Meta-analysis

Open and Percutaneous Approaches Have Similar Biomechanical Results for Primary Midsubstance Achilles Tendon Repair: A Meta-analysis

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Purpose: To evaluate the biomechanical properties of open versus percutaneous Achilles tendon repair. **Methods:** A systematic review of original research articles was performed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. To qualify for study inclusion, articles were required to be published in English, use a laboratory design using either human or animal tissue, and directly compare the biomechanical properties of open Achilles repair using a Krackow or Kessler technique with percutaneous repair using either a locking or nonlocking suture construct. The biomechanical outcomes evaluated were displacement (millimeters) and load to failure (Newtons). **Results:** Twelve studies met inclusion criteria, including 234 specimens (open: 97, percutaneous locking: 73; percutaneous nonlocking: 64) that underwent primary midsubstance Achilles tendon repair. Pooled analysis demonstrated no statistically significant difference in displacement ($P = .240$) or load to failure ($P = .912$) between the open and percutaneous techniques. Among the percutaneous approaches, there was no difference in displacement ($P = .109$) between the locking and nonlocking tendon repair systems. **Conclusions:** The results of this study suggest that both open and percutaneous techniques are biomechanically viable approaches for primary midsubstance Achilles tendon repair. **Clinical Relevance:** In clinical studies, similar rerupture rates have been observed after open or percutaneous Achilles tendon repair. It may be beneficial for surgeons to understand whether biomechanical differences exist between these repair techniques.

Achilles tendon ruptures are devastating injuries that cause substantial functional impairment, with 20% of patients never returning to play after operative repair.[1] Rupture of the Achilles tendon most commonly occurs in the midsubstance, 3 to 6 cm from the distal insertion, and multiple repair techniques have been described.[2]

Surgical repair techniques can be categorized as open or percutaneous. Open surgery typically is performed with Krakow or Kessler stitch patterns, whereas percutaneous repair is system dependent, with different repair systems offering locking or nonlocking suture configurations.[3,4] Despite the variability in repair techniques, there is a growing body of literature that supports similar rerupture rates (3.1%-6.4% for percutaneous and 1.4%-3.9% for open) and similar validated patient-reported outcomes with open and percutaneous Achilles tendon rupture repair.[5-10] Clinical meta-analyses have attempted to compare open and percutaneous techniques, but these studies have been unable to account for the potential effect that the specific suture technique and postoperative protocol may have on reported outcomes.[10-12]

Thus, it may be beneficial for surgeons to understand whether biomechanical differences exist between repair techniques. The purpose of this study was to evaluate the biomechanical properties of open versus percutaneous Achilles tendon repair. The null hypothesis was that no significant difference would exist between open and percutaneous techniques with regard to ultimate failure load and cyclic displacement.

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Methods

This meta-analysis was performed according to Preferred Reporting items in Systematic Reviews and Meta-analyses guidelines. A health sciences librarian developed the search strategy using a combination of keywords and specific database subject headings related to each concept (Appendix Fig 1, available at www.arthroscopyjournal.org). A search was conducted within PubMed, Medline (via Ovid), Embase (via Ovid), Web of Science Core Collection, and SPORTDiscus (via EBSCOhost) from inception to June 30, 2023. Editorials were excluded from the search, and duplicates were removed.

To qualify for inclusion in the systematic review, studies were required to be published in English, use a laboratory design with both human and animal Achilles tendons, and directly compare the biomechanical properties of open Achilles repair using a Krackow or Kessler technique versus percutaneous repair using either the PARS (Arthrex, Naples, FL) locking or Achillon (Integra LifeSciences, Princeton, NJ) nonlocking tendon repair systems. Studies that directly compared locking with nonlocking percutaneous repair systems also were included. Only original research studies were included. Studies that included in vivo repairs, nonbiomechanical studies, and studies without full text available were excluded. All abstracts and full-text articles were stored in Rayyan (Qatar Computing Research Institute), which allowed blinding of each independent reviewer to the inclusion/exclusion decisions made by the other reviewer throughout the article assessment process.

All identified articles were assessed for study eligibility by 2 reviewers, each of whom was blinded to the inclusion/exclusion decisions of the other reviewer. The 2 independent reviewers, a medical student (J.L.) and orthopaedic surgery resident (R.T.), followed an algorithm for abstract screening that was developed and piloted by the senior author (H.P.G.). After abstract screening, articles underwent full-length review to confirm inclusion in the study. In cases of disagreement between the 2 reviewers, blinding was removed, and the final eligibility of the article was resolved by a group consensus, with the senior author (H.P.G.) making the final decision.

