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ORIGINAL PAPER

Functional outcome of septic arthritis after anterior cruciate ligament surgery

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Abstract
Purpose Septic arthritis is a rare complication after cruciate ligament surgery. The lack of conclusive evidence makes it difficult to obtain a consensus concerning the best treatment option.
Methods From June 1993 to May 2010, 31 patients met the inclusion criteria for this prospective case series. The average age at ACL injury was 33.5 years. Treatment protocol was based on the grade of infection. Options included arthroscopic treatment for infections of Gaechter grades 1 and 2 or arthrotomy for infections of grades 3 and 4. Graft retention was decided based on the clinical findings. The setting was a specialized trauma hospital. Follow-up included International Knee Documentation Committee (IKDC) forms, Tegner score, and Lysholm scores at a mean of six years (71 months; range, 13–140) after treatment.
Results In all cases, treatment of infection was successful; overall, a mean of 2.6 operations were required. In eight cases, it was possible to salvage the graft. The Tegner activity level before the knee injury was 6.5 points. At follow-up, the average score was 4.5 points. The postoperative subjective IKDC score averaged 63. The mean Lysholm score was 63.9. On clinical examination, a mean extension deficit of 2.5° and a mean maximum flexion of 121° were found. In the single-legged hop test, a mean capacity of 68% compared with the uninjured side was measured.
Conclusion The stage-adapted procedure gives reliable results for septic arthritis after ACL surgery. There were no recurrences of septic arthritis or bone infection. Early infection can be managed arthroscopically with satisfactory results. More advanced infections should be addressed with a more radical approach. In conclusion, functional outcome in most of the presented cases was only fair compared with results from ACL surgery not complicated by infection.

Keywords Knee · Empyema · Cruciate · Ligament · Surgery · Treatment

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Introduction

Septic arthritis is a rare complication after cruciate ligament surgery with reported prevalence ranging from 0.14 to 1.7 % [1]. In a recent subgroup analysis of professional athletes the prevalence of this complication increased to 5.7 % [2]. If diagnosis and treatment are delayed, there is a risk of articular cartilage damage, graft failure and a long-term risk of joint dysfunction from ligamentous laxity, postinfectious arthritis and arthrofibrosis [3]. Generally, treatment options for septic arthritis after cruciate ligament surgery include long-term intravenous antibiotics, arthroscopic or open treatment, constant irrigation, and graft retention or graft removal with or without reimplantation [4]. Because of the small number of reported cases it is difficult to determine risk factors, the success of different treatment options and treatment results.

The lack of conclusive evidence makes it difficult to get a consensus relative to the best practices in the management of septic knee arthritis of the knee. Furthermore, the only outcome measured is the healing of the infection that leaves the

functional outcome of the joint unobserved in some studies [5].

The purpose of the present study was to determine the mid- and long-term clinical outcome after septic arthritis of the knee following ACL surgery. Data evaluation was prospective from the time of referral to the bone and joint infection unit. A standardized treatment protocol was used that is based on the grade of infection found. Options included transarthroscopic treatment or medial and lateral arthrotomy. Graft retention was decided based on clinical findings. The setting is the department of orthopaedics and traumatology of a specialized trauma hospital that acts as a tertiary referral centre.

Material and methods

Patients

Included in this study were consecutive patients referred to the orthopaedic infection unit with septic arthritis of the knee after ACL surgery from June 1993 to May 2005. Four patients were initially treated in our hospital (which would result in a 0.72 % knee joint infection rate after ACL reconstruction in this period). A further 27 patients were initially treated in 20 other hospitals. Excluded were three patients who had septic arthritis before that was unrelated to ACL injury. Thirty-one patients met the inclusion criteria for this study.

Methods

The standard diagnostic schemes included history and clinical examination, laboratory tests including full blood count and C-reactive protein (CRP) and radiographs. Average white blood count (WBC) on presentation was 9000 (range 3,300–18,000; normal range 3,000–9,000). Average CRP was 6.2 (range 0.5–18.2; normal range 0–0.7). Magnetic resonance imaging (MRI) or a three-phase bone scan was added when it was thought necessary. This was mostly the case in suspected chronic or late infections or to establish the extent of an infection, including which structures were involved and the extent of possible cartilage damage.

