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Failure risks in anatomic single-bundle anterior cruciate ligament reconstruction via the outside-in tunnel technique using a hamstring autograft

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ABSTRACT

Purpose: To retrospectively evaluate the failure risk factors in anatomic single-bundle anterior cruciate ligament (ACL) reconstruction via outside-in tunnel technique using a hamstring autograft, and investigate the relationship between each risk factor.

Methods: The patients who underwent the ACL reconstruction with a minimum 1-year follow-up were included. We divided the patients into two groups – those who experienced graft failure (the failure group) and those who did not experience graft failure (the no failure group) – and compared their age, height, weight, sports activity level, graft size, and muscle strength. We defined graft failure as patients who underwent revision ACL reconstruction or had a second injurious ACL episode and those with a graft grade of C or D based on the International Knee Documentation Committee score.

Results: The study included 232 patients (101 male, 131 female; mean age at operation was 26.1 ± 11.9 years). The failure rate was 11.6% (failure group: 27 patients; no failure group: 205 patients). The patients in the failure group were younger and had higher sports activity level than those in the no failure group. ($p < 0.001$ and $p < 0.001$, respectively). Patient body weight in the failure group was lower than that in the no failure group ($p = 0.047$). Regarding the graft size of the tibial side, the failure group had smaller graft sizes than the no failure group ($p = 0.030$). With respect to muscle strength, quadriceps strength 6 months after surgery in the failure group was stronger than that in the no failure group ($p = 0.001$). In addition, the hamstring/quadriceps strength (H/Q) ratios 3 and 6 months after surgery were lower in the failure group than that in the no failure group ($p = 0.041$ and $p = 0.001$, respectively). There was an association between the age and the body weight, between the body weight and the graft size of the tibial side, and between lower age and high sports activity. Moreover, the high quadriceps strength at 6 months and the low H/Q ratio at 3 months were related to the low H/Q ratio at 6 months.

Conclusion: Young age, high activity sports level, low body weight, small graft diameter of the tibial side, high quadriceps strength at 6 months, and low H/Q ratio at 3 and 6 months can be failure risk factors in anatomic single-bundle ACL reconstruction via the outside-in tunnel technique using a hamstring autograft.

1. Introduction

The goal of anterior cruciate ligament (ACL) reconstruction is a return to sports and prevention of knee osteoarthritis. To achieve this, it is important to know the failure risks of an ACL graft. Anatomic single-bundle ACL reconstruction using a hamstring autograft is a gold standard technique.[1] The ACL graft failure rate is reported to 3.2–15% in anatomic single-bundle ACL reconstruction using a hamstring autograft.[2,3] Young athletes who participate in high level sports are at the highest risk for ACL graft failure.[2,3] The failure rate in patients under 18 years of age is the highest[4] and the odds of an ipsilateral ACL retear increases by 0.09 for every year of decrease in age.[5] The other risk

Abbreviations: ACL, anterior cruciate ligament; CFI, comparative fit index; RMSEA, root mean square error of approximation; AIC, Akaike's Information Criterion; H/Q, hamstring/quadriceps strength; BMI, body mass index

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factors for ACL graft failure include sex, graft size, and incomplete rehabilitation in ACL reconstruction with various surgical techniques. Schilaty et al.[6] reported ACL graft failure differed by sex, occurring more in female patients younger than 25 years and male patients aged 26–45 years. Gans et al.[7] showed that among athletes who play in national collegiate teams, men had a significantly higher rate of ACL graft reruptures than women. Maguusen et al.[8] found that graft size less than or equal to 8 mm in diameter increased the failure risk. Grindem et al.[9] showed patients did not regain ≥90% of their muscle strength before return to sports increased failure rate.

Thus, many studies have reported the risk factors of ACL graft failure in ACL reconstruction with various surgical techniques. However, the relationship between each risk factor has not been investigated. Moreover, it is probable that failure risks depend on operation techniques because the femoral tunnel shape using the outside-in femoral tunnel technique is different from that in other techniques.

Therefore, the purpose of this study was to retrospectively evaluate the failure risk factors in anatomic single-bundle ACL reconstruction via the outside-in tunnel technique using a hamstring autograft. Moreover, the relationship between each risk factor was investigated.

2. Materials and methods

2.1. Patient recruitment

The ethics committee of our hospital reviewed and approved this retrospective study (approval number: 1804). We adopted an opt-out style for maintaining the rights of patients to end the participation in the study whenever they wanted.

