RBO REVISTA BRASILEIRA DE ORTOPEDIA
www.rbo.org.br

Original article

Biomechanical analysis on transverse tibial fixation in anterior cruciate ligament reconstructions☆

Edmar Stieven Filho[a,*], *Mariane Henseler Damaceno Mendes*[b], *Stephanie Claudino*[b], *Filipe Baracho*[a], *Paulo César Borges*[b], *Luiz Antonio Munhoz da Cunha*[a]

[a] *Universidade Federal do Paraná (UFPR), Curitiba, PR, Brazil*
[b] *Universidade Tecnológica Federal do Paraná (UTFPR), Curitiba, PR, Brazil*

ARTICLE INFO

Article history:
Received 7 November 2013
Accepted 6 December 2013
Available online 12 March 2015

Keywords:
Anterior cruciate ligament
Femur
Orthopedic fixation devices
Mechanics
Tendons

ABSTRACT

Objective: To verify whether the combination of tibial cross pin fixation and femoral screw fixation presents biomechanical advantages when compared to femoral cross pin fixation and tibial screw fixation for the reconstruction of the anterior cruciate ligament (ACL).
Methods: Thirty-eight porcine knees and bovine extensor digitorum tendons were used as the graft materials. The tests were performed in three groups: (1) standard, used fourteen knees, and the grafts were fixated with the combination of femoral cross pin and a tibial screw; (2) inverted, used fourteen knees with an inverted combination of tibial cross pin and a femoral screw; (3) control, ten control tests performed with intact ACL. After the grafts fixation, all the knees were subjected to tensile testing to determine yield strength and ultimate strength.
Results: There was no statistically significant difference in survival techniques in regard to strength, yield load and tension. There was a higher survival compared in the standard curves of yield stress ($p < 0.05$).
Conclusion: There is no biomechanical advantage, observed in animal models testing, in the combination of tibial cross pin fixation and femoral screw when compared to femoral cross pin fixation and tibial screw.

© 2015 Sociedade Brasileira de Ortopedia e Traumatologia. Published by Elsevier Editora Ltda. All rights reserved.

☆ Work developed at the Universidade Federal do Paraná (UFPR), Curitiba, PR, Brazil. It formed part of the doctoral project of Edmar Stieven Filho within the Postgraduate Program on Surgery at Universidade Federal do Paraná (UFPR).

* *Corresponding author.*
E-mails: filho2000@gmail.com, edmar.filho@ufpr.br (E.S. Filho).

http://dx.doi.org/10.1016/j.rboe.2015.02.012
2255-4971/© 2015 Sociedade Brasileira de Ortopedia e Traumatologia. Published by Elsevier Editora Ltda. All rights reserved.

Análise biomecânica da fixação tibial transversa na reconstrução do ligamento cruzado anterior

Palavras-chave:
Ligamento cruzado anterior
Fêmur
Dispositivos de fixação ortopédica
Mecânica
Tendões

RESUMO

Objetivo: Investigar se a fixação transversa tibial com parafuso femoral apresenta vantagens biomecânicas sobre a fixação transversa femoral com parafuso tibial na reconstrução do ligamento cruzado anterior (LCA).
Método: Foram usados como modelos de testes joelhos suínos e tendões extensores digitais bovinos. Foram submetidos à reconstrução do LCA 28 joelhos: 14 foram fixados com parafuso na tíbia e implante transverso no fêmur (grupo padrão) e 14 com parafuso no fêmur e fixação transversa na tíbia (grupo invertido). Os modelos foram submetidos aos testes de tração.
Resultados: Não houve diferença estatisticamente significante na sobrevivência das técnicas no que tange a força, força máxima sem falha e tensão. Houve uma sobrevivência maior no grupo padrão na comparação das curvas de tensão de limite elástico ($p < 0,05$).
Conclusão: Não há vantagem biomecânica da fixação transversa tibial com parafuso femoral em relação à fixação transversa femoral com parafuso tibial, observada em testes com modelos animais.

© 2015 Sociedade Brasileira de Ortopedia e Traumatologia. Publicado por Elsevier Editora Ltda. Todos os direitos reservados.

