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Open versus minimally-invasive surgery for Achilles tendon rupture: a meta-analysis study

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Abstract

Introduction Despite the presence of various different surgical procedures, the preferable technique for repair of acute Achilles tendon ruptures is unknown and, therefore, object of discussions. The purpose of this meta-analysis was to compare clinical outcomes and complication-rates between the minimally invasive and the standard open repair of acute Achilles tendon ruptures.

Materials and methods This meta-analysis was performed according to the PRISMA guidelines. In September 2019 the main databases were accessed. All clinical trials of evidence level I to III comparing minimally invasive vs. open surgery of Achilles tendon rupture were included in the present study. Only articles reporting quantitative data under the outcomes of interest were included. Missing data under the outcomes of interest warranted the exclusion from the present work. For the statistical analysis we referred to the Review Manager Software Version 5.3. (The Nordic Cochrane Centre, Copenhagen). Continuous data were analysed through the inverse variance method. For the effect estimate the mean difference was used. Dichotomous data were analysed through the Mante–Haenszel method via odd ratio effect measure. The confidence interval was set at 95% in all the comparisons. Values of $P < 0.05$ were considered statistically significant.

Results A total of 25 articles were included for meta-analysis. The funnel plot revealed poor data dispersion, attesting to this study a low risk of publication bias. The quality of the methodological assessment was moderate. Data from 2223 (1055 open, 1168 minimally invasive) surgical procedures were extracted. The mean follow-up was of 24.29 ± 22.4 months. The open group reported a lower value of post-operative palpable knot at last follow-up and a lower rate of sural nerve palsy. In the minimally-invasive group a shorter surgery duration and a lower rate of post-operative wound necrosis and reduced risk of wound scarring and adhesions has been evidenced. The minimally-invasive cohort detected the lowest values of superficial and deep infections. In both groups no significant difference was shown in re-rupture rate.

Conclusions Compared to the minimally-invasive Achilles tendon reconstruction, the open procedure evidenced a lower rate of sural nerve palsy and postoperative palpable knot, whereas in the minimally-invasive reconstruction group quicker surgery duration, a lower rate of post-operative wound necrosis, superficial and deep infections and less scar tissue adhesions could be observed. No relevant discrepancies were detected among the two techniques in terms of post-operative re-rupture.

Keywords Achilles tendon rupture · Percutaneous · Minimal invasive · Open surgery · Complications

Introduction

The adequate treatment of acute Achilles tendon rupture has been controversially discussed in the last decades and also in current literature. Both, non surgical and surgical treatment may be suitable, whereas surgical repair is regarded as achieving a better functional outcome, a decreased re-rupture rate and a shorter recovery time, therefore representing the favourable treatment especially for young patients [1, 2]. However, performing surgical repair might cause complications such as wound infections and necrosis resulting in devastating soft tissue complication which might require further surgical reconstruction. However, initially the percutaneous approach has been introduced 1977 by Ma and Griffth [3] to minimize the exposure of the Achilles tendon and thus to reduce complications in comparison to open procedures.

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The approach was supposed to be more challenging due to the missing exposure of the tendon and, furthermore, predisposed for re-ruptures based on insufficient suturing without direct visual control [4]. Therefore, in 1996 Assal et al. developed a device, called Achillon®, offering a minimally invasive (MIS) approach in combination with a percutaneous suture [5], which is partly based on the technique described by Kakiuchi in 1995 [6]. This combination of a percutaneous and mini-open technique offers direct visualisation of the rupture location, but a reduced risk for wound complications [4]. Nowadays, orthopaedic surgeons routinely use percutaneous-minimally invasive procedures and can make full use of surgical aid devices like Tenolig™, Achillon®, PARS® or the Dresden instrument in combination with ultrasound guided approaches [5, 7–9].

Previous meta-analysis concluded that minimally-invasive surgery for acute Achilles tendon repair promoted reduced infection rate and wound necrosis with a similar re-rupture risk in comparison to an open procedure [10, 11]. The most recent meta-analysis of randomized clinical trials (RCT) evaluating 358 procedures confirmed these findings and stated that patients treated with MIS surgery were more likely to report good or excellent subjective results without any difference according sural nerve injury, return to preinjury activity level or to work [12].

However, there is still discordance, since a systematic review of overlapping meta-analyses revealed that only superficial and not deep infections are reduced by MIS [10]. Moreover, previous meta-analysis pointed out, that their results are associated with a high heterogeneity and a considerable risk of bias due to limited high-quality studies [11, 12]. Recently, two additional RCT studies have been published evaluating a considerable higher number of procedures, which might improve the statistical value for recommendations [13, 14]. Additionally, previous meta-analysis are based on a limited amount of available RCT studies or on only a few included observational studies due to the evaluation of infrequent outcome parameters. Interestingly, numerous reports pointed out that there is only limited evidence for differences between effect estimations between RCTs and observational studies [15–17]. However, the addition of observational studies increases sample size, enabling evaluation of small treatment effects. Especially, analysis of a variety of populations, and long-term effects are not limited to the usually highly selected cohorts in RCTs [15, 18, 19].

