Return to Sport after ACL Reconstruction and Other Knee Operations

Limiting the Risk of Reinjury and Maximizing Athletic Performance

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Preface

The numerous benefits of sports participation are well recognized, and as such, involvement in athletics has increased dramatically. The 2019 Physical Activity Council's Overview Report on United States athletic participation stated that approximately 218.5 million individuals aged 6 and over participated in some type of sports activity [1]. In 2018, the National Federation of State High School Associations reported an all-time record of nearly 8 million athletic participants, approximately 3.4 million girls and 4.6 million boys [2]. In 2018, over 480,000 athletes participated in collegiate sports [3].

Unfortunately, the negative effect of increased participation in sports in young athletes has been an upward surge in the rate of injury. For instance, recent investigations [4–6] estimated that in the United States, high school soccer knee-related injuries would occur in 259,587 girls and in 114,384 boys on a yearly basis, with ligament tears the most common diagnosis. Knee injuries are also among the most common of all injuries sustained in collegiate basketball [7]. Nearly a million anterior cruciate ligament (ACL) injuries occur each year worldwide, most of which are sustained by young athletes less than 25 years of age.

The issue of return to sport (RTS) after knee injuries, particularly ACL tears, has become a relatively recent topic of widespread research. Over a decade ago, a few reports appeared in the literature citing unacceptable reinjury rates in both the ACL-reconstructed and contralateral knee [8, 9]. These injury rates were much higher than those typically reported in registry studies (<5%) and sounded an alarm to the orthopedic community as a whole to seriously study reinjury rates as related to RTS [10–12]. We conducted a systematic review of studies published from 2001 to 2011 that determined factors used to allow RTS after ACL reconstruction and found that only 13% of 264 studies included objective criteria. All of this information highlighted the serious need to re-examine the rehabilitation of serious knee injuries and the necessity to include further quantification of restoration of normal indices before release to unrestricted athletic activities.

Our Medline searches conducted in 2019 reveal hundreds of articles that discuss wide variability in RTS rates after ACL reconstruction, lack of consensus regarding objective criteria that should be achieved before release to unrestricted activities, problems with psychological readiness and fear not usually addressed clinically, and high reinjury rates in young athletes. Issues regarding rehabilitation principles and practices, including advanced neuromuscular and motor retraining, have become critical topics for evidence-based research.

The question of what is causing the sometimes alarming rate of reinjuries (to either knee) upon RTS, even though patients appear to have normal or very good knee function restored, remains unanswered. Although we have made major advances in terms of ACL graft selection, positioning, tensioning, and fixation, the need to address associated instabilities in the knee joint, and decreasing postoperative complications, we have not yet achieved a standard of care in crucial rehabilitation factors that allow a safe RTS.

Collectively, these issues provided the impetus for the development of this textbook. We invited worldwide experts to participate and discuss their research findings in a manner that offers realistic and clinically feasible concepts for all medical personal involved in the care of athletes. While this textbook focuses many chapters on ACL injuries, other common knee injuries and operations are included, such as meniscus procedures, patellofemoral realignment, articular cartilage restoration procedures, total knee arthroplasty, and partial knee arthroplasty. Four chapters focus on examination and testing to determine knee function, neuromuscular indices, muscle strength, dynamic balance and stability, and neurocognitive factors.

An important point to highlight is the essential team approach by medical professionals that is required to successfully return the high school, collegiate, or professional athlete to competition. As discussed recently by Wang et al. [13], this team encompasses not only the orthopedic surgeon but also the physical therapist and athletic trainer who spend the majority of time with the athlete over the course of rehabilitation. The therapist and trainer are responsible for forming a relationship of trust with the patient immediately and must understand their goals, personality, potential problems with fear, and compliance. This textbook provides eight chapters dedicated to rehabilitation principles essential for the successful RTS.

There is still much work to be done to continue to advance our knowledge in this area. That being said, we hope the material in this textbook provides clinically feasible principles that medical professionals may implement immediately in their practice.

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Abbreviations

ACI	Autologous chondrocyte implantation
ACL	Anterior cruciate ligament
ACL-QoL	Anterior Cruciate Ligament-Quality of Life
ACLR	Anterior cruciate ligament reconstruction
ACL-RSI	Anterior Cruciate Ligament-Return to Sport After Injury
ACT	Acceptance and commitment therapy
ADC	Apparent diffusion coefficient
AE	Athlete exposure
AM	Anteromedial
ANAM	Automated Neuropsychological Assessment Metrics
AP	Anteroposterior
BEAR	Bridge-enhanced anterior cruciate ligament repair
BFRT	Blood flow restriction training
bFGF	Basic fibroblast growth factor
BMI	Body mass index
BMPs	Bone morphogenetic proteins
BPTB	Bone-patellar tendon-bone
BW	Body weight
CKC	Closed kinetic chain
CNS	Central nervous system
CNTs	Computerized neurocognitive tests
cm	Centimeters
CogSport/CogState	Axon Sports Computerized Cognitive Assessment Tool
COM	Center of mass
COP	Center of pressure
COWA	Controlled word association
COX	Cyclooxygenase
CPG	Clinical practice guidelines
CPM	Continuous passive motion
CT	Computed tomography
DANA	Defense Automated Neurobehavioral Assessment
dGEMRIC	Delayed gadolinium-enhanced magnetic resonance imaging
DIS	Dynamic intraligamentary stabilization
DOC	Delaware-Oslo cohort