Introduction

The treatment of choice for young active symptomatic patients who present anterior cruciate ligament (ACL) injuries is reconstruction. This factor is the determinant for obtaining better results after returning to sports practice.[1]

The graft fixation method used in the reconstruction is what determines the stability in the immediate postoperative period. The majority of surgical failures occur during the initial months and the fixation site is the most vulnerable point.[2]

When grafts from knee flexors are used, it is common for the femoral fixation to be transverse or suspended, and for the tibial fixation to use interference screws. Transverse and suspended fixations are more resistant than interference screws.[3–5]

In addition to the implant, the bone quality is also a determining factor for the fixation.[6,7]

Femoral fixation has greater resistance than tibial fixation because of two factors: femoral spongy bone has greater density than the tibial bone and the fixation used in the femur presents higher resistance than that of the tibia.[7,8]

We did not find any studies in the literature that assessed the possibility of compensating for tibial bone fragility with the better mechanical quality of transverse fixations, as usually used in the femur. Most biomechanical tests have evaluated the tibial or femoral fixation separately, and few have evaluated the femur-ligament-tibia complex.[9–12]

The objective of this study was to ascertain whether transverse tibial fixation using a femoral screw presents any biomechanical advantages over transverse femoral fixation using a tibial screw, in an animal model.

Material and methods

This study was approved by the local ethics committee, under the number 064/09.

Twenty-eight fresh bovine digital extensor tendons were acquired. These were dissected and divided into two, in order to form pairs and simulate the flexor tendons of the human knee.[13]

The extremities of each tendon were sutured using Ethibond™ Polyester 2 surgical thread (Johnson & Johnson, Piscataway, NJ, USA).

After the suturing, an alginate impression was acquired using Jeltrade type II with normal setting (Dentsply, York, PA, USA). The tendon was immersed in this paste, which developed a rubbery consistency after a few seconds, thus forming a mold.

At this point, the tendon was removed from the alginate and this mold was sectioned transversally into blocks of 10 mm in thickness.[14,15]

The sections generated from the alginate mold were digitized at a resolution of 600 dpi using the HP J5780® digitizer. The cross-sectional areas of the molds were measured by means of the Image-Pro Plus® software.

The thinnest cross-section of each of the extremities of the tendon was selected in order to calculate the area. Since the pairs of tendons were folded in the middle to form quadruple grafts, the four smallest areas of each of the extremities of the tendons were summed.

After the impressions of the area had been made, the tendons were placed side by side with their respective pair. The pairs were folded in the middle, thus forming the quadruple graft. The quadruple grafts were solidified using polyester thread (Ethibond™ Polyester2) at the proximal extremity (Fig. 1).[15]

Twenty-eight knee specimens from pigs of the Large White breed were dissected.[16] Fourteen of these specimens were then subjected to reconstruction using transverse fixation in the femur and a screw in the tibia (standard group) and the other fourteen were reconstructed using a screw in the femur and transverse fixation in the tibia (inverted group), as shown in Fig. 2.

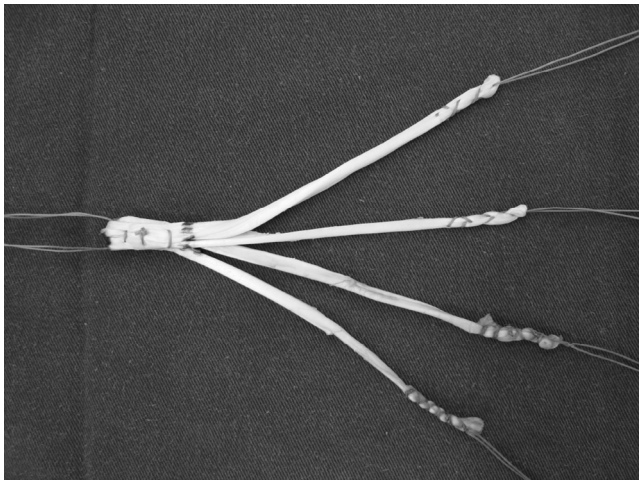


Fig. 1 – Solidified tendons – quadruple graft.

Metal interference screws of 9 mm in diameter and 30 mm in length were used. The transverse implant consisted of a pin made of polylactic acid (Rigidfix Cross Pin System, DePuyMitek, Raynham, MA, USA).

The entire process of acquiring the tendon and knee models and performing the mechanical tests was carried out within a 24-hour period, so that there would not be any need to freeze the material, which might have changed its elastic modulus and consequently the results. The samples were all kept under refrigeration, on ice, inside plastic bags containing a small quantity of 0.9% physiological serum, so that the samples would not dry out while they awaited mechanical testing.[17,18]

The knees were placed on a specific surgical table, in the 90° position.[15]

In both the standard and the inverted group, the tibial tunnel position was determined using a conventional guide configured at 55°. All the tunnels were drilled with a diameter of 9 mm.

