Minimally Invasive Versus Open Repair for Acute Achilles Tendon Rupture

Meta-Analysis Showing Reduced Complications, with Similar Outcomes, After Minimally Invasive Surgery

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Background: There is no consensus on the optimal technique for repairing an acute Achilles tendon rupture. The purpose of this meta-analysis was to compare the complications, subjective outcomes, and functional results between minimally invasive surgery and open repair of an Achilles tendon rupture.

Methods: A systematic literature search of MEDLINE/PubMed, Cochrane Central Register of Controlled Trials (CENTRAL), EBSCOhost, and ClinicalTrials.gov was performed. Eligible studies were randomized controlled trials (RCTs) comparing minimally invasive surgery and open repair of acute Achilles tendon ruptures. A meta-analysis was performed, while bias and the quality of the evidence were rated according to the Cochrane Database questionnaire and the Grading of Recommendations Assessment, Development and Evaluation (GRADE) guidelines. The meta-analysis was conducted according to the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) guidelines.

Results: Eight studies, with 182 patients treated with minimally invasive surgery and 176 treated with open repair, were included. The meta-analysis showed a significantly decreased risk ratio (RR) of 0.21 (95% confidence interval [CI] = 0.10 to 0.40, p = 0.00001) for overall complications and 0.15 (95% CI = 0.05 to 0.46, p = 0.0009) for wound infection after minimally invasive surgery. Patients treated with minimally invasive surgery were more likely to report good or excellent subjective results (RR = 1.18, 95% CI = 1.04 to 1.33, p = 0.009). No differences between groups were found with respect to reruptures, sural nerve injury, return to preinjury activity level, time to return to work, or ankle range of motion. The overall quality of evidence was generally low because of a substantial risk of bias, heterogeneity, indirectness of outcome reporting, and evaluation of a limited number of patients.

Conclusions: There was a significantly decreased risk of postoperative complications, especially wound infection, when acute Achilles tendon rupture was treated with minimally invasive surgery compared with open surgery. Patients treated with minimally invasive surgery were significantly more likely to report a good or excellent subjective outcome. Current evidence is associated with high heterogeneity and a considerable risk of bias.

Level of Evidence: Therapeutic Level I. See Instructions for Authors for a complete description of levels of evidence.

The treatment of Achilles tendon rupture is a source of controversy[1-4]. The advocates of surgical repair emphasize potentially lower rerupture rates, superior functional results, and a shorter time to return to activity[5-7], whereas those supporting nonsurgical treatment underline the fact that there are no surgical complications, such as postoperative infections, despite similar functional results[5]. However, when analyzing surgical treatment approaches, minimally invasive surgery and open repair of the tendon should be considered separately. It has been suggested that a percutaneous surgical approach, or minimally invasive surgery, reduces surgical exposure in order to minimize the risk of wound

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TABLE I Demographic and Methodological Details of Included Studies*

Study Details				Exclusion Criteria				
Author(s)	Year of Study	Study Design	Randomization	Age	Gap	Tear Location	Timing of Surgery After Injury	Comorbidities
Schroeder et al.[24]	1997	RCT	NA	NA	NA	NA	NA	NA
Majewski et al.[12]	2000	RCT	NA	NA	>0.5 cm at 20° plantar flexion	Myotendinous junction, calcaneus avulsion	NA	Corticosteroids
Lim et al.[10]	2001	Quasi-RCT	Patient hospital number	NA	NA	NA	>7 days	Open or previous injuries
Gigante et al.[9]	2008	RCT	Casio calculator	<20 and >60 yr	NA	NA	NA	DM, RA, SLE, corticosteroids
Aktas and Kocaoglu[20]	2009	RCT	NA	NA	NA	NA	NA	DM, immunosuppression, previous injuries
Aviña Valencia and Guillén Alcalá MA[21]	2009	RCT	NA	<18 and >50 yr	NA	>8 cm from calcaneus	>10 days	Chronic diseases
Kołodziej et al.[23]	2013	RCT	Opaque envelopes	<18 yr	NA	Calcaneus avulsion	>7 days	Open injuries, DM, RA, corticosteroids
Karabinas et al.[22]	2014	Quasi-RCT	Order of presentation	NA	>3 cm	>6 cm from calcaneus	>2 days	NA

*MIS = minimally invasive surgery, RCT = randomized controlled trial, Gap = distance between tendon stumps, NA = not assessed, DM = diabetes mellitus, RA = rheumatoid arthritis, and SLE = systemic lupus erythematosus. †Mean and standard deviation. ‡Mean with range in parentheses.

complications. However, this is a weaker repair construct that is technically more demanding to perform[8] because of the limited direct visualization, which makes it more difficult to approximate the stump, and because of the risk of sural nerve injury.

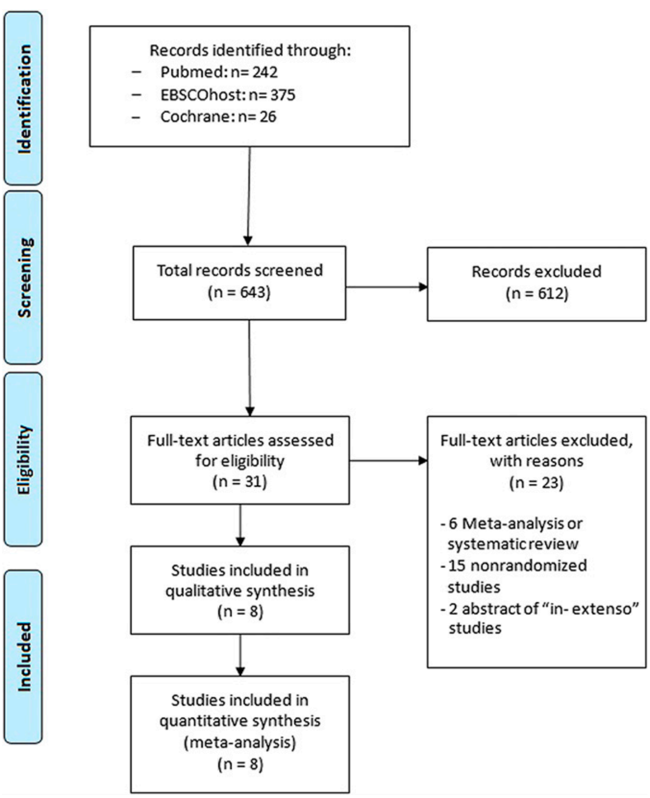

Fig. 1
PRISMA flow chart for study inclusion.

