Systematic Review and/or Meta-analysis

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Immediate mobilization after repair of Achilles tendon rupture may increase the incidence of re-rupture: a systematic review and meta-analysis of randomized controlled trials

Ruihan Wang, MS[a,f], Lei Huang, MS[a], Songtao Jiang, BS[b], Guixuan You, MS[a], Xin Zhou, MS[c,d,e], Guoyou Wang, MD, PhD[c,d,e,*], Lei Zhang, MD, PhD[c,d,e,*]

Background: Achilles tendon rupture (ATR) is a significant injury that can require surgery and can have the risk of re-rupture even after successful treatment. Consequently, to minimize this risk, it is important to have a thorough understanding of the rehabilitation protocol and the impact of different rehabilitation approaches on preventing re-rupture.

Materials and methods: Two independent team members searched several databases (PubMed, EMBASE, Web of Science, Cochrane Library, and CINAHL) to identify randomized controlled trials (RCTs) on operative treatment of ATR. We included articles that covered open or minimally invasive surgery for ATR, with a detailed rehabilitation protocol and reports of re-rupture. The study protocol has been registered at PROSPERO and has been reported in the line with PRISMA Guidelines, Supplemental Digital Content 1, http://links.lww.com/JS9/C85, Supplemental Digital Content 2, http://links.lww.com/JS9/C86 and assessed using AMSTAR Tool, Supplemental Digital Content 3, http://links.lww.com/JS9/C87.

Results: A total of 43 RCTs were eligible for the meta-analysis, encompassing a combined cohort of 2553 patients. Overall, the postoperative incidence of ATR patients developing re-rupture was 3.15% (95% CI: 2.26–4.17; $I^2 = 44.48\%$). Early immobilization group patients who had ATR had a 4.07% (95% CI: 1.76–7.27; $I^2 = 51.20\%$) postoperative incidence of re-rupture; Early immobilization + active range of motion (AROM) group had an incidence of 5.95% (95% CI: 2.91–9.99; $I^2 = 0.00\%$); Early immobilization + weight-bearing group had an incidence of 3.49% (95% CI: 1.96–5.43; $I^2 = 20.06\%$); Early weight-bearing + AROM group had an incidence of 3.61% (95% CI: 1.00–7.73; $I^2 = 64.60\%$); Accelerated rehabilitation (immobilization) group had an incidence of 2.18% (95% CI: 1.11–3.59; $I^2 = 21.56\%$); Accelerated rehabilitation (non-immobilization) group had a rate of 1.36% (95% CI: 0.12–3.90; $I^2 = 0.00\%$). Additionally, patients in the immediate AROM group had a postoperative re-rupture incidence of 3.92% (95% CI: 1.76–6.89; $I^2 = 33.24\%$); Non-immediate AROM group had an incidence of 2.45% (95% CI: 1.25–4.03; $I^2 = 22.09\%$).

Conclusions: This meta-analysis suggests the use of accelerated rehabilitation intervention in early postoperative rehabilitation of the Achilles tendon. However, for early ankle joint mobilization, it is recommended to apply after one to two weeks of immobilization.

Keywords: Achilles tendon re-rupture, Achilles tendon rupture, meta-analysis, rehabilitation

Introduction

The occurrence of Achilles tendon rupture (ATR) is on the rise, with a yearly occurrence rate ranging from ~26.95–31.17%. This injury is more prevalent in males and individuals over the age of 50[1]. There has been an ongoing debate about the best way to manage acute ATR, with each treatment option having advantages and disadvantages[2]. Research indicates that non-surgical treatments generally have a higher rate of re-rupture[3].

[a]School of Physical Education, Southwest Medical University, [b]School of Clinical Medicine, Southwest Medical University, [c]Department of Orthopedics, The Affiliated Traditional Chinese Medicine Hospital, Southwest Medical University, [d]Center for Orthopedic Diseases Research, The Affiliated Traditional Chinese Medicine Hospital, Southwest Medical University, [e]Luzhou Key Laboratory of Orthopedic Disorders, Luzhou and [f]Department of Rehabilitation, Yibin Integrated Traditional Chinese and Western Medicine Hospital, Yibin, China

R.W., L.H. and S.J. contributed equally to this work and co-first authors.

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*Corresponding authors. Address: Department of Orthopedics, The Affiliated Traditional Chinese Medicine Hospital, Southwest Medical University, Luzhou, Sichuan, China, 646000. Tel.: +86 152 8305 1308. E-mail: zhanglei0722@swmu.edu.cn (L. Zhang), and Tel.: + 86 139 8912 1399. E-mail: wangguoyou1981@swmu.edu.cn (G. Wang).

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Therefore, surgical intervention has been recognized as the primary approach to addressing the issue of re-ruptures of the Achilles tendon[4]. Managing ATR has proven to be a challenging problem due to major complications like re-rupture, deep infection, and deep vein thrombosis. These complications can lead to catastrophic results, making treatment even more complicated. While surgical intervention has been proven successful in reducing the incidence of re-rupture, there are still instances where re-rupture can occur[5]. Once the Achilles tendon ruptures again, patients typically have persistent functional impairments in the long-term and worse outcomes than primary ruptures[6]. Additionally, the results of a meta-analysis comparing open versus minimally invasive surgery for ATR indicate that the incidence of re-rupture is not significantly different[7]. It follows then that postoperative rehabilitation intervention is crucial for ensuring successful treatment of ATR, specifically in preventing complications such as the re-rupture.

Rehabilitation regimens mainly include cast immobilization, early mobilization, and accelerated rehabilitation (AR). Cast immobilization can be non-weight-bearing or weight-bearing, whereas the AR includes early weight-bearing, early motion, and functional exercises. Some studies demonstrated that early weight-bearing after surgery in combination with ankle joint active range of motion (AROM) exercises could lead to a more substantial improvement in functionality, as opposed to traditional measures[8–10]. A network meta-analysis of 2060 patients found that minimally invasive surgery and AR are advantageous in reducing the risk of major complications[5]. This demonstrates the importance of AR in minimizing post-surgery complications. However, there is still no consensus on the best rehabilitation program to follow after undergoing surgery for an ATR, and the evidence available is frequently disregarded[11]. The impact of various rehabilitation techniques on the incidence of re-rupture after surgery for ATR remains uncertain.

Therefore, in order to reduce the incidence of re-rupture of the Achilles tendon, we conducted a meta-analysis on early postoperative rehabilitation interventions to understand the re-rupture risks of different rehabilitation methods. We hope to provide evidence for surgeons and physical therapists in selecting optimal rehabilitation methods for early rehabilitation after ATR surgery.

HIGHLIGHTS

- The accelerated rehabilitation intervention has the lowest incidence of re-rupture.
- Immediate postoperative mobilization may have a higher incidence of re-rupture.
- It is recommended that ankle joint mobilization be delayed until 1–2 weeks after surgery.

Methods

This systematic review and meta-analysis was registered on the PROSPERO (CRD42023417161). This systematic review and meta- meta-analysis was reported following a detailed protocol according to the PRISMA checklist[12]. In addition, the study has been appraised in the line with the AMSTAR Guidelines[13].