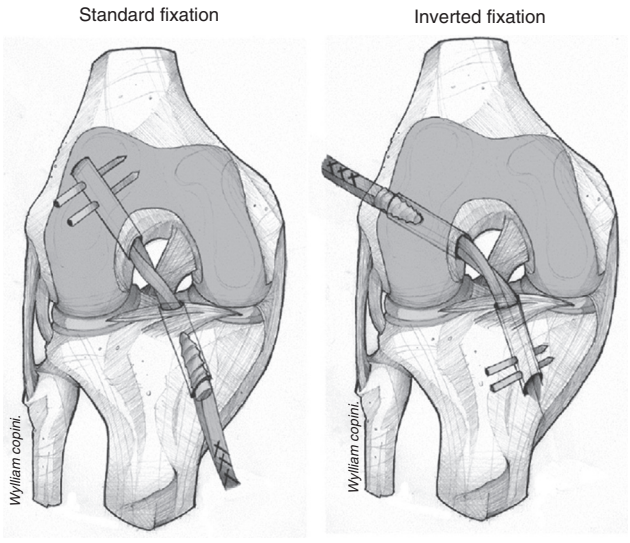


Fig. 2 – Groups with standard and inverted fixation.

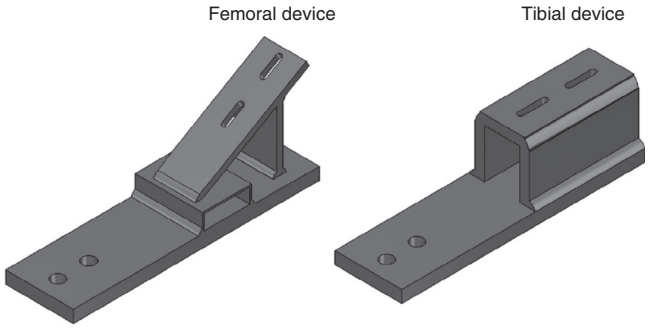


Fig. 3 – Devices for femoral and tibial fixation.

In the standard group, the femoral tunnel was constructed using a transtibial guide with an offset of 7 mm. After the drilling, the guide was placed in a U-shape (DePuyMitek, Raynham, MA, USA) in the femur in order to prepare for passing the fixation pins through. The graft was passed from the tibia to the femur. Firstly, proximal fixation using the transverse pins was performed and then fixation in the tibia using a screw.[15,19,20]

In the inverted group, the femoral tunnel was constructed using an outside-in guide (Phusis, Grenoble, France).[21] After the tunnels had been drilled, the U-shaped guide was positioned in the tibia in order to prepare for introduction of the implant. The graft was passed from the femur to the tibia. Firstly, the transverse fixation in the tibia was performed and then the femoral fixation.

For both the standard and the inverted group, a standardized graft length of 30 mm was used in the intra-articular portion.

Ten control tests with an intact ACL were also performed.

A metal device for positioning the knees in the test machine was developed. The device ensured the alignment and an angle of 30° between the femur and the tibia during the tests. This positioning aimed to simulate a critical condition for the ACL (Fig. 3).[22,23]

Stabilization was achieved through fixation of the diaphysis of the bone structure in the device using a nut and bolt (Fig. 4).

The groups were subjected to traction tests in the MTS 810 universal test machine (Material Test System Corporation, Minneapolis, MN, USA), with a load cell of capacity 10 kg/N (newtons).

The traction test conditions comprised pretensioning of 10 N and a velocity of 20 mm/min, until the tendon ruptured.

The following variables were determined: maximum force (MF); maximum force without failure (MFWF), which was obtained as the load supported by the material until the first significant change to the curve of load versus displacement; tension (T); tension at the elastic limit (TEL), i.e. the point at which the tendon started to undergo definitive plastic deformation; and stiffness (k).

The results from the tests comprised values for load versus displacement. From this curve, the maximum forces and their limits without failure were determined.

From the MF and MFWF values and the cross-sectional area of the ligaments, the tension and the tension at the elastic



Fig. 4 – Positioning of the samples in the test machine.

limit were determined through direct ratios between the variables of force and area.

The stiffness of the femur-ligament-tibia system was determined by means of the secant method.

