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ANKLE

Rehabilitation after anatomical ankle ligament repair or reconstruction

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Abstract The selection, implementation of and adherence to a post-operative regimen are all essential in order to achieve the best outcomes after ankle ligament surgery. The purpose of this paper is to present a best-evidence approach to this, with grounding in basic science and a consensus opinion from the members of the ESSKA-AFAS Ankle Instability Group. Basic science and clinical evidence surrounding tissue healing after surgical repair or reconstruction of the ligaments as well as around the re-establishment of sensorimotor control are reviewed. A consensus opinion based on this evidence as to the recommended rehabilitation protocol after ankle ligament surgery was then obtained from the members of the ESSKA-AFAS Ankle Instability Group. Rehabilitation recommendations are presented for the initial post-operative period, the early recovery phase and a goal-orientated late rehabilitation and return-to-sport phase. This paper presents practical, evidenced-based guidelines for rehabilitation and return to activity after lateral ankle ligament surgery.

Keywords Ankle · Instability · Rehabilitation · Brostrom · Gould · Anatomical reconstruction

Introduction

The selection, implementation and adherence to a post-operative regimen are all essential in order to achieve the best outcomes in most orthopaedic procedures [36, 46, 69]. Additional considerations arise with respect to safe return to play when dealing with an athletic patient in order to avoid complications and re-injury [4, 41].

There is always a conflict between immobilizing and offloading the limb or joint to protect the surgical repair, reconstruction or fixation and getting the joint moving and the patient bearing weight to avoid stiffness and the other complications of immobilization. Over the last several years, surgeons have been becoming more and more active with their rehabilitation programmes in many aspects of orthopaedic and sports surgery. Some of this is driven by the need for athletes, especially professionals, to return to play as quickly as is safely possible but more generally, as awareness of issues such as thromboembolic events, neuromuscular deconditioning and chronic regional pain syndrome increases; the balance has swung towards earlier mobilization and early weightbearing. Not only has this proven to be safe in a variety of situations, it is often actually beneficial in terms of many clinical outcomes (not just earlier return to activity). A good example of this in the foot and ankle is with Achilles tendon rupture where, either after surgery or in non-operative treatment, an accelerated rehabilitation programme has been shown to improve re-rupture rates [43, 50], increase calf muscle strength and reduce atrophy and tendon elongation [5] as well as decrease the time to return to activity without increasing

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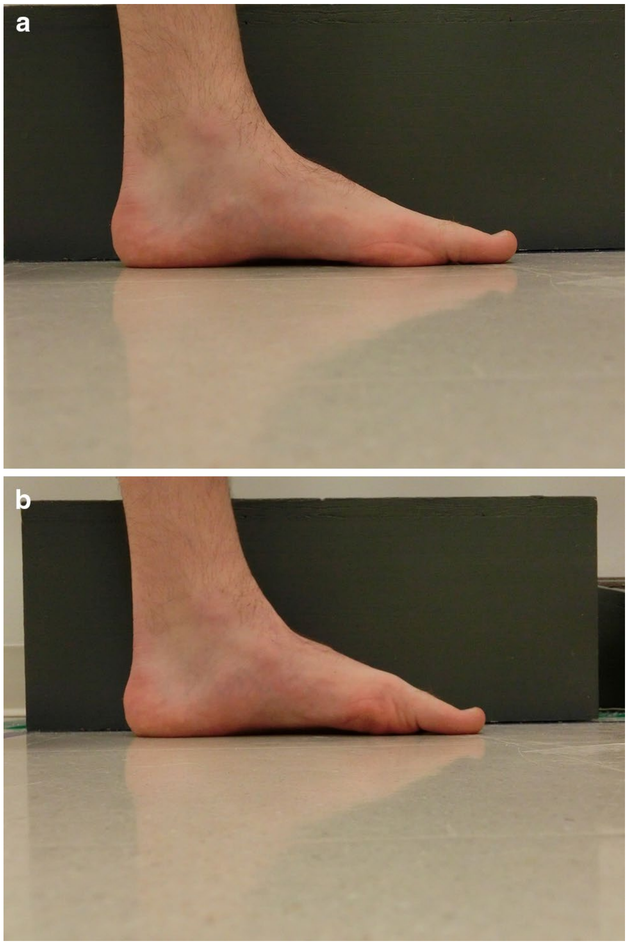

