



Achilles Tendon Ruptures and Repair in Athletes—a Review of Sports-Related Achilles Injuries and Return to Play

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Abstract

Purpose of Review Achilles tendon ruptures (ATR) are detrimental to sports performance, and optimal treatment strategy and guidelines on return to play (RTP) remain controversial. This current review investigates the recent literature surrounding nonoperative versus operative management of ATR, clinical outcomes, and operative techniques to allow the athlete a successful return to their respective sport.

Recent Findings The Achilles tendon (AT) is crucial to the athlete, as it is essential for explosive activities such as running and jumping. Athletes that sustain an ATR play in fewer games and perform at a lower level of play compared to age-matched controls. Recent studies also theorize that ATRs occur due to elongation of the tendon with fatigue failure. Biomechanical studies have focused on comparing modes of fixation under dynamic loading to recreate this mechanism.

Summary ATRs can be career-ending injuries. Fortunately, the recent incorporation of early weight-bearing and functional rehabilitation programming for non-operative and operative patients alike proves to be beneficial. Especially for those treated nonoperatively, with the incorporation of functional rehabilitation, the risk of re-rupture among non-operative patients is beginning to approach the historical lower risk of re-rupture observed among patients treated operatively. Despite this progress in decreasing risk of re-rupture particularly among non-operative patients, operative managements are associated with unique benefits that may be of particular interest for athletes and active individuals. Recent studies demonstrate that operative intervention improves strength and functional outcomes with more efficacy compared to nonoperative management with rehabilitation. The current literature supports operative intervention in elite athletes to improve performance and shorten the duration to RTP. However, we acknowledge that surgical intervention does have inherent risks. Ultimately, most if not all young and/or high-level athletes with an ATR benefit from surgical repair, but it is crucial to take a stepwise algorithmic approach and consider other factors, which may lead towards nonoperative intervention. These factors include age, chronicity of injury, gap of ATR, social factors, and medical history amongst others in this review.

Keywords Achilles tendon · Achilles tendon rupture · Athlete injury · Return to play

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Achilles tendon ruptures (ATRs) are one of the most common tendon injuries to plague athletes [1]. The overall incidence of ATRs is increasing, with sports-related injury being the most common cause [1–4]. In the general population, ATRs affect between 8 and 18 per 100,000 persons [5].

Anatomy and Biomechanics

The AT is the strongest and thickest tendon in the human body and is also the primary plantar flexor of the ankle [6]. It is subjected to immense loads, with 2–3 times a person's body weight with walking, and up to ten times a person's body weight with high-impact activities [5]. The AT is comprised of the medial and lateral gastrocnemius and soleus muscles, which course distally and rotate 90° internally before inserting on the posterior calcaneal tuberosity [6].

The histological properties of the AT are unique and allow the AT to exhibit specific properties. The AT lacks a synovial sheath unlike most tendons. Rather, the AT is surrounded by a single layer of paratenon, a thin membrane-like structure composed of loose connective tissue, and specialized cells (tenocytes), among other cell types [3, 7, 8]. The paratenon sheath allows the AT to slide and allows the blood vessels to enter and supply the AT [7]. The tenocytes, within the paratenon, are specialized cells formed from the tenoblasts which produce collagen cell types and allow for the regeneration of type III collagen after AT rupture. With increased production of type III collagen in contrast to type I, this causes the AT to become less resistant to tensile forces [3, 5, 9]. However, overall collagen contributes to AT's high tensile strength with 90% being type I collagen and the remainder being composed of type III, which can also be found in the fibrocartilage of the AT [3, 9].

There are several anatomical factors that contribute to AT ruptures. Based on cadaveric studies, the average length of the AT is 15 cm, with the narrowest point being 2–6 cm proximal to the calcaneal insertion [6, 9]. Chen et al.'s cadaveric study depicts the average width of the tendon at different distances from the calcaneal insertion point, with distances ranging from 1 to 14.8 cm [10]. This variability in muscle fiber length and thickness, predisposes the AT to rupture. The blood supply to the AT has also been studied, with the posterior tibial artery supplying the proximal and distal sections, and the peroneal artery supplying the mid-section [10]. Furthermore, the nature of the AT spiraling 90° as it inserts into the calcaneus and the hypovascular region of the AT contributes to a propensity for rupture in the AT [11]. Figure 1 depicts the region 2–6 cm proximal to the insertion point, having a vascular watershed area, making this region prone to pathology [10].

