Allograft Use in Anterior Cruciate Ligament Reconstruction

Patrick W. Jost, MD · Christopher J. Dy, MD, MSPH · Catherine M. Robertson, MD · Anne M. Kelly, MD

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Abstract Anterior cruciate ligament (ACL) reconstruction is one of the most common procedures performed by orthopedic surgeons. While autograft reconstruction remains the gold standard, allograft tissues have become a controversial option for ACL reconstruction. No data currently exist regarding recent trends in graft choices, and no consensus exists over which graft type is most appropriate for which patient. In this article, we examine trends in ACL graft choice at our institution, and review the pertinent information a surgeon must consider when making this decision. We reviewed operating room records from 2002 to 2008 to determine trends in graft choice for primary single bundle ACL reconstruction. Total number of procedures performed, graft choices, and patient ages were recorded. Patients were divided into the following age groups: less than 16, 16 to 20, 21 to 30, 31 to 40, 41 to 50, and over 50. Percent of ACL reconstructions using allograft was calculated for each year, as well as for each age group. Data were analyzed for trends in ACL graft choice over this time period as well as for trends in graft choice by age. We hypothesized that the rate of allograft use in primary ACL reconstruction had increased over time and that allograft use was associated with higher patient age. We also review the risks, safety, and standards for tissue procurement. Allograft use increased significantly ($p <$

0.001) from 2002 (17%) to 2008 (46%). There was also a significant difference ($p < 0.001$) in average age of patients receiving allografts (40.4 years) and autografts (26.4 years). Allograft use was significantly associated with higher patient age ($p < 0.05$) and increased with each successive age group from a rate of 9.9% in patients under 16 to 79.9% in patients over 50. Our study found that allograft use in primary ACL reconstruction has significantly increased from 2002 to 2008 and is significantly more common in older patients.

Keywords ACL · anterior cruciate · allograft · autograft · graft choice · knee ligament reconstruction

Introduction

Ruptures of the anterior cruciate ligament (ACL) are frequently treated surgically, with over 100,000 ACL reconstructions performed in the USA each year [1]. Despite the high frequency of this procedure, there remains considerable controversy and variability in the grafts chosen for primary reconstruction. Autograft choices include a central-third bone–patellar tendon–bone graft (BTB), a semitendinosus–gracilis graft from the hamstring (HS), or a quadriceps tendon graft. A number of allograft choices are available, including Achilles tendon, BTB, anterior or posterior tibial tendon, HS, and quadriceps tendon. The ideal graft would have rapid incorporation, low failure rates, a high degree of safety, low donor site morbidity, wide availability, and low cost. Unfortunately, no such graft exists. Autografts have the benefit of earlier incorporation [2] and no rejection or disease transmission, but require longer operative times, lead to potential donor site morbidity, and have been associated with increased overall cost [3]. Allografts have the advantages of decreased donor site morbidity, availability of multiple grafts, and shorter operative times, but carry a small but significant risk of disease transmission [4–6]. In revision surgery or in multiligamentous reconstruction, the use of allograft tissue may be required. These situations are beyond the scope of this article.

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Each author certifies that his or her institution has approved the reporting of this case, that all investigations were conducted in conformity with ethical principles of research.

Level of Evidence: Level IV (Retrospective Case Series)

P. W. Jost, MD (✉) · C. J. Dy, MD, MSPH · C. M. Robertson, MD · A. M. Kelly, MD
Hospital for Special Surgery,
535 E. 70th St.,
New York, NY 10021, USA
e-mail: pwjost@gmail.com

Patient age may affect graft choice. In older patients who are recreational athletes, the benefit of decreased donor site morbidity and faster initial recovery from surgery may outweigh the small risks of disease transmission and the documented slower tissue incorporation [7]. A retrospective review of ACL reconstructions comparing allograft versus autograft reported a significantly higher average patient age in the allograft group (33.1 vs 28.7 years) [8].

While use of allograft tissues seems to be increasing, there is no published data examining rates of allograft use over time in ACL reconstruction. For this reason, we chose to analyze trends in graft choice for ACL reconstruction at a single, high volume orthopedic hospital from 2002 to 2008. We hypothesized that the rate of allograft use in primary ACL reconstruction at our institution had increased over time, and that allograft use was associated with higher patient age. We also review the risks, safety, and standards for tissue procurement.

