Comparison of Outcomes of Anterior Cruciate Ligament Reconstruction with Hybrid Tibial Fixations Between Adjustable Suspensory Device with Interference Screw and Cortical Screw Post with Interference Screw: A Prospective Comparative Cohort Study

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Research Article

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Abstract

Background:

Previous studies have compared different kinds of fixations for anterior cruciate ligament reconstruction. Nevertheless, there is no optimal method to date. Furthermore, to the best of authors' knowledge, there is no article discussing the combination of suspensory device and interference screw for hybrid tibial fixation.

Methods:

In total, 66 patients (34, modified group; 32, traditional group) were enrolled. Their International Knee Documentation Committee score, Tegner score, and Single Assessment Numeric Evaluation score were evaluated after a 2-year follow-up. The range of motion, anterior knee irritation and Lachman test were assessed at least 12 months after surgery. To evaluate tunnel widening, anteroposterior and lateral view radiography was conducted 1 day after surgery and at least 12 months later. A more than 10% change in the tunnel was considered as tibial tunnel widening. Mann–Whitney *U* test, independent *t* test, and chi-squared test were used to compare the variables between the groups.

Results:

No variable except gender ($P = 0.006$) showed any significant difference with regard to demographic data. Functional scores and physical examinations also showed no statistically significant difference between the groups. Patients who underwent traditional hybrid fixation were more prone to anterior knee irritation ($P = 0.028$). Further, more patients who underwent traditional hybrid fixation showed greater percentage of tunnel widening in the lateral view of radiographs ($P = 0.033$). No significant difference was observed in the anteroposterior view of radiographs between the groups (P = constant).

Conclusion:

Patients who underwent modified hybrid tibial fixation had similar clinical outcomes at 2-year follow-up, but less tibial tunnel widening in lateral view radiographs and less anterior knee irritation at 1-year follow-up compared with patients who underwent traditional hybrid tibial fixation.

Trial Registration:

Joint Institutional Review Board of Taipei Medical University, Taipei, Taiwan (No: N201805094).

Study Design:

Prospective comparative cohort study; Level of evidence, II.

Introduction

Anterior cruciate ligament (ACL) reconstruction is one of the most frequently performed orthopedic operations worldwide. In the United States, more than 120,000 ACL ruptures were reported every year [1], and the annual incidence of ACL rupture was approximately 68.8 per 100,000 person-years [2]. The increasing participation in sports and recreational activities has increased the risk of ACL rupture at present. Although ACL reconstruction is routinely performed, the optimal choice of fixation remains controversial.

Several methods for ACL fixation are available, such as interference screw, fixed or adjustable suspensory devices, and hybrid fixation [3]. Nonetheless, no method has been shown superiority to other methods in terms of both graft strength and clinical results such as functional scores and physical examination. All fixation methods have their own pros and cons, and previous studies have attempted to determine the optimal choice of method for ACL reconstruction. In a previous meta-analysis, Browning *et al*. compared suspensory devices to interference screws and observed that suspensory devices resulted in a better overall knee stability and less graft rupture [4]; by contrast, a recent systematic review and meta-analysis by Fu *et al*. reported no significant difference in knee stability and graft strength between suspensory devices and interference screws, except for less tibial tunnel widening (TW) when suspensory devices were used [5]. Similarly, clinical outcomes such as functional scores and physical examinations showed no significant difference when either of the methods was used [4, 5]. With regard to suspensory devices, whether fixed or adjustable suspensory devices should be used remains debatable. Studies that involved the comparison of fixed and adjustable suspensory devices showed similar knee laxity when either type of device was used, and no significant difference was noted between the devices in terms of clinical outcomes [6, 7].