Biomechanics of Achilles Tendon Ruptures

The AT plays a major role in the absorption of energy caused by the mechanical shock of ground reaction forces. Although athletes often suffer ruptures due to acute loading, and approximately 90% occur during acceleration or deceleration during running, there is often evidence of prior degenerative changes [12–17]. The prevalence of ruptures during these explosive activities is due to the short relaxed tendon rapidly being lengthened with an oblique load [14, 15]. However, no evidence suggests that atypical kinematics are the cause of this, leading most to believe that fatigue failure may play a role. Despite the size and strength of the AT, the repetitive high energy loads experienced during sports accelerate degenerative changes causing elongation and fatigue failure. Finite element models have determined the AT tensile force to be 75% of the weight applied to the center of pressure in a balanced stance phase and has been recorded to be upwards of 10 times bodyweight during some activities [18–20]. Along with specific activities such as lateral jumping and hopping, different striking patterns during gait or running may further increase these loads [21, 22]. These activities incidentally change the moment arm of the AT through an increased shortening velocity or muscle fiber length during force generation [23]. Recent studies have focused on the AT moment arm and its importance during plantar flexion and the push-off phase of gait [24, 25]. In vivo methodologies involving both ultrasonography (US) and magnetic resonance imaging (MRI) have been employed to estimate the AT moment arm and to evaluate its function under loading [23, 24, 26, 27].

Post-operative analyses, various imaging techniques, computational models, and cadaveric studies have been performed to evaluate different fixations, postoperative weight-bearing protocols, and recovery. ATRs often stem from loading to fatigue amidst elongation of the tendon, correlating to outcomes involving re-rupture rate [28, 29]. Early rehabilitation protocols have been biomechanically modeled using stepwise increases in cyclic loading rather than ultimate load to failure conditions in order to simulate progressive and repetitive loading [30–33]. Dynamic loading, such as cyclic loading, at higher loads may be more representative of an AT injury during sport (Fig. 2).

Patients that experience an ATR have a 30% difference in heel-rise height between the previously injured extremity and the contralateral side after 1 year and demonstrate significant deficits in ankle kinetics when performing activities such as jumping and running. The heel-rise height has been found to correlate to the long-term ability to regain normal biomechanics [34]. Although typically recommended for athletes, surgical intervention has been found to significantly increase resting tendon length and stiffness while significantly decreasing elongation leading to asymmetrical gait and movements affecting sport performance [35]. While randomized controlled-