Methods

We performed a retrospective review of operating room records at a high volume orthopedic hospital from 2002 to 2008. Approval was granted by the hospital's Institutional Review Board. Surgeons' booking forms as well as post-operative nursing records were used to capture type of procedure, graft type, revision vs. primary status, and patient age. Patients from 24 surgeons were included in the study, totaling 4,004 procedures. All cases of primary, single bundle ACL reconstruction were analyzed. Patients were excluded if they underwent revision reconstruction or if they underwent reconstruction of any other ligament at the same time. Patients undergoing concomitant meniscal or cartilage surgery were not excluded, provided they met the other criteria. Graft type and patient age were recorded for each procedure.

Total number of primary ACL reconstructions was recorded for each year, as were total procedures using each graft type and each patient's age. Patients were divided into the following age groups: age less than 16, age 16 to 20, age 21 to 30, age 31 to 40, age 41 to 50, and age greater than 50 years. Percent of ACL reconstructions using allograft was calculated for each year, as well as for each age group. Data were analyzed for trends in ACL graft choice over this time period as well as for trends in graft choice by age. Statistical analysis was performed using Student's *t* test comparing total allograft use during each year. Allograft use for each specific age group was also compared, as well as during each yearly interval within each group. The threshold for statistical significance was determined using a standard Bonferroni correction for each analysis.

Results

From 2002 to 2008, the rate of allograft use in primary ACL reconstruction increased from 17.4% in 2002 to 45.6% in 2008. There was a statistically significant increase in allograft use over the course of the study period ($p < 0.001$; Bonferroni-adjusted threshold for statistical significance of $p = 0.007$), as well as in each successive year

except for 2005–2006, in which there was a decrease ($p = 0.01$; not statistically significant using the Bonferroni-adjusted threshold), and 2006–2007 in which there was no significant change (Fig. 1). Similarly, the absolute number of allografts used in ACL reconstruction increased over each successive year except for 2005–2006 (Fig. 2). The majority of allografts used in all years was Achilles tendon, which comprised 86% of all allografts used throughout the study period. Other allografts used included bone–patellar tendon–bone, tibialis anterior, and tibialis posterior tendons. Autograft choices included BTB (84.5% of all autografts), HS (14.7%), and a small number of other grafts (<1%).

The average age for primary ACL reconstruction was 33.4 years over the study period (11.5–71.5 years). The average ages of patients receiving allografts and autografts were 40.4 and 26.4 years. This difference was statistically significant ($p < 0.001$). In patients under 16, allografts were used in only 9.9% of patients over the study period. Allograft use increased with each increasing age group to a rate of 79.9% in patients over 50 years old. When directly comparing differences between an age group and the preceding age group, there were statistically significant increases between ages 21–30 and ages 31–40 ($p < 0.001$; statistically significant using the Bonferroni threshold of $p = 0.008$) and between ages 31–40 and ages 41–50 ($p = 0.003$). The differences between ages 16–20 and ages 21–30 ($p = 0.036$) and between ages 41–50 and over 50 ($p = 0.110$) did not meet statistical significance using the Bonferroni threshold (Fig. 3). Each age group was also analyzed independently for change in allograft use over time. There were statistically significant increases ($p < 0.05$) in allograft use in the 21–30, 31–40, and 41–50-year-old age groups from 2002 to 2003, and in each of the three groups over 30 years of age from 2003 to 2004. From 2007 to 2008, there was a significant increase in allograft use in the 16–20 age group, from 7.7% to 34.0% ($p < 0.001$; Fig. 4).

Fig. 1 Overall allograft use by year including all age groups. *p* values are displayed for differences from the previous year. Years in which allograft use significantly increased or decreased over the previous year are noted with *bold values*

Fig. 2. Total number of patients receiving allografts and autografts during each year. Allograft use increased throughout each successive year except 2005–2006

Discussion

Trends in Allograft Use

We hypothesized that allograft use in primary ACL reconstructions at our institution had increased over time and was more common in older patients. We tested these hypotheses by examining trends in graft choice for primary ACL reconstruction at a high volume orthopedic hospital over a 7-year period from 2002 to 2008. Allograft use as a whole increased over each successive year until a peak in 2005, after which a significant decrease was seen. After 2006, overall allograft use again increased over each successive year, but without reaching the level seen in 2005 (Fig. 1). The timing of this sharp decline may be reflective of a regional shift away from the use of allograft tissue, as this immediately followed a large recall of 26,000 allografts that was triggered by multiple regulatory violations at a tissue recovery company in our hospital's geographic region [9]. Incidents such as these are highly scrutinized in the lay media and raise concern about allograft safety in the minds of both the surgeon

Fig. 4. Yearly changes in allograft use within each age group. Statistically significant increases ($p < 0.05$) were found in the 21–30, 31–40, and 41–50-year-old age groups from 2002 to 2003, in the 31–40, 41–50, and over 50 age groups from 2003 to 2004. From 2007 to 2008, there was a significant increase in allograft use in the 16–20-year-old age group, from 7.7% to 34.0% ($p < 0.001$)

and the patient. Fortunately, this tissue bank was not used by our institution.

