Which Criteria Are Used to Clear Athletes to Return to Sport After Achilles Tendon Repair? A Scoping Review

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Context: Achilles tendon (AT) rupture is a devastating and potentially career-ending injury. Compared with other severe lower extremity injuries, such as anterior cruciate ligament reconstruction, it is associated with lower return to sport (RTS) rates, longer absence from training and competition, reduced sport-specific performance in the 2 years after rupture, shorter career length, and persistent long-term functional deficits. Therefore, better knowledge of the RTS criteria after AT rupture may support the optimization of rehabilitation outcomes and improve long-term RTS success.

Objective: The purposes of this scoping review were to (1) map the scientific evidence regarding criteria used to clear patients to RTS after surgical AT repair, and (2) describe the predominant outcome measurements reported in the literature.

Data Sources: Web of Science, Scopus, and MEDLINE databases.

Study Selection: A scoping review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews framework, including English-language studies published from 1995 to 2022 on "athletes" or "sportive patients" who underwent surgical AT repair.

Study Design: Scoping review.

Level of Evidence: Level 3.

Results: Of 589 studies identified, 34 met the inclusion criteria: 3% were randomized controlled trials, 50% were case series, and 47% were cohort studies. None defined an outcome measurement as a criterion to RTS. The main outcomes were timeframe from surgery to RTS (53%), ankle range of motion (47%), Achilles Tendon Rupture Score (47%), calf circumference (44%), and heel-rise test (44%).

Conclusion: None of the 34 studies defined an outcome measurements as criteria for RTS. The main measurements focused on the early rehabilitation stage, with limited standardization and a lack of assessment for the mid- and late stages of rehabilitation. Defining RTS criteria after AT repair may help optimize rehabilitation and the RTS process.

Keywords: Achilles tendon rupture; return to sport criteria; scoping review

Achilles tendon (AT) rupture is a common injury in physically active people, including athletes, with its incidence increasing over the last decades, ranging from 6 in 100,000 to 55 in 100,000 people per year.[40,41,88] Compared with other severe lower limb orthopaedic procedures, such as anterior cruciate ligament (ACL) reconstruction, AT repair is associated with lower return to sport (RTS) rates, longer mean time to RTS, and shorter career length.[48] The RTS rate after AT rupture ranges from 66% to 72% in the National Football League (NFL),[46,82] from 61% to 79% in the National Basketball Association (NBA),[33] and is 77% in football (soccer).[75] Time to RTS after AT repair ranges from 11 to 12 months in the NFL,[58]

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Table 1. Inclusion and exclusion criteria applied to include studies during the selection procedures

Inclusion criteria	Exclusion criteria
• English language • Studies published between 1995 and 2022 • RCT, case series, cohort studies • Population of "athletes", as defined within the parameters of each respective study, and/or "sportive patients" who underwent surgical AT repair	• Grey literature (handbooks, congress abstracts, documents, letters to Editors) • Reviews, systematic reviews, clinical comments, case reports • Studies addressing conservative AT treatment, and studies focusing on AT tendinosis, tendinitis (tendonitis), tendinopathy and other AT injuries
• No age or sex limitations	

AT, Achilles tendon; RCT, randomized control trial.

5 to 16 months in the NBA,[42] and from 9 to 10 months in football (soccer).[75] Recent studies analyzing player performance, including the number of games, total minutes played, and game statistics, found a reduction in games played per season, total time played, and game statistics in the 2 seasons after AT rupture compared with the preinjury season in the NFL, NBA and in football.[33] A low rate of RTS, prolonged lay-off time to RTS, reduced player performance, and shorter career length after AT repair highlight the need to investigate which criteria are used and which functional outcomes are obtained throughout the rehabilitation and RTS process. The basic function of the AT is to connect the triceps surae muscle to the heel and to transmit forces between them, allowing body movement.[37] High intensity sports activities can potentially stress the AT with excessive mechanical load.[64] The mechanisms of AT rupture have been investigated recently through video analysis, showing that injuries occur primarily during explosive acceleration actions, with 3 predominant patterns, including forward acceleration from standing, cross-over cutting, and vertical jumping.[83] Therefore, a key aspect of sporting rehabilitation and RTS after AT repair is to safely prepare the athlete to cope with these explosive sporting demands. This is particularly relevant given that AT rupture is also associated with several long-term deficits, including tendon elongation, limited functional ankle range of motion (ROM), prolonged calf muscle weakness, triceps surae muscle atrophy, and altered movement quality,[26,28,61] which may limit the athlete's ability to cope with explosive demands, impacting RTS rate, sport performance, and career longevity.[10] A criteria-based rehabilitation program with effective load progression is considered the gold-standard for a safe RTS,[13,14] as it improves functional outcomes,[71] and is associated with better RTS outcomes.[53] Therefore, a better knowledge of the RTS criteria after AT repair reported in the literature may support the optimization of rehabilitation outcomes and improve long-term RTS success. The aims of this scoping review were to (1) map the scientific evidence regarding which criteria are used to clear sporting patients and athletes to RTS after surgical AT repair and (2) describe the predominant outcome measurements reported in the literature after AT repair.

METHODS

Search Strategy

This study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist.[81] The literature search was performed by 2 separate authors during September 2022. This search covered all literature dated up to the search date using 3 databases: Web of Science, Scopus, and MEDLINE. To ensure the broadest possible coverage of pertinent literature, a combination of search terms and Boolean operators was employed. The search queries included terms such as ("Achilles tendon" OR "ATR") AND ("injuries" OR "surgery" OR "strain" OR "rupture") AND ("sport" OR "athlete") AND ("return to sport" OR "return to play" OR "return to competition" OR "criteria"). The search process was performed independently by the 2 authors, who later compiled the list of identified studies in a shared Excel file. Subsequently, they cross-verified their respective lists to establish a unified set of articles for each electronic database. In case of disagreement between the 2 reviewers, a third author was involved and the final decision was based on majority consensus among the 3 reviewers. Initial screening focused on eliminating titles of studies that were off-topic. Subsequent screening aimed at removing duplicates and studies that did not meet the eligibility criteria. Finally, the studies that remained after these screenings were downloaded and considered as the studies included in this scoping review.

Study Selection

Table 1 presents the inclusion and exclusion criteria. The terms "athlete" and "return to sport" were not restricted to a predefined definition. Instead, these terms were incorporated based on the definitions provided in each respective study.

Table 2. Variables extracted in the data-charting form

Participant demographics and study information	Subjective and objective outcome measurements
Year the article was published	Anthropometry
Country from which the article originates	Ankle ROM/tendon lengthening
Study design	Calf strength
Level of evidence	Calf capacity
Sample size	Performance
Demographics (age, sex, BMI)	PROMs
Athlete/patient sport at time of injury	
Athlete/patient athletic/sport level of participation	
How many athletes/patients returned to sport	
Timeframe to RTS	

BMI, body mass index; PROM, patient-reported outcomes measure; ROM, range of motion; RTS, return to sport.