Consequently, we conducted a comprehensive meta-analysis study comparing the complication-rates of open versus MIS for Achilles tendon repair including RCTs and observational studies without evaluating infrequent outcome parameters. The purpose of the present study was to update current evidences and to analyse the clinical trials presented in the current literature in order to clarify the role of these two techniques and to simplify the surgical decision making in selected patients.

Materials and methods

Literature research and data extraction

This meta-analysis was performed according to the Preferred Reporting Items for Systematic Review and Meta-Analysis: the PRISMA guidelines [20]. The PICO protocol was drafted to guide the search:

- P (population): Achilles tendon rupture
- I (intervention): open Achilles tendon reconstruction
- C (comparison): percutaneous/minimally-invasive Achilles tendon reconstruction
- O (outcomes): complications, functional outcome score

In September 2019 the main databases were accessed: Pubmed, Scopus, Google Scholar. The keywords were "Achilles tendon" combined through the Boolean operator AND with "rupture", "percutaneous", "minimally invasive", "mini-invasive", "open" as well as "Achillon", "PARS", "Tenolig" and "Dresden". Additionally, manual scanning of the reference lists of the included articles and reviews were performed. Two independent reviewers (FM, MG) independently screened the literature for inclusion. If title matched the topic, the abstract was accessed and, if of interest, the full-text was read. The bibliographies of the articles were also screened. Disagreements between the authors were debated and mutually solved.

Eligibility criteria

All the clinical trials comparing the minimally-invasive repair vs. open surgery after acute Achilles tendon rupture were included in the present study. The percutaneous and minimally-invasive approach were put together as "minimally-invasive" and were opposed to the open procedure. According to Oxford Centre of Evidenced-Based Medicine [21], only clinical trials levels I to III of evidence were considered for inclusion. According to the author language capabilities, articles in English, French, Italian, Spanish, German and Portuguese were considered for inclusion. Only articles published after 2000 were included. Data from national register, case series, expert opinion, editorials were excluded as well as biomechanical, in-vitro and animal studies. Articles dealing with chronic Achilles tendon ruptures were excluded. Only articles reporting quantitative data under the outcomes of interest were included. Missing data under the outcomes of interest warranted the exclusion from the present work. Disagreements between the authors were mutually debated and solved.

Outcomes of interest

Two independent authors (FM, MG) independently grouped data from the articles of interest. The following demographic data were collected: author and year of publication, type of study, mean follow-up, number of samples, location of rupture, pain before rupture, body mass index (BMI), age and gender distribution. Additionally, data about surgical techniques, the suture material used and post-operative care were collected. Moreover, for each endpoint, the following clinical data and post-operative complications were collected: surgery duration, superficial and deep tissue infection, tendon re-rupture, scare tissue formation, tissue adhesions, sural nerve palsy, wound necrosis and palpable knot. Since patient-reported outcome measurements (PROMS) are infrequently and inconsistently used, their inclusion has been refused, in order to not downsize the sample size.

Methodological quality assessment

For the methodological quality assessment, we referred to the Review Manager Software Version 5.3. (The Nordic Cochrane Centre, Copenhagen). The risk of bias summary tool was performed according to the authors' judgements about each risk of bias item for each included study.

Statistical analysis

For the statistical analysis we referred to the Review Manager Software Version 5.3. (The Nordic Cochrane Centre, Copenhagen). Continuous data were analysed through the inverse variance method. For the effect estimate (EE) the mean difference was used. Dichotomous data were analysed through the Mantel–Haenszel method via odd ratio (OR) effect measure. Heterogeneity was evaluated trough the χ^2 and Higgins-I^2 methods. If $\chi^2 > 0.5$ the I^2 test was evaluated. Ranges for interpretation of I^2 according to the Cochrane Handbook for Systematic Reviews of Interventions were 0–40% (poor), 30–60% (fair), 50–90% (moderate) and 75–100% (considerable). A fixed model effect was used when heterogeneity was acceptable. In event of high heterogeneity, a random model was used. The confidence interval was set at 95% in all the comparisons. Values of $p < 0.05$ were considered statistically significant.

Results

Search result

The literature search resulted in 4420 papers with 3229 articles screened for inclusion after removing duplicates (1191). A total of 2445 papers were excluded due to incompatibility with the eligibility criteria. Another 744 articles were excluded due to lack of quantitative data under the outcomes of interest. Further, 15 articles were excluded because of uncertain and/or ambiguous results. Finally, a total of 25 articles were included for the meta-analysis. The flow-chart of the literature search is shown in Fig. 1.

Risk of publication bias

To assess the risk of publication bias, the funnel plot of the most reported outcome was performed (infection). The plot detected good symmetrical distribution of the referral points. All the values are narrow to the no-effect line and none outside the range of acceptability. This revealed poor data dispersion, attesting to this study a low risk of publication bias. The funnel plot is shown in Fig. 2.

Methodological quality assessment

According to the risk of bias summary, high risk of detection bias was evidenced. This reflected the overall lack of samples blinding among the studies. The overall lack of randomization increased the selection bias. Incomplete outcome data detected a good risk of attrition bias, while the risk of other unknown bias was low. In conclusion, we attest to the present work a moderate quality of the methodological assessment. The authors' judgements about each risk of bias item for each included study are shown in Fig. 3.