As there was no optimal method of choice for single-mode fixation in ACL reconstruction, hybrid fixation, which combined the advantages of both methods, was proposed. Most of the hybrid tibial fixation techniques involve mounting of a cortical screw post in addition to an intratunnel interference screw to increase the strength of the graft. The tibial side was frequently considered the weak point of ACL reconstruction owing to the less dense metaphyseal bone and more parallel vector of force at this side [8]. Nevertheless, many studies on hybrid fixation have been published and Balazs *et al*. reported that hybrid tibial fixation afforded better initial graft strength and less knee laxity compared with single-mode fixation. Yet, no significant difference in clinical outcomes was observed after a follow-up of 1 to 3 years between patients who underwent hybrid tibial fixation and those who underwent single-mode fixation [9].

To determine the optimal fixation for ACL reconstruction, we combined adjustable suspensory devices and an interference screw on the tibial side (modified hybrid tibial fixation). To the best of our knowledge, this modified technique has not been discussed and compared with other types of fixations to date. We present this modified fixation by using the transtibial tunnel technique, which allowed us to apply an adjustable suspensory device and interference screw onto the tibial side. We hypothesized that compared with hybrid tibial fixation using a cortical screw post along with the interference screw (traditional hybrid tibial fixation), our modified method could yield similar clinical outcomes in terms of the Lachman test, range of motion (ROM), International Knee Documentation Committee score (IKDC), Single Assessment

Numeric Evaluation (SANE) score, and Tegner activity scale and fewer commonly reported complications such as tibial TW and anterior knee irritation [10, 11].

Materials And Methods

Patients

This study was approved by the Joint Institutional Review Board of Taipei Medical University, Taipei, Taiwan (No: N201805094). We recruited consecutive patients who had undergone arthroscopic ACL reconstruction with single-bundle and quadrupled hamstring autograft from July 2015 to March 2018. These patients had received either traditional hybrid tibial fixation or modified hybrid tibial fixation conducted by single surgeon, Dr. Pei-Wei Weng. Patients were assigned to the traditional or modified hybrid tibial fixation groups according to their own choice after our explanation. Initially, 108 patients were included. Patients with concomitant posterior cruciate ligament or medial collateral ligament injuries, those aged less than 18 years, those who underwent revision ACL reconstruction, those with avulsion fracture, those underwent meniscal repair and those with contralateral knee injuries were excluded. Eventually, 66 patients were enrolled into our study.

Operative technique

An exploratory arthroscopy was conducted anteromedially and anterolaterally to assess the presence of any additional lesions such as a meniscus tear, cartilage damage, or loose bodies.

A longitudinal skin incision measuring approximately 3 cm was then made on the anteromedial tibial surface at the level of the pes anserinus. The semitendinosus as well as gracilis tendons were then harvested from their distal insertion by a closed tendon stripper. The graft was then folded twice to make it four stranded to reach a proper length of around 65–75 mm (Fig. 1) while ensuring that a 1-minute pretension was performed; the diameter of the hamstring graft ranged from 8 to 11 mm. Finally, TightRope RT implants (Arthrex, Inc., Naples, Florida, USA) for the femoral side and TightRope ABS implants (Arthrex) for the tibial side were installed onto the hamstring graft of patients who underwent modified hybrid fixation (Figs. 2a and 2b). In patients who underwent conventional hybrid fixation, TightRope RT implants (Arthrex) were connected to the femoral side and whipstitches were placed at the tibial ends of the tendon with nonabsorbable sutures (No. 5 Ethibond) for later fixation with the cortical screw post (Figs. 3a and 3b) onto the proximal tibia.

Once the preparation was done, we started to establish the femoral socket and tibial tunnel. Under maximal knee flexion (≥ 130 degrees of flexion) on the table, we drilled the femoral socket through the anteromedial portal, attempting to reach the anatomical anteromedial bundle insertion site at the lateral femoral condyle. The femoral socket was positioned at 10 o'clock for the right knees and 2 o'clock for the left knees. A reamer was then used to create a proper depth (approximately 20–25 mm). The diameters and depths were decided according to the results of the calibrator during the preparation. For the tibial tunnel, the transtibial technique was performed. Under assistance of alignment device modulated to 47.5°

to 52.5°, a drill pin was passed through the center of the ACL footprint. The tibial tunnel was then adjusted to match the diameter of the graft.