A diagnostic arthroscopy was initially performed except when a joint infection stage 3 or 4 according to Gaechter had been confirmed before. During the arthroscopy the surgeon confirmed the diagnosis and determined the stage of septic arthritis. For the staging, a classification system was used that initially was proposed by Gaechter [6]. As prior published, in stage 1 there is beginning synovitis with isolated hyperemia of the synovia, the effusion is still translucent, and small petechial bleedings can be found in places [4]. In stage 2, the infection enters the pyogenic phase. There is a marked synovitis with fibrin depositions, pus can be found and the effusion is opaque. There is no cartilage damage and no visible changes on radiographs. In stage 3 the synovia is markedly thickened. It is transformed to a sponge-like structure up to 2 cm thick. Fibrous villae form and compartments are found that were caused by fibrous tissue reactions. There is beginning cartilage damage but no visible radiologic changes to the bony structures. Stage 4 we term synovial malignancy because the synovial "grows" over the cartilaginous structures and destroys them; it also undermines the cartilage and there are radiologic signs of subchondral bone involvement like erosions and subchondral cysts. Intra-operatively the cartilage can be peeled off the bone in places. The following treatment scheme was based on the stage of infection according to Gaechter [6]. After intra-operative staging a standardized treatment regimen was followed. As part of the index procedure, intra-articular application of antibiotic beads as a complementary treatment option to intravenous or oral antibiotic therapy was done in all cases. The use of antibiotic beads offers the major advantage of high, local antibiotic levels with negligible to no systemic antibiotic serum concentrations [7]. The limitation is that antibiotic beads are non-biodegradable and therefore must be removed. In patients with stage 1 to 2 septic arthritis the treatment was performed as an arthroscopic procedure. It included debridement and washout of the joint with 10 to 15 l. A partial synovectomy as extensive as possible via arthroscopy followed; we used an anteromedial and anterolateral portal in all cases and partially an additional superomedial or -lateral access. We did not use a posteromedial approach and therefore some synovial remained. This was followed by intraarticular deposition of gentamicin-containing polymethylmethacrylate (PMMA) beads (mini-beads with a diameter of 3 mm, each containing 1.7 mg gentamicin; Septopal, Biomet BioMaterials, Darmstadt, Germany); between 20 and 60 beads (mini) were used in this study (mean, 31). At the time of second-look-surgery, three to seven days after the index procedure, the beads were removed arthroscopically.

In patients with a more severe infection (stage 3 or 4) the diagnostic arthroscopy was finished and followed by medial and lateral parapatellar arthrotomy. Debridement and near total synovectomy were performed through the arthrotomy. The joint was filled with 60–180 (mean; 82 beads) beads (maxi-beads with a diameter of 7 mm, each containing 4.5 mg gentamicin; Septopal, Biomet BioMaterials, Darmstadt, Germany). The wounds were left open with only a sterile dressing applied and a period of open wound treatment followed. Open joint treatment consisted of daily physiotherapy and generous dressings. During the phase of open joint treatment daily physiotherapy in water was performed. This was done in a special bath tube on the ward [4]. After a period of usually seven to ten days removal of the chains and another debridement and secondary wound closure followed. In both procedures (open and arthroscopic), the number of beads was counted at the time of implantation and again at the time of

removal, so that no beads were left in situ. None of our patients suffered from loose body symptoms at the time of follow-up.

In the early postoperative period, all patients received antibiotics (five to eight days) delivered intravenously only on the day of surgery; from then on, they were orally administered. Antibiotics were prescribed according to the resitogram or the patients received ampicillin/sulbactam (Unacid, Pfizer Pharma, Karlsruhe, Germany).

The ACL graft was salvaged if possible without risk. If the graft was removed (Fig. 1a), all hardware was removed at the same procedure (Fig. 1b). After graft removal, the tunnels were debrided. Reasons for graft removal were as follows: autodigestion of the graft, bony involvement of the tibia, femur or graft block and a nonfunctional graft.

In all patients specimens of different tissue layers were collected for histological and bacterial analysis and routinely incubated for 14 days as described previously [8].

The follow-up period was on average 71 months (range 13–140). The follow up included a clinical examination including all tests of the International Knee Documentation Committee (IKDC) form [9], Tegner score [10], Lysholm score [10] and the single leg hop test [11]. A radiological examination was included if the patient consented.

Data sampling of this study was prospective from the time of admission; all previous data were entered retrospectively at this point. Prior to the follow-up examination, the data were extracted to a database. Data from the follow-up were added. The descriptive statistics were performed with SPSS (version 16.0, SPSS Inc, Chicago, USA). The significance level was set at $p<0.05$.

