DOI: https://doi.org/10.30795/jfootankle.2024.v18.1858

Special Article

Achilles tendon injuries in high-performance athletes: from tendinopathies to rupture!

Otaviano de Oliveira Júnior[1], Mateus Martins Marcatti[1], Rafael Medeiros Caetano[1], Rodrigo Grossi Pereira de Rezende[1], Thiago Ferrante Rebello de Andrade[1]

1. Department of Orthopedics, Faculty of Medical Sciences of Minas Gerais, Belo Horizonte, MG, Brazil.

Abstract

Objective: Synthesize the current literature on Achilles tendon injuries, focusing on incidence, risk factors, diagnostic methods, and decision-making among the various treatment options in high-performance athletes.

Methods: A search was conducted on PubMed, Scielo, and Scopus databases from 2010 to 2023 using inclusion criteria for studies with athletes and focusing on Achilles tendon injuries.

Results: The incidence of Achilles tendon ruptures is approximately 15% among athletes in high-impact sports. Conservative and surgical interventions have shown that individualized treatment plans optimize recovery and prevent the recurrence of injuries.

Conclusions: Emerging rehabilitation techniques and surgical interventions have demonstrated a positive impact on the results of returning to sport, offering a comprehensive view of the professionals involved in the care of this group.

Level of evidence V; Therapeutic studies - investigating the results of treatment; Expert opinion.

Keywords: Achilles tendon; Tendon injuries; Athletics injuries; Rehabilitation; Rupture.

Introduction

The Achilles tendon, the popular and already established name of the calcaneus tendon, is a robust structure composed mainly of type I collagen, proteoglycans, other structural proteins, and water, providing strength and elasticity. It is the largest and strongest tendon in the human body, with a mean length of 15 cm, formed by the union of fibers from the gastrocnemius and soleus muscles. Vascularization is from the peritendon vessels from the posterior tibial and peroneal arteries being innervated by the tibial nerve. The area of least vascularization is located between 2 and 6 cm near the insertion in the calcaneus, where its rupture occurs most frequently[1]. Achilles tendon injuries are among the most prevalent musculoskeletal injuries found in athletes, especially affecting those involved in high-impact sports, such as athletics (36%), or requiring sudden stops and rapid change of direction, such as basketball (20%) and football (5%). The tendon's limited vascular supply, combined with the repetitive biomechanical stress of sport, makes it highly susceptible to injury[1,2].

Biomechanical factors play a crucial role in Achilles tendon injuries, and inadequate movement patterns, especially in running and jumping, contribute significantly to the risk. Epidemiological data indicate that in the general population, Achilles tendon injuries predominantly affect individuals between the 3rd and 4th decades of life, with a ratio of approximately 2:1 between men and women. However, there is a distinct increase among athletes, predominantly in women and athletes aged 27 to 31, especially in the later stages of their careers. The frequency of tendinopathy is between

Study performed at the Department of Orthopedics, Faculty of Medical Sciences of Minas Gerais, Belo Horizonte, MG, Brazil.

Correspondence: Otaviano de Oliveira Júnior. Alameda Ezequiel Dias 275, Funcionários, 30130-110, Belo Horizonte, Minas Gerais, Brazil. **Email:** ooliveirajr@hotmail.com **Conflicts of interest:** None. **Source of funding:** None. **Date received:** November 12, 2024. **Date accepted:** December 06, 2024. **Online:** December 20, 2024.

How to cite this article: Oliveira Júnior O, Marcatti MM, Caetano RM, Rezende RGP, Andrade TFR. Achilles tendon injuries in high-performance athletes: from tendinopathies to rupture! J Foot Ankle. 2024;18(3):315-27.

1% and 2% in elite adolescent athletes and can reach 9% in recreational athletes. Studies have reported a cumulative incidence of approximately 24% in athletes[2-4].

The aim of this review is to provide a comprehensive analysis of the existing literature on Achilles tendon injuries in athletes. The focus is on epidemiology, risk factors, diagnostic methods, and decision-making among the various treatment options. By synthesizing current research, this review shows insights into best practices for prevention, surgical or nonsurgical treatment, and rehabilitation, emphasizing the need for individualized approaches to optimize outcomes and minimize the risk of new injuries. In addition, the review discusses emerging trends in therapeutic interventions and their potential impact on athletic performance and return to sport[2,5].

Diagnosis and clinical and functional evaluation of Achilles tendinopathies

The diagnosis of Achilles tendon injuries is mostly clinical, based mainly on physical examination. The evaluation of Achilles tendon injuries in the high-performance athlete goes far beyond simply diagnosing the specific condition involving the tendon, in a combination of clinical evaluation, semiological tests, and basic imaging tests for any patient. The clinical history of pain in the posterior region of the calcaneus, of gradual or acute onset with a "popping," "stinging sensation," or local trauma, are important diagnostic signs[2,6].

It is essential to differentiate between insertional and noninsertional injuries, as their clinical presentations, treatment, and prognosis are distinct. Insertional Achilles tendinopathy typically presents with pain and morning stiffness on the calcaneus, especially at the enthesis, where the tendon inserts into the calcaneus. It may or may not be associated with Haglund's deformity, posterior enthesophyte ("spur"), or swelling due to tendinosis with varying degrees of microtears, causing discomfort during running or jumping. Noninsertional injuries occur mainly in the middle portion of the tendon and usually present with higher pain and swelling in the tendon body and with a history of gradual onset, often related to increased physical activity[2,3].

The clinical examination should check for localized pain on palpation, increased body volume or at the Achilles tendon insertion, any local "gap," swelling, and reduced range of motion or strength. The inability of monopodal support in the "tip of the foot," even with physiological equinus and no apparent local "gap," may suggest partial ruptures, especially when associated with insertional tendinopathy[2].

The Silfverskiold test is an essential tool in assessing the flexibility of the gastrocsoleus complex. By evaluating the range of motion and elasticity of the tendon, it can be determined whether it has the necessary flexibility to withstand the repetitive stresses imposed by athletic activities or a shortening (functional equinus). Reduced flexibility can often occur during physical examinations, making this assessment crucial for prevention and rehabilitation strategies[7,8].

Total tendon rupture is typically diagnosed based on the report of a snapping sensation, often described as a "stoned sensation" in the calcaneus, accompanied by three clinical findings that collectively offer high sensitivity and specificity. Palpation revealing a gap in the tendon topography and the classic Thompson and Matles physical tests are particularly significant in this diagnostic context and are well-established methods for confirming a total rupture. Thompson test, performed by squeezing the calf while the patient is in a prone position with the feet hanging from the examination table, evaluates the integrity of the Achilles tendon; no plantar flexion suggests a complete rupture. In the Matles test, the patient needs to flex the knee at 90º while in the same decubitus position. An Achilles tendon rupture will cause the foot to assume a more neutral position instead of maintaining slight physiological plantar flexion. Clinical evaluation is essential and often sufficient for diagnosing tendon rupture[2,6,9].

