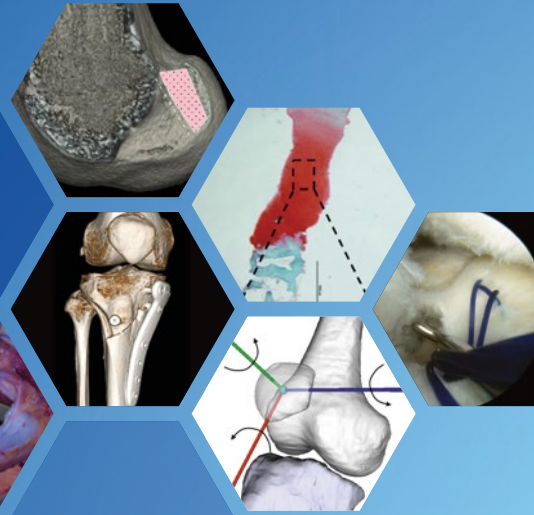


Norimasa Nakamura
Robert G. Marx
Volker Musahl
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Peter Verdonk
Editors



Advances in Knee Ligament and Knee Preservation Surgery



ISAKOS

International Society of Arthroscopy,
Knee Surgery and Orthopaedic Sports Medicine



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Editors

Norimasa Nakamura
Institute for Medical Science in Sports
Osaka Health Science University
Osaka
Japan

Robert G. Marx
Orthopedic Surgery, Sports Medicine
Hospital for Special Surgery
New York
USA

Volker Musahl
MSRC, Division of Sports Medicine
University of Pittsburgh
Pittsburgh, PA
USA

Alan Getgood
Fowler Kennedy Sport Medicine Clinic
London, ON
Canada

Seth L. Sherman
Orthopaedic Surgery
Stanford University
Palo Alto, CA
USA

Peter Verdonk
Department of Orthopedic Surgery
Antwerp Orthopaedic Center
Antwerpen
Belgium

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Foreword

Firstly I want to thank all the authors who have given up so much of their time to write this comprehensive book on knee ligament and conservation surgery. There is no financial gain to any of them, but to be successful surgeons we are judged by more than the amount of money we make. Teaching young surgeons is very fulfilling because we can all remember when we were taught and how much it meant to us. We have many ways to teach or to learn but what is great about a book is that it puts everything in order and explains where it all fits in. For me the “Why” in surgery is more important than the “How,” and this book will give you an insight into the latest hot topics and controversies in knee ligament and conservation surgery. Make sure you always know “why” you are doing the surgery and for this you need basic science and anatomy and then somebody (expert) who can explain how it all comes together.

There are multiple perspectives on this variety of topics from around the globe, making for a complete guide that will help knee surgeons take care of their patients.

Willem M. van der Merwe
President ISAKOS, Sport Science Orthopaedic Centre
Cape Town
South Africa

Preface

Thanks to an incredible collection of international surgeons, this textbook attempts to tackle all of the current hot topics and controversial areas in knee ligament and knee preservation surgery. Regarding the latest in ACL surgery, we cover indications, technique, lateral augmentation, return to play, and ACL revision surgery. We also review both multi-ligament surgery and patellofemoral surgery. Complex meniscal issues are tackled along with cartilage repair, osteotomy, and biologic treatments to prevent osteoarthritis.

We include multiple perspectives on these topics from around the globe, making for a complete guide that will help every knee surgeon take better care of their patients.

Osaka, Japan
New York, NY, USA
Pittsburgh, PA, USA
London, ON, Canada
Palo Alto, CA, USA
Antwerpen, Belgium

Norimasa Nakamura
Robert G. Marx
Volker Musahl
Alan Getgood
Seth L. Sherman
Peter Verdonk

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Who Needs ACL Surgery?

1

Kenneth M. Lin, Evan W. James,
and Robert G. Marx

1.1 Sequelae of Nonoperative Management of Acute ACL Injury

In order to understand who should get ACL surgery, we must first understand the benefits of ACL surgery. Surgical treatment of acute ACL rupture generally consists of reconstruction using a variety of graft options, including allograft and/or autograft using hamstring tendons, quadriceps tendon, or patella bone-tendon-bone graft. Historically, primary repair of the ACL was considered a viable treatment option following rupture; however, outcomes studies showed up to a 94% rate of instability at 5-year follow-up [1]. The advent of advanced suture constructs improved failure rates somewhat, but reconstruction, and not repair, is generally preferred due to more predictable outcomes in young active patients [2–4]. Therefore, in this chapter, evidence will be largely drawn from the reconstruction literature. To answer the question of which patients need ACL surgery, it is important to first understand what nonoperative man-

agement entails and how its outcomes differ from reconstruction.

1.1.1 Nonoperative Management Techniques

Nonoperative management for ACL ruptures is generally reserved for older patients, or those who wish to return to noncutting, straight-plane activities and do not have persistent functional instability [5]. It has been shown that nonoperative treatment has higher failure rate with younger age and higher activity level [6]. Nonoperative management largely consists of lifestyle and activity modification, as well as neuromuscular rehabilitation programs and movement pattern optimization strategies. Numerous protocols have been described, but components of programs that have been shown to lead to good physical performance and muscle strength are goal-oriented and progressive in nature: early phases focus on motion, neuromuscular control, and balance, while later phases focus on muscle strength, endurance of stabilizers, and functional performance [7–10]. Recently, the Knee Anterior Cruciate Ligament, Nonsurgical versus Surgical Treatment (KANON) trial showed that at 2- and 5-year follow-up, patients prospectively randomized to exercise program alone achieved similar rates of limb symmetry index >90% as those who underwent ACL reconstruction plus exercise [7].

K. M. Lin · E. W. James · R. G. Marx (✉)
Division of Sports Medicine and Shoulder Surgery,
Hospital for Special Surgery, New York, NY, USA
e-mail: linke@hss.edu;
jamese@hss.edu; marx@hss.edu

1.1.2 Biological Perspective

From a biological perspective, there are several important theoretical advantages to surgical treatment of acute ACL rupture. Native healing of intra-articular ligaments is limited, as the synovial healing response leads to stump retraction and lack of tissue bridging [2]. When bridging does occur, tension is often decreased due to the altered resting position of the femur and tibia, and newly formed tissue consists of fibrovascular scar rather than regeneration of native ligament and enthesis tissue [11]. For this reason, the tissue that forms through the native healing response is biomechanically, histologically, and morphologically inferior to the original ligament. Surgical reconstruction using quadrupled hamstring autograft yields a construct that is significantly stronger in tensile load and stiffness than the native ACL [12, 13]. Furthermore, the use of bone-tendon-bone grafts allows retention of a native tendon-bone insertion and relies on bone-bone healing which is more predictable [14]. During surgical reconstruction, tension of the graft construct can be directly manipulated and set. Finally, management of concurrent associated pathology, such as a meniscus tear or chondral injury, may also occur at the time of ACL reconstruction.

