OPERATIVE TECHNIQUE

Allogeneic Tendon Transplantation for the Treatment of Pathological Patellar Ligament Defect in Children: Technical Note and 4-Year Follow-Up

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Abstract

Objective: The absence of patellar ligament will bring about a severe negative impact on daily life. Many reconstruction techniques have been described in adults. However, there is a lack of technical introduction regarding the reconstruction of the patellar ligament in children. The purpose of this study was to report a surgical technique for reconstructing the patellar ligament in children.

Method: A retrospective analysis of the clinical data on a patellar ligament (tendon sheath fibroma) patient with allogeneic tendon reconstruction. An 8-year-old child with postoperative recurrence of left patellar ligament tumor was enrolled in our study. Anterior tibialis tendon allograft was used to reconstruct the patellar ligament after complete resection of the patellar ligament for the tumor. The tunnels were constructed on the deep surface of the tibial tubercle and the root of the quadriceps tendon (to decrease the harmful impact on patella development), respectively. The allogeneic tendon was passed through the tunnels above in the shape of "8," and the two ends of the tendon were attached to the bleeding bone bed at the inferior edge of the patella with suture anchors to achieve better bone-tendon healing. During the follow-up, the knee's range of motion and imaging manifestations were recorded.

Result: Postoperative pathology suggests chondromesenchymal hamartoma, a rare benign soft tissue tumor different from the previous operation (tendon sheath fibroma). During the 4-year follow-up, the patient's active range of motion of the knee achieved 0° to 120°; and the patient could walk normally without any external help. Physical examinations (the apprehension sign and J sign) showed no ligamentous instability or patellar ligament tenderness. Imaging analysis showed that the ratio length of the patellar ligament to the patella was almost normal. The integrity, continuity, and shape of the allogeneic ligament showed excellent results in MRI. Combined with clinical and imaging findings, allogeneic tendon patellar ligament reconstruction was deemed successful.

Conclusion: Allogeneic ligament reconstruction technique can provide a treatment option by reconstructing the extensor mechanism, minimizing the impact on patellar development, and augmenting biological healing for children with the absence of the patellar ligament.

Key words: allogeneic tendon; patellar ligament; reconstruction; tumor

Introduction

The patellar ligament is one of the four compositions that make up the extensor mechanism in the knee and plays an essential role in the process of knee extension. The absence of the patellar ligament, such as a ligament tumor around the knee that had been resected, can lead to dysfunction of the extensor mechanism and have serious negative effects on daily life. Although the probability of a tumor

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occurring on the patellar ligament is extremely rare, there have been several reports in recent years[1–3]. Surgical resection is the mainstay curative treatment for patellar ligament tumor patients. However, tumor resection will inevitably lead to the defect of patellar ligament and knee extension disorder. How to reconstruct the patellar ligament is a challenge.

There is currently no consensus on the best method to reconstruct the knee extensor mechanism[4]. Numerous techniques for patellar ligament reconstruction, including autologous tendon transfer or local transplantation[5], synthetic materials[6], and allograft tissue[7], have been reported. In terms of traditional patellar ligament reconstruction techniques, establishing a bone tunnel on the patella is often required[8]. However, constructing a bone tunnel on the patella of young patients might affect the development of the patella. Therefore, we present a different technique for the patellar ligament reconstruction by using the soft tissue tunnel between the superior patella and the quadriceps femoris tendon, to reduce the impact on patellar development, which is the highlight of this surgical technique. The challenge remains: to restore the full extensor function of the knee.

Herein, we describe the use and long-term success of a surgical technique using anterior tibialis tendon allograft for the reconstruction of the patellar ligament after complete resection of the patellar ligament caused by the tumor. The aim of the surgical technique was to restore knee extension mechanism integrity and knee function in a child.

Patient and Methods

Patient Presentation

Our case was a 8-year-old child who had undergone the first surgical resection for the patellar ligament tumor (tendon sheath fibroma) of the left knee before this hospitalization. The tumor was resected as far as possible while ensuring the integrity of the patellar ligament in the primary operation. Unfortunately, half a year after the first operation, the tumor recurred. Physical examination of the left anterior knee region revealed the longitudinal excision scar and tumor between the