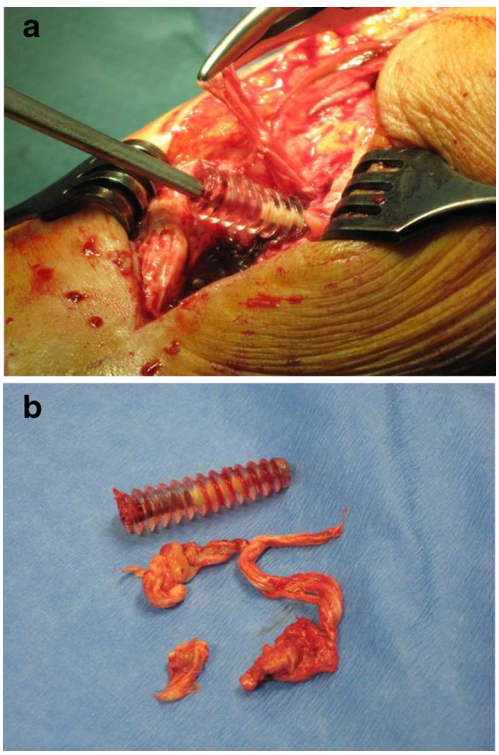

Fig. 1 **a**, **b** Functional outcome of septic arthritis after anterior cruciate ligament surgery

Results

The mean age of the patients at the time of ACL surgery was 34.7 years (range 17–49). The interval between knee injury and ACL surgery was on average 1.8 years (range zero to 12).

The ACL rupture was located close to the femoral ($n=7$) or tibial ($n=3$) insertion site and most often in the middle third of the tendon ($n=21$).

The average age at trauma was 33.5 years (range 14–49) and at the time of ACL surgery 34.7 years (range 17–49). The left leg was injured in 15 (48 %) and the right leg in 16 (52 %) cases. While a bone-patellar-bone transplant was used in 14 subjects, a hamstring transplant was less often utilized ($n=9$). The details of the used methods are given in Table 1.

Fifteen patients (48.4 %) in our series had knee surgery on the same knee before ACL reconstruction. In nine patients this surgery was for meniscal tears; in four patients it was a diagnostic procedure with resection of a ruptured ACL and in two patients no reliable information was available. Of these 15 patients, three had an arthrotomy and six had more than one operation in the past (maximum, 3).

Concomitant injury required surgery at the time of ACL reconstruction in 19 patients (58 %) in this study. Most frequently this was an injury to the medial meniscus ($n=14$) or collateral ligament ($n=3$).

After ACL surgery, but before referral to our centre, 22 patients (71 %) had further surgery to address infection or other complications (one to nine operations, mean of 2.42 procedures). In all cases the first intervention was transarthroscopic; while in eight (26 %) cases only a transarthroscopic lavage was performed, an additional synovectomy was done in 23 (74 %) cases. In eight (26 %) cases the initial arthroscopy was followed by constant irrigation. Seven (22.6 %) patients were treated by unilateral arthrotomy (all lateral) in a second

Table 1 Surgical methods used in the reported cases to address ACL-lesions

Method	Frequency	Percent
B-PT-B	14	45.2
Hamstrings	9	29.0
Refixation + augmentation with Vicryl©-Band	7	22.6
Trevira©-Band	1	3.2
Total	31	100

procedure; one of those had open joint treatment. All other patients were managed solely by arthroscopy.

The first surgical intervention in our department took place at a mean of 78 days (range three to 243). At the time of the index procedure, microbiological testing showed *S. aureus* to be the most common microbiological agent (n=16). The details of the microbiological examination are given in Table 2.

In ten patients (32 %) the infection was staged as 2, and therefore an arthroscopic treatment followed. In 18 patients (58 %) a stage 3 infection was found, and in three cases (10 %) a stage 4 infection was found. In these 21 patients (grade 3 and 4 infection) a medial and lateral arthrotomy and open joint treatment were performed. In seven patients in whom an arthrotomy had been performed before, we directly proceeded to an arthrotomy for staging and treatment. In all cases, treatment of infection was successful.

Overall, a mean of 2.6 operations were required (range two to five) in our department to treat infection. In two patients an initial arthroscopic treatment was converted to open joint treatment at a second-look procedure because of remaining infection. In two cases of open joint treatment a remaining infection was found at the second-look procedure necessitating a repeat debridement and insertion of gentamicin-PMMA beads.