Fig. 1 Example of 'short-foot' exercise. Patient begins with foot relaxed and then draws arch of the foot upward, engaging foot intrinsics

complication rates [7, 8, 31]. Of course, there are still valid concerns with rehabilitating patients too quickly. In an epidemiological study of foot injuries in professional rugby players [41], it was found that re-injuries kept players out of the game on average 3 and a half times longer than did the original injury, highlighting the dangers of not allowing for a complete recovery.

A Cochrane review on interventions for treating chronic ankle instability by de Vries et al. [11] in 2004 found only two studies that assessed rehabilitation [28, 29], and these reported earlier return to work and sports as well as a higher percentage of satisfactory functional results in the early mobilization groups. There is a recent case series that showed good results and no increased rates of complication with immediate weightbearing and early range of motion exercises after Brostrom–Gould lateral ankle ligament repair [44], and one recent randomized controlled trial has reported significantly faster return to full athletic activity with an accelerated rehabilitation programme after tendon reconstruction using a gracilis autograft [38].

The issues that must be considered when designing a rehabilitation protocol after ankle ligament surgery are: the strength of the initial repair, or fixation strength of the ligament to the bone if performing a reconstruction, compared to the stress that the ligament will be under during weightbearing or ankle movements, the mechanism by which ligaments or tendon grafts heal to bone and later the prevention of re-injury by safely returning the patient to activities based on an objective assessment of strength and neuromuscular control. This article presents a best-evidence approach to this, with grounding in basic science and a consensus opinion from the members of the ESSKA-AFAS Ankle Instability Group. The Ankle Instability Group is a group of orthopaedic foot and ankle and sports surgeons, within the Ankle and Foot Associates section of European Society for Sports Traumatology, Knee Surgery and Arthroscopy (ESSKA-AFAS). Its members have a keen interest in ankle instability and met in Chicago for a 3-day meeting in September 2014 to come to a consensus on rehabilitation after ankle surgery which formed the basis for this paper. All members of the group received the manuscript for their comments and approval prior to submission.

Anatomy and tissue healing

Perhaps the most important aspect of tissue healing in any orthopaedic procedure, especially where any foreign material is implanted, is the wound. Delayed wound healing in the oedematous limb and excessive wound exudate may contribute to increased wound infection rates. This fear leads many surgeons to advise a short (10–14 day) period of immobilization and elevation of the limb until the wound has healed, even where an accelerated rehabilitation programme is employed. The studies where immediate weightbearing after ankle ligament surgery was employed did not, however, report any increased wound complication rates [38, 44]; therefore, perhaps delay is unnecessary. Unfortunately, there is surprisingly little objective evidence to give a definitive answer in this regard.

The normal histological anatomy of the bone–tendon or bone–ligament interface is a four-zone gradient from bone to mineralized fibrocartilage, to unmineralized fibrocartilage to tendon or ligament [3]. The mechanical properties of each zone are different, and thus, this transitional arrangement limits stress concentration in any one region of the insertion by having a graduated evolution from the stiff bone to the elastic ligament [35, 58, 62, 63]. Re-establishment of this transitional insertion site is vital as without it the strength of the insertion is an order of

