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Current Concepts Review

Revision ACL reconstruction in female athletes: current concepts

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ABSTRACT

The challenge of revision anterior cruciate ligament (ACL) reconstruction lies in its complexity, varied presentation, and technical intricacies. A successful ACL reconstruction should allow patients to safely return to pre-injury activities. However, it is only sometimes simple, and many risk factors and concurrent pathologies come into play. Evaluating and analysing the cause of failure and associated conditions is paramount to addressing them effectively. Despite a plethora of research and improvements in knowledge and technology, e gaps exist in issues such as optimal techniques of revision surgery, graft options, fixation, concurrent procedures, rehabilitation and protocol for return to sports of high-level athletes. Female athletes need additional focus since they are at higher risk of re-injury, suboptimal clinical outcomes, and lower rates of return to sport following revision reconstruction. Our understanding about injury prevention and the protection of ACL grafts in female athletes needs to be improved. This review focuses on the current state of revision ACL surgery in female athletes and provides recommendations and future directions for optimising outcomes in this high-risk group.

Current Concepts

- The incidence of anterior cruciate ligament reconstruction is rising and therefore the number of revision ACL reconstruction surgeries has also increased.
- The primary goal of revision ACL reconstruction is to restore knee stability and maximise function allowing patients to return to preinjury activities with no or minimal disability.
- Revision ACL reconstruction is challenging; therefore, a comprehensive knowledge of graft options and fixation methods is necessary to optimise success.
- Greater attention should be given to female athletes due to their higher risk of re-tear after an ACL reconstruction.

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Future Perspectives

- Precise evaluation and analysis of the cause of ACL graft failure including associated comorbidities.
- The superiority of any particular graft type and fixation method has yet to be determined.
- Rehabilitation protocols and return to sport guidelines have yet to be optimised to ensure safe return to sport and prevention of further injury.
- The routine addition of lateral extra-articular procedures in all elite female athletes undergoing revision ACLR requires further research.

INTRODUCTION

The primary goal of anterior cruciate ligament reconstruction (ACLR) is to provide anteroposterior and rotational stability to the tibiofemoral joint. The importance of re-establishing rotational stability of the knee must be emphasised; as it correlates with functional outcomes, return to sport, patient satisfaction, and reducing the development of osteoarthritis [1]. With a growing number of ACLR surgeries performed worldwide combined with an increasing frequency of athletic pursuits, there has been an increased burden of revision surgery for recurrent patholaxity after failed ACLR [2,3]. The complexity of anatomic and technical factors unique to each patient makes decision-making for ACL revision surgery challenging. The outcomes of revision ACLR are generally inferior compared to primary ACLR, with a higher risk of graft failure, poorer patient-reported function, and rates of return to preinjury activity [2,4–8]. For elite-level athletes, the available evidence reports as many as 40% of athletes to be unable to return to the same level of sport or activity after an ACL revision procedure. Younger female athletes returning to pivoting sport, demonstrate a high frequency of subsequent ACL graft injury ranging from 8% to 42% [1], Finally, after a revision ACLR, there is a substantial risk (19%) of further injury leading to a re-revision ACLR [1,6].

Revision ACLR aims to restore knee stability and maximise function, allowing patients to return to preinjury activities with no or minimal disability. Female athletes constitute a unique subgroup because of the anatomic, kinematic and biomechanical factors predisposing them to a higher risk of anterior cruciate ligament (ACL) injury. The purported risk of inferior outcomes and a lower rate of return to sport in females compared to male counterparts following ACLR is disquieting [9,10]; however, no conclusive evidence is yet supporting this claim. More research needs to be done on prevention, injury mechanisms, rehabilitation, patient-reported outcomes and return to sport in high-level female athletes. Furthermore, there is minimal research specifically regarding the failed ACLR and results of revision ACLR in female athletes. This article provides an overview of the relevant issues regarding the revision of ACLR with a specific focus on female athletes. It examines the current practices, explores strategies for ACL injury prevention in athletes and offers insights into future perspectives.

THE ACL AND SEX DIFFERENCE

ACL injury risk is 2–8 times higher in women than men. Several factors contribute to women being more susceptible to an ACL tear, such as a smaller ACL with lower tensile linear stiffness, an increased posterior tibial slope, a narrow femoral notch width, a larger quadriceps angle, decreased neuromuscular coordination, and higher rates of generalised ligamentous laxity [9–11]. A second ACL injury, graft retear or contralateral ACL injury, is observed in the female athlete with higher frequency after returning to pivoting and cutting sports within two years of ACLR [12]. Sex differences have also been reported in outcomes after ACLR. Patient-reported functional outcome and ability to return to sport were reported to be lower in women than men, with female athletes having a 25% reduced odds of returning to sports [13,14]. However, it is important to approach the metrics concerning outcomes and return to sport in female athletes with caution, as socio-cultural-economic factors and gender-related biases in outcome measures could potentially serve as confounding variables.