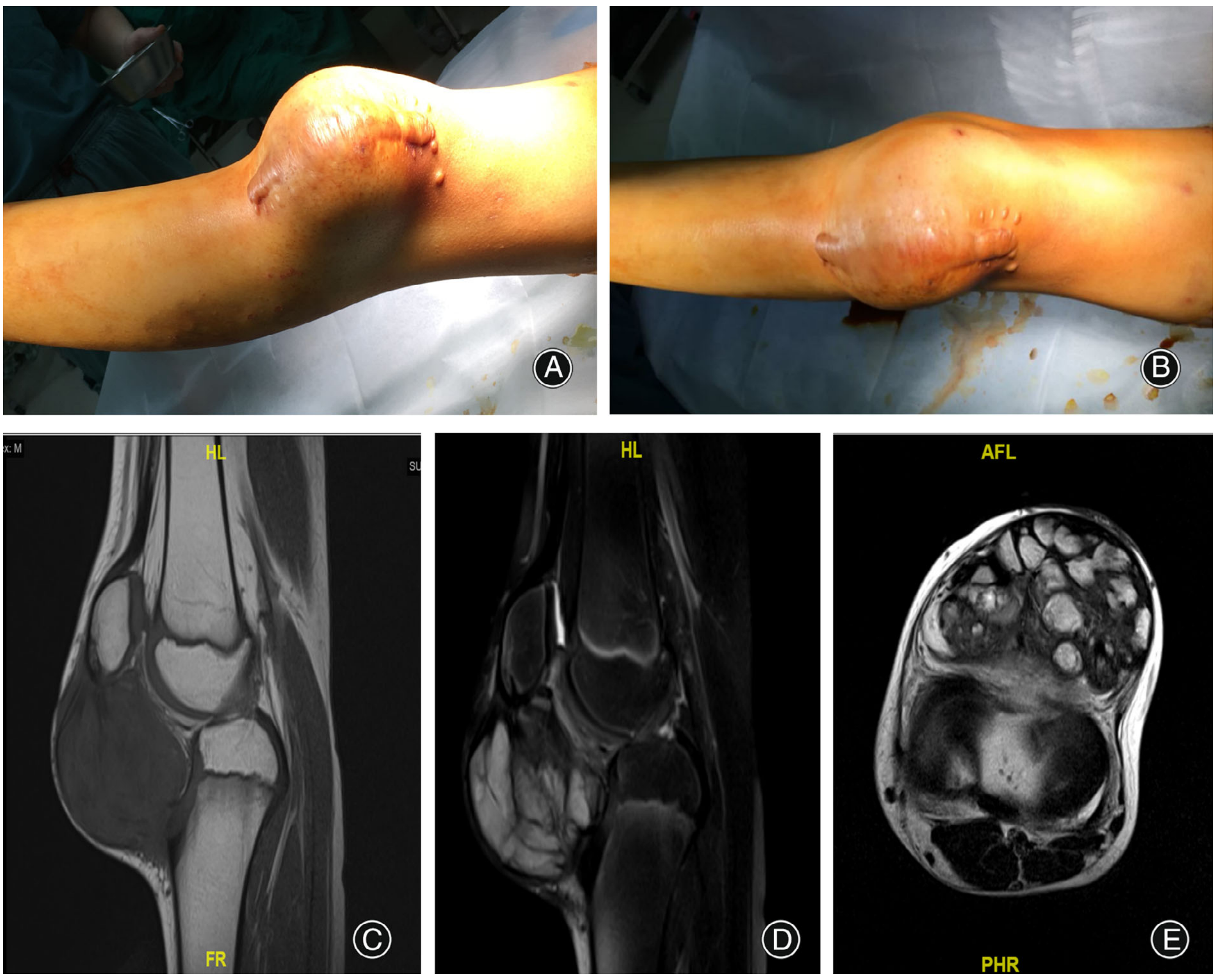

Fig. 1 Preoperative assessment of patellar ligament in gross appearance and imaging. Gross appearance of patellar ligament tumor (A, B). The tumor showed equal signal intensity on MRI T1 (C) and slightly high signal intensity, mixed strip low signal area on MRI T2 (D, E)

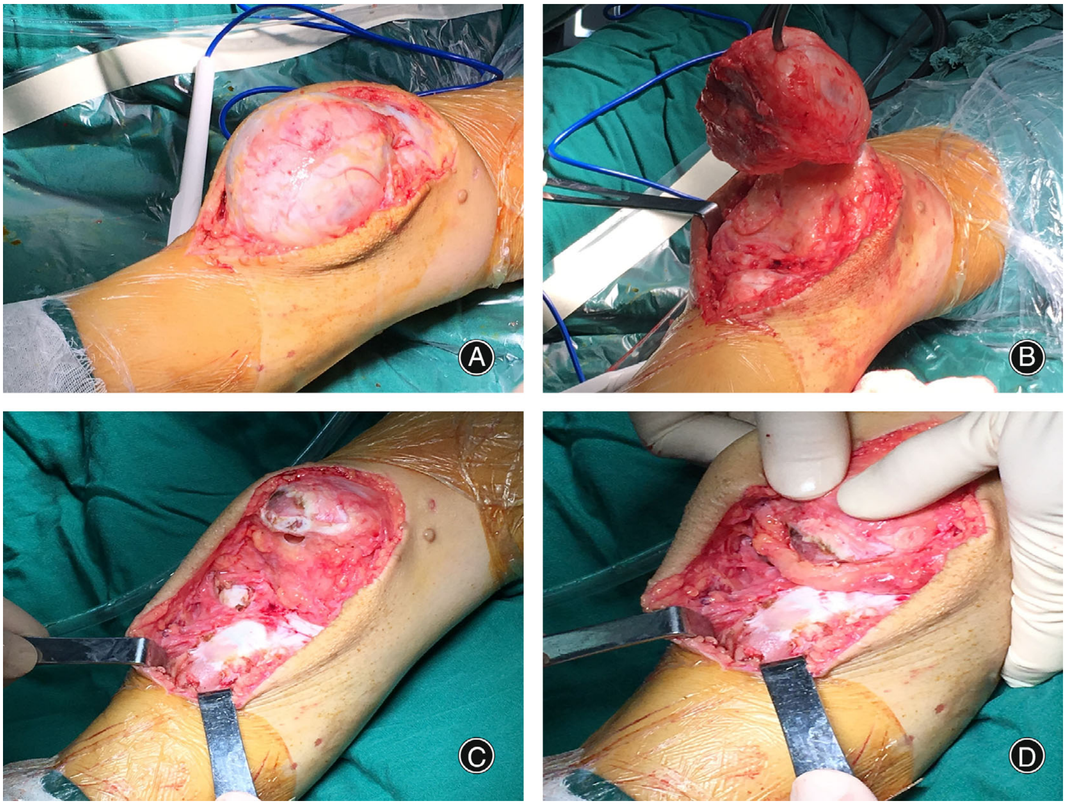

Fig. 2 Intraoperative evaluation of patellar ligament. The tumor shows infiltrative growth of patellar ligament (A, B). The tumor and the infiltrated patellar ligament were resected completely (C, D)