Subsequently, the graft was placed into the joint. The passing suture was employed so that the TightRope sutures and TightRope button could be passed through. Following 10 sets of flexion and extension, the tibial-sided graft was secured with a bioabsorbable interference screw in the tibial tunnel for patients in both the groups. Lastly, the Tightrope ABS was firmly tied in the modified fixation group and the cortical screw post was placed in the traditional fixation group.

Rehabilitation

After the operation, quadriceps and active ROM exercises in sitting or lying positions without weight-bearing were initiated as soon as possible (1 day postoperatively). Weight-bearing training was also initiated under assistance of a knee brace (starting from full extension and flexed 10° weekly thereafter) for 2 months. The majority of the patients could resume jogging approximately 6 months postoperatively.

Assessment of clinical outcomes

Clinical evaluation was performed before as well as at least 12 months after the operation. ROM measurement and Lachman test were conducted by experienced orthopedic surgeons to evaluate the knee ROM, stability, and laxity. The examiners were blinded with regard to the operative methods. In terms of functional scores, subjective IKDC score, SANE score, and Tegner activity level scale were documented during the patients' visit to the clinic or via telephonic inquiry 2 years after the operation.

With regard to tibial TW assessment, all patients underwent anteroposterior (AP) and lateral (LAT) view radiography on the next day of the operation and at least at the 1-year follow-up. The interval between two evaluations was decided based on previous studies [12–14]. To determine the width of the tibial tunnel, we measured the diameter between two sclerotic edges approximately 3 mm below the tibial plateau [13]. Further, to compare with the width of the tunnel on Day 1 after the operation, the diameter was divided by the maximal width of the proximal tibia in the AP view and that of the patella in the LAT view (Figs. 4a and 4b). A minimal enlargement of 10% in the tunnel diameter is defined as TW, and this definition was also used in our study [12, 15]. With regard to tunnel measurement, we performed test-retest reliability (repeatability test) as tunnel measurement was carried out by single resident. Measurements were performed separately a month apart. Pearson correlation coefficient more than 0.8 indicated high correlation while less than 0.4 indicated low correlation. The correlation coefficient from each variable ranged from 0.903 to 0.981 in this study, representing good reliability.

Statistical analysis

Statistical analysis was conducted using IBM SPSS Statistics for Mac OS (IBM Corporation, Armonk, NY, USA). First, we checked whether our data showed normal distribution. As both groups comprised fewer than 50 patients, the Shapiro–Wilk test was used. The P values for each continuous variable from both the groups were interpreted while only the IKDC scores revealed a significant difference between the groups ($P < 0.05$), indicating that all continuous variables except for IKDC score displayed normal

distribution. We then analyzed the statistical differences in all continuous variables except for the IKDC score by using the independent *t* test, and the IKDC score was analyzed using the Mann–Whitney *U* test instead. The chi-squared test was used for categorical variables. The level of significance was set at $P < 0.05$.

Results

Patients

A total of 108 patients who underwent ACL reconstruction with single-bundle and quadrupled hamstring graft were reviewed. Among these patients, 55 patients had undergone modified hybrid fixation whereas 53 had undergone conventional hybrid fixation. Several patients were excluded owing to the following reasons: nine patients from the modified group and ten patients from the traditional group were lost to follow-up, eight patients had simultaneous posterior cruciate ligament injury, six patients had concomitant medial collateral ligament injury, one patient had ACL avulsion fracture, five patients had undergone meniscal repair and three patient was undergoing revision ACL reconstruction. Eventually, 34 patients in the modified group and 32 patients in the traditional group were enrolled in the study.