PLANNING THE REVISION SURGERY

Before performing a revision ACLR, the initial and crucial step involves performing a comprehensive clinical and radiological assessment of the patient to accurately identify the underlying cause of the previous procedure's failure. The causes of ACL graft failure can be broadly divided into traumatic and atraumatic. Atraumatic causes include technical errors such as improper tunnel position and failure of the graft to incorporate (biologic failure). Traumatic causes include trauma-induced increased forces across the ACL graft. These are accentuated with unaddressed ligamentous or meniscal pathology or limb malalignment. The MARS study reported that trauma and technical error with suboptimal graft placement are the significant reasons for the failure of primary ACLR [3,6].

The patient assessment starts with a detailed history: symptoms and duration of instability, history of trauma, activity level, medical and detailed surgical records, post-operative course and complications, rehabilitation program as well as a history of return to activity/sport. The history of pain should be delineated from the instability symptoms. Variables crucial for the subsequent management of failed ACLR are the type of graft used in index surgery and fixation methods, intraoperative findings of any meniscal or chondral pathology, and any other concurrent intervention performed on the knee. Clinical examination should demonstrate objective laxity and delineate any further ligamentous and capsular injury or instability; previous surgical scars should be recorded. Alignment should be assessed, and in malalignment, varus or valgus thrust during gait must be critically noted [2]. Radiological evaluation will note the location of the tunnels, hardware type and placement, tunnel expansion, and presence of any other concomitant injury around the knee, meniscus and cartilage status [4].Additionally, anatomic risk factors such as increased posterior tibial slope should be measured on long tibial films (Fig. 1).

HOW TO PROCEED- SINGLE-STAGE VERSUS TWO-STAGE REVISION

Revision ACLR can be performed in one or two stages. Literature shows no differences in patient-reported function and failure risk between single-stage and two-stage revision ACLR [5,7]. Potential indications for two-stage revision include one or more of the following criteria: tunnel enlargement (>12 mm) (Fig. 2), improper tunnel position at risk of conflict with the proposed revision tunnel, arthrofibrosis, and infection. Revision surgery can also be staged when a high posterior tibial slope or coronal malalignment needs corrective tibial osteotomy. No gender-based discrepancies have been reported whether a revision is performed in single or two stages. Against this backdrop, a single-stage revision is efficient, allows an earlier return to activity but is technically more challenging, especially for a less experienced surgeon who may not be as accustomed to dealing with the unexpected. A two-stage

Fig. 1. Measurement of posterior tibial slope. Draw a vertical line down the proximal anatomical axis of the tibia by doing the following.
a. Pick two points - 10 cm and 20 cm distal to the joint (or 5 cm and 15 cm if short X-ray film).
b. Identify the midpoint by measuring the diameter between the posterior and anterior cortex then halving this (or use a circle tool if available).
c. Connect these two points with a vertical line which passes proximally through the joint using the angle measurement tool.
d. Using the angle measurement tool draw a second line from the highest to the lowest point of the tibial plateau and this will display the tibial slope.

revision is more predictable, allowing the surgeon to sequentially address pathology, but requires multiple surgeries with a longer return to activity. In a developing country with limited resources, instruments, and workforce, single-stage reconstruction would appear attractive if there are no contraindications.

THE IDEAL ACL-R REVISION GRAFT?

There are multiple choices suitable to use as a graft for revision ACLR, albeit each case should be evaluated individually to select the best possible graft for a selected patient. Considerations include previous graft use, tunnel placement and enlargement, previous skin incision, patient age, level of activity, patellofemoral problems, graft availability, and other concomitant surgical procedure planned along with revision ACLR [15].

Fig. 2. CT scan showing tibial tunnel dilatation.

Allografts present an attractive option and are frequently used in revision situations, however, concerns about slow incorporation and higher failure rates in younger, more active patients are concerning [16, 17]. This caution should be extended to high-level female athletes. Autografts are generally favoured in young active athletes since they have shown consistently better patient-reported outcomes (PROM), better laxity parameters, and a low failure rate compared to allografts in both primary and revision ACLR [1,2,4,5,7,18,19].

