tibial Insertion Avulsion Fractures

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Abstract: Anterior cruciate ligament (ACL) tibial insertion avulsion fracture is a bony avulsion injury at the ACL tibial insertion site caused by trauma. Although clinically uncommon, with an annual incidence of approximately 3 per 100,000, it represents an intra-articular fracture that often compromises knee stability due to concomitant ACL functional impairment and meniscal injuries, causing significant clinical challenges. Consequently, the selection of appropriate internal fixation methods and surgical approaches is critical. Current debates persist regarding optimal surgical strategies for different fracture subtypes. This review systematically summarizes recent advances in the management of ACL tibial insertion avulsion fractures.

Keywords: Anterior Cruciate Ligament; Tibial Insertion Avulsion Fractures; Internal Fixation; Surgical Approaches.

1. Introduction

Anterior cruciate ligament (ACL) tibial avulsion fractures are osseous avulsion injuries at the tibial insertion of the ACL caused by trauma, which are not commonly seen clinically, with an incidence of about 3 per 100,000 per year [1]. Previous studies have suggested that due to the mechanical weak zone caused by the immature development of the proximal tibial epiphysis in adolescents, ACL tibial avulsion fractures are more common in children aged 8 to 14, and the cause of injury is often related to cycling [2]. In recent years, sports injuries have become the main cause of adolescent ACL tibial avulsion fractures [3]. With the increase in sports injuries, traffic injuries, and falls from height, the incidence of ACL tibial avulsion fractures in adults is also on the rise, accounting for about 14% of all ACL injuries [4]. Since the ACL is an important structure for maintaining anterior and rotational stability of the knee joint, ACL tibial avulsion fractures may lead to knee joint instability and cause secondary injuries to other intra-articular structures, affecting knee function, and therefore require active and reasonable intervention [5].

2. Fracture Classification and Treatment Options

According to the fracture classification established by Meyers, Zaricznyj, et al. [6], tibial avulsion fractures of the ACL are mainly divided into four types. Type I fractures have no displacement or minimal displacement, and there is no limitation in knee extension; Type II fractures involve the anterior 1/3 or posterior 1/2 of the avulsed bone fragment being elevated, connected to the tibial plateau either anteriorly or posteriorly; Type III fractures are completely displaced and rotated; Type IV fractures are comminuted fractures with complete displacement. Type I fractures can be treated conservatively, with the affected knee fixed in a flexed position of 20° to 30° or in extension using plaster or a knee brace [7-10]. Compared to fixation in extension, fixation in slight flexion may lead to limitation of knee extension in the short term, but the long-term outcomes are equivalent for both. The duration of fixation is determined by the healing of the fracture, typically 4 to 6 weeks, which can be extended to 8 weeks [8]. For displaced Type II to IV fractures, conservative treatment can lead to complications such as nonunion, knee instability, intercondylar notch impingement, and residual intra-articular bodies [6-8]. Fyfe et al. [7] believe that fractures with displacement less than 5mm, which are not obviously displaced, can be treated conservatively. Leeberg et al. [1] point out that a fracture displacement of no more than 2mm is acceptable. Qi et al. [9] found that the nonunion rate after conservative treatment for completely displaced fractures is high. Arroume et al. [11] reported that the incidence of knee instability in non-surgical treatment of tibial avulsion fractures of the ACL can range from 0 to 67%. Type III and IV fractures, which are completely displaced, often require surgical intervention [7, 10]. Type II fractures can attempt closed reduction, but due to soft tissue interposition between the fracture ends and the tension of the anterior horn of the meniscus, reduction failure is common, and long-term plaster or brace external fixation can lead to complications such as quadriceps muscle contracture and joint adhesions. Therefore, most scholars recommend surgical treatment [12, 13]. Traditional open surgery causes significant soft tissue damage, heavy joint interference, obvious postoperative pain, long hospital stays, and slow rehabilitation, and is no longer used as a routine method [10]. With the development of arthroscopic technology, arthroscopic fracture reduction and internal fixation have become the preferred treatment for such fractures, offering advantages such as minimal trauma, less joint interference, and rapid postoperative recovery, while also allowing for better observation and treatment of intra-articular concomitant injuries [10]. The surgical approach usually employs the conventional anteromedial and anterolateral approaches of knee arthroscopy. Some scholars believe that the conventional approach is too close to the fracture site, which is not conducive to arthroscopic observation and manipulation, and suggest using a high patellofemoral medial or lateral approach for surgery, which can reduce interference from the infrapatellar fat pad and the meniscus transverse ligament, better observe the fracture site, and perform reduction and fixation of the fracture [13]. The application of the anterior cruciate ligament (ACL) reconstruction tibial guide, suture hooks, and suture passers significantly enhances the precision and success of arthroscopic procedures.

