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The Mechanisms, Diagnosis and Rehabilitation of CAI Following ATFL Injury

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Abstract. Anterior talofibular ligament injury is one of the most common injuries associated with lateral ankle sprains,which may contribute to chronic ankle instability (CAI). This review summarizes recent evidence on the mechanisms, diagnosis, treatment, and rehabilitation of CAI following ATFL injury. ATFL injury will not only result in ligamentous laxity, but also cause altered ankle mechanics, proprioceptive deficits, muscle weakness, and impaired postural control. Diagnosis should combine clinical history, physical examination, functional assessment, and appropriate imaging. Conservative treatment remains the first-line approach, while surgical may be considered for persistent symptomatic instability. Rehabilitation should be individualized and include range-of-motion exercises, progressive loading, strength training, balance training and proprioceptive, neuromuscular control. Emerging technologies, including biofeedback and some virtual reality methods can further enhance rehabilitation. Overall, ankle function and reducing recurrent instability can be restored by comprehensive assessment and impairment-driven rehabilitation, while the emerging technologies may provide additional rehabilitation strategies.

Keywords: Anterior talofibular injury, Chronic ankle instability, Rehabilitation

1. Introduction

The anterior talofibular ligament (ATFL) is an important part of the lateral ankle ligament complex. Lateral ankle sprain is one of the most common musculoskeletal injuries. There are approximately 85% of all ankle sprains will lead to injury of the lateral ligamentous complex, and total ligament ruptures occur in 10% of the case, while the ATFL is the most frequent injured structure (65%-85%) compared to the other lateral ligaments [1, 2].

Although many acute ankle sprains can recover with appropriate treatment, some patients continue to suffer the symptoms and develop to CAI. Up to 70% of patients who experience the acute lateral ankle sprain can go on to develop CAI [3]. Meanwhile, it can have substantial functional consequences.Recurrent ankle sprains and repeated episodes of ankle instability may contribute to progressive secondary damage to the surrounding tissues [4]. Up to 34% of patients may suffer from ankle sprain within one year after an initial lateral ankle sprains [5]. Over the longer term, recurrent ankle injury may also increases the risk of post-traumatic ankle osteoarthritis and negatively effects the health-related quality of life [4].

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Previous studies have provided important information about the anatomy, injury mechanisms, clinical diagnosis and rehabilitation of lateral ankle sprains and CAI. However, existing literature focus more on lateral ankle sprain or CAI, which includes whole ligament complex and ATFL injury is often discussed as part of lateral ankle sprain, while the specific way from ATFL injury to CAI is less clearly synthesized. Also, the rehabilitation methods are often discussed separately. Therefore, this review summarized the current information on mechanisms, functional impairments and rehabilitation of CAI following ATFL injury. Especially discover the current evidence on ATFL injury and its progression to the CAI, with more attention on injury mechanisms and rehabilitation strategies. It also aims to illustrate emerging technologies which help rehabilitation and identify some potential direction for future research.

2. Anatomy and injury mechanisms of ATFL

The ATFL is an important part of the lateral ankle ligament complex and plays an essential role in keeping ankle stability. It originates from the anteroinferior border of the fibula and inserts on the neck of the talus, together with the clacaneofibular ligament (CFL) and posterior talofibular ligament (PTFL). And the ATFL mainly helps limit anterior translation of the talus and restraints inversion in the planter flexion and rotation movements [6]. Its mechanical position will change with ankle position. In a neutral position, the ATFL runs horizontally, while during the plantarflexion, it becomes more aligned with long axis of the leg.

The ATFL becomes vulnerable when ankle is in latter position. In this position, the ligament is placed under great strain, especially when ankle is inverted, the ATFL will bends around the talar articular cartilage and and then cause sprain and ligament tear, which may results in stretching, partial tearing or complete rupture [6]. This case commonly occurs when athletes are landing in a wrong position or suddenly change the direction, especially when the ankle is unable to maintain a stable position.

