Cost Analysis of Converting From Single-Bundle to Double-Bundle Anterior Cruciate Ligament Reconstruction

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Background: Recent studies comparing double-bundle anterior cruciate ligament reconstruction to single-bundle anterior cruciate ligament reconstruction have reported some biomechanical advantages but little or no short-term clinical benefit from the double-bundle technique. In the current healthcare environment, the potential economic implications of widespread conversion to a double-bundle anterior cruciate ligament reconstruction are an important consideration.

Purpose: To determine the economic implications of widespread use of the double-bundle technique for anterior cruciate ligament reconstruction.

Study Design: Economic analysis; Level of evidence, 2.

Methods: A cost model to assess the effect of double-bundle anterior cruciate ligament reconstruction was constructed using standard accounting methodology. The model was based on actual 2008 cost figures (in US dollars) for ligamentous allografts, fixation implants, and operating room time. Revision rate (4%) and time to revision surgery (mean, 4 years) for single-bundle anterior cruciate ligament reconstruction was based on the available literature. Assumptions about the prevalence of double-bundle versus single-bundle anterior cruciate ligament reconstruction, the number of grafts used, and the revision rate for double-bundle reconstruction were varied to assess their effect on cost.

Results: The potential additional cost for widespread conversion to the double-bundle technique for anterior cruciate ligament reconstruction ranges from $36 million to $792 million per year in the United States alone. To offset this increased cost, the double-bundle technique would have to reduce the revision rate at a minimum from 4% to 1.5% and potentially from 24.1% to 0%.

Conclusion: Double-bundle anterior cruciate ligament reconstruction has the potential of adding considerable cost to the healthcare system.

Clinical Relevance: While further research is warranted to determine if there are other benefits from this technique, widespread adoption of a double-bundle anterior cruciate ligament reconstruction does not appear to be cost-effective at this time.

Keywords: ACL; reconstruction; double-bundle; cost; analysis

Anterior cruciate ligament (ACL) reconstruction is being performed with increasing frequency in the United States as approximately 200 000 ACL injuries occur each year.[13] With the increasing interest in sports participation and physical fitness throughout adult life, as well as more intense sports involvement at the pediatric level, the number of ACL injuries—and reconstructions—is likely to continue to grow.

The ACL has been acknowledged to consist of 2 distinct functional bundles—the anteromedial and posterolateral—since at least 1938,[24] but reconstruction techniques have traditionally focused on re-creating 1 bundle of the ACL, to effectively act as a checkrein to anterior tibial translation and tibial rotation. Recently, there has been growing interest in double-bundle (DB) reconstruction to improve outcomes after ACL surgery. The benefits of the DB technique are thought to be more exact reproduction of knee kinematics and rotational stability,[25,26,34,36] potentially leading to a lower rate of revision surgery and possibly reducing the risk of developing osteoarthritis over the long term.

A number of recent biomechanical[19,34,35] and clinical studies[6,20,25,26,30] have compared the DB-ACL reconstruction with a traditional single-bundle (SB) ACL reconstruction technique. While biomechanical data suggest that the DB reconstruction has some advantages over SB reconstruction,[19,34,35] the limited

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TABLE 1
The Cost Model Used for All Calculations[a]

X (cost differential) = X_{DB} – (X_{DBR} – X_{SBR})
X_{DB} = Additional cost of DB technique = Number of ACL reconstructions × Percentage converted from SB to DB technique × Additional cost per DB surgery
X_{DBR} – X_{SBR} = Savings from reduction in revision rate with DB versus SB technique
X_{DBR} = No. ACL reconstructions converted to DB technique × Revision rate DB × Cost DB revision (present value $20 000 plus additional cost DB technique discounted 4 years at 5% per year)
X_{SBR} = Number of ACL reconstructions converted to DB technique × Revision rate SB technique × Cost SB revision (present value $20 000 discounted 4 years at 5% per year)