This retrospective study included 316 patients who underwent primary ACL reconstruction between April 2012 and March 2017 in our hospital. The anatomic single-bundle ACL reconstructions using a hamstring autograft, the outside-in technique, and with a minimum 12 months of follow-ups were included. The ACL reconstructions using double bundle (n = 7) and transtibial tunnel approach (n = 16), quadriceps tendon graft (n = 26), and follow-up of less than 12 months (n = 35) were excluded. The ACL reconstructions were performed by four experienced surgeons.

2.2. Surgical procedure

After performing a standard arthroscopic examination via anteromedial and anterolateral portals, we harvested the semitendinous tendon alone or both semitendinous and gracilis tendons at the level of the pes anserine via oblique skin incision of approximately 3 cm. Then, we created a multi-strand tendon graft. The femoral end of the graft was passed through TightRope RT (Arthrex, Naples, FL, USA). The tibial end of the graft was sutured using FiberLoop or TigerLoop (Arthrex, Naples, FL, USA).

We established anatomically a 10–12 mm length femoral tunnel with the outside-in technique. We placed a drill guide (RetroConstruction: Arthrex, Naples, FL, USA) posterior to the resident's ridge via anterolateral portal and passed the guide pin from the femoral of the lateral side (Fig. 1). After measuring the tunnel's length, we drilled 10–12 mm along the length of the femoral tunnel using the FlipCutter (Arthrex, Naples, FL, USA) (Fig. 1).

Next, we established the tibial tunnel. We placed the drill guide (ACUFEX: Smith & Nephew Endoscopy, Andover, Massachusetts, USA) via anteromedial portals at the center of the footprint. We passed the guide pin from the tibia of the medial side and drilled a tunnel. Finally, we passed the graft through both tunnels and fixed the graft with 20° of knee flexion position and applying mild tension (10–40 N) using a screw and washer on the tibial side.

2.3. Postoperative rehabilitation

Partial weight-bearing and range of motion exercise were started 2 days after surgery. Full weight-bearing walking was allowed 3 weeks after surgery. Running was allowed 3 months after surgery and return to sports 6–12 months after surgery. The postoperative rehabilitation schedule was the same for all patients.

2.4. Data collection

We obtained data from our hospital's clinical records and operation records. We defined graft failure as patients who underwent revision ACL reconstruction or had a second injurious ACL episode and those with a graft grade of C or D based on the International Knee Documentation Committee score.[10] We divided the patients into two groups: those who experienced graft failure (the failure group) and those who did not experience graft failure (the no failure group) and compared their age, height, weight, sports activity level, graft size, muscle strength and Tegner activity score.[11] Regarding the muscle strength, isokinetic concentric quadriceps and hamstring strength were measured twice (postoperative 3 and 6 months) using Biodex system 3 (SAKAI MED, Tokyo, Japan) at 60°/s.

2.5. Statistical analysis

The failure risk according to the patient's age, height, weight, Tegner activity score, graft size, and muscle strength between the failure and no failure groups were evaluated using the Student's *t*-test. The failure risk for patient's sex and previous contralateral ACL injury were evaluated using the $\chi 2$ test. P value of < 0.05 was considered statistically significant. After detecting a significant difference in the failure risks, we also created models of how each failure risk contributed to the ACL failure by covariance structure analysis using AMOS version 25. Model fit was assessed using the comparative fit index (CFI), root mean square error of approximation (RMSEA), and Akaike's Information Criterion (AIC). In addition, all path coefficients were indicated by standardized estimated values.

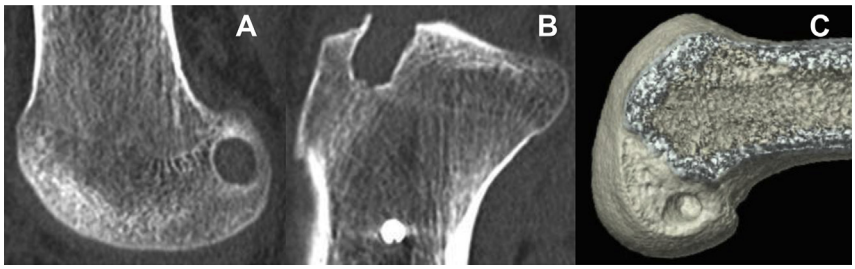

Fig. 1. Computed tomography image of anterior cruciate ligament reconstruction. (A) Sagittal view with a femoral tunnel position. (B) Sagittal view with a tibial tunnel position. (C) 3D reconstruction with a femoral tunnel position.