1.1.3 Clinical Perspective

Nonoperative management of acute ACL rupture has generally been considered inferior to surgical management for young and active patients [5, 6, 15, 16]. Clinical outcomes of importance in the setting of acute ACL injury include knee stability, prevention of subsequent repairable and irreparable meniscus tears or chondral injury, clinical outcome scores, return to work or sports, and patient satisfaction. Compared to nonoperative management, previous studies have shown that ACL reconstruction leads to improved stability and functional outcomes at 10-year [17] and even 20-year follow-up [18, 19]. It should be noted, though, that short-term outcomes have been shown to be similar [7, 20]. Nonoperative man-

agement is known to lead to persistent laxity and incomplete tissue healing on MRI. For example, van Meer et al. [21] showed in a prospective multicenter study of over 150 patients that at 2 years post-injury, only 32% of patients had improved Lachman exams (improved but not normal exam), with only 2% showing improvement on KT-1000. In this population, 60% showed improvement in fiber continuity on MRI and 44% showed resolution of empty intercondylar notch. However, all other MRI-based parameters of ACL structure and tissue quality remained abnormal, likely reflecting the presence of fibrovascular scar tissue, rather than regeneration of native ligamentous tissue, from the native healing response. It should be noted that several studies have highlighted advantages to nonoperative management. The KANON trial showed that at 5-year follow-up, patients who underwent exercise therapy alone (nonoperative treatment) had fewer knee symptoms compared to those who underwent early reconstruction followed by exercise program [8]. The authors suggest that this is because ACL reconstruction involves iatrogenic damage to the knee, such as surgical incision, graft harvest site morbidity, and bone tunnel drilling.

ACL reconstruction for acute ruptures leads to decreased rates of secondary injury, namely of the meniscus [22, 23], and thus in theory decreases the likelihood of downstream arthritis, although the long-term data to date is somewhat mixed regarding late arthritis. ACL reconstruction is known to decrease reoperation rates as it is thought to be protective against meniscal and cartilage injury [24]. In a retrospective cohort study by Sanders et al. [18] of nearly 1000 patients at mean 13.7 years follow-up, patients treated with nonoperative management for ACL rupture had a 5.4-fold increased risk of secondary meniscus tear. In this study, the nonoperatively treated cohort had a 6.0-fold increased risk of being diagnosed with arthritis. A case-control study by the same authors compared nonoperatively managed acute ACL ruptures to age- and sex-matched controls without ACL tears [25]. There was a significantly increased risk of secondary meniscal injury, osteoarthritis, and need for total knee

arthroplasty in the nonoperative ACL rupture group compared to the healthy matched controls. Studies by other authors in different populations have shown similar results regarding decreased arthritis in surgically treated patients with acute ACL rupture compared to nonoperative management [26]. However, several large studies have also reported similar rates of arthritis in operative versus nonoperative ACL injury patients [17, 23, 27]. Nonetheless, despite similar rates of arthritis, these studies report fewer subsequent knee injuries and improved overall knee function in the surgical groups [17, 23, 27]. Because the operative groups tend to achieve higher function and activity, perhaps the comparison of arthritis rates is confounded, as increased activity-level or high-level sports participation may also be an independent risk factor for arthritis [28, 29]. A study comparing long-term outcomes in ACL-reconstructed knees to the contralateral “healthy” knee in the same individual showed no significant difference in radiographic arthritis (on X-ray and MRI) at 10-year follow-up [30]. However, longer-term follow-up is still needed since many patients do not convert to total knee replacement until up to 20 or 30 years after ACL reconstruction. Taken together, the results in the literature to date largely suggest that the natural history of acute ACL rupture, which is thought to lead to worsened knee function and eventually degenerative disease of the knee, is altered with surgical management, although the data surrounding risk of downstream arthritis are not definitive.

1.2 Return to Sport Following ACL Injury

Given the high prevalence of acute ACL injuries in the athletic population, return to sport is another important outcome to consider in the ACL rupture population. Following ACL reconstruction, return to similar level of sport is extremely high in elite or professional athletes. Reports from National Basketball Association (NBA) athletes suggest return to play rates of up to 88%; however, performance upon return to sport declined based on statistical performance

[31–33]. Similar studies from other professional sports show high return to same level of play rates: 77% in Major League Soccer (MLS) [34], 92% (quarterbacks) and 74% (defensive players) in the National Football League (NFL) [35], and 97% in the National Hockey League (NHL) [35]. Post-return performance was similar to pre-injury level in MLS, NHL, and NFL quarterbacks, but significantly reduced in NFL defensive players. In a nonprofessional athletic population, general return to sport rates are high, but return to same level of play is less predictable. Overall return to some form of sport has been reported up to 90%, with return to pre-injury level up to 72% [36–40]. In the pediatric population, return to play after ACL reconstruction has been reported to be as high as 91%, but with high rate of second ACL injury, many of which were to the contralateral knee [41]. While the goal is to return all patients to their pre-injury level of competition, it is important to counsel patients that a subset of ACL reconstruction patients will struggle to attain these levels of activity.

It should be noted that while the vast majority of the literature on return to sport following ACL injury focuses on ACL reconstruction, there have been reports of return to elite sport following nonoperative treatment [42].

1.3 Patient Stratification

In developing a framework for patient selection for ACL surgery following acute injury, the general patient population should be stratified by age and activity level. With respect to age, patients can be split into pediatric and adolescent, younger adult (20–50), and older adult populations (>50). With respect to activity level, patients can be divided into high-level athletes, recreational athletes, or sedentary individuals. In addition to age and activity level, there are several other factors that play into the decision-making for ACL surgery indications. First, medical comorbidities must be considered and patients physiologically unfit for surgery should be contraindicated. Psychosocial factors, such as access to rehabilitation resources or ability to comply with

postoperative restrictions, are also important to consider. Injury factors, such as chronicity, degree of laxity, and functional limitation, are important factors that can shape decision making, as they can influence the type of surgery that is performed. Similarly, the presence of other intra-articular pathology, such as repairable meniscus tears or arthritis, may be indications or contraindications for surgery, respectively, and are extremely important for predicting long-term outcomes. While balancing this constellation of factors is integral for surgical decision-making, indicating a patient for ACL surgery is based principally on the patient's age, desired activity level, and functional goals [6].