Several studies that have compared minimally invasive surgery and open repair have had discordant results[9-12]. Authors of meta-analyses on this topic have concluded that minimally invasive surgery reduces surgical complications without increasing the rerupture risk[4,13]. However, functional outcomes, such as the time to return to work or rate of return to preinjury activity, have not been thoroughly investigated because of the limited number of randomized controlled trials (RCTs) on the subject. A recent systematic review of the results of 4 overlapping meta-analyses comparing minimally invasive surgery and open surgery inconsistently included only the same 6 original studies[13], all published in 2009. The latest Cochrane Review[14], published in 2010, evaluated only 4 RCTs, while a more recent meta-analysis[15] expanded its evaluation to include 1 additional RCT. The low numbers of RCTs in these analyses have mostly been due to the searches being limited to the English-language literature and to publication status restrictions.

The aim of the present study was to perform an updated meta-analysis with a broad and comprehensive literature search to investigate the complications, subjective outcomes, and functional results after minimally invasive surgery and open repair of Achilles tendon rupture. The hypothesis was that minimally invasive surgery would be followed by a similar rerupture rate and functional and subjective outcomes compared with open repair, but with the advantage of a lower risk of surgical complications.

Materials and Methods

Literature Search

This meta-analysis was conducted according to the Preferred Reporting Items for Systematic reviews and Meta-Analysis

TABLE I (*continued*)

No. of Patients		Mean Age *(yr)*		
MIS	Open	MIS	Open	Follow-up *(mo)*
15	13	37.7	43.9	8
25	22	NA	NA	30
33 (19 M, 14 F)	33 (20 M, 13 F)	40.1	36.9	6
20	20	NA	NA	12
20 (18 M, 2 F)	20 (17 M, 3 F)	39.2	40.6	22.4
28	28	NA	NA	4
22	25	44.8 ± 9.2†	47.1 ± 13.3†	24
19 (15 M, 4 F)	15 (13 M, 2 F)	42 (25-58)‡	40 (28-50)‡	20-22

(PRISMA) guidelines[16]. A systematic electronic search of PubMed/MEDLINE, Cochrane Central Register of Controlled Trials (CENTRAL), EBSCOhost, and ClinicalTrials.gov was performed in February 2017. The key words were "Achilles tendon," combined through the Boolean operator AND with "repair OR suture" and "mini-invasive OR minimally invasive OR percutaneous." Manual scanning of the reference lists of included articles and screening of the ePublication lists of the leading orthopaedic and sports medicine journals were done as well.

Article Selection

Eligible studies were RCTs comparing minimally invasive surgery and open surgical repair for acute Achilles tendon

TABLE II Details of Surgical Procedure and Rehabilitation in Included Studies*

Study Details		MIS		Open		Rehabilitation		Prophylaxis	
Author(s)	Year of Study	Technique	Suture Type	Technique	Suture Type	Immobilization Position (Duration in Weeks)	WB (Duration in Weeks)	Antibiotics	DVT
Schroeder et al.[24]	1997	Modified Ma and Griffith	NA	Kessler suture	NA	Plantar flexion (4), progression to neutral (4)	NA	NA	NA
Majewski et al.[12]	2000	Ma and Griffith	NA	NA	NA	NA	NA	NA	NA
Lim et al.[10]	2001	Modified Ma and Griffith	#1 absorbable	Kessler suture	#1 absorbable	Plantar flexion (4-6), neutral (6-8)	NA	No	NA
Gigante et al.[9]	2008	Tenolig	NA	Kessler suture	#1-0 absorbable	MIS: plantar flexion (2), neutral (2); open: 30° plantar flexion (4), neutral (3)	MIS: no WB (2), progressive WB (4-5); open: NA	Yes	Yes
Aktas and Kocaoglu[20]	2009	Achillon	NA	Krackow suture	#2 nonabsorbable	Plantar flexion (6)	No WB (3), progressive WB (3)	Yes	Yes
Aviña Valencia and Guillén Alcalá MA[21]	2009	Achillon	NA	End-to-end suture + plantaris augmentation	#1 absorbable	NA	NA	NA	NA
Kolodziej et al.[23]	2013	Achillon	NA	Krackow suture	Absorbable	20° plantar flexion (6)	No WB (6)	Yes	Yes
Karabinas et al.[22]	2014	Ma and Griffith + sural nerve identification	#1 nonabsorbable	Krackow suture	#1 nonabsorbable	Max. plantar flexion (3), progression to neutral (3-4)	No WB (3), progressive WB (3-4)	NA	NA

*MIS = minimally invasive surgery, WB = weight-bearing, DVT = deep venous thromboembolism, and NA = not assessed

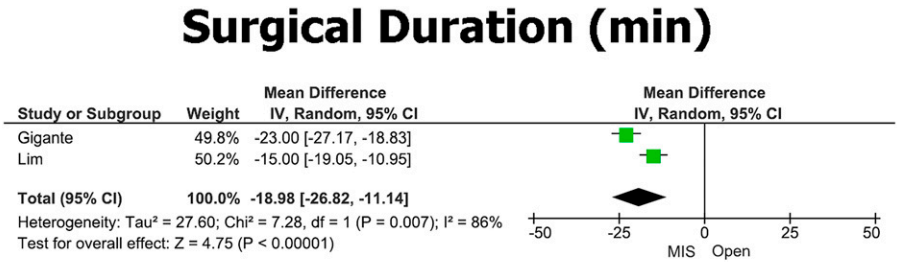

Fig. 2

Figs. 2 through 6 Forest plots. Each study is represented by a line indicating the CI; the squares on the lines represent the mean difference, risk difference, or risk ratio as indicated by the figure; and the black diamond at the bottom of the graph shows the average effect size of the studies. IV = inverse variance, M-H = Mantel-Haenszel, and df = degrees of freedom. **Fig. 2** Forest plot showing the mean duration (minutes) of the minimally invasive surgery (MIS) and open repairs.

rupture. Both published and unpublished studies in all languages were eligible. Biomechanical and in vitro studies were excluded. There were no criteria regarding the technique used in the surgical procedure, study sample size, or duration of follow-up.

Two of us (A.B. and M.R.) independently reviewed the title and abstract of each article identified by the literature search. The assessors were not blinded to the authors of the publications. The full text of an article was obtained and evaluated when eligibility could not be determined from the first screening. Any disagreements were addressed via a consensus discussion between the reviewers, and a third reviewer was consulted if the disagreement could not be resolved.