[a]DB, double-bundle; DBR, double-bundle reconstruction; SBR, single-bundle reconstruction; SB, single-bundle; ACL, anterior cruciate ligament.

clinical evidence, to date, has not shown a clear difference in terms of significant objective and/or subjective outcome measures between the 2 techniques.[6,20,25,26,30] In the increasingly cost-conscious healthcare environment, new technologies and techniques may face economic as well as clinical scrutiny, particularly in the absence of any demonstrated clinical benefit. It was our hypothesis that the DB method would add significant potential cost, independent of surgeon expertise or other variables, due to the extra hardware and number of grafts necessitated by this method. Therefore, the purpose of this study was to assess the cost implications of transitioning from SB-ACL reconstruction to the DB technique.

METHODS

A cost accounting net present value model was used to perform a cost minimization analysis of the implications of transitioning to DB-ACL reconstruction (Table 1). Our model includes assumptions about the number of ACL reconstructions, the percentage of ACL reconstructions performed using a DB versus an SB, the cost of allograft tissue for ACL reconstruction, the cost of fixation devices, the percentage and timing of revision surgery, the cost of revision surgery, and the discount rate for future expenditures. Based on these assumptions, the model calculates the additional cost at the time of ACL reconstruction using the DB technique compared to the SB technique. The model then calculates the present value of the savings generated if the DB technique reduces the revision rate compared with the SB technique. The present value of a future revision (based on the mean time to revision) is multiplied times the number of revisions (based on the assumed revision rate) saved with the DB technique compared with the SB technique. The reduction in revision rate necessary to offset the increased upfront costs is calculated for each scenario.

We used a cost minimization model due to the complete lack of clinical utility data on DB reconstruction and the lack of clear demonstrated clinical differences between SB and DB reconstruction to date. We reviewed public and private data sources to determine the number of ACL reconstructions performed in the United States on an annual basis and the costs associated with surgical implants and

TABLE 2
Cost Assumptions Based on Current Data From the Authors' Institution[a]

Item	Cost
Revision ACL reconstruction	$20 000
Tibialis anterior allograft	$1500
30 minutes' OR time	$600
EndoButton	$220
Metal interference screw	$142

[a]ACL, anterior cruciate ligament, OR, operating room.

allografts. We assumed that 200 000 ACL reconstructions occur in the United States per year.[11,13]

We ran the cost model under 5 progressive scenarios depending on the percentage of ACL reconstructions converted to the DB technique and the number of allografts used. The first scenario assumed that 50% of ACL reconstructions were converted to DB reconstruction using 1 additional method of fixation. For the purposes of this study, we based our calculations on the use of the EndoButton device (Smith & Nephew, Andover, Maryland) for femoral fixation and 1 additional metal tibial interference screw compared to an SB reconstruction. This scenario assumes the use of autogenous tissue only for DB reconstruction. The second scenario also assumed 50% conversion to the DB technique, and that a DB reconstruction would require 1 additional EndoButton, 1 additional metal interference screw, and the cost of an additional 30 minutes of operating room time compared to an SB-ACL reconstruction. Thirty minutes was chosen as a conservative estimate of the mean increase in operative time necessitated by the DB technique taking into consideration the learning curve involved with this method.

The third scenario also assumed 50% conversion to the DB technique, and that a DB reconstruction would require one additional EndoButton, 1 additional metal interference screw, and 1 additional soft tissue allograft (tibialis anterior) compared to an SB-ACL reconstruction. Under the fourth scenario, also assuming 50% conversion to the DB technique, the cost of 2 soft tissue tibialis anterior allografts plus similar proximal and distal fixation was added for the DB technique.

The final scenario assumed that 100% of ACL reconstructions were performed with the DB technique and added the cost of an additional 30 minutes of operating time as well as 2 tibialis anterior allografts and proximal and distal fixation.

