Injury to the anterior cruciate ligament (ACL) is arguably the most devastating injury that an athlete can encounter during their sporting career, influencing not only the player but often their parents, teammates, managers and coaches as well. Having an ACL injury unavoidably triggers questions ranging from “when will I be able to compete again?” to “will I compete again at all?” The positive note is that research around predictors and prognosis in ACL reconstruction and rehabilitation is rapidly evolving in a wide variety of domains. The main focus of this review is to provide current evidence on predictive parameters and interventions which can have an impact on quality and speed of recovery after ACL reconstruction. This information should help clinicians in their day to day decision-making. Reviewed parameters and variables can help clinicians to find an ideal, individualised path from injury to return to play (RTP) for each unique athlete and are divided in two groups: preoperative and postoperative predictors.

PREOPERATIVE PREDICTORS

Preoperative rehabilitation

It is well-established that improving knee function in the pre-surgical phase has a positive effect on post-surgical outcome. Pre-surgical rehabilitation generally aims at reducing swelling, restoring knee extension range of motion, gait re-education and muscle reinforcement. Preoperative quadriceps strength symmetry has been shown to be a meaningful predictor of an individual’s ability to pass or fail return to sport criteria 6 months after surgery. Quadriceps strength preoperatively predicts IKDC 2000 (International Knee Documentation Committee) scores and has an influence on self-reported knee function 6 months after ACL reconstruction. Marked preoperative deficits in this phase are also predictive of on-going deficits at 2 year follow-up. Thus maximising quadriceps strength preoperatively might reward the patient with optimal outcomes after surgery. It is important to consider that weakness of the quadriceps can be an actual muscle weakness, but might also be due to neuromuscular inhibition. Deficits in voluntary activation have been identified post ACL injury in both the involved and uninvolved leg. This is of importance as patients who showed a better improvement in terms of voluntary activation eventually returned to higher levels of activity.
the use of EMG analysis during isokinetic testing and questions the usage of the contralateral leg as the reference leg during test interpretation. Bottini et al. explored the influence of acutely performed reconstruction on range of motion and general clinical outcome. Although they did not advocate generalising this approach, they established that surgery in the acute phases did not result in loss of range of motion or suboptimal clinical results.

**Gait analysis**

Alterations in gait pattern are shown in ACL deficient subjects and normalisation of gait is an important factor in restoring function. These alterations could be explained by quadriceps weakness, but another important contributor might be altered neuromuscular strategies. Previously, clinicians advocated quadriceps and hamstring co-contraction as a means of reducing the anterior shear at the knee, however Lewek et al. suggest that those who adopt this strategy are less likely to achieve a good functional outcome. Hartigan et al. investigated if this inability to use normal kinetic and muscular control strategies had an impact on the ability to achieve higher level goals such as RTP. They found that a difference in knee flexion moments measured at peak knee flexion angle in the involved leg during preoperative gait is indeed a meaningful predictor of the ability to pass or fail RTP 6 months post-surgery.

**Patient-specific parameters**

Patient-specific parameters which negatively influence outcome are older age, smoking, higher body mass index and female gender. Patients should be made aware of these factors and for the modifiable parameters (smoking and body mass index), appropriate advice for alterations should be suggested. In older patients, on the other hand, advice for a more cautious RTP may be warranted.

**Questionnaires**

Questionnaires such as the IKDC, Tegner Lysholm Knee Scoring Scale and Knee Injury and Osteoarthritis Outcome Score can help us to monitor progression and evaluate outcomes. Normative data for these questionnaires is well-established and is a valid point of reference. Preoperatively, these questionnaires have not yet shown prognostic significance, but questionnaires such as Marx-scale and the psycho-vitality questionnaire have shown predictive value in determining the chances to return to pre-injury activity levels. Preoperative self-efficacy of knee function can be determined with the knee self-efficacy scale (K-SES) and is of predictive value for players returning to acceptable levels of physical activity, symptoms and muscle function 1 year after ACL reconstruction. Pre-intervention Tegner activity levels are important predictors for postoperative health-related quality of life.

**Radiographic findings**

Although the prevalence of a typical bone bruising pattern post ACL injury is very high, there seems to be no association with symptoms or pain at the time of ACL reconstruction. Furthermore the presence of bone bruising has no effect on IKDC outcomes. Additional work to identify possible relationships might be needed.
along with agreement on quantification of bone bruising. The influence of this typical bone bruising on the eventual development of osteoarthritis (OA) remains unknown. The importance of the meniscus in this context is well-appreciated. It is known that the incidence of OA in the presence of normal menisci is low, even despite continued participation in sporting activity\textsuperscript{17,25,26} as opposed to commonly reported radiographic abnormalities in subgroups who underwent meniscectomy\textsuperscript{27,28}. Pre-operave cartilage lesions have also been related to an earlier onset of OA\textsuperscript{3,17,26,27,29}. This raises the importance of early surgery in a functionally unstable knee of a non-coping patient as recurring episodes of giving way have been linked to an increased prevalence of meniscal and cartilage injury\textsuperscript{30} and therefore a likely increased incidence of later OA.