3. Pathogenesis and effect of CAI

Following ATFL injury, laxity ligaments can cause the decrease of mechanical restraint of the lateral ankle, and the persistent ankle instability can increase the risk of recurrent ankle sprain and develop to CAI [4, 6]. ATFL injury can also affect the sensory function of the ankle, and the damage of ligament mechanoreceptors will contribute to proprioceptive impairments. A systematic review and meta-analysis found that patients with CAI had deficits in eversion force sense compared with uninjured control [7]. Reduced in proprioception will further cause the impairment of sensorimotor control, which results in difficult controlling ankle position during the movements and lead to impairment of postural contro and lack of muscle strength. Mechanical instability, proprioceptive deficits and impaired postural control will increase the risk of recurrent ankle sprain and ankle giving way.

4. Assessment and diagnosis

4.1. Clinical history

Clinical history should include previous ankle sprains, recurrent episodes of giving way, pain, swelling and limitation in patients' daily sports life, and this is particularly important when

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establishing a diagnosis of CAI. A systematic review including 3804 participants demonstrated a 46% prevalence of CAI among individuals with a previous ankle sprain [5].

4.2. Physical examination

Physical examination should assess ligament integrity(via palpation and stress tests),ankle range of motion, swelling, tenderness, ligament stability test, muscle strength and functional examination. Netterström-Wedin et al. conducted a systematic review which includes 14 studies with 6302 participants and evaluated 9 clinical tests against imaging assessments. The results show that palpation of the ATFL has high sensitivity (around 95%-100%) and useful for ruling out ligament injury when tenderness is absent, but the specificity is low(0-31%). Another effective way stability tests which include both anterior drawer test and talar tilt test. The anterior drawer test demonstrates relatively high specificity(around 87%) but limited sensitivity(around 54%) for assessment, while negative results cannot excluded the injury [8]. No single test provides sufficient accuracy for ankle instability. Therefore, clinical test results should be evaluated in the context of the patient's ankle injured history and complementary examination findings [9].

4.3. Functional assessment

Functional assessment is significantly important for evaluate CAI because the ligament laxity dose not mean the patient's function status. CAI may involve persistent sensorimotor deficits that are not identified through ligament laxity testing alone, and common functional assessments including the Y-balance test (YBT), single-leg balance and hop tests. Functional performance tests such as landing assessment or single-leg can provide additional information about dynamic ankle instability [10].

Among the various functional assessments, the YBT is one of the most representative and widely used tools. Because the YBT demonstrates excellent test-retest reliability (ICC:0.85-0.91) and good validity. During the test, the participants is instructed to stand on one leg and move the reach indicator with the free leg alone three directions as far as possible. Cut-off values provide clinicians with a useful reference for detecting deficits in dynamic balance.

4.4. Imaging assessment

Imaging will be considered when fracture or more severe damage is suspected. The main methods of imaging assessment include X-ray, ultrasound and MRI. Each imaging assess method answers different question. X-ray is mainly used to exclude the fracture and other bony abnormalities but cannot see the soft tissues like ATFL; Ultrasound is convenience, cheaper and dynamic with extremely high sensitivity. A meta-analysis of 1409 observations found that ultrasound had a pooled sensitivity of around 98.7% and specificity of 94% for chronic ATFL injury, which is even higher than the MRI. However, it cannot detect the whole joint, cartilage or bone edema, for these structures, MRI examination is superior. Additionally, ultrasound is operator-dependent, and its accuracy is affected by the probe frequency and the examiner's experience [11]. MRI is important because the CAI may include more than isolated ligament damage, it can identify other associated lesions and also important for surgical treatment assessment. But it also have some inherent limitations because it is limited to three traditional views (axial, sagittal, coronal), this may lead to diagnostic errors due to the scanning slice. Furthermore, MRI is a static examination which cannot provide dynamic assessment of ligament instability under stress conditions [12].

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Overall, the diagnosis of CAI should combine clinical history, physical examination, functional assessment and imaging together.

5. Treatment

Treatment of ATFL depends on the severity of injury and whether the patients develop ATFL injury to chronic ankle instability. Conservative treatment is generally suggested as the first approach for acute lateral ankle sprains because it may brings better outcome and avoid some risks that happened in surgery, whereas surgical treatment is considered for patients with persistent ankle instability.