Literature search

Relevant randomized controlled trials (RCTs) of the English language were identified by systematic search of PubMed, EMBASE, Web of Science, Cochrane Library, and CINAHL from inception to 11 October 2023, using the keywords “Achilles tendon rupture,” “surgery,” “operation,” and “percutaneous” with appropriate MeSH terms (Supplementary file 1, Supplemental Digital Content 4, http://links.lww.com/JS9/C88). We excluded non-RCTs, lack of availability of full text and letters, and studies lacking rehabilitation protocol and complication reports. Two authors (RW and LH) evaluated articles for eligibility based on the given criteria. Any disparities were resolved by mutual communication and agreement. Both reviewers independently collected data which was then reviewed by the corresponding author (LZ).

Eligibility criteria

Following the screening of titles and abstracts, the full text were reviewed independently by the same two authors (RW and LH). The criteria for inclusion involved the surgical treatment (open or minimally invasive surgery) of ATR, with a detailed rehabilitation protocol and reports of re-rupture. Any disagreements between reviewers regarding eligibility could be resolved through consensus or discussion with the corresponding author (LZ).

Patient: Achilles tendon rupture.

Intervention: Surgery.

Control: None (no eligibility constraints).

Outcome: Re-rupture.

Study design: RCTs that reported the details of rehabilitation and complication (re-rupture) with at least 1 year of follow-up.

Data extraction

The data that was retrieved contained the following: study features (title, authors, year, study period, study design, country, and rehabilitation protocol) and participants’ characteristics (follow-up, number of patients, and number of re-rupture). In addition, to improve the accuracy of calculating the Achilles tendon re-rupture rate, we have excluded patients who were lost to follow-up from the total number in some literature.

Risk of bias assessment

The Cochrane Risk of Bias (ROB2) tool was used for the risk of bias by two authors independently (RW and LH)[14]. The bias was on the basis of the randomization process, deviations from the intended interventions, missing outcome data, measurement of reported all primary outcomes, and selection of the reported result. Risk of bias was judged to be “low”, “uncertain” and “high”, respectively.

Statistical analysis

All statistical analysis was carried out using MedCalc (Windows) version 22.001 - 64-bit (MedCalc Software, Ostend, Belgium). A Forest plot was used to represent the incidence rates of Achilles tendon re-rupture on early postoperative rehabilitation intervention with their corresponding 95% CIs calculated using the random effects model. To determine the presence of heterogeneity among studies, the Cochran Q test was used, where a P value less than 0.05 indicated significant heterogeneity. The I^2 statistic was employed to assess the level of variability in research findings

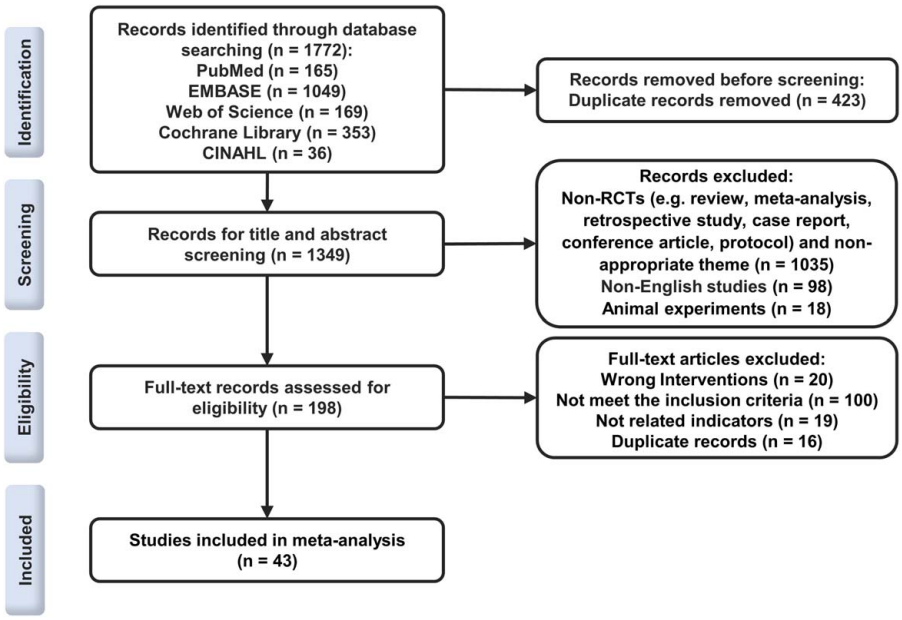

Figure 1. The PRISMA flowchart. RCT, randomized controlled trial.

caused by heterogeneity. The I^2 was assigned the following meanings: poor heterogeneity (0–40%), fair (30–60%), moderate (50–90%), and considerable (75–100%)[15]. The presence of publication bias was evaluated through the Egger regression test, where a P value of greater than or equal to 0.1 suggests that there is no significant publication bias[16].

Sensitivity analysis

A sensitivity analysis was conducted as part of the meta-analysis to evaluate the potential influence of including or excluding certain studies on the results. Specifically, we excluded studies with large effects from the meta-analysis and proceeded to rerun the analysis.

