25 Basic Concepts in Revision Anterior Cruciate Ligament Reconstruction

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In recent 10 years, anterior cruciate ligament (ACL) reconstruction surgery has been rapidly popularized, and the total number of patients undergoing reconstruction has increased significantly. However, more and more patients have failed or suffered various complications after ligament reconstruction, which brings introspection and challenges to our clinical work.

The concept of clinical failure after ACL reconstruction is broad. In general, failure of restoration of sports function after ACL reconstruction is considered a clinical failure. Clinical failure can also be defined as a significant harmful effect on daily life function due to joint pain and limited range of motion. Literally, any reoperation after ACL reconstruction is called revision surgery, such as the release for joint stiffness after ACL reconstruction and debridement for wound or joint infection.

In this context, ACL revision surgery refers only to ligament reconstruction-related surgery after ACL reconstruction due to poor knee stability. After ACL reconstruction with the artificial ligament, if the knee motion is significantly limited due to improper positioning, the artificial ligament should be removed for reconstruction. The surgical plan is like that for the recurrence of knee instability after ligament reconstruction with autograft or allograft.

The task of ACL revision surgery is much more difficult than that of primary reconstruction (PR). First, it is crucial to determine why the previous operation failed so that the same mistake cannot be made again. Secondly, it is necessary to overcome or eliminate the influence of previous surgery on the expected surgery, such as the interference of the internal fixation and the tunnel. Thirdly, every step of ligament reconstruction, from the selection of the graft to the final fixation, requires the selection of the best reconstruction method. Finally, the best method of rehabilitation should be chosen.

The Causes of Failure After ACL Reconstruction

There are many reasons for failure after ACL reconstruction [1, 2]. In a case of failure after reconstruction, these causes may exist at the same time, but usually one is dominant. The causes of failure can be categorized in three types: PR-nonrelated type, PR strategy-related type, and PR-tactic related type. In primary ACL reconstruction, three rules, which include

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ultra-strong reconstruction, correction of bony abnormalities such as high posterior tibial slope, varus knee, and femoral notch stenosis and addressing soft tissue abnormalities such as general laxity and anterolateral stability deficiency, should be followed. When the three rules are abided by, a super stable knee without unfavorable combined situations should be obtained, and the ACL reconstruction failure at this level is not related to the specific techniques and strategies taken. The reasons of failure at this level include mainly failed graft ligamentization or severe trauma. Special measures should be taken to address the failed graft ligamentization and avoid severe trauma during sports. When any of the three rules are not abided by, such as in the case the high posterior tibial slope or high anterolateral instability is not addressed, the cause of failure is related to PR strategy. Special attention should be paid to the rules not followed in primary surgery. Otherwise failure will be doomed following the revision. The technique-related causes are the lowest level, such as tunnel location error or fixation failure. When the failure predictors involved in all three levels, such as the combination of wrong femoral tunnel location, weak graft chosen, and ligamentization deficiency, the failure of primary ACL reconstruction is inevitable.

The specific causes of ACL failure after reconstruction can be divided into four categories, namely, trauma, surgical technique error, failed graft healing, and failed graft ligamentization.

Trauma

Trauma is a common cause or inducement of ACL failure after reconstruction. A detailed history should therefore be taken to determine whether it is a traumatic failure following successful ligament reconstruction or a failure based on poor ACL function following ligament reconstruction. For patients with ACL reconstruction, the initial reconstruction is successful if the patient has good clinical stability of the knee joint, good image signal of the ligament, and has returned to contact sports within a period after reconstruction. These patients tend to have more serious new injuries, such as jumps from playing basketball or handball or severe sprains from football.

More patients may have traumatic failure based on poor ligament function after ACL reconstruction. If the patient has poor recovery of knee stability after the primary ACL reconstruction, poor signal of ligament in imaging examination, and no recovery of cutting and pivoting function after the first ACL reconstruction, the initial reconstruction is not successful. This requires detailed postoperative information to judge. Without detailed follow-up and lack of clinical data, especially stability examination and imaging data, it is indeed difficult to determine whether the patients were successful before the trauma and after the first operation.

Restoration of sports status after primary surgery alone does not mean successful ligament reconstruction. In some patients, which are classified as coper, the ligaments have been completely absorbed on image examination after ligament reconstruction, but they still have good sports function. There are many reasons for this, but in general, these patients face a higher risk of re-injury.

In some patients, ligament failure after reconstruction is not due to severe trauma but due to overly aggressive rehabilitation. In these patients, early clinical examination showed reliable joint stability and good image signals and intermediate stage of overly aggressive rehabilitation without significant trauma followed by ligament failure. At present, the rehabilitation protocol after ligament reconstruction basically follows the aggressive and safe rehabilitation plan. If it is too aggressive, it obviously violates the law of graft healing and remodeling.