Table 1
Demographic data of patients*

	Modified group	Traditional group	P value
Number of cases	34	32	
Age	34.91 ± 9.05	33.09 ± 8.05	0.393‡
Gender (Male/Female)	27/7	15/17	0.006œ
Surgical site (R't/L't)	14/20	14/18	0.833œ
Pre-OP pivot shift test (Positive/Negative)	22/12	20/12	0.852œ
Meniscus injury (Yes/No)	23/11	20/12	0.661œ

* Continuous values are documented as mean and standard deviation unless there is other indication; ‡ Independent T test; œ Chi-square test

The demographic data of the patients are presented in Table 1. The preoperative pivot shift test was conducted under anesthesia, and the results were categorized as positive and negative. No significant difference was observed between the groups with regard to age ($P = 0.393$), surgical site ($P = 0.833$), simultaneous meniscus injury ($P = 0.661$), and preoperative pivot shift test ($P = 0.852$). With regard to meniscal injury, there was no significant difference between the groups. These patients had undergone

partial meniscectomy if necessary. The distribution of sex significantly differed between the groups (*P* = 0.006). The modified fixation group consisted of 27 men and 7 women, and the traditional fixation group consisted of 15 men and 17 women.

Clinical evaluation

The results of the Lachman test are presented in Table 2. The majority of patients showed a grade between 2 and 3 before the operation. One patient from the modified fixation group showed grade 3 and three patients from the modified fixation group showed grade 2. No significant difference was observed in the results of the Lachman test between the groups (*P* = 0.184). All patients had undergone magnetic resonance imaging some or the other time before ACL reconstruction. After at least 1-year follow-up, 30 patients from both groups showed a grade no more than 1. One patient from the modified fixation group showed grade 2 in the Lachman test; three patients from the modified fixation group and two patients from the traditional fixation group presented with a grade between 1 and 2. No significant difference was observed between the two groups even at the 1-year follow-up (*P* = 0.139).

Table 2
Lachman test

	Modified group	Traditional group
Pre-operative (P = 0.184*)		
I	0	0
I ~ II	0	0
II	3	0
II ~ III	30	32
III	1	0
2-year Follow-up (P = 0.139*)		
< I	11	4
I	19	26
I ~ II	3	2
II	1	0
* Chi-square test		

ROM was documented at least 1 year after the operation, and the data are shown in Table 3. Almost all patients from both groups had presented with full ROM, whereas only one patient from the traditional fixation group had presented with limitation of knee flexion, which decreased only less than 10 degrees in comparison with the contralateral side. No significant difference was observed between the groups (*P* = 0.299). The analysis of anterior knee irritation is presented in Table 4. Among the 34 patients who

underwent modified hybrid fixation, 4 showed anterior knee irritation, whereas among the 32 patients who underwent traditional hybrid fixation, 11 showed anterior knee irritation at least 1 year after the operation. Significant difference was observed in the incidence of anterior knee irritation between the groups (*P* = 0.028).

Table 3
Range of motion

	Modified group	Traditional group	P value
Limited	0	1[#]	
Full	34	31	
			0.299*
[#] less than 10 degrees flexion than opposite; * Chi-square test			

Table 4
Anterior knee irritation

	Modified group	Traditional group	P value
Negative	30	21	
Positive	4	11	
			0.028*
* Chi-square test			

With regard to functional scores, postoperative IKDC score, SANE score, and Tegner activity scale were all evaluated 2 years after the operation. The IKDC scores are shown in Table 5. The mean total IKDC score of the modified fixation group was 70.38 ± 6.358 and that of the traditional fixation group was 71.66 ± 6.434. No significant difference was observed between the two groups (*P* = 0.317). The SANE scores are shown in Table 6. The mean SANE score in the modified fixation group was 76.91 ± 12.43 and that in the traditional fixation group was 82.97 ± 13.55. No significant difference was observed between the two groups (*P* = 0.063). The postoperative results of the Tegner activity scale are shown in Table 7. The mean score of the modified fixation group was 4.15 ± 1.69 and that of the traditional fixation group was 4.94 ± 1.56. No significant difference was observed between the groups (*P* = 0.053).