Included articles underwent data extraction to obtain the following variables: species, sex, age, fixation technique, and mechanism of failure. The biomechanical outcomes evaluated were displacement (millimeters) and load to failure (Newtons). Weighted averages were calculated for all quantitative values. When standard deviations were absent and only standard errors were reported, standard deviations were computed using the methodology described in the *Cochrane Handbook for Systematic Reviews of Interventions* (Version 6.2.0; Cochrane Collaboration, London, England). Using a random-effects model, standardized mean differences with 95% confidence intervals were calculated and embedded within the forest plot. Meta-analysis statistics and generation of forest plot figures were performed using OpenMetaAnalyst, which implements metaphor R console code.

Results

A total of 667 articles were assessed for eligibility, and 12 of these met the inclusion criteria (Fig 1). Sixteen articles ultimately satisfied eligibility criteria for inclusion in the qualitative systematic review. Twelve of these studies, including 234 specimens, included data that could be used to generate a quantitative meta-analysis (Table 1). In total, 97 cadavers were repaired using an open technique, 73 were repaired using a percutaneous locking technique, and 64 were repaired using a percutaneous nonlocking technique. Seven of the studies used human cadavers,[13-19] 5 of which included cadaver age and the mean age across these studies was 58.3 years.[13-17] Two other studies used porcine models,[20,21] 2 used bovine models,[22,23] and 1 used an ovine model.[24]

Methodologic Quality Assessment

The risk of bias and methodologic quality of the studies were assessed using the QUACS scale (QUality Appraisal for Cadaveric Studies).[25] The mean QUACS score was 84.0% (range, 69.2%-92.3%; Table 2). Eleven of the 12 included studies satisfied the threshold for a satisfactory level of methodologic quality (>75%).[13-19]

Surgical Technique

Eight studies implemented a similar Krackow surgical technique for open repair. Each study used a standard Krackow locking stitch technique to secure the tendon after appropriate tensioning. Three studies implemented a Kessler suture technique for open repair. Eight studies followed the technique guide associated with the Arthrex PARS Achilles Jig System (Arthrex). Lastly, 7 studies performed the percutaneous method using the Achillon device (Integra LifeSciences). The number of sutures crossing the repair site and suture material used for each repair technique are in Table 1.

Displacement: Open Versus Percutaneous Repair

Seven studies evaluated differences in displacement between open and percutaneous techniques. Three studies[13,19,22] demonstrated that open repair was associated with less displacement than percutaneous repair, whereas 4 studies[14,18,20,21] demonstrated that open repair led to more displacement than percutaneous repair. One study[19] demonstrated no difference in displacement between open and percutaneous repair. The pooled analysis from 7