Data Charting Process and Data Items

A data-charting form was developed jointly by the 2 reviewers to determine which variables to extract (Table 2). The 2 reviewers discussed the data collected and updated the data continuously charting form in an iterative process. Subsequently, dedicated columns were added to the data-charting form for each variable, providing an overview of how each variable was reported across the included studies. For example, if the variable "PROMs" was reported in various formats, each format was assigned to a dedicated column. In addition, a descriptive quality appraisal was conducted using the Joanna Briggs Institute's critical appraisal tools appropriate to each study design (cohort, case series, randomized control trial [RCT], qualitative studies), following updated methodological guidance for the conduct of scoping reviews.[62] The articles cited in the results tables are identified by author name and year, and number in the reference list (eg "Maffulli et al[45] (2011)"). All of these studies are fully referenced in the bibliography.

RESULTS

The initial electronic database search produced a total of 598 records. After removal of duplicates, 405 unique records remained. Subsequently, 297 of these records were screened and 34 conformed to the eligibility criteria. Among these 34, 16 (47%) were cohort studies, 17 (50%) were case series, and 1 (3%) was an RCT (Figure 1).[57] Although all included studies were primarily quantitative, 1 article with a qualitative design was retained due to its possible relevance to RTS criteria after AT repair. Its inclusion did not influence the synthesis of outcome measures.

RTS Criteria After ATR

None of the 34 articles included in the review delineated specific RTS criteria explicitly after AT rupture. All pertinent outcome measurements extracted from each study are summarized in Table 3. Figure 2 presents the percentage of included studies reporting each specific measurement, offering an overview of their frequency across the literature.

Participant Demographics

This scoping review reported RTS outcome measurements from a total of 1624 participants who underwent AT repair. The average age of participants was 39 ± 8 years (range 19-86). Not all the studies provided explicit information regarding sex distribution. Based on the available data, we can approximate that 80% of the subjects were male, while the remaining 20% were female. The average follow-up time from surgery was 38 months (range 3-171).

Participant Time From Surgery to RTS

Time from surgery to RTS was reported as an outcome measure in 18 (53%) of the included studies. These time frames are summarized in Table 3 under the category "Time."

Participants RTS Information

A total of 16 studies (47%) reported on RTS rates, 13 studies (38%) provided data on patients who returned to the same preinjury level, and 12 studies (35%) reported reinjury rates. The studies reporting this information are listed in Table 3 under category "Patients RTS information."

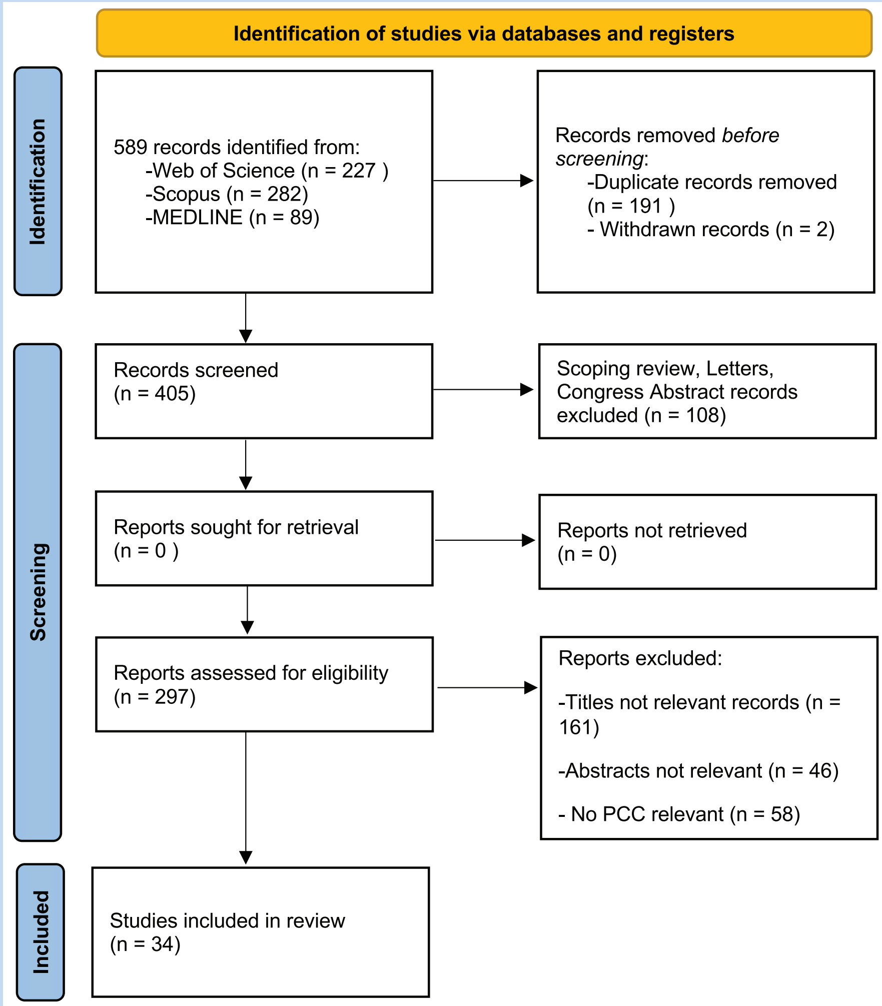

Figure 1. Study search flow diagram. PCC; population, context, content.

Ankle ROM and Tendon Lengthening

The 16 studies (47%) that reported ankle ROM data are listed in Table 3 under section "Objective outcome measurements." Two studies (6%) (Porter et al[66] and Gamal et al[19]) included data on both dorsi and plantar flexion ROM for both the involved and uninvolved limbs. Yeung et al[86] and Miyamoto et al[51] reported dorsiflexion and plantar flexion ROM for the involved limb only, while Porter et al[65] and Guillo et al[23] reported only dorsiflexion ROM for both the involved and uninvolved limbs. Seven (21%) studies (Prejbeanu et al[67], Nam et al[52], Manegold et al[47], Ryu et al[69], Won Lee et al[87], Jennings et al.[31,32], and Stein et al[77]) reported assessment of ROM. Zhang et al[90] and Biz et al[5] reported the average ankle ROM range achieved. Two articles (6%) (Abdelatif and Batista[1] and Carmont et al[11]) reported the AT resting angle (ATRA), which offers an indirect measure of AT length after repair. Similarly, 2 articles (6%) (Manegold et al[47] and Biz et al[5]) reported the Matle test, a diagnostic sign indicating a loss of the tenodesis effect during knee movement from extension to flexion, potentially leading to increased ankle dorsiflexion after acute AT rupture.

Calf Muscle Strength Outcome Measurements

A total of 15 studies (44%) included outcome measures related to calf muscle strength. These studies are listed in Table 3, under the category "Calf muscle strength." In these studies, 3 different approaches to evaluate calf muscle strength were identified. These are described in Table 4.