Table 1
Patient characteristics.

	Failure group	No failure group	p-value
	(N = 27)	(N = 205)	
Age (y)	18.6 ± 6.0	27.0 ± 12.2	< 0.001[a]
Weight (kg)	61.3 ± 9.3	65.5 ± 12.6	0.047[a]
Height (cm)	165.2 ± 7.9	165.8 ± 8.1	0.371
Male	11	90	0.597
Female	16	105	
Tegner activity score	7.0 ± 0.8	6.3 ± 1.0	< 0.001[a]

Date are presented as mean ± SD.
[a] Achieved statistical significance.

3. Results

A total of 232 patients were included in this study. There were 101 men and 131 women. Their mean age at operation was 26.1 ± 11.9 years. The mean follow-up period was 18.9 ± 9.7 months. The failure rate was 11.6% (failure group: 27 patients and the no failure group: 205 patients). Contralateral ACL injury was 3.9% (failure group: no patients (0%) and no failure group: 9 patients (4.4%), p = 0.267).

The patients in the failure group were younger and had a higher Tegner activity score than those in the no failure group. (p < 0.001 and p < 0.001, respectively) (Table 1). Patient body weight in the failure group was lower than that in the no failure group (p = 0.047). There were no significant differences in height, and proportion of women between the two groups (Table 1).

Regarding the graft size on the tibial side, those in the failure group had smaller graft sizes than those in the no failure group (p = 0.030) (Table 2). On the other hand, there were no differences in graft size of the center and the femoral side between the groups.

With respect to the muscle strength, those in the failure group had a quadriceps strength at 6 months after surgery that was higher than that of the no failure group (p = 0.001). In addition, the hamstring/quadriceps strength (H/Q) ratios at 3 and 6 months after surgery were lower in the failure group than that in the no failure group (p = 0.041 and p = 0.001, respectively) (Table 3).

Fig. 2 shows the models of how each failure risk factor contributed to the ACL failure by covariance structure analysis. There was a relationship between the age and body weight, between the body weight and the graft size of the tibial side, and between younger age and high sports activity. Moreover, the high quadriceps strength at 6 months and low H/Q ratio at 3 months were related to the low H/Q ratio at 6 months. The model fit indices indicated that the model was a good fit (CFI = 0.966, RMSEA = 0.040, AIC = 76.662).

4. Discussion

The patients who were young, with high activity sports level, low body weight, small graft diameter of the tibial side, high quadriceps strength at 6 months, and low H/Q ratio at 3 and 6 months had a high failure rate with anatomic single-bundle ACL reconstruction via the outside-in tunnel technique using a hamstring autograft.

Table 2
Graft size.

Graft position	Failure group	No failure group	p-value
	(N = 27)	(N = 205)	
Center (mm)	7.8 ± 0.7	8.0 ± 0.7	0.116
Femoral side (mm)	7.6 ± 0.7	7.9 ± 0.7	0.061
Tibial side (mm)	8.5 ± 0.7	8.8 ± 0.7	0.030[a]

Date are presented as mean ± SD.
[a] Achieved statistical significance.

Table 3
Isokinetic concentric muscle strength.

	Failure group	No failure group	p-value
3 months	N = 14	N = 131	
Hamstring (Nm)	81.7 ± 16.4	77.2 ± 64.2	0.603
Quadriceps (Nm)	76.5 ± 31.5	78.0 ± 21.9	0.411
H/Q	43.0 ± 8.0	48.6 ± 11.6	0.041[a]
6 months	N = 12	N = 115	
Hamstring (Nm)	81.6 ± 18.9	88.3 ± 22.1	0.840
Quadriceps (Nm)	97.6 ± 24.4	82.0 ± 15.8	0.001[a]
H/Q	40.3 ± 7.0	50.8 ± 11.4	0.001[a]

Date are presented as mean ± SD.
H/Q mean hamstring to quadriceps ratio.
[a] Achieved statistical significance.

