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Hamstring graft sizes differ between Chinese and Caucasians

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Abstract
Purpose The use of hamstring tendon autografts for anterior cruciate ligament (ACL) surgery has become more and more common. The purposes of this study were to determine whether anthropomorphic measurement correlated with tendon sizes in Chinese patient group and whether tendon sizes in Chinese and Caucasian patient groups differed.
Methods From 2008 to 2009, 100 patients that received double-bundle ACL reconstruction with autologous hamstring tendons were prospectively enrolled. The original lengths and triple-folded graft diameters of the individual semitendinosus (ST) and gracilis (Gr) tendons were recorded and correlated with the anthropometric data (height, weight, body mass index, gender, thigh length, shank length, leg length and bilateral thigh circumference) of the patients. Later, using height for predictions, the original heights of patients were added to the equations previously used for regression models to compare the tendon lengths in different ethnic groups.
Results After stepwise multiple linear regression analysis, the height and leg lengths showed greatest correlation with the lengths of both tendons. The lengths of both the semitendinosus and gracilis tendons in Caucasian patients were significantly longer than in the Chinese patients.
Conclusions The results of this study showed that anthropomorphic measurements (height and leg length) correlated with tendon lengths. In addition, Caucasians had significantly longer hamstring tendons than the Chinese patients.
Level of evidence Prospective cohort study (prevalence), Level I.

Keywords Anterior cruciate ligament · Hamstring tendon · Graft size prediction · Reconstruction

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Introduction

There continues to be many controversies regarding anterior cruciate ligament reconstruction, including graft selection, discussed in the medical literature [1, 13]. As this procedure has become a more and more popular procedure, the use of autograft hamstring tendons has also increased. Compared to other autografts, the hamstring tendon has many advantages: (1) less donor site morbidity; (2) better plasticity, so that the final graft size can be adjusted by folding; (3) the possibility of regrowth after harvesting [7]; and (4) the tibial tendon insertion can be preserved for fixation augmentation [3, 15]. Besides from impaired tendon to bone healing potential with tunnel expansion [4], another major concern in autologous hamstring tendon grafting is an inadequate graft size. Since the normal ACL is about 7 mm in diameter and autologous grafts may not maintain their initial strength after transplantation, using grafts greater than 7 mm in diameter for single-bundle ACL reconstruction has been recommended [12]. Therefore, predicting whether the hamstring graft size is

adequate pre-operatively for anterior cruciate ligament reconstruction, or for double-bundle reconstruction, is mandatory.

The purpose of this study was to determine whether there were anthropomorphic predictors of tendon sizes in Chinese patient group and whether the tendon sizes of Chinese patients differed from Caucasians. The hypothesis was that anthropomorphic measurements, such as height, body weight, body mass index, leg length and bilateral thigh circumference, could predict the length and diameter of the hamstring tendons (semitendinosus and gracilis tendons).

Materials and methods

From 2008 to 2009, 100 Chinese patients that received double-bundle anterior cruciate ligament reconstruction with hamstring tendons were prospectively enrolled. This study was approved by the institutional review board at the Taipei Veterans General Hospital (IRB ID No.: 97-06-06A). Seventy-nine men and 21 women were enrolled in this study, and the average age of the patients was 28.4 years. The average height was 172.1 cm, average weight was 70.6 kg and average BMI was 23.7 kg/m^2.

The semitendinosus (ST) and gracilis (Gr) tendons were harvested through a 3-cm incision over the farthest distal insertion of the proximal tibia. The tendons were removed with tendon strippers. After removal of the fat and muscle tissue attached to the tendons, the lengths of each tendon were measured from the tibial insertion end to the tendon tail. The lengths were determined to the first decimal place in centimeters. Each tendon was triple-folded and whip-stitched with No. 2 and No. 5 Ethibond nonabsorbable sutures (Ethicon, Somerville, NJ, USA). The diameters of each tendon were determined by passing the folded graft through the sizing cylinders with incremental size changes of 0.5 mm (the final diameter was determined as the average of the femoral side diameter and tibial side diameters).

Using stepwise multiple linear regression analysis, the intra-operative graft size measurements were correlated with the pre-operative anthropometric data obtained from the patients. The anthropometric data included the following: gender, weight, age, body mass index (BMI), leg length [LL, anterior superior ischial spine (ASIS) to medial malleolar], thigh length [TL, ASIS to medial joint line (MJL)], shin length (SL, MJL to medial malleolar) and bilateral thigh circumferences 10 cm above the patella with the knee in 90° flexion (Tc: the operation side; Tch: the healthy side).