In eight patients (26 %) it was possible to salvage the graft. In 12 cases (39 %) the ACL-graft had to be removed. In the remaining patients the graft already had been autodigested. In two patients a second graft was implanted at six and eight months. One patient required a total knee arthroplasty five years after our treatment for osteoarthritis with gross instability.

The Tegner activity level before the knee injury was determined at 6.5 points. At follow-up, the average score was 4.5 points. The IKDC subjective module at follow-up revealed an average score of 63 (range 31–92). The mean Lysholm score was 63.9 (range 25–91), with two patients scoring very good, eight patients good, four patients fair and 17 patients poor with <70 points.

On clinical examination a mean extension deficit of 2.5° (range 0–15) and a mean maximum flexion of 121° (range 60–140) were found. In the single-legged hop test, a mean capacity of 68 % (range 0–100 %) of the non-injured leg was measured.

Table 2 Results of microbiological agents found

Organism	Number of occurrences
Staphylococcus aureus	16
Staphylococcus epidermidis	6
Cultures negative	6
Streptococci	2
S. warneri	1

The results of the IKDC forms are detailed in Tables 3 and 4. There was no correlation between the clinical and radiographic results (Spearman correlation). A comparison of the score results of the clinical evaluation showed a mean period of nine days between primary ACL surgery and our revision for patients with an IKDC clinical score "A". Patients with a "B" and "C" result had a mean period of 55.5 and 48.8 days, respectively. In the patients with a "D" score, this period was a mean of 183 days.

Regarding the difference between patients with or without a remaining ACL graft, there appeared to be no gross difference in the subjective results; the largest difference was detectable in the Tegner activity score. Behind the background of the clinical results, there appeared to be a better result if there was still a functional ACL graft (Table 4).

Grading according to Gaechter did not have a significant impact on the results of the Lysholm score (Gaechter 1 and 2: 65.3 [range 32–91]; Gaechter 3 and 4: 62.9 [range 25–83]) and IKDC form (Gaechter 1 and 2: 64.8 [range 45–96]; Gaechter 3 and 4: 63.5 [range 40–79]). Values of the Tegner score were higher in subjects with grades 1 and 2 (4.8 [range 2–6]) according to Gaechter compared with their counterparts with grades 3 and 4 (3.6 [range 1–5]).

The clinical course was complicated in two cases by a deep venous thrombosis that was treated according to the present guidelines [12].

Discussion

Knee joint empyema is predominantly caused by surgical interventions and untreated it can lead to rapid destruction of the joint [13].

Recently, Sonnery-Cottet et al. reported a 0.37 % prevalence of knee joint infection following ACL reconstruction in the general population [2]. In a subgroup of professional athletes the prevalence of this complication raised to 5.7 % in this series.

As 23 % of these athletes had a combined lateral tenodesis at the time of ACL reconstruction, the authors concluded that concomitant surgery at the time of ACL reconstruction may be a risk factor for development of infection [5]. Our data are in accordance with the literature that in most of the cases studied concomitant surgery was performed at the time of ACL reconstruction and may have triggered septic arthritis. A shortcoming of the present study is that we could not evaluate the rates of previous or additional surgery in patients who did not develop an infection. Because patients were initially operated in 20 different hospitals, it was impossible to explore all the relevant data. As all of the infections could be controlled, concomitant surgery did not have an impact on the infection control rate in our series.

Table 3 IKDC score results of clinical and radiological evaluation (IKDC, International Knee Documentation Committee)

IKDC results	Clinical evaluation (*n*/group)	Radiological evaluation (*n*/group)
Normal/nearly normal	11	10
Abnormal/severely abnormal	20	19

Two patients did not want radiographs at follow-up

Regarding further predisposing factors for joint infection, previous knee surgery and the graft choice in ACL reconstruction have been discussed [3]. In our series, most of the ACL reconstructions had been done with a BTB (bone-patella-bone) graft. Previous studies have reported a higher incidence of infections in hamstring tendon autografts compared with other grafts [1]. Specifically, one study showed that despite the nearly equal use of hamstring and patellar tendon autografts, all the infections in their cohort occurred in patients with hamstring tendon autografts [14]. Another study in a cohort of 3,126 patients pinpointed to a 3.3 times higher incidence of infections when hamstring tendons were used compared to patellar tendon autografts or allografts [15]. Why hamstring tendon grafts have an increased risk of infection is unclear. For an infection to occur, there must be both bacterial contamination and an environment conducive to bacterial growth [1]. Hantes et al. evaluated the bacterial contamination of autografts at the time of implantation and found that 13 % of hamstring tendon autografts had a positive bacterial culture as did 10 % of patellar tendon autografts [16]. In a cohort of 221 autografts and 640 allografts no increased risk of infection with allograft tissue was detected [17].