Autograft choices for revision ACLR include four or six strand hamstrings tendon (HT), bone-patellar tendon-none graft (BPTB), and quadriceps tendon (QT) with or without bone block. BPTB is often a preferred choice for revision surgery due to the benefit of a bone graft built into the tendon graft to address any tunnel issues. Harvest site morbidity associated with these grafts is a potential concern. A hamstring graft is a good choice for revision, especially in the older athlete despite reports of relatively higher early re-rupture rate for hamstring autograft than BPTB graft in young athletes [1,2,28]. Studies report that in women, hamstring grafts have increased rates of postoperative laxity compared with a BPTB graft, as well as compared to men who have had a hamstring graft [19,20].

In the last decade, there has been a rise in the use of QT graft for both primary and revision ACLR; the literature is replete with evidence of its versatility and usefulness [21–23]. Favourable anatomic and biomechanical properties, less donor site morbidity, and the provision of harvesting QT graft with a bone block make it an attractive solution in revision situations. Several recent studies have found that in primary ACLR, QT autograft is comparable to HT and BPTB autografts regarding knee stability, functional outcomes testing, and graft re-tear risk, with less donor site morbidity than BPTB [1,17,24,25]. A recent systematic review and meta-analysis showed a trend toward better outcomes, favourable laxity parameters, PROMs, and return to sports with QT graft compared to HT in revision ACLR [26]. Moreover, with a minimally invasive harvesting technique, the burden of scarring can be minimised,

which may have aesthetic implications. For revision surgery, BPTB or QT grafts may be helpful because of the ability to fill enlarged tunnels with the bone block.

In revision situations, the available literature fails to show any definitive advantage of one autograft tissue graft over another. Amidst the plethora of options, it is incumbent on the operating surgeon to make an individualised and informed choice that best suits each particular patient. For instance, in the presence of wide tunnels, opting for BPTB or QT graft with a bone block to fill up an expanded tunnel and potentially avoid the burden of a two-stage reconstruction is a good option. Likewise, in a young female elite athlete with high-risk factors such as generalised ligament laxity and high posterior tibial slope, one can steer away from HT autograft and be inclined towards BPTB or QT graft. On the contrary, HT autograft could safely be kept in the armamentarium in lower-demand or older patients without any identifiable high-risk factors. Should the involved limb not be suitable for harvesting a particular graft, the contralateral limb could be used for the same; however, the risk of contralateral limb ACL injury must always be considered.

NEED FOR LATERAL EXTRA-ARTICULAR RECONSTRUCTION

Despite improvement in our understanding of knee kinematics and advancement of ACLR techniques, the high rate of persistent rotational laxity after ACLR surgeries continues to be a concern [27]. This has led to renewed interest in the knee's anterolateral complex (ALC), which prompted the resurgence of various lateral extra-articular reconstruction techniques to augment intra-articular ACLR for improved rotational stability [5].

Lateral extra-articular tenodesis (LET) or anterolateral ligament reconstruction (ALLR) are increasingly being considered to supplement ACLR and provide better rotational control. The evidence is increasing that combining lateral extra-articular procedure such as modified Lemaire (Fig. 3), modified Ellision or anterolateral ligament reconstruction with concurrent ACLR has decreased graft re-rupture and failure rate [1,7,19].

When does one consider LET along with ACLR? Available literature does recommend adding lateral extra-articular procedures in selective situations; where the patient might be at increased risk of graft failure and reinjury, such as in active young patients, returning to high-demand pivoting/cutting sports, generalised ligament laxity, high tibial slope, knee hyperextension, meniscal deficiency high-grade pivot-shift test and revision surgery. The addition of an LET to a revision ACLR has demonstrated favourable outcomes compared to ACLR revision alone [7,18,28–30]. Recent evidence also supports adjunctive LET with revision ACLR results in lower failure rate, better stability and subjective outcome [28,31]. Given that women have increased rates of generalised ligamentous laxity and a higher risk of ACL tear and graft rupture, LET/ALLR should be considered as part of the treatment algorithm for females requiring revision ACL, particularly for high-level elite athletes [19,27,32].