Imaging tests such as ultrasound and, preferably, magnetic resonance imaging are part of the therapeutic assessment. They are essential for high-performance athletes to confirm the diagnosis and better assess the type and extent of the injury, guiding treatment decision-making. Radiographs help evaluate any association with Haglund's syndrome and rule out intra-tendinous or insertional calcifications[2] (Figure 1).

Diagnosis, clinical, and functional evaluation of high-performance athlete

The professional should be familiar with multidisciplinary assessments involving a comprehensive understanding of pathophysiology and biomechanics, physiotherapy, physical preparation, and sports physiology, considering the underlying biomechanical factors contributing to the injury.

A detailed assessment of the mechanical axis, the balance of muscle forces, degrees of flexibility, and restrictions of joint movements, ankles, and feet is crucial to developing a targeted treatment plan that addresses the primary causes of the injury, especially in athletes, and not only the local treatment of Achilles tendinopathy.

The biomechanics of Achilles tendon injuries involve intrinsic and extrinsic factors. The Achilles tendon is subjected to significant mechanical loads during running, jumping, and accelerating activities. It is essential for effective management, such as sports nutrition and physiology, where overweight influences biomechanical overload[2,10].

Lunge test and ankle dorsiflexion restriction assessments

The Lunge test is a valuable tool for assessing ankle dorsiflexion restriction, often implicated in Achilles tendon injuries. The test is performed with the patient standing upright, aligning the second toe with the front axis while positioned in front of a wall. The dorsiflexion angle is measured by instructing the patient to move their knee forward to touch the wall without lifting their heel from the ground. We make an average of three measurements for each side, the ideal being about 40º of dorsiflexion[8].

Limited dorsiflexion can lead to compensatory mechanisms during gait and athletic activities, increasing tension in the Achilles tendon. Ensuring adequate dorsiflexion through targeted interventions can help reduce the risk of injury and improve functional outcomes in athletes[8].

Biomechanical and axis evaluation

Evaluating the mechanical axis is a fundamental part of the functional evaluation, starting with a standard orthopedic clinical examination associated with static tools such as the podoscope and preferably dynamically, such as the force platform of a kinetic assessment of the lower limbs and even in motion analysis laboratories for a kinematic evaluation.

These evaluations provide information about deviations in valgus or varus alignment, type of steps and dysmetria, and functional due to deficits in strength, muscle fatigue, or joint flexibility, which may increase tension on the Achilles tendon. For the sake of natural selection and sports performance, we rarely encounter high-performance athletes with excessive mechanical axis deviations. Unlike other patients, the most common are functional deficits or subtle deviations[8].

Biomechanical factors predisposing to injury include quadriceps and gluteal muscle strength deficit, reduced impact absorption in running and jumping, abnormal foot alignment with excessive pronation or supination, and changes in gait mechanics. Excessive eccentric load increases tendon tension, especially when slowing down or running uphill activities. Biomechanical imbalances, such as reduced ankle dorsiflexion or restricted internal hip rotation, result in compensatory stresses on the tendon, increasing the risk of injury. Understanding these factors is crucial to developing effective preventive and rehabilitation strategies[8].

According to Aubol and Milner[11], two dominant biomechanical mechanisms exist for developing tendinopathies in running athletes. The “whip” mechanism occurs when runners exhibit excessive and prolonged eversion of the hindfoot, which causes the calcaneal tendon to undergo a “whip” movement. The “tearing” mechanism occurs when excessive contraction of the plantar flexor muscle at the beginning of the posture causes micro tears in the calcaneal tendon[11].

Muscle strength assessment

Several tools are used to assess the muscle strength of the lower limbs and the function of the Achilles tendon and gastrocsoleus complex. The following stand out:

Manual dynamometer

A portable isometric force meter for muscles associated with the Achilles tendon offers a cost-effective and practical solution for rapid clinical evaluations. These devices are particularly useful in a specialist’s office for monitoring pre- and post-intervention outcomes[8].

Isokinetic dynamometers and training platforms (Cybex®, Kineo®)

The isokinetic dynamometer (Cybex®) evaluates muscle strength in controlled movement at constant speed, especially in the knee flexor and extensor muscles, and may have the specific variation for gastrocnemius and soleus, offering a detailed and reliable analysis of muscle performance and balance between agonists and antagonists. Kineo® is a platform that combines training with concentric and

Figure 1. T2-weighted MRI of the ankle comparing Achilles acute rupture types. Simple Achilles tendon (A) vs complex delaminative rupture (B).

eccentric endurance, assessing muscle strength and function during complex movements. The higher cost of these devices is a factor that restricts their use daily, being more restricted to high-performance sports centers[8].

NordBord hamstring testing® and force Frame®

Australian devices developed by Vald Performance are designed to assess the eccentric strength of the hamstring muscles and facilitate training with Nordic exercises (NordBord®). They also enable strength assessments of various core-related joints in the pelvic and hip regions, including the adductors, abductors, and rectus abdominis (Force Frame®), indirectly influencing the gastrocnemius and soleus regions and the Achilles tendon[8].

Hip mobility and biomechanical considerations

Hip mobility assessment, particularly internal rotation, is important in understanding Achilles tendon injuries. The hip-limited internal rotation can lead to compensatory movements that alter the biomechanics and sports movements with an external rotation gait of the lower limb and, consequently, a lateral overload on the foot, increasing the tension in this more lateral portion of the Achilles tendon. These biomechanical changes in a chronic way are particularly harmful, especially in the context of insertional tendinopathy in its central lateral portion, already under greater tension due to the anatomical issue of torsion of the Achilles tendon fibers of each component from the gastrocnemius or soleus[12].

Evaluation of movement in open and closed kinetic chain

The evaluation of open kinetic chain motion involves analyzing movements where the distal limb segment, such as the foot, is free to move, not attached to an object or surface. This contrasts with the closed kinetic chain, where the distal segment is fixed. Both methods are essential in assessing the Achilles tendon, as they help identify weaknesses, muscle imbalances, and specific strength deficits that could contribute to injuries or impair recovery[8].

Evaluation in force platform and gait laboratory

The closed kinetic evaluation on a force platform, such as Vald Performance's ForceDecks model, allows the analysis of different components during these jumping activities, such as concentric (when the muscle shortens) and eccentric (when the muscle stretches) contraction force, in addition to evaluating jump power, performance (height), and unilateral and bilateral movements. The reactive force index (RSI) functional algorithm is also used to measure the ability of the tendon and muscles to generate force quickly and efficiently during activities that involve stretching-shortening cycles and fatigue, such as repetitive jumping. The RSI is particularly important for assessing athletic performance and risk of injury[8].