**POSTOP PREDICTORS**

**Rehabilitation**

Criteria rather than timeline-based rehabilitation has been generally accepted as being the gold standard\textsuperscript{5,31}. Benchmarks for progression in ACL-rehabilitation have been described with the main aim being minimisation of the risk of injury to the healing tissue, while maximising the patient’s response to exercise at the current level of functioning\textsuperscript{5}. A number of individual parameters and interventions are shown to aid in reducing the time needed to reach specific criteria and will be discussed below.

**Extension**

Residual extension deficits have been linked to inferior subjective and objective results\textsuperscript{32}. Risberg et al have shown an association with persisting extension deficits and a lower Cincinnati knee score at the 2-year follow-up\textsuperscript{32}. Since early active and passive knee extension did not increase postoperative knee laxity up to 2 years after bone-tendon-bone (BTB) ACL reconstruction\textsuperscript{33}, early restoration of extension is a priority.

**Quadriceps strengthening**

Quadriceps muscle performance, especially when accompanied by pain, is identified as a significant predictor of disability\textsuperscript{4}. Accordingly, a specific postoperative strengthening regimen should be initiated as soon as appropriate. Early isometric quadriceps exercises should be encouraged during the first 2 postoperative weeks since this leads to significantly more favourable Cincinnati scores for symptoms and less problems with sport 6 months postoperatively when compared with no isometric quadriceps exercises during the first 2 weeks\textsuperscript{34}. A well-balanced programme will incorporate both open kinetic chain (OKC) and closed kinetic chain strengthening exercises. There is on-going debate regarding the timing of initiating OKC strengthening and the importance (or not) of possible effects on anterior knee laxity. Heijne et al investigated the effect of early (4 weeks postoperative) versus late (12 weeks postoperative) OKC quadriceps exercises in both hamstring (HS) versus BTB graft and found no difference in quadriceps muscle torques 7 months postoperative in any of the subgroups. They did, however, find an increased anterior knee laxity in the early HS OKC group\textsuperscript{35}. According to Mikkelsen et al, addition of OKC quadriceps training as early as 6 weeks after ACL reconstruction results in a significantly better improvement in quadriceps torque without reducing knee joint stability at 6 months and also leads to a significantly higher number of athletes returning to their previous activity earlier and at the same level as before\textsuperscript{36}. Both study-groups had a relatively small sample size: 68 and 44 patients respectively, however, given the possible importance of these findings, the most appropriate time or criteria to initiate OKC strengthening warrants further investigation.

**Strengthening principles**

Traditional strengthening protocols have been well described\textsuperscript{37}. When comparing neuromuscular exercises with traditional strength exercises, Risberg et al found a significant improvement in knee function (global function) and reduced pain during activity in the neuromuscular training group, compared with the traditional strengthening group. On the other hand, these authors found significantly improved
maximising quadriceps strength preoperatively might reward the patient with optimal outcomes after surgery

**GRAFT CHOICE**

Graft choice impacts outcome in a variety of ways. Although some authors report similar outcomes in terms of OA at follow-up\(^{40-41}\), anterior knee pain, donor site morbidity\(^1\), functional outcomes\(^2\) and graft failure\(^41-44\) in BTB vs HS graft, others have found a lower incidence of OA and improved functional performance after HS compared to BTB graft\(^45-46\), more anterior knee pain in BTB grafts\(^47-48\) and lower donor site morbidity in HS grafts\(^49\). These findings should be considered during surgical decision-making and should be accounted for during subsequent rehabilitation. Special attention is needed when working with patients with an allograft as re-rupture rates have been reported to be five times higher when compared to autografts\(^49,50\). This might be explained by the fact that on one hand the absence of donor site morbidity speeds up the process of recovery post-reconstruction and possibly shortens the time to RTP, but on the other hand the integration of the graft is delayed when using allograft\(^51\). Further research is required given these outcomes and the incidence of allograft reconstructions. Until clarification is forthcoming, it seems prudent to be more cautious in this group of patients.

**Perturbation training**

Perturbation training as an addition to the standard ACL protocol appears to reduce the risk of continued episodes of giving way of the knee during athletic participation and allows subjects to maintain their functional status for longer periods\(^38\).

**CONCOMITANT MENISCUS INJURY/SURGERY**

Injury to the ACL is frequently accompanied by injury to the meniscus. A slight predominance of lateral meniscal tear (LMT) has been reported in acute ACL rupture (56% LMT vs 44% MMT) whereas significantly higher incidence of medial meniscal tears (MMT) has been described in the chronic ACL deficient knee (70% MMT vs 30% LMT)\(^52\). Meniscal repairs and partial or total arthroscopic meniscectomy are therefore frequently performed during ACL reconstruction. Although there is some disagreement in the literature\(^18\), it seems that meniscus injury or surgery around the time of ACL reconstruction has a negative effect on the final functional outcome\(^1,28,30,53\). It may be that rehabilitation needs to be altered in the presence of these co-pathologies. To date no comparative studies have been performed to investigate the effects of initial weight-bearing and/or range of motion restrictions in case of the aforementioned concomitant injuries/surgeries and thus most guidelines are still based on clinical experience. More evidence is needed to support our current practice in these cases.