When patients were analyzed separately by age groups, significant increases were seen from 2002 to 2003 in the 21–30, 31–40, and 41–50-year-old age groups, and in each of the three groups over age 30 from 2003 to 2004. We believe these early increases were seen in the older patient groups as surgeons and patients began to gain interest in an option that might allow an older population to recover more quickly and return to work earlier. As time went on and the negative publicity of 2006 passed, enthusiasm over the potential benefits of allograft use may have increased once again, leading to significantly increased use in the 16–20 age group from 2007 to 2008 (Fig. 4). This increase may have also been fueled by Edgar et al.'s 2008 prospective comparison of allograft vs. autograft hamstring ACL reconstructions, which showed no difference in all outcome measures at 3–6-year follow-up between groups [10].

Fig. 3. Percent of allograft ACL reconstructions over the entire study period within each age group. p values are displayed for differences from the preceding age group. Groups in which allograft use was significantly greater than the group below are denoted with **bold values**

Allograft Safety

In general, the majority of orthopedic surgeons feels that allograft tissues are safe for use, as supported by 86% of American Orthopaedic Society for Sports Medicine (AOSSM) members stating that they use allografts [11]. The overall incidence of suspected allograft infection was 0.014% during a 2-year time period, with a probable/confirmed allograft infection incidence of 0.00015% [12, 13]. While the risk of infection transmitted through allografts should certainly be acknowledged and respected, it should be placed in the appropriate context of the overall risk of perioperative nosocomial infection [14, 15].

Allograft safety is of primary concern to both surgeons and patients; it is extremely important for the surgeon to be familiar with the practices of his or her tissue bank of choice. Allograft safety relies on adherence to rigorous standards, which are not always uniform depending on the

region of practice [6]. New York and Florida are the only two states to inspect and license tissue banks, while California, Georgia, and Maryland require tissue bank licensure only [16]. Voluntary accreditation for tissue banks is provided by the American Association of Tissue Banks (AATB), a not-for-profit organization that provides voluntary standards to promote the quality and safety of donated human tissues. Because the majority of tissue recalls is the result of inadequate donor evaluation or abnormal serologic tests [6], both the surgeon and patient must trust that tissue banks are adherent to the appropriate safety standards. While the AATB guidelines are widely regarded as the standard of care, final authority governing tissue banks in the USA rests with the Food and Drug Administration. A report published by the United States Office of the Inspector General found that over 60% of tissue banks is not accredited by the AATB, with some never having been inspected by the FDA [16]. Furthermore, the FDA estimates that only 75–80% of registered tissue banks meet AATB standards [17]. The variability in tissue bank practices has prompted the AAOS to call upon surgeons who use allografts to “know their tissue banker” [18]. Unfortunately, 21% of AOSSM survey respondents did not know whether the allografts they use are from an AATB-accredited tissue bank [11].

Allograft Procurement and Processing

The allograft retrieval process begins with procurement of tissues immediately following the death of the donor. The vast majority of tissue banks adheres to a limit of tissue procurement within 24 h of death for refrigerated cadavers and within 12 h for cadavers stored at room temperature [19]. Medical histories and donor blood screenings for known pathogens are required by the FDA, with the advent of donor nucleic acid testing having decreased the “window period” in which disease such as HIV, HBV, and HCV cannot be detected to 7–8 days [20, 21]. The actual retrieval of tissues usually occurs in the operating room, hospital morgue, or coroner’s office, with one third of AATB-accredited tissue banks procuring tissues exclusively in the operating room [19]. The quarantine period that occurs from donor death until time of further tissue processing at AATB-accredited tissue banks is a minimum of 14 days and an average of approximately 5 weeks [19], allowing the previously mentioned “window period” for disease detection to lapse.