In selected cases, three-dimensional kinetic and kinematic analysis of movements may be necessary in a motion analysis laboratory, where several cameras with infrared sensors capture the movements of the lower limbs during activities such as gait and running, jumping and squatting on an instrumented treadmill with markers (Figure 2), being able to identify abnormal movement patterns that may predispose to Achilles tendon overload and injury. This assessment helps to understand how the athlete's body moves in specific activities and under fatigue, allowing to identify muscle imbalances or compensations that can be corrected to prevent injuries. They may or may not be associated with an electromyographic evaluation to analyze the electrical activity of the muscles during movement. The electromyographic analysis is performed by placing surface electrodes on the muscles of interest, and electrical activity is recorded during dynamic activities such as running or jumping. It allows you to identify which muscles are being activated, at what intensity, and at what time during a specific activity. This analysis is especially useful in athletes to understand how the muscles of the gastrocnemius soleus complex and other muscles of the lower limbs, mainly hamstrings, quadriceps, and gluteus maximus, are contributing to movement and impact absorption, as well as whether there are abnormal activation patterns that may predispose to injury. These data

Figure 2. Gait lab analysis with 3-D motion capture.

help guide training and rehabilitation interventions, ensuring muscles are activated correctly and efficiently[8].

Physiology of Achilles tendon injury

Achilles tendon injuries encompass a variety of conditions, including tendinopathy, partial ruptures, and complete ruptures. The pathophysiology of Achilles tendinopathy involves both degenerative and inflammatory processes. In chronic tendinopathy, the normal collagen I matrix is interrupted, with increased type III collagen and accumulation of extracellular matrix components, such as proteoglycans and glycosaminoglycans. These processes lead to the loss of the tendon's structural and functional integrity, which becomes macroscopically evident during surgical intervention. The intact fibers of the tendon exhibit an organized white appearance, contrasting with the grayish and duller aspect of the fibrous scar tissue present in areas affected by tendinosis or micro-ruptures. On microscopic examination, it is common to find a disorganized arrangement of collagen fibers, increased vascularization (neovascularization), and tenocytes with altered morphology[13,14]. From a histopathological point of view, edema and less neovascularization are more common in acute tendon injuries[14].

Structural changes lead to a lower capacity to withstand mechanical stresses and losses of elasticity. Due to its elastic properties, the Achilles tendon can stretch up to 4% of its length without injury. An elongation of 6% to 8% leads to microscopic rupture of the fibrils and from 8% to macroscopic failure[1,15].

Physiology of tendinopathy healing

The Achilles tendon healing process is complex and requires careful management at all stages to ensure a successful recovery. By aligning treatment and rehabilitation strategies with the biological stages of healing, we can optimize outcomes and help patients safely return to their activities[14,16].

Achilles tendon healing occurs in three main stages:

Inflammatory stage

This stage occurs immediately after the injury, for a few days, and is characterized by pain, edema, and, in some cases, hyperemia and local heat. Inflammatory cells, such as neutrophils and macrophages, migrate to the injury site to remove damaged tissue and release cytokines and growth factors, including IL6, IL10, COX2, and TGF-β1. These factors are essential to stimulate initial tissue repair. However, prolonged inflammation can lead to complications, such as chronic tendinopathy, characterized by a lower amount of inflammatory cells in the long term, as observed in chronic injuries than acute ones. In addition, early inflammation may involve the activation of neural and inflammatory markers, such as PGP9.5 and CD45, related to the pain and regeneration process. In practice, the difficulty is removing the high-performance athlete for the appropriate treatment at this time of minor injuries[13,14].

Proliferative stage

Tenocyte proliferation and tendon matrix reconstruction with type III collagen and other extracellular components occur during this stage, which lasts from days to weeks. New blood vessels form to nourish the healing tissue. However, the tendon remains weak, and rehabilitation must be careful to avoid new injuries or worsening, as the athlete often remains active and withdraws for treatment only in major injuries or when there is a loss of performance[14,17].

Remodeling stage

This final stage can last from months to stability in about two years, usually the final functional recovery time. In more extensive ruptures and chronic injuries, the tissue may present a denser and more compact structure, with common tendinous fatty infiltrations associated with edema and inflammation in the surrounding tissues, changing tissue conformity[14,16].

Introduction to treatment

Achilles tendon injuries are significant due to their potential impact on an athlete's mobility and performance and the financial loss from being away from activities. Effective treatment is crucial to ensure optimal recovery and prevent long-term complications, especially in minor injuries where the athlete often remains active.

There are two main approaches to managing these tendinopathies: surgically and conservatively. The choice between these treatments depends on several factors, including the severity of the injury, the level of activity, whether or not the athlete's performance is maintained, and their overall health. Understanding the nuances of each approach is essential to personalize the best possible care and achieve successful results[5,9].

The conservative approach to treating Achilles tendon injuries involves several strategies that can be adjusted according to each patient's needs and clinical progression, performed until the athlete maintains performance, even with the injury. Soft tissue treatment was impacted by the PEACE and LOVE protocol[18] an acronym for Protection (P), Elevation (E), Avoid Anti-Inflammatories (Avoid), Compression (C), Education (E), and Load (L), Optimism (O), Vascularization (V), Exercise (E). Since then, we have been changing the concept, reducing the use of cryotherapy and stimulating vascularization with local heat techniques and greater local oxygen supply, evolving exercise protocols described in the middle of the last decade such as Alfredson[19] and "Heavy Slow Resistance" (HSR)[20] which were already widely used, currently level A of evidence mainly in cases of body tendinopathy, with variations for insertional tendinopathies[19,21].

Alfredson Protocol: preferred method for athletes who can maintain regular activity, with three sets of 15 repetitions of eccentric exercises twice a day for six consecutive weeks. This strengthening of the muscles applied daily reduces pain and effectively improves function in patients with tendinopathy[2,22].

"Heavy Slow Resistance" (HSR)[20]: involves high mechanical loads in slow and controlled resistance movements with concentric and eccentric exercises, applied three times a week for 12 consecutive weeks, effectively promoting tissue healing and improving tendon function. The load is adjusted according to the patient's progression, preferably with the athlete away from activities for treatment associated with other rehabilitation methods[20].

In addition, combining Alfredson and RSH protocols, adding core exercises at least twice a week, with the strengthening of the quadriceps and gluteus maximum and medius, may be advantageous, allowing the personalization of rehabilitation based on clinical evolution[23].

Advanced therapies adjuvant to treatment

Shock wave therapy (SWT): Uses high-intensity sound waves to promote mechanical microtrauma in biological tissue, promoting controlled tendon healing, effective in treating chronic tendinopathy, level B of evidence when associated with eccentric exercises in physiotherapy. It can be the radial model, which is more accessible, or the focal model, which is reserved for more severe cases and with the athlete's removal for treatment. Radial SWT can also be used for myofascial release, especially for Silfverskiold-positive athletes[24,25] (Figure 3).