Data Extraction and Synthesis

Data on patient demographics, surgical details, and rehabilitation were extracted. The outcomes that we evaluated, defined prior to the study start, were functional outcomes, defined as the American Orthopaedic Foot & Ankle Society (AOFAS) score[17], ankle range of motion, subjective patient satisfaction (dichotomized into good/excellent versus fair/poor), return to preinjury activity, and time to return to work, as well as

TABLE III Dichotomous Outcomes*

	No. of Patients			RR					RD						
							Heterogeneity					Heterogeneity			
Outcome	MIS	Open	No. of Studies	ES	95% CI	P Value	I^2 (%)	P Value	ES	95% CI	P Value	I^2 (%)	P Value	RRR (%)	NNT
Reruptures	182	176	8	0.64	0.11 to 3.77	0.62	0	0.76	0.00	−0.04 to 0.03	0.83	0	1.00	36	NA
Total other complications	182	176	8	0.18	0.10 to 0.31	**0.00001**	14	0.32	−0.31	−0.38 to −0.24	**0.00001**	81	0.00001	**82**	**4**
Wound complications	182	176	8	0.13	0.05 to 0.35	**0.00001**	0	0.96	−0.16	−0.25 to −0.07	**0.0008**	62	0.01	**87**	**7**
Infections															
Total	182	176	8	0.15	0.05 to 0.46	**0.0009**	0	0.96	−0.11	−0.16 to −0.05	**0.0001**	44	0.09	**85**	**10**
Superficial	182	176	8	0.17	0.05 to 0.64	**0.0090**	0	0.73	−0.07	−0.11 to −0.02	**0.006**	42	0.10	**83**	**15**
Deep	182	176	8	0.35	0.06 to 2.14	0.25	0	1.00	−0.02	−0.05 to 0.02	0.36	0	0.99	65	50
Delayed wound-healing	97	97	4	0.22	0.05 to 1.01	**0.05**	0	1.00	−0.07	−0.14 to −0.01	**0.03**	0	0.95	**78**	**15**
Adhesions	81	81	3	0.18	0.04 to 0.79	**0.02**	0	0.99	−0.11	−0.19 to −0.03	**0.007**	0	0.43	**82**	**10**
Keloids	57	60	2	0.27	0.03 to 2.33	0.23	0	0.86	−0.05	−0.12 to 0.02	0.17	0	0.54	73	20
Sural nerve problems	141	137	6	3.00	0.13 to 71.07	0.50	NA	NA	0.01	−0.03 to 0.04	0.70	0	0.99	−200	10
Pain/tendinitis	116	112	5	0.52	0.11 to 2.54	0.42	41	0.16	−0.06	−0.17 to 0.06	0.34	72	0.006	48	17
Ankle stiffness	45	42	2	0.33	0.11 to 1.01	**0.05**	0	1.00	−0.13	−0.36 to 0.10	0.28	68	0.08	67	8
Deep venous thromboembolism	80	75	4	0.33	0.01 to 7.72	0.49	NA	NA	−0.01	−0.07 to 0.04	0.65	0	0.91	67	100
Return to preinjury activity	64	57	4	1.23	0.97 to 1.56	0.09	0	0.47	0.14	−0.01 to 0.29	0.08	0	0.54	−23	8
Good/excellent outcome	92	83	4	1.18	1.04 to 1.33	**0.009**	0	0.71	0.14	0.04 to 0.24	**0.007**	0	0.72	**−18**	**8**

*RR = risk ratio, RD = risk difference, MIS = minimally invasive surgery, ES = effect size, CI = confidence interval, RRR = relative risk reduction, NNT = number needed to treat, and NA = not assessed. Values in bold are significant.

TABLE IV Continuous Outcomes*

	No. of Patients			Mean Difference				
							Heterogeneity	
Outcome	MIS	Open	No. of Studies	ES	95% CI	P Value	I^2 *(%)*	P Value
AOFAS	39	35	2	−2.74	−5.19 to −0.29	**0.03**	57	0.13
Operating time *(min)*	53	53	2	−18.98	−26.82 to −11.14	**0.00001**	86	0.007
Time to return to work *(wk)*	58	55	3	−0.07	−2.04 to 1.91	0.95	78	0.01
Ankle range of motion *(°)*	69	73	3	3.95	−6.52 to 14.43	0.46	89	0.0001

*MIS = minimally invasive surgery, ES = effect size, and CI = confidence interval. Values in bold are significant.

complications, defined as reruptures, superficial or deep infections, delayed wound-healing, adhesions, keloid formation, sural nerve problems, residual pain/tendinitis, ankle stiffness, and deep venous thrombosis. The data obtained at the final follow-up were extracted for the analysis when multiple follow-up evaluations had been performed. Two authors (M.M. and E.S.) separately extracted all of the data. Discrepancies were resolved by the critical judgment of the first author (A.G.) after discussion.