Table 5
IKDC score

	Modified group	Traditional group	P value
Total score	70.38 ± 6.358	71.66 ± 6.434	0.317*
* Mann-Whitney U test			

Table 6
SANE score

	Modified group	Traditional group	P value
SANE	76.91 ± 12.43	82.97 ± 13.55	0.063*
* Independent T test			

Table 7
Tegner activity scale

	Modified group	Traditional group	P value
Tegner	4.15 ± 1.69	4.94 ± 1.56	0.053*
* Independent T test			

Images

We compared the percentage TW in the AP and LAT view of radiographs. The data are presented in Table 8 and Figs. 5a, 5b, 6a, and 6b. With regard to the percentage of TW in the AP view, no patient from either group showed more than 10% TW during the follow-up period of at least 1 year after surgery. No significant difference in the percentage of TW was observed between the two groups (*P* = constant). The mean percentage TW in the modified fixation group was 1.923 ± 2.19 and that in the traditional fixation group was 2.65 ± 2.25 at the 1-year follow-up. No significant difference was observed between the groups even at 1 year after the operation (*P* = 0.188).

Data regarding the incidence and magnitude of percentage TW in the LAT view are shown in

Table 9. None of the patients in the modified fixation group showed a TW greater than 10%; four patients showed more than 10% TW during follow-up at least 1 year after the operation. Significant differences were observed between the two groups with regard to the incidence of percentage TW in the LAT view (*P* = 0.033). The mean percentage TW change in the modified fixation group was 2.586 ± 3.25 and that in the traditional fixation group was 4.364 ± 2.92. A significant difference was observed between the groups (*P* = 0.023).

Table 8
Tunnel widening AP view

	Modified group	Traditional group	P value
>= 10%/ < 10%	0/34	0/32	Constant[œ]
Percentage TW change (A-B)	1.923 ± 2.19	2.65 ± 2.25	0.188*
* Independent T test; [œ] Chi-square test; A = percentage value of TW at least 1 year post-OP; B = percentage value of TW at 1 day post-OP			

Table 9
Tunnel widening LAT view

	Modified group	Traditional group	P value
>= 10%/ < 10%	0/34	4/28	0.033[œ]
Percentage TW change (A-B)	2.586 ± 3.25	4.364 ± 2.92	0.023*
* Independent T test; [œ] Chi-square test; A = percentage value of TW at least 1 year post-OP; B = percentage value of TW at 1 day post-OP			

Discussion

To the best of our knowledge, this is the first study to investigate and compare the outcomes of modified hybrid tibial fixation (combining adjustable suspensory device and bioabsorbable interference screw) in ACL reconstruction. A major highlight of this study was that patients who underwent modified hybrid tibial fixation showed less anterior knee irritation and tibial tunnel widening in the LAT view radiographs compared with patients who underwent traditional hybrid fixation. Moreover, the functional scores and clinical examinations of the patients in both the groups showed similar results. This confirmed our hypothesis.

In terms of development of TW, it was considered to be multifactorial in previous studies. Micromotion between the graft and bone interface, early rehabilitation, synovial fluid infiltration, and misplaced graft could all lead to a higher incidence of TW [15–18]. The type of fixation was considered one of the most important factors for tibial TW, and thus previous studies have compared all types of fixations to determine the optimal type [15–18]. With regard to suspensory devices, two commonly observed phenomena with fixed suspensory devices were the “bungee cord effect” and the “windshield wiper effect,” secondary to the longitudinal motion and transverse movement created by the gap between the graft and the fixation, respectively [15, 19]. Many studies have reported that a greater gap would lead to a greater TW, and therefore adjustable suspensory devices were introduced to overcome this deficit [6, 20, 21]. Although, in theory, adjustable suspensory devices could diminish the disadvantage of fixed suspensory devices, Choi *et al*. reported no significant difference between these two types of devices in terms of tunnel enlargement as well as clinical outcomes [6]. In addition, Bressy *et al*. reported insufficiency of tibial graft stability when only adjustable suspensory devices were used [22].