To compare the differences in hamstring tendon sizes between Chinese and Caucasian patient groups, the anthropometric data (height) of the 100 patients in this study were substituted in the equations used for the regression models in the study of Treme et al. [18]; by this method, the predicted tendon sizes of Chinese and Caucasian patients were compared. The predicted tendon lengths (for the Chinese and Caucasian patients) were then compared to the intra-operative measurements obtained in this study.

Statistical analysis

Statistical Statistiby cal analysis was performed using the SPSS (version 17.0; SPSS, Chicago, IL, USA) software. A level of significance set at 0.05 was used. A comparison of anthropomorphic measurements between male and female patients was performed using the independent t test. The correlation between anthropomorphic measurements and intra-operative tendon sizes was determined using stepwise multiple linear regression analysis. In addition, comparison of the tendon length between Chinese and Caucasian patients was performed with the independent *t* test.

Results

Linear regression model for tendon sizes

The average lengths for semitendinosus and gracilis tendon were 28.5 ± 2.48 and 26.1 ± 3.21 cm, respectively. After triple-folding, the average graft diameter for the semitendinosus and gracilis tendon was 7.3 ± 2.4 mm and 5.8 ± 1.9 mm, respectively. The difference between male and female measurements was significant (Table 1). After stepwise multiple linear regression analysis, the height and leg length measurements showed a significant correlation with the lengths of both tendons (Table 2). However, there were no significant correlations with the diameter of the

Table 1 Comparison of male and female patients in anthropometric data (mean ± SD)

	Male ($N = 79$)	Female ($N = 21$)	P
Height (cm)	174.5 ± 6.4	162.7 ± 5.6	$P < 0.05$
BW (kg)	74.3 ± 10.5	56.8 ± 5.8	$P < 0.05$
BMI (kg/cm^2)	24.3 ± 3.1	21.4 ± 1.8	$P < 0.05$
Tc (cm)	44.0 ± 4.1	40.4 ± 3.8	$P < 0.05$
Tch (cm)	46.1 ± 3.9	42.8 ± 3.8	$P < 0.05$
TL (cm)	48.4 ± 3.4	45.9 ± 4.2	$P < 0.05$
SL (cm)	40.5 ± 2.8	37.7 ± 1.6	$P < 0.05$
LL (cm)	88.9 ± 5.9	83.6 ± 4.8	$P < 0.05$
ST length (cm)[a]	28.8 ± 2.5	27.3 ± 1.8	$P < 0.05$
Gr length (cm)[b]	26.6 ± 3.2	24.2 ± 2.4	$P < 0.05$

[a] Semitendinosus tendon

[b] Gracilis tendon

Table 2 Correlation coefficient of anthropometric data for tendon lengths

	ST length[a]		Gr length[b]	
	Male	Female	Male	Female
Age	−0.071	−0.016	−0.064	−0.036
Height	0.451$^{P<0.001}$	0.629$^{P<0.001}$	0.348$^{P<0.001}$	0.428$^{P<0.05}$
BW	0.103	0.303	−0.026	0.419
BMI	−0.143	−0.142	0.210	0.162
Tc	−0.149	0.254	−0.151	0.000
Tch	−0.187	0.374	−0.177	0.090
TL	0.337$^{P<0.001}$	0.300	0.187	−0.278
SL	0.196	0.103	0.068	0.491$^{P<0.05}$
LL	0.339$^{P<0.001}$	0.302	0.168	−0.078

[a] Semitendinosus tendon length

[b] Gracilis tendon length

triple-folded ST or Gr tendons (data not shown). The equations for tendon length prediction by patient height were: (Fig. 1)

$$\text{Male: ST} = -2.15 + 0.177 \times (\text{height in cm}), R^2 = 0.203$$
$$\text{Gr} = -3.79 + 0.174 \times (\text{height in cm}), R^2 = 0.121$$

$$\text{Female: ST} = -6.645 + 0.209 \times (\text{height in cm}), R^2 = 0.296$$
$$\text{Gr} = -5.235 + 0.181 \times (\text{height in cm}), R^2 = 0.183$$

$$\text{Overall: ST} = -0.945 + 0.16 \times (\text{height in cm}), R^2 = 0.261$$
$$\text{Gr} = -5.624 + 0.184 \times (\text{height in cm}), R^2 = 0.206$$

Comparison of tendon length in Chinese and Caucasian patient groups

A summary of the measured and predicted length of both the ST and Gr tendons by patient height is shown in Table 3. The comparison between the predicted and measured Chinese and predicted Caucasian tendon lengths showed significant differences; Caucasians had longer hamstring tendons ($P < 0.05$; Fig. 2).