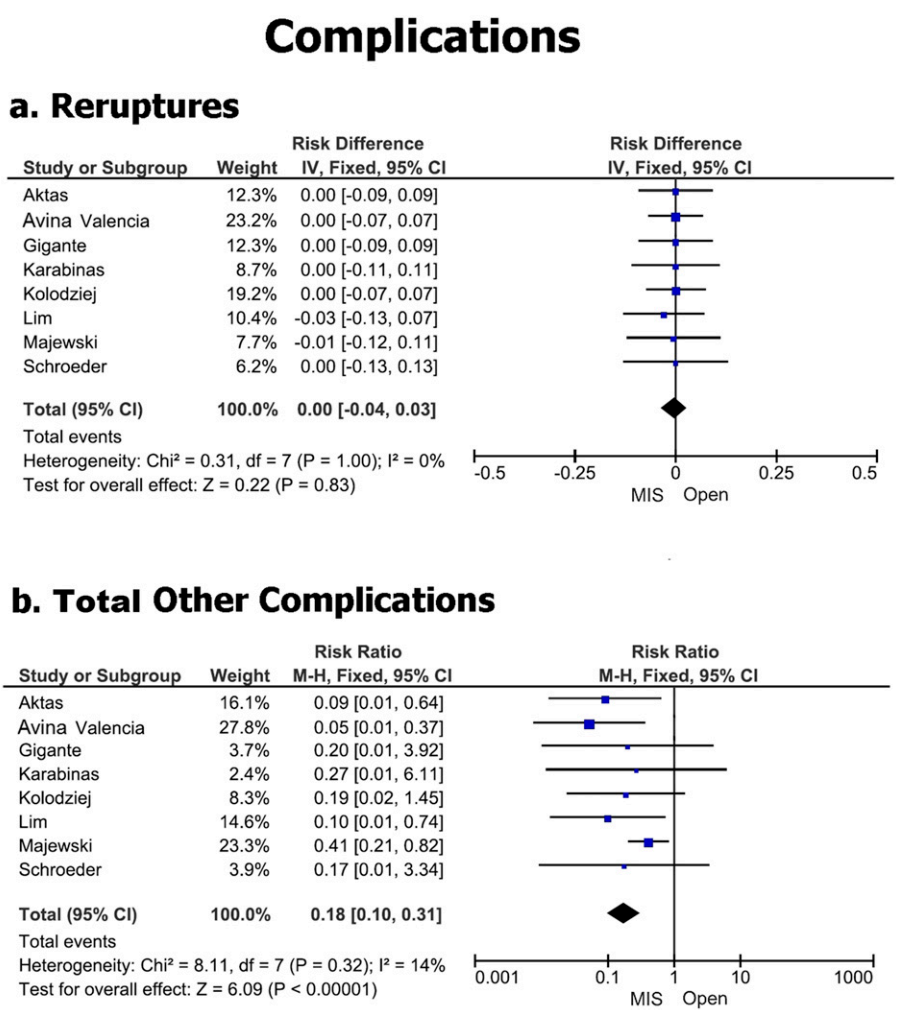

Fig. 3

Forest plots showing the rates of reruptures (**Fig. 3-A**) and total other complications (**Fig. 3-B**) in patients treated with minimally invasive surgery (MIS) or open repair.

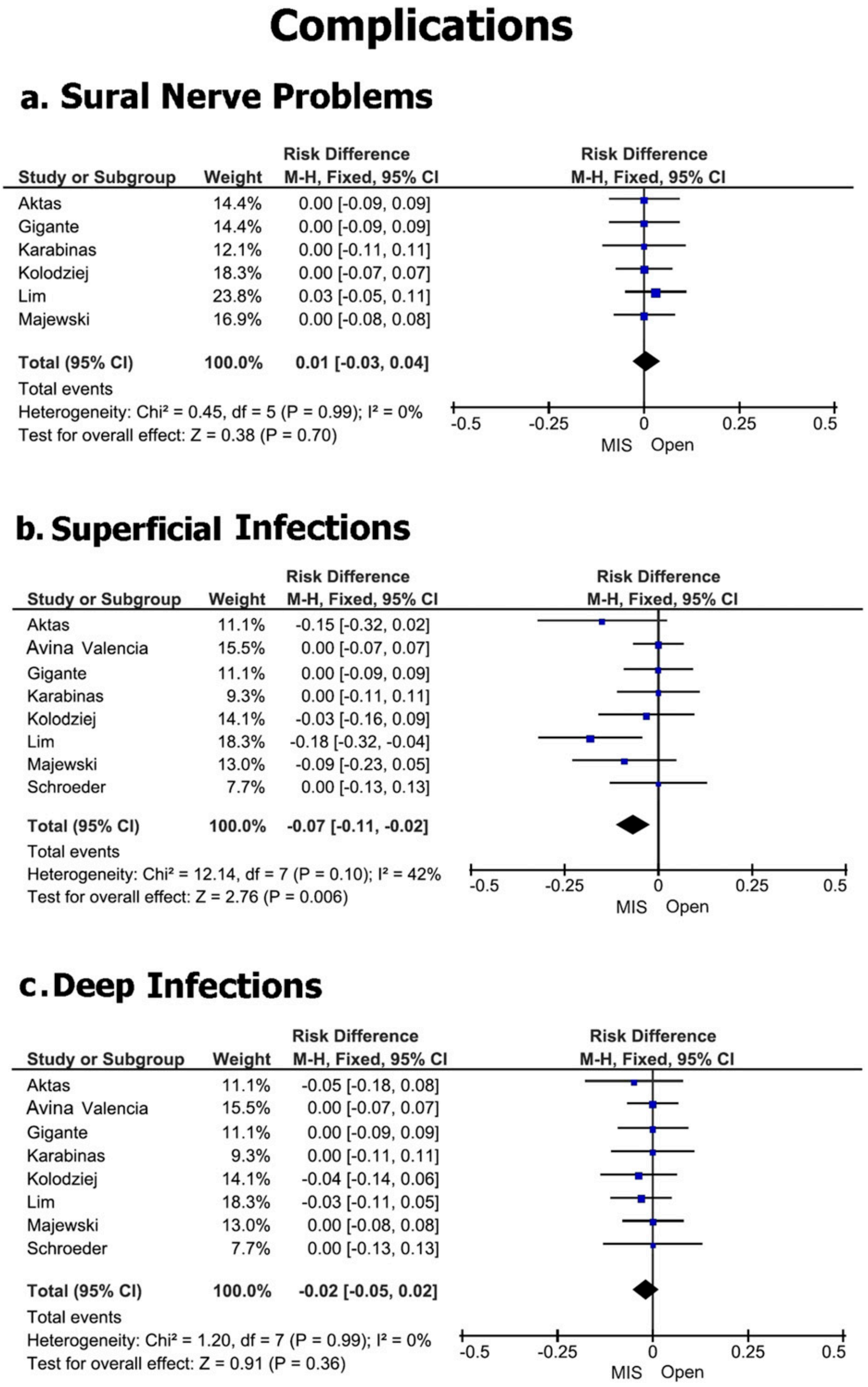

Fig. 4

Forest plots showing the rates of sural nerve problems (**Fig. 4-A**), superficial infections (**Fig. 4-B**), and deep infections (**Fig. 4-C**) in patients treated with minimally invasive surgery (MIS) or open repair.

Assessment of Risk of Bias and Quality of Evidence

The risk of bias was categorized as high, low, or unclear according to the standardized Cochrane Risk of Bias Tool[18]. The overall quality of evidence for each outcome was graded as high, moderate, low, or very low on the basis of the study design, risk of bias, inconsistency, indirectness, imprecision, and publication bias, according to the Grading of Recommendations Assessment, Development and Evaluation (GRADE) guidelines[19]. The risk of bias and the quality of evidence according to the GRADE guidelines were based on a consensus by 2 authors (A.G. and

