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Outcome measures

In all patients, QOL was evaluated by SF-36 before surgery and 6 and 24 months after surgery, and the results were compared with the Japanese national standard (NBS; norm-based scoring: absolute scores of 0-100 were recalculated by standardizing each scale to have a mean score of 50 and standard deviation of 10 in the general Japanese population). In addition, the knee function in the same periods was assessed using the Visual Analog Scale (VAS, a clinical pain scale) > @ /\VKROP VFRULQJ VFDOH PLQLPXP VDOXH PD[LPXP score 100; scores below 65 are interpreted as poor function) [22], posterior tibial displacement rate measured from a stress plain radiograph taken while using a Telos SE device (Telos Japan, Tokyo, Japan) (Measurement was made with the knee ÀH[HG WR ƒ DQG D IRUFH RI . 3D DSSOLHG WR WKH DQWHULRU aspect of the center of tibia. Displacement was measured as the mid-point displacement rate. PCL impairment was diagnosed when the displacement rate was 45% or below) > @ DQG WKH GLuHUHQFH LQ UDQJH RI PRWLRQ EHWZHHQ WKH DuHFWHG DQG XQDuHFWHG NQHHV 7KHVH VFRUHV ZHUH compared between group S and group D.

SF-36 is composed of the following 8 subscales: physical functioning (PF) role- physical (RP), bodily pain (BP) and general health (GH), which constitute the physical health component; as well as vitality (VT), social functioning 6) UROHÅHPRWLRQDO 5(DQG PHQWDO KHDOWK 0+ which constitute the mental health component.

Surgical techniques

$OO WKH VXUJHULHV ZHUH SHUIRUPHG E\ WKH VDPH RSHUDWRU as the main operator.

To harvest and prepare the graft tendon, the patient was SODFHG VXSLQH ZLWK WKH NQHH ƒ 7KURXJK D VNLQ LQFLVLRQ RI on the medial side of the tibial tubercle, the semitendinosus tendon was elevated, together with the gracilis tendon if needed. Then the harvested tendon was bundled, and the two HQGV ZHUH DWWDFKHG WR DUWL¿FLDO DQG (QGREXWWRQ &/ $FXIH[6PLWK 1HSKHZ 0DQV¿HOG Massachusetts) to prepare the tendon graft. An arthroscope ZLWK ƒ REOLTXH YLHZ ZDV XVHG were conducted via the antero-medial, antero-lateral and postero-medial portals.

Single-bundle reconstruction

8VLQJ WKH 3UR WUDF 3&/ *XLGH 6\VWHP $FXIH[6PLWK 1HSKHZ D VSHFLDOL]HG JXLGH ZLUH ZDV LQVHUWHG LQWR WKH center of the PCL tibial footprint, and a cannulated drill and dilator were used to create bone tibial tunnel with a diameter determined according to the width of the tendon JUDIW 1H[W XVLQJ D)OLS &XWWHU WKH tunnel with a diameter depending on the width of the tendon graft was created by the outside-in method on the femoral side DSSUR[LPDWHO\ PP SRVWHULRU WR FDUWLODJH DW DSSUR[LPDWHO\ R¶F (left knee) position. The tendon graft on the femoral side was ¿[HG XVLQJ (QGREXWWRQ $FXIH[DQG using spike staples by double stapling method. The graft was ¿[HG DW ƒ NQHH ÀH[LRQ ZLWK D WHQ tendon graft. All the tendon grafts prepared had diameters of 8.5 mm or larger (8.5 to 9.0 mm) and lengths of 65 mm or longer (65 to 75 mm).