inferior patella and the tibial tuberosity (Figure 1(A,B)). No apparent abnormalities can be found in the active and passive mobilization of the knee. However, the magnetic resonance imaging revealed a well-circumscribed ligament tumor involving the entire patellar ligament (Figure 1(C–E)). Therefore, the preoperative diagnosis was considered the postoperative recurrence of the patellar ligament tumor. Considering such circumstances happened in a child, the preoperative plan was finalized for complete resection of the patellar ligament and allogeneic tendon reconstruction for it may be difficult to obtain an acceptable tendon from himself. Reconstruction of the patellar ligament with allogeneic tendon was an ideal candidate for a patient with these conditions: (i) chronic patellar ligament rupture; (ii) complete removal of patellar ligament due to soft tissue tumor of the knee; (iii) failure of the previous reconstruction of the patellar ligament with an autologous tendon. Exclusion included: (i) severe bone defect of the knee; (ii) severe infection of the knee; (iii) dysfunction of the femoral nerve or quadriceps muscle[9].

Surgical Technique

Anesthesia and Position

After successful general anesthesia, the patient was bound with an inflatable tourniquet at the proximal end of the left thigh, and the pressure was maintained at 25 kPa during the operation. A lateral stress column was placed at the level of the tourniquet to perform lateral X-ray radiographs of the knee conveniently during the operation. It was then routinely sterilized and covered with aseptic operating towels in the operation area.

Resection of Patellar Ligament Tumor and Evaluation Loss of Patellar Ligament

The original surgical approach for the primary operation was taken. After the fibrous tissue around the tumor had been resected, a tumor with the size of 7*5*5 cm had been exposed in surgical field of view (Figure 2(A)). The tumor was characterized by hard texture and poor mobility and showed infiltrative growth of the patellar ligament (Figure 2(B)). Due to the extensive infiltration of the tumor, part of the patella and tibial tubercle were resected entirely along with the patellar ligament and sent for pathological examination (Figure 2(C,D)). Check cautiously to make sure there was no residual tumor in the knee. Considering a child with a complete patellar ligament defect, it may be difficult to obtain an acceptable tendon. For this case, the operation plan of tendon allograft reconstruction was performed.

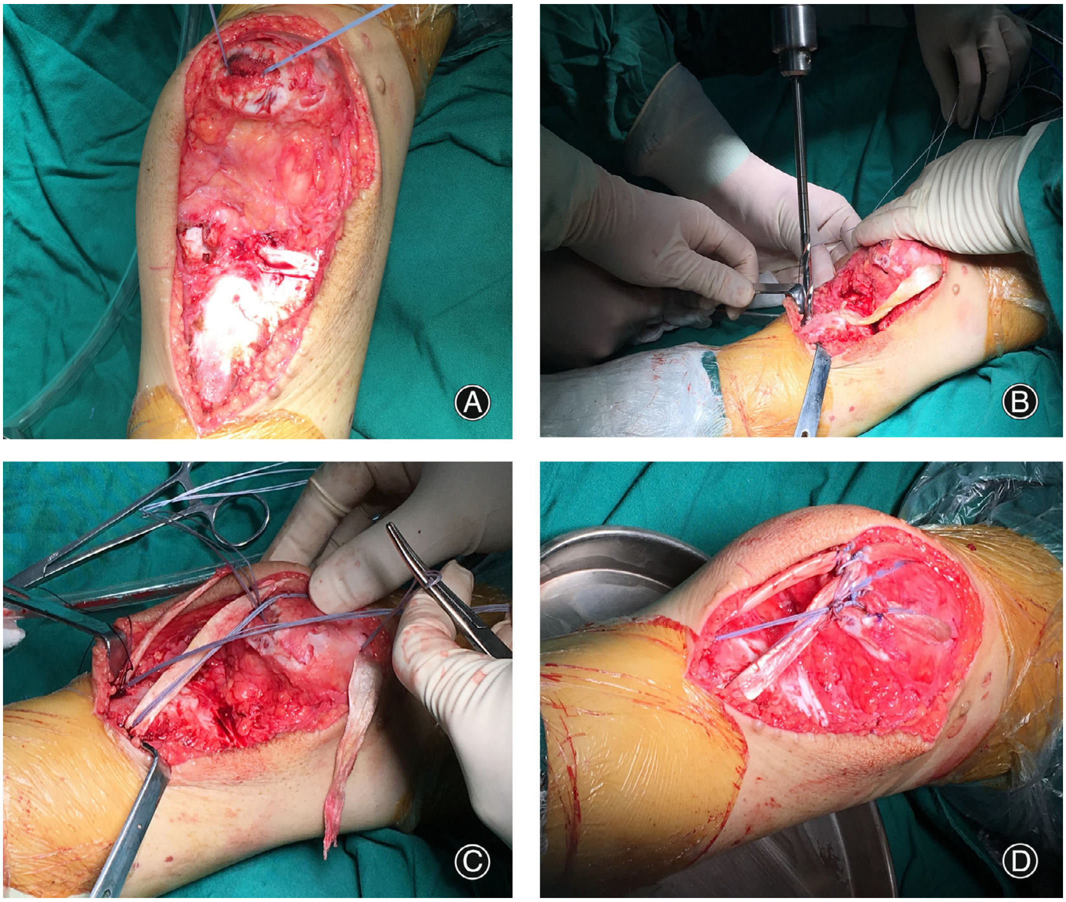

Fig. 3 Patellar ligament reconstruction. A fresh bleeding bone bed was constructed in the inferior pole of the patella (A). A transverse bone tunnel and a transverse soft tissue tunnel was created in the tibia and tendon of the quadriceps femoris near the patella, respectively (B). The tension-reducing wire and allogeneic tendons were passed through the above tunnel in a figure of eight pattern (C). The allogeneic tendon was tightened and then, the ends of the tendon were fixed to the bleeding bone bed in the inferior patella with those two absorbable suture anchors (D)

Preparation of Graft

An allogeneic tendon of the tibialis anterior muscle (Shanxi OsteoRad Biomaterial Co., Ltd., Shanxi, China) was chosen for reconstruction, which had been irradiated by Co 60 and stored in 80° refrigerator for a long time. Before being used, the tendon was thawed in 500 ml isotonic saline containing 240,000 units of gentamicin and then soaked in iodophor solution for 10 min.