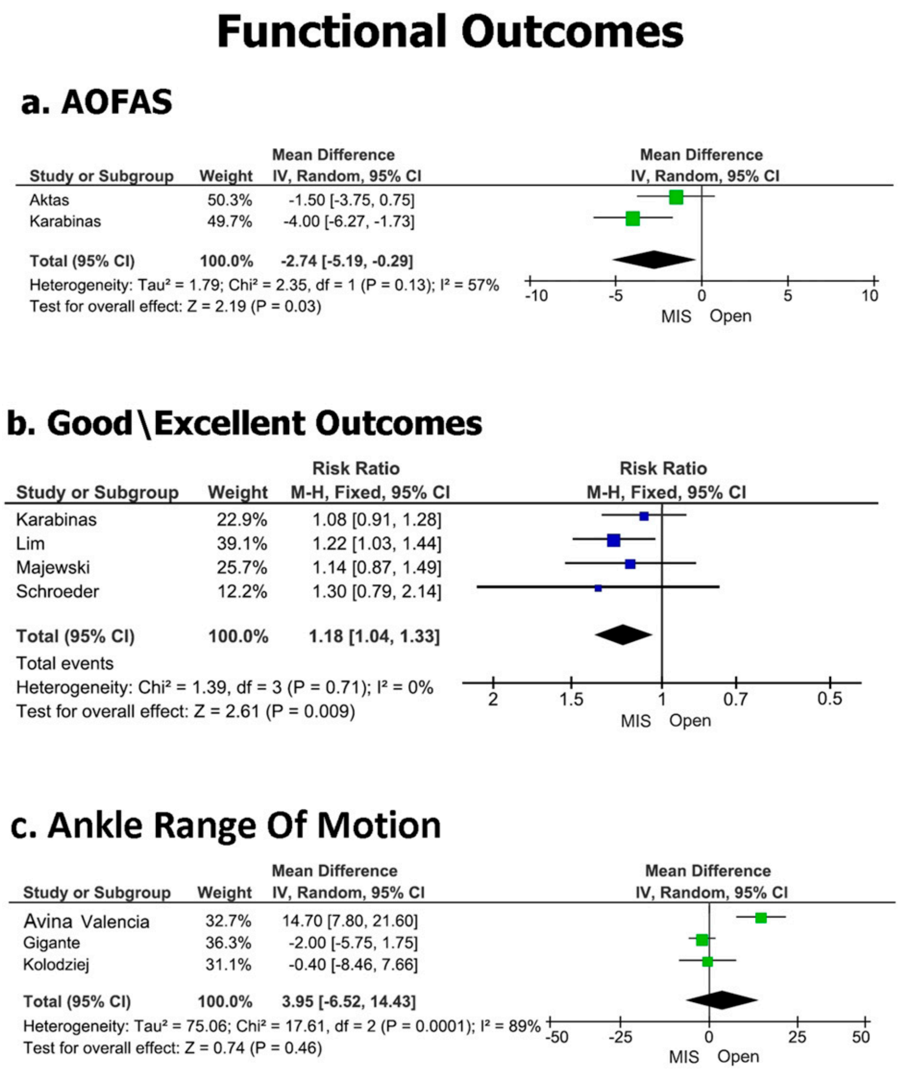

Fig. 5

Forest plots showing the mean difference in AOFAS score (**Fig. 5-A**), rates of patients rating the procedure as excellent or good (**Fig. 5-B**), and mean difference in ankle range of motion in degrees (**Fig. 5-C**) after minimally invasive surgery (MIS) or open repair.

S.Z.). The intervention of a third reviewer was not needed because the authors reached consensus for all of the items after discussion.

Statistical Analysis

The meta-analysis was performed using RevMan, version 5.0.18.33 (Cochrane Collaboration). Continuous variables were extracted and analyzed as the mean and standard deviation (SD). The corresponding author of the article was contacted and asked to provide the data if the SD was not reported. In the event of no response, the SD was calculated from the available data, according to a previously validated formula[18]: (higher range value – lower range value)/4. If the SD could not be calculated using this approach, the highest SD was used. The mean difference and 95% confidence interval (CI) were calculated for continuous variables. The risk difference (RD), the risk ratio (RR), the relative risk reduction (RRR), and the number needed to treat (NNT) were calculated for dichotomous variables. We tested for heterogeneity using the chi square and Higgins I^2 tests[18]. According to Cochrane guidelines[18], in cases with I^2 of <30% and a chi square result with a p value of >0.05, heterogeneity was considered low and therefore a fixed-effect meta-analysis was performed. In cases of high heterogeneity—with I^2 of >50% or a chi square with a p value of <0.05, or both—a Mantel-Haenszel random-effect model was used. In cases of moderate heterogeneity—with I^2 between 30% and 50% and a chi square with a p value of >0.05—both fixed and random-effect models were used. A p value of <0.05 was considered significant in all analyses.

Results

Article Selection

A total of 643 articles were screened and, after application of inclusion and exclusion criteria, 8 studies[9,10,12,20-24] were included in the final analysis (Fig. 1).

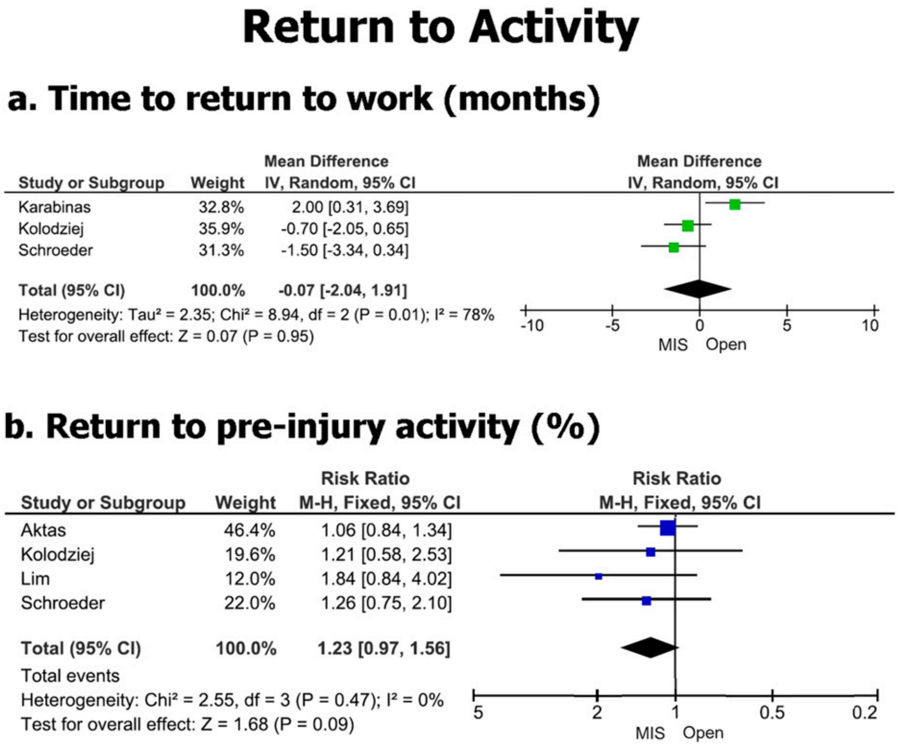

Fig. 6

Forest plots showing the time (months) to return to work (**Fig. 6-A**) and the rate of patients returning to the same preinjury activity (**Fig. 6-B**) after minimally invasive surgery (MIS) or open repair.