Patient demographic

A total of 2223 procedures were examined. The mean follow-up was of 24.29 ± 22.4 months. In the open repair group, data from 1055 procedures were collected; the minority of these patients were females (19%) with a mean age of 42.17 ± 3.6 years and a mean BMI of 26.08 ± 1.8 kg/m^2. In the MIS group, data from 1168 procedures were collected. Again, the minority of these patients were females (26%), the mean age was 41.16 ± 2.8 years and the mean BMI 26.15 ± 1.7 kg/m^2. Among the two groups an optimal

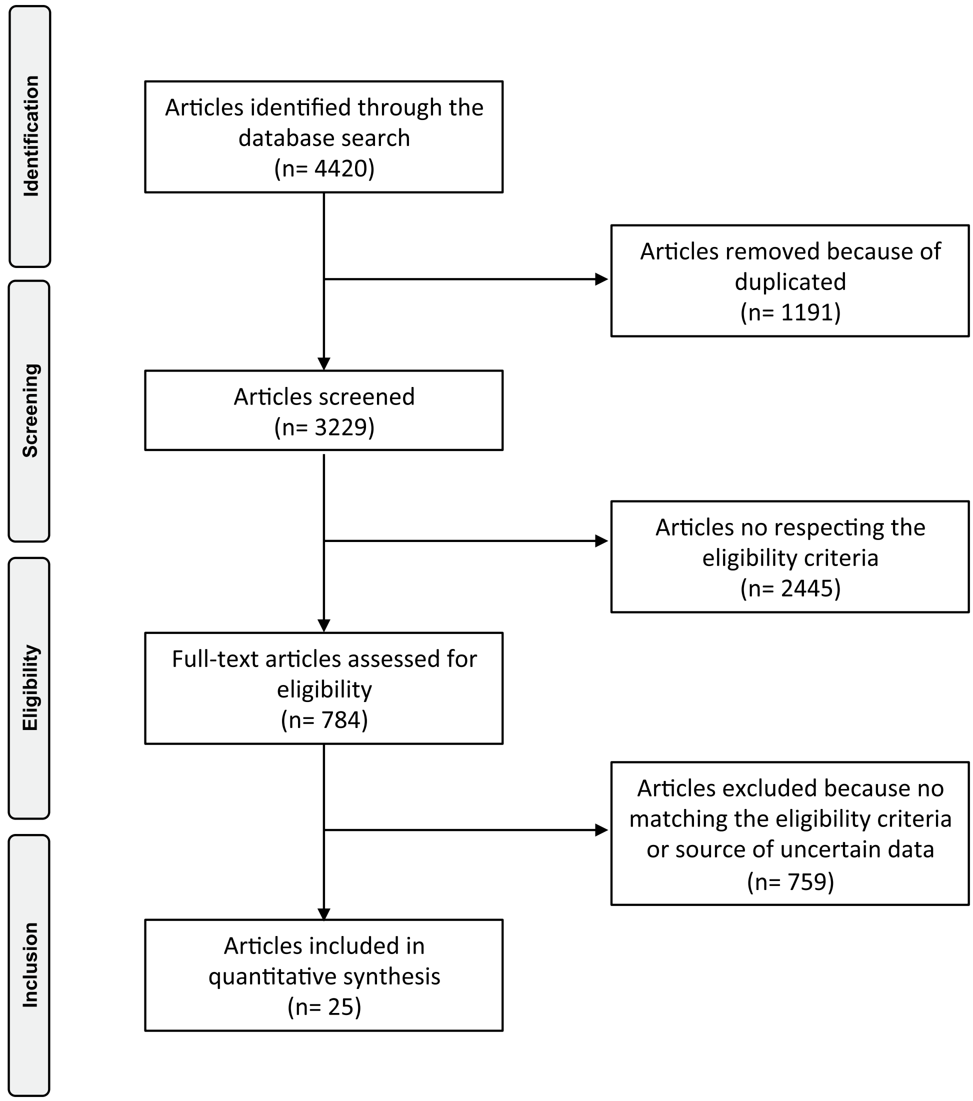

Fig. 1. Flow-chart of the literature search

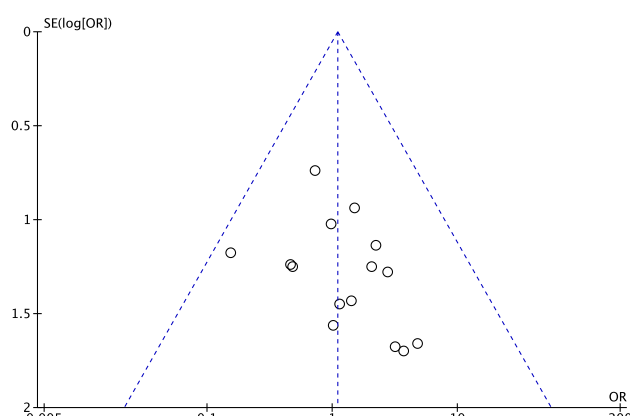

Fig. 2 Funnel plot of the most reported outcome (infection)

comparability with regard to patients' age ($P=0.9$) and BMI ($P=0.9$) was present. Demographic data are reported in Table 1.