With reference to the option of either leaving the graft in situ or replacing it at a later stage, no clear conclusions can be drawn from this study. There was no detectable difference in the subjective score and by knowing this, one might choose the safer option in cases where there is doubt that the bone block or the drilling canals are infected [4]. On the other hand, the clinical results were clearly better in patients with an existing graft, which is in accordance with the literature [18]. In a retrospective case review of eight patients treated with graft removal, favourable results were seen in cases who had a reimplantation at a later stage [18]. In case of revision ACL surgery the graft choice does not affect the outcome of the procedure [19]. In a recent study, successful results have been reported following infection eradication in both graft retention and early revision ACL reconstruction scenarios [20].

As for many other infectious processes, early detection can often alter the natural course of the disease and ultimately improve long-term outcomes for patients [21]. There might be clinical signs highly suggestive of infection, but diagnosis can be a difficult task, particularly in the case of late and/or chronic infections [22]. In this series, no significant increase of the inflammatory laboratory markers was observed. Laboratory markers such as C-reactive protein, erythrocyte sedimentation rate, and white blood count are sensitive markers of inflammation and plausible infection, but they are unable to localize the exact site of infection and they are associated with low specificity [23].

With regard to the infecting microorganism, our results are in accordance with the literature. *Staphylococcus aureus* and coagulase negative *Staphylococcus* were the most common bacteria found in septic arthritis after cruciate ligament surgery [15, 20]. We used the standard analyses for detecting microorganisms—gram staining (for microscopic investigation) and culturing of tissue biopsy specimens obtained during surgical revision [24]. Many molecular tools for bacterial DNA detection from clinical samples have been developed. One of the most significant contributions thus far has been amplification-based techniques (PCR), since some studies have confirmed its excellent sensitivity and specificity [21]. Behind this background we recently added molecular analysis in the diagnostic

Table 4 Outcome of patients with and without an ACL graft at follow-up (IKDC, International Knee Documentation Committee)

Subjective	Remaining graft / regraft (*n*=10)	No remaining graft (*n*=21)
Tegner score	4.6	3.5
Subjective IKDC	64.6	63.1
Lysholm score	66.8	62.2
Clinical		
Hop test	49.5	60.8
Clinical IKDC	46.1	28.3
% normal/near normal		
Radiological IKDC	53.7	15.3
% normal/near normal		

procedure in septic arthritis, but the results are too premature for broad generalization [25].

Both of the surgical concepts described displayed high infection control rates with preservation of a functional knee in most cases. Functional outcome of joint empyemas should be discussed on the basis of the most precise local and general staging. For this reason, we used the Gaechter classification system as it is one of the most widely used scoring systems in this field [8]. The first priority in septic surgery is infection control that was achieved in all cases studied. However, patients tend to judge the outcome of an operation on pain relief and functional outcome. Clinical tests of functional outcome of this special patient population should take this conflict into account. Behind this background we present the results of different functional outcome scores in this study. The Lysholm score in our series of 63.9 was slightly worse than in other reported series [4, 26]. Although the Tegner activity level of 4.5 was markedly lower than the preoperative values (6.5), the results are comparable with the literature [4, 26, 27].

Early infection can be managed arthroscopically and satisfactory results can be expected. As shown in the present series, the time between ACL surgery and revision surgery in septic arthritis is an important factor. If in doubt, an early arthroscopic arthroscopy may be helpful. Riel et al. reported successful outcomes in one of the first series of septic arthritis patients after ACL reconstruction treated with arthroscopic instead of open surgery [28]. It has been suggested that the choice of whether to treat via arthroscopy or arthrotomy should be decided by the underlying pathologic abnormalities [29]. Unsuccessful arthroscopic attempts to treat infection after ACL surgery have been reported [4]. In advanced or chronic infection a more radical approach seems favourable, although we have no comparative results to statistically support this [30]. Kohn pointed out that the extent of the infection has to be considered when instituting a method of treatment [31]. Behind the background of a series of 121 arthroscopic treatments it is concluded that patients who had a fracture or ACL graft should be treated via an arthrotomy [31].