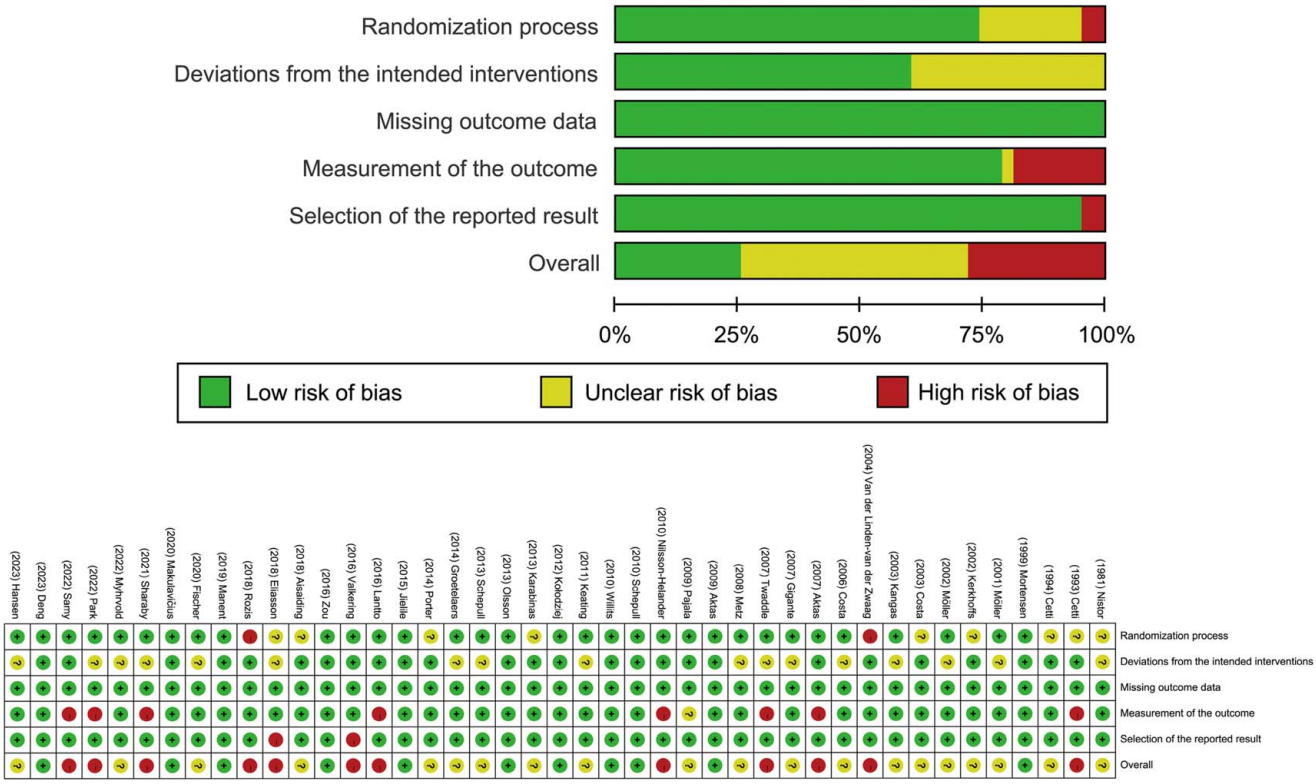

Figure 2. Risk of bias in included studies.

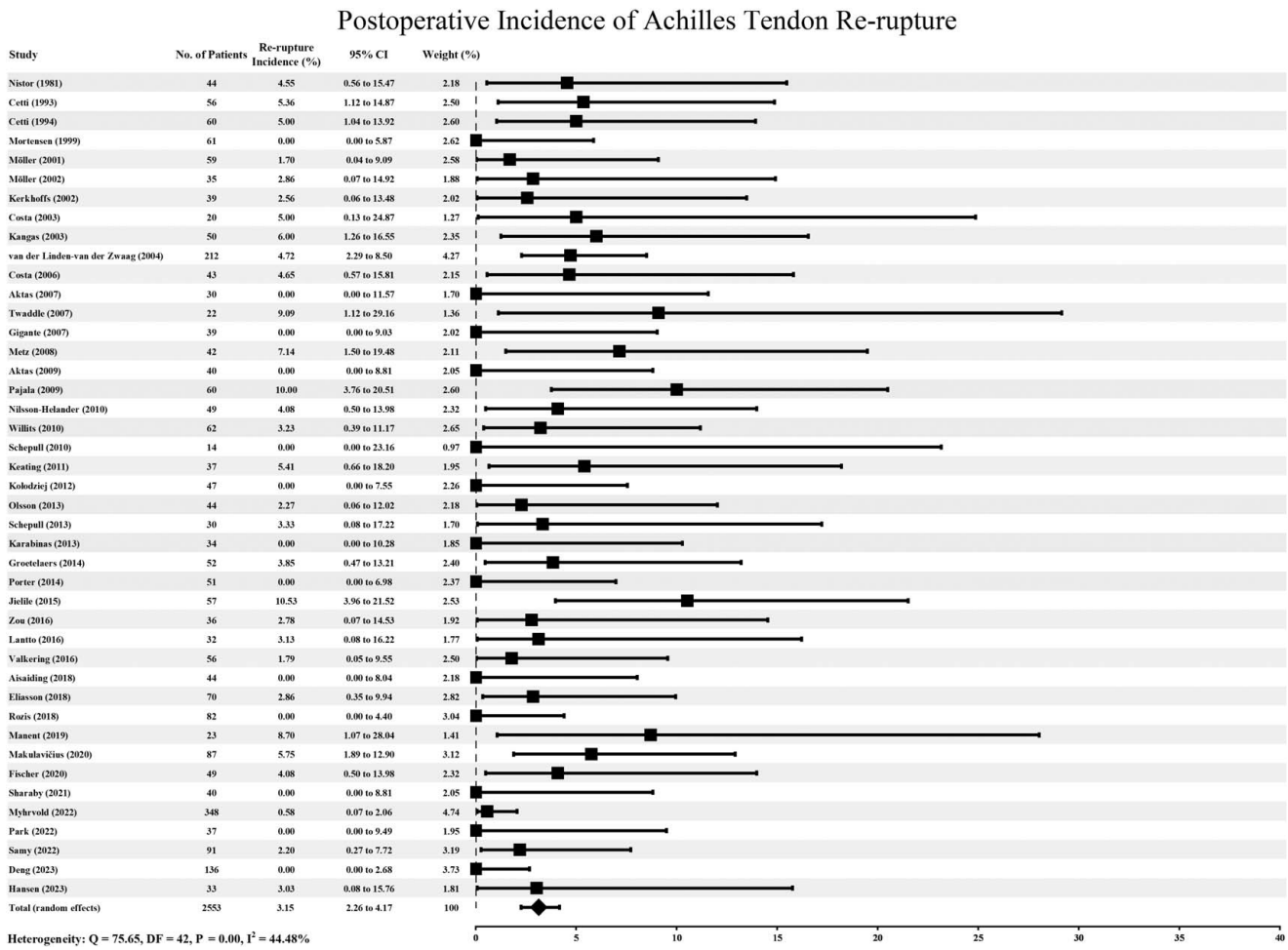

Figure 3. Forest plots of all studies on the postoperative incidence of Achilles tendon re-rupture.

Results

Study selection

The search process yielded a total of 1772 articles, out of which 198 studies were identified as potentially eligible, and their full texts were reviewed in Figure 1. Ultimately, our analysis included 43 articles, and summarized their demographic data in Table 1.

Study characteristics

In this meta-analysis, we incorporated a total of 43 RCTs. These studies were categorized based on their publication dates, with 4 published before 2000, 16 between 2000 and 2010, 17 between 2011 and 2020, and 6 after 2020. They originated from different regions, including Europe (31 studies, 72.09%), Asia (7 studies, 16.28%), Oceania (2 studies, 4.65%), Africa (2 studies, 4.65%), and North America (1 study, 2.33%). To ensure consistency in the meta-analysis results, we only considered studies with a follow-up time of at least 1 year.

Participant characteristics

A total of 2553 patients were included in this study. The studies covered various aspects of Achilles tendon rupture, with 12 examining surgical and non-surgical treatments, 7 exploring open and minimally invasive surgical treatments, 15 focusing on rehabilitation interventions, 6 investigating Achilles tendon repair techniques, 2 studying platelet-rich plasma therapy, and 1 analyzing gait analysis. In cases where there were missing data, loss to follow-up, or inadequate follow-up duration among the patients within the included studies (or already accounted for in the total number of follow-up patients), we removed these cases to maintain the accuracy of the re-rupture rate calculation. It's important to note that while some bias may still be present, the Achilles tendon re-rupture frequency was not the primary outcome in the respective studies we included.