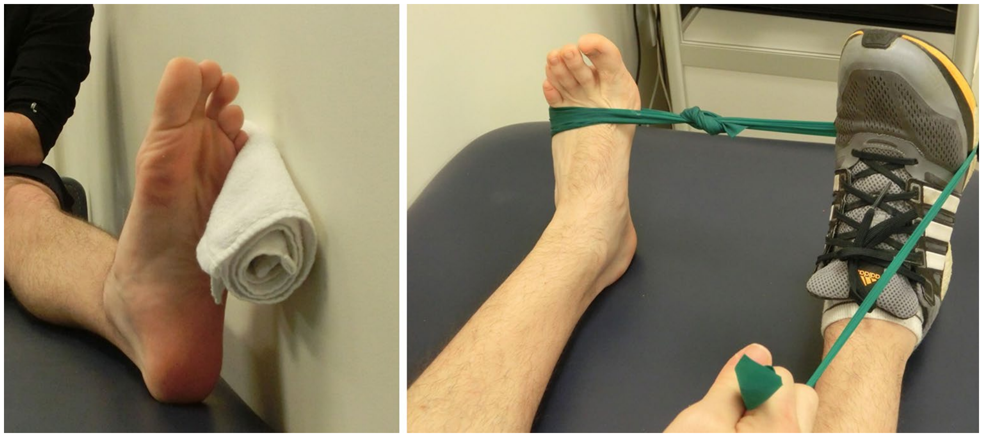

Fig. 2 On the *left* is early progression of isometric foot eversion for initiation of strengthening progression. The patient is instructed to gently push foot outwards into the wall. On the *right* is continued progression with use of a resistive band as the patient moves the foot outwards

magnitude weaker [63]. It has been known since the nineteenth century, from Wolff's law, that bone in a healthy person or animal will adapt to the loads under which it is placed and that increased loading leads to increased tensile strength. Loading of both bone and ligament is critical for homoeostasis, and it is well established in animal models that stress deprivation leads to a decrease in the mechanical properties of both ligaments themselves and their insertions [24, 68]. Many of these animal studies have been done on the rotator cuff insertion into the humerus, which is a similar situation to the anterior talofibular ligament (ATFL) and calcaneofibular ligament (CFL) repairing to the fibula after a Broström-type procedure, and in anterior cruciate ligament (ACL) reconstruction, which is a similar situation to the tendon graft procedures in the ankle. When performing an anatomical repair of the lateral ankle ligaments, as in a modified Brostrom (or Broström-Gould) procedure, we are trying to re-establish the normal bone–ligament interface, and when performing an anatomical reconstruction with a tendon graft in bone tunnels, we equally require the tendon to attach to the bone tunnel. There is much basic science evidence [2, 9, 20–23, 42, 59–61, 63, 64] to advocate that, in order to establish the best quality repair in both of these situations, some mechanical stimulus is required. Without the correct mechano-biological environment, the four-zone gradient from tendon to bone is not established and fibrovascular (scar) tissue forms in the gap instead [20, 22]. There is, of course, a balance to be achieved between excessive load, which will damage the repairing insertion site and insufficient load leading to a catabolic environment [9, 20, 64]. Animal studies of the attachment of the rotator cuff to the humerus have confirmed that the strength of the repaired insertion site is adversely affected if this transitional arrangement is not reconstituted during healing [21, 59, 63]. Further animal studies have shown that cast immobilization after detachment and reattachment of tendon into bone leads to improved morphology of the insertion site and improved strength of the repair compared to exercise or immediate passive motion [23, 42, 63]. However, the absence of load has also been shown to be detrimental to tendon-to-bone healing [60, 61, 64]. Another study on rats evaluating ACL graft integration concluded that 'controlled mechanical loads after a delay to allow resolution of acute postoperative inflammation may be most favourable to the healing enthesis' [2].

Exactly how these findings in animal studies translate into the ideal post-operative regimen in human lateral ligament surgery is yet to be determined, but the increasingly common approach of a short period of immobilization followed by gradually increased movement and load bearing would seem to be reasonable from a basic science perspective.

Neuromuscular rehabilitation

Sprains may damage the integrity of the passive, capsuloligamentous stabilizing structures of the ankle but also, even if active neuromuscular structures are not directly affected, it is well established that functional deficits are frequent following such injuries in terms of both strength and proprioception [39]. These issues must be considered to be equally important as the physical injury when rehabilitating a patient and returning them to activity.

