Reconstruction of the extensor mechanism augmented with reverse transferred iliotibial band after proximal tibia tumor resection and mega-prosthetic replacement

The corrections made in this section will be reviewed and approved by a journal production editor.

Kunihiro Ikuta[a,*] k-ikuta@med.nagoya-u.ac.jp, Yoshihiro Nishida[a,b], Satoshi Tsukushi[c], Tomohisa Sakai[a], Hiroshi Koike[a], Shiro Imagama[a]

[a]Department of Orthopedic Surgery, Nagoya University Graduate School and School of Medicine, Nagoya, Japan

[b]Department of Rehabilitation, Nagoya University Hospital, Nagoya, Japan

[c]Department of Orthopedic Surgery, Aichi Cancer Center Hospital, Nagoya, Japan

*Corresponding author at: Department of Or[Instruction: Corresponging author at: Department of Orthopedic Surgery]thopaedic Surgery, Nagoya University Graduate School and School of Medicine, 65 Tsurumai, Showa, Nagoya 466-8550, Japan.

Abstract

***Background*:** The optimal procedure for functional reconstruction of the extensor mechanism after proximal tibia mega-prosthetic replacement remains unclear.

***Methods*:** Since 2006, 14 consecutive patients with aggressive bone tumors in the proximal tibia who underwent mega-prosthetic replacement were prospectively treated with reconstruction of the extensor mechanism using an ipsilateral iliotibial band. The surgical procedure consisted of wrapping the reversed iliotibial band around the tibia component, firmly suturing it to the remaining patellar tendon and tibialis anterior fascia, and covering it with a muscle flap. At the last follow up, the function was assessed based on extensor lag, active flexion of the knee, and Musculoskeletal Tumor Society score. Patellar height was measured with the Insall–Salvati ratio (ISR) preoperatively, postoperatively, and at the last follow up.

***Results*:** At the last follow up, the extensor lag and active flexion in 14 patients averaged 2.5° and 86°, respectively. Musculoskeletal Tumor Society score could be obtained in nine surviving patients at the last follow up and was a mean of 20.7 points. The mean ISR preoperatively, postoperatively, and at the last follow up was 1.04, 0.75, and 0.89, respectively. The extensor lag was not associated with the ISR value at any points, while reduced active flexion significantly correlated with a low ISR at the last follow up ($P = 0.015$). Four patients underwent additional surgeries due to postoperative infection, but none required eventual revision or amputation.

***Conclusion*:** The extensor mechanism reconstruction with the reverse transferred iliotibial band for mega-prosthetic replacement after proximal tibia resection yielded reliable outcomes with functional benefit to stabilize active knee extension.

Keywords:

Extensor mechanism, Iliotibial band, Proximal tibia, Mega-prosthesis

1 Introduction

With improved survival of patients treated with limb-salvage surgery for malignant bone tumors, postoperative function has become critical, particularly for young or physically active patients. The knee is a primary weight-bearing joint, and any instability or restricted range of motion (ROM) will compromise patients' quality of life [1]. In patients with malignant bone tumors at the proximal tibia, tumor prosthesis replacement often results in functionally unfavorable outcomes when the extensor mechanism of the knee is insufficient. Resection of the proximal tibia involving the tibial tuberosity can cause an extensor lag even with repair of the patellar tendon. Several reconstruction procedures for the extensor mechanism have been reported. The remaining patellar tendon has been reattached with sutures directly to the tibial component or augmented with synthetic materials [2–7]. However, the value of these procedures is reduced by technical problems. Jentzsch et al. described that 22% of patients, who received reconstruction with direct suture of the remaining patellar tendon, had an extensor lag of greater than 20° [2]. Dominkus et al. reported on 22 patients treated with reconstruction using a synthetic ligament, in whom a rupture of the synthetic ligament occurred in five (23%), four (18%) of whom required revision surgeries[Instruction: This ref (8) changes to (6).] ~~[8]~~. In addition to these difficulties in reconstructing the extensor mechanism, soft tissue defects resulting from wide resection are another concern for surgeons. A rotational gastrocnemius flap is considered useful not only for the coverage of defects but also for reinforcing the reconstructed extensor mechanism [Instruction: 4,9-11 ---> 4,8-10][4,9–11].

Change in patellar height has been found after proximal tibia mega-prosthetic reconstruction. Several studies have described an appropriate patellar height following the repair of the extensor mechanism associated with favorable postoperative function[Instruction: 2,12,13 ---> 2,11,12] [2,12,13]. Jentzsch et al. demonstrated that patients with a normal patellar height had better functional scores than those with patella alta after reconstruction of the extensor mechanism [2]. However, it is challenging for surgeons to determine the appropriate patella height during the extensor mechanism reconstruction. Several studies have documented stretching of the reattached patellar tendon with time after reconstruction with a mega-prosthesis and gastrocnemius flap [Instruction: 12,14 ---> 11,13][12,14].