3. Selection of Internal Fixation

With the increasing maturity of arthroscopic technology and the continuous enrichment of internal fixation materials, the methods of fracture reduction and fixation under the arthroscope are also becoming more diversified. Clinically, the internal fixation materials used for ACL tibial avulsion fractures mainly include Kirschner wires, steel wires, sutures, screws, suture anchors, TightRope®, and EndoButton®, each with its own advantages and disadvantages.

3.1. Kirschner Wire and Tension Band Wiring Fixation

Kirschner wire fixation and wire fixation are earlier methods applied in clinical practice [4, 14]. Kirschner wires are smooth and have a small diameter, allowing them to fix small bone fragments with minimal damage to the epiphyseal plate of children, and they are still used by many scholars to treat tibial avulsion fractures of the ACL in children [9, 15]. Havlas et al. [15] treated 35 pediatric patients with crossed Kirschner wire fixation, and the average Lysholm knee function score was 98.6 points at the two-year follow-up, indicating satisfactory results. Due to the small friction force between the Kirschner wire and the bone fragment, the holding power on the bone fragment is poor, unable to create compression between the fracture ends, and lacking sufficient anti-rotational effect, the fixation is not very stable, requiring a longer period of immobilization post-surgery, and thus they are less commonly used in adult patients. Nakagawa et al. [16] achieved compression at the fracture ends by bending the ends of the Kirschner wires, thereby increasing the stability of the Kirschner wire fixation, allowing patients to bear weight and perform functional exercises earlier post-surgery. Wire fixation is economical in material and has a good tensile strength, and by the wire extraction method, it can assist in reducing fractures, tightening and compressing the fixation on the medial side of the tibial tuberosity. Ding et al. [17] treated 15 adult patients with wire fixation, all fractures healed well, and there were no cases of knee instability at the two-year follow-up, with an average Lysholm knee function score of 97.5 points. The authors believe that wire fixation is stable, the fixed area of the bone is the footprint area of the ACL, which does not cause cutting damage to the ACL, and it can be applied to type II to IV fractures, with a wide range of indications. However, the compliance of the wire is relatively poor, and if the operation is not skillful, there can be difficulties in threading the wire during surgery. During the tightening of the wire, there may be situations of bone marrow canal cutting or wire breaking [18]. If exercises are started too early post-surgery or the wire is not removed in a timely manner, leading to wire breakage, this is a disadvantage of wire application. To improve the fixation strength, some scholars have combined the use of Kirschner wires and wires, fixing the ACL tibial avulsion fractures through a tension band method, with satisfactory biomechanical test results [19].