Study Characteristics

A total of 182 patients were treated with minimally invasive surgery and 176 patients, with open repair. The mean age ranged from 37.7 to 44.8 years in the minimally invasive surgery group and from 36.9 to 47.1 years in the open repair group. The mean follow-up time in the included studies ranged from 4 to 30 months (Table I).

Different surgical techniques, postoperative care, and rehabilitation protocols were used both for minimally invasive surgery and open repair (Table II). The operating time was reported in 2 studies, and the random-effect meta-analysis revealed a significantly shorter time for the minimally invasive surgery group, with a mean difference of −18.98 minutes (95% CI = −11.14 to −26.82 minutes, p = 0.00001) (Fig. 2). The pooled data for each individual outcome are summarized in Tables III and IV.

Reruptures

The rerupture rate ranged from 0% to 4% for the patients treated with minimally invasive surgery and from 0% to 6% in the open repair group. The fixed-effect meta-analysis revealed no significant difference in terms of the risk of rerupture (RR = 0.64, p = 0.62, and RD = 0.00, p = 0.83) (Fig. 3-A).

Other Complications

The prevalence of ≥1 types of other complications apart from rerupture was reported in all of the studies. The fixed-effect meta-analysis for overall other complications revealed a significantly decreased RR (0.18, p = 0.00001) and RD (−0.31, p = 0.00001) for the patients treated with minimally invasive surgery (Fig. 3-B). This resulted in an RRR of 82% and an NNT of 4 patients. Specifically, wound complications had a significantly decreased RR (0.13, p = 0.00001) and RD (−0.16, p = 0.0008) in favor of minimally invasive surgery, resulting in an RRR of 87% and an NNT of 7 patients. Complications such as sural nerve problems (Fig. 4-A), pain/tendinitis, and deep venous thrombosis were similar between minimally invasive surgery and open repair, while ankle stiffness was significantly less common after minimally invasive surgery (Table III).

Regarding the specific wound complications, the overall RR (0.15, p = 0.0009) and the RD (−0.11, p = 0.0001) for wound infection were decreased after minimally invasive surgery in both the fixed and random-effect models, which were performed because of moderate heterogeneity (see Appendix). However, when deep and superficial infections were analyzed separately, only the superficial infections remained significantly decreased in the minimally invasive surgery group after both random and fixed-effect meta-analysis (see Appendix), with an RRR of 83%, while the RD with the NNT of 15 patients (Figs. 4-B and 4-C) was significant only using the fixed-effect model (see Appendix). Delayed wound-healing and the presence of adhesions were significantly less common in the minimally invasive surgery group.

Functional and Subjective Outcome Measurements

Random-effect meta-analysis revealed a significantly higher AOFAS score, by 2.74 points (p = 0.03), in the open repair group (Fig. 5-A). The fixed-effect meta-analysis of patients with good or excellent subjective results revealed an increased RR (1.18, p =

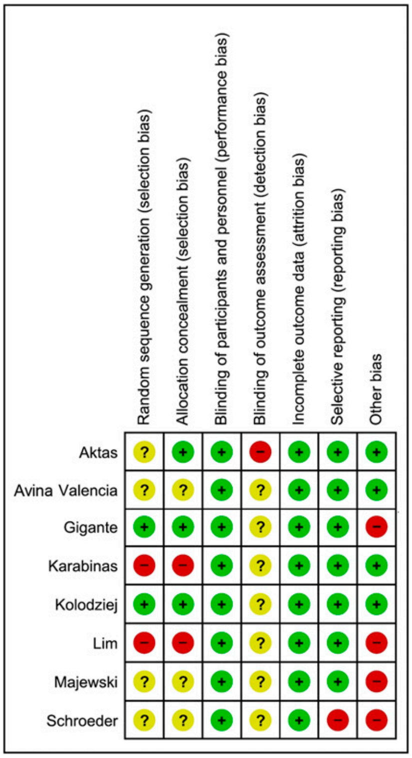

Fig. 7

Risk of bias in each study. Red circles = high risk, green circles = low risk, and yellow circles = unclear risk.

0.009) and RD (0.14, p = 0.007) in favor of minimally invasive surgery, with an RRR of 18% and an NNT of 8 patients (Fig. 5-B). Ankle range of motion (Fig. 5-C), time to return to work (Fig. 6-A), and return to preinjury activity level (Fig. 6-B) were similar between the 2 treatments.

Risk-of-Bias Assessment

All of the studies showed an unclear or high risk of bias in at least 1 domain of the Cochrane Risk of Bias Tool (Fig. 7). Selection bias was high due to the inconsistent reporting of randomization and concealment methods. Although the patients were not blinded to the allocated treatment, the risk of performance bias was considered low, since most of the outcomes evaluated were objective and not likely to be influenced by the patient's knowledge of a specific treatment. However, the risk of detection bias was considered to be high since most of the outcomes were assessed by investigators with inadequate or unknown blinding. The risks of attrition bias and reporting bias were considered low, since the dropout rates were minimal and the results of all of the outcome measures described in the methods section were reported in all but 1 study. Bias may also have been introduced by the fact that the authors of some studies did not perform an adequate evaluation of homogeneity between the treatment groups (Fig. 8).

Quality Assessment

The quality of evidence regarding the rerupture rate and most of the complications was low due to the high risk of selection and detection bias. Moreover, the high heterogeneity (>50%) of the RD and the limited number of patients evaluated, in relation to the absolute risk of a specific outcome, further limited the quality of evidence. The quality of evidence for the reduced rates of total and superficial wound infections in the minimally invasive surgery group was classified as moderate (the highest quality of evidence among the investigated outcomes) since its statistical heterogeneity was low and the absolute risk was relatively high in relation to the sample size (Fig. 9). The quality of evidence for the functional and subjective outcomes was very low due to a substantial risk of bias, heterogeneity, indirectness of outcome reporting, and the evaluation of a limited number of patients. The return to activity was not investigated in a homogeneous population regarding activity level, and no information on the patients' professions was provided (Fig. 10).