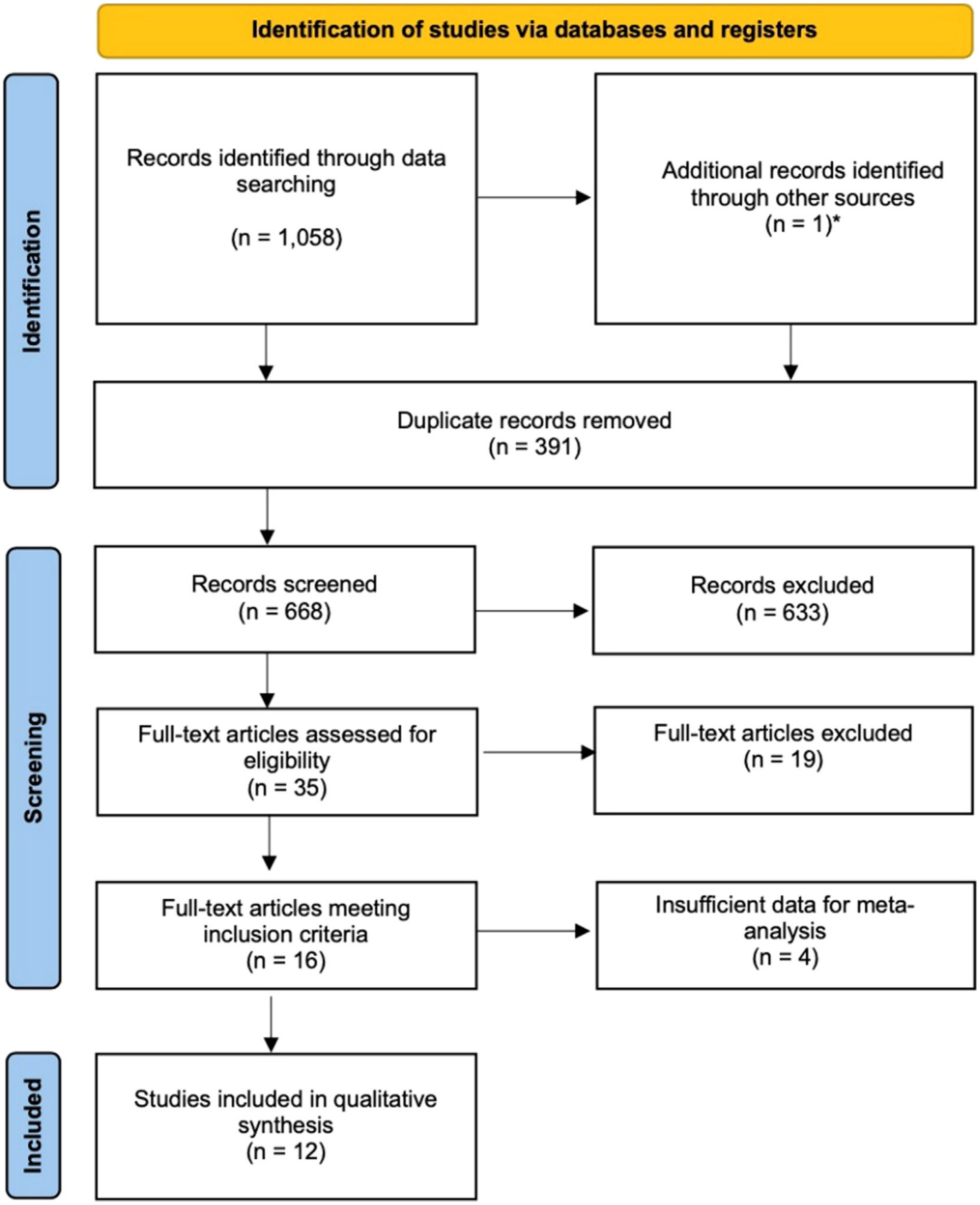

Fig 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) diagram illustrating study inclusion and exclusion. *Primary data search included all possible related articles so additional sources were not needed.

studies did not reveal a statistically significant difference in displacement between open and percutaneous repair ($P = .240$, Fig 2).

Ultimate Load to Failure: Open Versus Percutaneous Repair

Eight studies evaluated differences in ultimate load to failure between open and percutaneous techniques. Two studies[14,15] reported that percutaneous repair yielded a greater ultimate load to failure than open repair, whereas 3 studies[18,19,22] reported that open repair yielded a greater ultimate load to failure than percutaneous repair. Three other studies[16,17,24] demonstrated no difference in ultimate load between open and percutaneous techniques. Of note, 1 study[17] reported a significant difference between the 2 groups using a Wilcoxon rank sum, whereas no significant difference is noted if an unpaired *t*-test is used. The pooled analysis from 8 studies did not reveal a statistically significant difference in ultimate load to failure between open and percutaneous repair ($P = .912$, Fig 3).