DTI	Diffusion tensor imaging
ECM	Extracellular matrix
EEG	Electroencephalography
EMG	Electromyographic or electromyography
EMS	Electrical muscle stimulation
ER	External rotation
ES	Effect size
FA	Fractional anisotropy
FAIR	From activity to injury to rehabilitation/reintegration
FGF	Fibroblast growth factors
FTA	Functional testing algorithm
GAG	Glycosaminoglycans
EGF	Epidermal growth factors
GRF	Ground reaction force
GRFV	Ground reaction force vector
rGRFV	Resultant ground reaction force vector
GRS	Global rating score
H/Q	Hamstrings/quadriceps
HR	Hazard ratio
HSS	Hospital for Special Surgery
HT	Hamstring tendon
IC	Initial contact
ICC	Intraclass correlation coefficients
IKDC	International Knee Documentation Committee
ImPACT	Immediate Post-concussion Assessment and Cognitive Testing
IPC	Ischemic preconditioning
IR	Internal rotation or incidence rates
IR/ER	Internal rotation/external rotation
ITB	Iliotibial band
JPS	Joint position sense
KE	Knee extensor
KF	Knee flexor
KOOS	Knee Injury and Osteoarthritis Outcome
KT and KT-2000	Knee arthrometer
LEFT	Lower Extremity Functional Test
LOP	Limb occlusion pressure
LSI	Limb symmetry index
M	Meters
MACI	Matrix-induced autologous chondrocyte implantation
MAT	Meniscal allograft transplantation
min	Minutes
mo	Month
MOON	Multicenter Orthopedic Outcomes Network
MRI	Magnetic resonance imaging
ms	Milliseconds
MSCs	Mesenchymal stem cells
MSI	Musculoskeletal injuries

MUA	Manipulation under anesthesia
MVIC	Maximal volitional isometric contraction
N	Newton
NA	Not available
NAR	Norwegian Arm
NBA	National Basketball Association
NCAA	National Collegiate Athletic Association
NCACL	Noncontact anterior cruciate ligament
NFL	National Football League
NHL	National Hockey League
NIHTB-CB	National Institutes of Health Toolbox Cognition Battery
NKLR	Norwegian National Knee Ligament Registry
Nm	Newton meters
NMES	Neuromuscular electrical stimulation
NS	Not significant (statistically)
NSAIDs	Nonsteroidal anti-inflammatories
NWBE	Non-weight-bearing exercises
OA	Osteoarthritis
OAT	Osteochondral autograft transplant
OCA	Osteochondral allografts
OKC	Open kinetic chain
OPG	Osteoprotegerin
OR	Odds ratio
PA	Posteroanterior
PDGF	Platelet-derived growth factors
PDLLA	Poly-d-lactide
PEC	Parallel elastic components
PL	Posterolateral
PLLA	Poly-l-lactide
PMN	Polymorphonuclear
PRiSM	Pediatric Research in Sports Medicine
PRP	Platelet-rich plasma
PT	Patellar tendon
PTBML	Post-traumatic bone marrow lesions
PTOA	Post-traumatic osteoarthritis
QI	Quadriceps index
QOL	Quality of life
QT-PB	Quadriceps tendon-patellar bone
RCT	Randomized controlled trial
RFD	Rate of force development
RM	Repetition max
RR	Relative risk
ROM	Range of motion
RTS	Return to sport
s	Seconds
SEC	Series elastic components
SSC	Stretch-shortening cycle

SMCL	Superficial medial collateral ligament
StARRT	Strategic Assessment of Risk and Risk Tolerance
STG	Semitendinosus-gracilis
STIR	Short tau inversion recovery
T (as in 3-T)	Tesla
TGF	Transforming growth factors
TIMPs	Tissue inhibitors of metalloproteinases
TKA	Total knee arthroplasty
TMS	Transcranial magnetic stimulation
TSK	Tampa Scale for Kinesiophobia
US	United States
UTE	Ultrashort echo time
vGRF	Vertical ground reaction force
VLO	Vastus lateralis obliquus
VMO	Vastus medialis oblique
VO_2max	Maximal oxygen uptake
WB	Weight bearing
wk	Week
x	Times
yr	Year
3-D	Three dimensional
2-D	Two dimensional

Part I

Problems and Barriers for Successful Return to Sport

1 Advantages and Potential Consequences of Return to Sport After ACL Reconstruction: Quality of Life, Reinjury Rates, and Knee Osteoarthritis

Frank R. Noyes and Sue Barber-Westin

1.1 Introduction

The majority of patients who undergo anterior cruciate ligament (ACL) reconstruction are athletes <25 years of age [1]. While there are several major goals of surgery, returning these individuals to their desired sport is paramount for patient satisfaction [2–8] and is the main motivating factor for patients to undergo surgery and months of rehabilitation. Physicians and others involved with patient care often believe return to sports (RTS) is one of the most important outcome criteria after ACL reconstruction [9]. The ultimate RTS goals vary widely and include returning professional athletes back to their careers, allowing collegiate athletes to receive scholarships, providing high school athletes a chance to play additional seasons, and returning recreational athletes back to their desired active lifestyle. Although historic rates of RTS have been acceptable, this topic has come under increased scrutiny due to high reinjury rates recently reported (to the ACL in either knee) upon return to athletics after surgery [10].

In addition to reinjury rates, several barriers that prevent or delay full RTS have recently come under rigorous investigation. These include fear, anxiety, depression, preoperative stress, motivation, self-esteem, locus of control, and self-efficacy [3, 7, 11–26]. Persistent knee symptoms of pain, swelling, stiffness, and instability may also hamper the expected progress of rehabilitation and negatively affect the time to RTS [18, 27–29].