Isokinetic Calf Strength Test

Six (18%) studies reported isokinetic strength outcomes. These studies are listed in Table 3 under the category "Calf muscle strength," item "Isokinetic test for the ankle." Measurements were reported at both low (30 deg/s, 60 deg/s, 90 deg/s) and high (120 deg/s,180 deg/s, 240 deg/s) angular velocities. Two (6%) studies reported isokinetic measurements using the Isokinetic Strength Score (ISS), which is a component of the

Table 3. RTS outcome measures reported in included studies after AT repair

Section	Category	Item	Studies reported	Authors (year)
Study information		Studies included	34 (100%)	
	Study design			
		Cohort study	16 (47%)	Peterson et al[63] (2021), Zhang et al[90] (2018), Obut et al[55] (2013), Hansen et al[24] (2016), Porter et al[65] (2014), Miyamoto et al[51] (2017), Nam et al[52] (2019), Sanada et al[70] (2022), Abdelatif and Batista[1] (2022), Baumfeld et al[4] (2019), Carmont et al[11] (2020), Amin et al[2] (2013), Jack et al[29] (2017), Porter et al[66] (1997), Prejbeanu et al[67] (2021), Jennings et al[31] (2004)
		Case series	17 (50%)	Maffulli et al[45] (2011), Holzgrefe et al[27] (2020), Gamal et al[19] (2021), Gaiani et al[18] (2012), Grassi et al[21] (2020), Manegold et al[47] (2018), Won Lee et al[85] (2022), Maffulli et al[44] (2013), Biz et al[5] (2021), Tasatan et al[80] (2016), Rungprai and Phisitkul[68] (2018), Stein et al[77] (2015), Guillo et al[23] (2013), Jennings et al[31] (2002), Ryu et al[69] (2018), Yeung et al[86] (2019), Talbot et al. (2012)[79]
		RCT	1 (3%)	Groetelaers et al[22] (2014)
RTS outcome measurements	Patient RTS information			
		RTS rates	16 (47%)	
		100%	5 (15%)	Peterson et al[63] (2021), Holzgrefe et al[27] (2020), Abdelatif and Batista[1] (2022), Tasatan et al[80] (2016), Jennings et al[32] (2002), Amin et al[2] (2013), Jack et al[29] (2017)
		89-99%	9 (26%)	Miyamoto et al[51] (2017), Grassi et al[21] (2020), Manegold et al[47] (2018), Maffulli et al[44] (2013), Stein et al[77] (2015), Guillo et al[23] (2013), Porter et al[66] (1997), Ryu et al[69] (2018), Yeung et al[86] (2019)
		79-89%	1 (3%)	Rungprai and Phisitkul[68] (2018)
		<69%	1 (3%)	Biz et al[5] (2021)
		Patients who returned to the same preinjury athletic level	13 (38%)	

(continued)

Table 3. (continued)

Section	Category	Item	Studies reported	Authors (year)
		100%	1 (3%)	Tasatan et al[80] (2016)
		89-99%	2 (6%)	Miyamoto et al[51] (2017), Grassi et al2[1] (2020)
		79-89%	2 (6%)	Abdelatif and Batista[1] (2022), Amin et al[2] (2013)
		<69%	8 (24%)	Peterson et al[63] (2021), Obut et al[55] (2017), Gamal et al[19] (2021), Gaiani et al[18] (2012), Jennings et al[32] (2002), Jennings et al[31] (2004), Ryu et al[69] (2018),Yeung et al[86] (2019)
		Patients reinjured rate	12 (35%)	
		0%	7 (21%)	Obut et al[55] (2017), Gamal et al[19] (2021), Gaiani et al[18] (2012), Jennings et al[32] (2002), Jennings et al[31] (2004), Ryu et al[69] (2018), Yeung et al[86] (2019)
		2-8%	5 (15%)	Nam et al[52] (2019), Sanada et al[70] (2022),Grassi et al[21] (2020), Groetelaers et al[22] (2014), Amin et al[2] (2013)
	Time			
	1	Time from surgery to RTS	18 (53%)	
		<6 months from AT repair	7 (21%)	Miyamoto et al[51] (2017), Gamal et al[19] (2021), Nam et al[52] (2019), Sanada et al[70] (2022), Gaiani et al[18] (2012), Won Lee et al[85] (2022), Rungprai and Phisitkul[68] (2018)
		≥6 months to <9 months	10 (29%)	Zhang et al[90] (2018), Obut et al[55] (2017), Maffulli et al[45] (2011), Abdelatif and Batista[1] (2022), Biz et al[5] (2021), Stein et al[77] (2015), Porter et al[66] (1997), Jennings et al[32] (2002), Jennings et al[31] (2004), Talbot et al[79] (2012)
		≥12 months	1(3%)	Holzgrefe et al[27] (2020)
Objective outcome measurements	Ankle ROM/AT lengthening		19 (56%)	
	1	ROM	16 (47%)	Zhang et al[90] (2018), Porter et al[65] (2014), Miyamoto et al[51] (2017), Gamal et al[19] (2021), Nam et al[52] (2019), Manegold et al[47] (2018), Won Lee et al[85] (2022), Biz et al[5] (2021), Guillo et al[23] (2013), Porter et al[66] (1997), Prejbeanu et al[67] (2021), Jennings et al[31] (2004), Jennings et al[32] (2002), Ryu et al[69] (2018), Yeung et al[86] (2019), Stein et al[77] (2015)

(continued)

Table 3. (continued)

Section	Category	Item	Studies reported	Authors (year)
	2	ATRA	2 (6%)	Abdelatif and Batista[1] (2022), Carmont et al[11] (2020)
	3	Matle test (tendon lengthening)	2 (6%)	Manegold et al[47] (2018), Biz et al[5] (2021)
	Calf muscle strength		15 (44%)	
	1	Isokinetic test for the ankle	6 (18%)	Porter et al[65] (2014), Holzgrefe et al[27] (2020), Baumfeld et al[4] (2019), Porter et al[66] (1997), Talbot et al[79] (2012), Ryu et al[71] (2018)
	2	Isometric plantarflexion strength	7 (21%)	Maffulli et al[45] (2011), Abdelatif and Batista[1] (2022), Groetelaers et al[22] (2014), Maffulli et al[44] (2013), Guillo et al[23] (2013), Jennings et al[32] (2002), Jennings et al[31] (2004)
	3	ISS	2 (6%)	Holzgrefe et al[27] (2020), Talbot et al[79] (2012)
	Calf capacity/ endurance		15 (44%)	
	1	Heel (or calf) rise test	15 (44%)	Obut et al[55] (2017), Maffulli et al[45] (2011), Miyamoto et al[51] (2017), Nam et al[52] (2019), Sanada et al[70] (2022), Won Lee et al[85] (2022), Biz et al[5] (2021), Tasatan et al[80] (2016), Stein et al[77] (2015), Guillo et al[23] (2013), Prejbeanu et al[67] (2021), Jennings et al[32] (2002), Jennings et al[31] (2004), Ryu et al[69] (2018), Carmont et al[11] (2020)
	Calf muscle size		16 (47%)	
	1	Calf circumference	15 (44%)	Zhang et al[90] (2018), Maffulli et al[45] (2011), Porter et al[65] (2014), Nam et al[52] (2019), Manegold et al[47] (2018), Baumfeld et al[4] (2019), Maffulli et al[44] (2013), Biz et al[5] (2021), Carmont et al[11] (2020), Stein et al[77] (2015), Guillo et al[23] (2013), Porter et al[66] (1997), Jennings et al[32] (2002), Jennings et al[31] (2004), Ryu et al[69] (2018)
	2	Cross-sectional area	1 (3%)	Prejbeanu et al[67] (2021)
	Performance measurements (functional results and sport statistics)		7 (21%)	