The subsequent disinfection process after procurement will vary depending on the tissue bank, with different proprietary technologies utilized to kill bacteria and inactive viruses. It is important to draw a distinction between *disinfection*, which is the process of removing contamination from allograft tissue, and *sterilization*, which is the process of killing all forms of life [14].

While over one quarter of the AOSSM membership has expressed concern over the safety of non-sterilized allografts (AOSSM), the practicing orthopedic surgeon must understand that sterilization is not required by the FDA and that commercially available allograft tissues are not sterile.

The deleterious effects of terminal sterilization techniques such as gamma irradiation on the biomechanical properties of the collagen render it practically impossible to absolutely sterilize allograft tissues [22]. The reduction in allograft stiffness and strength caused by gamma irradiation is dose-dependent, and recent work suggests that there is a significantly higher failure rate after using irradiated allograft when compared to non-irradiated allograft for ACL reconstruction [23]. Other sterilization techniques, such as ethylene oxide gas, can cause reactions of the host tissue and have since fallen out of favor.

There is no established superior or standardized protocol for tissue disinfection, with a complex combination of proprietary disinfective and sterilization techniques used by different tissue banks [15]. The most commonly used technique involves aseptic harvest and processing, as well as antibiotic soaks and low-dose gamma irradiation [22]. While the irradiation dose of 1 to 3.5 Mrads used by most tissue banks [12] for low-dose irradiation is effective in killing bacteria [24], the higher doses required to kill viruses such as Human Immunodeficiency Virus [25, 26] cannot be used because of their deleterious effects. However, proprietary techniques such as Biocleanse (Regeneration Technologies, Alachua, FL), Allowash (Lifenet, Virginia Beach, VA), and Clearant Process (Clearant, Inc, Los Angeles) combine modalities of disinfection and sterilization in attempts to maximize graft integrity while minimizing the chance of disease transmission. Additionally, some tissue banks utilize freeze-drying in an attempt to decrease the viability of any chemical or biologic activity in allograft tissue [15]. One such technique is the slow freezing and extended antitoxic soaking method used by Cryolife (Kennesaw, GA) [22].

Orthopedic surgeons should be knowledgeable about the tissue processing methods used in allograft preparation, particularly the potential clinical implications of disinfection and sterilization techniques. Unfortunately, a survey of 236 hospitals revealed that 34% of orthopedic surgeons utilizing allograft tissue was unaware of the processing methods used for the graft [27]. Furthermore, the orthopedic surgeon plays an active role in allograft selection in only 15% of hospitals surveyed [27]. The increased utilization of allograft tissues in sports medicine and reconstructive surgeries, such as ACL reconstruction, should serve as a call-to-action for orthopedic surgeons to learn more about tissue processing and the source of their allograft tissue.

Graft Choice Considerations

While graft safety is at the forefront, there are other considerations with regards to choice of graft for ACL reconstruction. In our study, allograft use was significantly associated with higher patient age. Figure 4 shows that the rapid increase in allograft use from 2002 to 2005 was largely attributable to increases in the older patient groups. Allografts may be favored in older patients undergoing ACL reconstruction because of a perceived benefit of decreased donor site morbidity and a quicker initial recovery. Rapid return to work may be more important to these patients than rapid return to sport. However, available data are not

uniformly in support of allograft use for older patients. Barrett et al., in their series of 63 patients over age 40, found increased laxity and failure among allograft recipients but a faster return to athletics [28]. However, none of their three allograft failures (one with frank instability and two by KT1000 criteria) elected to undergo further treatment. Grafe et al. reported a series of 23 consecutive patients who underwent Achilles tendon allograft ACL reconstruction [29]. They reported one infection, two frank failures, and two failures by KT1000 criteria and noted that four of the five failed grafts came from tissue donors greater than 40 years old. Clinical outcomes between autografts and allografts have been examined, both by measuring KT1000 side-to-side differences (with failure typically defined as a difference of at least 3 mm) and clinical failures resulting in reoperation. A meta-analysis by Prodromos et al. found significantly higher rates of abnormal stability, defined as KT100 side-to-side difference of >5 mm, in allografts (14%) compared with autografts (5%) [30]. Among allografts, they noted significantly increased abnormal stability among irradiated grafts, with irradiated grafts showing 31% abnormal results. Even among non-irradiated grafts, abnormal stability was still 12%. However, these differences were not found by other authors. In a randomized controlled trial of autograft versus allograft HS reconstructions, both groups showed similar outcomes for stability and failure rates [10]. In two separate prospective studies, Shelton [31] and Kleipool [32] each followed patients at regular intervals after ACL reconstruction using BPTB allograft or autograft. Patients receiving autografts and allografts showed no significant difference in stability or rupture rates at final follow-up. Autografts and allografts have also been compared histologically and biomechanically as well. Though initial biomechanical properties are similar between allografts and autografts, both lose significant strength during the religamentization and incorporation processes, which occurs over a longer period in allografts [7]. Animal models have shown delayed incorporation and remodeling of allograft tissue, resulting in a prolonged decrease in biomechanical strength [33].