We used actual costs (in 2008 US dollars) from our institution (an academic medical center in the central United States) (Table 2). We reviewed the actual hospital costs for all ACL revision surgeries during the latest 2-year period with data available for the 2 senior authors (R.W.W., M.J.M.) (composed predominantly of a mix of SB bone-patellar tendon-bone [BTB] allografts and contralateral BTB autografts). We had complete cost information available for 42 of 44 ACL revisions performed during this period. The mean cost per revision, including surgeon and anesthesiologist fees, for these 42 cases was $21 429.04 ± $5836.28, and the median cost per revision was $20 501.93. The range of cost per revision was $14 420.72 to $51 211.13. We elected to use $20 000 per revision as the cost estimate for our model. Based on a systematic review of the literature regarding

TABLE 3
Cost Implications of Adopting DB Reconstruction Technique[a]

Scenario (additional costs included in model)	% Conversion From SB → DB	Additional Cost: Per Surgery	Additional Cost: Total	Reduction in Revision Rate Necessary to Offset Increased Cost
1- Additional proximal and distal fixation	50%	$362	$36.2 million	4% → 1.5%
2- Scenario 1 + 30 minutes' extra operating room time	50%	$962	$96.2 million	5.9% → 0%
3- Scenario 1 + 1 allograft	50%	$1862	$186.2 million	11.4% → 0%
4- Scenario 1 + 2 allografts	50%	$3362	$336.2 million	20.5% → 0%
5- Scenario 3 + 30 minutes' extra operating room time	100%	$3962	$792.4 million	24.1% → 0%

[a]SB, single-bundle ACL reconstruction; DB, double-bundle ACL reconstruction.

TABLE 4
Sensitivity Analysis

Scenario (additional costs included in model)	Reduction in Revision Rate Necessary to Offset Increased Cost Under Different Assumptions From the Base Model: 10% Discount Rate	2 Years to Revision	Cost of Revision $40 000
1- Additional proximal and distal fixation	4% → 1.1%	4% → 1.7%	4% → 2.6%
2- Scenario 1 + 30 minutes' extra operating room time	7.1% → 0%	5.4% → 0%	3% → 0%
3- Scenario 1 + 1 soft tissue allograft	13.7% → 0%	10.3% → 0%	5.7% → 0%
4- Scenario 1 + 2 soft tissue allografts	24.7% → 0%	18.6% → 0%	10.3% → 0%
5- Scenario 3 + 30 minutes' extra operating room time	29.1% → 0%	21.9% → 0%	12.1% → 0%

outcome of arthroscopic SB-ACL reconstructions using accepted graft insertion sites and modern fixation methods,[29] we assumed a revision rate of 4% for the SB technique. The estimated time to revision surgery was set at 4 years, based on the mean time to revision from the available literature on revision ACL surgery.[†] For all 5 scenarios, we assumed that revision of DB-ACL reconstructions would also use the DB technique and require the use of 2 tibialis anterior allografts. Therefore, we added the appropriate costs to DB revision surgery. We estimated that revision of a DB reconstruction would also occur at an average of 4 years after the index surgery due to the fact that there are currently no published data on revision of DB reconstructions. The costs of revision surgeries were converted to a present-day value using a 5% discount rate.

We calculated the additional upfront costs associated with the DB reconstruction under each of the 4 scenarios. We then calculated the reduction in the rate of revision surgery after DB reconstructions that would be necessary to offset the additional upfront cost of this technique. Finally, as a sensitivity analysis, we ran the scenarios under different assumptions regarding the discount rate (10%), mean time to revision surgery (2 years), and cost of revision surgery ($40 000).