Fig. 1 Achilles tendon vascular supply

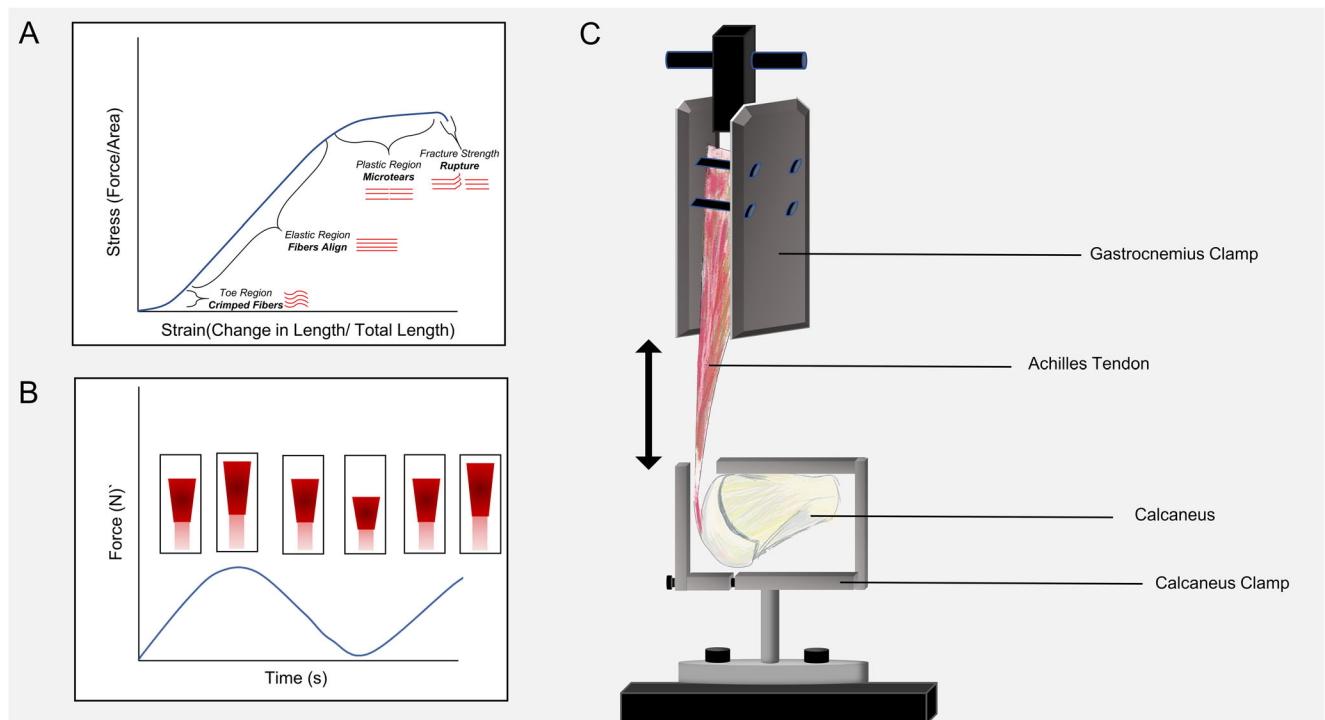
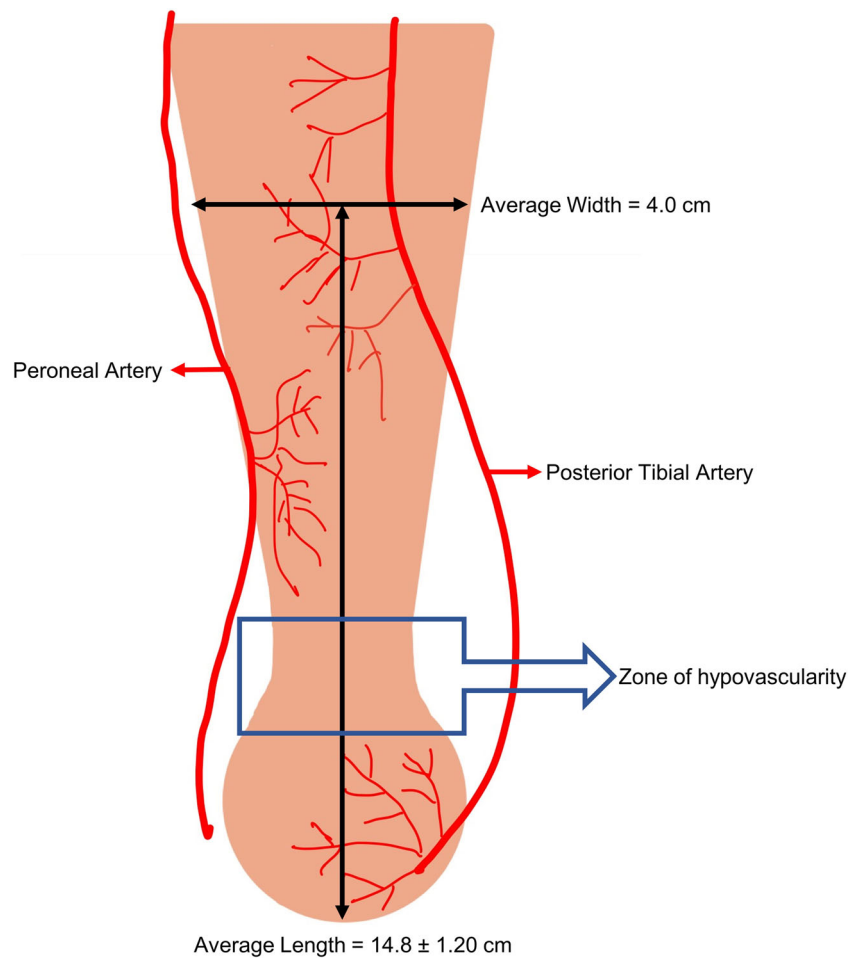


Fig. 2 **A** Representative stress-strain curve for AT under monotonic loading. **B** Example of cyclic loading plot with corresponding lengthening of the Achilles tendon. **C** Image of general biomechanical setup for Achilles tensile test

trials have not found significant outcomes between loading protocols, loading of the tendon has been found to stimulate the cells required for healing [36, 37]. Restoring AT tensile strength, elasticity, and fatigue strength are critical in reintroducing an athlete to the super-physiologic loads that are experienced during sport.