Discussion

We believe that the present study represents the most comprehensive investigation comparing the results of minimally invasive surgery and open repair of Achilles tendon rupture to date because it includes the largest number of RCTs available in the literature. Because our study was based on the synthesis of data from several individual studies, we were able to investigate

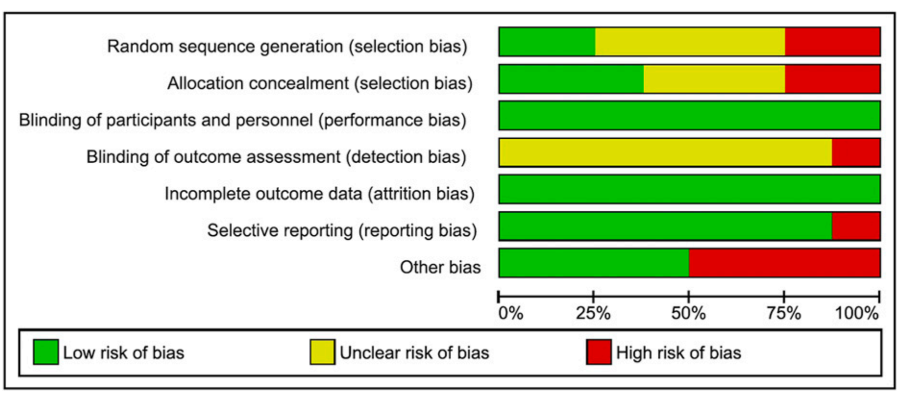

Fig. 8

Summary of the risk of bias across the included studies.

Minimally Invasive Surgery compared to Open surgery for Acute Achilles Tendon Rupture

Outcomes	№ of participants (studies) Follow-up	Quality of the evidence (GRADE)	Relative effect (95% CI)	Anticipated absolute effects: Risk with Open surgery	Anticipated absolute effects: Risk difference with Minimally Invasive Surgery
Reruptures assessed with: Clinical evaluation	362 (8 RCTs)	⊕⊕◯◯ LOW [a,b]	**RR 0.64** (0.11 to 3.77)	17 per 1.000	**6 fewer per 1,000** (15 fewer to 47 more)
Total Other Complications assessed with: Clinical evaluation	362 (8 RCTs)	⊕⊕◯◯ LOW [a,c]	**RR 0.18** (0.10 to 0.31)	371 per 1.000	**293 fewer per 1,000** (334 fewer to 222 fewer)
Wound Complications assessed with: Clinical evaluation	362 (8 RCTs)	⊕⊕◯◯ LOW [a,c]	**RR 0.13** (0.05 to 0.35)	202 per 1.000	**176 fewer per 1,000** (192 fewer to 131 fewer)
Infections assessed with: Clinical evaluation	362 (8 RCTs)	⊕⊕⊕◯ MODERATE [a]	**RR 0.15** (0.05 to 0.46)	112 per 1.000	**96 fewer per 1,000** (107 fewer to 61 fewer)
Superficial Infections assessed with: Clinical evaluation	362 (8 RCTs)	⊕⊕⊕◯ MODERATE [a]	**RR 0.17** (0.05 to 0.64)	73 per 1.000	**61 fewer per 1,000** (69 fewer to 26 fewer)
Deep Infections assessed with: Clinical evaluation	362 (8 RCTs)	⊕⊕◯◯ LOW [a,b]	**RR 0.35** (0.06 to 2.14)	17 per 1.000	**11 fewer per 1,000** (16 fewer to 19 more)
Delayed Wound Healing assessed with: Clinical evaluation	194 (4 RCTs)	⊕⊕◯◯ LOW [a,b]	**RR 0.22** (0.05 to 1.01)	72 per 1.000	**56 fewer per 1,000** (69 fewer to 1 more)
Adhesions assessed with: Clinical evaluation	162 (3 RCTs)	⊕⊕◯◯ LOW [a,b]	**RR 0.18** (0.04 to 0.79)	123 per 1.000	**101 fewer per 1,000** (119 fewer to 26 fewer)
Keloids assessed with: Clinical evaluation	117 (2 RCTs)	⊕⊕◯◯ LOW [a,b]	**RR 0.27** (0.03 to 2.33)	50 per 1.000	**37 fewer per 1,000** (49 fewer to 67 more)
Sural Nerve Problems assessed with: Clinical evaluation	278 (6 RCTs)	⊕⊕◯◯ LOW [a,b]	**RR 3.00** (0.13 to 71.07)	0 per 1.000	**0 fewer per 1,000** (0 fewer to 0 fewer)
Pain\Tendinitis assessed with: Clinical evaluation	228 (5 RCTs)	⊕◯◯◯ VERY LOW [a,b,c]	**RR 0.52** (0.11 to 2.54)	125 per 1.000	**60 fewer per 1,000** (111 fewer to 193 more)
Ankle Stiffness assessed with: Clinical evaluation	87 (2 RCTs)	⊕◯◯◯ VERY LOW [a,b,c]	**RR 0.33** (0.11 to 1.01)	214 per 1.000	**144 fewer per 1,000** (191 fewer to 2 more)
Deep Venous Thromboembolism assessed with: Clinical evaluation	155 (4 RCTs)	⊕⊕◯◯ LOW [a,b]	**RR 0.33** (0.01 to 7.72)	13 per 1.000	**9 fewer per 1,000** (13 fewer to 90 more)

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: Confidence interval; **RR:** Risk ratio; **MD:** Mean difference

GRADE Working Group grades of evidence
High quality: We are very confident that the true effect lies close to that of the estimate of the effect
Moderate quality: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
Low quality: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
Very low quality: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

a. Selection and detection bias due to allocation concealment and non-blinded outcome assessors
b. Limited number of patients included for this outcome with respect to the absolute risk of each outcome
c. Heterogeneity >50% of Risk Difference

Fig. 9

Summary of the quality of evidence according to the GRADE guidelines for the complications after minimally invasive surgery or open repair.

Minimally Invasive Surgery compared to Open surgery for Acute Achilles Tendon Rupture

Outcomes	№ of participants (studies) Follow-up	Quality of the evidence (GRADE)	Relative effect (95% CI)	Anticipated absolute effects	
				Risk with Open surgery	Risk difference with Minimally Invasive Surgery
Return to pre-injury activity assessed with: patient interview	121 (4 RCTs)	⊕○○○ VERY LOW a,b,c	RR 1.23 (0.97 to 1.56)	614 per 1,000	**141 more per 1,000** (18 fewer to 344 more)
Good\Excellent Outcome assessed with: Subjective report by patients	175 (4 RCTs)	⊕○○○ VERY LOW a,c,d	RR 1.18 (1.04 to 1.33)	795 per 1,000	**143 more per 1,000** (32 more to 262 more)
AOFAS assessed with: Subjective score administered to the patient	74 (2 RCTs)	⊕○○○ VERY LOW a,e,f	-		MD **2.74 points lower** (5.19 lower to 0.29 lower)
Surgery Time assessed with: Medical records	106 (2 RCTs)	⊕⊕○○ LOW a,e,f,g	-		MD **18.98 minutes lower** (26.82 lower to 11.14 lower)
Return to work assessed with: Patient interview	113 (3 RCTs)	⊕○○○ VERY LOW a,e,f,h	-		MD **0.07 months lower** (2.04 lower to 1.91 higher)
Ankle Range Of Motion assessed with: Direct measurement	142 (3 RCTs)	⊕○○○ VERY LOW a,e,f	-		MD **3.95 degrees more** (6.52 fewer to 14.43 more)