Table 1. Specimens and Fixation Details of Included Studies

First Author	Year	Fixation Technique (and No. of Specimens)	Sample Size (No. of Achilles)	Species, Mean Age, yr [range], (if human)	No. of Sutures Crossing Repair Site	Suture Type
Chuckpaiwong[19]	2023	Krackow (5), percutaneous nonlocking (5)	10	Human, age not given	Krackow: 4; percutaneous nonlocking: 6	All repair techniques: No. 2 braided polyethylene/ polyester multifilament nonabsorbable suture (FiberWire; Arthrex)
Clanton[13]	2015	Kessler (9), percutaneous nonlocking (6), percutaneous locking (9)	24	Human, 53 [26-65]	Kessler: 3; percutaneous nonlocking: 6; percutaneous locking: 4	All repair techniques: No. 2 braided polyethylene/ polyester multifilament suture (FiberWire or TigerWire; Arthrex)
Cottom[18]	2017	Krackow (12), percutaneous locking (12)	24	Human, age not given	Krackow: 4; percutaneous locking: 6	All repair techniques: No. 2 braided polyethylene/ polyester multifilament nonabsorbable suture (FiberWire; Arthrex)
Dekker[16]	2017	Krackow (9), percutaneous locking (9)	18	Human, 66 [53-77]	Krackow: 4; percutaneous locking: 6	All repair techniques: No. 2 braided polyethylene/ polyester multifilament nonabsorbable suture (FiberWire or TigerWire; Arthrex)
Heitman[15]	2011	Krackow (9), percutaneous nonlocking (10)	19	Human, 75 [65-85]	Krackow: 4; percutaneous nonlocking: 6	All repair techniques: No. 1 nonabsorbable synthetic suture (Ethibond; Ethicon, Somerville, NJ)
Huffard[17]	2008	Krackow (10), percutaneous nonlocking (10)	20	Human, 50.2 [40-59]	Krackow: 4; percutaneous nonlocking: 6	All repair techniques: No. 1 nonabsorbable synthetic suture (Ethibond)
Ismail[24]	2008	Kessler (8), percutaneous nonlocking (8)	16	Sheep	Kessler: 2; percutaneous nonlocking: 6	All repair techniques: No. 2 nonabsorbable, silicone-coated, braided polyester suture (Ticron; Tyco Healthcare, Basingstoke, England)
Ko[21]	2022	Krackow (10), percutaneous locking (10), percutaneous nonlocking (10)	30	Porcine	Krackow: 3; percutaneous locking: 4; percutaneous nonlocking: 6	Krackow and percutaneous nonlocking: braided, nonabsorbable synthetic suture (Hi-Fi; Conmed Corp, Utica, NY); percutaneous locking: No. 2 braided polyethylene/polyester multifilament nonabsorbable suture (TigerTape; Arthrex)

(continued)

Table 1. Continued

First Author	Year	Fixation Technique (and No. of Specimens)	Sample Size (No. of Achilles)	Species, Mean Age, yr [range], (if human)	No. of Sutures Crossing Repair Site	Suture Type
Macaluso[14]	2022	Krackow (8), percutaneous locking (8)	16	Human, 69 [range not given]	Krackow: 5; percutaneous locking: 6	All repair techniques: No. 2 braided polyethylene/polyester multifilament nonabsorbable suture (FiberWire; Arthrex)
Qi[20]	2019	Krackow (7), percutaneous nonlocking (7), percutaneous locking (7)	21	Porcine	Krackow: 4; percutaneous nonlocking: 6; percutaneous locking: 4	All repair techniques: No. 2 polyester nonabsorbable suture (Ethibond; Ethicon, Inc., Cincinnati, OH)
Tian[22]	2020	Kessler (10), percutaneous locking (10)	20	Bovine	Kessler: 4; percutaneous locking: 4	All repair types: No. 2 braided polyethylene/polyester multifilament suture (FiberWire; Arthrex)
Wang[23]	2021	percutaneous nonlocking (8), percutaneous locking (8)	16	Bovine	Percutaneous nonlocking: 6; percutaneous locking: 4	All repair techniques: No. 2 Ultrabraid (Smith & Nephew; London, UK)

NOTE. Manufacturers: Achillon (Integra LifeSciences; Princeton, NJ), PARS (Arthrex, Naples, FL).

Table 2. QUACS Scores of the Included Studies

Study	QUACS Score
Chuckpaiwong[19]	76.9%
Clanton[13]	92.3%
Cottom[18]	84.6%
Dekker[16]	84.6%
Heitman[15]	84.6%
Huffard[17]	84.6%
Ismail[24]	69.2%
Ko[21]	84.6%
Macaluso[14]	76.9%
Qi[20]	92.3%
Tian[22]	84.6%
Wang[23]	92.3%

QUACS, QUality Appraisal for Cadaveric Studies.

Displacement: Locking Versus Nonlocking Percutaneous Repair

Four studies evaluated differences in displacement between the locking and nonlocking percutaneous repair techniques. Three studies[13,20,21] reported no differences in displacement between the 2 techniques, whereas 1 study[23] demonstrated that nonlocking repairs were associated with less displacement than locking repairs. The pooled analysis from all 4 studies did not reveal a statistically significant difference in displacement between percutaneous repair techniques ($P = .109$, Fig 4).

Mode of Failure

All 12 studies reported the mode of failure of each included specimen. In the open repair group (n = 97), failure occurred most frequently by knot breakage (42.3%), followed by suture failure (25.8%), suture pullout through the tendon (20.6%), and suture breakage at the suture-tendon interface (11.3%) (Fig 5). In the percutaneous repair group (n = 137), failure occurred most frequently by breakage at suture-tendon interface (34.3%), followed by suture knot breakage (27.7%), suture pullout through tendon (27.7%), tendon pullout (5.1%), suture failure (2.9%), and simultaneous suture failure + tendon pullout (2.2%) (Fig 6).