For the statistical analysis, nonparametric Kaplan–Meier reliability analysis and the log-rank test were used. The latter compared the curves in order to estimate p values. The analyses were performed using the R 3.0.2 software.

Results

The results found for the standard group are described in Table 1. The mean maximum force was 528 N, while the maximum force without detecting failure was 352 N.

The results found for the inverted group are described in Table 2 and the maximum force without detecting failure was 330 N.

Failures relating to the surgical procedure or to the coupling of the model to the test system were considered to be operational failures. We had one case in each group operated in which the femur became cracked at the time of fixing the diaphysis to the test device. Another four failures occurred in the inverted group, through breakage of the implant during tibial fixation. There were no operational failures in the control group.

The results from the control group are reported in Table 3.

To compare the results, the Kaplan–Meier survival test was applied to MF, MFWF, T and TEL.

In the survival test using the FM data, with a cutoff point of approximately 450 N, the survival rate in the standard group was 69% and in the inverted group, 67% ($p > 0.05$).

For MFWF, with a cutoff point of approximately 350 N, the survival rate in the standard group was 46% and in the inverted group, 33% ($p > 0.05$).

At the loads of 450 N for MF and 350 N for FMWF, the control group presented survival of 100%, which was statistically significant in comparison with either of the other two groups ($p < 0.05$).

In the tension analysis, a cutoff point of approximately 10 MPa (megapascals), the survival rate was found to be 69% in the standard group and 67% in the inverted group ($p > 0.05$).

For TEL, at a cutoff point of approximately 7 MPa, the survival rate was 62% in the standard group and 22% in the inverted group. This result was statistically significant ($p < 0.05$).

Discussion

The traction test was performed through gradually applying a deformational force to the sample, until it ruptured. The force was applied to the long axis of the test body. The test machine measured the instantaneous load applied and the displacement. The test body was stretched at a constant

Table 1 – Standard group: transverse femoral pin and tibial interference screw.

	MFWF (N)	MF (N)	A (mm²)	T (N)	TEL (N)	k (N/mm)	Failure site		
							Transverse	Screw	Operational
Median	350	528	46	11	8	43	0	13	1
Mean	352	528	48	11	8	43			
SD	108	96	10	3	3	15			

MF, maximum force; MFWF, maximum force without failure; T, tension; TEL, tension at elastic limit; k, stiffness; SD, standard deviation; N, newtons; A, area.

Table 2 – Inverted group: femoral interference screw and transverse tibial pin.

	MFWF (N)	MF (N)	A (mm²)	T (N)	TEL (N)	k (N/mm)	Failure site		
							Transverse	Screw	Operational
Median	280	496	46	10	6	45	2	7	5
Mean	330	511	49	11	6	47			
SD	109	117	11	1	2	14			

MF, maximum force; MFWF, maximum force without failure; T, tension; TEL, tension at elastic limit; k, stiffness; SD, standard deviation; N, newtons; A, area.

Table 3 – Control group.

	MFWF (N)	MF (N)	Failure site		
			Tibia	Femur	Fracture
Median	755	1032	8	1	1
Mean	780	986			
SD	108	129			

MF, maximum force; MFWF, maximum force without failure; SD, standard deviation; N, newtons.

rate by the equipment. These traction tests were destructive tests.[15]

The number of operational failures in the inverted group (five) was greater than the number in the standard group (one). There was one case of failure of the fixation in the traction machine in each group. The surgical failures occurred in the inverted group. This occurred because the guide for transverse tibial fixation had been adapted from the one used for the femur. These adaptations do not have the same level of reproducibility as seen with specific materials. The guides for implantation of the pins in the tibia became unstable, which led to breakage of the implant at the time when it was introduced.

The rupturing of the grafts in the standard group occurred at the screw. In the inverted group, there were two cases of failure of the transverse fixation. This shows that the screw had greater mechanical fragility than did the transverse fixation.

Regarding the two cases of failure of the transverse fixation in the inverted group, three hypotheses can be envisaged. One is that the screw in the outside-in positioning had greater resistance in the traction plane tested, since it was tested at a divergent angle. The second is that the bone quality of the spongy bone of the femur increased the resistance of the fixation. Lastly, the fact that the guide for fixation of the transverse tibial implant had been adapted may have been the decisive factor for these two failures.