Some authors have suggested that activity level is the most important predictor for necessity to perform an ACL reconstruction [43], and that chronologic age in isolation may not be a reliable predictor [44, 45]. Several studies in the literature have assessed outcomes of ACL surgery in differing age groups, with 40 years of age as a commonly-used cutoff [44, 46–48]. Results have shown no significant difference in outcomes, although interpretations are limited by study design and heterogeneous populations with regard to operative technique, graft choice, rehabilitation, and other factors. In some populations, older (>40 years of age) patients have been shown to have greater satisfaction than younger patients [46]. Beyond being a proxy for activity level and demand on a patient's knee, age is also thought of as a proxy for the amount of degenerative change in the knee. As older patients become increasingly active, there is growing interest to expand indications for ACL reconstruction, particularly in adult patients with mild to moderate knee osteoarthritis, which will be discussed later in this chapter. A list of factors to consider when indicating patients for ACL surgery is presented in Table 1.1. To answer the question of who needs ACL surgery, in the sections below, patients will be stratified by age group, as age is universal and does not rely on various scoring systems (as activity level does). Within each age group, decision-making for ACL surgery will be discussed.

Table 1.1 Important preoperative factors to consider in ACL surgery

<i>Patient factors</i>
Activity level
Age
Sports participation (volume, type, level, position)
Preexisting arthritis and prior injuries
Medical comorbidities
Ability to comply with rehabilitation protocol
<i>Injury factors</i>
Chronicity
Concomitant injuries (meniscus, cartilage, collaterals, fractures)
Partial vs. complete rupture
Degree of instability on physical examination (Lachman, pivot shift)

1.4 Pediatric and Adolescent

In the pediatric population, the incidence of acute ACL injury and ACL reconstruction is increasing [49–51], likely due to increased participation in organized sports, improved diagnostic capabilities, and a greater awareness among doctors and families. Historically, nonoperative or delayed operative management was recommended in the pediatric and adolescent populations to avoid the rare but potentially devastating complication of physeal injury, growth arrest, and subsequent limb deformity [52]. However, studies of nonoperative management reported poor outcomes [53–55], including poor return to sports participation, high rates of subsequent knee injury and surgery, and early degenerative change. Recently, comparative studies of operative versus nonoperative management of pediatric injuries strongly favor operative management [15, 16]. Numerous techniques for surgical treatment of acute ACL injury in the pediatric patient have been described and studied in the literature [56, 57]. Outcomes following ACL reconstruction in the pediatric population are favorable and predictable, with improved stability, functional outcomes, high rate of return to sport, and low rate of physeal arrest [58, 59]. It should be noted, however, that in a subset of pediatric patients, specifically those age <14 years, with partial ruptures of <50% and a grade B pivot shift exam, have been shown to

have good outcomes with nonoperative treatment [60]. Taken together, the current literature supports surgical treatment for the vast majority of acute ACL ruptures in the pediatric population to restore stability, maximize sports participation, and prevent subsequent meniscal tears and chondral injuries.

1.5 Young Adult (<40 Years)

The majority of patients with acute ACL rupture fall into the young adult category. In these patients, treatment is based on activity level and functional demands. For patients with medical contraindications to surgery in general, have sedentary occupation, and do not wish to return to jumping, cutting, or pivoting sports, nonoperative management can yield successful results [61, 62]. Outside of these groups, the vast majority of patients in this cohort should be indicated for ACL surgery in the setting of complete rupture. The extensive body of research surrounding outcomes following ACL reconstruction discussed previously strongly favors operative management in the young, active population, especially in athletic individuals [5, 17–19, 23, 25].

1.6 Older Adult (>40 Years)

Similar to other age groups, consideration for ACL surgery is largely based on activity demand and degree of instability or functional limitation. In general, as older individuals may be less active or have baseline degenerative disease, nonoperative management is a reasonable option; however, in the setting of continued symptomatic instability or further knee injury (such as meniscus tears), late ACL reconstruction may become necessary. For patients who elect to proceed with surgery, recent literature on ACL reconstruction in older patients has been shown to have good results even in those over 50 years of age [63] and 60 years of age [64].

It must be noted that there is a sub-population of middle age adults that has been reported to benefit from nonsurgical treatment of acute

injury. Specifically, recreational middle age alpine skiers (mean age 42, range 30–68), with MRI evidence of complete ACL tears but who have grade pivot shift and Lachman exams 6–12 weeks after injury, can have good outcomes with conservative management at 2-year minimum follow-up [65]. Postoperative activity scores were equivalent to preoperative scores, and knee laxity had returned to normal with mean side-to-side difference in KT-1000 under 1 mm, and 10 of 11 patients had a Lachman grade 0–1+. Based on these results, the authors suggest that middle-aged skiers presenting with an acute ACL tear may be re-evaluated at 6–12 weeks following injury. If the knee is stable to Lachman and pivot shift testing, nonoperative management should be considered and the patients can expect to return to their activities.

An important consideration in the middle age adult population is a preexisting degenerative disease. With increasing activity level and recreational sports participation in an aging population, there is a growing proportion of individuals who have early arthritis but are still active. These patients are difficult to classify into traditional diagnostic groups, as their activity level would place them in the ACL reconstruction category (as opposed to nonoperative), and despite their early arthritis, may be too active or not advanced enough for total knee arthroplasty. In these patients, joint preservation techniques, such as high tibial osteotomy, are frequently performed to offload the affected compartment. Recently, there is a growing body of evidence investigating ACL reconstruction in knees with early degenerative changes. Several cohort studies have assessed outcomes following simultaneous high tibial osteotomy (HTO) and ACLR [66–69]. The results show satisfactory to good outcomes following combined HTO and ACLR, with improved alignment, stability, and outcome scores compared to preoperatively. Rates of arthritis progression are variable, with some studies reporting minimal progression [67], and others reporting higher rates of discernible progression [66]. Major demographic groups in the treatment of ACL injury are listed in Table 1.2, with their suggested treatments.