(continued)

Table 3. (continued)

Section	Category	Item	Studies reported	Authors (year)
	1	Hopping test (functional performance results)	5 (15%)	Obut et al[55] (2017), Gamal et al[19] (2021), Won Lee et al[85] (2022), Tasatan et al[80] (2016), Ryu et al[69] (2018)
	2	Sport statistics (sport performance results)	2 (6%)	Amin et al[2] (2013), Jack et al[29] (2017)
Subjective outcome measurements	PROMs, global scales		14 (41%)	
	1	VAS	6 (18%)	Gamal et al[19] (2021), Nam et al[52] (2019), Manegold et al[47] (2018), Maffulli et al[44] (2013), Biz et al[5] (2021), Rungprai and Phisitkul[68] (2018)
	2	Tegner activity scale	6 (18%)	Holzgrefe et al[27] (2020), Abdelatif and Batista[1] (2022), Manegold et al[47] (2018), Carmont et al[11] (2020), Jennings et al[32] (2002), Jennings et al[31] (2004)
	3	SF-36	1 (3%)	Rungprai and Phisitkul[68] (2018)
	4	QoL score (SF-12 questionnaire)	1 (3%)	Groetelaers et al[22] (2014)
	PROMs, disease-specific scales		46 (135%)	
	1	ATRS	16 (47%)	Carmont et al[11] (2020), Stein et al[77] (2015), Guillo et al[23] (2013), Biz et al[5] (2021), Baumfeld et al[4] (2019), Manegold et al[47] (2018), Maffulli et al[44] (2013), Won Lee et al[85] (2022), Maffulli et al[45] (2011), Hansen et al[24] (2016), Gamal et al[19] (2021), Nam et al[52] (2019), Sanada et al[70] (2022), Abdelatif and Batista[1] (2022), Prejbeanu et al[67] (2021), Talbot et al[79] (2012)
	2	AOFAS-AH	14 (41%)	Ryu et al[69] (2018), Talbot et al[79] (2012), Prejbeanu et al[67] (2021), Tasatan et al[80] (2016), Biz et al[5] (2021), Baumfeld et al[4] (2019), Manegold et al[47] (2018), Zhang et al[90] (2018), Miyamoto et al[51] (2017), Gamal et al[19] (2021), Nam et al[52] (2019), Gaiani et al[18] (2012), Abdelatif and Batista[1] (2022), Obut et al[55] (2017)

(continued)

Table 3. (continued)

Section	Category	Item	Studies reported	Authors (year)
	3	Leppilahti score	1 (3%)	Zhang et al[90] (2018)
	4	Arner-Lindholm scale	2 (6%)	Ryu et al[69] (2018), Zhang et al[90] (2018)
	5	AAOS lower limb core, and foot and ankle modules	1 (3%)	Porter et al[65] (2014)
	6	FAAM	1 (3%)	Rungprai and Phisitkul[68] (2018)
	7	Hannover score	1 (3%)	Manegold et al[47] (2018)
	8	Trillat score	1 (3%)	Tasatan et al[80] (2016)
	9	Thermann score	1 (3%)	Obut et al[55] (2017)
	10	4-point Boyden scale	2 (6%)	Maffulli et al[44] (2013), Guillo et al[23] (2013)
	11	Halasi score	1 (3%)	Carmont et al[11] (2020)
	12	PPP	1 (3%)	Carmont et al[11] (2020)
	13	ARPS	1 (3%)	Groetelaers et al[22] (2014)
	14	PROMIS	1 (3%)	Peterson et al[63] (2021)
	15	Physical activity scores	1(3%)	Carmont et al[11] (2020)

AAOS, American Academy of Orthopaedic Surgeons; AOFAS-AH, American Orthopaedic Foot and Ankle Society-ankle hindfoot score; ARPS, Achilles rupture performance score; AT, Achilles tendon; ATRA, Achilles tendon resting angle; ATRS, Achilles tendon total rupture score; FAAM, foot and ankle ability measurement; ISS, isokinetic strength score; PPP, perception of performance; PROM, patient-reported outcomes measure; PROMIS, patient-reported outcome measurement information system; QoL, quality of life; ROM, range of motion; RCT, randomized controlled trial; RTS, return to sport; SF-12, short form 12 questionnaire; SF-36, short form 36 questionnaire; VAS, visual analog score.