Transverse fixation is used in the femur for technical reasons, to avoid the difficulties of placing a screw in the femur and its complications. This screw is introduced through the medial portal and crosses the intercondylar region. It often has to be placed in a tunnel at an angle that differs from that of the entry portal of the implant.[24,25] Transverse fixation and suspended fixation make femoral fixation a simpler surgical step.

Despite presenting greater resistance than that of screws, both transverse fixation and suspended fixation have their disadvantages. Their high mechanical resistance is only reached if a loop of quadruple tendon is used. At the other extremity, their use is limited. In these fixations, caution is required in relation to the diameter of the tunnel, since tunnels that are very wide may diminish the mechanical resistance and graft-bone contact.[26]

In the outside-in technique, the femoral screw is introduced through a lateral access into the femur, which takes away many complicating factors from femoral fixation with a screw.[21]

An association between the technical ease of fixing the femur using an outside-in screw and the mechanical advantage of transverse tibial fixation, in order to compensate for the low quality of the spongy bone, seems to be promising. The present study did not show this possible mechanical advantage in animal models.

Survival tests are ideal for comparing mechanical analyses on surgical techniques.[15] They show the degree to which a given procedure can be trusted, for the different loads applied. No statistical differences were found in relation to the MF, MFWF or T data. However, in relation to the TEL data, the standard group presented greater survival. This shows that in addition to the lack of advantage in using transverse fixation in the tibia, this method may signify diminished capacity to withstand the tension. One hypothesis for explaining this result lies in the use of guides adapted from the femoral region for the tibial region.

Despite the negative finding in relation to TEL, there have been clinical studies showing that use of transverse tibial fixation is safe.[27] Good results from mechanical tests on transverse tibial fixation can also be found in the literature. However, no previous studies have tested the femur-ligament-tibia complex; rather, they only evaluated the tibial region. Another important point is that we did not find any studies that had evaluated T or TEL in relation to transverse tibial fixation.[12]

Conclusion

There is no biomechanical advantage from transverse tibial fixation using a femoral screw, in comparison with transverse femoral fixation using a tibial screw, as observed in tests on an animal model for ACL reconstruction. There is the possibility that the group with transverse tibial fixation has lower capacity to withstand tension.

Conflicts of interest

The authors declare no conflicts of interest.

REFERENCES

1. Cohen M, Abdalla RJ, Ejnisman B, Filardi M. Estudo comparativo no tratamento das lesões do ligamento cruzado anterior no esporte. Rev Bras Ortop. 1977;32(35):337–41.
2. Noyes FR, Barber-Westin SD. Revision anterior cruciate ligament reconstruction: report of 11-year experience and results in 114 consecutive patients. Instr Course Lect. 2001;50:451–61.
3. Milano G, Mulas PD, Ziranu F, Piras S, Manunta A, Fabbriciani C. Comparison between different femoral fixation devices for ACL reconstruction with doubled hamstring tendon graft: a biomechanical analysis. Arthroscopy. 2006;22(6):660–8.
4. Kousa P, Järvinen TLN, Vihavainen M, Kannus P, Järvinen M. The fixation strength of six hamstring tendon graft fixation devices in anterior cruciate ligament reconstruction. Part I: Femoral site. Am J Sports Med. 2003;31(2):182–8.
5. Scheffler SU, Südkamp NP, Göckenjan A, Hoffmann RFG, Weiler A. Biomechanical comparison of hamstring and patellar tendon graft anterior cruciate ligament reconstruction techniques: the impact of fixation level and