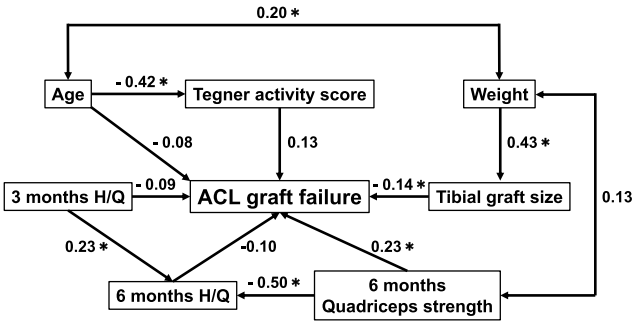

Fig. 2. The models of how each failure risk contributed to the ACL failure by covariance structure analysis. CFI = 0.966, RMSEA = 0.040, AIC = 76.662, *P < 0.05. There was a relationship between age and body weight, between body weight and graft size of the tibial side, and between younger age and high sports activity. Moreover, the high quadriceps strength at 6 months and the low H/Q ratio at 3 months were related to the low H/Q ratio at 6 months. The indices indicated the model was a good fit. ACL, anterior cruciate ligament; CFI, comparative fit index; RMSEA, root mean square error of approximation; AIC, Akaike's Information Criterion.

Those in the failure group were younger and had a higher Tegner activity score than the no failure group. Therefore, we identified young age and high Tegner activity score as risk factors for ACL graft failure. Moreover, young age and high Tegner activity score were related. Wiggins et al.[12] showed that the total second ACL reinjury rate was 15% in a systematic review. The second ACL injury rate for patients younger than 25 years was 21%, and athletes younger than 25 years who returned to sports had a second ACL reinjury rate of 23%. Grindem et al.[11] showed that the ACL reinjury rate was over four times higher in ACL reconstructed patients who returned to jumping, pivoting, and hard cutting sports. In our study, 25 of the 27 (92.6%) patients were younger than 25 years and 21 of the 27 (77.8%) patients had a Tegner activity score over 7. The reason was that younger patients were more likely to return to high risk sports that involve cutting, jumping, and pivoting movements. Similarly, the patients who had higher Tegner activity scores were more likely to perform high risk sports. Young athletes need strict time-based and functional return to sports criteria to prevent ACL graft failure.

In our study, with respect to the graft size of the tibial side, the failure group had smaller graft sizes than the no failure group. Therefore, small graft diameter of the tibial side can be a risk factor for ACL reconstruction failure. It may thus be necessary to prepare a thick graft for preventing graft failure, especially on the tibial side. We also noted an association between the body weight and the graft size of the tibial side. Therefore, since ACL grafts of low body weight patients are likely to have a small diameter, it may be necessary to harvest not only the semitendinosus tendon alone, but also the gracillis tendon, creating a multiple-strand thick tendon graft. Moreover, only the size of the graft

on the tibial side being a risk factor may be attributable to factors related to the surgical procedure, such as the bone tunnel position and/or bone tunnel angle. Some previous studies have evaluated the relationship between graft size and failure risk. Maguusen et al.[10] published the first clinical study demonstrating the association between graft size and revision rates in hamstring autograft ACL surgery. They found that graft size less than or equal to 8 mm in diameter increased failure risk. However, further investigation into the factors responsible for failure is necessary in the future.

The H/Q ratios at 3 and 6 months were lower in the failure group. Therefore, low H/Q ratio can be one of the risk factors for graft failure. Moreover, in our study, quadriceps strength at 6 months in the failure group (96.5 ± 24.4%) was higher than that in the no failure group (82.0 ± 15.8%). Furthermore, the high quadriceps strength at 6 months and the low H/Q ratio at 3 months were associated with the low H/Q ratio at 6 months. Low hamstring strength in comparison to quadriceps strength has been suggested as a risk factor for graft failure because it caused anterior tibial displacement.[13] Therefore, we may need to eliminate hamstrings/quadriceps strength imbalance in such patients, and it might be necessary to train not only the quadriceps but also the hamstrings for preventing graft failure.

For patients in the failure group, the weight of patients was lower than that of the no failure group patients in our study. Therefore, low body weight can be a risk factor for graft failure. Moreover, there was a relationship between age and body weight patients, i.e. the younger patients had lower body weights in this study. Therefore, those patients with low body weight may have a higher risk of ACL failure due to younger age and high sports activity. Persson et al.[14] showed that patients with a BMI $< 25\,kg/m^2$ had a higher risk of revision surgery compared to those with a BMI $> 25\,kg/m^2$. In contrast, van Eck et al.[15] showed that increased BMI was associated with single-bundle ACL graft failure. Thus, these results still remain controversial and further studies will be needed to identify the risk factors involved in ACL failure in this regard.