RESULTS

The DB technique was found to significantly increase the cost of ACL reconstruction (Table 3). In scenario 1, assuming only half of all ACL reconstructions were done with the DB technique (added cost of only 1 proximal and 1 distal fixation device) there will be $36.2 million per year in additional direct costs. To offset the added cost under these assumptions, the DB technique would have to reduce the revision rate from 4% to 1.5%. Under scenario 2 with the cost of 30 minutes' additional operating room time per case plus the cost of additional fixation, $96.2 million in cost is added each year. This cost would be offset by a reduction in the revision rate from 5.9% to 0%. Adding the cost of 1 allograft (scenario 3) and converting to the DB technique for half of all ACL reconstructions will increase surgical costs $186.2 million per year. The revision rate would have to drop from 11.4% with the SB technique to 0% with the DB technique to offset this increase in cost. Including the cost of 2 soft tissue allografts plus fixation for each DB reconstruction (scenario 4) leads to an increase of $336.2 million in annual costs. The revision rate would have to drop from 20.5% to 0% to offset this increase in cost. Finally, including the cost of distal and proximal fixation, 2 allografts, and an additional 30 minutes of operative time for the DB technique and assuming 100% adaptation of the DB technique (scenario 5), there is an increase in costs of $792.4 million per year. This would require a reduction in the revision rate from 24.1% to 0% to be cost neutral.

Varying our assumptions did not change the overall effect of our analysis (Table 4). Higher discount rates require a more significant reduction in the revision rate to offset the higher cost of the DB technique. Even under the assumption that revisions cost $40 000, the DB technique still has to generate significant reductions in the revision rate to offset the higher initial costs.

[†]References 2, 3, 7, 10, 12, 14, 15, 21-23, 27, 31, 32

DISCUSSION

This study confirms that DB-ACL reconstruction has the potential of adding considerable cost to the healthcare system for no demonstrated clinically relevant benefit to date. Even if orthopaedic surgeons could perform a DB reconstruction without adding any operative time compared with the SB technique, converting to widespread use of the DB technique has the potential to add hundreds of millions of dollars in direct cost to the healthcare system. To offset this added cost, the DB technique would need to drastically reduce the rate of revision surgery. While the rate of revision surgery after SB-ACL reconstruction has been reported to vary from 1.5%[5] to 23%[1] in the literature, systematic reviews usually put this rate at 5% or less.[8,29] The potential added clinical benefit of the DB technique is unlikely to reduce this rate enough to offset the costs of widespread conversion to the DB reconstruction.

Some recent studies have questioned whether DB reconstruction offers an advantage over the SB technique. A recent study of computer-navigated ACL reconstruction in 20 male subjects reported no difference in anteroposterior tibial displacement and internal and external rotation of the tibia between SB and DB reconstruction using autologous hamstring grafts.[6] If the in vivo kinematic differences between SB and DB reconstructions are shown to be negligible, the DB technique is unlikely to reduce the rate of revision surgery enough to justify the additional cost of this technique. Furthermore, it is unlikely the DB technique could reduce the revision rate to 0 for ACL reconstruction considering the multiple causes of graft failure, including the risk of additional trauma and the failure of graft incorporation. The model does not include the possibility of an increased rate of revision during the learning curve for this technique as surgeons convert to the DB method, which could drive costs even higher. However, this is likely to be a temporary effect that will lessen over time as the majority of surgeons become more adept with the DB technique. A recent prospective series of 100 DB-ACL reconstructions reported a failure rate of 8% and a revision rate of 7% at 2-year follow-up.[9] These data suggest that the DB technique may not be able to offset the increased cost of implants and allografts by reducing the revision rate, even in the hands of a surgeon experienced with this technique.

One potential advantage of the DB technique could be a reduction in the development of osteoarthritis after reconstruction as a result of improved knee kinematics and decreased rotational instability. Several studies suggest that SB reconstruction does not reduce the risk for osteoarthritis after ACL injury.[4,16,18,33] A recent study with 11-year follow-up after ACL injury reported a 42% incidence of osteoarthritis in patients who underwent SB-ACL reconstruction compared with a 24% incidence of osteoarthritis in patients who were treated nonoperatively.[16] If DB reconstruction results in superior functional knee stability and knee kinematics such that the risk for meniscal injury, chondral damage, and subsequent osteoarthritis is reduced, the technique could be worth the additional cost. Thus far, there is no long-term proven clinical benefit of this method over the SB technique in terms of either return to sports or a reduced rate of osteoarthritis. The cost analysis may not change significantly since a reduced rate of morbidity and need for a total knee replacement over a 10- to 20-year horizon does not generate significant cost savings due to the large economic discount applied to longer term cost savings. This would require a separate analysis taking into consideration other factors such as the cost of conservative treatment of osteoarthritis, the cost of implants, medical co-morbidities, and other, as yet, unidentified treatment methods for osteoarthritis that may reduce the need for total knee replacement.