fixation method under cyclic loading. Arthroscopy. 2002;18(3):304–15.
6. Rodeo SA, Arnoczky SP, Torzilli PA, Hidaka C, Warren RF. Tendon-healing in a bone tunnel. A biomechanical and histological study in the dog. J Bone Joint Surg Am. 1993;75(12):1795–803.
7. Nurmi JT, Sievänen H, Kannus P, Järvinen M, Järvinen TLN. Porcine tibia is a poor substitute for human cadaver tibia for evaluating interference screw fixation. Am J Sports Med. 2004;32(3):765–71.
8. Brand JC, Pienkowski D, Steenlage E, Hamilton D, Johnson DL, Caborn DN. Interference screw fixation strength of a quadrupled hamstring tendon graft is directly related to bone mineral density and insertion torque. Am J Sports Med. 2000;28(5):705–10.
9. Monaco E, Labianca L, Speranza A, Agrò AM, Camillieri G, D'Arrigo C, et al. Biomechanical evaluation of different anterior cruciate ligament fixation techniques for hamstring graft. J Orthop Sci. 2010;15(1):125–31.
10. Aga C, Rasmussen MT, Smith SD, Jansson KS, Laprade RF, Engebretsen L, et al. Biomechanical comparison of interference screws and combination screw and sheath devices for soft tissue anterior cruciate ligament reconstruction on the tibial side. Am J Sports Med. 2013;41(4):841–8.
11. Petre BM, Smith SD, Jansson KS, de Meijer P-P, Hackett TR, Laprade RF, et al. Femoral cortical suspension devices for soft tissue anterior cruciate ligament reconstruction: a comparative biomechanical study. Am J Sports Med. 2013;41(2):416–22.
12. Zantop T, Weimann A, Rümmler M, Hassenpflug J, Petersen W. Initial fixation strength of two bioabsorbable pins for the fixation of hamstring grafts compared to interference screw fixation: single cycle and cyclic loading. Am J Sports Med. 2004;32(3):641–9.
13. Donahue TL, Gregersen C, Hull MLHS. Comparison of viscoelastic, structural, and material properties of double-looped anterior cruciate ligament grafts made from bovine digital extensor and human hamstring tendons. J Biomech Eng. 2001;123(2):162–9.
14. Goodship AE, Birch HL. Cross sectional area measurement of tendon and ligament in vitro: a simple, rapid, non-destructive technique. J Biomech. 2005;38(3):605–8.
15. Stieven Filho E, Malafaia O, Ribas-Filho JM, Diniz OEDS, Borges PC, Albano M, et al. Biomechanic analysis of the sewed tendons for the reconstruction of the anterior cruciate ligament. Rev Col Bras Cir. 2010;37(1):52–7.
16. Nagarkatti DG, McKeon BP, Donahue BS, Fulkerson JP. Mechanical evaluation of a soft tissue interference screw in free tendon anterior cruciate ligament graft fixation. Am J Sports Med. 2001;29(1):67–71.
17. Viegas AC, Camanho GL. Avaliação biomecânica dos tendões dos músculos tibiais e proposta de sua utilização como aloenxertos nas reconstruções do ligamento cruzado anterior. Acta Ortop Bras. 2003;11(3):170–5.
18. Matthews LS, Ellis D. Viscoelastic properties of cat tendon: effects of time after death and preservation by freezing. J Biomech. 1968;1(2):65–71.
19. Faustino CAC. Reconstrução do LCA com o uso dos tendões dos músculos flexores mediais do joelho e fixação femoral com o sistema de Rigidifix®: relato preliminar. Acta Ortop Bras. 2004;12(4):212–6.
20. Jones KG. Reconstruction of the anterior cruciate ligament. A technique using the central one-third of the patellar ligament. J Bone Joint Surg Am. 1963;45:925–32.
21. Garofalo R, Mouhsine E, Chambat P, Siegrist O. Anatomic anterior cruciate ligament reconstruction: the two-incision technique. Knee Surg Sports Traumatol Arthrosc. 2006;14(6):510–6.
22. Miyata K, Yasuda K, Kondo E, Nakano H, Kimura S, Hara N. Biomechanical comparisons of anterior cruciate ligament: reconstruction procedures with flexor tendon graft. J Orthop Sci. 2000;5(6):585–92.
23. Woo SL, Hollis JM, Adams DJ, Lyon RM, Takai S. Tensile properties of the human femur-anterior cruciate ligament-tibia complex. The effects of specimen age and orientation. Am J Sports Med. 1991;19(3):217–25.
24. Walton M. Absorbable and metal interference screws: comparison of graft security during healing. Arthroscopy. 1999;15(8):818–26.
25. Milankov MZ, Miljkovic N, Ninkovic S. Femoral guide breakage during the anteromedial portal technique used for ACL reconstruction. Knee. 2009;16(2):165–7.
26. Simonian PT, Erickson MS, Larson RV, O'Kane JW. Tunnel expansion after hamstring anterior cruciate ligament reconstruction with 1-incision EndoButton femoral fixation. Arthroscopy. 2000;16(7):707–14.
27. Volpi P, Marinoni L, Bait C, Galli M, de Girolamo L. Tibial fixation in anterior cruciate ligament reconstruction with bone-patellar tendon-bone and semitendinosus-gracilisautografts: a comparison between bioabsorbable screws and bioabsorbable cross-pin fixation. Am J Sports Med. 2009;37(4):808–12.