Even though many studies have reported significant correlations of return to high-risk sports with ACL reinjuries, few have documented the results of rehabilitation in terms of restoration of normal muscle strength, balance, proprioception, and other neuromuscular indices required for return to high-risk activities that require pivoting, cutting, and jumping/landing. In addition, several studies have shown that changes in neurocognitive function and cortical activity occur after ACL injury and reconstruction [30–37]. The question of whether modern rehabilitation programs effectively resolve these impairments remains to be answered [38, 39]. Therefore, reinjuries may not be due simply to participation in high-risk activities; failure to restore multiple indices to normal (in both knees) may be one major source of this problem, and this will be explored later in this textbook.

The question of what factors play a role in the development of knee osteoarthritis (OA) after ACL reconstruction remains under study, with the exception of meniscectomy. Nearly every long-term study has reported a statistically significant correlation between meniscectomy (per-

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formed either concurrently or after the ACL reconstruction) and moderate-to-severe radiographic evidence of OA [40–48]. Other factors that may influence the development of knee joint OA include preexisting chondral damage, severe bone bruising, biochemical alterations after the injury, older patient age, elevated body mass index (BMI), excessive uncorrected varus or valgus lower limb malalignment, damage of other knee ligaments, failure of the reconstruction to restore knee stability, serious complications (such as infection, arthrofibrosis), and poor quadriceps strength [47, 49–54]. Whether return to high-impact sports after ACL reconstruction increases the rate of development of knee OA is unknown at present. Regardless of the cause, the development of symptomatic OA is especially concerning in young athletic individuals, in whom rates of total knee arthroplasty (TKA) continue to rise rapidly. In 2013, Weinstein et al. [55] estimated that over 1.5 million individuals aged 50–69 years had undergone TKA in the USA, tripling the number compared with the proceeding decade. With TKA survival rates of 20 years, many younger individuals may require a revision arthroplasty.

1.2 Quality of Life and Patient Satisfaction: Correlation with Return to Sport

One major goal of ACL reconstruction is to return patients to their desired sports activity level. Interestingly, a review published in 2015 found that, in 119 ACL-reconstruction studies, only 24% provided return to preinjury sports activity data [56]. The authors recommended enhanced reporting of these data due to the high level of relevance of RTS for both patients and clinicians. In the same year, a survey of 1779 orthopedic medical professionals reported a consensus of six measures believed important for successful outcome 2 years after ACL reconstruction [9]. These measures included no giving-way (indicated by 96.4% of respondents), RTS as indicated by playing 2 seasons at the preinjury level (92.4%), quadriceps strength symmetry >90% (90.3%), absence of joint effusion (84.1%), patient-reported outcomes (83.2%), and hamstrings strength symmetry >90% (83.1%).

Ardern et al. [2] questioned whether satisfaction of knee function according to the *patient* was associated with different measures, including psychological factors and personal opinion of knee function. These authors followed 177 ACL-reconstructed patients a mean of 3 years postoperatively, of whom 44% were satisfied with their outcome, 28% mostly satisfied, and 28% dissatisfied. There was a significantly greater percentage of patients in the satisfied group that returned to their preinjury sports level compared with the other groups (61%, 29%, and 22%, respectively, $P < 0.0001$). Participants who had returned to their preinjury activity level had 3 times increased odds of being satisfied (versus mostly satisfied or dissatisfied). The other two significant associations with satisfaction were knee-related self-efficacy and quality of life (QOL).

Another study performed a cross-sectional comparison of patients who underwent either operative or conservative treatment for acute ACL ruptures [57]. At 1 year post-injury or postoperative, 350 ACL-deficient knees and 350 ACL-reconstructed knees completed the Knee Injury and Osteoarthritis Outcome Score (KOOS). The ACL-reconstructed group had higher scores for pain, activities of daily living, sports, and quality of life 1 year postoperatively (Table 1.1). The authors concluded that patients who elected ACL reconstruction had superior

Table 1.1 KOOS scores in ACL-deficient and ACL-reconstructed knees at 1 year

KOOS domain	ACL-deficient	ACL-reconstructed	Mean difference (*P* value)
Symptoms	73.7 ± 18.4	76.3 ± 18.5	2.6 (NS)
Pain	80.5 ± 16.7	84.5 ± 16.3	4.0 (<0.05)
Activities of daily living	88.0 ± 15.1	91.3 ± 14.0	3.4 (<0.05)
Sport	54.5 ± 29.8	66.9 ± 26.6	12.4 (<0.05)
Quality of life	47.1 ± 24.3	60.3 ± 23.5	13.2 (<0.05)

KOOS knee injury and osteoarthritis outcome score, *NS* not significant outcomes for knee symptoms, function, and quality of life that remained for at least 5 years postoperatively.

Filbay et al. [4] studied QOL and psychological health outcomes in 162 patients who had residual knee pain, symptoms, or functional limitations a mean of 9 years (range, 5–20) postoperative. These investigators found that RTS was related to better knee-related KOOS and general health-related QOL (AQoL-8D) scores. In this study, 39% returned to competitive sports, 28% returned at a lower level of competition, and 32% did not return. When asked what activities they would consider most important to participate in (in the absence of knee pain), 80% of the patients indicated sports or exercise; 14%, family duties; 4%, social activities; and 2%, work duties. This high rate of patients that preferred sports/exercise over all other activities indicates the high priority athletics had in this cohort many years following their ACL injury and surgery.