Another important issue is that the DB technique may be beneficial in specific patient cohorts. In a retrospective case series review of primary ACL reconstructions using a tibialis anterior allograft, Singhal et al[28] reported a 35% rate of revision surgery in patients age 25 and younger compared with a 13% revision rate in patients older than age 25. In young patients playing contact, pivoting sports with a high risk of rerupture, the DB technique may prove to be cost effective, assuming the technique can be shown to reduce the risk for revision surgery. As of yet, there is no literature specifically addressing this issue.

A major limitation of this study is the necessity of making assumptions regarding cost, hardware used, added operative time, rate of revision, and time to revision. All assumptions were made as conservatively as possible with regard to the added cost of DB reconstruction. For example, the model ignores many secondary costs of ACL revision surgery such as physical therapy and time loss from work. The sensitivity analysis demonstrates that the results are robust to variance in these underlying assumptions. A number of unknowns that could have large implications for this analysis were excluded, however, because they could be construed as too speculative. For example, revision of DB reconstruction could be more likely to require a 2-stage revision for large bone defects if osteolysis is more likely and/or more substantial with 2 tunnels, particularly if the original tunnels were placed incorrectly. Another issue that may affect results from DB reconstruction relates to the concern over higher failure rates with allograft reconstructions.[17,28] It is unclear how the use of allograft versus autograft will affect the clinical outcome of DB reconstructions. Secondly, less expensive methods of graft fixation could have been used in our calculations (ie, simple screw and washer for proximal fixation) rather than the method we used (the EndoButton device). However, this less expensive hardware is not currently used by proponents of the method, and it is associated with its own technical concerns such as a larger lateral incision that may make it a less appealing option. Thirdly, the cost assumptions were made without regard to insurance discounts and other issues influenced by third-party payers. We based this economic analysis on 2008 actual costs derived directly from the tissue banks and implant companies our hospital system uses without regard for preferred rates or other factors influenced by volume-derived discount pricing. The actual charges assumed by a patient (or insurance carrier) for a DB reconstruction may, in actuality, be less. However, this variable would equally affect both SB and DB reconstruction costs, and therefore, would not change the fact that the DB method markedly increases the economic burden to the healthcare system.

This study is not intended to diminish the importance of evaluating the DB technique of ACL reconstruction or the growing emphasis on anatomic ACL reconstruction. Nor should it suggest that cost should be the primary motivation for or means of assessing new orthopaedic devices or procedures. However, the results of this cost analysis support the conclusion that DB reconstruction should not be accepted as the new standard for ACL surgery without evidence of better kinematic and clinical results. Evaluation of DB-ACL reconstruction should be performed as part of prospective, controlled trials assessing validated outcome measures in addition to cost comparisons. In the increasingly cost-conscious healthcare environment, there is a responsibility to practice cost-*effective* medicine. The use of more expensive techniques without evidence of better results is not in the best interest of the patient or the healthcare system. While further research is warranted to determine if there are other benefits from this technique, widespread adoption of DB-ACL reconstruction does not appear to be cost-effective at this time.