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: Confidence interval; **RR:** Risk ratio; **MD:** Mean difference

GRADE Working Group grades of evidence
High quality: We are very confident that the true effect lies close to that of the estimate of the effect
Moderate quality: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
Low quality: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
Very low quality: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

a. Selection and detection bias due to allocation concealment and non-blinded outcome assessors
b. Not homogeneous populations of athletes
c. Limited number of patients included for this outcome with respect to the absolute risk of each outcome
d. Indirect subjective measure of overall outcome
e. Heterogeneity >50% of Risk Difference
f. Limited number of patients included for this outcome respect to the mean difference
g. Great difference between MIS and Open repair
h. Works not reported

Fig. 10
Summary of the quality of evidence according to the GRADE guidelines for the functional and subjective outcomes and surgical time after minimally invasive surgery or open repair.

outcomes that had previously been sparsely reported, such as time to return to work, return to preinjury level, and ankle range of motion. The main finding of the present meta-analysis, which included more than 350 patients, was a reduced risk of postoperative complications, in particular superficial wound infections, when minimally invasive surgery was performed. Minimally invasive surgery was also associated with a lower frequency of delayed wound-healing and scar adhesions, whereas other factors such as the rerupture rate and return to preinjury activity and work were not affected by the surgical technique.

On the basis of the NNT calculated in this meta-analysis, it was estimated that 1 wound infection could be avoided for every 10 minimally invasive surgery procedures performed instead of open repair for Achilles tendon rupture, supporting the results of other meta-analyses[4,13].

The risk of the overall other complications apart from rerupture was significantly decreased in the minimally invasive surgery group and, according to the estimated NNT, 1 complication for every 4 Achilles tendon ruptures could be avoided if minimally invasive surgery was selected rather than open repair. However, there is a concern about injury to the sural nerve when performing minimally invasive surgery. Sural nerve entrapment was reported to occur in up to 27% of minimally invasive surgical procedures performed utilizing minimally invasive devices, such as the Achillon system (Integra), in cadaveric studies[25,26]. Moreover, the technique described by Ma and Griffith has been associated with rates of postoperative sural nerve problems of up to 60% in clinical settings[27-29]. However, the studies included in our meta-analysis demonstrated a low rate of sural nerve complications and no significant difference between minimally invasive surgery and open repair in this regard. Only 1 of the included studies[22] explored avoidance of damage to the sural nerve when applying the Ma and Griffith technique for minimally invasive surgery. In 4 of the included studies[9,20,21,23], the minimally invasive surgery was done using the Achillon or the Tenolig (FH Orthopedics) device, both of which have been associated with a low rate of sural nerve damage in clinical series[30,31]. Cadaveric studies have also indicated that it is possible to avoid sural nerve entrapment by applying external rotation of the Achillon device during Achilles tendon repair[25]. The risk of damage to the sural nerve may therefore be considerably affected by the surgical technique and the surgeon's skill. It is noteworthy that the authors of a recent meta-analysis[15] reported an approximately 3.5-fold, significantly increased risk of sural nerve injury during minimally invasive surgery compared with open repair. However, the study was not restricted to RCTs and, because most of the sural nerve injuries were reported in retrospective comparative studies[32-34], there is concern about a potential methodological bias in relation to these results.

The operating time for minimally invasive surgery was significantly shorter than that for open repair, but the quality of evidence relating to these data was limited because only 2 studies provided this information. The functional outcomes are comparable between the 2 procedures, as the 3-point difference in AOFAS scores does not appear to be clinically relevant; moreover, the AOFAS has been criticized for being only partially validated despite being commonly applied[23,35,36]. Patients who underwent minimally invasive surgery had a significantly higher probability of reporting a good or excellent outcome. Authors of another meta-analysis who reported a similar finding[37] concluded that the reasons for the superior patient satisfaction in the minimally invasive surgery group remains unknown, but it is possible that a reduced incidence of postoperative complications is one contributing factor. The 2 groups were found to have comparable results in terms of ankle range of motion, time to return to work, return to preinjury activity level, and rerupture rate. Therefore, functional performance testing would have been desirable to better understand factors associated with the superior patient-reported outcome in the minimally invasive surgery group, but this has not as yet been sufficiently investigated.

This meta-analysis has several limitations. Only acute Achilles tendon ruptures were investigated, preventing any conclusions about the treatment of chronic ruptures. Moreover, we did not include studies with special emphasis on Achilles tendon rupture in the athletic population and the return to sports. It has previously been reported that 78% of patients return to sports, after a mean of 18.1 weeks, following percutaneous Achilles tendon repair[38]. However, early tendon elongation has been reported in cadaveric models exposed to cyclic loading following minimally invasive surgery[8], which indicates the importance of vigilant care when managing professional athletes requiring accelerated rehabilitation. Finally, because of strict inclusion criteria, the original studies were restricted to healthy patients who were <60 years of age; thus, we could not determine whether minimally invasive surgery decreased complications in older patients with comorbidities or, conversely, increased the risk of rerupture in such patients because of the less solid construction obtained with minimally invasive surgery. Although promising results have been reported with minimally invasive surgery in this complex population[39], nonoperative treatment or open repair should be considered for this group.

This meta-analysis generally demonstrated a considerable risk of bias in the literature and methodological limitations of the assessment of the results of treatment of Achilles tendon rupture, which negatively affect the quality of the results presented in this study.

In conclusion, there was a significantly decreased risk of postoperative complications, especially wound infections, when acute Achilles tendon rupture was treated with minimally invasive surgery rather than open repair. Additionally, patients were significantly more likely to report a good or excellent subjective outcome after minimally invasive surgery. The techniques were comparable in terms of rerupture rate, ankle range of motion, time to return to work, and return to preinjury activity level. The evidence for these findings was, however, associated with high heterogeneity and a considerable risk of bias, thus requiring additional high-quality RCTs.

Appendix

eA A table showing the results of the random-effect meta-analysis of outcomes with moderate heterogeneity is available with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJS/E946). ■

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