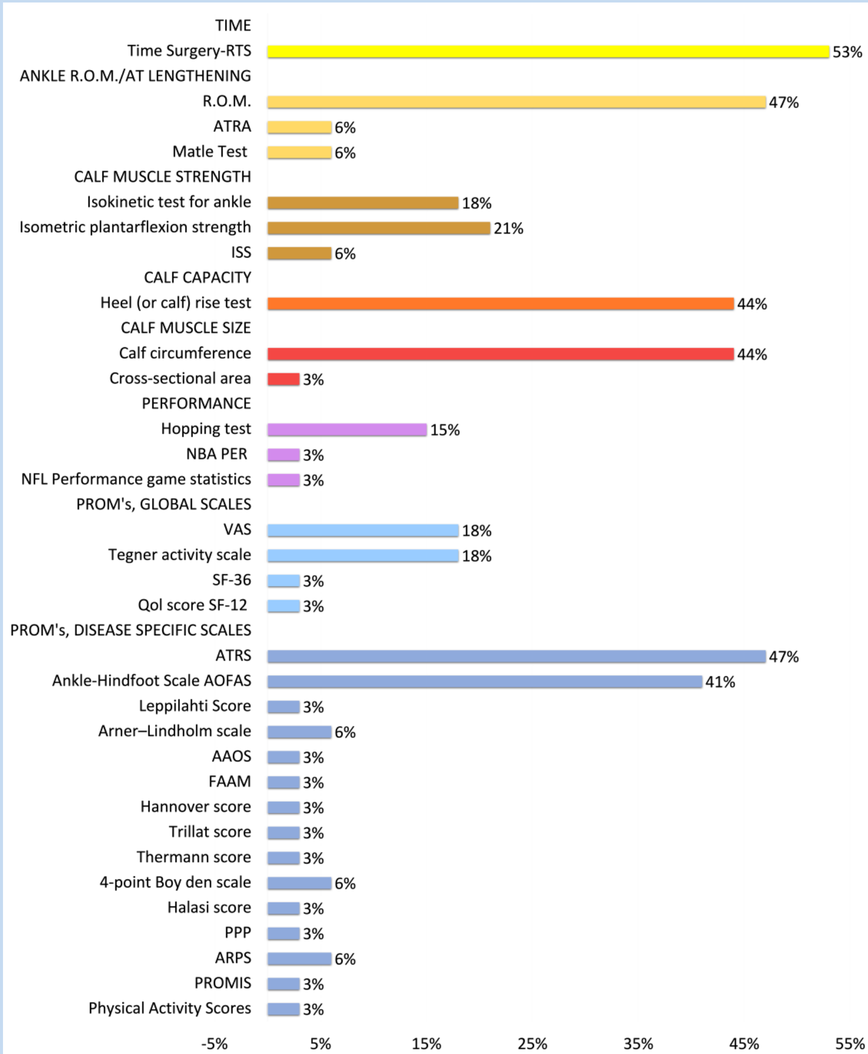

Figure 2. Percentage of included studies (n = 34) reporting each specific outcome measurement. This figure provides a quantitative overview of the outcome measures used most frequently for AT rupture in the included studies. The reported measures are grouped by category, each represented by a different color. AOFAS, American Orthopaedic Foot and Ankle Society; ARPS, Achilles rupture performance score; AT, Achilles tendon; ATRA, Achilles tendon resting angle; ATRS, Achilles tendon total rupture score; FAAM, foot and ankle ability measurement; HRHI, heel-rise height index; HRI, heel-rise repetition index; ISS, isokinetic strength score; NBA, National Basketball Association; NFL, National Football League; PER, player efficiency rating; PPP, perception of performance; PROM, patient-reported outcome measurement; PROMIS, patient-reported outcome measurement information system; QoL SF-12, quality of life score short form; ROM, range of motion; RTS, return to sport; SF-36, short form 36; VAS, visual analog score.

Leppilahti Score. These 2 studies are listed in Table 3 under the category “Calf muscle strength,” item “ISS.”

Isometric Plantarflexion Strength

The outcomes from the 7 (21%) studies that reported the isometric plantarflexion strength are collected in Table 5. One of these, Abdelatif and Batista,1 assessed toe plantar strength, using hallux dynamometry. Three of them (Maffulli et al[44,45], Guillo et al[23]), reported a significant isometric muscle strength deficit in the involved limb when compared with the uninvolved limb, highlighting a notable disparity in peak torque.

Calf Muscle Size

A total of 15 (44%) studies reported calf circumference measurement; these studies are listed in Table 3 under category “Calf muscle size,” item “Calf circumference.” One (3%) study,

Table 4. Calf muscle strength outcome measurements found in the included studies

Calf strength outcome measurements	Studies reporting, n (% of 34)	Authors (year)
(1) Isokinetic test for the ankle	6 (18%)	Porter et al[65] (2014), Holzgrefe et al[27] (2020), Baumfeld et al[4] (2019), Porter et al[66] (1997), Ryu et al[69] (2018), Talbot et al[79] (2012)
Plantar/dorsi flexion at 30 deg/s	4 (12%)	Holzgrefe et al[27] (2020), Baumfeld et al[4] (2019), Talbot et al[79] (2012), Ryu et al[69] (2018)
Plantar/dorsi flexion at 60 deg/s	1 (3%)	Porter et al[65] (2014)
Plantar/dorsi flexion at 90 deg/s	3 (9%)	Holzgrefe et al[27] (2020), Porter et al[66] (1997), Talbot et al[79] (2012)
Plantar/dorsi flexion at 120 deg/s	3 (9%)	Porter et al[65] (2014), Porter et al[66] (1997), Ryu et al[69] (2018)
Plantar/dorsi flexion at 180 deg/s	2 (6%)	Porter et al[65] (2014), Porter et al[66] (1997)
Plantar/dorsi flexion at 240 deg/s	2 (6%)	Holzgrefe et al[27] (2020), Talbot et al[79] (2012)
(2) Isometric plantarflexion strength	7 (21%)	Maffulli et al[45] (2011), Maffulli et al[44] (2013), Guillo et al[23] (2013), Jennings et al[23] (2002), Jennings et al[31] (2004), Abdelatif and Batista[1] (2022), Groetelaers et al[22] (2014)
(3) ISS	2 (6%)	Holzgrefe et al[27] (2020), Talbot et al[79] (2012)

ISS, isokinetic strength score.

Table 5. Isometric plantarflexion strength test used in the included studies

Study, authors (year)	Involved limb peak torque	Uninvolved limb peak torque	Reported *P* value
Maffulli et al[45] (2011)	382.8 ± 127.8 N	425.6 ± 141.1 N	0.03
Maffulli et al[44] (2013)	234.7 ± 124.8 N	285.2 ± 140.1 N	0.04
Guillo et al[23] (2013)	151.8 ± 40.8 N	158.2 ± 34.7 N	0.04
Jennings et al[32] (2002)	238.7 N	281 N	>0.05
Jennings et al[31] (2004)	NA	NA	NA
Abdelatif and Batista[1] (2022)	19.17 ± 2.75 kgm	19.08 ± 2.20 kgm	0.90
Groetelaers et al[22] (2014)	NA	NA	NA

kgm, kilogram meters; N, Newtons; NA, not available.

Prejbeabu et al[67], performed a “B mode ultrasound determination of cross-sectional area (CSA)” to measure the calf muscle size. The calf muscle size outcomes found are reported in Table 6.

Calf Capacity

A total of 15 (44%) studies assessed calf capacity using heel-rise test; these 15 studies are listed in Table 3 under category “Calf capacity/endurance.” The outcomes were reported using a

Table 6. Calf muscle circumference

Study, authors (year)	Average test follow-up from surgery	Involved limb MCC, cm	Uninvolved limb MCC, cm	Mean deficit of the involved compared with the uninvolved leg, cm	Significance reported, *P* value
Zhang et al[90] (2018)	12 months	NA	NA	0.7 ± 0.2	No significance difference
Maffulli et al[45] (2011)	72 months	42.3 ± 9.3	47.6 ± 7.8	NA	<0.05
Porter et al[65] (2014)	32 months (range, 12-80)	NA	NA	-1.9	<0.05
Nam et al[52] (2019)	12 months	38.3 ± 2.1 FG/38.3 ± 3.8 IG	NA	NA	0.90
Manegold et al[47] (2018)	3 years	36.4 ± 2.9	37.6 ± 2.6	1.2 ± 1.2	<0.05
Baumfeld et al[4] (2019)	NA	37.9 open/ 37.8 percutaneous	38.7 open/ 39.1 percutaneous	NA	0.59/0.17
Maffulli et al[44] (2013)	8.2 years (range, 7-10)	39.7 ± 7.1	41.5 ± 6.6	NA	0.30
Biz et al[5] (2021)	9.7 years (range 6.8-10.6)	NA	NA	3.30 ± 1.02 M&G group/ 2.40 ± 0.96 TT group	<0.05
Stein et al[77] (2015)	29.7 ± 6.1 months	37.7 ± 2.0	38.2 ± 2.0	0.5 ± 1.3	NA
Guillo et al[23] (2013)	25.7 months (range 24-32)	34.5 ± 6.2	35.1 ± 6.1	NA	0.28
Porter et al[66] (1997)	3.75 years (range, 1.5-7.4)	39 neglected group/ 39 acute group	40.8 neglected group/39.9 acute group	1.6 neglected group/0.9 acute group	NA
Jennings et al[32] (2002)	3 years (range 0.5-8.0)	32.1	36.6	NA	<0.05
Jennings et al[31] (2004)	3 years	NA	NA	1.87	<0.05
Carmont et al[11] (2020)	NA	NA	NA	NA	NA
Ryu et al[69] (2018)	19.8 months (range 12-30)	NA	NA	1.6 (range 0.5-4.0)	0.90

FG, functional group; IG, immobilization group; M&G, Ma and Griffith; MCC, maximum calf circumference; NA, not available; TT, Tenolig technique.