Table 1.2 Treatment of ACL injury by age

Treatment of ACL rupture by Demographic Group	
Demographic group	Treatment
<i>Pediatric</i>	
Complete rupture	ACL surgery
Partial rupture	Consider conservative management, especially if pre-pubescent
<i>Young adult (age 20–40 years)</i>	
Complete rupture with intact cartilage	ACL surgery
Alpine skier >30 years of age, stable Lachman and pivot shift at 6 weeks	Consider conservative management
Medical contraindications to surgery	Consider conservative management
<i>Older adult (age >40 years)</i>	
Sedentary	Consider conservative management
Medical contraindications to surgery	Consider conservative management
High activity level or participation in recreational/competitive sports	ACL surgery if no significant arthritis
Tricompartmental arthritis	Consider conservative management

In determining who needs ACL surgery following acute injury, patient factors and associated injuries must be taken into account. The most important factor to consider is activity demand, as active individuals and athletes will require a functional ACL. ACL reconstruction is recommended for active adults, and can be performed in patients over 50 and 60 years of age, if necessary, for symptoms of recurrent instability. Age is a proxy for activity and function, but also for the remaining “lifespan” of the joint and amount of degenerative change. In younger patients it is paramount to restore functional stability to prevent further injury and arthritis. For pediatric patients and young adults, ACL reconstruction is nearly universally recommended in the setting of complete rupture. There are two notable situations in which conservative management has been shown to produce good outcomes: partial ruptures in pediatric patients and acute ACL tears in middle-age alpine skiers. As our knowledge of ACL anatomy and the biology of ligament healing continues to evolve, further high-quality comparative studies are needed to further refine ACL indications across the general population.

1.7 Summary

As ACL rupture becomes increasingly common across all age groups with earlier sports participation and increasing activity level in the aging population, it is imperative to understand who needs ACL surgery after acute injury. There are multiple biological and clinical advantages to operative management of acute ACL injuries compared to nonoperative management. It is known that ACL reconstruction restores stability and function to the knee, and predictably leads to high rates of return to sport in elite athletes, and good but slightly lower rates in recreational athletes. Subsequent meniscal tears and chondral injuries occur less frequently and reoperation rates are reduced following ACL reconstruction. Many studies have reported decreased degenerative changes in patients who undergo surgery, although this remains controversial, as the increased activity level achieved by ACL-reconstructed patients is a likely positive confounder for the development of arthritis.

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Patient-Specific Graft Choice in Primary ACL Reconstruction

2

Martin Lind and Ole Gade Sørensen

2.1 Introduction

The choice of graft for anterior cruciate ligament (ACL) reconstruction has since the start of ACL surgery been a key factor for both surgical technique and the expected clinical outcomes. The three categories of grafts are autograft, allograft, and synthetic graft [1]. Autografts usually consist of either hamstrings tendon (HS), Bone patella tendon-bone (BPTB), or quadriceps tendon (QT), but also iliotibial tract and peroneus longus autograft have seen limited usage. Allografts are varied but can consist of tibialis posterior tendon, Achilles tendon, tibialis anterior tendon, BPTB, and peroneus longus tendon [2, 3].

Synthetic grafts were highly popular in the infancy of ACL reconstruction in the 1980s and 1990s. But catastrophic outcome and severe adverse effects led to these grafts being completely abandoned two decades ago [4, 5]. However, recently new synthetic grafts have been introduced both as complete grafts as the Ligament Augmentation Reconstruction System (LARS; Corin, Gloucestershire, England) or as augmentations to ACL reconstructions or repairs (Internal Brace, Arthrex, Naples, USA) [6].

The choice graft and technique to use during ACL reconstruction are based on patient's anat-

omy, previous surgical history, concomitant injuries as well as patient choice. Surgeon's choice is dictated by a combination of these factors including perceived functional outcome, rehabilitation speed, graft incorporation, graft availability, and donor site morbidity. The surgeon's familiarity with the graft harvest and implantation technique also influences the graft choice. Much research has been performed to identify which particular graft or technique results in the best clinical outcomes. Some of this research has been of good quality including meta-analyses, systematic reviews, and randomized controlled trials (RCT). Despite three decades of research there continues to be a wide variation in the choices made by surgeons. Limited research is available to guide surgeons to choose the best graft for ACL reconstruction when relating to patient-specific criteria such as age, sex, level of activity, and concomitant injuries. Also, long-term outcomes are not immediately available for newer techniques which makes graft choice decisions even more challenging.

The key clinical outcome parameters for presenting and comparing ACL reconstruction outcomes are the following: risk of reinjury/revision surgery, knee stability as evaluated by quantitative Lachman test, patient-reported outcomes, ability to return to sports, donor site morbidity, and functional outcomes such as muscles strength and hop tests. In the following data on these parameters will be presented.

M. Lind (✉) · O. G. Sørensen
Department of Orthopaedics, Aarhus University
Hospital, Aarhus, Denmark
e-mail: martinlind@dadlnet.dk

Our aim in this chapter is to present available knowledge on clinical outcome in relation to graft choice for ACL reconstruction and specifically present the knowledge of outcome impact with graft choice in relation to patient-specific factors. These data should provide a better decision platform for ACL surgeons to make optimized graft choice decisions based on current evidence.

2.2 Outcome with Bone Patella Tendon Bone Autografts

BPTB grafts for ACL reconstruction have been used since in 1969 and are still first choice in certain countries and for specific patient categories [7]. BPTB has historically been considered the gold standard for ACL reconstruction. The method of harvest includes a horizontal or longitudinal skin incision followed by resection of the mid-portion of the patella tendon with bone block at both ends with the intervening tendon as a complete unit. Thus, the graft has bone block at both ends which allows potentially superior integration of the graft into the tibial and femoral tunnels. The graft is then detached

and fed through the tibial tunnel into the femur. Fixation can take place using a variety of different methods ranging from an interference fit with no fixation device to screw or suspensory fixation [8].

Revision rates for BPTB graft usage have recently been reported in high patient volume registry studies from Scandinavia and the USA demonstrating revision rates from 1.5 to 3.2% [2, 9, 10]. Knee stability evaluated as percentage of patients with normal stability defined as less than 3 mm side to side Lachman laxity is between 66 and 81%. Patient-reported outcomes subjective IKDC and KOOS scores demonstrated improvement of 15 points for KOOS with follow-up KOOS₄ levels of 70 and Lysholm score of 90. Donor site morbidity incidence range from 5 to 27% but was influenced by very different evaluation methods (Table 2.1).