High-Intensity laser therapy: The bio-stimulation and acceleration of cellular processes stimulated by the laser reduce inflammation, stimulate oxygen uptake and blood circulation, facilitate and accelerate healing, and contribute to pain reduction. Long-term efficacy is still under study, and the higher cost of the equipment restricts its use to high-performance athletes[12] (Figure 3).

Tissue Regeneration Therapy (Tecar®-Therapy®): Technique with high-frequency electromagnetic energy to promote tendon healing with increased circulation by deep heat, allowing dynamic association with manual therapy techniques for myofascial release and muscle strengthening exercises during its application, very important as activation before physical activities and often requested by high-performance athletes for the feeling of well-being and rapid response, but which still requires further studies to confirm its long-term effectiveness[8] (Figure 3).

Figure 3. Adjuvant therapies for non-surgical treatment of Achilles disorders. (A) Extracorporeal shock wave therapy (B) High-intensity laser (C) Tecar Therapy (D) Intratissue percutaneous electrolysis.

Intratissue percutaneous electrolysis (EPI®): A technique described by Abat et al.[26] which uses a combination of mechanical (needles) and electrical (galvanic current) stimulation to promote a controlled reparative microinjury in the fibrocicatricial tissue area of the tendon, preferably guided by ultrasound images. It is also a therapy frequently used and requested by high-performance athletes due to the feeling of we ll-being and immediate analgesia for an active athlete, despite evidence still being limited to publications with small samples, clinical heterogeneity, and high risk of bias[27,28] (Figure 3).

Other physiotherapeutic devices, such as pulsatile ultrasound, LED light plates, magnetotherapy, and super inductive system (SIS®) with an electromagnetic field, in addition to the most diverse electrotherapy devices recently launched on the market, are part of the treatment in athletes. However, they still have limited evidence in isolation and may be more widespread in the future (Figure 4).

Pharmacological Interventions: There is no robust evidence to support the use of nonsteroidal anti-inflammatory drugs and systemic corticosteroids or in local infiltrations, with or without hyaluronic acid for treating Achilles tendinopathy, with limited benefits compared to conservative approaches. Intra-tendon infiltration is a risk for rupture and should not be performed, and peritendon hyaluronic acid may give some analgesia, even if transient[29,30].

Biologic therapies

The association of adjunct techniques such as platelet-rich plasma (PRP) infiltrations or stem cell therapy of iliac crest aspirates, whether pure (BMA) or concentrated (BMAC), have been studied to improve tendon healing and regeneration, with some satisfactory results mainly with the use of BMA for the non-surgical treatment of chronic insertional tendinopathies. The controversial PRP does not yet have scientific evidence, either for use in chronic tendinopathies or as an adjunct to treating acute ruptures and, so far, should not be indicated[9,31,32].

Thus, treatment selection should be based on the patient's individualized assessment, considering their response to treatment and the injury stage. The combination of conservative techniques and advanced therapies offers a comprehensive approach to Achilles tendon rehabilitation. The improvement in clinical outcomes with this treatment, especially for body tendinopathies in athletes, practically transformed in historical records surgical techniques described in the past, involving isolated tenoplasties, simple myofascial release, or Achilles paratendon. Surgery for chronic Achilles tendinopathies should be indicated when the athlete is losing physical or technical performance and has not responded to treatment with well-defined clinical protocols, which is why the surgeon is aggressive and reasonable when he sees the need to change the treatment conduct[7,8].

Approach to total Achilles tendon ruptures

Decision-making when facing a total rupture of the Achilles tendon in an athlete is an extremely controversial subject, even among sports trauma and foot and ankle surgery specialists. We have to be aware of the factors involved in the rupture, such as the age of the athlete (under 30 years, better prognosis), the specificity and position of performance in the sport practiced, the weight of the athlete (the authors

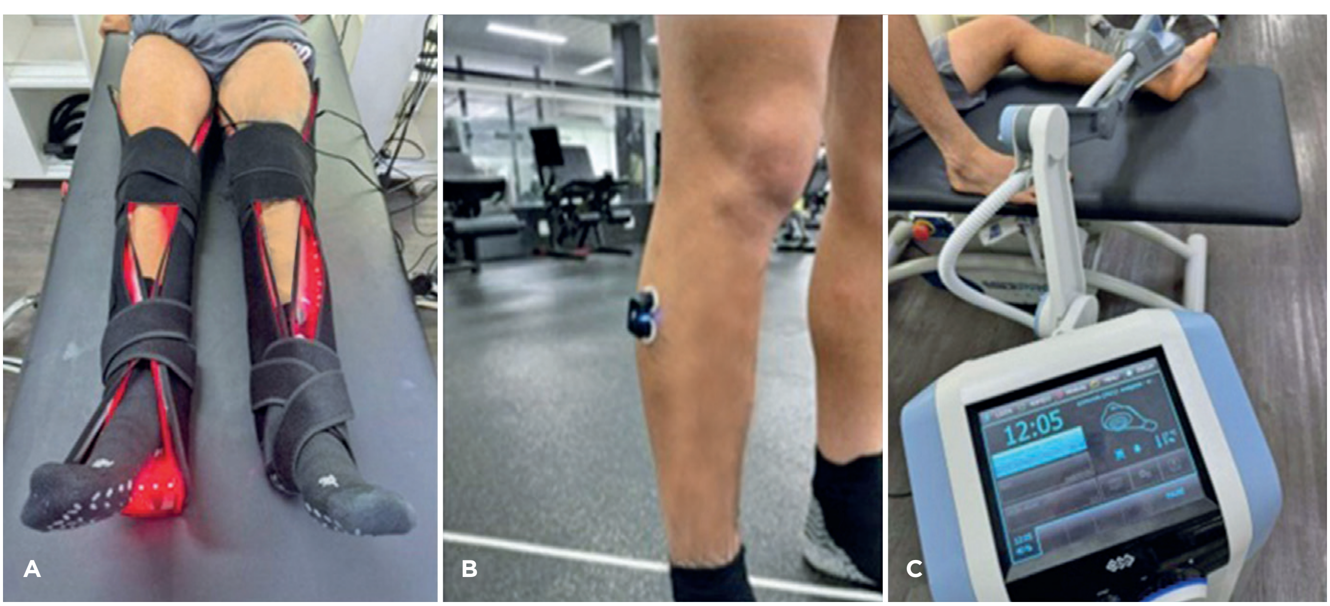

Figure 4. Devices used for athlete's management for prevention and treatment of Achilles disorders. (A) LED light therapy (B) Electromyography (C) Super inductive system®.

follow the Olympic division model between patients with less or over 90 kg of body weight), the tissue quality due to any previous tendinopathy, the rupture site (the lower and insertional the worse the healing potential), the rupture type (classic "cauda equina" in the body, proximal myotendinous junction, delaminative, insertional juxta with or without spur avulsion or calcifications, complex), as well as factors such as associated diseases (autoimmune, diabetes), smoking (traditional or electronic cigarettes), peripheral arterial insufficiency and even the misuse of anabolic steroids by athletes who are not subject to frequent and more rigorous anti-doping tests (Figure 5).