Discussion

The most important finding of the present study was that the patients' height was an ideal predictor of both ST and Gr tendon lengths. However, no measurements predicted single/tripled ST or Gr diameter. When the patient height was adequate, a triple-folded ST and Gr tendon provided suitable sizes for each bundle of the double-bundle anterior cruciate ligament reconstruction. By comparing the other prediction models, Caucasian patients seem to have longer hamstring tendon lengths as compared to Chinese patients.

The anterior cruciate ligament was anatomically divided into anteromedial (AM) and posterolateral (PL) bundles [5, 16, 19]. Each bundle contributes to partial knee stability during different ranges of motion activities [6]. Hence, in the double-bundle anterior cruciate ligament reconstruction, each bundle of the graft should have an adequate size to provide stability. In a study reported by Zhou et al., eight strands of the hamstring graft were noted to yield better clinical result than using only four strands [22]. Therefore, although the optimal diameter for each bundle in double-bundle anterior cruciate ligament reconstruction remains elusive, the result of this study implied that greater graft diameters may help improve stability of the knee. In the present study, the individual graft was triple-folded to obtain adequate size for the double-bundle anterior cruciate ligament reconstruction. In general, the triple-folded ST tendon was about 7–9 mm in diameter and 8–9 cm in length after folding; the Gr tendon was 5.5–7 mm in diameter and 7–8 cm in length after folding. The current dataset showed that these sizes were suitable for double-bundle reconstruction with intra-tunnel screw fixation. These findings imply that the original length of the tendon graft is important, since a shorter tendon length might result in a shorter intra-tunnel graft, which might preclude screw fixation. Hence, it is helpful pre-operatively to predict which patient may possess adequate size of the hamstring graft for double-bundle anterior cruciate ligament reconstruction.

Hamstring graft length prediction

There are many different methods used to evaluate the lengths of hamstring tendons pre-operatively. In the study reported by Yasumoto et al., there was a close positive correlation between the semitendinosus lengths measured intra-operatively and the measurements obtained by 3-dimensional computer tomography (3-D CT). However, only the ST, but not Gr tendon length, could be evaluated by this method. In addition, the cost and feasibility of 3-D