Surgical Technique Error

The most common error is that the graft is not strong enough. After implantation, the graft undergoes the process of necrosis and revascular-

ization, and the final strength is much lower than the initial strength. Using ultra strong grafts initially is reasonable to ensure the final strength of the ligament after remodeling. Four-stranded hamstring tendon graft may not be strong enough in most cases, and eight- to ten-stranded graft is recommenced [3].

Another common error is malposition of the tibial and/or femoral tunnel. Too anterior, medial, or lateral placement of the tibial tunnel may cause impingement of the graft by the femoral notch. Too posterior placement of the tibial tunnel results in the graft in a vertical position and less control over the anterior stability of the knee. Too anterior placement of the femoral tunnel causes the graft to overextend and fail as the knee is flexed. The main reason for the anteriorization of the femoral tunnel is that the angle between the tibial tunnel and the tibial axis is too small when the femoral tunnel is located through the tibial tunnel, and that the distal edge of the intercondylar ridge (resident ridge) is mistaken as its posterior edge. Mispositioning of the femoral tunnel too close to the top at 12 o'clock may result in graft impingement with the PCL and range of motion limitation [4].

When the implant is subjected to more tension than the elastic changes it may cause graft laxity, leading to instability. During posterolateral bundle reconstruction of the ACL, if the graft is tensioned and fixed at 90° flexion, the graft may fail due to overstretching during knee extension.

Overlooking Combined Structural Deficiency

High posterior tibial slope, varus knee, general laxity, high anterolateral instability, femoral notch stenosis, and so on are the risk factors of failure following ACL reconstruction. Correction of the posterior tibial slope and lower limb alignment, addressing general laxity and anterolateral instability by anterolateral structure reconstruction, and femoral notch plasty are critical in these conditions. Overlooking these risk factures may result in reconstruction failure.

Failed Graft–Tunnel Healing

The incidence of graft–bone tunnel nonunion is unknown, but it is generally believed that the causes are related to graft tunnel mismatch (too large tunnel) and unreliable fixation and may also be related to the material used. Animal experimental studies have proved that the healing time after allograft ligament reconstruction is prolonged. In clinical practice, it is often found that the tunnel is enlarged after ligament reconstruction, and its cause and significance remain to be studied. Although no relationship between this phenomenon and functional status has been found, tunnel enlargement may be related to graft healing or may be a precursor to graft failure.

Second-look arthroscopy of some patients after reconstruction demonstrated that graft revascularization and ligament–tunnel healing were accomplished in most cases, while no vascularization was shown in some cases. Whether there are specific individuals whose graft–tunnel healing after ligament reconstruction are impossible remains to be studied.

Failed Graft Ligamentization

In some patients, the entire process of ligament reconstruction has been analyzed to be perfect, with no postoperative trauma or overly aggressive rehabilitation, but magnetic resonance imaging (MRI) review 3–6 months after the surgery reveals that the graft in the joint is largely or completely absorbed.

This phenomenon is most common in patients with allogeneic tendons and may be related to the handling of the tendons, such as the fragmentation of collagen fibers of allogeneic tendons caused by excessive irradiation. Recent literature has reported that the failure rate of ACL reconstruction using allogeneic tendons is several times higher than that using autogeneic tendons, suggesting that we need to carefully consider the selection of grafts [5, 6].

However, it is true that there are some patients with unexplained graft absorption, even when autologous tissue is used. The specific

mechanism is not clear, it may be the defect of collagen formation or collagen remodeling ability, or the local over-absorption reaction caused by reconstruction surgery. For these patients, revision with biological tissue materials may be a repeat of the same experience, and artificial ligaments may be considered. Patients who had been infected after ACL reconstruction are prone to ligamentous absorption, which may be related to lysosomal tissue destruction during infection.

Strategies and Indications of Revision Operation

The primary indication for ACL revision surgery is failure and recurrence of symptoms after reconstruction. In this respect, the indications for revision surgery are like those for primary reconstruction. Decisions about revision are closely related to the patient's expectations. An elite athlete wants to return to the sports field. General patients only require joint stability to be able to adapt to daily work and maintain a static lifestyle. Patients must be informed preoperatively that revision surgery may need to be done in two stages and that the postoperative outcome is not as good as that after primary reconstruction. If patients have arthritis or other complications, their function cannot be fully restored. Therefore, physicians should choose the best treatment according to the patient's expectation of the operation and the goal that the operation can achieve [7–9].