3.2. Suture and Screw Fixation

Suture fixation and screw fixation are currently the most commonly used methods of fixation [10]. Suture fixation has low treatment costs and a wide range of indications. It involves ligation or suturing of the ACL base and then pulling through the tibial tunnel to tie off, which can be used for comminuted fractures and pediatric fractures. There is a variety of fixation techniques, including suture fixation, ligation fixation, "8" fixation, "three-point" fixation, "four-point" fixation, etc. [20-23]. There are also many types of sutures available, including Vicryl, PDS, Ethicon, and high-strength sutures. The main advantages of suture fixation are good stability and the absence of a need for secondary surgery to remove them. Ahn et al. [24] treated fresh and old ACL tibial avulsion fractures with suture fixation, and at the 4-year follow-up, the anterior drawer test, Lachman test, and pivot shift test were all negative, with all patients returning to their pre-injury level of activity. Verdano et al. [25] treated 22 adult patients with absorbable sutures, and at 8 weeks post-surgery, the fractures had healed, with the Lysholm knee function score and Marshall test results being excellent at the 2-year follow-up. To reduce stimulation of the epiphyseal plate, some scholars have adopted fixation methods that avoid the epiphyseal plate [20]. Gamboa et al. [21] designed a suture lever reduction fixation technique, which achieves satisfactory fracture reduction through suture traction alone and increases the stability of the fracture fixation through "three-point" fixation. Boutsiadis et al. [22] proposed a "four-point" fixation method, where two number 5 Ethicon sutures are used to ligate the ACL base from the front and back, allowing simultaneous fixation of the ACL anteromedial bundle and posterolateral bundle tibial insertion points, with a wider range and greater strength of fixation. Of course, suture fixation also has some issues. Like wire fixation, suture fixation may result in bone tunnel cutting. To reduce this risk, it is required that the tunnel outer mouth be 1cm to 2cm away when establishing the bone marrow tunnel. Additionally, if the bone tunnel is improperly positioned, there may be unsatisfactory reduction of the fracture fragments. Extensive research has shown that screw fixation is an effective method for treating ACL tibial avulsion fractures [10, 26-28]. Jain et al. [29] reported on 45 cases treated with cannulated screws, and at the 5-year follow-up, there were no special complications, knee range of motion was satisfactory, and the Lysholm knee function score averaged 86 points. Screw fixation has reliable strength, simple surgical operation, strong repeatability, but there are issues such as intercondylar notch impingement, meniscus and cartilage damage, and the need for secondary surgery to remove them. For this reason, some scholars use countersunk screws or absorbable screws for fixation, with satisfactory results [27, 28]. Mahar et al. [30] showed in their biomechanical study that absorbable screws also have good fixation strength. Due to the larger diameter of the screws, if the fracture fragments are too small or if there is improper intraoperative manipulation, iatrogenic fractures can easily occur. For comminuted fractures, they cannot be well fixed, and for pediatric fractures, they can easily damage the epiphyseal plate, leading to abnormal proximal tibial development, thus limiting their clinical application [31, 32]. To avoid epiphyseal plate damage, some scholars use short screws for complete epiphyseal internal fixation to treat pediatric ACL tibial avulsion fractures. Najdi et al. [33] treated 24 cases, and at the 2-year follow-up, knee function was satisfactory, with no epiphyseal plate damage or growth arrest found. Regarding the advantages and disadvantages of the efficacy of the two fixation methods, suture and screw, there is currently a lack of more systematic research. Pan et al. [34] compared 25 cases of screw fixation with 23 cases of suture fixation, and the results showed that the screw fixation group had higher postoperative IKDC knee function scores, better knee stability, and shorter operation times. However, from the perspective of fixation strength, numerous biomechanical studies have shown that suture fixation has an advantage [35].

3.3. Other Fixed Methods

To improve the stability of fixation and allow patients to engage in functional exercises and resume daily activities earlier post-surgery, several new fixation methods have emerged. Deng Yong et al. [36] summarized 19 cases of "8" figure suture fixation and 24 cases of suture anchor treatment for ACL tibial avulsion fractures. Both postoperative knee joints were stable and functional, with no related complications. Sawyer et al. [37] drew on the suture bridge technique used for rotator cuff injuries and humeral greater tuberosity fracture repair, combining sutures and external row anchors for fixation. Anchor fixation has many advantages, with its strength surpassing that of sutures and screws, suitable for comminuted fractures, without the risk of epiphyseal plate damage, and no need for a secondary surgery to remove internal fixation. However, the all-arthroscopic operation is more complex, requiring the surgeon to have proficient arthroscopic suturing and knot-tying skills, and the learning curve is relatively long. Additionally, the treatment cost with anchors is relatively high. In recent years, the application of Tightrope® and Endobutton has also provided new options for the surgical treatment of such fractures, and similar fixation methods have been used for the treatment of acromioclavicular joint dislocations and distal tibiofibular joint injuries, achieving good results [38-40]. Boileau et al. [41] used the Button system for fixation during arthroscopic shoulder joint dislocation bone blocking surgery and found that its stability and bone healing rate were superior to screw fixation. In the ACL tibial avulsion fracture cases of Loriaut et al. [40], patients were allowed to fully bear weight immediately post-surgery, began swimming and cycling training at 8 weeks post-surgery, and at the 2-year follow-up, the fractures had healed well and knee joint function was satisfactory. Theoretically, the Button system fixation has a larger contact area between the implant and bone, with fixation strength superior to sutures, screws, and anchors, which is beneficial for fracture healing and early functional exercise [41]. Due to the limited current clinical application, its exact efficacy and advantages require further research to confirm.