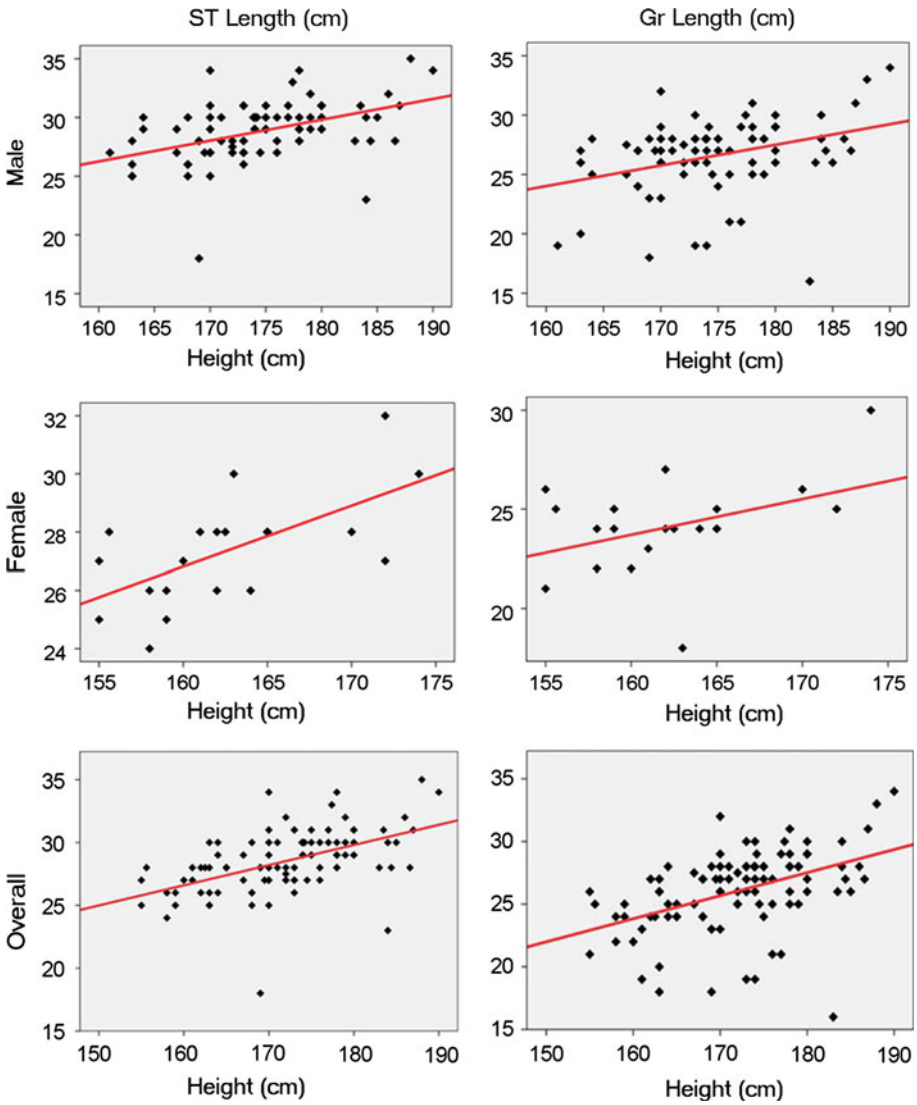

Fig. 1 Scatterplots showing the relationships between hamstring graft lengths and height in male, female and all patients. (*ST* semitendinosus tendon, *Gr* gracilis tendon)

CT is another concern [21]. Some investigators have used the anthropometric measurements to provide a simple, fast yet accurate prediction of the lengths of both individual hamstring tendons [9, 14, 18]. In a study of 50 consecutive patients, Treme et al. noted that height and leg length were strongly correlated with the hamstring tendon lengths. Similarly, Schwartzberg et al. found that leg length was the strongest predictor of tendon length [14]. However, he used "functional" tendon length, which was equal to half the length of the shorter of the two tendons, instead of the actual tendon length. In this study, the individual hamstring tendon lengths correlated mainly with height and some lower limb measurements of the patient. The regression model in this series showed that a male patient with a height of about 150 cm might have an insufficient tendon graft (i.e., tripled ST < 8 cm, tripled Gr < 7 cm in length) for a double-bundle anterior cruciate ligament reconstruction with screw fixation. Similarly, a female patient with a height less than 145 cm might have similar concern.

Hamstring graft diameter prediction

For prediction of the graft diameter, some investigators have used pre-operative magnetic resonance imaging (MRI) or 3-D CT to measure the cross sectional area (CSA) [2, 8, 21]. However, there was no significant correlation between the CSA of the ST tendon by 3-D CT and intra-operative measurements [21]. In additional, Hamade et al. reported that MRI was not practical for evaluating the tendon size since it requires a long scanning time and high cost [8]. The diameters of the hamstring graft can also be predicted by pre-operative anthropometric measurements. In the study reported by Schwartzberg et al., the patient's weight and leg length were moderately correlated with the

Table 3 Tendon length (cm) prediction by height in Chinese and Caucasian patient groups (mean ± SD)

	ST[a]	Gr[b]
Native length	28.5 ± 2.5	26.1 ± 3.2
Predicted Chinese length	28.5 ± 1.3	26.1 ± 1.5
Predicted western length	30.4 ± 1.7	28.9 ± 1.5

[a] Semitendinosus tendon

[b] Gracilis tendon

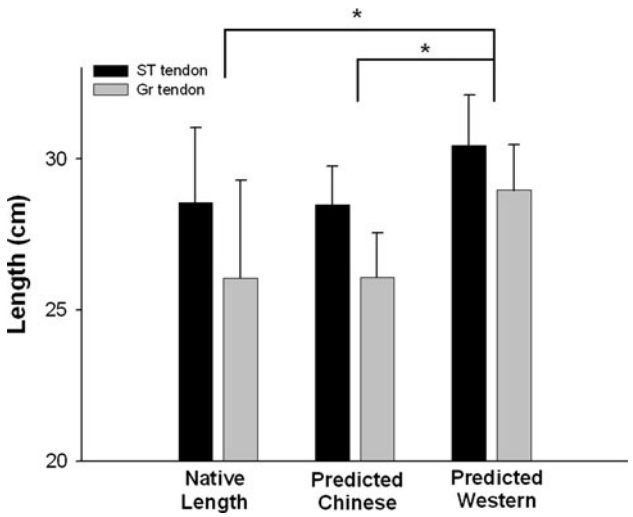

Fig. 2 Comparison of tendon lengths in Caucasian and Chinese patients (*ST* semitendinosus tendon, *Gr* gracilis tendon, $*P < 0.05$)