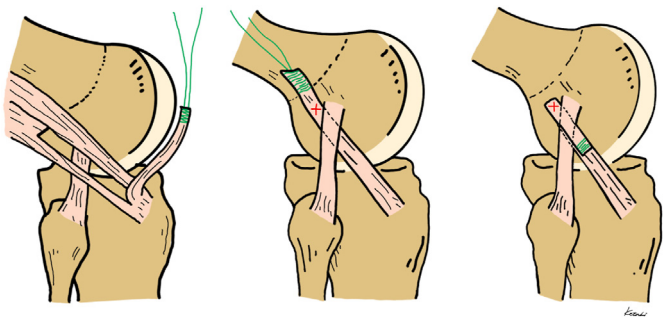

Fig. 3. Modified Lemaire lateral extra-articular tenodesis procedure.

PAY ATTENTION TO CONCURRENT INJURIES TO SECONDARY RESTRAINTS

It is crucial during revision ACLR to address injuries to secondary restraints, like ligaments, menisci, and capsular structures of the knee. Injuries to secondary restraints in the knee can place added strain on the reconstructed ACL, potentially leading to graft failure. It is important to carefully evaluate posterolateral rotatory instability, which is more commonly encountered in chronic ACL-deficient knees. Thorough assessment of the medial stabilisers (medial collateral ligament, oblique popliteal ligament) and secondary restraint to anterior tibial translation (posterior horn of medial meniscus) is necessary [33–36]. These accompanying injuries increase the likelihood of revision surgery failure, underscoring the need for their proper management and surgical intervention during revision ACLR [3,5].

In addition to addressing soft tissue restraints, it is crucial to consider osseous malalignment, which can cause increased stress on ACL grafts. Coronal or sagittal plane limb malalignment should be addressed with the appropriate corrective osteotomies. Similarly, a high posterior tibial slope (>12°) should be addressed with slope-reducing de-flexion proximal tibial osteotomy. Correction of osseous deformities must take priority before or during revision ACLR [2,6,37].

APPROACH TO REHABILITATION

The goals of postoperative rehabilitation are to minimise pain, swelling, and inflammation while regaining range of motion, strength and neuromuscular control. Strict vigilance is required to restore full passive and active knee extension, quadriceps activation, and neuromuscular strength and activation [1]. There is limited data to recommend a different rehabilitation plan for females than males. A more targeted approach would be wise for women, especially with those who have pre-existing altered neuromuscular control, anatomic or biomechanical risk factors, or generalised joint hypermobility. Despite this, there is not widespread acceptance for a gender specific iteration of the rehabilitation program after revision of an ACLR. Generally, for revision surgery, overly accelerated rehabilitation should be avoided to optimise clinical outcomes. The rehabilitation plan after revision ACLR should be tailored individually to optimise recovery, taking into consideration the cause of previous graft failure, intra-operative considerations, and concomitant pathology at the time of surgery [15]. Although dynamic functional bracing has demonstrated potential in preventing revision ACL graft failure, the routine use of a brace lacks sufficient evidence to support its widespread adoption [5]. Nonetheless, there are advocates who argue for implementing identical rehabilitation protocols for both primary and revision ACLR, considering comparable objective and subjective measures of laxity [36].

Relatively newer rehabilitation modalities, such as neuromuscular electrical stimulation, blood flow restriction, Kinesio taping, and psychosocial support, have shown promising effects in early strength recovery and improving patient-reported outcomes following ACL reconstruction [38]. For female athletes, integrating the concepts of optimising outcomes with understanding the unique risk factors experienced by women will be the key to optimising recovery and return to sport after revision ACLR.

RETURN TO SPORT

A key issue after revision ACLR is returning the athlete to sport safely and efficiently after surgery. Sufficient time must elapse to allow secure graft maturation and ligamentization to withstand the load of demanding sports; therefore, slower return to sport in revision reconstruction vis-à-vis primary ACLR is recommended. Slower rehabilitation and slower advancement in phases will maximise the chance of success after revision ACL reconstruction. This is particularly important for female athletes