Our study has limitations. The results shown here are from a single center, and may reflect regional and institutional bias. Also, while revision and multiligamentous procedures were excluded, information about concomitant meniscal or cartilage procedures was not included in the analysis. Finally, the source of each allograft was not available, nor was the age and radiation dose of each graft, all of which may have been useful information.

Our study provides data showing that allograft use is increasing in ACL reconstruction, especially in older patients. As the active population of the USA continues to age, we believe allograft use will continue to increase, bringing heightened relevance to issues of allograft performance, incorporation, longevity, and safety. Many variables are in play, and it is unclear if outcomes of allograft ACL reconstruction are inferior; but it is imperative that surgeons educate themselves about these

issues so they can help their patients make an informed decision.

References

1. Fu F, Christel P, Miller MD, Johnson DL. Graft selection for anterior cruciate ligament reconstruction *Instr Course Lect*. 2009;58:337–354.
2. Jackson DW, Grood ES, Goldstein JD, et al. A comparison of patellar tendon autograft and allograft used for anterior cruciate ligament reconstruction in the goat model *Am J Sports Med*. 1993;21(2):176–185.
3. Cole DW, Ginn TA, Chen GJ, et al. Cost comparison of anterior cruciate ligament reconstruction: autograft versus allograft *Arthroscopy*. 2005;21(7):786–790.
4. Kainer MA, Linden JV, Whaley DN, et al. Clostridium infections associated with musculoskeletal-tissue allografts *N Engl J Med*. 2004;350(25):2564–2571.
5. Simonds RJ, Holmberg SD, Hurwitz RL, et al. Transmission of human immunodeficiency virus type 1 from a seronegative organ and tissue donor *N Engl J Med*. 1992;326(11):726–732.
6. Mroz TE, Joyce MJ, Steinmetz MP, Lieberman IH, Wang JC. Musculoskeletal allograft risks and recalls in the United States *J Am Acad Orthop Surg*. 2008;16(10):559–565.
7. Malinin TI, Levitt RL, Bashore C, Temple HT, Mnaymneh W. A study of retrieved allografts used to replace anterior cruciate ligaments *Arthroscopy*. 2002;18(2):163–170.
8. Chang SK, Egami DK, Shaieb MD, Kan DM, Richardson AB. Anterior cruciate ligament reconstruction: allograft versus autograft *Arthroscopy*. 2003;19(5):453–462.
9. Walker C. Documents say more than 450 claims filed in body parts scam. *Associated Press*. May 15, 2007.
10. Edgar CM, Zimmer S, Kakar S, Jones H, Schepesis AA. Prospective comparison of auto and allograft hamstring tendon constructs for ACL reconstruction *Clin Orthop Relat Res*. 2008;466(9):2238–2246.
11. Leever Research (2006) Orthopaedic Surgical Procedure Survey on Allografts—American Orthopaedic Society for Sports Medicine. <http://www.sportsmed.org/tabs/research/downloads/AOSSM06AllograftsSurveyFINALREPORTFINAL.pdf>. Updated 2006. Accessed 17 October, 2010.
12. Vangsness CT, Dellamaggiora RD (2009) Current Safety Sterilization and Tissue Banking Issues for Soft Tissue Allografts. *Clin Sports Med* 28:183–189
13. Centers for Disease Control and Prevention. Workshop on Preventing Organ and Tissue Allograft-Transmitted Infection: Priorities for Public Health Intervention. http://www.cdc.gov/ncidod/dhqp/pdf/bbp/organ_tissueWorkshop_June2005.pdf. Updated 2005. Accessed 17 October, 2010.
14. McAllister DR, Joyce MJ, Mann BJ, Vangsness CT. Allograft Update : The Current Status of Tissue Regulation, Procurement, Processing, and Sterilization. *Am J Sports Med*. 2007;35:2148.
15. Vaishnav S C. New Techniques in Allograft Tissue Processing. *Clin Sports Med*. 2009;28:127–141.
16. Department of Health and Human Services—Office of Inspector General. Oversight of Tissue Banking. <http://oig.hhs.gov/oei/reports/oei-01-00-00441.pdf>. Updated 2001. Accessed 18 October, 2010.
17. Department of Health and Human Services. Current Good Tissue Practice for Human Cell, Tissue, and Cellular and Tissue-Based Product Establishments; Inspection and Enforcement; Final Rule. *Federal Register*. 2004;226:68611.
18. Joyce M, Greenwald A, Boden S, Brubaker S, Heim C. Musculoskeletal Allograft Tissue Safety—American Academy of Orthopaedic Surgeons. <http://aatb.kma.net/aatb/files/ccLibraryFiles/Filename/000000000103/AAOSTissuesafety.pdf>. Updated 2008. Accessed 18 October, 2010.
19. Vangsness C, Triffon M, Joyce M, Moore T. Soft Tissue For Allograft Reconstruction of the Human Knee: A Survey of the