Discussion

The findings of this systematic review suggest that both open and percutaneous techniques produce biomechanically similar results for primary midsubstance Achilles tendon repair. There were no statistically significant differences in displacement ($P = .240$) or ultimate failure load ($P = 912$) between the open and percutaneous techniques. Moreover, when comparing percutaneous techniques, there was no difference in displacement between locking and nonlocking repair techniques ($P = 109$).

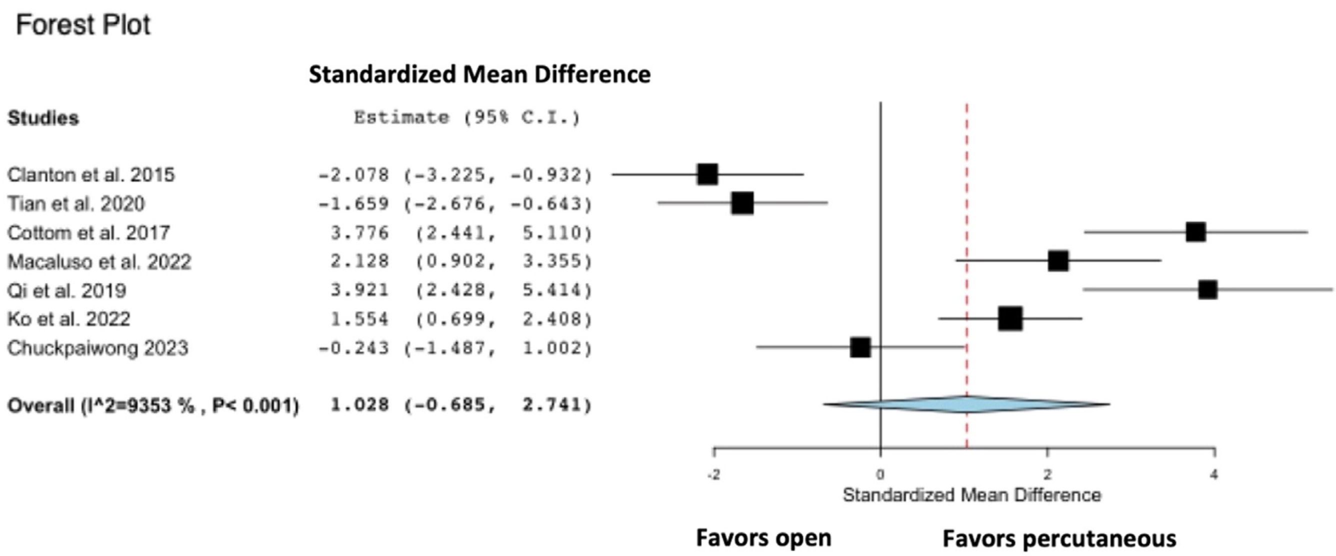

Fig 2. Displacement: open versus percutaneous repair. (C.I. confidence interval.)

Four studies met the criteria for inclusion in the systematic review but did not report quantitative data that were conducive to inclusion in the meta-analysis. Demetracopoulos et al.[26] was omitted from the meta-analysis because of the lack of other studies that directly compared percutaneous techniques against each other in load to failure. Melcher et al.[27] assessed biomechanical outcomes of the locking percutaneous technique but did not compare biomechanical results to a nonlocking or open technique. Lee et al.[28] evaluated percutaneous versus open repair in terms of ultimate failure; however, they reported outcome in terms of number of cycles to failure rather than load to failure. Murphy et al.[29] compared a traditional percutaneous locking repair technique versus a modified technique that involved distal suture anchors. We were unable to include these data because of a lack of studies that made a similar comparison.

Other studies comparing the biomechanical properties of various Achilles tendon repair techniques have been published. Yammine and Assi[30] compared Krackow open repair with nonlocking percutaneous repair in cadaveric lower extremities and also concluded that neither technique was biomechanically superior. However, the scope of this study was limited in that the authors only examined load to failure and