Although the conservative treatment of total Achilles tendon ruptures has advanced since the publications of the functional method in the middle of the last decade, with equinus immobilization and protected early load, when discussing treatment in professional athletes, it is predominantly surgical, intending to restore tendon integrity and function quickly and with the least possible loss of flexibility, strength, and endurance in repair. Suppose conservative treatment is chosen for total ruptures, even due to potential patient preference. In that case, we must consider the presence of clinical criteria such as no pain or previous tendinopathy, the rapid start of treatment still within stage I of the biological healing process, a rupture in the tendon body, and a distance between the stumps of less than 5 mm in plantar flexion or 10 mm in neutral[8,16]. A literature review showed that when appropriate criteria are met, conservative treatment can culminate in results comparable to surgical repair[13].

A meta-analytical review of Ochen in 2019[33] found no significant difference in re-rupture rates between surgical and conservative treatments, especially when mobilization and early loading protocols were employed. In addition, the risk of complications, such as wound infection and nerve damage, was significantly lower in the conservative group. The bias of these reviews is that among athletes, it is extremely common to report previous pain and the presence of tendinopathy to varying degrees, already being a reason for the contraindication of conservative treatment in this public of greater physical demand, different from the general population. Either way, informed decision-making is crucial. Patients should be educated about both approaches' potential risks and benefits, including the possibility of re-rupture, loss of tension through the indirect healing process, differences in rehabilitation time, and long-term functional outcomes[9,33,34].

The surgical management of Achilles tendon injuries is essential to restore the perfect tension and the quality of the tendon healing tissue after rupture, which are the main factors for adequate recovery of function, preventing performance loss and long-term complications. The choice of surgical technique depends on the type, time, and severity of the injury, as well as the functional demands and general health of the patient described above.

This section presents an overview of the main surgical approaches to Achilles tendon injuries, including open repair, percutaneous repair, and minimally invasive techniques, all supported by the latest literature[30,35,36].

Open repair

Open Achilles tendon repair is a well-established and classic method for treating complete ruptures and chronic tendinopathies. This technique involves a direct incision at the back of the ankle to access the damaged tendon, with excellent visualization and direct access to the tendon,

Figure 5. Different types of Achilles tendinopathy. (A) Simple midportion rupture (B) Complex delaminative rupture (C) Complex midportion and insertional rupture (D) Insertional with severe tendinopathy.

allowing accurate repair of the ruptured fibers. However, it is associated with a higher risk of wound complications and infection than less invasive methods[29,30,36,37] (Figure 6).

Key steps

Incision and exposure: A longitudinal incision is made along the back of the leg, which typically extends from just above the tendon insertion into the posterior tuberosity of the calcaneus to the middle part of the calf proximally. Careful dissection exposes the Achilles tendon, preserving the surrounding neurovascular structures[23,30,36].

Tenoplasty with debridement and repair: Any degenerated tissue is removed to expose the healthy tendon edges. The ruptured ends of the tendon are then united and sutured with non-absorbable suture (metalized polyester type FiberWire® Arthrex or UltraBraid® Smith & Nephew or similar from other manufacturers) or absorbable suture (Vicryl® 1.0 mm). Contraindications for single braided polyester threads (Ethibond®) are due to the high risk of inflammatory reaction and surgical wound complications due to the superficiality of the Achilles tendon. Techniques such as Krackow suture, modified Krackow with suture at a distance from the rupture focus (authors' preferences), and modified Kesller or Bunnell suture are commonly used to ensure a safe repair[29,30].

Rehabilitation and postoperative care: The leg is immobilized in physiological plantar flexion with a cast or orthosis in the postoperative period, facilitating tendon healing and with less local tension. The gradual introduction of load and rehabilitation exercises is performed according to the progress of healing, preferably with the assistance of a physiotherapist, who will perform the functional exercises early. The protected load is, so far, still controversial, despite evidence since the middle of the last decade that it stimulates growth factors with greater strength of resistance and speed in the biological healing process and the authors' preference for conducting the release after two to three weeks of surgery, provided that with adequate healing of the surgical wound[36,38].

Tendon reinforcements and transfers

Tendon reinforcement can be used to increase the resistance of the repair, leading to good quality type I collagen in cases of extensive Achilles tendon ruptures with chronic degeneration, insertional just tendinopathies, delaminative ruptures, athletes weighing more than 90 kg (authors' opinion) or when the surgeon does not feel total safety in their direct repair.

Reinforcement techniques include the most diverse tendon transfers described using autologous grafts, such as the flexor hallucis longus tendon, whether in a double (Wapner) or single (Wilcox, Hansen, Den Hartog), short peroneal (Turco, Teufler, Turco, and Spinela), thin plantar (Lynn), flexor digitorium longus (Mann, Clain, and Baxter), hamstring, either gracilis or semitendinosus, isolated or combined (Maffulli), which can be fixed in the calcaneus or sutured directly to the Achilles tendon to provide greater stability and mechanical strength in the repair. Although effective, grafts for reinforcement can increase the surgical time and complexity of the procedure.