Tunnel Preparation

In the depths of the tibial tubercle, a transverse bone tunnel was drilled to 4.5 mm. Then a transverse soft tissue tunnel was created in the tendon of the quadriceps femoris near the patella (Figure 3(B,C)). The purpose of two transverse tunnels was left for traveling through the tendon. After transverse tunnels were finished, a fresh bleeding bone bed was constructed at the inferior pole of the patella with a bone rongeur. Subsequently, two pilot holes were drilled at the bleeding bone bed with a punch for the 4.5-mm Bio-Composite Corkscrew FT anchor (Arthrex). Finally, two anchors were placed into the pilot hole for tendon-bone fixation in the later stage. (Figure 3(A)).

Patellar Ligament Reconstruction

Two strands of nonabsorbable #5 Ethibond sutures (Ethicon [Johnson & Johnson], Somerville, NJ) and allogeneic tendons were passed through the above tunnel in a figure-of-eight pattern (Figure 3(C)). Passive flexion of the knee at 30°, the Ethibond suture, as the tension-reducing sutures, were tightened and then tied tightly until the patella was pulled to the correct height. Subsequently, the allogeneic tendon was tightened. Both ends of the tendon were fixed to the bleeding bone bed in the inferior patella with those two absorbable suture anchors in an on-lay technique (Figure 3(D)).

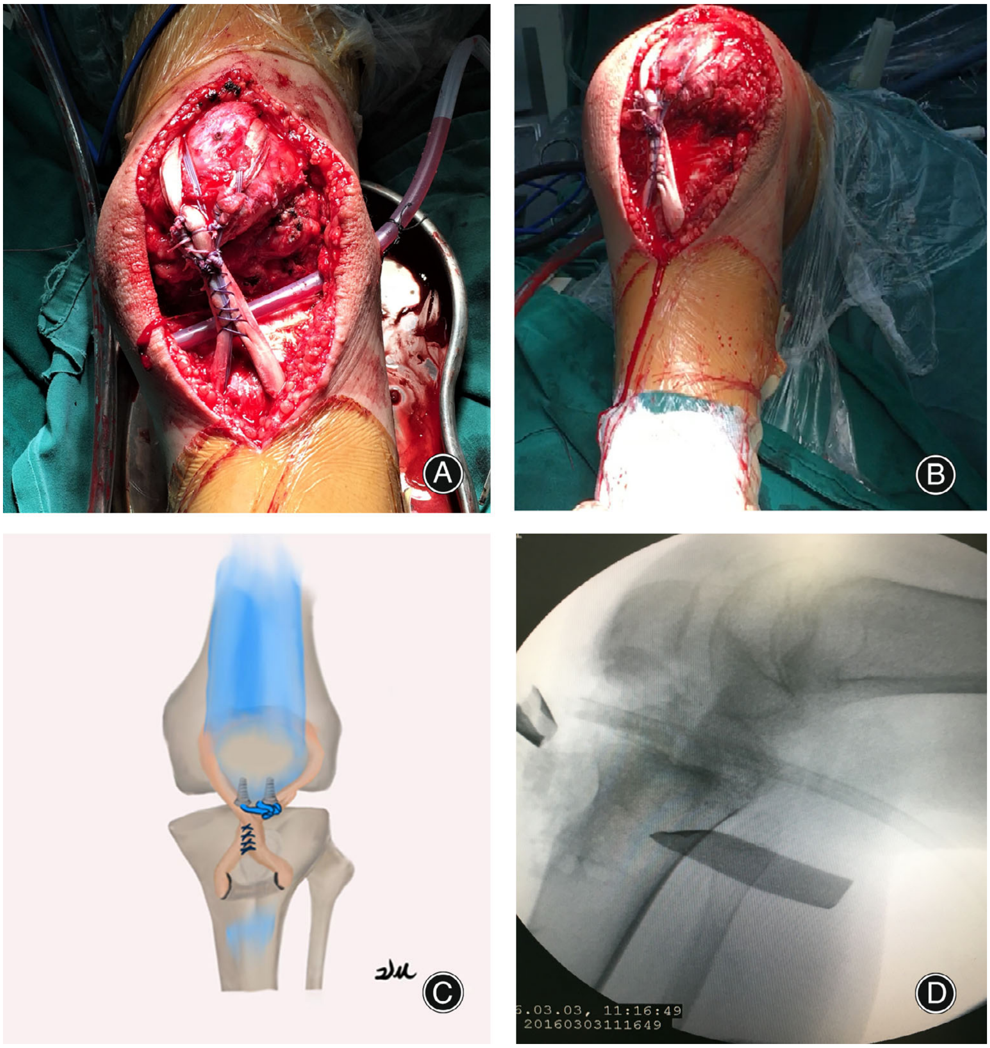

Fig. 4 Intraoperative examination of the patellar ligament after reconstruction and the diagrammatic sketch after reconstruction. Knee extension 0° after reconstruction (A). Knee flexion 90° after reconstruction (B). The diagrammatic sketch of patellar ligament reconstruction (C). Lateral X-ray examination to assess the height of patellar (D)

Final Inspection

After the tension-reducing sutures and allogeneic tendon were fixed firmly, the passive motion of the knee was performed for functional examination. The inspection contents included: (1) Check the passive range of motion of the knee to ensure that the range of motion of the reconstructed knee was at least 0 (extension) to 90 (flexion) (Figure 4(A,B)); (2) Check whether the patellar was on the normal track to ensure that there was no sign of patellar dislocation; (3) Finally, take the lateral radiograph of knee flexion at 30° with a C-arm X-ray machine to determine that the patellar was at the normal height (Figure 4(D)). After the above examinations were satisfactory, a wound drainage tube was placed, the surgical wound was sutured, and an antiseptic dressing was covered.