Risk of bias in included studies

The risk of bias assessment was shown detailed in Figure 2. Eleven (26%) studies were at low risk of bias overall, twelve (28%) studies were at high risk of bias mainly because the measurement of outcomes, most of these studies did not mention the blinding of evaluation or be absence of blinding for objective reasons. And nine (21%) studies did not mention specific randomization grouping process. All studies had relatively low missing outcome data rates. The published bias *P* value for the analysis of the re-rupture rate of all included literatures is 0.00. For the sub-analysis of different rehabilitation subgroups, the published bias *P* values are 0.81, 0.83, 0.23, 0.16, 0.00, and 0.67, respectively. Similarly,

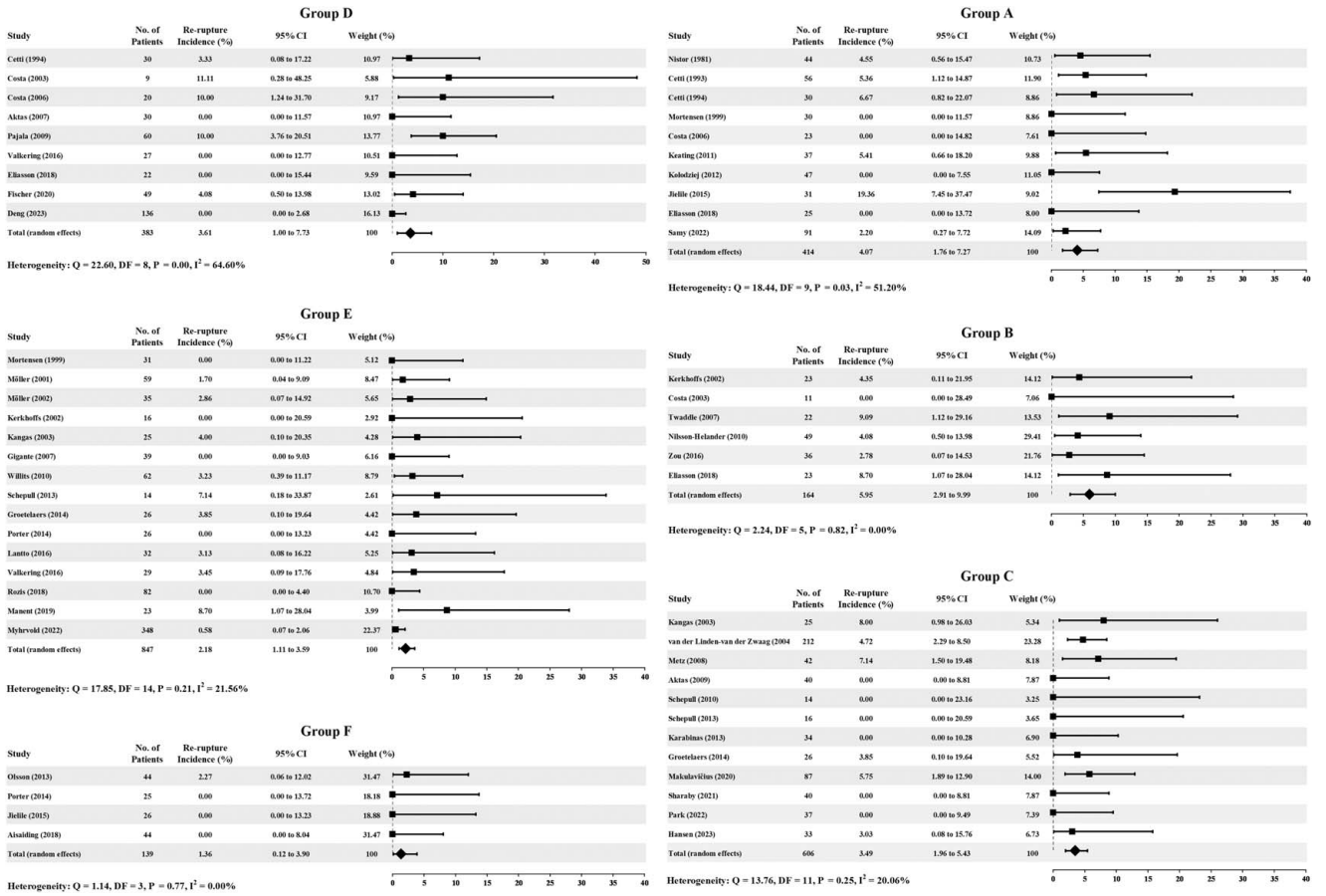

Figure 4. Forest plots of the subgroup on the postoperative incidence of Achilles tendon re-rupture. Group A: early immobilization; Group B: early immobilization + active range of motion; Group C: early immobilization + weight-bearing; Group D: early weight-bearing + active range of motion; Group E: accelerated rehabilitation (immobilization); Group F: accelerated rehabilitation (non-immobilization).

for the immediate or non-immediate AROM subgroup analysis, the published bias *P* values are 0.67, 0.01, respectively. Additionally, the funnel plot of publication bias was provided (Supplementary file 2, Supplemental Digital Content 5, http://links.lww.com/JS9/C89). It was noticed that the funnel plots of all groups were relatively symmetrical in shape. However, the funnel plots for some groups exhibited slightly asymmetric, which may suggest the presence of publication bias. It is also consistent with the results of Egger's test. However, since the incidence of re-rupture was not the primary outcome reported in included literatures, publication bias in this study may has little effect.

Findings of included studies

Analysis of postoperative incidence of re-rupture

Overall, the postoperative incidence of ATR patients developing re-rupture was 3.15% (95% CI: 2.26–4.17). There was observed evidence of statistical heterogeneity among the studies that reported the incidence of re-rupture (I^2: 44.48%, $P = 0.00$) (Fig. 3).

Subgroup analysis of different rehabilitation

We classified the 43 included articles into groups with homogeneous rehabilitation interventions, namely group A: early immobilization, group B: early immobilization + AROM, group C: early immobilization + weight-bearing, group D: early weight-bearing + AROM, group E: accelerated rehabilitation (immobilization), group F: accelerated rehabilitation (non-immobilization). Table 2 presents the summarized inclusion descriptions for each subgroup classification.

Group A patients who had ATR had a 4.07% (95% CI: 1.76–7.27) postoperative incidence of re-rupture. Some evidence of statistical heterogeneity revealed Q = 18.44, $P = 0.03$ and $I^2 = 51.20\%$. Group B had an incidence of 5.95% (95% CI: 2.91–9.99), with Q = 2.24, $P = 0.82$ and $I^2 = 0.00\%$. Group C had an incidence of 3.49% (95% CI: 1.96–5.43), with Q = 13.76, $P = 0.25$ and $I^2 = 20.06\%$. Group D had an incidence of 3.61% (95% CI: 1.00–7.73), revealing some evidence of statistical heterogeneity (Q = 22.60, $P = 0.00$, $I^2 = 64.60\%$). Group E had an incidence e of 2.18% (95% CI: 1.11–3.59), with Q = 17.85, $P = 0.21$ and $I^2 = 21.56\%$. Finally, Group F had an incidence of 1.36% (95% CI: 0.12–3.90), with Q = 1.14, $P = 0.77$, and $I^2 = 0.00\%$ (Fig. 4).