Outcomes of interest

The open group reported a lower value of post-operative palpable knot at last follow-up (OR: 0.10; 95% CI 0.01–0.81; $P<0.0001$) and a lower rate of sural nerve palsy (OR: 0.45; 95% CI 0.28–0.74; $P=0.001$). In the MIS group a shorter surgery duration (FE: 7.55; 95% CI 5.16–9.95; $P<0.0001$) has been evidenced, a lower rate of post-operative wound necrosis (OR: 3.01; 95% CI 1.30–6.59; $P=0.006$) and a reduced risk to develop scar tissue adhesions (OR: 4.10; 95% CI 2.13–7.88; $P<0.0001$) were noted. Moreover, in the MIS group the lowest values of superficial (OR: 3.90; 95% CI 1.68–9.06; $P=0.002$) and deep tissue infections (OR: 2.01; 95% CI 1.24–3.27; $P=005$) were observed. Re-rupture

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Other bias
Aktas et al. 2009	+	?	+	+	+
Araujo et al. 2018	−	+	−	+	?
Baumfeld et al. 2019	−	?	−	+	+
Bhattacharyya et al. 2009	?	?	−	+	?
Carmont et al. 2013	−	?	−	+	?
Chan et al. 2011	−	+	?	+	?
Cretnik et al. 2005	−	?	−	+	+
Daghino et al. 2016	−	+	?	+	+
Ebinesan et al. 2009	−	?	−	+	?
Gigante et al. 2008	+	+	+	+	+
Grubor et al. 2012	−	?	−	+	?
Haji et al. 2004	−	+	−	+	?
Henríquez et al. 2011	?	+	?	+	+
Hsu et al. 2015	−	?	−	+	+
Jallageas et al. 2013	−	+	−	?	?
Karabinas et al. 2013	+	+	?	+	+
Kolodziej et al. 2013	+	+	+	+	+
Lim et al. 2001	+	?	+	+	?
Lonzaric et al. 2017	−	+	−	+	?
Majewski et al. 2000	−	?	−	?	?
Makulavicius et al. 2019	+	+	−	+	?
Miller et al. 2005	−	+	−	+	?
Obada et al. 2015	−	?	?	+	+
Rebeccato et al. 2001	−	+	−	+	?
Riedl et al. 2002	−	?	−	?	?
Rosso et al. 2015	−	+	−	+	+
Rozis et al. 2018	?	+	−	+	?
Valencia et al. 2009	+	+	?	+	?

Fig. 3 Cochrane methodological quality assessment

rate has been equal among both groups without a significant difference (OR: 1.10; 95% CI 0.62–1.94; $P=0.75$). An overview of the meta-analysis results is shown in Table 2.

Discussion

This meta-analysis conducted an updated comparison between open versus minimally-invasive surgery for acute Achilles tendon ruptures. According to the main findings, in the MIS technique a lower complication rate for Achilles tendon repair was observed. The re-rupture rate between both techniques showed no significant differences. The MIS cohort showed a noteworthy lower rate of post-operative wound necrosis and scar tissue adhesions, as well as a considerable reduction of superficial and deep tissue infection. In addition, the surgery duration was quicker in the MIS group. In favour of the open group, a slightly lower value of sural nerve palsy has been observed, along with a minimally reduced rate of post-operative palpable knot. Putting the results of this meta-analysis in a clinical context, MIS should be recommended as the surgical method of choice for acute Achilles tendon rupture. Furthermore, also conservative treatment is a considerable therapeutic option with only a slightly higher re-rupture rate in comparison to surgery, but less frequent complications compared to surgery [15]. Therefore, if surgical therapy is required it should aim to have a low rate of relevant complications.

Re-rupture

Although we were not evaluating PROMS we examined the re-rupture rate as one of the most important failures in Achilles tendon surgery, finding no significant differences between both groups, which is in line with previous meta-analyses [10–12, 45]. Keeping this in mind, discussions about the adequate surgical approach should therefore focus on reducing complications rather than differences in outcome. However, for clinical practice it should be considered that previous meta-analyses with small sample sizes reported a slightly better or equal subjective result in general outcome measures or the AOFAS score in favour of MIS [12, 45].

Sural nerve palsy, scar tissue adhesion and palpable knot

The present meta-analyses reveals, that sural nerve palsy might be still a considerable complication of MIS, whereas previous meta-analysis stated equal palsy rates for both approaches [10, 12, 45]. Initially, using the Ma and Griffith percutaneous technique a sural nerve palsy rate up to 60% has been reported, whereas the most recent RCT studying of Rozis et al. in 2018 reported a decreased rate of only 7%

Table 1 Demographic data of the patients

Authors, year	Type of study	Number of tendons	Previous achillodynia	Rupture place	Exclusion criteria	Mean follow-up (months)	Technique	Tendons (n)	Female	Mean age	BMI	Technique	Suture	Post-operative care (duration in weeks)
Majewski et al. [22]	PCS	47	0%	Midportion 100%	(1) Musculotendinous and/or insertional ruptures (2) known achillodynia (3) dehisce < 0.5 cm at 20° plantar flexion	26	Open	22						Boot
							MIS	25						Boot
Lim et al. [23]	RCT	66	6%	Musculotendinous 15%, midportion 26% insertional 59%	(1) Previous non-operative treatment (2) open tears (3) previous ipsilateral ruptures (3) injury < 7 days (4) CCS therapy	6	Open	33	39%	36.9		Kessler	PDS® 1.0	0–6: Equinus, 6–8: neutral
							MIS	33	42%	40.1		Modified Ma and Griffith	PDS® 1.0	0–6: Equinus, 6–8: neutral
Rebeccato et al. [24]	RCS	52			(1) Injury < 3 days	12	Open	15				Bosworth	Non-absorbable	0–4: Equinus, 4–8: full wb heel pad 3 cm reducement 1 cm each 4 weeks
							MIS	37				Kakiuchi and modified Ma and Griffith	Non-absorbable	0–4: Equinus, 4–8: full wb heel pad 3 cm reducement 1 cm each 4 weeks