Postoperative Rehabilitation

After the operation, an external fixation brace was applied to protect the knee for 8 weeks. Quadriceps femoris isometric contraction exercise was performed on the first day post operation, and the knee was kept in the straightened position and immobilized for 2 weeks after the operation. Passive knee flexion was performed from week 3, until the knee flexion reached 90° by week 6 after the operation. Until the 6th week after the operation, active knee flexion exercise was permitted to be performed gradually. Within 12 weeks after the operation, the patient was followed up every 2 weeks to check the effect of the exercise and to guide the next stage of functional exercise. The patients were followed up at the time point of 6 months, 1, 2 and 4 years after the operation to examine the motion of the knee. In addition, the lateral 30° flexion X-ray and MRI examination of the knee were reviewed to evaluate the height of the patella and the condition of the patellar ligament, respectively.

Results

The pathological reports suggested chondromesenchymal hamartoma, a rare benign soft tissue tumor different from the previous operation (tendon sheath fibroma) (Figure 5).

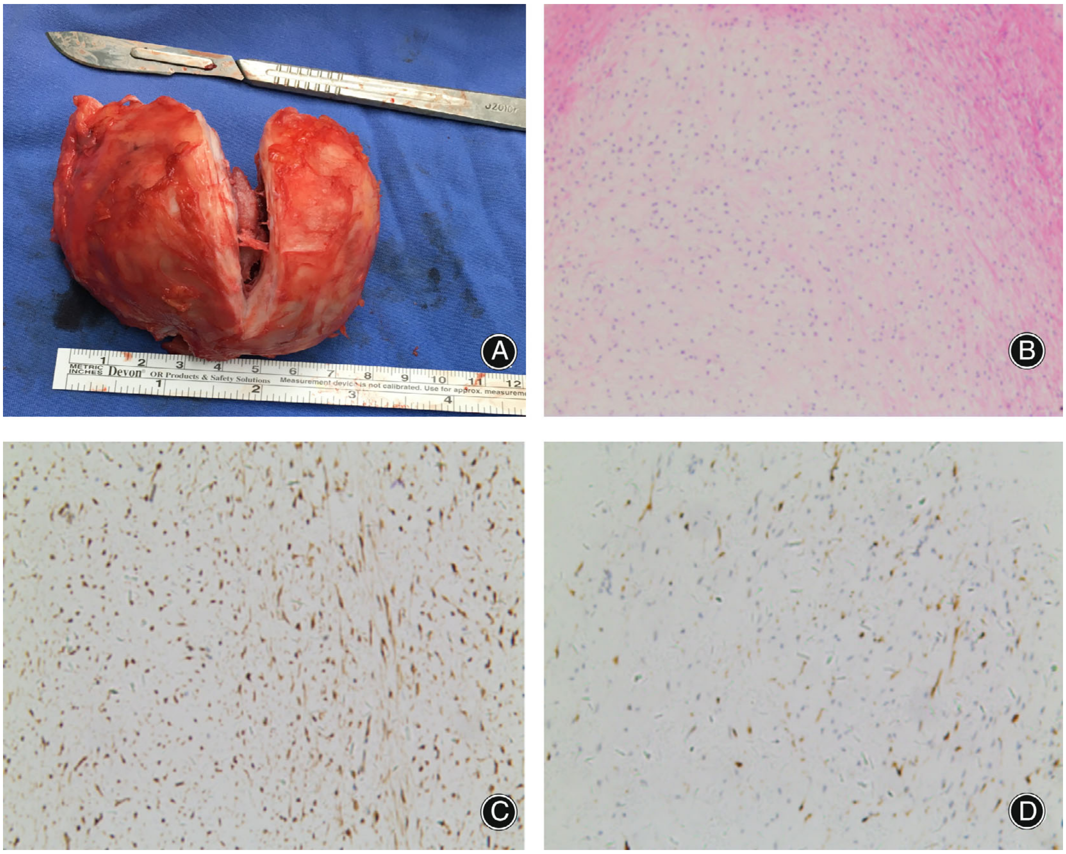

Fig. 5 Macroscopic and microscopic findings of the patellar tendon tumors. Macroscopic appearance of the patellar tendon tumors with the size of 7*5*5 cm (A). Tumor consisted of spindle cell, osteocyte, chondrocyte, and collagen fiber matrix in microscopic observation (B). Immunohistochemical markers CD34(+) (C), and Actin (+) (D)

After 4 weeks of the operation follow-up, the flexion of the knee was about 70° and the extension reserved about 40° lag (Figure 6). After the 4 years of postoperative follow-up, the lateral radiograph of the knee at 30° flexion showed that the ratio of the length of the patellar tendon (LT) and the greatest diagonal length of the patella (LP) was almost normal (1.08), which indicated that the reconstructed patellar ligament was not prolonged or broken (Figure 7(C)). The integrity, continuity, and shape of allogeneic ligament showed as excellent in MRI imaging (Figure 7(A,B)). The motion of the knee was in the range of 0°–120°, and the patient walked normally without any external help. The strength of the quadriceps femoris muscle had improved significantly relative to week 4 postoperatively, and the wound in the knee had healed well (Figure 7(D–F)). The patient did not complain of knee pain at the last follow-up. Physical examinations (the apprehension sign and J sign) showed no ligamentous instability or patellar ligament tenderness. Despite the occurrence complication of heterotopic ossification, the patient did not complain of any limited range of motion or tenderness at the site of ossification (Figure 7(C)).