Nwachukwu et al. [7] surveyed 231 patients a mean of 3.7 years following ACL reconstruction and reported that 87% had RTS and 85.4% were very satisfied with the outcome of the operation. A significantly greater number of patients who RTS were very satisfied with their outcome compared with those who did not return ($P < 0.001$). It is important to note that only 43.6% of the athletes played with unlimited effort and performance and no pain. The use of a patellar tendon autograft was associated with a significantly increased odds of returning to play compared with use of an allograft (odds ratio [OR] = 5.6; $P = 0.02$).

Faltstrom et al. [17] conducted a short-term study (mean follow-up, 1.5 years) in 182 female soccer players who underwent ACL STG autograft reconstruction. The survey study found that 52% were currently playing soccer, 80% at the same or higher preinjury level and 20% at a lower level. Players that returned had significantly higher scores compared with those who had not returned on all KOOS subscales and the ACL-Quality of Life scale. In addition, psychological readiness and motivation to return to sport correlated with return to preinjury levels. The negative effects of fear of reinjury and poor motivation on RTS are further discussed in Chap. 2.

Kocher et al. [5] followed a cohort of 201 patients whose mean age was 28.6 years (range, 14.4–60) an average of 3 years after primary ACL reconstruction. Patients were found to be significantly less satisfied with the outcome of surgery if they had a lower level of sports activity ($P < 0.001$) and if they had difficulty with specific athletic functions such as running, jumping, cutting, and twisting ($P < 0.001$). In this study, 75 patients (37%) were participating in sports with no limitations.

1.3 Reinjury Rates After ACL Reconstruction

The published rates of either reinjuring an ACL-reconstructed knee or sustaining an ACL rupture on the contralateral knee vary widely (Table 1.2) [58–83]. One problem is the definition of ACL failure; some studies consider only those knees that required ACL revision reconstruction (or reconstruction of the contralateral ACL) as failures, while others include knees in which a pivot shift grade 2–3 and/or Lachman grade 2–3 is detected clinically. Large registry studies or those that involved meta-analyzed data typically only used the number of ACL revision cases to calculate failure rates [65, 69, 76, 79, 81, 84]. There are many potential causes of ACL graft failure other than reinjuries that have been discussed in detail elsewhere [85–90]. The reinjury and failure rate data in Table 1.2 should therefore be interpreted cautiously.

Many studies have cited that the most frequent factors that appear to cause graft failure or injury to the contralateral ACL are younger patient age, return to cutting/pivoting sports, and use of an allograft. In a meta-analysis of data from 19 studies, Wiggins et al. [62] reported, in athletes <25 years of age who returned to high-risk sports, a pooled secondary ACL injury rate (to either knee) of 23%. In a group of 1415 patients who underwent ACL autograft reconstruction, Shelbourne et al. [60] reported the risk of subsequent injury to either knee was 17% for patients

Table 1.2 Rates of reinjury in ACL-reconstructed and contralateral knees

Study	Mean follow-up years	ACL graft[a] (no.)	Failed ACL reconstruction[b] (%)	Injured ACL contralateral knee (%)	Reinjuries associated with sports?	Factors associated with reinjuries, ACL graft failures
Salmon [58]	20	Hamstring adolescents (39)	38	13	Yes, nearly all associated with sports for both ipsilateral and contralateral	Age <18 years, posterior tibial slope ≥12° for ACL-reconstructed knee Posterior tibial slope ≥12° for contralateral knee
		Hamstring adults (161)	14	11		
		Total (200)	18.5	11		
Morgan [59]	16.6	Hamstring (194)	19.5	17.5	Yes, cutting, pivoting sports for contralateral knee reinjuries	Family history ACL injury for ACL-reconstructed knee Male gender for contralateral knee
		BPTB (48)	8	29		
		Total (242)	17	20		
Shelbourne [60]	5	BPTB (1,415)	4	5	Yes, participation in basketball or soccer for injuries to either knee.	Age <18 years, female gender for ACL-reconstructed knee Age <18 years, female gender <18 years for contralateral knee
Takazawa [61]	4.7	ST and Telos artificial ligament	16	7	All rugby players	Age <20 years for ACL-reconstructed knee
Wiggins [62]	4.2	9098 <25 years age	10	11	Yes, return to cutting, pivoting sports	Age <25 years for both knees
		913 <25 years age, returned high-risk sports	10	12		
		Total 72,054	7	8		
Grindem [63]	2	BPTB (33), hamstring (67)	Overall 8	Overall 2	Yes, return level I sports 4.32 times higher reinjury rate than other sport levels	Quadriceps strength deficit for ACL-reconstructed knee
Webster [64]	3	Hamstring (561)	4.5	7.5	Yes, return to cutting, pivoting sports for either knee	Age <20 years, contact mechanism for injury, family history for ACL-reconstructed knee. Age <20 years, family history for contralateral knee
Kaeding [65]	2	BPTB (1131)	3.2	NA	Yes, higher preinjury activity levels for reinjuries to either knee	Allografts for ACL-reconstructed knee Younger age for both knees
		Hamstring (891)	4.6	NA		
		Allograft (466)	6.9	NA		
		Total (2488)	4.4	3.5		
Kyritsis [66]	NA	BPTB (50)	14	Overall 7	Yes, all pro athletes	Low H:Q ratio 60°/s, athletes did not meet discharge criteria for ACL-reconstructed knee
		Hamstring (108)	17.5			