Double-bundle reconstruction

Using the Pro-trac ACL Guide System, a guide wire was inserted into the posteromedial part of the PCL tibial footprint, and then a cannulated drill and dilator were used to drill a bone tibial tunnel with the same diameter as the PMB of the graft tendon. Using the same method, another bone tibial tunnel with the same diameter as the ALB of the tendon graft was made in the anterolateral part of the PCL tibial footprint. 1H[W WZR IHPRUDO WXQQHOV HDFK Z PMB or ALB, were created using the outside-in method. The WXQQHO IRU 3 0% UHFRQVWUXFWLRQ mm posterior to the articular cartilage margin at the anterior DVSHFW RI WKH LQWHUFRQG\ODU IR o'clock (right knee) or 10:30 o'clock (left knee) position. The WXQQHO IRU $/% UHFRQVWUXFWLRQ PP IURP WKH DUWLFXODU FDUWLODJH o'clock (right knee) or 11:00 o'clock (left knee) position. For ERWK EXQGOHV WKH IHPRUDO VLGH Z the tibial side with spike staples by double stapling method. 7KH EXQGOHV ZHUH ¿[HG DW ƒ NQHH JXOO NQHH H[WHQVLRQ IRU WKH 3/% 40 N to the tendon graft. In all the tendon grafts harvested, both bundles had diameters of 6 mm or larger (6-7 mm) and lengths of 60 mm or longer (60-70 mm).

Postoperative management

The postoperative management protocol was the same for group S and group D. Range of motion training while wearing an orthosis with angle limitation was started from 2 weeks after surgery. Partial weight bearing was permitted from 3 weeks, and full weight bearing from 6 weeks. Sports activities were restarted from around 9 months after surgery.

Statistical analysis

Mann-Whitney's U test and two-way ANOVA were used for statistical analyses of data. A p value less than 0.05 was FRQVLGHUHG VLJQL¿FDQW 6WDWLVW XVLQJ %HOO&XUYH IRU ([FHO 6RF Information, Co., Ltd.) D ERQH IHPRUDO

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Results

No serious postoperative complications such as re-rupture and deep wound infection occurred in both group S and group D, and none of the patients required re-operation. None of the patients deviated from the protocol after surgery.

Subjective evaluation by SF-36

The results of evaluation using SF-36 are shown in figure 2. At 6 months after surgery, the scores of all the subscales improved to above the national standard values in group D, whereas none of the subscale scores reached the national standard values in group S. Furthermore, PF, RP and BP scores in group S were significantly worse than those in group D ($p < 0.05$).

At 24 months after surgery, both groups S and D achieved improvement of all subscale scores to above the national standard values. Moreover, PF, RP and BP scores improved significantly compared to before surgery in both groups ($p < 0.05$).

Evaluation by Lysholm score

The mean Lysholm scores before surgery and 6 and 24 months after surgery were respectively 47.2 ± 21.3, 79.3 ± 18.8 and 80.6 ± 20.5 in group S; and 51.9 ± 22.2, 90.3 ± 12.1 and 90.6 ± 8.8 in group D. Significant improvement was observed at 6 and 24 months after surgery compared to before surgery in both group S and group D, but no significant intergroup differences were found.

Evaluation of pain by VAS

The mean VAS scores before surgery and 6 and 24 months after surgery were respectively 45.5 ± 25.8, 19.4 ± 20.3 and 16.1 ± 23.5 in group S; and 54.5 ± 24.4, 16.4 ± 19.2 and 11.8 ± 15.5 in group D. Although significant improvement was achieved at 6 and 24 months after surgery compared to before surgery in both groups, there were no significant differences between the two groups.

Evaluation of knee instability by posterior tibial displacement rate

The mean posterior tibial displacement rates (%) before surgery and 6 and 24 months after surgery were respectively 44.6 ± 9.1, 51 ± 7.7 and 53.7 ± 6.8 in group S; and 43.9 ± 4.2, 52.3 ± 7 and 51.6 ± 5.9 in group D. Although significant improvement was obtained after surgery compared to before surgery in both groups, no significant intergroup differences were observed.