The rate of peri-prosthetic infection in the proximal tibia area has been reported to be 15–18%, even with the use of a gastrocnemius flap [Instruction: 4,9 ---> 4,8][4,9]. Considering the potential risk of infection using synthetic materials and the unavailability of allografts in our country, reconstruction with autologous tissue would be theoretically desirable if possible. The iliotibial band (ITB) has been used successfully as the autograft for the reconstruction of the anterior cruciate ligament (ACL)[Instruction: 15,16 ---> 14,15] [15,16]. The ITB graft is a robust local tissue used to compensate for abdominal wall defects or rotator cuff defects. It is also known that harvesting ITB graft disrupts neither the extensor nor flexor mechanism of the knee [Instruction: 15 ---> 14][15]. Thus, we assumed that supplemental ITB could be a reliable treatment option when patellar tendon reconstruction is indicated. However, there have been only a few reports on procedures using autologous graft, including ITB in the extensor mechanism reconstruction [Instruction: 17,18 ---> 16,17][17,18]. Since 2006, we have consecutively and prospectively utilized reverse transferred ITB to reconstruct the extensor mechanism in patients undergoing proximal tibia resection and replacement with a mega-prosthesis. The primary objective of this study was to evaluate the utility of a procedure with reverse transferred ITB to reconstruct the extensor mechanism of the knee. The secondary objective was to investigate changes in the patellar height after proximal tibia mega-prosthesis replacement and analyze its effects on knee function at the last follow up, including extensor lag, active flexion, and the Musculoskeletal Tumor Society (MSTS) score. This study evaluated changes in the patellar height after proximal tibia mega-prosthesis replacement and analyzed its effects on postoperative knee function, including extensor lag, active flexion, and the MSTS score.

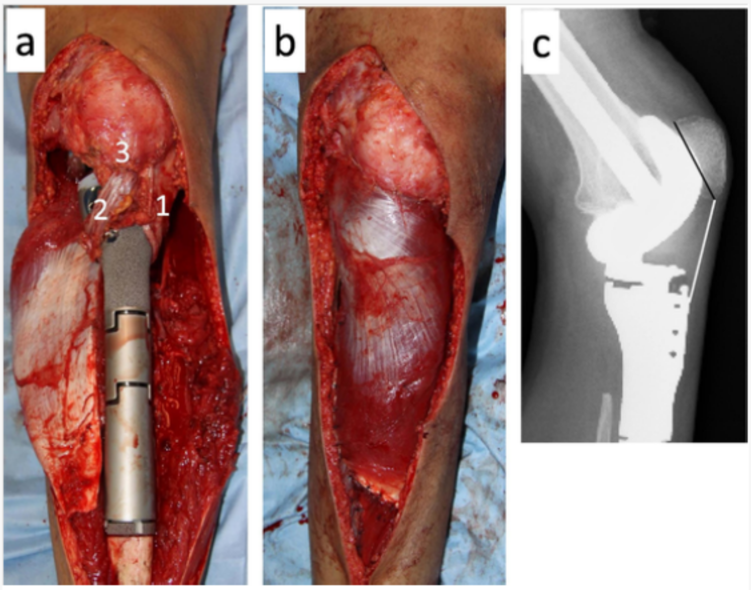
2 Patients and methods

2.1 Patients

This study was approved by our Institutional Review Board. Between 2006 and 2018, 26 patients underwent resection of aggressive bone tumors at the proximal tibia in our institutions. Of these, 19 patients had reconstruction with mega-prosthesis replacement, four amputation, and the remaining three treatment with a recycled pasteurized autograft. Of the 19 patients treated with mega-prosthesis, five were excluded from the present study for the following reasons. In three patients, the tumor was contained entirely within the bone, allowing retention of the surrounding soft tissues, and precluding the need for augmentation of the patellar tendon. The remaining two did not follow our postoperative therapy to immobilize the operated knee in the extended position for 4–6 weeks. Eventually, we retrospectively reviewed 14 consecutive patients with aggressive bone tumors who underwent proximal tibia resection, mega-prosthetic replacement, and reconstruction of the extensor mechanism with reverse transferred ITB (Fig. 1(a) and (b)). Data were extracted from a clinical database. There were eight males and six females, with a mean age of 24.4 years at the time of surgery (range, 10–66 years). All patients were followed up for at least 1 year or until dead of the disease. The histological diagnoses included osteosarcoma in 13 patients and giant cell tumor of bone in one. All patients with osteosarcoma received neoadjuvant and adjuvant chemotherapy. None of the patients in this study received radiotherapy. Soft tissue defects were covered with a medial gastrocnemius flap in 11 patients, both medial and lateral gastrocnemius flaps in two, and free anterolateral thigh flap in one. Skin grafts were performed in cases with skin defects. Patient and tumor characteristics are shown in Table 1.

Images are optimised for fast web viewing. Click on the image to view the original version.

Fig. 1



A 15-year-old male (patient 10) with osteosarcoma of the proximal tibia was treated with wide resection and mega-prosthetic replacement. (a) A reversed transferred iliotibial band (ITB) (1) was wrapped around the prosthesis (2) and sutured to the remnant patellar tendon (3). (b) A medial gastrocnemius was rotated anteriorly to cover the prosthesis and sutured to the ITB, remnant patellar tendon, and tibialis anterior fascia or the surrounding fascia. (c) A lateral radiograph of the knee after surgery. Postoperative Insall–Salvati ratio was the ratio of the length of the reconstructed patellar tendon (white line) to the patellar length (black line).

Table 1

The table layout displayed in this section is not how it will appear in the final version. The representation below is solely purposed for providing corrections to the table. To preview the actual presentation of the table, please view the Proof.

Characteristics of 14 patients treated with extensor mechanism reconstruction using reverse transferred iliotibial band after proximal tibia resection.