Table 1 (continued)

Authors, year	Type of study	Number of tendons	Previous achillodynia	Rupture place	Exclusion criteria	Mean follow-up (months)	Technique	Tendons (*n*)	Female	Mean age	BMI	Technique	Suture	Post-operative care (duration in weeks)
Riedl et al. [25]	RCS	97	5%			42	Open	49	22%	37	25	Lange and Bunnell	PDS® 2.0	0–2: Equinus, 2–4: neutral, 4–6: full wb heel pad 1,5 cm
							MIS	48	23%	38	25	Modified Kessler	PDS® chord 0.7 mm	0–1: Week equinus, 1–4: boot 4 cm heel pad PW, 4–8: boot 2 cm heel pad, 8-X: shoe 1,5 cm heel pad
Haji et al. [26]	RCS	108			(1) Injury < 4 days		Open	70		42.3		Bunnell		0–3: Equinus, 3–6: reduced equinus, 6–8: full wb neutral
							MIS	38		41.4		Modified Ma and Griffith	PDS®1.0	0–3: Equinus, 3–6: reduced equinus, 6–8: full wb neutral
Miller et al. [27]	RCS	89		Midportion 100%	(1) Open lesions (2) re-rupture (3) injury > 7 days (4) diabetes (5) inflammatory disease (6) fluoroquinolones therapy (7) CCS therapy	95	Open	59	14%	45		Kessler	Vicryl® 1.0	0–2: Equinus, 2–6: progressive neutral, 6-X: full wb heel pad 1.5 cm reducement of 0.5 cm each week

Table 1 (continued)

Authors, year	Type of study	Number of tendons	Previous achillodynia	Rupture place	Exclusion criteria	Mean follow-up (months)	Technique	Tendons (n)	Female	Mean age	BMI	Technique	Suture	Post-operative care (duration in weeks)
							MIS	30	23%	43		Cretnik	PDS® 1.0 and Vicryl® 1.0	0–2: Equinus, 2–6: progressive neutral, 6-X: full wb heel pad 1.5 cm reducement of 0.5 cm each week
Cretnik et al. [28]	RCS	244			(1) Age < 18 (2) open tears (3) injury > 7 days (4) insertional and musculotendinous ruptures (5) previous operation (6) previous local infiltration	24	Open	108	5%	40.2		Modified Lindholm	Vicryl® 2.0 and 4.0	0–3: Equinus partial wb, 3-X: neutral
							MIS	134	6%	40.2		Modified Ma and Griffith	Vicryl® 2.0	0–3: Equinus partial wb, 3-X: neutral
Gigante et al. [7]	RCT	40			(1) Diabetes mellitus (2) rheumatic arthritis (3) SLE (4) CCS therapy (4) age 20–60 (5) re-rupture	24	Open	20				Kessler	Vicryl® 1.0	0–4: Equinus, 4-X: neutral
							MIS	20				Tenolig®	Non-adsorbable	0–2: Equinus, 2–7: neutral partial wb
Bhattacharyya et al. [29]	PCS	51	0%	Midportion 100%	(1) Diabetes (2) re-rupture (3) psychiatric illness (4) open tears (5) injury > 7 days	12	Open	29		36.8			Delayed absorbable	0–2: Equinus, 2–8: progressive neutral orthesis

Table 1 (continued)

Authors, year	Type of study	Number of tendons	Previous achillodynia	Rupture place	Exclusion criteria	Mean follow-up (months)	Technique	Tendons (*n*)	Female	Mean age	BMI	Technique	Suture	Post-operative care (duration in weeks)
							MIS	23		42		Achillon®		0–2: Equinus, 2–8: progressive neutral orthesis
Ebinesan et al. [30]	RCS	51		Midportion 100%	-	9	Open	20	45%	46.3				0–2: Equinus partial wb
							MIS	31	84%	43.9				0–2: Equinus partial wb
Valencia et al. [31]	RCT	56		Midportion 100%	(1) Age 18 to 50 (2) injury > 10 days (3) other lesions (4) systemic diseases	4	Open	28				Lynn	Vicryl® 1.0	
							MIS	28				Achillon®		
Aktas et al. [32]	RCT	40		Midportion 100%	(1) Previous injury (2) functional impairment contralateral (3) diabetes mellitus (4) neurovascular disease (5) immune suppressed (6) augmentation procedure necessary	22.4	Open	20	15%	40.6		Krackow	Ethibond Excel® 2.0	0–3: Equinus, 3–6: full wb
							MIS	20	10%	39.2		Achillon®	Ethibond Excel® 2.0	0–3: Equinus, 3–6: full wb
Chan et al. [33]	RCS	19		Midportion 100%		6.1	Open	9		42.4		Krackow	Ethibond Excel® 2.0	0–2: Equinus, 2-X: boot progressive wb