Treatment and Outcomes

With no validated guidelines, RTP decisions largely rest on the clinical judgment and collaboration between the clinician, physical therapist, athletic trainer, and athlete [38^{**}]. RTP can be discussed in the terms of a continuum comprising return to participation, return to sport, and return to performance [39]. With this in mind, recommendations for RTP should be made in the context of the sport and when possible objective criteria should be assessed. There is currently no clear consensus on which treatment, either conservative management or surgical repair, is the best for ATR [40–42]. An aspect of treatment that is evident in lowering the rerupture rate among patients, whether or not they receive nonoperative or operative treatments, is the implementation of functional rehabilitation and should be included in the post-operative rehabilitation plan of care [43].

Despite the inherent risks of surgery, including postoperative wound infection, adhesions, and sural nerve injury, surgical intervention when compared with nonoperative conservative management has been noted to provide superior improvements in functional outcomes [44, 45]. The superior jumping and muscular endurance observed across surgery patients may be particularly important to elite athletes hoping to RTP, with the understanding that ATR can be a career-ending injury for many [46–48]. Surgical patients demonstrate superior early and late functional outcomes (in jumping tests and muscular endurance heel-rise work test), which may be impacted by the fact that surgical patients progress through the rehabilitation protocol more quickly [41, 44]. Surgery restores the calf muscle strength earlier over the entire range of motion of the ankle joint, such that patients who undergo surgery demonstrate a strength increase of 10 to 18% and peak torque increase of 14% over what is observed in patients undergoing nonoperative functional rehabilitation at an 18-month follow-up [48]. In turn, surgical interventions may be recommended to elite athletes, who experience unique benefits from these improved physical functional outcomes as well as decreased risk of re-rupture, which are well-aligned with their desire to RTP at a faster rate [41, 42, 46–48].

Despite the superior functional outcomes and reduced risk of re-rupture observed among patients with ATRs treated surgically, outcomes for patients treated nonoperatively have markedly improved with the recent incorporation of early weight-bearing and functional rehabilitation programming [41, 42, 44, 46, 47]. With the introduction of early weight-bearing and

functional bracing, patients with ATR treated nonoperatively in comparison to those treated operatively demonstrate similar efficacy (rate of re-rupture and patient reported outcomes), without the risk of surgical complications [41, 42, 44, 46, 47]. A randomized control trial comparing the efficacy of conservative treatment, open surgery, and percutaneous surgery, demonstrate comparable pain scores, ability to stand heel rise mono- and bi-podally for 3 s, and return to previous activity or sport among patients across the intervention at 1-year follow-up [42]. However, with very few patients performing sports at a high-intensity in this sample, it is unclear to what extent these findings may be generalizable to all athletes. In Lerch et al.'s retrospective observational study, the RTP rate among patients undergoing nonoperative management with functional rehabilitation was significantly higher for patients with lower activity levels (91%) in contrast to those with higher activity levels (67%) at 5-year follow-up [49].

Findings from recent research suggest, US may be a useful imaging modality to incorporate into clinical decision making regarding ATRs. More specifically, in their 45-patient study from a cohort of 97 patients participating in a randomized controlled trial comparing surgical and nonsurgical treatments, Westin et al. provides evidence that using US to measure tendon diastasis is a useful tool to incorporate into a clinical treatment algorithm [50]. Westin et al., using US to measure the diastasis of AT ends, demonstrated that patients in the nonsurgical groups with diastasis of >5 mm fare significantly worse with a greater ($p=0.004$) degree of symptoms (AT total rupture score) and significantly lower ($p=0.048$) heel-rise height at 12 months [50–52]. This is consistent with prior research by Thermann and Zwipp and Kotnis et al., both suggesting that an initial AT diastasis of more than 5 mm adversely affects functional outcomes for nonsurgical management. Moreover, Westin et al.'s study indicates patients with a diastasis of >10 mm who were treated without surgery had a higher degree of re-rupture, with three of four patients suffering re-rupture ($p<0.001$). Overall, Westin and his colleagues' findings suggest that US measurement of the gap between the ruptured AT ends may be one factor that can help guide providers' clinical decision making between surgical and nonsurgical treatments, based on the indication that larger gaps, especially those larger than ten millimeters, when treated nonoperatively may increase risk of re-rupture and poor outcomes. Additional research will need to be conducted in order to validate the use of US in guiding clinical decision making and treatment approaches for ATR [53, 54].