Evaluation of knee range of motion

The results of knee range of motion are shown in table 1. Limitation of flexion of 5 degree or more remained detectable at 6 and 24 months after surgery in 9 patients (45%) and 6 patients (30%), respectively, in group S; and in 2 patients

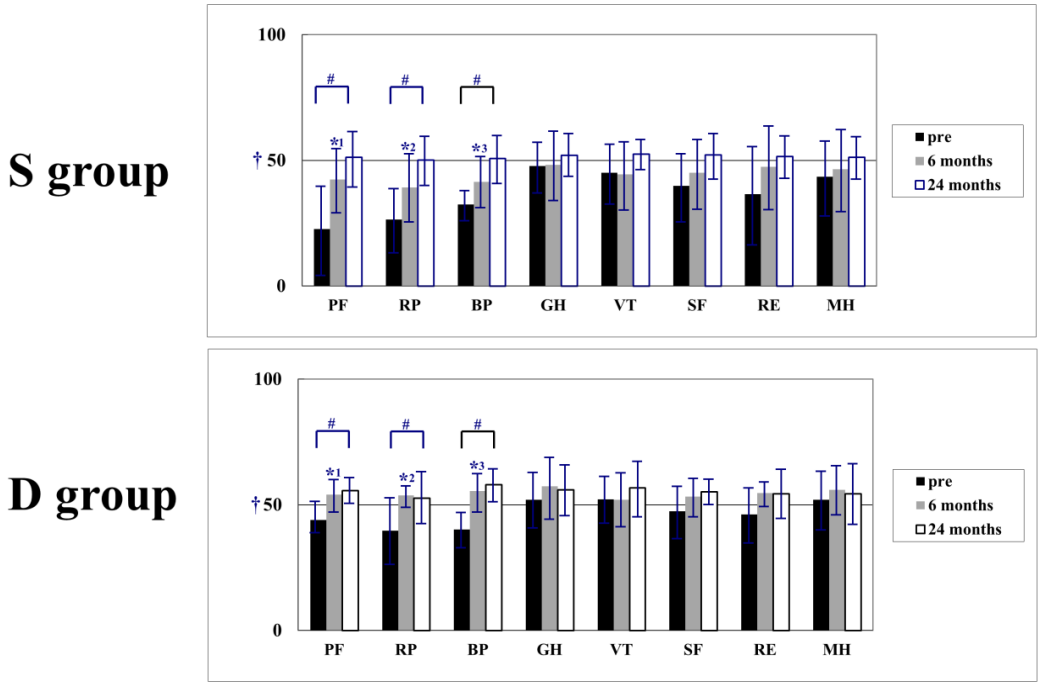

Figure 2: Group S: single-bundle posterior cruciate ligament (PCL) reconstruction. Group D: double-bundle PCL reconstruction. †: National standard values in Japan = 50. *$p < 0.05$, group S vs. group D; #$p < 0.05$, 24 months post-surgery vs. pre-surgery. At 6 months post-surgery, none of the subscale scores reached the national standard values in group S, and significant differences in three subscales between group S and group D were observed. At 24 months post-surgery, improvement of all subscale scores to above the national standard values was achieved in both groups, and significant improvement of PF, RP and BP compared to pre-surgery scores was observed in both groups.

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Table 1: Evaluation of knee range of motion.

		Group S	Group D	p
Flexion	**6 months**	9/20 (45%)	2/17 (12%)	0.021
	24 months	6/20 (30%)	1/17 (5.9%)	0.041
Extension	**6 months**	2/20 (10%)	1/17 (5.9%)	n.s.
	24 months	1/20 (5%)	0	n.s.

Group S: single-bundle posterior cruciate ligament (PCL) reconstruction. Group D: double-bundle PCL reconstruction. Data are expressed as number of patients with limitation of flexion ≥ 5 degree/total number of patients, with percentage in parenthesis.