Table 1.2 (continued)

Study	Mean follow-up years	ACL graft[a] (no.)	Failed ACL reconstruction[b] (%)	Injured ACL contralateral knee (%)	Reinjuries associated with sports?	Factors associated with reinjuries, ACL graft failures
Kamath [67]	NA	Graft NA, $N = 89$	9	15	All collegiate athletes	Athletes that had ACL reconstruction before entering college had higher incidence of graft failure and contralateral ACL tears
Lefevre [68]	1	Hamstring primary (468), BPTB primary (27), hamstring revision (18), BPTB revision (29)	Overall 1.4	Overall 0	Yes, all reinjuries (7 in primary group, 1 in revision group) during sports	None
Faltstrom [69]	5	Hamstring (20,824)	4.3	3.8	Yes for soccer	Age <16 years, age 16–25, surgery <90 days from injury, injured playing soccer for either knee
Ardern [70]	2	Hamstring (122)	4	2	Yes	Not assessed
Myklebust [71]	7.8	Various grafts	22	9	Yes, all while playing team handball	Not assessed
Mohtadi [72]	2	BPTB (110)	17	5	Not significantly related to sports	Age <27 years for ACL-reconstructed knee
		Hamstring (110)	26	5		
		Double bundle (110)	28	5		
Park [73]	4.5	Hamstring (296)	4	NA	Not related to sports	Grafts <8 mm in diameter.
Thompson [74]	20	BPTB (90)	10	30	Not assessed	Male gender, age ≤18 years, tunnel placement for ACL-reconstructed knee Age ≤18 years, BTB graft for contralateral knee
		Hamstring (90)	18	14		
Pinczewski [75]	10	BPTB (90)	8	22	Not assessed	Laxity for ACL-reconstructed knee Age <21 years, BPTB graft for contralateral knee
		Hamstring (90)	13	10		
Hettrich [76]	6	BPTB (469)	4.1	NA	Not assessed	Allografts, younger age
		Hamstring (343)	6.1	NA		
		Allograft (168)	21.2	NA		
		Total (980)	7.7	6.4		

(continued)

Table 1.2 (continued)

Study	Mean follow-up years	ACL graft[a] (no.)	Failed ACL reconstruction[b] (%)	Injured ACL contralateral knee (%)	Reinjuries associated with sports?	Factors associated with reinjuries, ACL graft failures
Schlumberger [77]	5	Hamstring (2467)	3	3	Not assessed	Male gender, age <25 years for ACL-reconstructed knee
Webster and Feller [78]	5	Hamstring (316) All <20 yrs age	18	18	Not assessed	Male gender, male age <18 years for ACL-reconstructed knee
Persson [79]	4	BPTB (3428)	2	NA	Not assessed	STG autograft, younger age
		Hamstring (9215)	5.1	NA		
		Total (12643)	4.2	NA		
Kamien [80]	>2	Hamstring (98)	15	NA	Not assessed	Age ≤25 years
Maletis [81]	2.4	BPTB (4231)	1.9	1.9	Not assessed	Allograft or STG autograft, male gender, younger age, BMI ≥25 for ACL-reconstructed knee Female gender, younger age, BPTB autograft for contralateral knee
		Hamstring (5338)	2.4	1.8		
		Allograft (7116)	2.8	1.5		
		Total (16,685)	2.5	1.9		
Leys [82]	15	BPTB (90)	8	26	Not assessed	Male gender, non-ideal tunnel position for ACL-reconstructed knee Age <18 years, BPTB graft for contralateral knee
		Hamstring (90)	17	12		

ACL anterior cruciate ligament, *BPTB* bone-patellar tendon-bone, *HR* hazards ratio, *ST* semitendinosus
[a]Autograft unless otherwise indicated
[b]Fully positive pivot shift and/or Lachman tests, Grade C or D International Knee Documentation Committee ligament grade, >5 mm on knee arthrometer testing, or required ACL revision

<18 years of age compared with 7% for patients 18–25 years and 4% for patients >25 years. These authors attributed the reinjuries to the high-risk sports patients had returned to, with basketball and soccer accounting for 67% of the reinjuries. Andernord et al. [84] reported data on 16,930 patients from the Swedish National Knee Ligament Register and found in both males and females a significantly increased twofold risk of revision surgery with ages 13–19 years ($P < 0.001$). In a separate study, Andernord et al. [91] reported a significantly increased twofold to threefold risk of contralateral ACL reconstruction in patients less than 20 years of age ($P < 0.001$).

Dekker et al. [83] followed 85 patients who were <18 years of age at the time of ACL autograft reconstruction a mean of 4 years postoperatively. A majority (91%) returned to sports activities; however, 32% suffered a subsequent ACL tear (19% ipsilateral graft tear, 13% contralateral ACL tear, and 1% both knees) a mean of 2.2 years postoperatively. The only significant risk factor associated with reinjury was earlier return to sport ($P < 0.05$). Longer times before returning to athletics were protective against a second ACL injury (hazard ratio per month, 0.87 for each 1-month increase).

Faltstrom et al. [92] followed 117 female soccer players (mean age, 19.9 ± 2.5 years) a mean of 2 years after primary ACL reconstruction and compared reinjury rates, proportion of players who stopped playing soccer, and patient satisfaction with a matched group of uninjured players. The ACL-reconstructed group had nearly a fivefold higher rate of new ACL injuries (29 versus 8, rate ratio 4.82, $P < 0.001$), a higher rate of players who stopped playing soccer (62% versus 36%, $P = 0.001$), and a lower satisfaction rate (47% versus 87%).