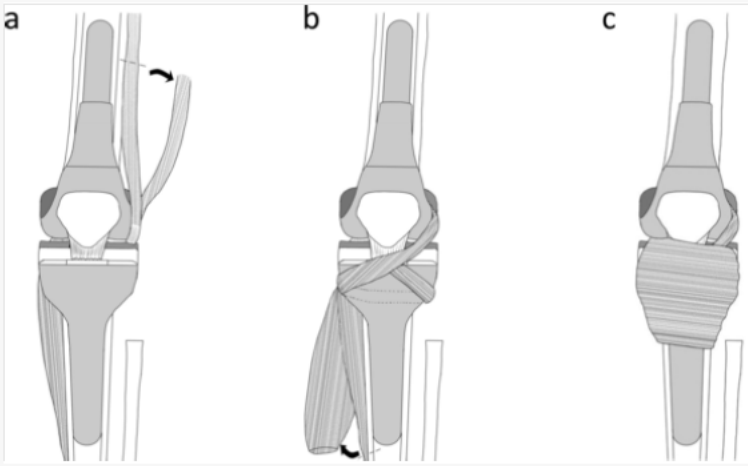
Patient number	Age	Sex	Diagnosis	Tibial resection length (cm)	Complications (time after surgery)	Oncological outcomes	Follow up (months)
1	66	F	OS	16	Superficial infection (12 weeks)	DOD	47
2	58	F	OS	16	None	DOD	43
3	15	M	OS	13	None	CDF	120
4	14	M	OS	17	Peri-prosthetic infection (2 weeks)	DOD	11
5	16	F	OS	15	Periprosthetic fracture (31 months)	NED	104
6	13	F	OS	13	None	NED	126
7	26	M	GCTB	13	None	AWD	95
8	10	F	OS	17	Peri-prosthetic infection (1 week)	CDF	105
9	39	F	OS	13	None	DOD	15
10	15	M	OS	21	None	NED	86
11	17	M	OS	15.5	Aseptic loosening (20 months)	CDF	63
12	17	M	OS	19	Superficial infection (2 weeks)	NED	47
13	19	M	OS	11	None	AWD	28
14	16	M	OS	14	None	DOD	10

AWD, alive with disease; CDF, continuous disease free; DOD, dead of disease; GCTB, giant cell tumor of bone; NED, no evidence of disease; OS, osteosarcoma.

2.2 Surgical procedure

In all patients, the patellar tendon was sectioned 1–2 cm proximal to the tibial tuberosity to secure an adequate oncological margin, resulting in a shortening of the residual patellar tendon. Intra-articular resection was performed in 13 patients. One underwent extra-articular resection with partial patellar resection. On histological examination of the resected tumors, the surgical margins were negative in all cases but that with giant cell tumor of bone. Eight patients received a replacement with the Howmedica Modular Resection System. Global Modular Replacement System was used in three, and Kyocera Modular Limb Salvage System, Kyocera Limb Salvage System, and Kotz Growing prosthesis in one each. There were no patients with patellar resurfacing. The proximal part of the fibula was excised in 12 patients because the tumor was close to or involved the proximal tibiofibular joint. After the mega-prosthesis replacement, ipsilateral ITB was harvested proximally, preserving its native distal attachment to the lateral femoral condyle (Fig. 2(a)). After rotating distally to the proximal tibia, the ITB was passed through the back of the prosthesis and wrapped around it. The remnant patellar tendon was overlapped and sutured tightly to the wrapped ITB in full extension (Fig. 2(b)). The muscle flap was transferred to cover the prosthesis and sutured to the underlying patellar tendon, wrapped ITB, and the tibialis anterior fascia to maintain their continuity (Fig. 2(c)). A lateral gastrocnemius flap was added in two patients based on the tumor location and resulting soft tissue defect.

Fig. 2



Schemas showing our procedure for the extensor mechanism reconstruction after mega-prosthetic replacement. (a) Ipsilateral iliotibial band (ITB) was harvested proximally and transferred to the proximal tibia without disrupting its distal attachment around the lateral femoral condyle. (b) The tibial component was wrapped with the ITB. Then, the wrapped ITB was sutured with the remaining patellar tendon. (c) The medial gastrocnemius flap was transferred to cover the prosthesis. Next, the muscle flap was sutured to the underlying patellar tendon, wrapped ITB, and the tibialis anterior fascia to maintain their continuity.

The affected knee was immobilized in full extension for 4–6 weeks after surgery. ROM exercises and weight-bearing were started after immobilization, depending on the patient's symptoms and findings. Patients began active and passive mobilization assisted by a physiotherapist. The weight-bearing increased stepwise until full weight-bearing, which was usually achieved within 3 months after surgery.

The patellar height was determined by the Insall–Salvati ratio (ISR). The ISR was expressed as the ratio of the patella to the patellar tendon. ISR values between 0.8 and 1.2 were considered normal and indicated as patella norma; ISR values lower than 0.8 were defined as patella baja; higher than 1.2 were considered patella alta. The ISR was measured at 30° of knee flexion in each patient preoperatively, postoperatively (after immobilization for 4–6 weeks), and at the last follow up. The length of the patellar tendon was measured on lateral radiographs from the lower pole of the patella to the tibial tuberosity or the anterior edge of the prosthesis where the reconstructed patellar tendon (residual patellar tendon and reversed ITB) was attached (Fig. 1(c)). Postoperative evaluation at the follow up was performed every 3 months for the first 3 years and every 6 months thereafter. Follow up evaluation included clinical examination with images, active flexion of the knee, and an extensor lag. Functional evaluation was assessed with the MSTS at the last follow up.

2.3 Statistical analyses

Mann–Whitney *U*-test was used to test for the significance of differences between mean values. Bonferroni–Dunn post hoc test for continuous variables was used to analyze the difference of means in patellar height at multiple time points. The linear regression model was used to assess the association of clinical variables with patient outcomes. P values < 0.05 were considered statistically significant. Follow up duration was defined from the date of the initial surgery to that of death or the last visit. SPSS 27.0 for Windows software (SPSS, Inc., Chicago, IL, USA) was used for the statistical analyses.