Modes of Fixation and Author's Preferred Surgical Technique

The standard repair for ATR involves a locked suture repair with core strands as well as an epitendinous suture (i.e.,

Krackow) [55]. Suture techniques, including the double loop knot stitch and Kessler stitch, have been biomechanically compared in cadaveric models displaying comparable gap-resistance in relation to elongation under cyclic loading [31]. Suture caliber and the number of core strands have also been studied to assess optimal techniques with regard to the strength, stiffness, and elongation of tendon constructs compared to the native tendon [33]. The addition of suture tape or doubling of the core-strands of a smaller caliber sutures show significant biomechanical advantages with regard to endurance limits [33]. Bone suture anchors and biotenodesis screws are commonly used treatments to augment a degenerative AT through a flexor hallucis longus tendon transfer anchored to the calcaneus. Concerns regarding these procedures involve pullout, suture integrity, and inadequate lengthening. Cadaveric models evaluating and comparing these fixations have determined both to be suitable; however, tendon stiffness is found to be greater using screws in female donors and significantly less tendon is required for the transfer when using suture anchors.

Percutaneous and open repair techniques in cadaveric models display a higher susceptibility to elongation in percutaneous repairs in early weight-bearing, although ultimate load to failure was similar between techniques [32]. Although a minimally invasive percutaneous approach provides similar ultimate, and fatigue load to failure and can potentially mitigate complications involving infections, adhesions, and nerve damage, the lack of visibility may raise the concern of insufficient tendon capture [32].

Preferred Technique

Ideally, active individuals, athletes, and active laborers should be considered for repair, whereas patients who are elderly, obese, sedentary individuals, poorly controlled diabetics, and/or smokers should attempt nonsurgical repair and management due to their increased risk of wound complications. For those receiving repair, the senior author (MA) prefers the mini-open technique with pre-operative localization of ruptured ends with ultrasound to minimize incision length. Supine positioning and a medial-based incision is favored as it minimizes anesthesia complications, operative time, and decreases wound complications (Fig. 3). The tendon is

repaired and overtightened in plantarflexion that barely exceeds the contralateral side to avoid elongation during healing. The contralateral side tone is measured preoperatively or may be prepped in the surgical field to compare. Suture repair is performed with a Krackow suture repair as well as an epitendinous running stitch. The suture type is left to the discretion of the surgeon, but our institution utilizes suture tape for repair. Postoperatively, patients remain in a splint for 10 days. After 10 days, patients' transition to a boot with wedges, weight bearing as tolerated (WBAT), early plantarflexion strengthening, and no dorsiflexion past neutral until the eighth week. During this transition, at 6 weeks, one wedge a week will be removed from the boot and patients can start to bike. Between weeks 8 and 10, patients can begin to wean off the boot and then progress towards walking and jogging during weeks 10–12. Lastly, if muscle strength returns, patients can begin to cut, jump, etc., at weeks 16s–20.

Return to Play

RTP is a major concern for athletes following an ATR. A recent meta-analysis by John et al. based on 15 studies demonstrated that the RTP rate was 76% among professional athletes, where the mean time to RTP was 11 months [56]. This is consistent with the RTP rate (80%) demonstrated in Zellers et al.'s systematic review and meta-analysis, which included 85 studies [57]. In comparison to other common lower extremity orthopedic procedures, including knee microfracture surgery, ACL reconstruction, patellar tendon repair, ankle, or tibial shaft fracture fixation, AT repair is associated with significantly lower RTP rates and significantly longer mean time to RTP [56]. Table 1 shows RTP rates for different sports observed across studies. Calf strength asymmetry, observed in many patients after ATR, likely contributes to the challenges athletes face to RTP [58, 59]. This has been found to be most prevalent in athletic competitions, including basketball and football, where the nature of the games demands a stop/start playing style, repetitive jumping, and short sprints [3, 60–62]. Muscle weakness, decreased endurance, and other functional deficits observed after ATR, which ultimately limit athletes' abilities to execute the physical demands of sport, in some cases persist for 10 years following injury [57]. In these