Subgroup analysis of immediate or non-immediate AROM

Upon observing statistical heterogeneity in Group D, we suspected that this might be due to the inclusion of articles on

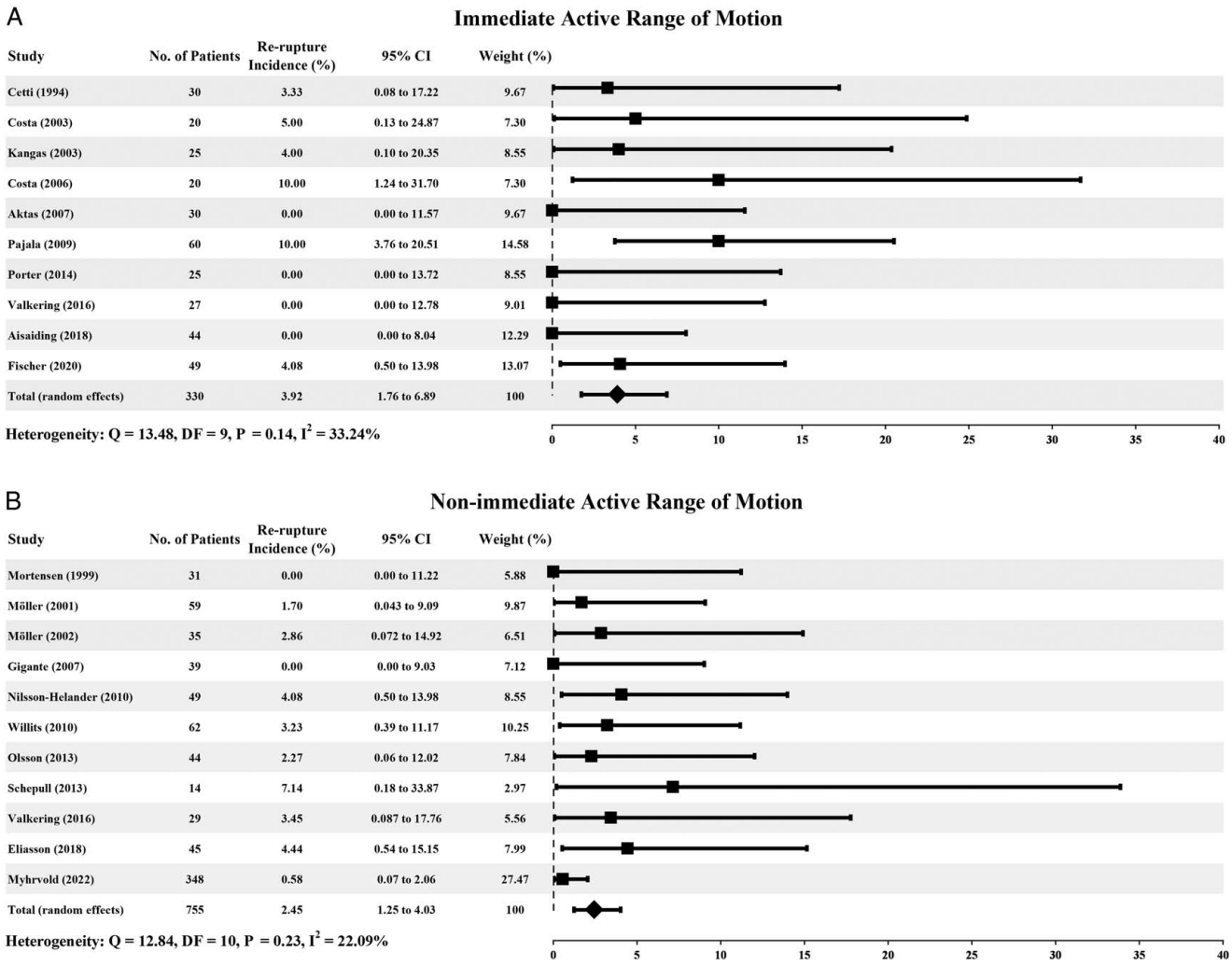

Figure 5. Forest plots of the subgroup on the postoperative incidence of Achilles tendon re-rupture. Group A: immediate ankle active range of motion; Group B: non-immediate ankle active range of motion.

immediately postoperative AROM. To clarify this, we performed another subgroup analysis on the available literature, distinguishing between those that reported immediate AROM and non-immediate AROM. Table 2 presents the summarized inclusion descriptions for each subgroup classification.

In the immediate AROM group, patients with ATR had a 3.92% incidence of postoperative re-rupture (95% CI: 1.76–6.89). Heterogeneity testing revealed $Q = 13.48$, $P = 0.14$, $I^2 = 33.24\%$. Non-immediate ankle AROM group had an incidence of 2.45% with a 95% CI of 1.25–4.03 and some evidence of statistical heterogeneity ($Q = 12.84$, $P = 0.23$, $I^2 = 22.09\%$) (Fig. 5).

Sensitivity analysis

We conducted a sensitivity analysis to remove a study with a large effect size in each subgroup and examined whether it influenced the overall results. The incidence of re-rupture was 2.98% in all ATR patients, 3.16% in group A, 5.32% in group B, 3.26% in group C, 2.63% in group D, 1.73% in group E, 3.02% in group immediate AROM and 2.18% in group non-immediate AROM. The results revealed that even after removing those studies, the overall trend of the results remained unaffected.

Discussion

An ATR is a severe injury that often needs surgical treatment due to its important in the human body. However, even after successful surgery, there is a chance that the Achilles tendon can re-rupture[9,17–19,21–27,29,31,33–35,37,39,40,42,44,46–49,51–53,55,57,59,60]. Therefore, it is crucial to have a comprehensive understanding of the rehabilitation procedure and the impact of different rehabilitation strategies on the incidence of re-rupture. To explore this issue, we included a collection of 43 RCTs, which is currently the largest collection of evidence to date on the incidence of re-rupture after Achilles tendon surgery. Our focus was specifically on rehabilitation protocol and its impact on the incidence of re-rupture. This meta-analysis provide evidence supporting that including early weight-bearing, AROM exercises, and functional training in rehabilitation protocols can result in lower incidence of re-rupture. Additionally, it's worth noting that postoperative immediate AROM may heighten the incidence of re-rupture.

Table 1

Characteristics of included studies.