3 Results

The functional outcomes of 14 patients treated with extensor mechanism reconstruction using reverse transferred ITB after proximal tibia resection are shown in Table 2.

Table 2

The table layout displayed in this section is not how it will appear in the final version. The representation below is solely purposed for providing corrections to the table. To preview the actual presentation of the table, please view the Proof.

Functional outcomes of 14 patients treated with extensor mechanism reconstruction using reverse transferred iliotibial band after proximal tibia resection.

Patient number	Active flexion	Extensor lag	Preoperative ISR	Postoperative ISR	ISR at the last follow up	MSTS score
1	65	15	1.08	0.70	0.85	NA
2	65	0	1.14	0.65	0.81	NA
3	100	5	0.95	0.99	1.07	25
4	90	0	1.19	1.60	1.56	NA
5	100	0	1.00	0.55	0.98	27
6	90	0	1.20	0.65	0.88	22
7	80	0	0.81	0.75	0.60	24
8	40	0	1.03	0.39	0.30	19
9	60	10	0.93	0.58	0.72	NA
10	110	0	1.13	0.70	1.21	18
11	95	0	0.84	0.48	0.76	24
12	110	0	1.04	0.80	0.98	17
13	100	5	1.15	0.81	1.00	10
14	100	0	1.16	0.78	0.76	14

ISR, Insall–Salvati ratio; MSTS, Musculoskeletal Tumor Society; NA, not available.

The mean duration of the follow up was 64 months (range, 10–126 months). Five patients died due to progression of the disease during the follow up period. The mean duration of the follow up for the nine surviving patients at the last follow up was 86 months (range, 28–126 months). Complications at the donor site of ITB were not observed in any of the patients. Four patients developed surgical site infection at a mean of 4 weeks (range, 1–12 weeks), two of whom had superficial wound healing disturbances. Although peri-prosthetic infections occurred in two, they successfully healed without revision surgery after treatment with irrigation, debridement, and intravenous administration of antibiotics (Patient 4 and Patient 8). None developed local recurrence or required amputation. Infection was not significantly associated with active knee flexion ($P = 0.45$), extension lag ($P = 0.95$), or MSTS score ($P = 0.22$). One patient underwent revision of the prosthesis due to aseptic loosening of the femoral component at 20 months postoperatively (Patient 11).

The mean length of tibial resection was 15.3 cm (range, 11–21.6 cm). No significant correlation was found between the length of resection and active flexion of the knee ($P = 0.70$), extensor lag ($P = 0.13$), and MSTS score ($P = 0.74$).

The mean preoperative ISR was 1.04 (range, 0.81–1.20). All but one of the patients had a normal patellar height before surgery. The mean postoperative ISR was 0.75 (range, 0.39–1.60). The mean ISR at the last follow up was 0.89 (range, 0.30–1.56). Postoperative ISR was significantly lower than preoperative ISR ($P < 0.01$). The last follow up ISR was lower compared with preoperative ISR in 11 patients and higher compared with postoperative ISR in 10 patients. At the last follow up, the ISR showed a patella alta in two patients, a patella norma in seven, and a patella baja in five. There was no statistical difference between the last follow up ISR and preoperative ISR ($P = 0.15$) or between the last follow up ISR and postoperative ISR ($P = 0.18$).

The mean maximum active flexion of the knee was 86° (range, 40–110°) at the last follow up. The patient (patient 8) treated with extra-articular wide resection developed knee contracture and thereafter achieved active flexion of 40°. At the last follow up, five patients presented active flexion with less than 90°, all of whom had a patella baja. The linear regression model revealed a significant correlation between active flexion and ISR at the last follow up ($R^2 = 0.40$, $P = 0.015$).

The overall mean extensor lag in all patients was 2.5° (range, 0–15°). Ten patients achieved full extension. Four patients had an extensor lag of a mean 8.5° (range, 5–15°) at the last follow up. In four patients retaining an extensor lag, one showed a patella baja, and three presented a patella norma at the last follow up. Of 10 patients without an extensor lag, four had a patella baja, four had a patella norma, and two a patella alta. The linear regression model in an extensor lag did not show any significant association with the value of ISR at any time points.

The mean MSTS score was 20.7 points (69%; range, 33–90%). These scores were available in nine surviving patients. There was no statistical difference between the MSTS score and ISR (postoperative: $P = 0.98$ or at the last follow up: $P = 0.78$) in our series. We did not find any correlation between an extensor lag and MSTS score ($P = 0.50$).

4 Discussion

In the current study, we described a case series of extensor mechanism reconstruction after proximal tibia resection, prospectively and consecutively treated with identical procedures using reversed ITB transfer in all 14 patients. To our knowledge, this was the first study designed to address the outcomes of the extensor mechanism reconstruction using supplementary autologous ITB after mega-prosthesis replacement for the proximal tibia. Our procedure was demonstrated to provide a durable reconstruction to restore and stabilize active knee extension.