**PSYCHOLOGICAL FACTORS**

Psychological factors have a strong influence on progression and outcome after surgery. Ardern et al reported in their systematic review that despite high rates of successful outcome in terms of knee impairment based function, only 44% of the athletes had returned to competition at follow-up. They suggested that this was partially contributed to by psychological factors\(^54\). In the Qatar Football League we see a much higher return to competition rate. A possible explanation is that this cohort only includes professional athletes in contrast to the more heterogeneous group of athletes (amateur and professional level) that were analysed in previous studies. Other variables to consider are demographic differences and general fitness level at the time of injury. Zaffagnini et al showed that patients instructed to watch a video producing positive therapeutic insight had significant positive improvements in IKDC, Tampa Scale of Kinesiophobia and shortened time on crutches when compared with a group that received a video with images unfavourable to psychological recovery\(^55\). This study has investigated only short-term impact of such strategies, but might also be promising in mid- to long-term implementations. A questionnaire that can help us to identify possible athletes with a lower psychological response is the ACL-Return to Sport after Injury scale (ACL-RSI). The ACL-RSI scale has shown good reliability and validity and may help the clinician to identify athletes who will find sport resumption difficult\(^56\).
It is suggested that such athletes would then benefit from an appropriately targeted psychological intervention to enhance their outcomes. While appealing, the validity of this approach is still to be confirmed.

FEAR OF RE-INJURY

Despite high rates of successful outcome in terms of knee impairment-based function, a relatively low rate of return to competitive sport is documented44. Lifestyle changes and fear of re-injury have been suggested to be contributors to this phenomenon44, where the former might be partially driven by the latter.

RE-INJURY RATES

Hettrich et al in a recently reported a re-rupture rate of 7.7% in the ipsilateral and 6.4% in the contralateral knee57. Wright et al earlier showed lower re-injury rates with 3% ipsilateral and 3% contralateral18. The individual numbers notwithstanding, both groups present the same injury rate in the contralateral leg when compared to the involved leg in their respective cohorts. If interventions are able to influence ACL rupture incidence, it is a strong motivator to focus intervention and prevention on both legs. Re-injury rate does not seem to be related to graft size or activity level but appears to be higher in patients younger than 25 years29,59 and it would seem sensible to factor this into RTP criteria. In the same breath it needs to be mentioned that revision surgery is generally associated with lower activity levels44.

REMAINING LAXITY

Although ACL injury and consequent surgery have an undisputable effect on anterior knee laxity and rotatory stability, this doesn’t appear to be related to dynamic stability and functional outcome52. Moller et al compared patients whom 2 years after surgery showed a side-to-side difference in anterior-posterior knee laxity of more than 3 mm with those with 3 mm or less and found no significant group differences in terms of knee function as determined by the Knee Injury and Osteoarthritis Outcome Score61. While a positive pivot-shift was found to be a good measure for functional instability52, this particular study was potentially hampered by recall bias as only 336 out of 1537 subjects were included due to lack of 2-year follow-up data61.

HOP TESTING

Preoperative single leg hop tests seem to have a poor ability to predict postoperative outcomes, but at 6 months post-operation they can predict likelihood of successful or unsuccessful outcome 1 year postop53.

A positive correlation between higher speed isokinetic knee extension peak torque, subjective knee scores and three hop tests has been reported64. Hop testing is widely accepted as a good measure for functional outcome but its current limitation is that we only evaluate limb symmetry index which is a quantitative measure comparing distance (or time) recorded during testing of involved and uninvolved limb64 and does not reflect altered movement strategies. Landing technique, foot placement, knee positioning, pelvic stability and hip-knee-ankle flexion moments might give us more information to separate patients who have acquired alterations in movement patterns from those who have truly recovered normal movement strategies. When we add these parameters to the equation, hop testing might be a stronger predictor of good functional outcome and could provide additional guidance towards more effective rehabilitation techniques64. More work is needed to establish easy and valid ways to assess aforementioned parameters and to confirm their individual significance on normal movement patterns and dynamic stability.

FUTURE RESEARCH

Although gap-analysis of the current literature was not the primary intention of this review, some fields have been identified to be potentially interesting topics for further research. Weight-bearing and range of motion restrictions in case of meniscal involvement, timing or criteria to start OKC quadriceps and psychological factors could have a significant impact on the final result, but need to be explored more in-depth. Hop testing has shown some predictive value but more investigation into quality of movement during this particular testing is required.

CONCLUSION

To date, a wide variety of predictive and prognostic parameters have been well-documented. They provide us with good tools to inform our patients regarding expected outcomes, but also help us to identify patients at risk in certain aspects. Appropriate intervention at this stage is warranted and seems to be spread out over different fields of expertise. A multidisciplinary approach should be the backbone in any given rehabilitation process, but even more so in a long-term intervention such as ACL-reconstruction. Decision-making and progression monitoring should be based on a perfect communication between surgeon, physician, physiotherapist, sports-rehabilitator, fitness-coach, dietician, psychologist, team medical staff and any other discipline involved. When accounting for all aforementioned factors and decision-making models, we can expect to have optimal outcomes minimising complications.

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