Table 7. Overview of calf capacity outcome measures reported across included studies

Author (year)	Description of calf capacity test	Outcome type[a]
Maffulli et al[45] (2011)	"Patients discharged once able to perform ≥5 single-leg toe raises without support"	Numerical data
Miyamoto et al[51] (2017)	"20 continuous heel raises"	Numerical data
Guillo et al[23] (2013)	"≥10 heel lifts"	Numerical data
Nam et al[52] (2019)	"Heel height, 12.2 ± 2 cm (intervention group); 12.1 ± 1.4 cm (control group)"	Numerical data
Sanada et al[70] (2022)	"Mean time to achieve SLR reported"	Numerical data
Won Lee et al[85] (2022)	"Mean time to achieve SLR reported"	Numerical data
Biz et al[5] (2021)	"In the M&G group, the single heel rise test on the operated side was weakly positive in 10%, positive in 6%, and weakly positive in 4% on the healthy side"	Descriptive data
Tasatan et al[80] (2016)	"1-min tiptoe standing without support"	Descriptive data
Stein et al[77] (2015)	"All patients could perform SLR at follow-up"	Descriptive data
Prejbeanu et al[67] (2021)	"LSI using a modified heel rise test (total height of single limb heel rises >5 cm measured manually at 30 repetitions per minute from a 2-cm rigid platform)"	Numerical data
Jennings et al[31] (2004)	"Ability to stand on tiptoe on injured side"	Descriptive data
Jennings et al[32] (2002)	"2 patients unable to stand on tiptoe"	Descriptive data
Obut et al[55] (2017)	"Tiptoe test same as normal side at last control"	Descriptive data
Ryu et al[69] (2018)	"Single heel raise was possible in all patients"	Descriptive data
Carmont et al[11] (2020)	"Single-leg heel-rise test (HRHI: delayed 79% vs acute 74%; HRRI: delayed 77% vs acute 71% at 12 months)."	Numerical data

HRHI, heel-rise height index; HRRI, heel-rise repetition index; LSI, limb symmetry index; M&G, Ma and Griffith; SLR, single leg rise.
[a]"Numerical data" refers to the quantitative reporting of heel-rise performance (e.g., number of repetitions, time in maintaining heel-rise position, height achieved). "Descriptive data" includes qualitative or categorical descriptions of the test outcome.

variety of formats, distinguishing between numerical and descriptive outcome data collected in Table 7.

Performance Measurements (Functional Results and Sport Statistics)

All 7 (21%) studies that reported performance measurements (functional results and sport statistics) are listed in Table 3, under category "Performance measurements (functional results and sport statistics)." Five (15%) of them use a hopping test to evaluate lower limb performance, while 2 (6%) reported sport performance statistics to evaluate the performance of the athlete in the seasons after the repair. Different formats of assessing hopping tests results were found. Won Lee et al[69,85] reported the time (in weeks) it took for participants to achieve a "double leg jump," without providing a definition of the test. Ryu et al[69] reported that "hopping was possible in every patient." Gamal et al[19] reported that "The single extremity jump-landing test did not differ in injured and healthy extremities at 1-year follow-up," without defining the test. Obut et al[55] reported that "jump test with knee flexion were the same compared with the normal side of the patients at last control examination," without defining the jump test. Tasatan et al[80] reported that "no differences were found in the single extremity jump-landing test," without defining the jump test. Two (6%) articles reported the sports performance measurements; Amin et al[2] used the NBA player efficiency rating (PER) to compare individual player performance before and after AT repairs, while Jack et al[29] collected and aggregated NFL player statistics before and after AT repairs to generate a player's performance score; 27 (79%) of the included studies did not provide measurements related to performance assessment.

Table 8. Common functional outcome deficits reported after AT repair

Functional outcome deficits reported	Studies reporting, n (% of 34)	Authors (year)
Isokinetic test for the ankle	3 (9%)	Porter et al[65] (2014), Porter et al[66] (1997), Ryu et al[69] (2018)
Isometric plantarflexion strength	4 (12%)	Maffulli et al[45] (2011), Maffulli et al[44] (2013), Guillo et al[23] (2013), Jennings et al[32] (2002)
Calf circumference	8 (24%)	Maffulli et al[45] (2011), Porter et al[65] (2014), Manegold et al[47] (2018), Maffulli et al[44] (2013), Porter et al[66] (1997), Jennings et al[32] (2002), Ryu et al[69] (2018), Yeung et al[86] (2019)
Calf capacity	3 (9%)	Carmont et al[11] (2020), Jennings et al[32] (2002), Talbot et al[79] (2012)
PROMs	3 (9%)	Peterson et al[63] (2021), Porter et al[65] (2014), Manegold et al[47] (2018)
Performance	2 (4%)	Amin et al[2] (2013), Jack et al[29] (2017)

AT, Achilles tendon; PROMS, patient-reported outcome measures.

Patients Reported Outcomes Measures

Patient-reported outcome measures (PROMs) can be categorized into 2 types of measurement: global and disease-specific.[76] All studies that reported PROMs, divided into these 2 categories, are listed in Table 3, under section "Subjective outcome measurements," with each item corresponding to a specific type of PROM.

Functional Outcome Deficits at Final Follow-Up

A total of 14 (41%) studies reported functional outcome deficits of the involved limb compared with the uninvolved limb in key assessments (such as, ankle ROM and calf strength, circumference and capacity) after AT repair. These studies are listed in Table 8.

Regarding PROMs deficits, 3 (9%) of the included studies reported deficits such as "fear of re-rupture," "shift in focus," or a feeling of "running on a flat tire."

DISCUSSION

The main result of this scoping review was that we did not find any study that defined a single measurement to be used as a "criteria" to RTS after AT repair. Thus, we collected the outcome measurements found in the included studies to describe and discuss the predominant outcome measurements that the literature suggests for the athlete RTS process after AT repair.