Table 1 (continued)

Authors, year	Type of study	Number of tendons	Previous achillodynia	Rupture place	Exclusion criteria	Mean follow-up (months)	Technique	Tendons (n)	Female	Mean age	BMI	Technique	Suture	Post-operative care (duration in weeks)
							MIS	10		41.7		Achillon®	Ethibond Excel® 2.0	0–2: Equinus, 2-X: boot progressive wb
Henríquez et al. [34]	RCS	32		Midportion 100%	(1) Open tears (2) CCS use (3) re-rupture (4) previous surgery in the Achilles tendon (5) musculotendinous and/or calcaneal avulsion (6) injury > 14 days	18	Open	15				Kessler	FiberWire® 2.0	0–3: Equinus, 3–6: no cast no wb, 6–9: progressive wb 1 cm heel pad, 9–12: full wb
							MIS	15				Achillon®	FiberWire® 2.0	0–3: Equinus, 3–6: no cast no wb, 6–9: progressive wb 1 cm heel pad, 9–12: full wb
Grubor et al. [35]	RCS	34				12	Open	15				Lindholm		0–7: Equinus
							MIS	19				Ma and Griffth	Dexon®, Vicryl® or PDS® 1.0	0–7: Equinus
Carmont et al. [36]	RCS	84				12	Open	35	14%	41		Kessler	Ethibond Excel® or PDS®	0–6: Equinus no wb
							MIS	49	22%	45		Modified Ma and Griffith	Maxon™ 1.0	0–2: Equinus, 2–6: progressive neutral, 6-X: 1.5 cm heel pad

Table 1 (continued)

Authors, year	Type of study	Number of tendons	Previous achillodynia	Rupture place	Exclusion criteria	Mean follow-up (months)	Technique	Tendons (*n*)	Female	Mean age	BMI	Technique	Suture	Post-operative care (duration in weeks)
Karabinas et al. [37]	RCT	34		Midportion 100%		21	Open	15	13%	40		Krackow	Non-absorbable 1.0	0–3: Equinus, 3–7: progressive neutral and wb in brace
							MIS	19	21%	42		Ma and Griffth	Non-absorbable 1.0	0–3: Equinus, 3–7: progressive neutral and wb in brace
Kolodziej et al. [38]	RCT	47			(1) Chronic tears (2) concomitant injuries (3) open tears (4) avulsion from the calcaneus (5) any medications that might impair tendon healing	24	Open	25	8%	47.1		Krackow	PDS® or Maxon™	0–6: Equinus, 6-X full wb
							MIS	22	5%	44.8		Achillon®	PDS® or Maxon™	0–6: Equinus, 6-X full wb
Jallageas et al. [39]	RCS	31	0%	Musculotendinous 100%	(1) Previous AT rupture (2) Achilles tendinopathy or injury to the leg (3) any condition that can influence the study	15	Open	15	13%	39	25.1	Kessler		0–3: Equinus, 3–6: neutral, 6-X: partial wb with 3 cm heel pad reducement 1 cm each week

Table 1 (continued)

Authors, year	Type of study	Number of tendons	Previous achillodynia	Rupture place	Exclusion criteria	Mean follow-up (months)	Technique	Tendons (*n*)	Female	Mean age	BMI	Technique	Suture	Post-operative care (duration in weeks)
							MIS	16	19%	37	24.6	Tenolig®	Dacron	0–2: Equinus, 2–6: crutches and 3 cm heel pad reduction 1 cm each week, 6-X: full wb
Hsu et al. [8]	RCS	270			(1) Achilles tendinopathy (2) insertional avulsion (3) chronic tears (4) > 3 months follow-up	9	Open	169		41	28.1	Krackow	FiberWire® 2.0 and Vicryl® 0.0	0–2: Equinus, 2–4: neutral, 4–8: boot heel pad progressive wb, 8–12: weaning boot
							MIS	101		40	27.7	PARS®	FiberWire® 2.0	0–2: Equinus, 2–4: neutral, 4–8: boot heel pad progressive wb, 8–12: weaning boot
Rosso et al. [40]	RCS	37			(1) Re-rupture (2) re-operation (3) infection (4) neuromuscular disorder (5) ankle valgus > 15° (6) ankle varus > 5°	90	Open	21		48.2	24.8			
							MIS	16		46.4	25.3			
Obada et al. [41]	RCS	68				40	Open	34				Kessler and Krackow		
							MIS	34				Achillon® and Tenolig®		

Table 1 (continued)