In traditional hybrid fixation, interference screws present some well-known disadvantages such as migration, loosening, cyst formation and TW. These might be attributable to the less dense structure of the proximal tibia [8, 19]. Thus, the cortical screw post was frequently applied to augment the stability and strength. Indeed, hybrid tibial fixation did result in stronger initial fixation and less knee laxity compared with interference screw alone; yet, this method did not yield significantly better clinical results [9, 23]. Our modified method was proposed to afford the advantages of both fixation methods and reduce the subsequent complications. As the interference screws had been reported to be associated with graft migration and loosening, we secured the graft by adding adjustable suspensory device to the tibial side, which could reduce the possibility of graft migration; furthermore, the “bungee cord effect” and the “windshield wiper effect” might be decreased owing to less direct graft-to-bone contact and micro-movement owing to the barrier created by the surrounding interference screw.

TW is more apparent in the femoral tunnel than in the tibial tunnel, as reported in previous studies [19–21]; however, the current study revealed that the evident TW could happen in the tibial tunnel, even with hybrid fixation. As the development of TW is multifactorial, not yet fully clarified, and inevitable in most cases [8], we emphasize the importance of tibial hybrid fixation for its double guarantee and safety for accelerated rehabilitation. Kawaguchi *et al*. reported that anatomic double-bundle ACL reconstruction resulted in less TW in the femoral tunnel [12], and our study found that anatomic single-bundle ACL reconstruction using the anteromedial trans-portal technique also yielded stable outcomes in most cases.

Further, we observed that three out of the four patients with TW from the traditional hybrid fixation group were female (age range, 40–48 years), and none of them reported that they were exercising regularly in the past. Although a previous study has reported that the transtibial technique could cause more damage to the bony structure than the inside-out method could [24], all patients included in this study had received the same transtibial technique, which potentially eliminated this concern. Thus, the lifestyle and the natural process of bone loss among middle-age women might weaken the structure in the proximal tibia, presumably leading to greater percentage of TW compared with other patients. Meanwhile, we attributed the percentage of TW to the loosening of the suture. This could have resulted from the cutting off by the sharp margin of the cortical screw or even the tibial tunnel opening, consequently leading to instability between the graft and the interference screw [10, 11]. By contrast, the modified method seemed to overcome this issue by replacing the cortical screw post with an adjustable suspensory device. Moreover, considering the routine usage of four stranded autografts with gracilis and semitendinosus, this technique can be used to obtain grafts of sufficient diameter but possess the potential risk of notch impingement for the narrower notch, especially in female patients. Some studies have reported that the notch impingement could account for the TW [12, 25]; hence, more attention should be paid to notchplasty during the procedure. The visualization of TW only in the LAT view might be attributable to the application of a more anterior translation force than the rotatory force for the tibia under the weight-bearing activity after anatomic single-bundle ACL reconstruction.

Despite the statistical difference in percentage TW, we observed no significant difference in clinical outcomes such as functional scores and clinical examinations between patients who underwent modified

and traditional fixation. Our results were compatible with those of many other studies [4–7, 9], indicating that TW had no clear correlation with clinical outcomes. Nevertheless, patients who underwent modified hybrid fixation showed less anterior knee irritation. Previous studies have reported anterior knee irritation with the use of cortical screw post in traditional hybrid tibial fixation [10, 11]. Thus, our modified hybrid fixation method could be considered as an option to improve the quality of life of patients scheduled to undergo ACL reconstruction in the future.

This study has some limitations. Firstly, the patients included in the study were not randomized. The composition of patients might potentially confound the results. As there was no blinding in the study, the preference of examiner and the expectation of patients could influence the assessment. We had had the examiners blinded for physical examination and performed repeatability test for measurement of tunnel widening in order to decrease the influence. In addition, sex distribution showed a significant difference between the groups. Most of the patients in the traditional fixation group as well as most patients who experienced TW were female. Whether there was any correlation between sex and percentage of TW was unclear.