Whilst some joint immobilization may be deemed necessary to respect the tissue healing process, we must be aware of the associated deleterious effects on functional joint stability. Electroencephalography studies have demonstrated cortical reorganizations, leading to functional

Fig. 3 Example of balance progression from narrow base of support (*left*) to tandem standing (*centre*) to single-limb standing (*right*)

deconditioning, after even a short (48-h) period of joint immobilization [17]. Supervised joint movements that are unlikely to stress the surgical repair (dorsiflexion/plantarflexion movements as well as a safe and specific inversion of the rearfoot) are therefore probably advisable as early as possible after surgery (see the section on 'moving forward' below) from a neuromuscular rehabilitation standpoint. Some authors have even shown that specific tendinous vibrations can elicit illusory movements to be perceived by the central nervous system without having to actually move the joint [47]. These vibrations may be generated by means of specific devices applied through windows in the cast during the joint immobilization period to generate the perceived movements and thus prevent the cortical reorganization and deconditioning caused by immobilization [47]. This is yet to be established as standard practice, however.

There have been several studies [6, 10, 18, 19, 26, 45, 48, 49, 57, 66] concerning neuromuscular rehabilitation in acute injuries and for non-operatively treated chronic ankle instability but none, as far as we are aware, specifically assessing this after surgery. It is therefore necessary to extrapolate the findings from these studies when considering post-operative rehabilitation. There have traditionally been two important goals. The first involves strengthening the active stabilizers of the ankle. The physiological role of the ankle evertor muscles is to control potentially traumatic ankle inversion movements (see Table 1 for the specific recommendations). Weakness of the evertors is known to be one of the main factors in chronic instability [26]. There is evidence to suggest that an efficient evertor reinforcement protocol should

Fig. 4 Example of additional balance progression methods with unstable surface (*left*) and dynamic throwing task (*right*)

combine weightbearing (functional) and targeted strengthening [49, 66], employing the maximal joint amplitude [57] (through a carefully supervised progression from 10° to 40° inversion amplitude) and with the integration of eccentric muscular recruitment [6, 10]. Strengthening exercises alone are not sufficient, and although there may be some controversy in terms of how best to achieve the restoration of proprioceptive acuity [45], proprioceptive training has been a major part of ankle instability rehabilitation since Freeman's original publications in 1965 [18, 19]. Restoring the sensorimotor loop acuity aims to reduce functional deficits, symptoms of giving way, the

Table 1 Early rehabilitation phase

Goal	Suggested interventions
Increase lower extremity strength	Leg press Knee extensions Hamstring curls
Increase range of motion	Stationary bicycle A/AROM of ankle in all planes
Increase foot/ankle strength	Isometric to isotonic to resistive ankle strengthening (emphasize peroneals) Foot intrinsic exercises (e.g. ‘short-foot’/lifting of arch in closed chain) Rearfoot inversion/eversion control in a limited amplitude (10–15°) in seated position
Improve balance and proprioception	Standing with narrowed base of support progressing to single-leg standing Progress static standing from eyes open to eyes closed Progress from static balance to dynamic balance (e.g. single-leg standing with ball toss)
Restore symmetrical gait	Gait training beginning with straight plane walking and progressing to zigzag walking

risk of re-injury and improve postural control [48]. This should be an equally important goal after surgery as it is in the non-operative rehabilitation of ankle sprains. However, ankle proprioceptive training has been confounded with balance exercises on unstable supports (plate, foam, etc.). It has been demonstrated that ankle proprioception is not targeted by this kind of exercise [32]. A recent study [15] showed that ankle proprioception can be targeted by equilibration on specific unstable supports, inspired by rearfoot functional anatomy. As highlighted in this study, two main characteristics are necessary to design an unstable situation targeting ankle proprioception. Firstly, the localization of the unstable element must be limited to the rearfoot, whilst maintaining forefoot anchorage capacity, and thus a forefoot–rearfoot dissociation. Secondly, the orientation of the destabilization must be around the functional axis of the rearfoot (Henke axis), to improve proprioceptive acuity relative to inversion mobility. Such specific destabilization, targeting ankle proprioception, may play a role before more global postural perturbations in the rehabilitation process. More work is required before this is globally adopted as part of the standard rehabilitation protocol however.