General Participant and Athlete Characteristics

To define the appropriate RTS for each athlete, it is necessary to consider individual athlete characteristics, such as demographics (age, sex, physical information), type of sport activities (e.g., pivoting or nonpivoting, contact or noncontact sports), intensity of the sport activities, frequency of sport exposure, level of participation (e.g., elite, competitive, or recreational), and performance indicators (e.g., match/training/role statistics).[14] Without such contextual information, it may not be possible to appropriately achieve these targets that refer to preinjury levels. Several studies in our review reported only general information about participants, often neglecting sport-contextual factors such as playing level, positional role, physical demands, and preinjury sport exposure. Such details are key indicators for practitioners managing recovery after AT repair, particularly during the mid- and late-stage of rehabilitation. An elevated level of competitiveness would likely elevate the athletes demands for force production and the stress to which the AT may be exposed.[38] Furthermore, different sports involve distinct movement patterns, biomechanical demands, and risk factors for injury.[87] Thus, defining the athlete's profile and understanding the athlete's specific sport and performance demands can support the rehabilitation and RTS process, particularly during the late stage of rehabilitation, potentially increasing the likelihood of a successful RTS with the use of Global Positioning System (GPS) during on-field rehabilitation (OFR) to fulfill the athlete preinjury GPS metrics.

Participant Time From Surgery to RTS

Almost half (47%) of the included studies did not provide information on the RTS timeline. Time to RTS is considered one of the criteria for RTS decision-making in other severe injuries.[9] RTS needs to be considered as a continuum comprising 3 elements: return to participation (RTP), RTS, and return to performance.[3] Buckthorpe et al[8] updated the RTS continuum to include OFR, return to training, return to competitive match play, and, finally, return to performance. Each of these stages represents a crucial milestone in the RTS process. Therefore, studies that provide clear information about the timeline for achieving each stage of the continuum, as well as how the athlete progresses between them, can be valuable for practitioners working with athletes recovering from AT repair. However, although temporal references are important, they should not be the sole criteria leading the athlete through the RTS continuum; it must be combined with a functional criteria-based RTS process. After AT rupture, average RTP time is reported to be 6 (±1.8) months for recreational players,[88] and 11 months for professional athletes,[33] with no clear evidence of premature RTP as a risk factor for recurrence.

RTS Rate, Return to Preinjury Level, and AT Reinjury Rate

Although 14 (41%) included papers reported that >89% of patients returned to sport after AT repair, a suboptimal trend in the percentage of players who returned to the same preinjury level was observed. Only 3 (9%) studies reported between 89% and 100% of patients returned to the same level as preinjury level (Table 3, section "return to sport information"). This trend is in line with studies with research comparing athlete performance after AT rupture with their preinjury performance levels. Studies on NBA players found a significant decrease in the number of games played in the first 2 years after injury,[36,50,82] as well as a decrease in minutes per game and total minutes played during this period.[2,36,82] In addition, the PER—a standardized measurement tool used commonly in evaluating NBA players—showed significantly decreased values after injury in the first 2 seasons.[2,50,82] In professional football (soccer), 1 study reported that 18% of 76 athletes did not return to preinjury performance level during the 2 seasons after RTS,[21] while another found a significant decrease in football (soccer) games during the first year after return, which was not evident in the second season.[20] It appears that the majority of the athletes who returned to play did so at lower performance levels. A quarter (26%) of the studies included documented a reinjury rate from 0 to 8% (Table 3, item "Patients reinjured rate"). This may be considered a favorable outcome when compared with other long-term injuries such as ACL injuries.[6] Therefore, given the low reinjury rate and the limited return to preinjury level, greater attention during the RTS process should be directed toward optimizing the recovery of ankle-calf performance, rather than focusing primarily on Achilles tendon reinjury.

Altered Ankle ROM and Achilles Tendon Elongation

Almost half (47%) of our included studies reported ROM measurements, although a lack of standardization in how these outcomes are reported was observed. Only 6% provided data on dorsi and plantar flexion for both injured and uninjured limbs. Altered ROM can dramatically impact ankle function and subsequent functional performance, due to changes in the muscle-tendon unit and shift in the force-length relationship of the plantar-flexors.[78] After AT repair, the AT heals in a permanently elongated position,[34] with a shorter triceps surae fascicle length and with increased angle of pennation.[15] This shifts the force-length curve to the left, reducing gastrocnemius muscle force during functional tasks, such as heel-rises, that emphasize end-range plantar flexion deficit.[35,73,89] To minimize the risk of AT elongation, dorsiflexion stretching should be avoided until the beginning of the remodeling phase, around 6 weeks postsurgery.[49]

Calf Muscle Strength Deficit

A total of 15 (44%) studies reported measurements regarding calf muscle strength (Table 4). Of the 5 studies assessing isometric plantar flexor strength (Table 4), 4 reported a strength deficit in the injured limb compared with the contralateral side, with deficits of 11%,[45] 21%,[44] 5%,[23] or 18%.[32] Only 1 study reported peer outcomes.[1]

These deficits align with research indicating persistent calf muscle isometric strength deficits in the injured limb, even in the long term.[25,28,39] However, Orishimo et al[56] observed greater EMG activity during toe-walking on the operated side compared with the nonoperated side, suggesting increased neuromuscular engagement in the repaired limb. This observation, aligns with the compensatory mechanism hypothesized by Suydam et al,[78] who proposed that increased muscle activation may help pretension the elongated tendon and reduce slack before ankle movement. This supports the aforementioned findings in which the triceps surae muscles can still produce force after AT rupture but within a limited ROM, showing weakness in end-range plantar flexion. This deficit may have implications for high-demand activities like jumping and sprinting after AT repair, with the ankle joint in plantar flexion. Strategies to prevent elongation, in the early stage of rehabilitation, and the assessment of movement quality, in the mid stage of rehabilitation, to understand implications for sport performance are recommended.

Calf Muscle Size Deficit

The trend across these studies showed a lower calf circumference in the injured leg compared with the uninjured leg (Table 6). Leppilathi et al[43] reported that, after AT repair, only 30% of subjects regained normal calf size, while 73% achieved excellent or good isokinetic strength results. The authors concluded that muscle strength normalized more effectively than calf size due to adaptive changes in the neural system from strength training, which resulted in greater calf muscle strength per unit cross-sectional area on the injured side than on the noninjured side during follow-up.[43] Therefore, measuring calf circumference is useful for screening calf muscle mass, but it is also recommended to include assessments of the plantar-flexors strength and ankle functional performance.

Calf Capacity Deficit

Although the single-leg heel raise test was the main test used to assess calf capacity (Figure 2), many studies reported only qualitative comments as outcomes for this test (Table 7). They do not provide specific data on the number of rises or the height achieved as recommended by the literature to encourage optimized outcomes after ATR repair.[72] The heel rise test typically reveals reduced repetitions, decreased heel-rise height, and diminished work of the injured leg, even 6 months after AT surgery,[16] and these deficits may persist as long-term effects.[26] This persistent weakness in end-range plantar flexion force production may be attributed to increased tendon length coupled with a shortened gastrocnemius muscle. In a plantar flexed position, the muscle operates on the ascending limb of the active length-tension curve, already in a shortened state and below the optimal angle for force generation.[56] It is recommended that athletes should be able to perform at least 25 valid single-leg heel rises before RTS, with a limb symmetry index >80% compared with the contralateral limb.