Author (year)	Study period	Follow-up	Study design	Country	No. patients	Re-rupture	Rehabilitation protocol[a]	Classification[b]
Nistor (1981)[17]	1973–1977	2.5 years (mean)	RCT	Sweden	44	2	Weeks 0–6: IM	A (①)
Cetti *et al.* (1993)[18]	1982.10–1984.5	1 year	RCT	Denmark	56	3	Weeks 0–6: IM	A (①)
Cetti *et al.* (1994)[19]	1985.9–1986.11	1 year	RCT	Denmark	30	1	Weeks 0–6: FWB + AROM; > Week 6: FE	D (②③)[c]
Cetti *et al.* (1994)[19]	1985.9–1986.11	1 year	RCT	Denmark	30	2	Weeks 0–6: IM + NWB; > Week 6: FWB + FE	A (①)
Mortensen *et al.* (1999)[20]	1991.1–1992.12	1 year (mean)	RCT	Denmark	31	0	Weeks 0–2: IM; Weeks 2–4: AROM; Weeks 4–6: AROM + PWB	E (①②③)[d]
Mortensen *et al.* (1999)[20]	1991.1–1992.12	1 year (mean)	RCT	Denmark	30	0	Weeks 0–8: IM; > Weeks 8: PWB	A (①)
Möller *et al.* (2001)[21]	1995.1–1997.7	2 years	RCT	Sweden	59	1	Weeks 0–2: IM; Weeks 3–8: AROM + FWB	E (①②③)[d]
Möller *et al.* (2002)[22]	1995–1997	1 year	RCT	Sweden	35	1	Weeks 0–2: IM; Weeks 3–8: AROM + FWB	E (①②③)[d]
Kerkhoffs *et al.* (2002)[23]	1990–1993	6.7 years (mean)	RCT	Netherlands	23	1	Week 1: IM + NWB; > Week 2: AROM; > Week 10: FWB	B (①②)
Kerkhoffs *et al.* (2002)[23]	1990–1993	6.7 years (mean)	RCT	Netherlands	16	0	Week 1: IM + NWB; > Week 2: AROM; Weeks 2–4: PWB; > Week 4: FWB	E (①②③)
Costa *et al.* (2003)[24]	1999.5–2000.11	1 year	RCT	UK	9	1	Weeks 0–8: FWB + AROM	D (②③)[c]
Costa *et al.* (2003)[24]	1999.5–2000.11	1 year	RCT	UK	11	0	Weeks 0–8: NWB + AROM	B (①②)[c]
Kangas *et al.* (2003)[25]	1995.7–1998.7	60 weeks (mean)	RCT	Finland	25	1	Weeks 0–3: NWB + AROM; Weeks 3–6: FWB + AROM; > Week 6: FE	E (①②③)[c]
Kangas *et al.* (2003)[25]	1995.7–1998.7	60 weeks (mean)	RCT	Finland	25	2	Weeks 0–3: NWB; Weeks 3–6: FWB; > Week 6: FE	C (①③)
van der Linden-van der Zwaag *et al.* (2004)[26]	1990–2000	6 years	RCT	Netherlands	212	10	Weeks 0–2: IM; Weeks 2–6: FWB	C (①③)
Costa *et al.* (2006)[27]	2001.1–2002.11	1 year	RCT	UK	20	2	Weeks 0–8: FWB + AROM	D (②③)[c]
Costa *et al.* (2006)[27]	2001.1–2002.11	1 year	RCT	UK	23	0	Weeks 0–8: IM	A (①)
Aktas *et al.* (2007)[28]	2003.1–2005.5	17.8 months (mean)	RCT	Turkey	30	0	Weeks 0–4: AROM; Weeks 4–8: FWB; > Week 8: FE	D (②③)[c]
Twaddle and Poon (2007)[29]	1997.12–2002.2	12 months	RCT	New Zealand	22	2	Days 0–10: IM; Days 10–weeks 6: NWB + AROM; > Weeks 6: PWB; > Week 8: FE	B (①②)
Gigante *et al.* (2007)[30]	—	24 months	RCT	Italy	39	0	Days 0-15/30: IM; Days 15–45: PWB + AROM; > Days 45–50: FWB + FE	E (①②③)[d]
Metz *et al.* (2008)[31]	2004.1–2005.9	12 months	RCT	Netherlands	42	3	Week 1: IM; > Week 2: IM + FWB	C (①③)
Aktas *et al.* (2009)[32]	2004.2–2007.5	22.4 months (mean)	RCT	Turkey	40	0	Weeks 0–3: IM; > Weeks 3: FWB; > Week 6: FE	C (①③)
Pajala *et al.* (2009)[33]	1998.10–2001.1	52 weeks	RCT	Finland	60	6	Weeks 0–6: PWB + AROM; > Week 6: FWB + FE	D (②③)[c]
Nilsson-Helander *et al.* (2010)[34]	2004–2007	12 months	RCT	Sweden	49	2	Weeks 0–2: IM; Weeks 2–8: AROM; Weeks 6–8: PWB; > Week 8: FE	B (①②)[d]
Willits *et al.* (2010)[35]	2000–2005	2 years	RCT	Canada	62	2	Weeks 0–2: NWB; Weeks 2–6: PWB + AROM; > Week 6: FE	E (①②③)[d]
Schepull *et al.* (2010)[36]	2005.5–2007.4	18 months	RCT	Sweden	14	0	Weeks 0–7: IM + FWB; > Week 7: FE	C (①③)
Keating *et al.* (2011)[37]	2000–2004	12 months	RCT	UK	37	2	Weeks 0–6: IM + NWB; Weeks 7–8: FWB + AROM; > Week 8: FE	A (①)
Kołodziej *et al.* (2012)[38]	2008.3–2010.6	24 months	RCT	Poland	47	0	Weeks 0–6: IM + NWB; > Week 6: FWB	A (①)
Olsson *et al.* (2013)[39]	2009.4–2010.10	12 months	RCT	Sweden	44	1	Weeks 0–2: FWB; Weeks 2–6: FE	F (③④)[d]
Schepull *et al.* (2013)[40]	2009.2–2011.10	52 weeks	RCT	Sweden	14	1	Weeks 0–2: IM + FWB; Weeks 3–7: FE	E (①③④)[d]
Schepull *et al.* (2013)[40]	2009.2–2011.10	52 weeks	RCT	Sweden	16	0	Weeks 0–7: IM + FWB	C (①③)
Karabinas *et al.* (2013)[41]	2007.1–2011.12	20/22 months (mean)	RCT	Greece	34	0	Weeks 0–3: IM + NWB; > Weeks 3–4: PWB	C (①③)
Groetelaers *et al.* (2014)[42]	—	12 months	RCT	Netherlands	26	1	Week 1: IM; Weeks 2–6: FWB + AROM	E (①②③)
Groetelaers *et al.* (2014)[42]	—	12 months	RCT	Netherlands	26	1	Weeks 2–3: IM; Weeks 4–6: FWB	C (①③)
Porter *et al.* (2014)[43]	2009.4–2011.10	12 months	RCT	Australia	26	0	Weeks 0–1: IM; > Week 1: AROM; > Week 6: PWB; > Week 8: FWB; > Week 10: FE	E (①②③)
Porter *et al.* (2014)[43]	2009.4–2011.10	12 months	RCT	Australia	25	0	Days 0–10: AROM; Days 10–14: PWB; > Week 4: FWB; > Week 5: FE	F (②③④)[c]
Jielile *et al.* (2015)[44]	2007.5–2012.6	2 years	RCT	China	26	0	> Day 3: PWB; > Day 10: AROM; > Week 4: FWB + FE	F (②③④)
Jielile *et al.* (2015)[44]	2007.5–2012.6	2 years	RCT	China	31	6	Weeks 0–8: IM	A (①)
Zou *et al.* (2016)[45]	2013.1–2014.1	2 years	RCT	China	36	1	Week 0–3: IM; Weeks 4–10: NWB + AROM; 11–16 weeks: PWB; > 3 Mo: FWB	B (①②)
Lantto *et al.* (2016)[46]	2009.4–2013.11	18 months	RCT	Finland	32	1	Week 1: IM + NWB; > Week 2: FWB; > Week 5: AROM	E (①②③)
Valkering *et al.* (2016)[47]	2013.11–2014.11	12 months	RCT	Sweden	27	0	Weeks 0–6: FWB + AROM	D (②③)[c]
Valkering *et al.* (2016)[47]	2013.11–2014.11	12 months	RCT	Sweden	29	1	Weeks 0–2: IM; Weeks 3–6: FWB + AROM	E (①②③)[d]
Aisaiding *et al.* (2018)[48]	2009.8–2015.12	2 years	RCT	China	44	0	Days 0–2: AROM; > Day 3: PWB + FE; > Week 5: FWB + FE	F (②③④)[c]
Eliasson *et al.* (2018)[49]	2012.8–2015.11	52 weeks	RCT	Denmark	22	0	Weeks 0–4: PWB; Weeks 3–6: AROM; > Week 6: FWB	D (②③)[d]