ACL revision surgery can be performed in two ways. One is a staged procedure, in which the joint is cleared first and the bone defect caused by the original ligament reconstruction is amended by bone grafting, followed by a second stage of reconstruction. This seemingly complex approach simplifies revision surgery, turning all revision surgery into two parts, namely addressing bone defect and ligament reconstruction that allow for better control of the outcome [8]. The other is one-stage reconstruction, in which ACL reconstruction is performed while the bone defect is avoided, utilized, or overcome [10–12]. The complexity of this one-stage procedure increases the degree of unpredictability of the outcome. Therefore, if the original bone tunnel and internal fixation have no effect on reconstruction, a one-stage revision is recommended. If the original bone tunnel or internal fixation interferes with the reconstruction, it is recommended to perform it in stages to ensure the effect of the second reconstruction.

Preoperative Planning and Preparation

The supreme goal of revision surgery is to obtain a knee with function better than that following the primary surgery. When the causes of the failure of primary reconstruction have been defined and measures are taken accordingly, this goal in not inaccessible. However, the clinical results of revision ACL reconstruction are not comparable to that of primary surgery, which may be mainly due to those measures are not necessarily taken at the three levels addressing specific causes of failure, and the internal environment of the knee at revision surgery is unfavorable that that at primary surgery [13, 14].

Review of Medical Histories

Primary and post-reconstruction mechanisms of injury can be helpful in diagnosis. Patients often describe pivot-shift injuries with noise, followed by swelling of the joint. Patients should be asked if they have giving-away. It should be found out as much as possible about the patient's previous surgery, including initial diagnosis, surgical notes, arthroscopic photos, grafts used for reconstruction, relevant pathology (integrity of meniscus, cartilage, and other ligaments), and details of the reconstruction instruments. You also need to know what rehabilitation plan the patient was following.

Physical Examination

Carefully examine the gait, lower limb line and previous surgical incisions. In addition to looking for anteroposterior knee laxity, check for varus-valgus and rotational stability. The range of motion of the affected knee was recorded and compared with that of the unaffected side to determine whether there was any reduction in range of motion. The most common examination instruments for the objective degree of laxity are KT-1000 or KT-2000. However, if the examiner does not know the standard testing method, the results may not be reliable.

Imaging Examination

Imaging examination can supplement the history and physical examination, explain the cause of failure, and provide information on the position and state of the graft and the surrounding bone and soft tissue. Routinely anterior–posterior and lateral view radiography, CT and MRI imaging examinations are taken. Tunnel enlargement, posterior tibial slope, and lower limb alignment are evaluated. The condition of the patellofemoral joint is also evaluated. Imaging examination is helpful in determining the position and type of internal fixation and whether removal is required to prepare for the use of special instruments in revision surgery.

Selection of Grafts

As with the previous reconstruction, there are three types of grafts available for revision: autologous tissue, allogeneic tissue, and artificial ligament. At present, the biocompatibility of artificial ligaments is not a problem, and the strength can be compared with that of autografts. However, artificial ligaments, which do not heal with the bone, require mechanical fixation to keep the ligaments attached to the bone. Patients requiring ligament revision are not suitable for the use of artificial ligaments in case of bone defects and local osteoporosis. Of course, the use of an artificial ligament is recommended if the patient had an unexplained fibrous absorption, especially after the use of an autograft.

The use of allograft ligaments for revision has many advantages, such as easy availability of tissue, no donor site morbidity, short operation time, and the possibility of large bone plugs to fill osteolytic tunnels. The disadvantages of allogeneic tissue include delayed graft healing and widening of the bone tunnel, high probability of graft failure, and the presence of immune reactions [5, 6].

Some surgeons prefer to use autogenous hamstring tendon as the graft [15], which is often the preferred graft material due to the minimal donor site morbidity, especially following ACL reconstruction with bone–patellar tendon–bone (B-T-B). Other grafts include the quadriceps femoris tendon [16]. Zhao et al. developed an autograft source, the anterior half of the peroneal longus tendon (AHPLT), which has been proven to be reliable in many clinical applications and can be considered in ligament revision surgery [17].

Of course, the choice of graft for ACL revision depends on many factors, such as availability of this tissue, the anatomical location of the previous bone tunnel, the technical experience and habits of the surgeon, and the patient's wishes.

Revision Methods

The specific revision methods depend on all aforementioned factors reviewed. No universal method can be taken to address all the varieties [18, 19]. Two main principles should be followed. First, structure abnormalities, such as femoral notch stenosis, high posterior tibial slope, should be corrected and unfavorable conditions such as 3-degree positive pivot shift and general laxity should be addressed [20–24]. Second, ultra-strong ACL reconstruction should be taken. When artificial ligaments (ligament augmentation reinforcement system, LARS) are

used, we prefer double-bundle transtibial anatomical ACL reconstruction. These principles should be strictly followed in re-revision cases when we have the second opportunity to make up for all previous errors [25–27]. In case of ACL revision with autograft or allograft, we prefer a three-in-one procedure, in which we combined ACL reconstruction, ALS reconstruction and ITB transfer to address general laxity, high-degree pivot shift, subcritical posterior tibial slope along with the ACL deficiency [28].

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