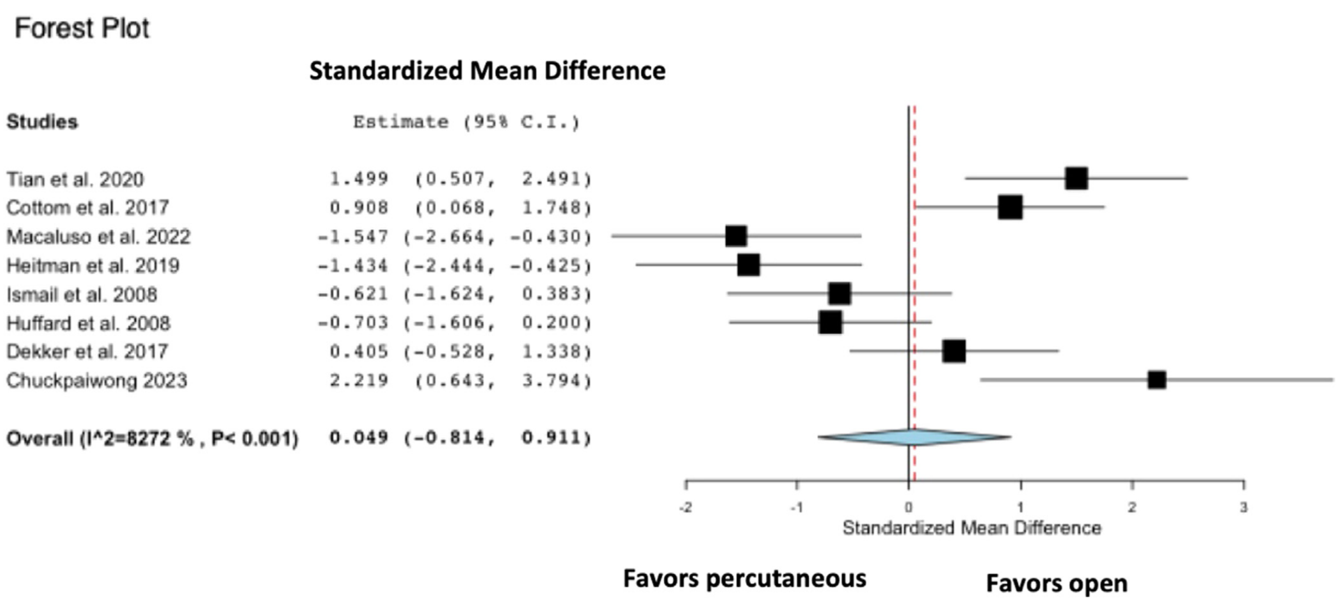

Fig 3. Ultimate load to failure: open versus percutaneous repair. (C.I. confidence interval.)

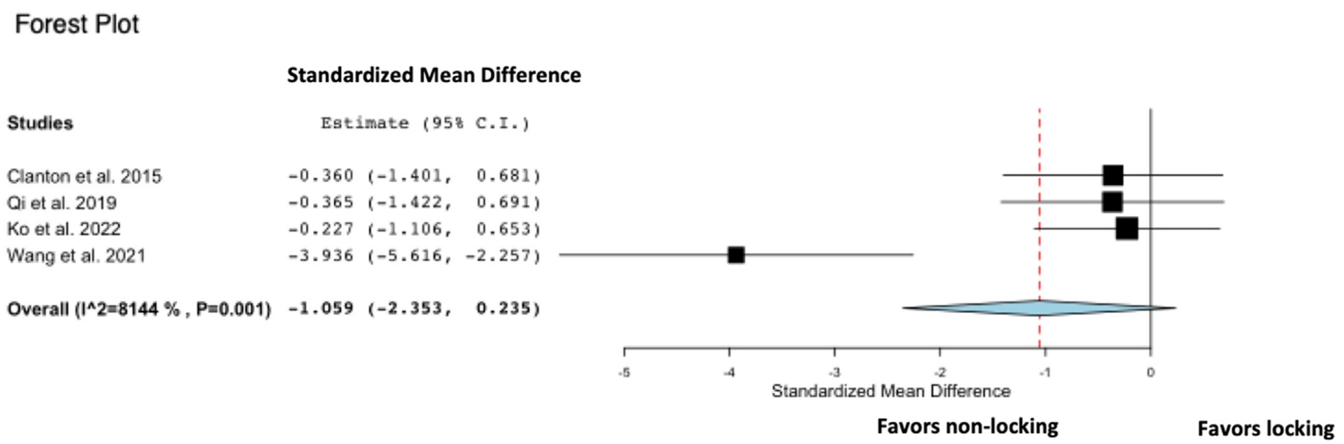

Fig 4. Displacement: locking versus nonlocking percutaneous techniques. (C.I. confidence interval.)

did not include cyclic gap formation as a biomechanical outcome.[30] We chose to include gap formation as a result of the well-established correlation between Achilles tendon rupture gap and patient-reported outcomes.[31] Furthermore, we included studies that assessed both locking and nonlocking percutaneous systems. Four studies compared displacement in percutaneous locking versus nonlocking techniques,[13,20,21,23] and only 1 of these studies[23] demonstrated a significant difference in displacement between locking and nonlocking percutaneous repair, favoring the nonlocking technique.