Eliasson *et al.* (2018)[49]	2012.8–2015.11	52 weeks	RCT	Denmark	23	2	Weeks 0–6: NWB; Weeks 3–6: AROM; Weeks 7–8: PWB; > Week 9: FWB	B (①②)[d]
Eliasson *et al.* (2018)[49]	2012.8–2015.11	52 weeks	RCT	Denmark	25	0	Weeks 0–6: NWB; Weeks 7–8: PWB; > Week 9: FWB	A (①)
Rozis *et al.* (2018)[50]	2009–2016	12 months	RCT	Greece	82	0	Weeks 0–3: IM; Weeks 4–5: PWB; > Week 5: FWB + FE	E (①③④)
Manent *et al.* (2019)[51]	2014.2–2017.2	52 weeks	RCT	Spain	23	2	Days 0–10: IM + NWB; > Day 11: FWB + FE	E (①③④)
Makulavičius *et al.* (2020)[52]	2013.9–2017.12	27 months (mean)	RCT	Lithuania	87	5	Weeks 0–3: IM; Week 4: PWB; Weeks 5–6: FWB	C (①③)
Fischer *et al.* (2020)[53]	2012–2015	24 months	RCT	Germany	49	2	Weeks 0–2: PWB + AROM; Weeks 3–6: FWB + AROM; > Week 7: FE	D (②③)[c]
Sharaby *et al.* (2021)[54]	2017.3–2018.12	27.1 months (mean)	RCT	Egypt	40	0	Weeks 0–6: IM + PWB; > Week 6: FWB + FE	C (①③)
Myhrvold *et al.* (2022)[55]	2013.2–2018.5	12 months	RCT	Norway	348	2	Weeks 0–2: IM; Weeks 3–8: PWB + FE	E (①③④)[d]
Park *et al.* (2022)[56]	2018.6–2020.4	12 months	RCT	Korea	37	0	Weeks 0–2: NWB; Weeks 3–6: PWB; > Week 6: AROM; > Week 12: FE	C (①③)
Samy (2022)[57]	2014.5–2020.12	51.38/47.52 months (mean)	RCT	Egypt	91	2	Weeks 0–6: IM; Weeks 7–12: PWB + AROM + PROM; Month 3: FWB	A (①)
Deng *et al.* (2022)[58]	2018.1–2021.1	12 months	RCT	China	68	0	Day 3: FWB + AROM	D (②③)
Deng *et al.* (2022)[58]	2018.1–2021.1	12 months	RCT	China	68	0	Day 3: AROM; > Day 14: FWB	D (②③)
Hansen *et al.* (2023)[59]	2018.6–2019.9	12 months	RCT	Denmark	33	1	Weeks 0–3: IM + NWB; Weeks 4–7: PWB; > Week 8: FWB; > Week 9: FE	C (①③)

[a]AROM, active range of motion; FE, functional exercises (range of motion, strength training and so on); FWB, full weight-bearing; IM, immobilization; NWB, non-weight-bearing; PROM, passive range of motion; PWB, partial weight-bearing.
[b]A: ①; B: ①②; C: ①③; D: ②③; E: ①②③/①③④/①②③④; F: ③④/②③④ (①: IM or/and NWB; ②: AROM; ③: PWB or/and FWB; ④: FE).
[c]Immediate AROM.
[d]Non-immediate AROM.

Kha *et al.*[60] published a meta-analysis report in 2005 on ATR. They discovered that treating acute ATR with open surgery significantly reduces the re-rupture in comparison to non-surgical treatments. The incidence of re-rupture for patients who underwent surgical treatment was 3.5%, whereas for those who underwent non-surgical treatment it was 12.5%. However, we must admit that surgical treatment will increase the occurrence of other complications (infections and sural nerve injury)[3]. A multicenter randomized controlled study reported by Costa *et al.*[61] in 2020 examined non-operative treatment options for ATR. The study concluded that there was no significant distinction observed in Achilles tendon re-rupture rates when comparing the use of a plaster cast versus a functional brace. The research indicated that 6% of patients in the plaster cast group experienced re-rupture, while the incidence for those using a functional brace was slightly lower at 5%. The study presented a notable decline in the possibility of re-rupture as opposed to the rate documented by Khan and colleagues' report. This implies that non-surgical therapy may be a reasonable alternative for patients primary Achilles tendon rupture, although surgical intervention still holds a lower re-rupture compared to the findings of our analysis. In 2020, however, a comment by Maffulli *et al.*[62] was made stating that while conservative treatment did not lead to the tendon re-rupture, the non-isometric healing of the Achilles tendon has altered the normal anatomy association between the gastroc-soleus muscle complex. This resulted in a functional deficit in plantarflexion, similar to patients with an old ATR. Reconstructive surgery can correct this issue, but it requires more advanced techniques and is more expensive than primary repair.

The American Academy of Orthopaedic Surgeons released treatment guidelines for acute ATR in 2010. A review of previous research indicates two recommendations with moderate strength: the commencement of early postoperative protective weight-bearing (within 0–2 weeks) and protective postoperative activity (within 2–4 weeks)[63]. Furthermore, according to Cramer *et al.*[64], study, there was no increase in tendon collagen tissue turnover during the first 2 weeks after an ATR. This indicates that the generation of new tendon collagen during the healing process was not an immediate phenomenon. This is consistent with our meta-analysis indicates that performing AROM exercises immediately following surgery is not recommended, and it is advised to wait for at least one or 2 weeks before engaging in early AROM exercises. Considering the process of tendon healing is significant in postoperative rehabilitation treatments[65,66]. The rehabilitation protocol should be implemented at the right pace to ensure favourable clinical results.