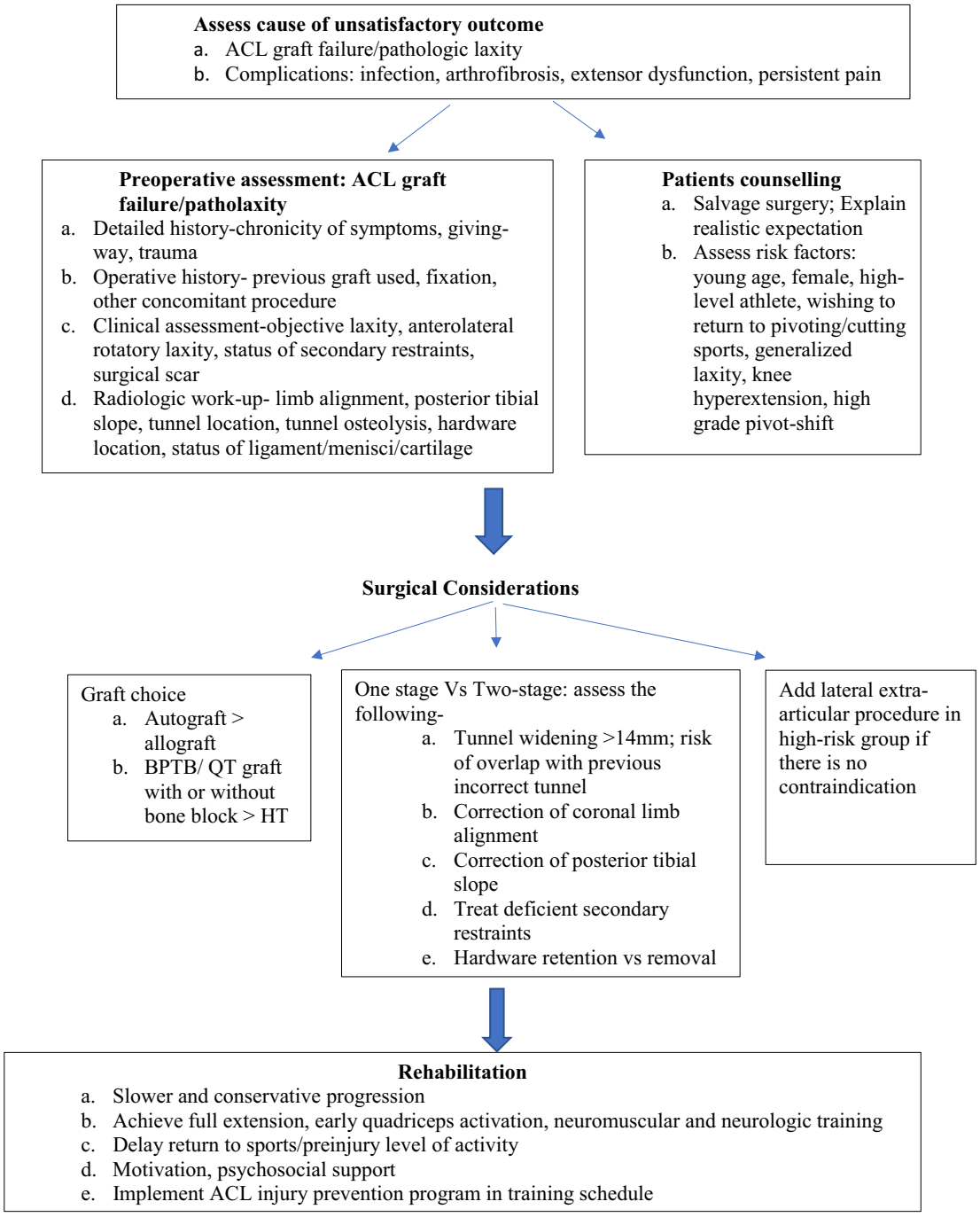

Fig. 4. Approach to revision ACLR in female athletes.

who show higher rates of re-injury. Currently, no consensus exists on the definitive time at which athletes can be allowed to return to sport. The process is more complex than the traditional time-based criteria and will be dependent on the sport and the athlete. Considerations such as graft type, fixation method, rehabilitation strategy, nature of sports, will also play a role. Functional and psychological testing has a place to incorporate in the algorithm to decide the optimal time to return to sport [39]. It cannot be overemphasised that overly aggressive rehabilitation and early return to play before complete graft incorporation and restoration of neuromuscular control could potentially compromise revised ACL graft.

Various psychosocial factors such as motivation, self-efficacy, mood changes, the patient-reported functional outcome, lack of athletic expectation, psychological readiness, fear of reinjury, and insufficient social support affect safe and effective return to sport. Surgeons, physical therapists and sport psychologists can all play a critical role in addressing these factors and ensure favourable psychosocial support, which would have a positive effect in facilitating athletes to return to their preinjury level of sports [5,13,38]. For female athletes, lower rates of return to sport have been reported after ACLR. A higher rate of psychological readiness recorded in men has been offered as an explanation to explain this disparity [1,13,14]. Female patients were observed to have a negative outlook concerning readiness to return to sport, and they may benefit from a psychosocial support program [14]. However, reported a lower return to sports in female athletes must be viewed cautiously since it is an interplay of various socio-economic factors, which are critical determinants. For instance, females in their childbearing years at the time of ACLR or certain obligations in a job may be confounding influences on