Other authors have performed clinical studies to investigate the success rates of open versus percutaneous repair using these specific locking and nonlocking repair techniques. A recent randomized controlled study by Myhrvold et al.[32] compared open versus percutaneous versus nonoperative treatment of AT rupture in more than 500 patients. Their study demonstrated no difference in rerupture rates or Achilles' tendon Total Rupture Score between open and percutaneous techniques.[32] Kołodziej et al.[9] conducted a smaller randomized controlled trial comparing open Achilles tendon repair with a modified Krackow technique versus nonlocking percutaneous repair and demonstrated no significant differences in rerupture or infection rates.[9] Their infection rate finding differ from what is commonly reported in the literature, as open repair has been shown to

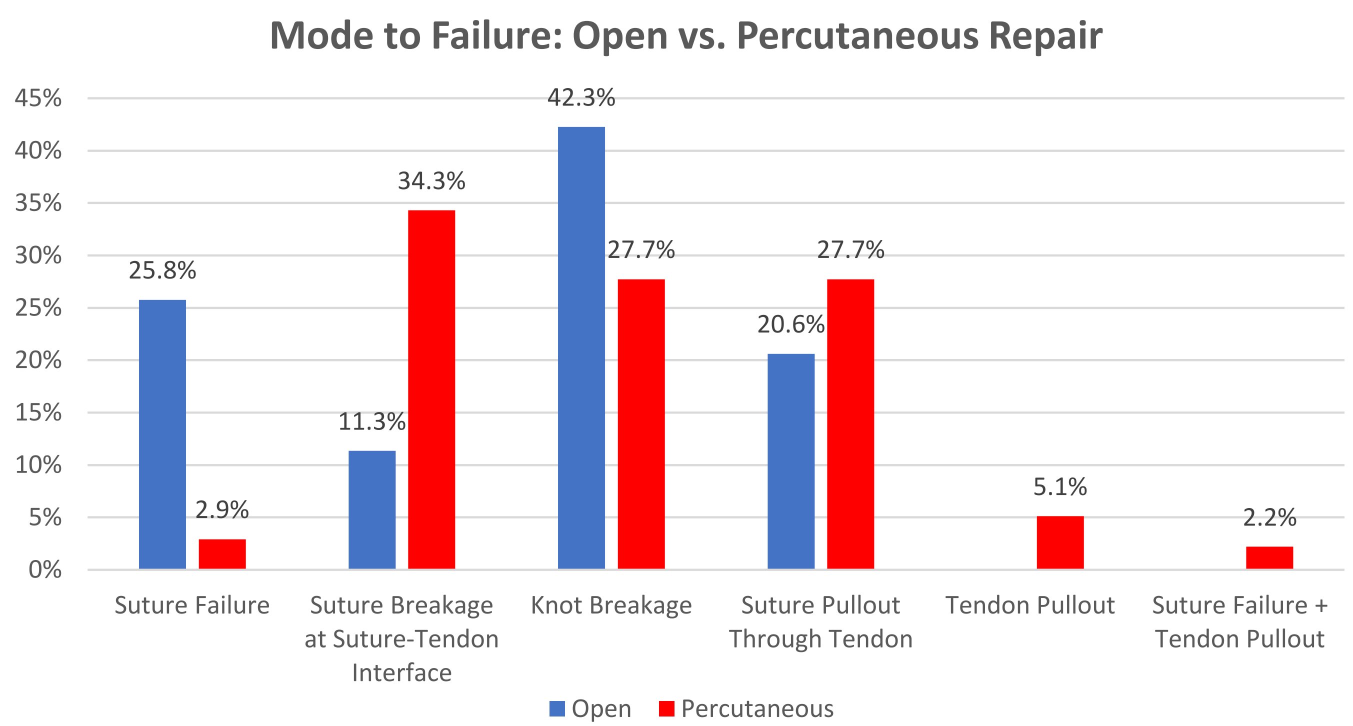

Fig 5. Mode of failure for open versus percutaneous repair techniques.