Following the widespread adoption of surgical procedures to repair ATR, the conventional approach to postoperative rehabilitation involved immobilization of the affected area with plaster or other support until complete healing had occurred. Only afterward was the range of motion (ROM) and strength training initiated[17,18,20,27,37,38]. We found that the re-rupture rate of such rehabilitation programs is higher than that of early weight-bearing and early AROM. Nevertheless, based on research on the healing process of connective tissues, some scholars suggest early utilization of AROM to minimize the detrimental repercussions of immobilization[67,68]. In recent years, there have been many RCTs that compare different postoperative techniques such as traditional fixation, early

Table 2

Subgroup descriptions of different rehabilitation protocols.

Classification	Description
Group A: early immobilization	(1)Weeks 0–6: IM or/and NWB
Group B: early immobilization + active range of motion	(1)Weeks 0–2: IM or/and NWB + Weeks 3–6: AROM
Group C: early immobilization + weight-bearing	(1)Weeks 0–2: IM or/and NWB + Weeks 3–6: PWB or/and FWB
	(2)Weeks 0–6: IM or/and NWB + PWB or/and FWB
Group D: early weight-bearing + active range of motion	Weeks 0–6: PWB or/and FWB + AROM
	Weeks 0–2: AROM + Weeks 3–6: PWB or/and FWB
	Weeks 0–4: AROM + Weeks 5–6: PWB or/and FWB
Group E: accelerated rehabilitation (immobilization)	(1)Weeks 0–1/2/3: IM or/and NWB + Weeks 2/3/4–6: PWB or/and FWB + AROM
	(2)Weeks 0–2: IM or/and NWB + Weeks 3–6: PWB or/and FWB + AROM
	(3)Weeks 0–3: IM or/and NWB + Weeks 4–6: PWB or/and FWB + AROM
	(4)Weeks 0–2: IM or/and NWB + Weeks 3–6: PWB or/and FWB + FE
	(5)Weeks 0–3: IM or/and NWB + Weeks 4–6: PWB or/and FWB + FE
	(6)Weeks 0–4: IM or/and NWB + Weeks 5–6: PWB or/and FWB + FE
Group F: accelerated rehabilitation (non-immobilization)	(1)Weeks 0–2: PWB or/and FWB + Weeks 3–6: FE
	(2)Weeks 0–6: PWB or/and FWB + FE
	(3)Weeks 0–3: PWB or/and FWB + AROM + Weeks 4–6: FE
	(4)Weeks 0–6: AROM + PWB or/and FWB + FE
	(5)Weeks 0–4: AROM + PWB or/and FWB + Weeks 5–6: FE
Immediate AROM	AROM was allowed immediately after surgery
Non-immediate AROM	AROM was allowed 2 weeks after surgery

AROM, active range of motion; FE, functional exercises (range of motion, strength training and so on); FWB, full weight-bearing; IM, immobilization; NWB, non-weight-bearing; PWB, partial weight-bearing.

ROM, and early weight-bearing to determine which methods are best for promoting speedy recovery of preoperative motor function[9,19,20,24,25,27,40,42,44,45,47,58]. In addition to early weight-bearing and ROM, there are also several AR programs that have been shown to be effective in promoting faster recovery after surgery. These programs aid in reducing complications like scar hyperplasia, adhesions, and sensory disorders[5,60].

During the late 20th century, several scholars suggested that patients should be allowed to engage in early postoperative activities to reduce the negative impact of immobility[69,70]. Recent RCTs have studied early ROM exercises by introducing protective AROM exercises as early as the first day after surgery in some studies[9,19,24,25,27,28,33,43,47,48,53], while others have initiated such exercises after two weeks from the surgery[9,20–22,30,34,35,39,40,47,49,55]. We found that the immediate AROM group (3.92%) had a higher incidence of Achilles tendon re-rupture than the non-immediate AROM group (2.45%) in this type of subgroup analysis. Moreover, early weight-bearing is also crucial in rehabilitation protocol. It is recommended to initiate weight-bearing exercises right after surgery and not more than 2 weeks later[24,71]. Depending on the meta-analysis conducted by Ochen *et al.*[72], after operative treatment was used, both early and late full weight-bearing showed a decrease in the rate of re-rupture. Despite the numerous researches on postoperative rehabilitation for ATR, there is no standard early rehabilitation protocol.

Despite these findings, there are still many unanswered questions when it comes to rehabilitation protocol after Achilles tendon surgery. For instance, it is not clear which specific exercises or movements are most effective in reducing the incidence of re-rupture or how different patient populations may respond differently to different rehabilitation strategies. Further research is needed to answer these questions and to help surgeons and physical therapists develop more effective rehabilitation protocols that can reduce the risk of re-rupture and improve patient outcomes. The rehabilitation process after Achilles tendon injury must follow the pathophysiological mechanism of Achilles tendon healing, preventing excessive stress on the tissue that was not healed while also preventing negative impacts of immobilization and disuse on the already healed tissue. The design of a rehabilitation plan should take into account age, underlying conditions, and patient compliance to ensure optimal healing. Creating a flexible plan that can be tailored to individual case is thus highly important[73].

Limitation

It is important to consider several potential limitations while reviewing this research. These limitations are similar to those found in other meta-analyses. They include differences in the studies analyzed and potential bias in the primary studies that were reviewed.

Firstly, the analysis only focused on the impact of varied rehabilitation programs on the re-rupture rate, without taking into account different surgical methods employed in the literature. This may lead to potential heterogeneity in the meta-analysis. Secondly, the current literature on rehabilitation protocol cannot be fully standardized for sub-analysis due to variations in the included protocol. Therefore, grouping is limited to similar rehabilitation protocols. Moreover, rehabilitation protocol dos not consider the individual characteristics of patients, such as their talents, motivation for rehabilitation, and other injuries or illnesses they may have.

Conclusion

AR intervention has the lowest re-rupture rate of Achilles tendon as compared to other treatments. However, immediate postoperative mobilization may have a higher incidence of re-rupture as compared to non-immediate mobilization analysis. Therefore, we suggest the use of AR intervention in postoperative

rehabilitation of the Achilles tendon. However, for ankle joint mobilization, it is recommended to apply after one to two weeks of immobilization.

Ethical approval

Not applicable.

Consent

Not applicable.

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Author contribution

R.W., L.H., and S.J.: conceived the study; R.W. and L.H.: carried out the research; R.W., L.H., S.J., G.Y., and X.Z.: prepared the first draft of the manuscript; G.W. and L.Z.: directed the manuscript to completed. All authors were involved in the revision of the draft manuscript and have agreed to the final content.

Conflicts of interest disclosure

R.H.W., L.H., S.T.J., G.X.Y., X.Z., G.Y.W., and L.Z. have no conflicts of interest or financial ties to disclose.

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Guarantor

Lei Zhang, Guoyou Wang, Ruihan Wang.

Data statement

All data generated or analyzed during this study are included in this published article (and its supplementary information files). Raw data are available from the corresponding author on reasonable request.

Provenance and peer review

None.

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