Moreover, static exercises alone are also not sufficient to enhance functional ankle stability. As demonstrated by Thonnard [65], a pre-activation (activation before foot contact with the floor) of 80–100 ms of the ankle evertor muscles is observed in healthy subjects when walking on uneven ground, running and on landing from a jump. This pre-activation pre-empts the 75 ms of electromechanical delay (i.e. delay between the electrical muscle activation and the beginning of force production) of the evertor muscle [33] and thus ensures an effective eversion force when the foot hits the ground. As such, a progression of functional and sports-specific activities are of importance (see Tables 1, 2, 3, 4, 5 below). Other studies [55] highlighted the fact that patients with chronic ankle instability showed

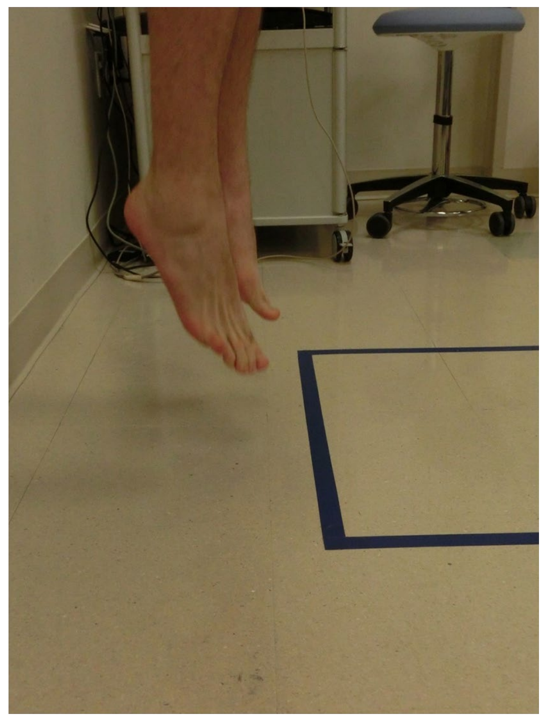

Fig. 5 Example of bilateral jumping task in which patient is instructed to jump forward and backward over a line

impaired ankle evertor muscle pre-activation. There is evidence that locomotion exercises with specific rearfoot destabilization devices, designed to target ankle proprioception during static unipodal balance exercises, play a role in the restoration of the correct pre-activation delays [12, 16].

Moving forward

The initial post-operative regimen that the ESSKA-AFAS Ankle Instability group advocates therefore is 10–14 days

Table 2 Late rehabilitation phase

Goal	Suggested Interventions
Improve balance and proprioception	Single-leg standing/ambulation on unstable surfaces (global balance perturbations)
Improve performance on functional testing	Slow speed progressing to fast speed jogging Bilateral progressing to unilateral anterior–posterior/medial–lateral hopping

Table 3 Return-to-sport phase

Goal	Suggested Interventions
Return to running	Running progression
Improve agility	Jogging with zigzag, Fig. 8 s, turns
	Forward/backward jogging/running
	Side shuffle
	Carioca
	Sport-specific drills equipped with a pair of specific rearfoot destabilization devices (inversion amplitude 15°) to restore ankle muscles pre-activation during specific sport activities
Return to sport-specific activity	Sport-specific self-drills → sport-specific drills performed one-on-one → return to practice with team [17]

Table 4 Soreness rules [14]

Criterion	Action
Soreness during warm-up that continues	2 days off, drop down 1 level
Soreness during warm-up that goes away	Stay at level that led to soreness
Soreness during warm-up that goes away but redevelops during session	2 days off, drop down 1 level
Soreness the day after lifting (not muscle soreness)	1 day off, do not advance programme to the next level
No soreness	Advance 1 level per week or as instructed by healthcare professional