One of the primary objectives of the reconstruction after proximal tibia mega-prosthesis is to prevent an extensor lag. Several authors have described a broad range of extensor lag in patients treated with proximal tibia mega-prosthesis. Bickels et al. attached the remnant patellar tendon to the prosthesis with Dacron tape, augmented with autologous bone graft in 55 patients, and reported that 22% of them had an extensor lag greater than 20° [5]. In their study, patients achieving an extensor lag of 20° or less had no limitations in their activities of daily living. Albergo et al. showed a mean extensor lag of 13.6° (range, 0–80°) in 88 patients, in whom the patellar tendon was attached to the transposed gastrocnemius to restore the extensor mechanism [Instruction: 19 ---> 18][19]. Mavrogenis et al., who studied the largest series with 225 patients, including various reconstruction methods, reported that the mean extensor lag was 12°, ranging from 0° to 60°[Instruction: 11 ---> 10] [11]. Before 2006, our methods for extensor mechanism reconstruction after mega-prosthetic replacement in the proximal tibia were inconsistent, and the duration of immobilization was less than 3 weeks. The mean extensor lag in the seven patients available for sufficient data as a historical cohort was 36° (range, 8–80°). In the current series, the mean extensor lag was 2.5° (range, 0–15°), which was superior to or comparable with that described in previous studies. Although various augmentation methods such as use of allografts and synthetic materials have been widely used for the extensor mechanism reconstruction of the knee, the specific procedures employed have not been consistent [Instruction: 11,13 ,19-21 ---> 10,12,18-20][11,13,19–21]. The techniques have been based on various patient factors, surgeon preference, and the degree of soft tissue loss.

Several authors have argued the significance of securing the continuity of the patellar tendon to the prosthesis with or without synthetic materials in the extensor mechanism reconstruction[Instruction: 7,12,22 ---> 7,11,21] [7,12,22]. Tumor prostheses with an area for attachment of the patellar tendon have been commonly used. Gosherger et al. showed that a reliable attachment of the patellar tendon to both the prosthesis with synthetic material and a gastrocnemius flap was essential to decrease extensor lag after proximal tibia prosthetic replacement [Instruction: 22 ---> 21][22]. Conversely, the reinforcement of the patellar tendon with synthetic materials was prone to rupture because healing did not occur between the patellar tendon and synthetic materials[Instruction: 20 ---> 6,19] ~~[8,20]~~[20]. Edmund et al. reported a residual extensor lag of more than 20° in 9–33% of patients who underwent direct attachment of the patellar tendon to the prosthesis in their review of the previous literature[Instruction: 20 ---> 19] [20]. For reliable fixation between the patellar tendon and the prosthesis, a contact interface to adjust tension would be required. Recently, a mesh wrapped around the prosthesis has been reported with favorable results in the extensor mechanism reconstruction[Instruction: 13,23 ---> 12,22] [13,23]. However, there has been concern expressed by orthopedic oncologists that foreign material such mesh might increase the risk of infection.

In this study, we developed reconstruction with supplementary ITB as a physical interface around the prosthesis to secure the continuity of the patellar tendon and to anchor the surrounding tissues. ITB could serve as a base for host tissues and contribute to the biological healing of the attached patellar tendon. This procedure could create a robust soft tissue envelope that enhanced the remodeling of the extensor mechanism. Our outcomes resulted from the continuity of the patellar tendon to the prosthesis through wrapped ITB and the integration of the patellar tendon and wrapped ITB with the tibialis anterior fascia and gastrocnemius flap.

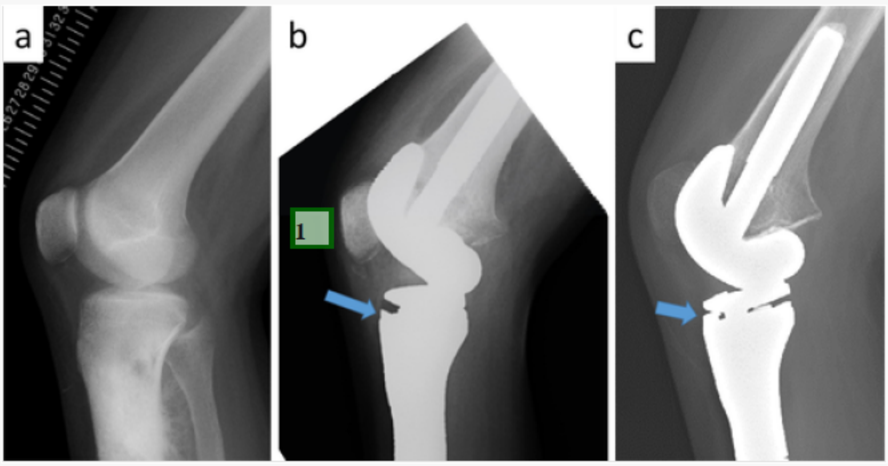
However, the direct attachment of the extensor mechanism to the prosthesis has been reported to not result in significantly better MSTS function compared with the attachment mainly to a gastrocnemius muscle flap[Instruction: 11

---> 10] [11]. Shimose et al. also described a case in which a patellar tendon was detached from the prosthesis that could achieve no extensor lag[Instruction: 14 ---> 13] [14]. Other authors described that the insertion of the patellar tendon at the prosthesis using a particular fixation device provided only temporary mechanical support for the healing of the overlying reconstructed leg extensors [2]. The scar formation between the patellar tendon and leg extensors caused by prolonged immobilization with the knee in full extension could contribute to the continuity of the extensor mechanism[Instruction: 14 ---> 13] [14]. Considering these observations, once the combination of the patellar tendon, gastrocnemius flap, and leg extensors provides continuity of the extensor mechanism, the initial fixation between the patellar tendon and prosthesis may no longer be essential.