functional diameter of the 4-stranded hamstring graft [14]. In another series of 536 patients, height was found to be a strong predictor of quadrupled hamstring graft diameter in male patients (234 patients) [11]. Tuman et al. reported that the quadrupled hamstring graft diameter was related to height, mass and age but not the BMI [20]. These results indicate that some anthropometric measurements correlate with the diameter of 4-stranded (2 ST and 2 Gr tendons) grafts in single-bundle anterior cruciate ligament reconstruction. To the best of our knowledge, the methods needed to precisely predict the *individual* tendon diameter have not been established or widely discussed to date. The results of this study showed that there was no anthropometric measurement that was a strong predictor of a single/tripled hamstring graft diameters.

Comparison of Chinese and Caucasian patient groups in hamstring tendon lengths

There is limited information available of the anatomical difference between Chinese and Caucasian patients with regard to their ACL and reconstruction procedures. In the study of Tan et al., the ACL in Chinese patients appeared to be shorter and narrower than Caucasian patients [17]. On the other hand, the patellar tendon length in the Chinese was comparable to Caucasians [10]. In this series, by using the height of the 100 patients and the regression model reported by Treme et al., Caucasian patients were found to have longer hamstring tendons (about 2 cm longer with the same height). The significance of these discordant measurements in different ethnic groups with regard to anterior cruciate ligament reconstruction remains to be clarified. However, if it could be determined pre-operatively that the hamstring graft was inadequate in size, the surgeons would have the option of choosing another graft source or fixation methods.

The limitations of this study include the following: First, the measurement of the tendon diameter and length might be inaccurate. Since a 5 mm increment in measuring the diameter was used, the diameter within the same 0.5-mm scale would be recorded as the same. The grafts were harvested from their farthest insertion, just medial to the tibial tubercle, to minimize concern of inaccurate length measurement inaccuracy. Second, since there was no actual Caucasian patient group in this study, the comparison between these two ethnic groups was indirect. Inaccuracies for the predicted tendon lengths likely existed in the regression models. Finally, additional factors, such as the type of sports the patient was involved in and pre-injury activity levels, were not included in this study. These factors may also play some role in the prediction of graft size.

The clinical relevance of this study showed that in shorter or female patients, there was a relatively higher risk of obtaining inadequate individual hamstring tendon lengths for double-bundle anterior cruciate ligament reconstruction procedures. In different ethnical groups, it was also noted that Chinese patients, as compared to Caucasian patients, might have increased the possibility of shorter graft lengths.