Several investigations have reported discouraging percentages of athletes who RTS even though muscle strength and neuromuscular function appeared to be restored to normal levels [28, 29, 93–96]. A meta-analysis of 69 articles involving 7556 athletes reported that only 65% returned to their preinjury sports level and 55% returned to competitive sports [94]. Factors associated with RTS included symmetrical hopping performance, younger age, male gender, playing elite sports, and having a positive attitude. A study of 205 soccer players reported that only 54% returned to the sport a mean of 3.2 years postoperatively [29]. Of those that returned, 39% experienced pain, 43% had stiffness, and 42% reported instability during or after physical activity. Male gender, no cartilage injury, and no pain during physical activity were associated with greater odds of RTS. An investigation of 99 athletes reported that although 92% returned to sports, only 51% returned to their preinjury level [23]. Factors associated with RTS in this study included female gender and higher scores on the International Knee Documentation Committee (IKDC) Subjective Knee scale and the Lysholm scale. Rosso et al. [28] reported that, although 90% of 161 patients RTS after primary ACL reconstruction, only 58% did so at the preinjury level. The main reasons for not returning were knee symptoms (37%), personal reasons (30%), or both (29%).

A meta-analysis that assessed RTS and reinjury rates of 1008 children and adolescents (aged 6–19) from 19 studies reported a pooled return to preinjury activity level in 79% (range, 41–100%) [97]. ACL reinjury rates were provided for 717 patients, 13% of whom sustained ACL graft ruptures. Contralateral ACL rupture rates were provided for 652 knees, 14% of whom sustained injuries. Ten of the studies reported that the majority of injuries occurred during sports activities.

Critical Points

- Long-term failure rates vary widely (2–32%).
- Factors correlated with ACL graft failure: younger age, high sports activity level, vertical graft angle, and use of a small STG autograft or allograft.
- Contralateral ACL at risk for rupture, higher than ACL graft in some studies.

1.4 Factors Involved in the Development of Knee Osteoarthritis After ACL Surgery

Long-term clinical studies documenting radiographic OA after ACL reconstruction show high variability in the percent of knees that develop moderate or severe joint damage (Table 1.3) [40, 41, 45–48, 75, 99–101, 103–106, 108, 110–114]. These studies most frequently used weight-bearing anteroposterior (AP) and posteroanterior radiographs (Fig. 1.1), as well as lateral and Merchant, to determine the presence and severity of OA, although a few used MRI [110, 111, 114, 116, 117] or computed tomography [118]. The two most commonly used radiographic rating systems to classify OA are the Kellgren-Lawrence (K-L) [119] and the IKDC system [120]. It is also important to note that few investigators have determined if OA is accompanied by pain, swelling, and impaired knee function. The longest clinical studies published to date have followed patients for 16–24.5 years postoperatively [102, 121–123]. As investigations obtain longer follow-up periods, one may speculate that the OA findings will become more severe and correlate

Table 1.3 Prevalence of radiographic osteoarthritis in long-term ACL reconstruction studies

Study	No. of patients	Mean follow-up year	ACL graft[a] (failure rate[b])	OA KL grade 2–3 IKDC grade abnormal, severely abnormal	OA related to sports or activity level resumed postoperatively?	Statistically significant risk factors for OA unrelated to sports
Shelbourne [98]	423	22.5	BPTB (1%)	29%	Unknown	Lack of normal knee flexion or extension, medial meniscectomy, older age
Gerhard [45]	63	16	BPTB (3%)	23%	Unknown	Meniscectomy
Oiestad [99]	181	12.3	BPTB (8%)	26%	Unknown	Increased age, poor quadriceps strength
Holm [100]	53	11.8	BPTB (21%)	80%	Unknown	Meniscectomy, chronicity of injury
Ahn [40]	117	10.3	BPTB (9%)	31%	Unknown	Partial meniscectomy and sagittal tibial tunnel position in medial compartment, BMI in lateral compartment
Murray [101]	83	13	BPTB (17%)	40%	Unknown	Meniscectomy, pre-existing chondral damage
Shelbourne and Gray [48]	502	14.1	BPTB (1%)	23% in patients with bilateral meniscectomies 4% in patients with intact menisci	Hypothesized	Meniscectomy, preexisting chondral damage
Pernin [102]	100	24.5	BPT + iliotibial band extra-articular procedure (20%)	54%	Unknown	Meniscectomy, preexisting chondral damage, time to surgery, higher age at injury and surgery
Inderhaug [103]	83	10.2	Hamstring (20%)	8%	Unknown	Meniscectomy
Salmon [58]	200	20	Hamstring (18.5%)	17%	Unknown	NA
Struewer [104]	52	10.2	Hamstring (3%)	25%	Unknown	Increased anterior tibial displacement
Streich [105]	40	10	Hamstring (8%)	7%	Unknown	Positive pivot shift, high BMI
Janssen [106]	88	10	Hamstring (NA)	54%	Unknown	Medial meniscectomy, age ≥30 years, preexisting chondral damage
Thompson [74]	180	20	BPTB (10%) Hamstring (18%)	BPTB 20% Hamstring 13%	Unknown	Graft type (BPTB), further surgery
Bjornsson [107]	147	16	BPTB (7%) Hamstring (8%)	BPTB 49% Hamstring 41%	Unknown	NA

Table 1.3 (continued)