Performance Deficit (Functional Results and Sport Statistics)

Only 5 (15%) studies of the included studies reported hop tests to evaluate the lower limb performance (functional results and sport statistics) after AT repair. These studies lack in defining which type of hop/jump test was used and the outcomes achieved. Terms such as "hopping test" were used without providing further data clarification. If we look at the literature, there is limited research about how changes in muscle-tendon unit architecture after AT rupture may affect lower limb performance and movement quality during athletic activities.[30,74,84] Available research suggests differences in kinetics and kinematics before and after the AT rupture,[73] as well as side to side asymmetries between the affected and the unaffected limb.[84] In particular, 2 compensatory motor strategies were identified during running after AT rupture: (1) increased ankle dorsiflexion during the stance phase, and (2) a reduced knee angle at the initial foot contact to the ground coupled with a greater knee ROM during the bodyweight acceptance phase compared with a healthy group.[30] This limited literature suggests a shift in motor strategy post AT repair, with a loading shift from ankle to greater knee joint in both the involved and uninvolved limbs during athletic activities, which is thought to result in ~7% higher peak patellofemoral joint stress in the involved limb during jogging and hopping.[30] This may predispose the affected limb's knee to a greater risk of mechanical overloading during athletic activities, potentially leading to patellar tendinopathy.[30] Furthermore, the reduced knee flexion angle at initial foot contact during running and hopping may have implications for subsequent risk of ACL rupture.[30] Clinicians must consider these altered movement patterns during the landing phase and their potential short- and long-term effects. We recommend a qualitative movement assessment as part of AT rehabilitation and RTS testing. To achieve optimal outcomes, athletes should achieve proper movement quality, in fundamental movement patterns such as walking gait, single leg squat, single-leg hopping, running, deceleration, change of direction, and sport-specific gestures. Alongside the evaluation of movement quality, assessing the athlete's capacity to perform sport-specific tasks is equally important. Monitoring an athlete's game statistics provides valuable insights into their performance level. Having access to this information can serve as a useful tool for comparing pre- and postinjury performance and evaluating whether the athlete has returned fully to their previous performance level. Thus, assessing game statistics during the seasons after RTS may offer further information on whether the athlete has effectively regained their preinjury standard.

Patient Reported Outcome Measurements

PROMs are tools used to assess how patients perceive their health and the effects of medical treatments on their wellbeing, functioning, and overall quality of life.[59] Over the years, the use of PROMs has become increasingly common among healthcare providers.[12] In alignment with findings from a recent systematic review regarding PROMs used after AT repair,[60] we observed a wide heterogeneity in their use. The Achilles tendon total rupture score (ATRS) was the most used PROM, featured in 47% of the included studies (Figure 2). ATRS is a disease-specific PROM that contains subjective questions, and is regarded as a tool with high clinic utility for measuring symptoms and physical activities after AT repair.[54] The second most frequently used PROM was the American Orthopedic Foot and Ankle Society Ankle-Hindfoot score (AOFAS-AH) featured in 41% of the included studies. AOFAS-AH is a global measurement that contains subjective and objective components. It allows assessment of pain, function, and alignment in the region of the ankle and hindfoot, including, but not limited to, the AT. We suggest the incorporation of PROMs as integral components of athlete assessment during the RTS process post-AT repair.

The Need to Develop RTS Criteria After AT Repair

An ideal AT rehabilitation pathway based on functional criteria is needed to support practitioners in optimizing rehabilitation outcomes and improving long-term RTS success. According to our findings, the literature suggests that current assessments focus predominantly on the early stage of rehabilitation. However, in line with the updated RTP continuum,[8] a shift in focus from traditional rehabilitation towards a performance-oriented RTS process has been developed. This is particularly important, as many patients RTS with persistent performance deficits despite meeting standard RTS timelines. To support this transition, specific and progressive criteria should be developed to guide progression across the early, mid, and late stages of rehabilitation and RTP (Figure 3). During the mid-stage of rehabilitation, a better understand of body kinetics and kinematics, through movement quality video analysis, might support the possible adaptations occurring after AT repair and inform evidence-based program design. For the late stage of rehabilitation, more insight is needed regarding load progression and the most appropriate RTS monitoring and testing strategies to be applied during the OFR phase after AT rupture.[7,17]

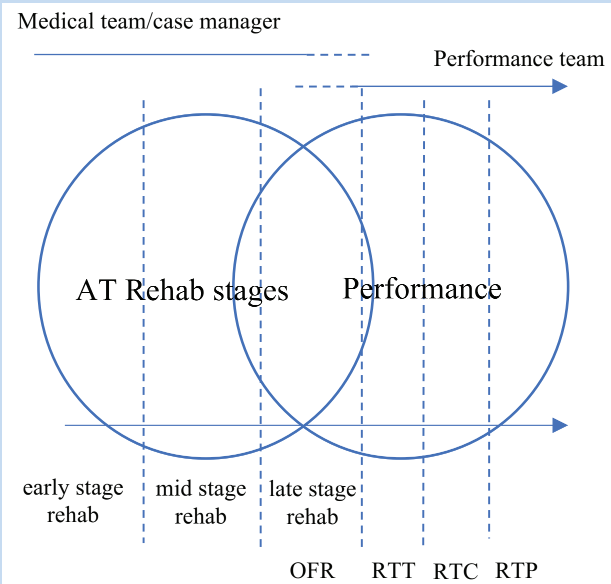

Figure 3. AT functional recovery model (RTS and RTP). Adapted from Buckthorpe et al.[8] AT, Achilles tendon; OFR, on-field rehabilitation; rehab, rehabilitation; RTC, return to competition; RTP, return to performance; RTS, return to sport; RTT, return to training.

Limitations

Our scoping review has several limitations. The review protocol was not registered on public platforms such as the Open Science Framework or Figshare. We included only articles published in English, which may have excluded relevant studies in other languages. During the initial screening phase, articles were excluded based on title and abstract if they were clearly unrelated to the research question. The surgical technique used for AT repair (e.g., open vs percutaneous) was not considered as an inclusion or exclusion criterion, which may contribute to variability in the data. We also did not include gray literature. The search strategy relied on broad-concept keyword combinations, which may have missed studies using alternative terminology. In addition, no supplementary search strategies (e.g., snowballing, citation tracking) were used, which might have limited the comprehensiveness of the search. Although the methodological quality of included studies varied, no formal quality appraisal was performed, as this is not required in scoping reviews. Finally, in line with the PRISMA-ScR guidelines, our analysis focused on mapping and describing the frequency of reported outcomes and RTS criteria in the included studies, without conducting comparative or inferential analyses. Future systematic reviews might offer more detailed comparisons.

CONCLUSION

None of the 34 studies included in our scoping review defined an outcome measurement as criteria to RTS after AT repair. The main measurements identified focus primarily on the early stage of the rehabilitation, and a lack of standardization in reporting these key measurements was found. A lack of measurement assessment for the mid and late stages of AT rehabilitation were observed. The definition of RTS criteria after AT repair might support the optimization of rehabilitation and the RTS process.

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