Table 5 Running progression [1]

Level	Treadmill	Track
Level 1	0.1-mile walk/0.1-mile jog, repeat 10 times	Jog straights/walk curves (2 miles)
Level 2	Alternate 0.1-mile walk/0.2-mi jog (2 miles)	Jog straights/jog 1 curve every other lap (2 miles)
Level 3	Alternate 0.1-mile walk/0.3-mile jog (2 mile)	Jog straights/jog 1 curve every lap (2 miles)
Level 4	Alternate 0.1-mile walk/0.4-mile jog (2 miles)	Jog 1.75 laps/walk curve (2 miles)
Level 5	Jog full 2 miles	Jog all laps (2 miles)
Level 6	Increase workout to 2.5 miles	Increase workout to 2.5 miles
Level 7	Increase workout to 3 miles	Increase workout to 3 miles
Level 8	Alternate between running/jogging every 0.25 miles	Increase speed on straights/jog curves

of immobilization in a backslab or similar device and non-weightbearing. After wound inspection at this time, the patient is put into a walker boot and allowed to fully weightbear with the boot on. Patients may also remove the boot to mobilize the ankle in the dorsi/plantarflexion range and in inversion/eversion under safe conditions (restricted amplitude of 10–15° associated with lateral semi-rigid supports), but should not walk without protection until week 6.

The early rehabilitation phase typically occurs between weeks 6 and 10 post-surgery and begins when a patient is able to ambulate without bracing. The goals of this phase include increasing strength and range of motion of the entire lower extremity, restoring full ankle/foot active range of motion and improving gait symmetry to allow for pain-free completion of activities of daily living. A variety of treatment strategies can be employed to achieve these goals (Table 1, Fig. 1). Stationary bicycle exercises [53] and gentle range of motion [29] can aid in range of motion gains. Global lower extremity strengthening can be accomplished via leg press, knee extensions and hamstring curls [53]. Progressive loading of the bone–ligament interface as described in the prior section can be initiated with local strengthening progressing from isometric to isotonic to resistive strengthening, emphasizing peroneal strength [37, 67] (Fig. 2). Ankle and foot strengthening should incorporate exercises to address the following muscles: tibialis anterior, tibialis posterior, peroneus longus and brevis, gastrocnemius, soleus and the foot intrinsics. Ankle strengthening can also be progressed from non-weightbearing to weightbearing positions for increased tissue loading, for example progressing plantarflexion active range of motion to a seated heel rise to a standing heel rise (Fig. 3). As described previously, proprioception and balance exercises (e.g. single-leg standing) should also be initiated at this phase of recovery [29, 34, 44]. Ankle proprioception may also be targeted by means of safe balance exercises on specific destabilization tools (Fig. 4) with a moderate inversion range of motion (10–15°) localized only under the rearfoot [15]. Finally, gait training progressing from straight plane ambulation to ambulating with turns should be included at this stage [29]. Considerations for progression to the next phase of rehabilitation include a patient's static balance performance and ability to ambulate with turns—such as figure-of-8 walking—without increased pain.

The late rehabilitation phase typically occurs between weeks 8–12 post-surgery (Table 2). To enter this phase, patients should demonstrate symmetrical gait patterns and ankle strength at least 90 % of the contralateral side. Ankle strength can be reliably measured via handheld dynamometry [30, 40] or using a Biodex [44]. However, this type of strength testing does not assess functional ankle strength. More functional tests assessing the ability of weightbearing ankle inversion control and eversion production against body weight resistance have recently been proposed [56]. It has been demonstrated that such tests, which are easily transferable to clinical practice, are able to highlight the evertor weakness that is associated with chronic ankle instability. At this phase, strengthening is advanced to unilateral, full weightbearing activity via a standing, unilateral heel rise. Plyometrics, beginning bilaterally and progressing to unilateral positions, are initiated when a patient is able to complete 25 unilateral heel rises. Jogging should begin at slow speeds and progress to higher speeds for progressively longer distances. Utilization of soreness rules (Table 4), commonly utilized in physical rehabilitation [14], can provide a guide appropriate dosage of activity. During the late rehabilitation phase, functional tests can be particularly useful in identifying when to progress a patient to the return-to-play phase. Functional tests include the single-leg hop for distance [54] and triple hop for distance (in the forward or lateral direction) [52] as well as the vertical jump for height, drop jump, crossover hop, six-metre hop and stair hop pending sport-specific requirements [27] (Fig. 5). Other functional tests as the Star Excursion Balance Test [25] or questionary (FAAM test) [13] can be useful to detect and assess functional deficits.