(30%) and 1 patient (5%) in group D. The proportions of patients with limitation of flexion were significantly higher in group S than in group D (6 months after surgery: $p = 0.021$, 24 months after surgery: $p = 0.041$).

Discussion

PCL has a strong innate healing capacity, and many patients with PCL injury attain good improvement with conservative therapy [26-29], but surgery is selected by patients in whom severe posterior instability remains and subjective symptoms persist [30]. Among the surgical modalities, arthroscopic single-bundle PCL reconstruction is widely used in view of its low invasiveness and safety. However, according to a systematic review reported by Kim et al. [31], arthroscopically assisted single-bundle PCL reconstruction for high-grade PCL injuries provides some improvement of instability, but does not restore normal knee stability or prevent the development of degenerative osteoarthritis. In our previous studies, we found that persistent limitation of flexion accompanied by pain deteriorated the treatment result of single-bundle PCL reconstruction [17,18].

Low reproducibility of the unique course and anatomy of the PCL was considered to be the cause of unsuccessful PCL reconstruction [32]. To overcome these issues, the anatomic double-bundle reconstruction method was developed [5,6]. In this study, we compared the relative merits and demerits of the single-bundle and double-bundle reconstruction techniques using the patient-based SF-36 health-related QOL scale with scientifically proven reliability and validity [33,34] together with the conventional objective clinical measures.

In the present study, improvements in Lysholm score, VAS score, and posterior tibial displacement rate after surgery compared to before surgery were achieved by both single-bundle and double-bundle reconstruction techniques, with no significant intergroup differences in all three objective assessment methods. On the other hand, evaluation using SF-36 showed improvement of all subscale scores to above the national standard values in group D from the early post-surgical period of 6 months, whereas none of the subscale scores reached the national standard values in group S, and significant intergroup differences in three subscales belonging to the physical health component were observed. At 24 months after surgery, improvement of all subscale scores to above the national standard was attained in both groups, and all the subscale scores were apparently higher in group D than in group S, although there were no significant differences. Regarding range of motion of the knee, significantly higher proportions of knees in group S had residual limitation of flexion compared to group D, both at 6 and 24 months after surgery.

By reconstructing the ALB and PMB separately, the double-bundle reconstruction technique is considered capable of mimicking the native PCL both anatomically and functionally [7,35-37]. We speculate that in the double-bundle reconstruction, the morphology of the tendon graft divided into two bundles more closely reproduces the flat structure of the native PCL and reduces the interference in the popliteal region during flexion, which may have decreased the limitation of flexion after reconstruction as observed in this study. Smooth knee motion relieves the physical pain from the early period after surgical, which probably contributes to favorable subjective evaluation of the double-bundle reconstruction technique by patients.

At the last evaluation of treatment outcome, overall improvement was observed in both subjective and objective evaluations for both surgical techniques, with no clear differences. However, we believe that anatomic double-bundle reconstruction, which confers benefits of smooth knee motion early after surgery and low rate of residual limitation of flexion, should be recommended.

Abbreviations

PCL: posterior cruciate ligament; ALB: anterolateral bundle; PLB: posteromedial bundle; SF-36: 36-item short-form health survey; NBS: norm-based scoring; VAS: visual analog scale; ROM: range of motion; PF: physical functioning; RP: role- physical; BP: bodily pain; GH: general health; VT: vitality; SF: social functioning; RE: role-emotional; MH: mental health

Declarations

Ethical approval and consent to participate

We carried out a prospective clinical trial Ethical

approval was obtained from the institutional review board of the National Hospital Organization, Kofu National Hospital. Informed consent was obtained from all the patients.

Consent for publication

Not applicable

Availability of data and materials

All data and materials were in the compliance with the journal's policy fully.

Competing interests

The authors declare that they have no competing interests.

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None

Author's contributions

SO designed and wrote the manuscript. SS, NF, NT and TA collected and analyzed research data. TH and HH interpreted research data and edit the manuscript. All authors read and approved the final manuscript.

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