Authors, year	Type of study	Number of tendons	Previous achillodynia	Rupture place	Exclusion criteria	Mean follow-up (months)	Technique	Tendons (*n*)	Female	Mean age	BMI	Technique	Suture	Post-operative care (duration in weeks)
Daghino et al. [4]	RCS	140			(1) Open tears (2) metabolic disorders	24	Open	72	17%	42.5	24.8	Kessler	Absorbable 2.0 3.0 4.0	0–4: Equinus, 4–8: neutral, 8–12: full wb cast 2,5 cm heel pad
							MIS	68	87%	43.1	25.4	Achillon®		0–6: Equinus, 6–9: neutral 2.5 cm heel pad
Lonzaric et al. [42]	RCS	262			(1) Age < 18 (2) injury > 3 days (3) inflammatory rheumatic disease (4) CCS (5) rupture of the other AT within 1 year (6) fractures of lower limbs (7) previous local infiltration of CCS and anaesthetics (6) immunosuppression therapy (7) posttraumatic osteoarthritis of a large lower limb joint		Open	42	12%	44.5		Modified Lindholm		0–2: Equinus boot, 2–3: neutral, 3-X: partial wb
							MIS	220	6%	41.1		Cretnik, Kosanovic, Kruscic		0–3: Equinus, 3–6: neutral, 6-X: heel pad partial wb

Table 1 (continued)

Authors, year	Type of study	Number of tendons	Previous achillodynia	Rupture place	Exclusion criteria	Mean follow-up (months)	Technique	Tendons (n)	Female	Mean age	BMI	Technique	Suture	Post-operative care (duration in weeks)
Araujo et al. [43]	RCS	20			(1) Chronic rupture (2) bilateral rupture (3) rheumatic disease	12	Open	10	40%	48.5	28.7	Kessler and FHL transfer	FiberWire® 2.0	0–3: Equinus, 3–6: partial wb boot equinus, 6–9: partial wb neutral,9-X: full wb
							MIS	10	0%	38.2	28.9	PARS®	FiberWire® 2.0	0–3: Equinus, 3–6: partial wb boot equinus, 6–9: partial wb neutral,9-X: full wb
Rozis et al. [13]	RCT	82		Midportion 81%, insertional 1%	(1) Age 18 to 65 (2) diabetes mellitus (3) autoimmune disease (4) CCS therapy (5) smoking and/or alcohol abuse (6) injury > 48 h	12	Open	41	22%	41		Krackow	Non-absorbable 1.0	0–3: Equinus, 3–6: partial wb neutral, 6–8:boot full wb
							MIS	41	24%	43		Ma and Griffth	Non-absorbable 1.0	0–3: Equinus, 3–6: partial wb neutral, 6–8:boot full wb
Baumfeld et al. [44]	RCS	38	3%	Midportion 100%		33	Open	20				Bunnell		0–2: Equinus, 2–6: boot progressive wb neutral, 6-X: full wb

Table 1 (continued)

Authors, year	Type of study	Number of tendons	Previous achillodynia	Rupture place	Exclusion criteria	Mean follow-up (months)	Technique	Tendons (*n*)	Female	Mean age	BMI	Technique	Suture	Post-operative care (duration in weeks)
							MIS	18				Modified Ma and Griffith		0–2: Equinus, 2–6: boot progressive wb neutral, 6-X: full wb
Makulavicius et al. [14]	RCT	87			(1) Injury > 1-week (2) age 18 to 65 (3) any ankle pathology (4) no serious co-morbidities and/or immunodeficiency	27	Open	44	11%	37.8		Bunnell with crown procedure	Vicryl® 1.0	0–3: Equinus, 3–6: progressive partial wb neutral, 6-X: full wb
							MIS	43	12%	35.9		Modified Bunnell	Vicryl® 1.0	0–3: Equinus, 3–6: progressive partial wb neutral, 6-X: full wb

PCS Prospective Cohort Study, *RCS* Retrospective Cohort Study, *RCT* Randomized Clinical Trial, *WB* weight bearing

Table 2 Meta-analysis results

Outcome of interest	Open (*n*)	Percutaneous (*n*)	Final effect [95% CI]	*P*
Surgical duration (minutes)	110	101	7.55 [5.16, 9.95]	< 0.0001
Re-rupture (*n*)	24/1009	23/1097	1.10 [0.62, 1.94]	0.75
Palpable knot (*n*)	2/940	6/1047	0.10 [0.01, 0.81]	< 0.0001
Sural nerve palsy (*n*)	23/940	76/1047	0.45 [0.28, 0.74]	0.001
Scar tissue adhesions (*n*)	43/940	9/1047	4.10 [2.13, 7.88]	< 0.0001
Wound necrosis (*n*)	21/940	4/1047	3.01 [1.38, 6.59]	0.006
Superficial infection (*n*)	24/940	2/1067	3.90 [1.68, 9.06]	0.002
Deep infection (*n*)	48/940	23/1047	2.01 [1.24, 3.27]	0.005

[12, 13]. However, it has to be emphasized that the present meta-analysis includes studies from the last two decades, while surgical techniques have been improved and several operation devices have been introduced during this time [12]. Therefore, in recent studies of Lacoste et al. using the Tenolig™ system and of Amlang et al. using the Dresden instrument none of the patients had a permanent sural nerve damage [9, 46]. For clinical practice it has to be considered that the risk of sural nerve palsy mainly depends on the surgeon's skills. Traditionally, the open approach to the Achilles tendon is performed through a medial exposure to avoid affections to the sural nerve, allowing a good overview on the anatomical structures. However, tissue scarring and adhesions increase on the basis of exposure of the peritendineum leading to mild pain and discomfort. Contrary, the reduced exposure of the MIS makes the tendon repair more prone to nerve damage. Especially when the needles are pierced laterally into the proximal portion of the Achilles tendon, an increased risk of direct sural nerve injury or indirect irritation by sutures exists. However, in clinical practice there are surgical precautions to reduce the risk: usage of ultrasound guidance or tenoscopy as well as external rotation of the Achillon® suture device [1, 47].