In addition, we had only documented most of our functional scores and clinical examinations after the operation. Any significant difference in these results failed to reflect improvement or regression in each patient but could only indicate the postoperative difference between the groups resulting from the different operative methods used, as no previous measurement could be referred to. Moreover, we only documented the TW right after the operation and at least 1 year after the operation. Hence, we could not determine the long-term influence of each operative technique on TW. Nonetheless, as stated in previous research, our course of follow-up yielded adequate results, as the majority of tunnel change occurred within 6 months after the operation [13, 14].

Another limitation was that we did not use the KT-1000 or KT-2000 arthrometer for objective evaluation. We focused on postoperative TW, and previous studies have also recommended that the KT-1000 arthrometer be used as a diagnostic tool only, as it is unsuitable for use as an outcome tool [26].

Moreover, radiography was used instead of computed tomography (CT) in this study to measure TW. A previous study reported that CT could provide more accurate and reliable measurements of TW [27]; yet, several studies have reported that radiography could yield acceptable results [6, 28, 29]. Further, postoperative CT was not a routine clinical practice allowed by Taiwan National Health Insurance for follow-up of ACL reconstruction. Consequently, we decided to evaluate the imaging changes through radiographs instead.

Conclusion

Patients who underwent traditional hybrid tibial fixation and modified hybrid tibial fixation showed similar results in clinical examinations at least 12 months after the operation and similar functional scores at the 2-year follow-up; further, patients who underwent modified fixation showed less percentage of tibial TW and anterior knee irritation after at least 1 year of the operation.

Abbreviations

1. Anterior cruciate ligament: ACL
2. Range of motion: ROM
3. International Knee Documentation Committee score: IKDC score
4. Single Assessment Numeric Evaluation score: SANE score
5. Tunnel widening: TW
6. Anteroposterior: AP
7. Lateral: LAT
8. Computed tomography: CT

Declarations

Ethics approval and consent to participate: Our study design had been approved by the Joint Institutional Review Board of Taipei Medical University (TMU-JIRB N201805094). All methods in this study were performed in accordance with relevant guidelines and regulations. As our modified method is based on surgical technique and implants that were proven to be beneficial, the committee had granted us the waiver of written informed consent and asked us to obtain oral informed consent during the visit to outpatient department instead. All of the participants had agreed to join the study.

Consent for publication: Not applicable.

Availability of data and materials: The authors confirm that the data supporting the conclusions of this study is available within the article.

Competing interest: The authors declare no conflict of interest.

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Authors' contribution: PJ Lai helped draft the manuscript, conduct the analysis, and interpret the results. WP Chang processed the experimental data and performed the analysis. CK Liaw contributed to the study design and assisted in data acquisition. CC Wong also participated in forming the concept of the study and collecting data for the study. CH Chen provided critical opinion for the study design and helped in further revision of the manuscript. PW Weng was the corresponding author who coordinated the study and assisted in drafting the manuscript. All authors have read and approved the final manuscript.

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Figures

Figure 1

Single-bundle hamstring graft used in anterior cruciate ligament reconstruction

Figure 2

a Modified hybrid fixation with TightRope ABS implants (Arthrex) on the tibial side **b** Postoperative radiograph revealing application of suspensory devices in modified hybrid tibial fixation

Figure 3

a Whipstitches at tibial ends of the graft with nonabsorbable sutures (No. 5 Ethibond) for later fixation with a cortical screw post **b** Postoperative radiograph showing traditional hybrid tibial fixation using a

bioabsorbable interference screw and cortical screw post

Figure 4

a Measurement of percentage of tunnel widening in anteroposterior view of radiographs **b** Measurement of percentage of tunnel widening in lateral view of radiographs

Figure 5

a Anteroposterior view of radiograph of traditional hybrid tibial fixation at least 1 year after operation **b** Lateral view of radiograph of traditional hybrid tibial fixation at least 1 year after operation

Figure 6

a Anteroposterior view of radiograph of modified hybrid tibial fixation at least 1 year after operation **b** Lateral view of radiograph of modified hybrid tibial fixation at least 1 year after operation