- American Association of Tissue Banks. *Am J Sports Med.* 1996;24:230.
20. Stramer S, Glynn S, Kleinman S, et al. Detection of HIV-1 and HCV infections among antibody-negative blood donors by nucleic acid-amplification testing. *New Engl J Med.* 2004;351(8):760–8.
 21. Zou S, Dodd R, Stramer S, Strong D. Probability of viremia with HBV, HCV, HIV, and HTLV among tissue donors in the United States. *New Engl J Med.* 2004;351(8):751–9.
 22. Suarez L, Richmond J. Overview of Procurement, Processing, and Sterilization of Soft Tissue Allografts for Sports Medicine. *Sports Med Arthrosc Rev.* 2007;15:106–113.
 23. Sun K, Tian S, Zhang J, Xia C, Zhang C, Yu T. Anterior cruciate ligament reconstruction with BPTB autograft, irradiated versus non-irradiated allograft: a prospective randomized clinical study. *Knee Surg Sports Traumatol Arthrosc.* 2009;17(5):464–74.
 24. Shelton W, Treacy S, Dukes A, Bomboy A. Use of allografts in knee reconstruction: I. Basic science aspects and current status. *J Am Acad Orthop Surg.* 1998;6(3):165–8.
 25. Campbell D, Li P. Sterilization of HIV with irradiation: relevance to infected bone allografts. *Aust N Z J Surg.* 1999;69(7):517–21.
 26. Fideler B, Vangsness C, Moore T, Li Z, Rasheed S. Effects of gamma irradiation on the human immunodeficiency virus. A study in frozen human bone-patellar ligament-bone grafts obtained from infected cadavera. *J Bone Joint Surg.* 1994;76-A(7):1032–5.
 27. Lavernia C, Malinin T, Temple H, Moreyra C. Bone and Tissue Allograft Use by Orthopaedic Surgeons. *J Arthroplasty.* 2004;19(4):430–5.
 28. Barrett G, Stokes D, White M. Anterior cruciate ligament reconstruction in patients older than 40 years: allograft versus autograft patellar tendon *Am J Sports Med.* 2005;33(10):1505–1512.
 29. Grafe MW, Kurzweil PR. Anterior cruciate ligament reconstruction with Achilles tendon allografts in revisions and in patients older than 30 *Am J Orthop.* 2008;37(6):302–308.
 30. Prodromos CC, Han YS, Keller BL, Bolyard RJ. Stability results of hamstring anterior cruciate ligament reconstruction at 2- to 8-year follow-up *Arthroscopy.* 2005;21(2):138–146.
 31. Shelton WR, Papendick L, Dukes AD. Autograft versus allograft anterior cruciate ligament reconstruction *Arthroscopy.* 1997;13(4):446–449.
 32. Kleipool AE, Zijl JA, Willems WJ. Arthroscopic anterior cruciate ligament reconstruction with bone-patellar tendon-bone allograft or autograft. A prospective study with an average follow up of 4 years *Knee Surg Sports Traumatol Arthrosc.* 1998;6(4):224–230.
 33. Nikolaou PK, Seaber AV, Glisson RR, Ribbeck BM, Bassett FH, 3rd. Anterior cruciate ligament allograft transplantation. Long-term function, histology, revascularization, and operative technique *Am J Sports Med.* 1986;14(5):348–360.