There were several limitations to this study, and thus, the results should be interpreted with caution. First, because this study was a retrospective study, some data was missing. Second, the sample size of this study was small. Third, the follow-up period was only one year.

5. Conclusion

Young age, high activity sports level, lower body weight, small graft diameter of the tibial side, high quadriceps strength at 6 months, and low H/Q ratio at 3 and 6 months can be failure risk factors in anatomic single-bundle ACL reconstruction via the outside-in tunnel technique using a hamstring autograft. Because this study was a retrospective study, a prospective study with a larger number of patients and a longer follow-up period is necessary to clarify failure risk factors for ACL reconstruction using this surgical method.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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References

1. Chen H, Tie K, Qi Y, Li B, Chen B, Chen L. Anteromedial versus transtibial technique in single-bandle autologous hamstring ACL reconstruction: a meta-analysis of prospective randomized controlled trials. *J Orthop Surg Res.* 2017;12:176.
2. Svantesson E, Sundemo D, Hamrin Senorski E, et al. Double-bundle anterior cruciate ligament reconstruction is superior to single-bundle reconstruction in terms of revision frequency : a study of 22,460 patients from the Swedish National Knee Ligament Register. *Knee Surg Sport Traumatol Arthrosc.* 2017;25:3884–3891.
3. Suomalainen P, Moisala AS, Paakkala A, Kannus P, Järvelä T. Double-bundle versus single-bundle anterior cruciate ligament reconstruction. Randomized clinical and magnetic resonance imagin study with 2-year follow-up. *Am J Sports Med.* 2011;39:1615–1622.
4. Webster KE, Feller JA. Exploring the high reinjury rate in younger patients undergoing anterior cruciate ligament reconstruction. *Am J Sports Med.* 2016;44:2827–2832.
5. Kaeding CC1, Pedroza AD, Reinke EK, Huston LJ, MOON Consortium, Spindler KP. Risk factors and predictors of subsequent ACL injury in either knee after ACL reconstruction: prospective analysis of 2488 primary ACL reconstructions from the MOON cohort. *Am J Sports Med.* 2015;43:1583–1590.
6. Schilaty ND, Nagelli C, Bates NA, et al. Incidence of second anterior cruciate ligament tears and identification of associated risk factors from 2001 to 2010 using a geographic database. *Orthop J Sports Med.* 2017;5 2325967117724196.
7. Gans I, Retzky JS, Jones LC, Tanaka MJ. Epidemiology of recurrent anterior cruciate ligament injuries in national collegiate athletic association sports. The injury surveillance program, 2004-2014. *Orthop J Sports Med.* 2018;13(6) 2325967118777823.
8. Magnussen RA, Lawrence JT, West RL, Toth AP, Taylor DC, Garrett WE. Graft size and patient age are predictors of early revision after anterior cruciate ligament reconstruction with hamstring autograft. *Arthroscopy.* 2012;28:526–531.
9. Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction; the Delaware-Oslo ACL cohort study. *Br J Sports Med.* 2016;50:804–808.
10. Hefti F, Muller W, Jakob RP, Staubli HU. Evaluation of knee ligament injuries with the IKDC form. *Knee Surg Sport Traumatol Arthrosc.* 1993;1:226–234.
11. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res.* 1985;198:43–49.
12. Wiggins AJ, Grandhi RK, Schneider DK, Stanfield D, Webster KE, Myer GD. Risk of secondary injury in younger athletes after anterior cruciate ligaments reconstruction a systematic review and meta-analysis. *Am J Sports Med.* 2016;44:1861–1876.
13. Kyritsis P, Bahr R, Landreau P, Miladi R, Witvrouw E. Likelihood of ACL graft rupture: not meeting six clinical discharge criteria before return to sports is associated with a four times greater risk of rupture. *Br J Sports Med.* 2016;50:946–951.
14. Persson A, Fjeldsgaard K, Gjertsen JE, et al. Increased risk of revision with hamstring tendon grafts compared with patellar tendon grafts after anterior cruciate ligament reconstruction. A study of 12,643 patients from the norwegian cruciate ligament registry, 2004-2012. *Am J Sports Med.* 2014;42:285–291.
15. van Eck CF, Schkrohowsky JG, Working ZM, Irrgang JJ, Fu FH. Prospective analysis of failure rate and predictors of failure after anatomic anterior cruciate ligament reconstruction with allograft. *Am J Sports Med.* 2012;40:800–807.