2.3 Outcome with Hamstring Grafts

Hamstring tendons are one of the more commonly used grafts for ACL reconstruction since Lipscombe in 1982 first described the technique

Table 2.1 Literature overview of Bone Patella Tendon Bone graft for ACL reconstruction

Bone patella tendon bone graft for ACL reconstruction						
Study	Study type	Revision rate (5 years)	Knee stability	PROM	Return to sport ability	Donor site morbidity
Rahr-Wagner (2014) [10]	Registry	3.0%	81% normal (<2 mm)	KOOS ₄ 55–70	–	–
Gifstad (2014) [9]	Registry	2.7%	–			
Maletis (2017) [2]	Registry	2.5%	–	–	–	–
Kaeding (2015) [11]	MOON group	3.2%	–	--	–	–
Mohtadi (2011) [12]	Cochrane review	2.6%	66% normal (<2 mm)	Lysholm FU 89	77%	29%
Lind (2019) [13]	Registry	1.5%	1.0 STS		–	–
Lund (2015) [14]	RCT	0%	0.8 mm STS	KOOS ₄ 55–72 IKDC 61–70	–	40% unable to knee-walk

Outcome with BPTB graft for ACL reconstruction

STS side to side difference in instrumented sagittal knee stability

Table 2.2 Literature review of hamstring graft for ACL reconstruction

Hamstring graft for ACL reconstruction						
Study	Study type	Revision rate (5 years)	Knee stability	PROM	Return to sport ability	Donor site morbidity
Rahr-Wagner registry (2014) [10]	Registry	4.5%	84% normal (<2 mm)	KOOS ₄ 55–71	–	–
Gifstad (2014) [9]	Registry	4.2%	–	–	–	–
Maletis (2017) [9]	Registry	2.3%	–	–	–	–
Kaeding (2015) [11]	MOON group	4.8%	–	–	–	–
Mohtadi (2011) [12]	Cochrane review	3.3%	59% normal (<2 mm)	Lysholm FU 90	81%	20%

[15]. The semitendinosus tendon with or without the gracilis tendon is harvested, typically from the ipsilateral leg. The resultant tissue is folded into a four-strand graft of 7–10 mm diameter, which is then used to reconstruct the ACL with different fixation techniques such as metal button with loops, transfixation pins, or interference screws.

Revision rates for hamstring graft usage have been reported in several valid high patient volume registry studies from both Europe and the USA. These studies describe 5-year revision rates ranging from 2.5 to 4.5% (Table 2.2). Knee stability evaluated as percentage of patients with normal stability defined as less than 3 mm side-to-side Lachman laxity, was between 59 and 84%. The patient-reported outcome scores used are numerous with Lysholm score, subjective IKDC and KOOS score being the most used instruments. For all scores patients generally experience significant improvements in score from preoperative to follow-up with Lysholm score and IKDC score 35- and 25-point improvement respectively.

Return to sport ability after hamstring ACLR for light sports was 81% as seen in a Cochrane review [12]. Donor site morbidity as evaluated by subjectively experienced anterior knee pain was seen in 20% of patients [12].

2.4 Outcome with Quadriceps Autograft

The present literature on QT autografts for ACLR has until recently been limited by small study sizes, which has prevented reporting of failure rates and outcomes from a generalized surgical population. Now national clinical registries that contain high volume data enable investigation of accurate low incidence failure rates (ACL revision). For example the Danish Knee Ligament Reconstruction Registry (DKRR), that has recently published outcome from more than 500 QT ACLRs and more than 20,000 PT and HT ACLRs with comparison of revision rates and objective clinical outcomes for these graft types alone [16]. But metanalysis and a two-level 1 RCTs have also contributed to the present outcome knowledge for QT ACLR [14, 17, 18].

QT grafts for ACL reconstruction were first described by Marshall in 1979 [19], but did not gain popularity as a graft for primary ACLR until the last 6–8 years [13]. Before this the QT graft was mainly used for ACL revision surgery and PCL reconstructions. The method of harvest includes a horizontal or longitudinal skin incision at the proximal part of the patella and distal part of the QT followed by resection of a 9–10 mm broad and 7–8 cm long tendon band from the

mid-portion of the QT. The graft can involve the full tendon thickness or partial thickness by leaving the deep tendon portion that involves the vastus intermedius. The graft can be harvested with or without a 15–20 mm long bone block from the proximal aspect of the patella tendon as a complete unit. Fixation are made with metal interference screw for the bone block end and the soft tissue part fixation can take place using absorbable and non-absorbable screws or suspensory fixation.

Revision rates for QT graft usage have recently been reported in a high patient volume registry study from Denmark [13]. This study found an overall revision rate of 4.7% which was higher compared to case series and RCTs where revision rates were between 2 and 3% [18].

Knee stability as side-to-side difference quantitatively evaluated has generally been found to be very good with laxity differences from 1.1 to 2.8 mm. Normal pivot shift was seen in 75 to 85%. Patient-reported outcome score subjective IKDC and KOOS scores demonstrated improvement of 15 points for KOOS and 20 points for IKDC with follow-up KOOS₄ levels of 84 and IKDC levels 82 to 85. Donor site morbidity incidence ranged from 5 to 27% but was influenced by very different evaluation methods (Table 2.3).

2.5 Outcome with Allograft

The use of allograft is appealing particularly to the complete lack of donor site morbidity, reasonably good availability, and a range of graft sizes with the options of bone blocks attached to the graft. Allograft material does come with its own unique risks including risk of microbiological disease transmission and is an expensive option compared to autografts. The most commonly used allograft tendons are tibialis posterior/anterior and Achilles tendon allografts; however, patellar tendon and HT are also widely available in some countries. Other disadvantages with the use of an allograft include the immunogenic response of the host to the graft and delayed graft incorporation when compared to the autografts. A histological study assessing allografts retrieved during autopsy at 2 years after implantation demonstrated poor vascularization in the center portion of the graft, which had remained acellular [20]. Thus, unlike previous reports of good incorporation of allograft at 18 months, this study shows that graft incorporation might take 3 years or more [21]. Allografts have been widely used for primary ACLR in the USA whereas only minimally used in the rest of the world due to cost, limited availability, and legal issues.