We assessed the patella height by ISR in the present study. The mean postoperative ISR was 0.75, and the final follow up was 0.89 (P = 0.39). Evaluation of the ISR in our series showed a lengthening of the patellar tendon after reconstruction with time (Fig. 3). This change could be affected by various factors such as stretching and tensioning the reattached patellar tendon. In the previous literature, the short length of the patellar tendon (patella baja) led to flexion restriction, while the excess length (patella alta) was associated with an extensor lag [2]. Although we examined whether patellar height was associated with an extensor lag, none of the correlations between these were significant statistically. Jentsch et al. showed an increased patella height in the first 2 years after reconstruction [2]. Eleven of their 16 patients had developed patella alta with a mean extensor lag of 17° after a mean follow up of 2 years. Shimose et al. reviewed seven consecutive patients with malignant tumors of the proximal tibia who underwent prosthetic reconstruction and found that the patellar tendon stretched after surgery, whereas the extensor lag improved continuously for 12 months postoperatively with rehabilitation. Cipriano et al. noted that active extension could improve in the long term as the quadriceps continued to gain strength [7]. Conversely, several case series using the mesh technique described that evaluation of all postoperative radiographs showed no lengthening of the patellar tendon with time, which was an advantage of the mesh over grafts for decreasing an extensor lag[Instruction: 13,21 ---> 12,20] [13,21]. The mesh technique showed favorable outcomes regarding extensor lag as compared with other surgical procedures[Instruction: 13,23 --->12,22] [13,23].

Images are optimised for fast web viewing. Click on the image to view the original version.

Fig. 3



1 We would like to remove blue arrows from figure (b) and (c).

Lateral views of radiographs of a 17-year-old male (patient 12) with osteosarcoma of the proximal tibia. (a) X-ray with 1.04 of Insall–Salvati ratio (ISR) before surgery. (b) X-ray with 0.80 of ISR 2 months after surgery. (c) X-ray with 0.98 of ISR at the last follow up (47 months after surgery). These demonstrated a lengthening of the reconstructed patellar tendon with time after surgery.

Data regarding active flexion were collected from preoperatively to the last follow up in the present study. The mean active flex was 86°, comparable with that noted in previous studies reporting the functional outcomes for the reconstruction of the extensor mechanism[Instruction: 10,21,24 ---> 9,20,23] [10,21,24]. In our study, greater flexion was observed in patients with patella alta. The two patients with patella alta had a mean active flexion of 100° (90–110°), whereas patients without it had a mean active flexion of 84° (40–110°). Despite the small number of patients in our series, we found a statistically significant association between patellar height as measured by the ISR and active flexion of the knee. Grimer et al. reported mean flexion of 104° and extensor lag of 30° in 50 patients reconstructed with proximal tibia mega-prostheses[Instruction: 24 ---> 23] [24]. Most patients in our series had patella baja postoperatively, which resulted in the avoidance of any extensor lag at the cost of knee flexion. Postoperative interventions such as shortening the period for fixation and ROM exercise at an early phase will be required to achieve improved flexion.

Infections often result in unfavorable outcomes due to the need to delay adjuvant chemotherapy and rehabilitation. A deep infection in patients treated with endoprosthesis was reported to be associated with a high risk of amputation (36%) [Instruction: 25 ---> 24][25]. This makes it clear that peri-prosthetic infection needs to be avoided at all costs. Conversely, the rates of peri-prosthetic infection in the proximal tibia were reported to be higher in comparison with other locations[Instruction: 3,4,11,25 ---> 3,4,10,24] [3,4,11,25]. In the proximal tibia, the transfer of a gastrocnemius muscle flap could decrease postoperative infection risk after mega-prosthetic replacement. Mavrogenis et al. used various types of extensor mechanism reconstruction in addition to tibial mega-prosthesis and reported a 12% infection rate with gastrocnemius coverage [Instruction: 11 ---> 10][11]. Despite our use of autogenous ITB as a biological graft for the interface between the patellar tendon and prosthesis, postoperative infection occurred in four of our patients (29%). Two of them had superficial wound healing disturbances, and the remaining two peri-prosthetic infection. However, all infections healed with debridement and irrigation, which did not require additional surgeries such as amputation or revision of the prosthesis.

At the last follow up, the mean MSTS score of the nine surviving patients was 20.7 points (69%; range, 33–90%), comparable to those of other studies ranging from 68% to 77% [Instruction: 2,11,21,24 ---> 2,10,20,23][2,11,21,24]. Although not directly compared because these studies vary in terms of patient population and numbers, surgical methods, and outcomes assessed, our functional outcomes were consistent with those of previous studies.

This study has several limitations. First, only a small number of patients were included because we investigated reconstruction of the extensor mechanism of the knee using ITB. However, our series was prospectively and consecutively treated with identical surgical procedures, and thus given the rarity of this procedure, the present study is considered to have some validity. Second, we did not include concurrent controls and compared our outcome only with observations or data taken from the previous literature. Third, the quality or type of the prosthesis changed during the study period. Finally, the loss of the tibial tuberosity as a reference could make it difficult to measure the ISR on postoperative radiographs.

5 Conclusions

The extensor mechanism reconstruction with reverse transferred ITB sutured to the remnant patellar tendon could restore and stabilize active knee extension in patients with mega-prosthesis replacement of the proximal tibia; and although this successful case series does not offer sound clinical evidence of the efficacy of our procedure, it does suggest that it may be promising and thus deserving of further evaluation.

Funding

This work was supported by the Ministry of Education, Culture, Sports, Science and Technology of Japan (Grant-in-Aid 19K16769 for Young Scientists).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank Dr. Shunsuke Hamada for providing clinical data for this study.

References

The corrections made in this section will be reviewed and approved by a journal production editor. The newly added/removed references and its citations will be reordered and rearranged by the production team.