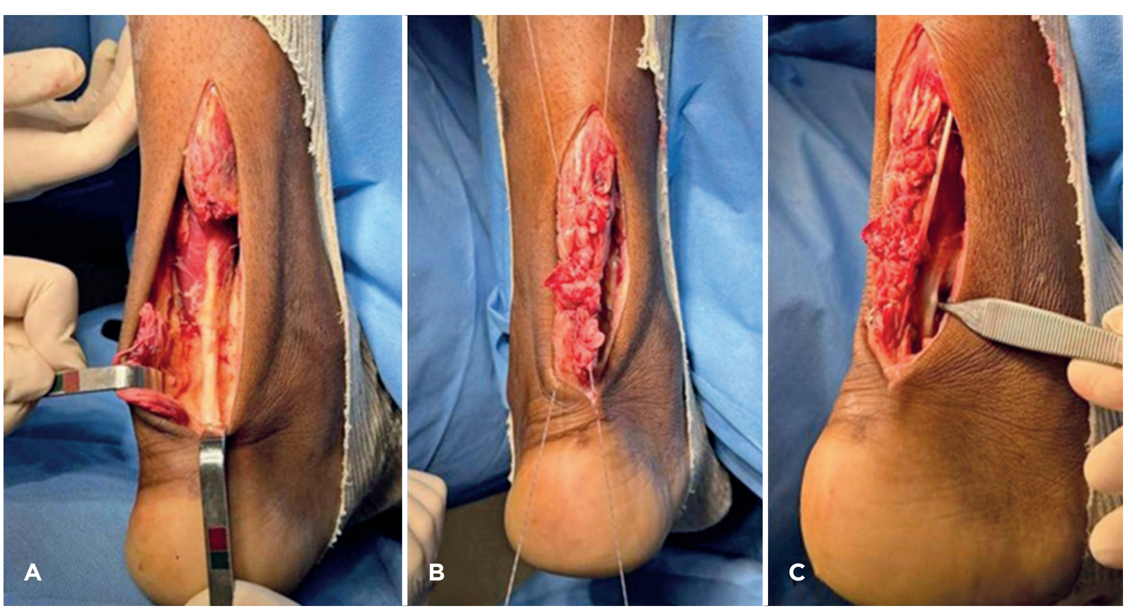

Figure 6. Open Achilles tendon repair in a soccer player with complete rupture with flexor hallucis longus tendon transfer and reinforcement of plantaris tendon. (A) Achilles tendon gap with associated flexor hallucis longus tendon transfer (B) Krakow suture of the tendon stumps (C) Final appearance.

The allograft tends to be reserved for cases of failure in conventional techniques or in exceptional situations, such as in cases of re-rupture in athletes who have already used the grafts available for any other reason[9,22,36].

Since Wapner's publications in 1993[22], still using the dual route, the transfer of the flexor hallucis longus tendon has been widespread, being considered an excellent substitute even when the Achilles tendon is very compromised due to its anatomical proximity and biomechanical function similar to the Achilles tendon. Currently, with the wide dissemination of the technique and the safety in the use of the single route for the transfer of flexor hallucis longus tendon, fixed in a bone tunnel in the calcaneus using an interference screw, we have additional support to the repaired Achilles tendon and promoting a functional recovery process without major secondary losses, even in athletes who require starting and jumping in their sports modalities, increasing very little the time and complexity of the procedure[9,22,39].

Biological and synthetic materials

Biological materials such as collagen matrices, fibrin-rich plasma (FRP) membranes, and other biomaterials are being studied extensively. They can be used as adjuvants to support tissue regeneration and offer additional reinforcement in the healing process. Studies suggest that this biological material can help guide the growth of new tendon tissue, improving repair resistance over time, but still without great scientific evidence[32].

Alternatively, synthetic materials such as polyester grafts, metalized polyester ribbons, or polypropylene may provide immediate structural support, especially in patients with significant tendon degeneration. To date, this synthetic material is without evidence of improvement when publications are withdrawn without conflict of interest and may even be a source of calcaneal pain due to the different mechanical resistance with the biological tissue when under tension upon return to sport[9,10,13,37].

Percutaneous repair

Percutaneous repair is a less invasive alternative to open surgery, often used for acute and less complex ruptures of the Achilles tendon body. This technique involves small incisions to perform the repair through the skin, using a specialized set of instruments, including percutaneous needles or specific suture threads, with several techniques described since the first publications of Ma and Griffith in 1977,[40] without a devitalization of peritendon soft tissues, the need for tourniquet and the greater risk of surgical wound complications, but with greater complications of iatrogenic injuries in the sural nerve, loss of suture tension or re-rupture. The evolution of percutaneous repair methods, as in the studies of Webb and Bannister (1999)[41], Assal and Achillon (2002)[42], Carmont and Maffulli (2007)[43], as well as the introduction of instruments that allow intra-tendinous suture threads (Amlang et al., 2006)[44], or intra-tendinous and blocked in the stumps with specific guides (PARS Arthrex® 2012, Figure 7), reduced the risks of sural nerve injuries or re-rupture, especially when associated with the functional protocol with protected early load. After week three, postoperative conduction may be in the protected early load functional protocol. Still, percutaneous techniques may be less effective in cases when precise alignment and tendon tension are crucial, such as, in the authors' opinion, in athletes

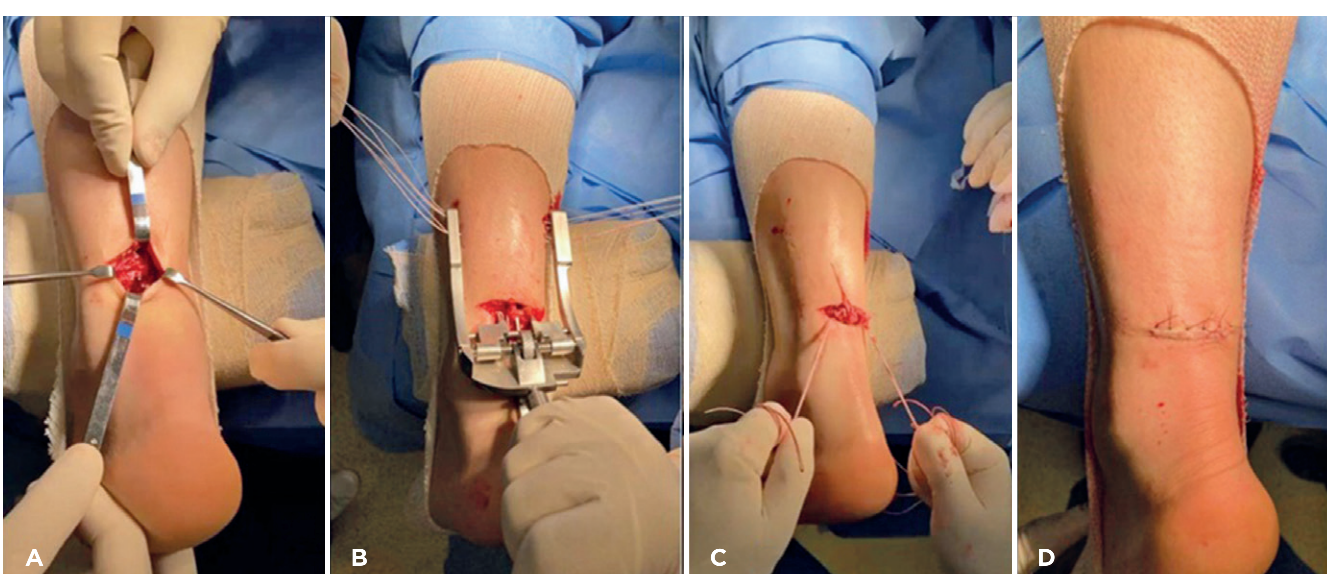

Figure 7. Minimally invasive Achilles tendon repair (PARS Achilles Jig System-Arthrex®) in a gymnastic athlete with complete rupture.

weighing more than 90 kg, extensive tendon degeneration, delaminative ruptures, or insertional tight ruptures with poor tissue mass quality for repair, even with modern specific tools and the use of guides with metalized polyester tapes and accessory fixation with anchor screws (PARS Speed Bridge Arthrex® 2019)[36,45].