The return-to-sport phase typically falls between 12 weeks and 4 months following surgery (Table 3). In order to progress to this phase, a patient should demonstrate ≥90 % of function via one of the aforementioned tests compared to the unaffected side [29, 44, 51]. In this phase, jogging should be progressed to jogging with direction changes. Running can be initiated when a patient is able to perform straight plane jogging without pain [38]. All of the studies reviewed allowed running when a patient is more than 16 weeks post-Broström repair, so this timeframe may act as a guideline for return to running although athletic patients will often be significantly quicker than this. Running progression should be initiated with straight plane running at slower speeds and progress to running at faster speeds as well as with turns for increasing distances (Table 5). Agility drills are also included in this phase of rehabilitation progressing to sport-specific drills at approximately 16 weeks post-repair. Advanced functional testing such as stair/slope running, Star Excursion Balance Test, figure-of-8 drills and shuttle runs can aid in the decision of when a patient may return to practice [27]. Additionally, an athlete's perception of his/her ability to return to play is an important consideration in making the final return-to-play decision [38]. Once a patient is able to participate in practice without increased symptoms, return to competitive play should be considered. Use of prophylactic ankle supports such as taping and bracing is recommended during practice and game play to avoid re-injury [54]. However, this use is not a satisfactory solution in the long term, and functional stability parameters (strength and proprioception) have to be regularly assessed and stabilized by means of specific and accessible tests and exercises. Additionally, an increased number of recovery days between bouts of running/agility activity may be required, whilst the athlete accommodates to advancing activities.

These recommendations serve to guide treatment; however, further studies specifically addressing late rehabilitation and return-to-play criteria are required. It is also important to consider the individual when designing a treatment plan. For example, in a study by Petrera et al. [44], gross ligamentous laxity (Beighton score > 4) was suggested to be a possible indicator of increased risk of re-injury; however, all re-injuries were also associated with a new, traumatic event. Whilst an increased Beighton score has not been significantly correlated with re-injury, factors such as gross ligamentous laxity, return of a positive sign of increased ankle laxity (e.g. anterior drawer, talar tilt) or major neuromuscular deficits (strength or proprioception) may warrant a more conservative approach to treatment and return-to-play decision-making.

Conclusion

After the initial post-operative immobilization to allow tissue healing and the resolution of the inflammatory response, it would appear that an accelerated rehabilitation programme with early range of motion and protected weightbearing is appropriate, followed by a protocol with criteria-based milestones for progression to return patients safely back to activity.

However, providing a definitive, evidence-based answer as to what is the best post-operative rehabilitation protocol after lateral ankle ligament surgery is difficult because very few studies have been conducted to specifically answer this question. There are, of course, various publications of case series which mention the rehabilitation protocol that was used, but generally speaking, it was not the rehabilitation protocol that was being tested in the study and there are certainly very few studies which compare two or more rehabilitation protocols whilst keeping everything else the same. This means that, essentially, what we have been doing has been largely based on level 5 evidence (expert opinion).

There are issues to consider around how tissues heal and how the neuromuscular control mechanisms (strength and static/dynamic targeted ankle proprioception) are regained after injury or surgery and how these are affected by activity, which can guide our decisions. It is clear that there should be equally as many problems with an overcautious approach as there are with an overzealous one. The suggested rehabilitation protocol applies after anatomical repair or reconstruction surgery.

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