4. Prognosis

If diagnosed and treated in a timely manner, nonunion of fractures rarely occurs. Gans et al. [9] summarized the treatment outcomes of 580 patients, with only 10 cases of nonunion, of which 4 were in the surgical treatment group and 6 in the non-surgical treatment group. Due to the involvement of minors, improper handling may lead to abnormal development of the proximal tibial epiphysis. Case reports of knee joint deformity caused by epiphyseal plate injury can be seen in the literature [31, 32]. Knee joint instability and limited mobility are the main complications of ACL tibial avulsion fractures. In fact, whether treated conservatively or surgically, knee joint instability may occur. When the injury occurs, the ACL is stretched and lengthened, and even with anatomical reduction of the fracture, anterior instability of the knee joint may occur [42]. Li Bing et al. [43] believe that for patients with fresh ACL tibial avulsion fractures of Meyers & Mckeever type III and IV who are willing to undergo surgery and have combined anterior instability of the knee joint, surgical treatment should be actively pursued for early recovery of knee function. Morag et al. [44] pointed out that with growth and development, the laxity of the ACL can be compensated to some extent, so the prognosis is better for younger patients. Although not all instabilities cause clinical symptoms, they will adversely affect the long-term function of the knee joint. If there is obvious ACL anterior instability, ACL reconstruction is required. With the advancement of concepts and technology, the treatment outcomes of ACL tibial avulsion fractures have been improving, and most patients can return to their pre-injury activity levels. However, postoperative knee joint adhesion, fibrosis, and limited mobility remain an important issue that needs to be addressed in clinical practice. This may be related to factors such as patient age, gender, physical constitution, treatment method, and surgery time. Studies have shown that adult patients are more prone to knee joint adhesion than children, and that a time from injury to surgery greater than 7 days and a surgery time exceeding 2 hours are risk factors for postoperative joint fibrosis [45]. Osti et al. [10] retrospectively analyzed 312 patients treated surgically, of which 13.5% had varying degrees of postoperative knee joint mobility limitation, with 18 cases of flexion limitation and 21 cases of extension limitation. Montgomery et al. [46] reported that 53% of patients experienced severe postoperative knee joint mobility disorders, of which 24% required arthroscopic surgery for release and 24% required manual release under anesthesia. The lack of a reasonable postoperative rehabilitation program and the inability to perform early functional exercises may be an important reason for this problem. Due to the different types of fractures, the stability and reliability of various fixation methods also vary, and a unified postoperative rehabilitation program has not yet been established. In many studies, to avoid failure of internal fixation and fracture displacement, postoperative bracing immobilization is usually required for 3 to 4 weeks [47]. Through more reliable fixation materials and methods, early appropriate knee joint flexion and extension functional exercises can reduce the occurrence of joint adhesions and promote the recovery of joint function.

5. Summary

There is no standardized treatment protocol for ACL tibial avulsion fractures. Non-displaced fractures can usually be treated conservatively, while displaced fractures are recommended for surgical intervention. Open surgery is traumatic, has a slow recovery, and has many complications; arthroscopic surgery should be the preferred option. The choice of internal fixation materials and methods should be individualized based on factors such as the patient's age, the type of fracture, the surgeon's experience, and the patient's financial situation. Postoperative rehabilitation is important, and it is best to choose a fixation method with reliable fixation strength that can meet the needs of early functional exercise after surgery.

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