Minimally Invasive Techniques

Minimally invasive techniques have gained popularity for their potential to reduce surgical trauma and speed recovery. These techniques range from percutaneous exostectomies of bony prominences, as in Haglund, to endoscopic tendon transpositions, either for chronic tendinopathies or for acute ruptures, as described in the study of Abdelatif and Batista[39], pointing out that this approach may be promising in the future if reproducible in other centers[39,46,47].

These techniques provide less postoperative pain, smaller incisions, and faster recovery. They are particularly suitable for patients with less extensive injuries requiring a faster return to activity[5,9,15,35,47].

Final considerations

The pathophysiology of these injuries reveals a multifaceted process of degeneration and inflammation that compromises the structural and functional integrity of the tendon. Understanding biomechanical changes and predisposing factors is essential for prevention and treatment. Diagnostic approaches that combine detailed clinical evaluation, semiological testing, and imaging are crucial for accurate diagnosis and to guide appropriate treatment.

The surgical approach to Achilles tendon injuries should be tailored to the specific characteristics of the injury and the patient's needs. Open repair remains the gold standard for complex cases, offering direct access for proper tendon repair and tension, while percutaneous and minimally invasive techniques offer less surgical trauma and faster recovery for simpler cases. Advances in surgical techniques and biological therapies continue to improve the effectiveness of Achilles tendon repair, leading to better outcomes for patients. Understanding the nuances of each technique allows orthopedists to make informed decisions and optimize treatment strategies for Achilles tendon injuries.

High-performance sports may not be as healthy as recreational sports. A comprehensive understanding of Achilles tendon injuries in athletes, from pathophysiology and biomechanics to diagnostic and therapeutic approaches, is critical for effectively managing these complex conditions. Tendon injuries represent a significant challenge in orthopedic practice due to the high functional demand and biomechanical requirements imposed by the sport.

Achilles tendon injuries are frustrating for athletes and physicians, and some performance loss must occur after an injury, whether total or partial.

In short, an integrated, evidence-based approach to Achilles tendon injuries is essential to optimize clinical outcomes and long-term functionality. Continuous research and innovation in diagnostic and treatment strategies will improve the management of these injuries and promote effective recovery for affected patients.

Authors' contributions: Each author contributed individually and significantly to the development of this article: OOJ *(https://orcid.org/0000-0001-7766-9974), and MMM *(https://orcid.org/000-0002-8045-3178) Conceived and planned the activities that Led to the study, performed the surgeries, data collection, approved the final version; RMC *(https://orcid.org/0000-0002-1007-3532) Performed the surgeries, formatting of the article, bibliographic review, approved the final version; RGPR *(https://orcid.org/0009-0006-1426-798X) Wrote the article, formatting of the article, bibliographic review, approved the final version; TFRA *(https://orcid.org/0009-0006-3426-2334) Wrote the article, formatting of the article, bibliographic review, approved the final version. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Dayton P. Anatomic, Vascular, and Mechanical Overview of the Achilles Tendon. Clin Podiatr Med Surg. 2017;34(2):107-13.
2. Silveira PF, Santos CM, Oliveira LF, Silva JB. Lesões do Aquiles - Parte 1: Tendinopatias. Rev Bras Ortop. 2020;55(3):239-44.
3. Patel KA, O'Malley MJ. Management of Achilles Tendon Injuries in the Elite Athlete. Orthop Clin North Am. 2020;51(4):533-9.
4. Khalil LS, Jildeh TR, Tramer JS, Abbas MJ, Hessburg L, Mehran N, et al. Effect of Achilles Tendon Rupture on Player Performance and Longevity in National Basketball Association Players. Orthop J Sports Med. 2020;8(11):2325967120966041.
5. Lantto I, Heikkinen J, Flinkkila T, Ohtonen P, Siira P, Laine V, et al. A Prospective Randomized Trial Comparing Surgical and Nonsurgical Treatments of Acute Achilles Tendon Ruptures. Am J Sports Med. 2016;44(9):2406-14.
6. Hattrup SJ, Johnson KA. A review of ruptures of the Achilles tendon. Foot Ankle. 1985;6(1):34-38.
7. Buddecke D Jr. Acute Achilles Tendon Ruptures. Clin Podiatr Med Surg. 2021;38(2):201-26.
8. Malliaras P. Physiotherapy management of Achilles tendinopathy. J Physiother. 2022;68(4):221-37.