Fig. 3 Example of preferred mini-open technique repair involving **A** ultrasound imaging, **B** incision length marking, and **C** using end to end Krakow repair

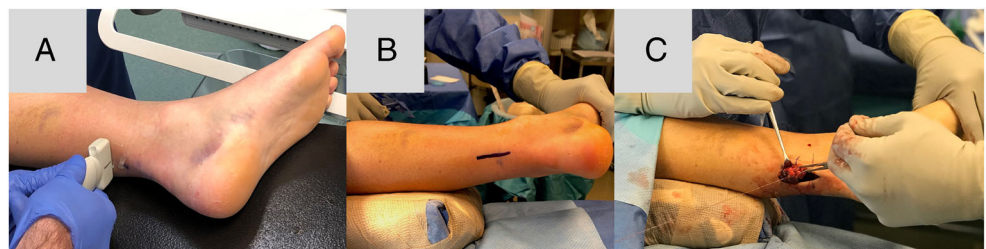


Table 1 Return to play rate observed across eight studies from 2016 to 2020 across five different sports

| Author | Year | Sample (n) | Sport | Return to play rate |
|--------------------|------|---------------------------------------|--|---|
| Wise et al. [38] | 2020 | 57 | Football (NCAA Division I FBS) | 92.5% |
| Trofa et al. [11] | 2018 | 62 (25 NBA, 32 NFL, and 5 MLB, 0 NHL) | Basketball (NBA), Football (NFL), Baseball (MLB), Hockey (NHL) | 69.4% (68.0% NBA, 65.6% NFL, 100%, MLB) |
| Jack et al. [60] | 2017 | 98 | Football (NFL) | 72.4% |
| Mai et al. [64] | 2016 | 80 | Football (NFL) | 72.5% |
| Yang et al. [65] | 2019 | 80 | Football (NFL) | 61.3% |
| Lemme et al. [61] | 2019 | 44 | Basketball (NBA) | 79.5% |
| Grassi et al. [63] | 2020 | 118 | Soccer (European) | 96.0% |
| Minhas et al. [62] | 2016 | 24 | Basketball (NBA) | 70.8% |

cases, it is valuable to note prolonged functional deficits experienced by patients after a surgically repaired AT, as this could be associated with the AT healing in an elongated position. This may be misdiagnosed as muscle weakness; however, most muscle will be regained within the first two of years of recovery [29, 34]. In instances when a muscle tendon unit length-tension relationship is compromised, the only treatment to restore the tension is through revision surgery; in some instances, a deep tendon transfer, such as a flexor hallucis longus transfer, is necessary to augment the repair.

Despite these challenges, a majority of athletes are able to RTP; however, decreased performance levels affect many athletes' abilities to play at their baseline levels [38**, 63]. For NFL players, in their first year returning from ATR, studies demonstrate that athletes play in significantly fewer games, with reduced play time, and worse performance compared to age-matched controls and their preinjury baseline [11, 40, 64]. At 2 to 3 years after surgery, athletes recover to their baseline performance levels and numbers of games played; however, the duration of their NFL career is significantly shorter than controls (3.6 ± 2.1 years, $p < 0.05$) [60, 64].

Among NCAA Football Bowl Subdivision (FBS), defensive players with ATRs do not suffer the same impacts in regards to their RTP rates (92.5%) and performance scores when compared to NFL players with ATR [38**]. Across all FBS defensive positions, players did not experience a drop-off in performance from their preinjury baseline after ATR. With the exception of defensive backs demonstrating decreased improvements with regard to tackling against matched controls, defensive lineman, linebackers, and defensive backs overall show no significant changes with regard to their abilities to rush the passer, stop running plays at the line of scrimmage, and provide pass coverage when compared against controls [38**].