Study	No. of patients	Mean follow-up year	ACL graft[a] (failure rate[b])	OA KL grade 2–3 IKDC grade abnormal, severely abnormal	OA related to sports or activity level resumed postoperatively?	Statistically significant risk factors for OA unrelated to sports
Sanders [108]	600	13.7	BPTB, hamstring, or allograft (NA)	8.5%	Unknown	Age >21 at injury, meniscectomy, preexisting chondral damage, use of allograft
Cantin [42]	589	11.9	BPTB (NA) Hamstring (NA)	Overall 19%	Unknown	Age >34 at injury, residual laxity (IKDC grade C or D), meniscectomy
Barenius [41]	134	14	BPTB (4%) ST (5%)	BPTB 55% ST 70%	Manual labor	Meniscectomy, age at follow-up, BMI ≥ 25 kg/m², positive pivot shift
Ferretti [109]	140	10.5	Hamstring isolated (14%) or combined with EA (0%)	Hamstring 18% Hamstring + EA 14%	Unknown	Meniscectomy for STG isolated group only

AP anteroposterior, *auto* autograft, *BMI* body mass index, *BPTB* bone-tendon-bone, *EA* extra-articular, *IKDC* Internal Knee Documentation Committee, *KL* Kellgren-Lawrence, *NA* not available, *OA* osteoarthritis, *ST* semitendinosus
[a]Autografts unless otherwise indicated
[b]ACL failure rate: graft rupture, knee arthrometer >5 mm, or pivot shift grade 2–3

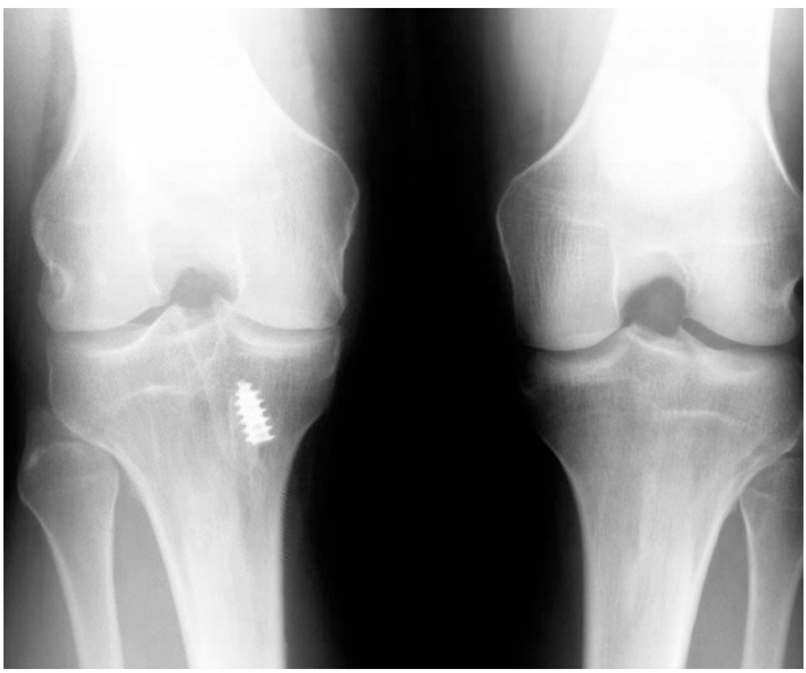

Fig. 1.1 Standing radiographs of a patient 14 years after a right ACL reconstruction and subsequent medial meniscectomy. The pivot-shift test was negative, indicating a stable reconstruction. However, narrowing to the medial tibiofemoral compartment is evident and the patient demonstrated 2° of varus alignment (Reprinted from Noyes and Barber-Westin [115])

with clinical symptoms such as loss of extension and swelling with daily activities.

Studies have shown that, regardless of the outcome of ACL reconstruction in terms of restoration of knee stability, meniscectomy accelerates degenerative joint changes [40, 41, 45–48, 124, 125]. Claes et al. [43] systematically reviewed 16 long-term ACL reconstruction studies (follow-up range, 10–24.5 years) involving 1554 subjects. The investigators reported that the estimate for the prevalence of moderate to severe OA (IKDC ratings of C or D) for all patients was 27.9%. The prevalence of OA was 16.4% in patients with isolated ACL injuries and 50.4% in patients with concurrent meniscectomy (OR 3.54).

Barenius et al. [41] followed 164 patients a mean of 14 years after ACL reconstruction and reported symptomatic OA (K-L grade ≥2) in 57% of ACL-reconstructed knees compared with 18% of contralateral knees. Statistically significant risk factors for medial tibiofemoral OA were BMI ≥25 kg/m^2 at follow-up (OR 3.3), manual labor (OR 3.2), positive pivot shift at 2-year follow-up (OR 2.5), and medial meniscectomy (OR 4.2). Statistically significant risk factors for lateral tibiofemoral OA were lateral meniscectomy (OR 5.1) and use of a B-PT-B autograft (OR 2.3). Statistically significant risk factors for patellofemoral OA were BMI ≥25 kg/m^2 at follow-up (OR 3.5) and medial meniscectomy (OR 2.3). There was no significant difference in the prevalence of OA between the two graft types.

We conducted a systematic review of the treatment of meniscus tears during ACL reconstruction of studies published from 2001 to 2011 [126]. Data on 11,711 meniscus tears (in 19,531 patients) from 159 studies showed that 65% were treated by meniscectomy; 26%, by repair; and 9%, by no treatment. This was concerning because many meniscus tears can be successfully treated by repair, thereby salvaging this important structure.