Discussion

This technique seeks to describe allograft patellar ligament reconstruction in a child with recurrent patellar ligament tumor. The illustrations of allogeneic tendon transplantation for the treatment of pathological patellar ligament defect was summarized in Figure 8. No complications such as wound infection, dehiscence, or delayed healing occurred in 4 weeks after operation follow-up. At 4 years postoperatively, almost normal full range of the knee joint motion was achieved without extension lag, and imaging results demonstrated that the integrity, continuity, and shape of the allogeneic ligament was almost perfect. Although there was mild genu recurvatum postoperatively due to resection of the tibial tubercle, the presented technique did not lead to patellar instability or ligament tenderness with high patient satisfaction.

As is well known, defects of the patellar ligament will bring serious complications, such as knee extension disorder, quadriceps atrophy, and patellar pain[10]. Patellar ligament lesions could occur in diseases such as trauma, long-term use of corticosteroids, chronic renal failure, and patellar ligament tumors[11]. Our case was a recurrent chondromesenchymal hamartoma with infiltration of the patellar ligament, part of

Fig. 6 Results 4 weeks after the operation. The flexion of knee was about 70° and the extension reserved about 40° lag (A, B). The height of patellar was almost regular on X-ray examination (C)

the patella, and tibial tubercle. Chondromesenchymal hamartoma is a rare benign tumor that generally occurs in the nasal, also called nasal chondromesenchymal hamartoma[12]. According to the statistical analysis of previous literature, the tumor mainly appeared in infants and children, but adults were not wholly exempted.[13] Although chondromesenchymal hamartoma is a benign tumor, the case about malignant change has been reported in the literature[14]. Given the rapid progression of the tumor in a short time and extensive infiltration of the patellar ligament, inferior pole of the patella, and part of the tibial tubercle, hence, complete resection of the patellar ligament and reconstruction of the extensor mechanism should be performed.

Surgical Technique of Patellar Ligament Reconstruction for Tumor

To this day, there have been few reports of extensive resection and reconstruction of the patellar ligament due to patellar ligament tumors. Fukui *et al.*[1] had reported a surgical technique in a case of soft tissue sarcoma near the patellar ligament. Due to the extensive infiltration of the tumor, the patellar ligament and tibial trochanter had been completely removed. After resection, the patellar ligament was reconstructed with the graft composed of the ipsilateral hamstring tendon and iliotibial band. The two ends of the autograft were fixed in the bone tunnel of the patella and tibia with screws. During the follow-up 20 months after the operation, the function of the knee returned to normal, and there was no limitation of extension. Machens *et al.*[2] had reported a surgical technique in a case of prepatellar myxofibrosarcoma, which completely removed the distal quadriceps femoris, patella, and patellar ligament for limb salvage and radical resection. In order to reconstruct the knee extensor mechanism, the authors used a free latissimus dorsi myocutaneous flap to repair, connecting the starting point of the flap to the remaining quadriceps femoris, while the flap replaced the patellar ligament. At 12 weeks after the operation, patients can actively extend the knee without any external force help. But the flexion of the knee was only about 70° and the extension reserved about 10° lag. Nakashima *et al.*[3] had reported a