REFERENCES

1. Barrett GR, Noojin FK, Hartzog CW, Nash CR. Reconstruction of the anterior cruciate ligament in females: a comparison of hamstring versus patellar tendon autograft. *Arthroscopy*. 2002;18:46-54.
2. Battaglia MJ 2nd, Cordasco FA, Hannafin JA, et al. Results of revision anterior cruciate ligament surgery. *Am J Sports Med*. 2007;35:2007-2066.
3. Colosimo AJ, Heidt RS Jr, Traub JA, Carlonas RL. Revision anterior cruciate ligament reconstruction with a reharvested ipsilateral patellar tendon. *Am J Sports Med*. 2001;29:746-750.
4. Daniel DM, Stone ML, Dobson BE, Fithian DC, Rossman DJ, Kaufman KR. Fate of the ACL-injured patient. A prospective outcome study. *Am J Sports Med.* 1994;22:632-644.
5. Feller JA, Webster KE. A randomized comparison of patellar tendon and hamstring tendon anterior cruciate ligament reconstruction. *Am J Sports Med*. 2003;31:564-573.
6. Ferretti A, Monaco E, Labianca L, Conteduca F, De Carli A. Double-bundle anterior cruciate ligament reconstruction: a computer-assisted orthopaedic surgery study. *Am J Sports Med*. 2008;36:760-766.
7. Fox JA, Pierce M, Bojchuk J, Hayden J, Bush-Joseph CA, Bach BR Jr. Revision anterior cruciate ligament reconstruction with nonirradiated fresh-frozen patellar tendon allograft. *Arthroscopy*. 2004;20:787-794.
8. Freedman KB, D'Amato MJ, Nedeff DD, Kaz A, Bach BR Jr. Arthroscopic anterior cruciate ligament reconstruction: a metaanalysis comparing patellar tendon and hamstring tendon autografts. *Am J Sports Med.* 2003;31:2-11.
9. Fu FH, Shen W, Starman JS, Okeke N, Irrgang JJ. Primary anatomic double-bundle anterior cruciate ligament reconstruction. A preliminary 2-year prospective study. *Am J Sports Med*. 2008;36(7):1263-1274.
10. Garofalo R, Djahangiri A, Siegrist O. Revision anterior cruciate ligament reconstruction with quadriceps tendon-patellar bone autograft. *Arthroscopy.* 2006;22:205-214.
11. Gottlob CA, Baker CL Jr. Anterior cruciate ligament reconstruction: socioeconomic issues and cost effectiveness. *Am J Orthop*. 2000;29:472-476.
12. Grossman MG, El Attrache NS, Shields CL, Glousman RE. Revision anterior cruciate ligament reconstruction: 3- to 9-year follow-up. *Arthroscopy*. 2005;21:418-423.
13. Hewett TE, Shultz SJ, Griffin LY. *Understanding and Preventing Noncontact ACL Injuries*. Champaign, IL: Human Kinetics Publishers; 2007.
14. Johnson DL, Swenson TM, Irrgang JJ, Fu FH, Harner CD. Revision anterior cruciate ligament surgery: experience from Pittsburgh. *Clin Orthop Relat Res*. 1996;325:100-109.
15. Kartus J, Stener S, Lindahl S, Eriksson BI, Karlsson J. Ipsi- or contralateral patellar tendon graft in anterior cruciate ligament revision surgery. A comparison of 2 methods. *Am J Sports Med.* 1998;26:499-504.
16. Kessler MA, Behrend H, Henz S, Stutz G, Rukavina A, Kuster MS. Function, osteoarthritis and activity after ACL-rupture: 11-year follow-up results of conservative versus reconstructive treatment. *Knee Surg Sports Traumatol Arthrosc*. 2008;16(5):442-448.
17. Krych AJ, Jackson JD, Hoskin TL, Dahm DL. A meta-analysis of patellar tendon autograft versus patellar tendon allograft in anterior cruciate ligament reconstruction. *Arthroscopy*. 2008;24:292-298.
18. Lohmander LS, Ostenberg A, Englund M, Roos H. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players 12 years after anterior cruciate ligament injury. *Arthritis Rheum*. 2004;50:3145-3152.