The limitations of this study should be acknowledged and addressed. The first limitation concerns the heterogeneous patient population, which reflects the situation of patients with knee joint empyema. However, from another perspective, these data are representative of the general patient population. The second limitation concerns the extent to which the findings can be generalized beyond the cases studied, and we consider the number of cases to be too limited for broad generalization. Based on the rarity of the illness the case number is limited, but it is higher compared to other studies published in the literature [4, 32]. Prior published data report short- to midterm results, while the present study shows long-term results with a mean of six years.

References

1. Maletis GB, Inacio MC, Reynolds S, Desmond JL, Maletis MM, Funahashi TT (2013) Incidence of postoperative anterior cruciate ligament reconstruction infections: Graft choice makes a difference. Am J Sports Med 41(8):1780–1785. doi:10.1177/0363546513490665
2. Sonnery-Cottet B, Archbold P, Zayni R, Bortolletto J, Thaunat M, Prost T, Padua VB, Chambat P (2011) Prevalence of septic arthritis after anterior cruciate ligament reconstruction among professional athletes. Am J Sports Med 39(11):2371–2376. doi:10.1177/0363546511417567
3. Sechriest VF 2nd, Carney JR, Kuskowski MA, Haffner JL, Mullen MJ, Covey DC (2013) Incidence of knee sepsis after ACL reconstruction at one institution: The impact of a clinical pathway. J Bone Joint Surg Am 95(9):843–849. doi:10.2106/JBJS.L.00408, S841-846
4. Schulz AP, Gotze S, Schmidt HG, Jurgens C, Faschingbauer M (2007) Septic arthritis of the knee after anterior cruciate ligament surgery: A stage-adapted treatment regimen. Am J Sports Med 35(7):1064–1069. doi:10.1177/0363546507299744
5. Torres-Claramunt R, Pelfort X, Erquicia J, Gil-Gonzalez S, Gelber PE, Puig L, Monllau JC (2012) Knee joint infection after ACL reconstruction: Prevalence, management and functional outcomes. Knee Surg Sports Traumatol Arthrosc 21(12):2844–2849. doi:10.1007/s00167-012-2264-3
6. Gaechter (1985) The joint infection (in German). Inform Arzt 6:35–43
7. Kent ME, Rapp RP, Smith KM (2006) Antibiotic beads and osteomyelitis: Here today, what's coming tomorrow. Orthopedics 29(7):599–603
8. Oheim R, Gille J, Schoop R, Magerlein S, Grimme CH, Jurgens C, Gerlach UJ (2012) Surgical therapy of hip-joint empyema. Is the Girdlestone arthroplasty still up to date. Int Orthop 36(5):927–933. doi:10.1007/s00264-011-1351-2
9. Kreuz PC, Muller S, Ossendorf C, Kaps C, Erggelet C (2009) Treatment of focal degenerative cartilage defects with polymer-based autologous chondrocyte grafts: Four-year clinical results. Arthritis Res Ther 11(2):R33. doi:10.1186/ar2638
10. Briggs KK, Steadman JR, Hay CJ, Hines SL (2009) Lysholm score and Tegner activity level in individuals with normal knees. Am J Sports Med 37(5):898–901. doi:10.1177/0363546508330149
11. Brumitt J, Heiderscheit BC, Manske RC, Niemuth PE, Rauh MJ (2013) Lower extremity functional tests and risk of injury in division iii collegiate athletes. Int J Sports Phys Ther 8(3):216–227
12. Barrera LM, Perel P, Ker K, Cirocchi R, Farinella E, Morales Uribe CH (2013) Thromboprophylaxis for trauma patients. Cochrane Database Syst Rev 3:CD008303. doi:10.1002/14651858.CD008303.pub2
13. Ateschrang A, Albrecht D, Schroeter S, Weise K, Dolderer J (2011) Current concepts review: septic arthritis of the knee pathophysiology, diagnostics, and therapy. Wien Klin Wochenschr 123(7–8):191–197. doi:10.1007/s00508-011-1554-y
14. Judd D, Bottoni C, Kim D, Burke M, Hooker S (2006) Infections following arthroscopic anterior cruciate ligament reconstruction. Arthroscopy 22(4):375–384. doi:10.1016/j.arthro.2005.12.002
15. Barker JU, Drakos MC, Maak TG, Warren RF, Williams RJ 3rd, Allen AA (2010) Effect of graft selection on the incidence of postoperative infection in anterior cruciate ligament reconstruction. Am J Sports Med 38(2):281–286. doi:10.1177/0363546509346414
16. Hantes ME, Basdekis GK, Varitimidis SE, Giotikas D, Petinaki E, Malizos KN (2008) Autograft contamination during preparation for anterior cruciate ligament reconstruction. J Bone Joint Surg Am 90(4):760–764. doi:10.2106/JBJS.G.00806