[1] ~~MALAWER~~Malawer ~~MARTIN M.~~MM, ~~MCHALE~~McHale ~~KATHLEEN A.~~KA Limb-sparing surgery for high-grade malignant tumors of the proximal tibia. Surgical technique and a method of extensor mechanism reconstruction. Clin Orthop Relat Res 1989~~;&NA;(~~;(239):~~231???248~~231~~. doi:~~–~~10.1097/00003086-198902000-00027~~248.

[2] Jentzsch ~~T.~~T, Erschbamer ~~M.~~M, Seeli ~~F.~~F, Fuchs ~~B.~~B Extensor function after medial gastrocnemius flap reconstruction of the proximal tibia tumor. Clin Orthop Relat Res 2013;471:2333–2339. doi:10.1007/s11999-013-2851-8.

[3] ~~Puchner S.E., ~~Kutscha-Lissberg ~~P.~~P, Kaider ~~A.~~A, Panotopoulos ~~J.~~J, Puchner ~~R.~~R, Böhler ~~C.~~C, et al. Outcome after reconstruction of the proximal tibia – Complications and competing risk analysis. PLoS ONE 2015;10(8):e0135736. doi:~~10.1371/journal.pone.013573610.1371/journal.pone.0135736.g00110.1371/journal.pone.0135736.g00210.1371/journal.pone.0135736.t00110.1371/journal.pone.0135736.t002~~10.1371/journal.pone.0135736.

[4] Hardes ~~J.~~J, Henrichs ~~M. P.~~M-P, Gosheger ~~G.~~G, Guder ~~W.~~W, Nottrott ~~M.~~M, Andreou ~~D.~~D, et al. Tumour endoprosthesis replacement in the proximal tibia after intra-articular knee resection in patients with sarcoma and recurrent giant cell tumour. Int Orthop 2018;42(10):2475–2481. doi:10.1007/s00264-018-3893-z.

[5] Bickels ~~J.~~J, Wittig ~~J.C.~~JC, Kollender ~~Y.~~Y, Neff ~~R.S.~~RS, Kellar-Graney ~~K.~~K, Meller ~~I.~~I, et al. Reconstruction of the extensor mechanism after proximal tibia endoprosthetic replacement. ~~Arthroplasty~~J Arthroplasty 2001;16(7):856–862. doi:10.1054/arth.2001.25502.

[6] ~~Dominkus M, Sabeti M, Toma C, Abdolvahab F, Trieb K, Kotz RI. Reconstructing the extensor apparatus with a new polyester ligament. Clin Orthop Relat Res 2006:328-34. https://doi.org/10.1097/01.blo.0000229368.42738.b6.~~Dominkus M, Sabeti M, Toma C, Abdolvahab F, Trieb K, Kotz RI Reconstructing the extensor apparatus with a new polyester ligament. Clin Orthop Relat Res 2006;328–334. doi:org/10.1097/01.blo.0000229368.42738.b6.

[7] Cipriano ~~C.A.~~CA, Dalton ~~J.~~J, McDonald ~~D.J.~~DJ Does patellar tendon repair with gastrocnemius flap augmentation effectively restore active extension after proximal tibial sarcoma resection? Clin Orthop Relat Res 2019;477(3):584–593. doi:10.1097/CORR.0000000000000564.

~~[8] Dominkus M, Sabeti M, Toma C, Abdolvahab F. Reconstructing the extensor apparatus with a new polyester ligament. Clin Orthop Relat Res 2006:328-34. https://doi.org/10.1097/01.blo.0000229368.42738.b6.~~

[Instruction: (9) ---> (8)] [9] Myers ~~G.J.C.~~GJ, Abudu ~~A.T.~~AT, Carter ~~S.R.~~SR, Tillman ~~R.M.~~RM, Grimer ~~R.J.~~RJ The long-term results of endoprosthetic replacement of the proximal tibia for bone tumours. J Bone Joint Surg Br 2007;~~89-B~~89(12):1632–1637. doi:10.1302/0301-620X.89B12.19481.

[Instruction: (10) --- Puerta-GarciaSandoval ~~P.~~P, Lizaur-Utrilla ~~A.~~A, Trigueros-Rentero ~~M.A.~~MA, Perez-Aznar ~~A.~~A, Alonso-Montero ~~C.~~C, Lopez-Prats ~~F.A.~~FA Successful mid- to long-term outcome after reconstruction

> (9)] [10] of the extensor apparatus using proximal tibia-patellar tendon composite allograft. Knee Surg Sports Traumatol Arthrosc 2021;29(3):982–987. doi:10.1007/s00167-020-06062-w.

[Instruction: (11) ---> (10)] [11] Mavrogenis ~~A.F.~~AF, Pala ~~E.~~E, Angelini ~~A.~~A, Ferraro ~~A.~~A, Ruggieri ~~P.~~P Proximal tibial resections and reconstructions: Clinical outcome of 225 patients. J Surg Oncol 2013;107(4):335–342. doi:10.1002/jso.23216.

[Instruction: (12) ---> (11)] [12] He ~~F.~~F, Hu ~~C.~~C, Shen ~~Y.~~Y, Bao ~~Q.~~Q, Wen ~~J.~~J, Qiu ~~S.~~S, et al. Patellar height influences knee function in patients with aggressive bone tumors of the proximal tibia after endoprosthetic reconstruction. Knee 2018;25(5):952–958. doi:10.1016/j.knee.2018.07.008.

[Instruction: (13) ---> (12)] [13] Ichikawa ~~J.~~J, Matsumoto ~~S.~~S, Shimoji ~~T.~~T, Ae ~~K.~~K, Tanizawa ~~T.~~T, Gokita ~~T.~~T A new technique using mesh for extensor reconstruction after proximal tibial resection. Knee 2015;22(6):659–663. doi:10.1016/j.knee.2015.01.001.