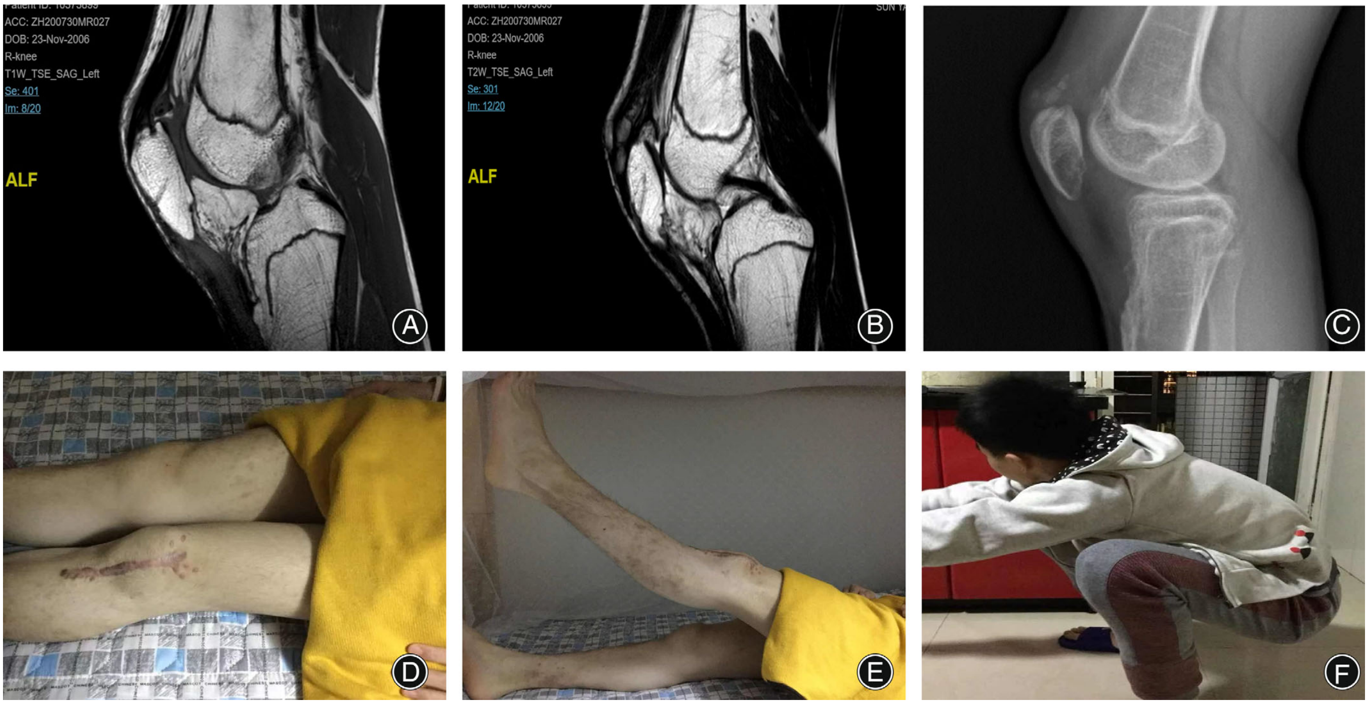

Fig. 7 Results 4 years after operation. The graft shows low signal intensity on T1-weighted images and high signal intensity on T2-weighted images of MRI (A, B). The height of patellar was almost regular on X-ray examination. (C). The flexion and extension of knee showed no lag (D–F)

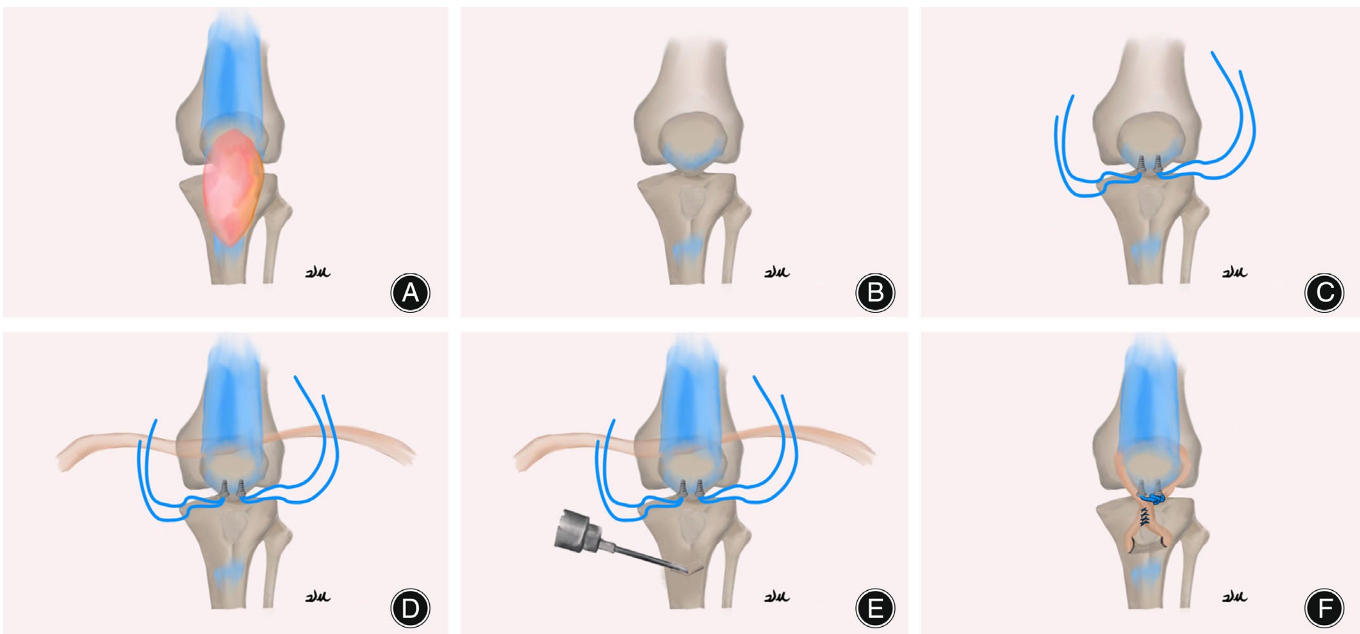

Fig. 8 Illustration of allogeneic tendon transplantation for the treatment of pathological patellar ligament defect

surgical technique in a 43-year-old patient, who had undergone extensive resection of the tumor and patellar ligament for poorly differentiated parapatellar myofibroblastic sarcoma. After resection, the patellar ligament was reconstructed with autogenous fascia lata with iliac bone block. The authors fixed the bone block on the tibial groove with absorbable screws and then divided the fascia lata into three branches: the central branch was fixed through the patellar tunnel, and the medial and lateral branches were fixed on the medial and lateral retinaculum of the patella, respectively. The knee was followed up for 3 years after the operation. The range of motion of the knee finally reached 0°–110°. We also introduced in detail a surgical technique for complete resection of the patellar ligament caused by a tumor in a child and reconstruction of the patellar ligament with the allogeneic tibialis anterior tendon. After complete resection of the invaded patellar ligament, a soft tissue tunnel in the quadriceps tendon and a bone tunnel on the depth of the tibial tubercle were made, respectively. In this step, we avoided drilling bone tunnels in the patella, which was one of the differences from other researchers[8]. This detail could minimize the impact on patellar development in children. Then the allograft was crossed in a figure of eight through the aforementioned tunnels. Finally, the two ends of the allograft were fixed to the bleeding bone bed inferior to the patella with the suture anchors to promote tendon-bone healing (Figure 3(D)). After 4 years of follow-up, almost normal full range of the knee joint motion was achieved without extension lag, while imaging results demonstrated that the integrity, continuity, and shape of the allogeneic ligament were almost perfect (Figure 7).