Besides, lower sural nerve palsy rates, in the open group a decreased risk for palpable knots was observed. The clinical relevance of this outcome is fair, and it might show a reduced prevalence in the future thanks to modern knotless percutaneous techniques with suture anchoring in the calcaneus [48].

Wound necrosis, deep and superficial infections

The reduced risk of wound necrosis or tissue infections observed in the MIS group are clinically relevant, since being the most common reasons besides tendon re-rupture requiring revision surgery. Grassi et al. revealed that one wound infection could be avoided for every 10 minimally-invasive procedure performed instead of an open approach representing previous findings of higher infection rates and wound necrosis [12] Contrary to our findings, the meta-analyses of Li et al. and Yang et al. concluded that a reduced infection rate in favour of the minimally invasive approach only counts for superficial infections and not for deep infections [10, 11]. For clinical practice, Achilles tendon surgery should focus on a minimal wound area. Due to low skin perfusion over the Achilles tendon, there is a higher risk for wound necrosis followed by superficial tissue infections [49] even increased by means of individual risk factors such as smoking, vascular diseases or diabetes [50]. As a result perioperative prophylactic antibiotics do not reveal a significant reduction of infection prevalence [1, 51].

Operation time

Besides the lower rate of tissue infections and wound necrosis, MIS revealed a significant shorter operation time. However, analysing three studies offering suitable data, the average duration of both procedures was less than 60 min, assuming that adverse effects of general anaesthesia or tourniquet time most probably do not have that much impact on outcome. Additionally, the importance of short overall surgery duration reflects the need for higher cost-effectiveness, as the total estimated costs of open tendon repair comparison to a minimally-invasive repair excluding theatre time are nearly twice as high [36].

Strength, limitations and implications for future research

Point of strength of the present study is represented by the strict eligibility criteria and inclusion of only frequently reported findings along with the comprehensive nature of the literature search including observational studies and RCTs, so that the largest sample sizes compared to previous meta-analysis has been achieved [10, 12, 45]. Moreover, the adequate follow-up and the optimal baseline comparability represent a further important point of strength.

Nevertheless, caution should be taken with regard to the following limitations: According to inconsistent data of the underlying studies we were unable to evaluate outcomes according to subgroups like the location of tendon rupture. Only a few of the studies included classified the exact location of tendon rupture (insertion, mid-portion, musculotendinous transition) or the gap between the tendon stumps. Amlang et al. introduced an ultrasound based classification in 2011 making rupture classification also practicable in a MIS approach [52]. Consequently, we encourage future studies to classify the exact location of tendon rupture in order to achieve valuable information minimizing future failures and impaired functional outcome, potentially providing clear indications in favour of certain augmentation procedures. Moreover, most recently a knotless MIS procedure with calcaneal suture anchor fixation has been described, offering wider surgical use of MIS, not being limited to repair of mid-portion tendon ruptures [48].

With regard to subgroup analysis, pre-existing comorbidities like vascular diseases might have influenced the infection or necrosis rate, since in clinical practice they are already used as clear contraindication for open repair. To avoid bias, this data needs to be completely reported in future studies. According to the methodological quality assessment this study had a moderate level of quality, since there was a high risk of detection bias and a low rate of overall RCT studies (8/25). Moreover, this meta-analysis reported a considerable risk of bias in the given data due to various techniques and post-operative rehabilitation, suture materials and developing surgical procedures influencing outcome measures. In both approaches, there are numerous techniques using different suture types (Bunnell, Kessler, Krackow etc.), suture material (PDS®, Vicryl®, FiberWire® etc.), tendon augmentation and flap-down strategies (Lindholm, Bosworth, Lynn etc.). Based on this data recommending the superior technique is challenging and mainly based on the surgeon's skill. According to biomechanical aspects, recent systematic reviews and meta-analyses showed improved outcomes for double or triple sutures and higher resistance for Krackow and Bunnell instead of Kessler suture techniques, without finding a difference between Achillon® versus Krackow techniques [53, 54]. Moreover, bioabsorbable sutures might cause less tissue irritation while maintaining sufficient strength capacity [1]. Additionally, early and prolonged functional rehabilitation and mobilisation is recommended with a lots of varieties as discussed by Yang et al. [1]. A further limitation is that, we did not include functional parameters such as the toe-rising test or calf circumference. However, it was not possible to examine persistent functional deficits like weakness or tendon elongation, due to missing data and/or consensus of a testing protocol of isokinetic muscle force evaluation.

Conclusion

Compared to the MIS technique, the open Achilles tendon reconstruction evidenced a slightly lower rate of sural nerve palsy and postoperative palpable knot, whereas in the MIS reconstruction group, a quicker surgery duration, a lower rate of post-operative wound necrosis, superficial and deep tissue infections as well as scar tissue adhesions was detected. No relevant discrepancies were detected among the two techniques in terms of post-operative re-rupture. Consequently, MIS should be used as the surgical technique of choice.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent For this type of study informed consent is not required.

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