[Instruction: (14) ---> (13)] [14] Shimose ~~S.~~S, Sugita ~~T.~~T, Kubo ~~T.~~T, Matsuo ~~T.~~T, Ochi ~~M.~~M Reconstructed patellar tendon length after proximal tibia prosthetic replacement. Clin Orthop Relat Res 2005;439~~(NA.):~~:176–180. doi:10.1097/01.blo.0000176150.16509.33.

[Instruction: (15) ---> (14)] [15] Stensbirk ~~F.~~F, Thorborg ~~K.~~K, Konradsen ~~L.~~L, Jørgensen ~~U.~~U, Hölmich ~~P.~~P Iliotibial band autograft versus bone-patella-tendon-bone autograft, a possible alternative for ACL reconstruction: a 15-year prospective randomized controlled trial. Knee Surg Sports Traumatol Arthrosc 2014;22(9):2094–2101. doi:10.1007/s00167-013-2630-9.

[Instruction: (16) ---> (15)] [16] Jørgensen ~~U.~~U, Bak ~~K.~~K, Ekstrand ~~J.~~J, Scavenius ~~M.~~M Reconstruction of the anterior cruciate ligament with the iliotibial band autograft in patients with chronic knee instability. Knee Surg Sports Traumatol Arthrosc 2001;9(3):137–145. doi:10.1007/s001670000163.

[Instruction: (17) ---> (16)] [17] Ogihara ~~Y.~~Y, Sudo ~~A.~~A, Fujinami ~~S.~~S, Sato ~~K.~~K Limb salvage for bone sarcoma of the proximal tibia. Int Orthop 1991;15:377–379. doi:10.1007/BF00186883.

[Instruction: (18) ---> (17)] [18] Espregueira-Mendes ~~J.~~J, Andrade ~~R.~~R, Michael ~~M.J.S.F.~~MJSF, Sarmento ~~A.~~A, Sevivas ~~N.~~N, Rocha ~~R.~~R, et al. Augmentation of patellar tendon repair with autologous semitendinosus graft—Porto technique. Arthrosc Tech 2017;6(6):e2271–e2276. doi:10.1016/j.eats.2017.08.035.

[Instruction: (19) ---> (18)] [19] Albergo ~~J.I.~~JI, Gaston ~~C.L.~~CL, Aponte-tinao ~~L.A.~~LA, Frcs ~~L.M.J.~~LMJ, Frcs ~~S.R.C.~~SRC, Frcs ~~R.M.T.~~RMT, et al. Proximal tibia reconstruction after bone tumor resection : Are survivorship and outcomes of endoprosthetic replacement and osteoarticular allograft similar ? Clin Orthop Relat Res 2017;475(3):676–682. doi:10.1007/s11999-016-4843-y.

[Instruction: (20) ---> (19)] [20] Ek ~~E.W.~~EW, Rozen ~~W.M.~~WM, Ek ~~E.T.~~ET, Rudiger ~~H.A.~~HA Surgical options for reconstruction of the extensor mechanism of the knee after limb-sparing sarcoma surgery: An evidence-based review. Arch Orthop Trauma Surg 2011;131(4):487–495. doi:10.1007/s00402-010-1158-4.

[Instruction: (21) ---> (20)] [21] Pilge ~~H.~~H, Holzapfel ~~B.M.~~BM, Rechl ~~H.~~H, Prodinger ~~P.M.~~PM, Lampe ~~R.~~R, Saur ~~U.~~U, et al. Function of the extensor mechanism of the knee after using the "patellar-loop technique" to reconstruct the patellar tendon when replacing the proximal tibia for tumour. Bone Joint J 2015;97-B(8):1063–1069. doi:10.1302/0301-620X.97B8.35440.

[Instruction: (22) ---> (21)] [22] Gosheger ~~G.~~G, Hillmann ~~A.~~A, Lindner ~~N.~~N, R??dl ~~R.~~R, Hoffmann ~~C.~~C, B??rger ~~H.~~H, et al. Soft tissue reconstruction of megaprostheses using a trevira tube. Clin Orthop Relat Res 2001;393:264–271. doi:10.1097/00003086-200112000-00030.

[Instruction: (23) ---> (22)] [23] Liu ~~B.~~B, Tan ~~J.C.~~JC, Wang ~~H.L.~~HL, Wu ~~Z.~~Z, Yuan ~~Z.C.~~ZC, Wei ~~C.Y.~~CY The role of mesh technology with tumor prosthesis reconstruction to reconstruct the extensor mechanism of knee joint after resection of proximal tibial tumors. J Orthop Surg Res 2019;14~~:~~(1~~–~~);~~5~~64. doi:10.1186/s13018-019-1105-1.

[Instruction: (24) ---> (23)] [24] Grimer ~~R.J.~~RJ, Carter ~~S.R.~~SR, Tillman ~~R.M.~~RM, Sneath ~~R.S.~~RS, Walker ~~P.S.~~PS, Unwin ~~P.S.~~PS, et al. Endoprosthetic replacement of the proximal tibia. ~~J Bone Jt Surg~~J Bone Joint Surg Br 1999;81(3~~:~~):488–494. doi:10.1302/0301-620x.81b3.9234.

[Instruction: (25) --- Lee Jeys ~~R.G.~~RG The long-term risks of infection and amputation with limb salvage surgery using endoprostheses. Recent Results Cancer Res 2009;179:75–84. doi:10.1007/978-3-540-77960-5_7.

> (24)]

[25]