9. Machado S, Moreira F, Ribeiro de Oliveira P. O aloenxerto osteotendinoso aquiliano: uma alternativa valiosa para a reconstrução em contexto de lesão crônica do tendão de Aquiles. Rev Med Desportiva Informa. 2021;12(5):17-19.
10. Trofa DP, Noback PC, Caldwell JE, Miller JC, Greisberg JK, Ahmad CS, et al. Professional Soccer Players' Return to Play and Performance After Operative Repair of Achilles Tendon Rupture. Orthop J Sports Med. 2018;6(11):2325967118810772.
11. Aubol KG, Milner CE. Whipping or tearing? The biomechanics of Achilles tendinopathy in rearfoot strike runners. The Foot. 2024;59:102082.
12. Ko VM, Cao M, Qiu J, Fong IC, Fu SC, Yung PS, et al. Comparative short-term effectiveness of non-surgical treatments for insertional Achilles tendinopathy: a systematic review and network meta-analysis. BMC Musculoskelet Disord. 2023;24(1):102.
13. Pabón MA, Naqvi U. Achilles tendinopathy. StatPearls Publishing; 2024.
14. Klatte-Schulz F, Minkwitz S, Schmock A, Bormann N, Kurtoglu A, Tsitsilonis S, et al. Different Achilles Tendon Pathologies Show Distinct Histological and Molecular Characteristics. Int J Mol Sci. 2018;19(2):404.
15. Mansfield K, Dopke K, Koroneos Z, Bonaddio V, Adeyemo A, Aynardi M. Achilles Tendon Ruptures and Repair in Athletes-a Review of Sports-Related Achilles Injuries and Return to Play. Curr Rev Musculoskelet Med. 2022;15(5):353-61.
16. Massen FK, Shoap S, Vosseller JT, Fan W, Usseglio J, Boecker W, et al. Rehabilitation following operative treatment of acute Achilles tendon ruptures: a systematic review and meta-analysis. EFORT Open Rev. 2022;7(10):680-91.
17. Cook JL, Rio E, Purdam CR, Docking SI. Revisiting the continuum model of tendon pathology: what is its merit in clinical practice and research? Br J Sports Med. 2016;50(19):1187-91.
18. Dubois B, Esculier JF. Soft-tissue injuries simply need PEACE and LOVE. Br J Sports Med. 2020;54(2):72-73.
19. Habets B, Cingel R. Eccentric exercise training in chronic mid-portion Achilles tendinopathy: A systematic review on different protocols. Scand J Med Sci Sports. 2015;25(1):3-15.
20. Beyer R, Kongsgaard M, Hougs Kjær B, Øhlenschlæger T, Kjaer M, Magnusson SP. Heavy slow resistance versus eccentric training as treatment for Achilles tendinopathy: A randomized controlled trial. Am J Sports Med. 2015;43(7):1704-11.
21. Laurent D, Walsh L, Muaremi A, Beckmann N, Weber E, Chaperon F, et al. Relationship between tendon structure, stiffness, gait patterns, and patient-reported outcomes during the early stages of recovery after an Achilles tendon rupture. Sci Rep. 2020;10(1):20757.
22. Wapner KL, Pavlock GS, Hecht PJ, Naselli F, Walther R. Repair of chronic Achilles tendon rupture with flexor hallucis longus tendon transfer. Foot Ankle. 1993;14(8):443-9.
23. Fabião L, Araújo de Azevedo J, Andrade R, Espregueira-Mendes J, Pereira BS. Rutura do Tendão de Aquiles: do Diagnóstico à Retoma Desportiva. Rev Med Desp Inf. 2023;14(1):8-11.
24. Feeney KM. The Effectiveness of Extracorporeal Shockwave Therapy for Midportion Achilles Tendinopathy: A Systematic Review. Cureus. 2022;14(7):e26960.
25. Silbernagel KG, Hanlon S, Sprague A. Current Clinical Concepts: Conservative Management of Achilles Tendinopathy. J Athl Train. 2020;55(5):438-47.
26. Abat F, Sánchez-Sánchez JL, Martín-Nogueras AM et al. Randomized controlled trial comparing the effectiveness of the ultrasound-guided galvanic electrolysis technique (USGET) versus conventional electro-physiotherapeutic treatment on patellar tendinopathy. J Exp Orthop 2016;3:34.
27. Calder JD, Saxby TS. Early, active rehabilitation following mini-open repair of Achilles tendon rupture: a prospective study. Br J Sports Med. 2005;39(11):857-9.
28. Augustyn D, Paez A. The effectiveness of intratissue percutaneous electrolysis for the treatment of tendinopathy: a systematic review. S Afr J Sports Med. 2022;34(1):1-7.
29. Kadakia AR, Dekker RG 2nd, Ho BS. Acute Achilles Tendon Ruptures: An Update on Treatment. J Am Acad Orthop Surg. 2017;25(1):23-31.
30. Maffulli N, Giai Via A, Oliva F. Chronic Achilles Tendon Rupture. Open Orthop J. 2017;11:660-9.
31. Keene DJ, Alsousou J, Harrison P, Hulley P, Wagland S, Parsons SR, et al. Platelet rich plasma injection for acute Achilles tendon rupture: PATH-2 randomised, placebo controlled, superiority trial. BMJ. 2019;367:l6132.
32. Batista J, Quesada A, Pereira HMD, Casola L, Matías-Joannas G, Arrondo G. Preliminary results of acute Achilles tendon rupture treated with platelet-rich plasma and immobilization. J Foot Ankle. 2024;18(2):202-8.
33. Ochen Y, Beks RB, van Heijl M, Hietbrink F, Leenen LP, van der Velde D, Heng M, van der Meijden O, Groenwold RH, Houwert RM. Operative treatment versus nonoperative treatment of Achilles tendon ruptures: systematic review and meta-analysis. BMJ. 2019;364:k5120.
34. Hsu AR, Jones CP, Cohen BE, Davis WH, Ellington JK, Anderson RB. Clinical Outcomes and Complications of Percutaneous Achilles Repair System Versus Open Technique for Acute Achilles Tendon Ruptures. Foot Ankle Int. 2015;36(11):1279-86.
35. LaPrade CM, Chona DV, Cinque ME, Freehill MT, McAdams TR, Abrams GD, et al. Return-to-play and performance after operative treatment of Achilles tendon rupture in elite male athletes: a scoping review. Br J Sports Med. 2022;56(9):515-20.
36. Maffulli G, Buono AD, Richards P, Oliva F, Maffulli N. Conservative, minimally invasive and open surgical repair for management of acute ruptures of the Achilles tendon: a clinical and functional retrospective study. Muscles Ligaments Tendons J. 2017;7(1):46-52.
37. Jack RA 2nd, Sochacki KR, Gardner SS, McCulloch PC, Lintner DM, Cosculluela PE, et al. Performance and Return to Sport After Achilles Tendon Repair in National Football League Players. Foot Ankle Int. 2017;38(10):1092-9.
38. Amendola F, Barbasse L, Carbonaro R, Alessandri-Bonetti M, Cottone G, Riccio M, De Francesco F, Vaienti L, Serror K. The Acute Achilles Tendon Rupture: An Evidence-Based Approach from the Diagnosis to the Treatment. Medicina. 2022;58(9):1195.
39. Abdelatif NMN, Batista JP. Outcomes of Percutaneous Achilles Repair Compared With Endoscopic Flexor Hallucis Longus Tendon Transfer to Treat Achilles Tendon Ruptures. Foot Ankle Int. 2022;43(9):1174-84.
40. Ma GW, Griffith TG. Percutaneous repair of acute closed ruptured achilles tendon: a new technique. Clin Orthop Relat Res. 1977;(128):247-55.
41. Webb JM, Bannister GC (1999) Percutaneous repair of the ruptured tendon Achilles. J Bone Joint Surg 81-B:877–880
42. Assal M, Jung M, Stern R, Rippstein P, Delmi M, Hoffmeyer P. Limited open repair of Achilles tendon ruptures: a technique with a new instrument and findings of a prospective multicenter study. J Bone Joint Surg Am. 2002;84(2):161-70.

43. Carmont MR, Maffulli N. Modified percutaneous repair of ruptured Achilles tendon. Knee Surg Sports Traumatol Arthrosc. 2008;16(2):199-203.
44. Amlang MH, Christiani P, Heinz P, Zwipp H. The percutaneous suture of the Achilles tendon with the Dresden instrument. Oper Orthop Traumatol. 2006;18(4):287-99.
45. Cukelj F, Bandalovic A, Kuharic I, Bobinac D, Miletic D, Bakota B, et al. Histological and biomechanical analysis of Achilles tendon rupture. Int Orthop. 2015;39(12):2379-84.
46. Baltes TPA, Zwiers R, Wiegerinck JI, van Dijk CN. Surgical treatment for midportion Achilles tendinopathy: a systematic review. Knee Surg Sports Traumatol Arthrosc. 2017;25(6):1817-38.
47. Pereira VA, de Oliveira Junior O, Bertolinni FM, Silveira GHC Fortes, Pádua BJ, Marcatti MM. Description of minimally invasive technique for the surgical treatment of acute Achilles tendon ruptures with locking suture – a low-cost option. J Foot Ankle. 2023;17(1):79-85.