While there are many factors that may contribute to the higher RTP rate and the overall improved performance observed among collegiate athletes in contrast to professional athletes, it is likely that the player's age at time of injury is one notable difference [38**]. For example, among

professional soccer players with ATR, age was identified as an important risk factor for worse outcomes [63]. Age greater than 30 years is associated with an increased risk of not returning to the same level of play (OR=4.46, $p=0.030$), increased risk of re-rupture within the first two seasons after RTP (OR=6.36, $p=0.05$), as well as increased risk of postoperative complications, such as surgical site infection, nerve injury, and wound healing complications. Carmont et al.'s study, which focused on identifying factors that influence functional outcomes at 1 year from postoperative intervention (percutaneous and minimally invasive repair), indicates age to be the strongest predictor of outcome after ATR through multiple regression analyses of symmetrical heel-rise to height index (HRHI) [66*]. In this study, HRHI was selected as the primary variable of interest due to its association with reduced tendon elongation, which contributes to decreased plantar flexion and overall worse ATR outcomes in the long term [66*]. When considering age and its relationship to HRHI, these findings suggest that younger patients with ATRs experience reduced tendon elongation, thus increasing their likelihood of regaining ankle plantar flexion and achieving more successful AT recovery based on long-term outcomes.

Beyond age, other differences between the NFL and NCAA athletes that may provide insight to potential factors impacting ATR outcomes, such as RTP, include degeneration and level of play [38**]. Tendinosis is a naturally occurring process that accompanies aging as the tensile strength of collagen decreases with the decreasing blood flow to regions [7]. With these changes, the tendon stiffness increases, decreasing its ability to withstand repetitive stress. Failed healing responses observed in the setting of tendinosis are often impacted by continued exposure to ongoing mechanical forces, poor blood supply, or a combination of both factors [67]. More specifically, ongoing exposure to mechanical forces play a major role in many foot and ankle tendinopathies, such that the term tendinopathy is used to describe overuse tendon injuries in the absence of a pathologic diagnosis [68, 69]. Tendinopathies of the AT, posterior tibial tendon, and peroneal tendon, as well as other foot

and ankle tendinopathies, often occur when patients' physical activity or athletic training changes with respect to mode, intensity, or duration. While overuse injuries affecting the peroneal tendon most often result in chronic tendonitis and interstitial tears, the same overuse injuries affecting the AT are more prone to rupture due to the added insult of poor blood supply that often occurs in the vascular watershed region of the AT [70]. In turn, it is this combined progression of decreasing blood supply and decreasing collagen strength that occurs with aging and ongoing overuse, that increases the likelihood of rupture of the AT, unlike other foot and ankle tendinopathies. Furthermore, the same poor vascular supply that contributes to the weakening of the tendon that increases the risk of rupture also creates an environment that is less conducive to healing and recovery when an ATR takes place [7].

Understanding that NFL players are generally older than their NCAA counterparts, it is likely that there is a higher incidence of tendinosis and tendinopathy. The degeneration older athletes' experience and the corresponding challenges these degenerative changes produce during the recovery phase following ATR are only exacerbated by the increased stress and physical demands professional athletes endure when trying to return and compete at an elite level. In turn, considering an athlete's age, their history of degeneration, and the level of competition are all factors the clinical team and patient should appraise when selecting a treatment plan and discussing the athlete's likelihood of returning to play.

Conclusion

In conclusion, the Achilles tendon plays an important role in sports performance due to its vital role in ankle stability and allowing athletes to perform explosive activities. While non-operative management may be sufficient in some non-athletes, multiple studies support operative intervention in elite athletes. Recent studies have shown that operative intervention improves postoperative strength and functional outcomes as well as lowers re-rupture rates compared to nonoperative management with rehabilitation. The current literature supports operative intervention in elite athletes to improve performance and shorten their RTP. However, we acknowledge that surgical intervention does have inherent risks. Ultimately, most if not all athletes with an ATR benefit from surgical repair, but it is crucial to take a critical stepwise algorithmic approach and consider other factors, which may lead towards nonoperative intervention. These factors include age, chronicity of injury, gap of ATR, social factors, medical history, and other factors which are discussed in this review. The RTP rate for athletes that experience an ATR still remains to be 80%, with difficulty in achieving baseline performance until 2 to 3 years after surgery, impacting the overall career of an athlete. This is an area where post-operative rehabilitation, with an emphasis on

early weight-bearing, may prove to be beneficial in reducing the time back to peak performance.

Declarations

Conflict of interest The authors did not receive support from any organization for the submitted work. Dr. Michael Aynardi is a consultant for Arthrex Inc., Zimmer Biomet, and Stryker. The other authors have no relevant financial or non-financial interests to disclose.

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- Of importance
- Of major importance

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