Advantages and Disadvantages of Different Grafts in Ligament Reconstruction

Currently, the material selection of ligament reconstruction includes autografts, allografts, and synthetic materials[6,15,16]. Based on the fact that different grafts have their own advantages, the selection of grafts was mainly based on individual needs and surgeons' experience. Autografts included bone-patellar tendon-bone, quadruple-bundle gracilis-semitendinosus of hamstring tendon, iliotibial band, quadriceps tendon, and Achilles tendon[3,17]. Autografts have the advantages of being free of rejection and infectious diseases, can provide sufficient mechanical strength, heal quickly, are inexpensive, and have no storage and sterilization issues[18,19]. However, autograft reconstruction will be limited in young and frail patients or in patients who require extensive tendons. Allografts have the advantages of shortening operation time, without extra trauma and complications at the tendon acquisition, and at low risk of joint fibrosis[20]. Although the histological characteristics of allograft and autograft are different, it's considered that the histological evolution process, which includes four stages of graft necrosis, revascularization, cell proliferation, and collagen reconstruction, is the same after application[21]. However, allografts also have a series of problems, such as difficulty in source, infectious disease transmission, sterilization, and preservation[22]. Presently, the most commonly used sterile and storage techniques are aseptic harvesting, antibiotic soaking, low-dose radiation sterilization, and low-temperature storage[23]. Improper sterilization and preservation will bring infectious diseases and seriously affect the biomechanics of reconstructed tendons and the healing of tendon bones[24]. As a matter of fact, autografts or allografts are difficult to obtain. As a substitute for autologous or allogenic ligaments, artificial ligaments have the advantages of sufficient sources, simple manipulation, no rejection, and no disease transmission[25]. At the same time, artificial ligaments can provide sufficient biomechanical strength, which has been gradually approved by surgeons[26–28]. Although artificial ligament has achieved good results in the early and middle stage of many studies, but there is a lack of research on the long-term effect at present, especially in young children[29]. Considering these circumstances, the surgical strategy for this case had adopted allogeneic tibial anterior tendon to patellar ligament reconstruction, and this case had gained good recovery at the last follow-up.

TABLE 1 Surgical steps, tips, and pitfalls of technique

Surgical step	Tips	Pitfalls
Preparation of allogeneic tendon	Preliminary measurement of the length of allogeneic tendon is convenient for the implementation of the operation plan	Make sure that the allografts are removed from the tissue bank for the first time, and to avoid the use of repeated freeze-thaw allografts
Tibial tunnel	The tibial tunnel was tunneled as close as possible to the insertion of the patellar ligament to facilitate reconstruction of the original biomechanics	To avoid the fracture of the tibial tunnel in rehabilitation phases, the tunnel should be deeper
Tendon tunnel of quadriceps femoris	Constructing the tunnel should as close to the superior of the patella as possible can prevent the relaxation of the reconstructed ligament	The tunnel must be traversed just midway between the superior pole of the patella and the quadriceps tendon to prevent reconstructive failure
Fixation of the tendon	A fresh bleeding bone bed was constructed at the inferior pole of the patella, which is beneficial for tendon-bone healing	Prevention of osteoarthritis by avoiding damage to the cartilage

Tips and Pitfalls of the Allograft Technique in Patellar Ligament

The surgical procedures, tips, and technical defects are described in detail in Table 1.

Advantages and Limitations of the Allograft Technique in Patellar Ligament

The technique we described had several advantages. First, the graft tunnel is established outside the patella, which could reduce the impact of the development of the patella. Second, it is unnecessary to drill a large hole in the patella, which increases the risk of fractures. Third, it allowed the surgeon to adjust the length of the reconstruction based on intraoperative imaging. Fourth, Ethibond sutures provided additional augmentation to the construction, particularly during the tendon-to-bone healing phase of the allograft.

This technique is not without limitations. First, the inherent limitations of allogeneic transplantation, such as the intrinsic possibilities for infectious disease transmission and possible rejection reaction, have become the main obstacle to tendon-bone healing. Second, due to the phenomenon of "creep" of the allograft, patella alta may result, leading to reconstruction failure. Third, since this technique will destroy the growth plate of the tibial tubercle, it may lead to complications such as premature tibial tuberosity and patella baja in young patients. However, this issue does not need to be considered in patients undergoing tibial tuberculectomy for tumors or in adult patients.

Conclusions

This allograft technique was only a single successful case in patellar ligament reconstruction, which needs more extensive use to verify the reliability and effectiveness of this technology. However, the experience from this technique can provide a reference for orthopaedists to deal with the reconstruction of the patellar ligament in children with chronic ruptures of the patellar ligament or other lesions.

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Authors' Contributions

MZ designed the study and contributed to writing of the draft. YL and MLY contributed to data analysis and solved technical problems in software. JG, YYT and FQL participated in data extraction and analysis assistance. LQY, YHZ and ZZZ contributed to data collection. JYH and RY participated in the design of this research and provided guidance and troubleshooting. All authors agree to be accountable for all aspects of the work. All authors read and approved the final manuscript.

Conflict of Interest

The authors have no conflicts of interest to declare.

Ethics Approval and Consent to Participate

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Ethics Committee of Sun Yat-sen Memorial Hospital of Sun Yat-sen University and informed consent was taken from all individual participants.

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