19. Mae T, Shino K, Miyama T, et al. Single versus 2-femoral socket anterior cruciate ligament reconstruction technique: biomechanical analysis using a robotic simulator. *Arthroscopy*. 2001;17:708-716.
20. Muneta T, Koga H, Mochizuki T, et al. A prospective randomized study of 4-strand semitendinosus tendon anterior cruciate ligament reconstruction comparing single-bundle and double-bundle techniques. *Arthroscopy*. 2007;23:618-628.
21. Noyes FR, Barber-Westin SD. Revision anterior cruciate surgery with use of bone-patellar tendon-bone autogenous grafts. *J Bone Joint Surg Am.* 2001;83:1131-1143.
22. Noyes FR, Barber-Westin SD, Roberts CS. Use of allografts after failed treatment of rupture of the anterior cruciate ligament. *J Bone Joint Surg Am*. 1994;76:1019-1031.
23. O'Neill DB. Arthroscopically assisted reconstruction of the anterior cruciate ligament. A follow-up report. *J Bone Joint Surg Am*. 2001;83: 1329-1332.
24. Palmer I. On the injuries to the ligaments of the knee joint: a clinical study. *Acta Chir Scand*. 1938;91:1-282.
25. Seon JK, Park SJ, Lee KB, Yoon TR, Seo HY, Song EK. Stability comparison of anterior cruciate ligament between double-and single-bundle reconstructions [published online ahead of print March 7, 2008]. *Int Orthop*. DOI:10.1007/s00264-008-0530-2.
26. Seon JK, Song EK, Bae BH, et al. Kinematic study following double-bundle, anterior cruciate ligament reconstruction. *Int Orthop*. 2007;31:623-628.
27. Shelbourne KD, O'Shea JJ. Revision anterior cruciate ligament reconstruction using the contralateral bone-patellar tendon-bone graft. *Instr Course Lect*. 2002;51:343-346.
28. Singhal MC, Gardiner JR, Johnson DL. Failure of primary anterior cruciate ligament surgery using anterior tibialis allograft. *Arthroscopy*. 2007;23:469-475.
29. Spindler KP, Kuhn JE, Freedman KB, Matthews CE, Dittus RS, Harrell FE Jr. Anterior cruciate ligament reconstruction autograft choice: bone-tendon-bone versus hamstring. Does it really matter? A systematic review. *Am J Sports Med*. 2004;32:1986-1995.
30. Streich NA, Friedrich K, Gotterbarm T, Schmitt H. Reconstruction of the ACL with a semitendinosus tendon graft: a prospective randomized single blinded comparison of double-bundle versus single-bundle technique in male athletes. *Knee Surg Sports Traumatol Arthrosc*. 2008;16:232-238.
31. Taggart TF, Kumar A, Bickerstaff DR. Revision anterior cruciate ligament reconstruction: a midterm patient assessment. *Knee*. 2004;11:29-36.
32. Uribe JW, Hechtman KS, Zvijac JE, Tjin-A-Tsoi EW. Revision anterior cruciate ligament surgery: experience from Miami. *Clin Orthop Relat Res*. 1996;325:91-99.
33. von Porat A, Roos EM, Roos H. High prevalence of osteoarthritis 14 years after an anterior cruciate ligament tear in male soccer players: a study of radiographic and patient relevant outcomes. *Ann Rheum Dis*. 2004;63:269-273.
34. Yagi M, Wong EK, Kanamori A, Debski RE, Fu FH, Woo SL. Biomechanical analysis of an anatomic anterior cruciate ligament reconstruction. *Am J Sports Med*. 2002;30:660-666.
35. Yamamoto Y, Wei-Hsiu Hsu, Woo SL-Y, Van Scyoc AH, Takakura Y, Debski RE. Knee stability and graft function after anterior cruciate ligament reconstruction. A comparison of a lateral and an anatomic femoral tunnel placement. *Am J Sports Med*. 2004;32:1825-1832.
36. Zelle BA, Vidal AF, Brucker PU, Fu FH. Double-bundle reconstruction of the anterior cruciate ligament: anatomic and biomechanical rationale. *J Am Acad Orthop Surg*. 2007;15:87-96.