why fewer females return to sport. Finally, the poorer outcome reported in female athletes may be due to inherent gender bias in the outcome measure used. Patient reported outcome measures are usually validated on males and contain questions that pertain more to males than females such as participation in contact sport. The importance of knowing gender specific normal data in this population for disease specific patient reported outcome measures cannot be understated. For example, even in an uninjured population women may score 5–10 points lower on a specific outcome measure. If a study then shows that women score 5–10 points less post operatively, they are actually reporting equal outcomes to men. Although some studies have demonstrated poorer outcome in women, other authors have reported the same rate of return to sport between females and males after the revision of ACLR [40]. Even at elite-level sports, women have shown 82% return to the same level of sport after ACLR, which is comparable to men [41].

ACL INJURY PREVENTION

What is still unclear is why women have a higher rate of ACL injury and graft re-rupture than men. Is it anatomy, biomechanics, endocrine-related, or poorer neuromuscular training as children, the so-called "ball versus doll?" Of these, neuromuscular literacy is the most modifiable. A significant positive impact of reducing ACL injuries in female athletes with neuromuscular training (NMT) has been demonstrated by some authors, but other data contradict the claim (ref). A recent systematic review concluded that there is moderate evidence of the protective role of preseason neuromuscular training, including plyometrics, in preventing ACL injuries in female athletes (ref). Given the minimal risk to this preventative strategy, it seems reasonable to recommend; however, more data is needed to see whether adopting its universal use as a valuable adjunct to training regimens is worthwhile [42]. Attention is being directed to risk-stratifying athletes according to specific biomechanical variables associated with a high risk of ACL so that NMT can be specifically targeted and individualised on the athlete's movement profile. For instance, a training program can help reduce high knee abduction moment (KAM) at a 90-degree direction change associated with high ACL loading. However, there is no consensus on the routine screening of athletes and the effectiveness of targeted NMT on athletes' movement profiles. Integrating a secondary ACL injury prevention program into ACLR rehabilitation seems plausible. With the adequate restoration of neuromuscular function, targeted neuromuscular training for patient-specific biomechanical risk factors, and sports conditioning, we could potentially reduce the dreaded task of revision and re-revision ACLR in active young patients [1].

FUTURE DIRECTION

As our knowledge and understanding of the failed ACLR improve and technology advances, we will be better able to reduce the incidence of ACL graft rupture and be better equipped to treat it. For female athletes, a concerted effort must be directed to maximise the outcome of ACL reconstructive surgery and return them to their preinjury level of sport participation and performance. It remains to be seen whether any particular graft type, fixation method, reconstruction strategy and tailored rehabilitation protocol would prove distinct superiority. Significant consideration should be given to women and other high-risk individuals for the addition of lateral extraarticular procedures to a revision ACLR. Improving rehabilitation programs with neuromuscular and neurologic intervention will benefit patients' recovery and safe return to sport. Athletes' return to the sport must move from time-based to evidence-based, objective criteria. It should include a battery of assessment strategies that would identify patients who are sport-ready and can resume the preinjury level of performance without jeopardising the revision ACL graft [43]. How psychological conditioning and social support can be added to athletes' path to recovery needs more evidence but it is clear that it plays a role in recovery after ACLR. There is still a need for research into the risk factors for ACL injury in female athletes and their mitigating strategies. Future studies must include gender-specific analysis of data. Current outcome measures need to be assessed for gender bias and modified accordingly. After the revision of ACLR, the rehabilitation aspect needs more focus, including the need to approach female athletes differently. Finally, research must analyse the gender-specific determinants of outcome, including return to sports/preinjury activities. Fig. 4 shows approach to revision ACLR in female athletes.

CONCLUSION

Revision ACLR is a challenging procedure with increased complexity in high-level female athletes because of their inherent susceptibility to high risk of reinjury. Presurgical preparation is important to reduce unforeseen situations during the revision reconstruction. Pre-operative planning to deal with previous tunnels and hardware, new or unaddressed concomitant injury, and thoughtfulness regarding rehabilitation and return to sport is all necessary to optimise outcome. It is imperative to pay attention to detail and technical aspects, adopt a comprehensive approach to patient evaluation, develop a strategy, and identify patients at risk of failure. The surgeon and physical therapist must work together to return high-risk athletes, including women, to their pre-injury level of activities without re-injury. Last but not least, patients must be counselled about the outcome of surgery, engage them in the rehabilitation process, and have realistic expectations about the outcome of revision ACL surgery.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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