Conclusion

The results of this study showed that stepwise multiple linear regression analysis for the correlation of hamstring graft size and anthropomorphic measurements was useful, and the analysis showed that the patients' height could be used to predict both ST and Gr tendon lengths in Chinese patients. In addition, the findings showed that men had significantly longer tendons than women. However, no measurement could be used to predict a single/tripled ST or Gr diameter. Finally, Caucasian patients appear to have longer hamstring tendon lengths than Chinese patients; however, the importance of ethnic difference with regard to this reconstructive procedure requires further study.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Bartlett RJ, Clatworthy MG, Nguyen TN (2001) Graft selection in reconstruction of the anterior cruciate ligament. J Bone Joint Surg Br 83:625–634
2. Bickel BA, Fowler TT, Mowbray JG, Adler B, Klingele K, Phillips G (2008) Preoperative magnetic resonance imaging cross-sectional area for the measurement of hamstring autograft diameter for reconstruction of the adolescent anterior cruciate ligament. Arthroscopy 24:1336–1341
3. Carneiro M, Navarro RD, Nakama GY, Barretto JM, de Queiroz AA, Luzo MV (2009) Arthroscopic anterior cruciate ligament double-bundle reconstruction using hamstring tendon grafts-fixation with two interference screws: technical note. Knee Surg Sports Traumatol Arthrosc 17:321–323
4. Chen CH, Chang CH, Su CI, Wang KC, Liu HT, Yu CM, Wong CB, Wang IC (2010) Arthroscopic single-bundle anterior cruciate ligament reconstruction with periosteum-enveloping hamstring tendon graft: clinical outcome at 2 to 7 years. Arthroscopy 26:907–917
5. Chhabra A, Starman JS, Ferretti M, Vidal AF, Zantop T, Fu FH (2006) Anatomic, radiographic, biomechanical, and kinematic evaluation of the anterior cruciate ligament and its two functional bundles. J Bone Joint Surg Am 88(Suppl 4):2–10
6. Gabriel MT, Wong EK, Woo SL, Yagi M, Debski RE (2004) Distribution of in situ forces in the anterior cruciate ligament in response to rotatory loads. J Orthop Res 22:85–89
7. Gill SS, Turner MA, Battaglia TC, Leis HT, Balian G, Miller MD (2004) Semitendinosus regrowth: biochemical, ultrastructural, and physiological characterization of the regenerate tendon. Am J Sports Med 32:1173–1181
8. Hamada M, Shino K, Mitsuoka T, Abe N, Horibe S (1998) Cross-sectional area measurement of the semitendinosus tendon for anterior cruciate ligament reconstruction. Arthroscopy 14:696–701
9. Limitlaohaphan C, Kijkunasatian C, Saitongdee P (2009) Length of semitendinosus and gracilis tendons and the relationship of graft length and leg length. J Med Assoc Thai 92(Suppl 6):S200–S203
10. Luk KM, Wong NM, Cheng JC (2008) Anthropometry of the patellar tendon in Chinese. J Orthop Surg (Hong Kong) 16:39–42
11. Ma CB, Keifa E, Dunn W, Fu FH, Harner CD (2010) Can preoperative measures predict quadruple hamstring graft diameter? Knee 17:81–83
12. Maeda A, Shino K, Horibe S, Nakata K, Buccafusca G (1996) Anterior cruciate ligament reconstruction with multistranded autogenous semitendinosus tendon. Am J Sports Med 24:504–509
13. Reinhardt KR, Hetsroni I, Marx RG (2010) Graft selection for anterior cruciate ligament reconstruction: a level I systematic review comparing failure rates and functional outcomes. Orthop Clin North Am 41:249–262
14. Schwartzberg R, Burkhart B, Lariviere C (2008) Prediction of hamstring tendon autograft diameter and length for anterior cruciate ligament reconstruction. Am J Orthop 37:157–159
15. Sonnery-Cottet B, Lavoie F, Ogassawara R, Scussiato RG, Kidder JF, Chambat P (2010) Selective anteromedial bundle reconstruction in partial ACL tears: a series of 36 patients with mean 24 months follow-up. Knee Surg Sports Traumatol Arthrosc 18:47–51
16. Takahashi M, Doi M, Abe M, Suzuki D, Nagano A (2006) Anatomical study of the femoral and tibial insertions of the anteromedial and posterolateral bundles of human anterior cruciate ligament. Am J Sports Med 34:787–792
17. Tan JL, Chang PC, Mitra AK, Tay BK (1998) Anthropometry of anterior cruciate ligament in Singaporean Chinese. Ann Acad Med Singapore 27:776–779
18. Treme G, Diduch DR, Billante MJ, Miller MD, Hart JM (2008) Hamstring graft size prediction: a prospective clinical evaluation. Am J Sports Med 36:2204–2209
19. Tsukada H, Ishibashi Y, Tsuda E, Fukuda A, Toh S (2008) Anatomical analysis of the anterior cruciate ligament femoral and tibial footprints. J Orthop Sci 13:122–129
20. Tuman JM, Diduch DR, Rubino LJ, Baumfeld JA, Nguyen HS, Hart JM (2007) Predictors for hamstring graft diameter in anterior cruciate ligament reconstruction. Am J Sports Med 35:1945–1949
21. Yasumoto M, Deie M, Sunagawa T, Adachi N, Kobayashi K, Ochi M (2006) Predictive value of preoperative 3-dimensional computer tomography measurement of semitendinosus tendon harvested for anterior cruciate ligament reconstruction. Arthroscopy 22:259–264
22. Zhao J, He Y, Wang J (2007) Double-bundle anterior cruciate ligament reconstruction: four versus eight strands of hamstring tendon graft. Arthroscopy 23:766–770