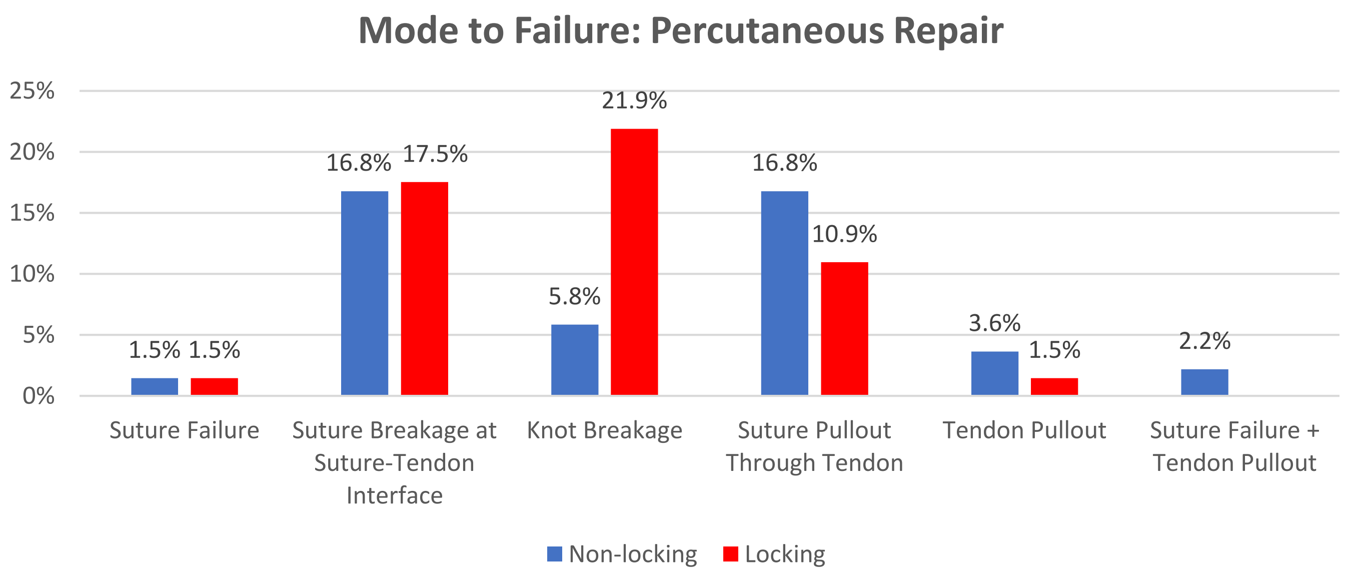

Fig 6. Mode of failure for the locking and nonlocking percutaneous repair techniques.

increase the incidence of infection.[8,10,33,34] Similarly, Aktas and Kocaoglu[8] also performed a randomized controlled trial comparing open AT repair versus non-locking percutaneous repair and reported no differences in rerupture rates. Notably, however, the authors of that study did report a significant increase in infection rates with open repair.[8]

Another significant finding of our study was the clear dichotomy among studies that assessed gap formation between open and percutaneous techniques, with only the study by Ismail et al.[24] showing no difference between the 2 techniques. Studies that favored percutaneous repair implemented a 6-strand percutaneous repair compared with a 2-core open repair. The opposite finding also was observed, as studies favoring open repair typically implemented a 6-core strand repair compared with 6-strand percutaneous techniques. This finding is consistent with existing hand surgery literature, which has historically documented that the number of sutures that cross a repair site is positively correlated with increased repair strength and decreased gap formation.[35,36] Although our study only sought to compare open and percutaneous techniques, the results of this systematic review suggest that surgeons performing Achilles tendon repair should consider additional sutures across the repair site to create a more biomechanically stable construct.

Limitations

There are several limitations of this study. The biomechanical evaluation of the specimens was presented at time zero. This is compared with the clinical context, where the rehabilitation protocol gradually increases activity load as the tendon heals biologically. Furthermore, there was variability between the included articles regarding the species of tissue studied, which introduced heterogeneity into the results. Combining findings using human tissue with animal tissue also contributes to heterogeneous results, as human ATs have different cross-sectional and longitudinal profiles compared with ATs from the animals included in this study.[24] The age of the tendon samples at time of harvest also may have contributed to the findings, as tendon stiffness and Young's Modulus decrease and cross-sectional area increases as humans age.[37] In addition, the suture material and surgical technique varied widely between studies, which makes it difficult to directly compare their biomechanical results.

Conclusions

The results of this study suggest that both open and percutaneous techniques are biomechanically viable approaches for primary midsubstance Achilles tendon repair.

Disclosures

All authors (J.L., R.T., S.S., C.I., M.T., G.G., W.H., H.G.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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