Table 2.3 Literature review of quadriceps tendon graft for ACL reconstruction

Quadriceps tendon graft for ACL reconstruction						
Study	Study type	Revision rate (5 years)	Knee stability	PROM	Return to sport ability	Donor site morbidity
Lind (2019) ACL registry [13]	Registry	4.7%	1.8 mm STS 76% neg. Pivot shift	–	–	–
Lind (2019) [17]	RCT	0%	1.8 mm STS 84% neg. Pivot shift -	KOOS ₄ 84 IKDC 82	–	Any complaint 27%
Lund (2015) [14]	RCT	0%	1.1 mm STS	KOOS ₄ 65–82 IKDC 68–84	–	5% unable to knee walk
Slone (2015) [18]	Meta-analysis	0–2.9%	1.1–2.8 mm STS	85–92% good/ exc Lysholm 88–93	–	5–15%

Outcome with quadriceps tendon graft ACL reconstruction
STS side-to-side difference in instrumented sagittal knee stability

Table 2.4 Allograft for ACL reconstruction

	Study type	Revision rate (5 years)	Knee stability	PROM	Return to sport ability	Donor site morbidity
Maletis [24]	Registry	3.6–13%	–	–	–	–
Keading [11]	MOON multicenter cohort	4.8%	–	–	–	–
Foster [22]	Review	8%	KT-1000: 1.6 mm	Lysholm 91		

Outcome with allograft tendon graft ACL reconstruction
STS side-to-side difference in instrumented sagittal knee stability

The literature comparing autograft and allograft have been scarce, with mainly small case series. A review of these studies concludes no differences in knee laxity and subjective outcome but higher failure rate between allografts and autografts [22, 23]. Revision rates with allograft used for primary ACLR have recently been reported in the USA in high patient volume registry studies from the MOON and MARS groups and the Kaiser Permanente ACL registry and demonstrating crude revision rates from 3.6 to 10% [11, 24]. The highest revision rates were seen for allografts that were either chemically processes or irradiated. Especially young patients under 21 years were demonstrated to have an increased risk of revision when reconstructed with an allograft with revision rates of 13% [24]. Similarly in the MOON cohort the revision rate for allograft in 20-year-old patients was found to be 10 times higher compared to BPTB autograft with revision rates of 2.5% and 25% for BPTB and allograft respectively [11, 25].

Knee stability evaluated as percentage of patients with normal stability defined as less than 3 mm side-to-side Lachman laxity was between 66 and 81%. Patient-reported outcomes, subjective IKDC and KOOS scores demonstrated improvement of 15 points for KOOS with follow-up KOOS4 levels of 70 and Lysholm score of 90 (Table 2.4).

2.6 Comparison of Graft Types Regarding Outcome

Regarding graft failure comparisons a meta-analysis found that patients undergoing primary ACL reconstruction with bone-tendon-bone

autograft were less likely to experience graft rupture and/or revision ACL reconstruction than patients treated with hamstring autograft (OR, 0.83) [10, 26]. As seen in Tables 2.1 and 2.2, revision rates for patella tendon grafts ranged from 2.6 to 3.2% and hamstring from 2.5 to 4.8%, with all large volume studies finding lower revision rates for patella tendon graft compared with hamstring grafts.

Among patients who did not experience graft rupture or revision, there were no differences observed between the two graft types in graft laxity as evaluated by KT 1000 knee arthrometer, pivot shift testing, or Lachman testing. Patients who received a hamstring tendon autograft reported superior KOOS in the sport and recreation subscale (up to 7 points higher) at each follow-up compared with patients who received a patella tendon autograft [10, 16]. Patients who received a hamstring tendon autograft also had a higher Tegner Activity Scale compared with patients who received a patella tendon autograft (mean 4.9 versus mean 4.7) 1-year postoperatively [10]. Patients who received hamstring tendon autografts had increased odds of achieving functional recovery (defined as KOOS pain ≥ 90 , symptoms ≥ 84 , ADL ≥ 91 , sport and recreation ≥ 80 and QoL ≥ 81) and were less likely to report subjective treatment failure (defined as a KOOS QoL < 44 points) compared with patients who received patella tendon autografts [27]. A recent randomized study comparing hamstring graft, double bundle hamstring graft, and patella tendon graft found equal subjective outcome and pivot shift stability at both 2 and 5 years follow-up [28].

2.7 ACL Graft Choice and Age

The choice of graft in ACL-R in adolescents and young patient groups is important because of an increased risk of graft rupture and revision surgery. Kaeding et al. reported on young patients graft rupture risk from the MOON cohort [11]. In 2683 patients, the risk of an ipsilateral ACL graft rupture was 4.4%, highest in the young population. The odds of an ACL graft tear significantly decreased by 0.09 for every yearly increase in age. A similar correlation between younger age and risk of ACL revision surgery is found in other studies [29–31]. Persson et al. found similar results. They reported on the revision risk following ACL-R in more than 12,000 patients. The hazard ratio for ACL revision was 4.0 for the youngest age group (15–19 years of age) compared to the oldest age group (>30 years of age) [32].

Looking into study data of the effect of graft choice in the young patient group then one study found that after 5 years follow-up, the youngest age group showed a crude revision risk of 9.5% with the use of HT graft compared to 3.5% with the use of a BPTB graft for primary ACL-R [32]. Ho et al. also showed a difference in revision rate after ACL-R depending on graft choice. In 561 patients with a mean age of 15.4 years, they found that soft tissue grafts had a failure rate of 13% compared to a failure rate of 6%, when BPTB grafts were used [33]. Similar findings were reported by the MOON group. In a young, active patient group from 14–22 years of age, they reported a 2.1 increased risk of ACL revision in the HT autograft group compared to the BPTB autograft group [25].

Smaller cohort studies have shown promising outcomes scores and revision rates after the use of Q-tendon autograft in ACL-R in young patient groups [34, 35]. There are no comparative studies addressing both age and QT graft in ACL-R.

2.8 Graft Consideration in Relation to Gender

Several papers have shown an increased relative risk in females to sustain an ACL rupture compared to males, and especially young females

have a very high risk of graft rupture after ACL-R if they return to contact and pivoting sports [36–38]. For these reasons there is a high interest in finding the best surgical treatment options for the female ACL patient. Most studies on the subject compare HT autografts to BPTB autografts and the results are controversy.