5.1. Conservative treatment

Early principle(in acute phase) should be followed is the PEACE. It focus more on protection, elevation, compression and patient education while avoid unnecessary anti-inflammatory modalities.

After that phase, external support such as ankle brace and taping can be used to protect the injured ankle while allowing early functional activity, and flexible supports can help preserve muscle strength compare with rigid immobilization. According to a a systematic review and meta-analysis of 10 randomized controlled trials involving 6662 participants (included athletes from basketball, American football, and soccer, as well as military paratroopers) showed that external ankle support can reduced the risk of recurrent injury compared with no support (OR=0.40, 95%CI:0.3-0.53) .For more severe ankle sprains, immobilization should be used for short-term (up to 10 days according to the same research). However, external support does not directly restore the proprioception or muscle strength. Furthermore, prolonging immobilization period can cause muscle weakness and joint stiffness [10].

Beyond external support and early mobilization, conservative treatment for CAI also includes other approaches such as manual therapy. It mainly consists of ankle joint mobilization and soft tissue techniques which can effectively increase the ankle range of motion.

5.2. Surgical treatment

Around 80%-85% of patients can recover through conservative treatments, but there still some kind of patient those who need surgery. For those who suffered repeated pain, re-injury and ankle instability, surgical treatment can effectively deal with it, especially when the conservation management is failed. The main surgical treatments include anatomical repair and ligament reconstruction. The anatomical repair is aims to restore the native ATFL to its original anatomical position while the ligament construction is considered when the native ligament tissue is severely damaged and cannot keep ankle stability.

For ATFL injury, arthroscopic anatomical repair, particularly the modified Broström procedure is increasingly common because of it's less invasive and can reduce blood loss, also this way can relief painful and return to sports faster. Both open and arthroscopic Broström-Gould procedures can be used to restore the ankle stability. A meta-analysis of 11 studies involving 686 patients (351 use open repair, 335 use arthroscopic repair) compares this two way for treating chronic ankle instability. The results showed that arthroscopic repair associated with earlier ankle weight-bearing (WMD=-1.33 weeks, 95%CI -1.91 to -0.76). Previous meta-analysis of 8 comparative studies involving 408 patients evidence reported mean time to weight-bearing of approximately 9.0 weeks after arthroscopic repair and 14.25 weeks after open repair. Zhao's research also found no significant

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differences between those 2 ways in talar tilt, anterior talar translation, or return to previous level of activities [13].

Surgical is invasive and does not restore all the functional impairments associated with chronic ankle instability, so the rehabilitation after is very important.

6. Rehabilitation

Rehabilitation should target the main functional impairments associated with ATFL injury, which mean it should be tailored for different patients and different impairments. And the main goal is to restore ankle mobility, muscle strength, proprioception and functional performance [10]. The main rehabilitation approaches for ATFL injury and CAI include restoration of range of motion and progressive loading, muscle strength training, proprioception and balance training, neuromuscular control training, functional and sport-specific training, and technology-assisted rehabilitation.

6.1. Early mobility and progressive loading

In the early stage of rehabilitation, range of motion exercise should be introduced to restore ankle mobility and prevent ankle stiffness. Training like ankle circle and dorsiflexion stretch can be practiced and progressed according to the pain. The clinical practice guideline about lateral ankle sprain and chronic ankle instability recommends structured therapeutic exercise including protected active range of motion and progressed functional activity after lateral ankle sprain [10].

6.2. Strength restoration

Strength training is also needed to restore ankle muscle strength, which is the fundamental of normal movement pattern. Progressive resistance and functional strengthening should be added to peroneal muscles and other ankle stabilizers in order to control joint motion and provide dynamic stability.

A randomized controlled trial involving 67 athletes with CAI compared 8 weeks of neuromuscular training, resistance-based strength training and no training. The results show that strength training produce substantial improvements compared with the control condition in measures including the posteromedical direction of the Star Excursion Balance Test. This indicates that restoring muscle strength can improve force production and functional performance at the same time in individuals with CAI [14].