17. Greenberg DD, Robertson M, Vallurupalli S, White RA, Allen WC (2010) Allograft compared with autograft infection rates in primary anterior cruciate ligament reconstruction. J Bone Joint Surg Am 92(14):2402–2408. doi:10.2106/JBJS.I.00456 92/14/2402
18. Burks RT, Friederichs MG, Fink B, Luker MG, West HS, Greis PE (2003) Treatment of postoperative anterior cruciate ligament infections with graft removal and early reimplantation. Am J Sports Med 31(3):414–418
19. Mahmoud SS, Odak S, Coogan S, McNicholas MJ (2014) A prospective study to assess the outcomes of revision anterior cruciate ligament reconstruction. Int Orthop 38(7):1489–1494. doi:10.1007/s00264-014-2324-z
20. Scully WF, Fisher SG, Parada SA, Arrington EA (2013) Septic arthritis following anterior cruciate ligament reconstruction: a comprehensive review of the literature. J Surg Orthop Adv 22(2):127–133
21. Gallo J, Raska M, Dendis M, Florschutz AV, Kolar M (2004) Molecular diagnosis of prosthetic joint infection. A review of evidence. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub 148(2):123–129
22. Schulz AP, Faschingbauer M, Seide K, Schuemann U, Mayer M, Jurgens C, Wenzl M (2009) Is the wave plate still a salvage procedure for femoral non-union? Results of 75 cases treated with a locked wave plate. Eur J Trauma Emerg Surg 35(2):127–131. doi:10.1007/s00068-008-8009-9
23. Virolainen P, Lahteenmaki H, Hiltunen A, Sipola E, Meurman O, Nelimarkka O (2002) The reliability of diagnosis of infection during revision arthroplasties. Scand J Surg 91(2):178–181
24. Ince A, Rupp J, Frommelt L, Katzer A, Gille J, Lohr JF (2004) Is "aseptic" loosening of the prosthetic cup after total hip replacement due to nonculturable bacterial pathogens in patients with low-grade infection. Clin Infect Dis 39(11):1599–1603. doi:10.1086/425303
25. Gille J, Wallstabe S, Schulz AP, Paech A, Gerlach U (2012) Is non-union of tibial shaft fractures due to nonculturable bacterial pathogens? A clinical investigation using PCR and culture techniques. J Orthop Surg Res 7:20. doi:10.1186/1749-799X-7-20
26. Schollin-Borg M, Michaelsson K, Rahme H (2003) Presentation, outcome, and cause of septic arthritis after anterior cruciate ligament reconstruction: a case control study. Arthroscopy 19(9):941–947
27. Fong SY, Tan JL (2004) Septic arthritis after arthroscopic anterior cruciate ligament reconstruction. Ann Acad Med Singap 33(2):228–234
28. Riel KA, Primbs J, Bernett P (1994) Arthroscopic distension irrigation in acute postoperative infection of the knee joint–long-term follow-up. Chirurg 65(11):1023–1027
29. Lane JG, Falahee MH, Wojtys EM, Hankin FM, Kaufer H (1990) Pyarthrosis of the knee. Treatment considerations. Clin Orthop Relat Res 252:198–204
30. Balabaud L, Gaudias J, Boeri C, Jenny JY, Kehr P (2007) Results of treatment of septic knee arthritis: A retrospective series of 40 cases. Knee Surg Sports Traumatol Arthrosc 15(4):387–392. doi:10.1007/s00167-006-0224-5
31. Kohn D (1988) Unsuccessful arthroscopic treatment of pyarthrosis following anterior cruciate ligament reconstruction. Arthroscopy 4(4):287–289
32. Gille J, Ince A, Gonzalez O, Katzer A, Loehr JF (2006) Single-stage revision of peri-prosthetic infection following total elbow replacement. J Bone Joint Surg (Br) 88(10):1341–1346. doi:10.1302/0301-620X.88B10.17952