A review by Paterno et al. included 11 cohort studies. They reported increased A-P knee laxity in a HT autograft female group compared to a BPTB female group. Moreover, they indicated inferior knee laxity results after ACL-R in the female HT group compared with male patients undergoing the same procedure. No randomized controlled trials were included in the review [8]. Ryan et al. also reported on gender differences in outcomes after ACL-R. They included 13 studies, which all were level 2 studies or less. They reported a graft failure risk of 4.0% for males and 4.7% for females after ACL-R with use of a BPTB autograft. Hamstring graft failure risk was 6.4% for males and 9.2% for females. Meta-analysis found no difference in graft failure risk according to sex [1].

The most recent review regarding graft choice and gender was performed by Tan et al. [3]. The study reported on outcomes in female patients only, having ACL-R with either HT autograft or BPTB autografts. Fifteen studies were included in the review, three randomized controlled trials, and 12 prospective cohort studies. These studies included a total of 948 female patients with ACL-R. Almost half of the ACL-R were performed with BPTB autograft, the remaining with HT autograft. Meta-analysis found no difference in female patients between the two graft types at follow-up regarding knee laxity, pivot shift, graft rupture, or graft failure. Furthermore, no differences in objective or subjective outcome scores were found. The magnitude of anterior knee pain was the same in both groups. The study found a tendency to increased risk of anterior kneeling pain in the BPTB group compared to the HT group.

The QT has been used for ACL graft in both males and females. To our knowledge, no study address outcomes after ACL-R according to both QT graft and gender.

2.9 Graft Choice and Sports Activity

2.9.1 Pivoting Sports

The surgeon choice of graft in ACL-R differs according to the sport, the patient is planning to participate in or return to. Bradley et al. reported on the treatment trends in primary ACL-R among team physicians treating American football players. The majority (83%) would use BPTB autograft as the first choice ACL graft [39]. Similar numbers are reported by Ericksen et al. with 86% of the physicians favoring the BPTB graft [40]. The same group investigated the practice patterns among team physicians treating knee injuries in elite athletes competing in ice hockey, soccer, and alpine skiing. Seventy percent of the physicians favored the BPTB tendon as the primary graft choice for ACL-R, 14.9% would use a four-strand semitendinosus graft, whereas the quadriceps tendon autograft was chosen by 4.3% of the physicians [41].

The medical group guiding the international football association (FIFA) still advocates for the use of BPTB autograft in ACL-R in soccer players.

For several reasons, the BPTB autograft has been the graft of choice for cutting and pivoting sport. The properties of the BPTB graft might resemble the native ACL better compared to other graft types. Harvest of the patella tendon might result in a more favorable impairment of the muscle strength following ACL-R because of the sparing of the medial hamstring tendons, which are crucial in cutting and pivoting movements. Moreover, the BPTB graft might have a superior fixation potential and better ingrowth because of the bone-to-bone interface which could lead to a faster return to play.

As mentioned earlier in this chapter, a lot of studies compare outcomes after primary ACL-R after the use of different graft types. Papers reporting on outcome according to both graft type and specific sports are sparse. Gifstad et al. reported on data from the Scandinavian ACL registries. Almost 46,000 patients were undergoing primary ACL-R. They found a lower risk of ACL

revision with the use of a BPTB autograft compared to HT autograft if the cause of primary ACL rupture happened at soccer, team handball, or alpine skiing [9]. The paper does not address the sport activity causing new graft rupture and subsequent ACL revision. The MOON knee group reported a cohort study of 770 high school or college athletes, aged 14–22 years, who had primary ACL-R. The patients were followed for 6 years. The majority of the patients competed in pivoting sports such as basketball, American football, and soccer prior to the primary ACL tear. The MOON knee group found a 2.1 times higher risk of ACL revision surgery if a HT autograft was used compared to a BPTB autograft. As with Scandinavian registry study, the MOON study did not report the sport activity leading to graft rupture and ACL revision [25].

The use of quadriceps tendon graft has become more and more popular in primary ACL-R and the graft has performed well in comparative studies [42]. Some studies report acceptable outcomes in patient with a high pre-operative activity score [43, 44], even in an adolescent patient group [34]. To our knowledge no studies compare outcomes after use of quadriceps tendon according to specific sports activity.

2.9.2 Recreational Sports

A wide variety of grafts is used in ACL-R among recreational athletes. There is no real evidence in the literature for stating that one graft should be superior to other graft types in primary ACL reconstruction. It seems as if the use of graft for recreational athletes is based on surgeon preferences, donor site morbidity, and patient requests.

2.10 Graft Choice and Concomitant Injuries

Concomitant injuries to ACL injury such as collateral ligament, cartilage, and meniscus injuries all influence the structure and biomechanical function of the ACL insufficient knee joint. Compromised function of these structures could

therefore impact the overall knee function after ACL-R and graft choice should optimally consider and optimize knee function in relation to concomitant injuries.

Especially concomitant injury to the medial collateral ligament (MCL) which is normally treated non-surgically has raised concerns since residual valgus laxity caused by MCL deficiency increases the strain on the ACL and may jeopardize ACL graft survival [45]. Also, recent biomechanical studies have shown that the medial hamstrings are important to resist valgus forces in the MCL-deficient knee [46]. This has led to the dogma that hamstring graft should not be used in combined ACL and MCL injuries.

There is limited literature on the subject of graft choice in combined ACL and collateral ligament injuries. But one biomechanical study has demonstrated that the hamstring tendons are important valgus stabilizers in the MCL insufficient knee and therefore suggest that hamstring tendons should not be used in MCL insufficient knees [46].

The only clinical study that has investigated the issue is a registry study from Sweden that looked at revision rates in MCL injured knees when the ACL was reconstructed with either HT or BPTB grafts. The study included 622 patients with combined ACL and MCL injuries and found no difference in revision rates between HT and BPTB grafts [47].

In conclusion, there is minor clinical evidence that suggests hamstring graft usage in ACL-R in combined ACL+ MCL injured knees is safe without increased revision rates.

No studies have investigated the impact of graft choice with the presence of meniscus and cartilage injuries.

2.11 Conclusion

The graft choice for ACL-R and patient-specific factors do influence the outcome after ACL-R, but the literature in this area is not strong and mainly derived from recent registry studies that contain enough data for investigation for these factor combinations.