6.3. Proprioception, balance and neuromuscular control

Proprioception, balance and neuromuscular control are interconnected components of sensorimotor function and they are placed together in rehabilitation because they represent a hierarchical continuum of motor control.

Proprioception provides the fundamental sensory input about ankle position and joint motion. Balance is the behavioral outcome of effective proprioceptive processing, it requires the central nervous system to integrate proprioceptive, visual, and vestibular inputs to maintain the body's center of mass within the base of support. Neuromuscular control represents the efferent motor response, which is the ability of the nervous system to activate muscles in a coordinated manner to generate appropriate corrective movements based on sensory information.

The proprioceptive training is the essential part of rehabilitation because it can improve the speed and precision of sensorimotor responses to loss of balance. And the balance training can be seen as an important part of proprioception training, patients usually start with double-leg standing, then

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move to single-leg balance, followed by unstable-surface exercises, dynamic balance and perturbation-based activities. A 2024 systematic review and meta-analysis including 9 randomized controlled trials and 341 patients with CAI found that balance training significantly improved CAIT scores (MD=3.95, 95%CI 3.26-4.64), posteromedial SEBT performance (MD=4.94, 95%CI 1.88-8.00) and FAAM-sports scores (MD=17.74, 95%CI 14.36-21.11) compared with control group. These findings provide evidence that the balance training can improve perceived stability and dynamic balance [15]. However, when compared with strength training, balance training produced greater improvement in CAIT and FAAM-ADL. Recent year research emphasis neuromuscular training, because it has been discovered that though the ROM and strength is recover, the neuromuscular deficits may still exist. The detail methods involve single-leg landing control, dynamic balance, perturbation training, reactive training and external focus training are aim to improve sensorimotor control. And a randomized controlled trial involving 62 athletes with CAI found that though neuromuscular training itself is effective, adding neurofeedback to neuromuscular training generated more improvements in postural control and ankle poprioception than neuromuscular alone [16].

6.4. Technology-assisted rehabilitation

Emerging technologies may enhance convention rehabilitation by providing the objective measurements and real-time feedback. Biofeedback has emerged as a promising adjunct to conventional rehabilitation for individuals with chronic ankle instability, because it provides real-time information about abnormal movement and loading patterns. By providing immediate feedback during movement, biofeedback can help motor learning and help patients adjust their movements [17].

Virtual reality is a promising technology-assisted approach. A recent year study involving 555 patients with ankle instability found that virtual reality bases interventions significantly improved ankle function((SMD=0.86, 95%CI:0.24-1.49), static balance(SMD=1.6, 95%CI=0.74-2.4) and dynamic balance(SMD=0.81, 95%CI:0.36-1.25). improvements were observed in plantar-flexor and eversion muscle strength. So VR is a useful way to enhance balance, functional performanceand patient engagement [18].

By the way, new technology assisted way should not replace the conventional rehabilitation therapeutic exercise. Current studies mainly support that it can used as an additional tool to give more feedback and motivation.

7. Conclusion

ATFL injury can impair lateral ankle stability and, in some cases, contribute to the progression toward chronic ankle instability when mechanical instability, proprioceptive deficits and impaired sensorimotor control persist. Therefore, the management of ATFL injury should not only focus on ligament integrity or pain relief, but should also consider the functional impairments associated with CAI.

Accurate assessment requires a combination of clinical history, physical examination, functional assessment and appropriate imaging. Conservative treatment remains the primary approach for most patients, while surgical intervention may be considered for those with persistent instability despite adequate conservative management. Regardless of the treatment approach, rehabilitation plays an essential role in restoring ankle range of motion, muscle strength, proprioception, balance, neuromuscular control and sport-specific function.

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Current evidence supports the use of progressive exercise programs that incorporate strength, balance, and neuromuscular training to improve functional recovery. Emerging technologies such as biofeedback and virtual reality may provide additional feedback and improve functional outcome. Future research should further investigate individualized rehabilitation strategies and the long-term effectiveness of technology-assisted interventions. Overall, early and comprehensive management of ATFL injury can help reduce recurrent ankle sprains and prevent the progression to CAI.

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