It is important to note that there are many factors other than meniscectomy that may influence the development of knee joint OA, including preexisting chondral damage, severe bone bruising, biochemical alterations in the knee joint after the injury, older patient age, elevated BMI, failure of the reconstruction to restore normal AP displacement, complications (such as infection, arthrofibrosis), and poor quadriceps strength [47, 49–54]. In many studies, these variables are not controlled for, making reaching conclusions on these factors difficult.

Occult injuries to the bone, commonly referred to as bone bruises, occur with ACL ruptures in 80–100% of knees (Fig. 1.2) [127–133]. Occult osteochondral lesions vary, and therefore, the relationship between the presence of these injuries with ACL ruptures and subsequent OA remains unclear. Several studies have reported that bone bruises resolve with time [110, 132, 134]. Conversely, Frobell [134] followed 61 consecutive patients who had acute ACL injuries with MRI within 4 weeks of the injury and then 2 years later. Subjects were treated either with early ACL reconstruction (34 subjects), delayed ACL reconstruction (11 subjects), or rehabilitation alone (16 subjects). Posttraumatic bone marrow lesions noted in the lateral tibiofemoral compartment resolved in 57 of 61 knees by 2 years after the ACL injury. However, new lesions developed in the lateral tibiofemoral joint for unknown reasons in one-third of the population, and significant thinning of the cartilage in the trochlea was noted that was not detected during the baseline MRI. Evidence does exist that the most severe injuries are associated with future

Fig. 1.2 Bone bruise on MRI following rupture of the ACL

cartilage degeneration, and they therefore should be considered part of the sequela of post-traumatic OA.

A few studies that longitudinally followed patients with acute ACL ruptures for several years demonstrated a strong potential for joint deterioration [54, 131, 134]. For instance Potter et al. prospectively followed 40 patients who underwent baseline MRI within 8 weeks of the injury and again 7–11 years later [131]. The MRI evaluation used a cartilage-sensitive, pulse sequence evaluation with T2 techniques which have shown increased ability to detect traumatic chondral injuries. None of the patients had concurrent damage to the menisci or other knee ligaments or an articular cartilage lesion rated as Outerbridge grade 3 or higher. ACL reconstruction was performed in 28 patients, while no surgery was done in 14. At baseline, all knees had an MRI-detectable cartilage injury, most severely over the lateral tibial plateau. Regardless of surgical intervention, by 7–11 years after injury, the risk of cartilage damage as viewed on MRI for the lateral femoral condyle was 50 times that of baseline, 30 times for the patella, and 18 times for the medial femoral condyle. The nonsurgical group had a significantly higher OR effect of cartilage loss over the medial tibial plateau compared with the surgical group.

ACL ruptures create biochemical alterations in the knee joint which many investigators hypothesize play a major role in the development of OA [135–150]. The sequence of events begins immediately after the injury and continues for years thereafter (Table 1.4) [135, 136, 149]. The injury causes collagen rupture, joint hemarthrosis, subchondral bone edema, elevated glycosaminoglycan (GAG) levels, and cell necrosis. In the ensuing months, the inflammatory process (indicated by elevated levels of several cytokine mediators such as IL-1β, IL-6, and tumor necrosis factor α [TNFα]), decrease in lubricin concentrations, release of enzymes, production of metalloproteinase (MMP), degradation of the extracellular matrix and proteoglycans, chondrocyte apoptosis, and cell death all contribute to articular cartilage deterioration.

Table 1.4 Pathogenesis of posttraumatic articular cartilage deterioration after ACL injury

Initial effects of ACL injury • Rupture of collagen • Separation of cartilage from subchondral bone • Edema of subchondral bone (bone bruise) • Hemarthrosis (intraarticular joint bleeding) • Elevated levels of GAG • Cell necrosis
Sub-acute (months) • Increased levels of inflammatory cytokines mediators, including IL-1β, IL-6, TNFα • Release of enzymes and production of MMP, including MMP-1, MMP-3, MMP-13 • Release of cartilage proteoglycan fragments, type II collagen • Decreased levels of lubricin (lubricants) • Degradation of proteoglycans • Chondrocyte apoptosis (death)
Chronic (years) • Elevated levels TNFα • Joint tissue remodelling • Articular cartilage deterioration, loss

GAG glycosaminoglycan, *MMP* metalloproteinase, *TNFα* tumor necrosis factor α
Reprinted from Noyes and Barber-Westin [151]

Our analysis of current long-term studies provided no answer regarding the potential deleterious effect of returning to high athletic activity levels on subsequent risk of symptomatic OA. One may hypothesize that knees with intact menisci and no other ligament damage (that do not sustain reinjuries) will have no statistically significant increased risk for symptomatic OA compared with matched controls. The need to preserve meniscal function remains paramount for the long-term welfare of the joint, and we have long advocated meniscal repair for tears in the red/red (periphery) and red/white (central) regions (Fig. 1.3) [152–156]. Complex tears are evaluated on an individual basis for repair potential (Fig. 1.4). The indications and contraindications for meniscus repair procedures have been discussed in detail elsewhere [153]. Our long-term study (10–22 years) of single longitudinal meniscus repairs that extended into the central region in patients ≤20 years of age showed the potential longevity of this procedure [155]. Twenty-nine repairs were evaluated; 18 by follow-up arthroscopy, 19 by clinical evaluation, 17 by MRI, and 22 by weight-bearing pos-