There are only comparative studies for hamstring and patella bone tendon bone grafts and different patient factors such as gender, age, sport types, and concomitant injuries. The key point from the literature is presented below.

Key Points

- Patella tendon graft choice results in reduced revision risk in young patients compared to hamstring graft.
- Patella tendon graft choice results in reduced revision risk in female patients compared to hamstring graft.
- Patella tendon graft choice results in reduced revision risk in athletes performing contact sport compared to hamstring graft.
- Patella tendon graft choice results in increased donor site morbidity and poorer subjective outcome compared to hamstring graft.
- Hamstring graft usage for ACL-R does not result in increased revision rates in MCL injured knees.

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Assessment of Risk Factors for Failure of ACLR: When to Address Concomitant Pathology

Gian Luigi Canata, Valentina Casale,
and Antonio Pastrone

3.1 Introduction

Tears of the anterior cruciate ligament (ACL) are one of the most common knee injuries in the active population. They are often associated with concomitant injuries, such as other ligamentous injuries, meniscal and chondral or osteochondral lesions. These concomitant afflictions may predispose patients to the development of functional instability, cartilage degeneration, and subsequent osteoarthritis within 10 to 15 years [1, 2]. ACL reconstruction (ACLR) is consequently one of the most common orthopedic procedures, with approximately 75,000 to 100,000 surgeries performed annually in the United States alone [3].

Surgical reconstruction techniques have evolved considerably over the years, although there is still no consensus on the optimal technique [4]. Nevertheless, very satisfying results of ACLR restoring functional knee stability have been frequently reported [5].

Several studies have evaluated and cited the most common risk factors for native ACL tears. Some examples are female sex, reduced activity level, participation in cutting sports, anatomic factors such as intercondylar notch width and

tibial slope, neuromuscular control, and lower extremity biomechanics [6–12]. However, there is a relative lack of scientific data analyzing risk factors for graft failures or re-tears after an ACLR [13].

The incidence of ACLR failure has been estimated at between 2% and 6% in short term (less than 5-year) follow-up [14], while longer follow-ups (5–10 years) are associated with a higher failure risk, between 3% and 10% [15, 16]. After 10 years, the incidence stabilizes within the 5-to-10-year range [17, 18].

To minimize this rate of failure, it is fundamental to identify the major risk factors, which may include poor surgical techniques, as well as a new trauma, failure of biological incorporation, the graft type used, postoperative infections, and missed concurrent knee injuries. Further risk factors may be patient-related, such as altered neuromuscular control, age, sex, or level of activity [13].

Risk factors may also be distinguished according to time to development of recurrent postoperative instability. An early instability (<6 months after surgery) is usually caused by technical errors, failure of graft incorporation, premature return to high-demand activity, or an overly aggressive rehabilitation. A later development may be a consequence of repeated trauma to the graft, poor graft placement, generalized ligamentous laxity, and concomitant abnormalities not addressed during the ACLR [19].

G. L. Canata (✉) · V. Casale · A. Pastrone
Centre of Sports Traumatology, Koelliker Hospital,
Torino, Italy
e-mail: studio@ortosport.it; canata@ortosport.it

3.2 Patient Risk Factors

3.2.1 Sex

While native ACL injuries occur more frequently in women than men, some recent studies highlight that male patients have a higher risk of revision ACLR [20, 21]. However, other authors have reported different findings [22, 23], therefore an univocal consensus is still lacking. It has been widely demonstrated that female sex is a strong predictor of native ACL injury, but this has not been reported for ACL graft tears [24–27]. A possible explanation is the lower activity level of women post-surgery [5].

Another aspect to consider regarding the sex differences in ACLR results is the graft type used and the consequent presence or absence of post-operative side-to-side difference in antero-posterior (AP) knee laxity [13]. In fact, it has been largely reported that women with hamstring tendon (HS) grafts show greater AP knee laxity than those with bone-patellar tendon-bone (BPTB) grafts [25, 28–32].

In summary, evidence for considering sex as a risk factor for ACLR failure is still lacking, mostly due to confounding factors such as activity level after surgery [13]. Nevertheless, women are usually more at risk for native ACL tears than males. This discrepancy may be explained by ACL graft being stronger than native ACL, by the patient returning to a lower level of activity after surgery, or by a neuromuscular adaptation during the postoperative rehabilitation [13].

3.2.2 Age

Younger age is the most frequently and widely reported risk factor for ACLR revision [33]. Females younger than 25 years and males aged 26 to 45 years are more likely to develop a second ACL tear [34], according to current evidence on this issue [1, 5, 20, 33–35]. Increasing age, in fact, has been demonstrated to be associated with a decreased risk of ACLR revision, regardless of the postoperative level of activity [13]. According to the Grading of Recommendations and the

Assessment and Development and Evaluation (GRADE) approach, age shows the highest quality evidence and correlation with ACLR failure: high relative risk increases with each incremental decrease in age [33].

3.2.3 Neuromuscular Factors

Recent studies have identified that biomechanical and neuromuscular factors are predictive of ACLR revision [35]. Some examples are hip internal rotation moment, altered postural stability, knee valgus, and asymmetric sagittal-plane knee moment during landing [12, 36]. Deficits of hip muscle external rotation torque are particularly correlated with ACLR failures: addressing the impaired hip strength may effectively reduce this risk [13].

3.2.4 Anatomical Abnormalities

Knee alignment plays a relevant role when approaching ACLR surgery. It is commonly known in fact that ACLR in knees with a varus thrust tends to fail secondarily, if the varus alignment is not addressed at the time of the reconstruction [37–39]. It has been highlighted that a varus alignment may cause gait abnormalities, such as decreased flexion moment, increased external adduction moment, increased external knee extension moment, and increased hyperextension during the stance phase [38, 40]. Furthermore, it has been reported how ACL deficiency increases the thrusting pattern in a pre-existing varus alignment [38].

Recently, increased posterior tibial slope (PTS) has been reported among the anatomic risk factors for ACLR failure [41]. In particular, a slope $\geq 12^\circ$ is associated with a higher risk of revision [42–44]. Several studies have suggested, in the case of an ACL-deficient knee, to decrease the PTS to normal values to avoid the risk of anterior tibial translation after ACLR [40, 45]. Normal PTS values may be considered as 9° – 11° in the medial plateau and 6° – 8° in the lateral plateau. As a further result of the PTS reduction,