

# Does Medial-Row Fixation Technique Affect the Retear Rate and Functional Outcomes After Double-Row Transosseous-Equivalent Rotator Cuff Repair?

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**Background:** Double-row transosseous-equivalent (TOE) rotator cuff repair techniques have been widely accepted because of their superior biomechanical properties when compared with arthroscopic single-row repair. Concerns regarding repair over-tensioning with medial-row knot tying have led to increased interest in knotless repair techniques; however, there is a paucity of clinical data to guide the choice of technique.

**Hypothesis:** Arthroscopic TOE repair techniques using knotless medial-row fixation will demonstrate lower re-tear rates and greater improvements in the Constant score relative to conventional knot-tying TOE techniques.

**Study Design:** Systematic review; Level of evidence, 4.

**Methods:** A systematic review of 3 databases (PubMed, Cochrane, and Embase) was performed using PRISMA (Preferred Reporting Items for Systematic Meta-Analyses) guidelines. Inclusion criteria were English-language studies that examined repair integrity or Constant scores after arthroscopic rotator cuff repair with TOE techniques. Two investigators independently screened results for relevant articles. Data regarding the study design, surgical technique, re-tear rate, and Constant shoulder score were extracted from eligible studies. A quality assessment of all articles was performed using the Methodological Index for Non-Randomized Studies (MINORS) criteria.

**Results:** The systematic review identified a total of 32 studies (level of evidence, 1-4) that met inclusion and exclusion criteria. Of the 32 studies, 5 reported on knotless TOE techniques, 25 reported on knot-tying TOE techniques, and 2 reported on both. In the knotless group, re-tear rates ranged from 6% to 36%, and Constant scores ranged from 38-65 (preoperative) to 73-83 (postoperative). In the knot-tying group, re-tear rates ranged from 0% to 48%, and Constant scores ranged from 42-64 (preoperative) to 55-96 (postoperative).

**Conclusion:** Despite several theoretical advantages of knotless TOE repair, both knotless and knot-tying techniques reported considerable improvement in functional outcomes after rotator cuff repair. Although tendon failure rates showed a downward trend in knotless studies, additional prospective studies are warranted to better understand the role of medial-row fixation on tendon repair integrity and postoperative clinical outcomes.

**Keywords:** knot; knotless; arthroscopic; shoulder; surgical techniques; systematic review; meta-analysis

Despite significant advances and numerous improvements in arthroscopic rotator cuff repair techniques, a tendon re-tear remains a very common postoperative complication.<sup>3,19,21,42</sup> Many factors, including a patient's overall health and tendon quality, have been implicated in rotator cuff healing.<sup>4,38,65</sup> Additionally, nonbiological factors such as suture repair technique have also been shown to affect the biomechanical properties of the repair construct and eventual clinical outcomes.<sup>16,31</sup> Regardless of the method, current techniques

aim to restore the anatomic configuration and provide an optimal environment for tendon-to-bone healing. While several techniques, including single-row and double-row anchor-based repair, have been described with good clinical outcomes, recent studies have demonstrated that transosseous-equivalent (TOE) techniques optimize footprint contact while maintaining high initial fixation and minimizing gap formation.<sup>16,31,34,35,39,51</sup> TOE repair has also been shown to be superior to other methods in achieving tendon compression for healing and a higher ultimate load to failure.<sup>13,20,59</sup>

TOE repair can be performed using various configurations but generally can be divided into all-knotless repair

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or repair in which the medial or lateral row is tied.<sup>13,59</sup> A recent systematic review noted that biomechanical properties, including ultimate load, stiffness, gap formation, and contact area, are significantly improved when medial knots are tied compared with knotless TOE constructs.<sup>41</sup> Despite the biomechanical advantages of medial knots in TOE repair, controversy still remains regarding the clinical significance of tying the medial row. Recent investigations have reported medial-row failure with knot-tying TOE repair as a result of tension overload or decreased tendon perfusion due to medial stress.<sup>8,9,14,23,67,74</sup> Blood supply to the rotator cuff tendon is critical to the healing process, and tendon perfusion is an important variable to consider when evaluating a suture technique.<sup>12,28,37,75</sup> All-knotless repair has gained interest because of its improved vascularity and decreased risk of tissue strangulation and overtensioning.<sup>9,37</sup> By eliminating the burden of a subacromial knot, knotless techniques also decrease irritation and the risk of impingement on the repair site. The advantages of this technique allow surgeons to achieve anatomic footprint restoration without compromising tissue circulation and decreasing the risk of tissue cut-through.<sup>18</sup> Additionally, a recent study showed superior biomechanics of knotless TOE repair over knotted TOE repair via an improved self-reinforcement mechanism.<sup>50</sup>

Although the superior biomechanical characteristics of TOE constructs have been recognized, fewer studies have evaluated clinical healing rates and functional outcomes of these techniques. Studies have reported inconsistent results of repair site integrity with knot-tying TOE repair, with retear rates ranging from 12% to 30% in some reports.<sup>18,70</sup> An even fewer number of published studies have reported outcomes after knotless repair, but small case series have reported failure rates as low as 6%.<sup>56</sup> Given such limited existing clinical data, the purpose of this systematic review was to compare the outcomes of knot-tying with knotless medial-row anchors in TOE constructs to provide better guidance regarding the use of both techniques. We hypothesized that tying the medial row in TOE constructs would lead to higher failure rates and less clinical improvement as measured by the Constant score.

## METHODS

### Search Strategy

A systematic literature search was performed in accordance with the 2009 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement

(Figure 1). Two reviewers (A.M.E., N.L.R.) independently searched 3 online databases (PubMed, Cochrane, Embase) to identify all relevant articles published before June 2017. Reference lists of included studies and relevant reviews were examined for supplementary eligible studies. The search terms and inclusion/exclusion criteria were established a priori (Appendix Table A1). Key terms used in the search were “rotator cuff,” “repair,” “double row,” “suture bridge,” “speedbridge,” “knot tying,” “knotless,” and “transosseous equivalent.” Eligible studies were included based on the following criteria: (1) level of evidence 1 to 4, (2) articles published in the English language, (3) human studies, (4) arthroscopic rotator cuff repair, (5) studies reporting repair failure rates or Constant scores, and (6) full-text availability. Exclusion criteria were (1) basic science articles, (2) studies on rotator cuff repair associated with shoulder arthroplasty or trauma, and (3) potential overlap of patient populations when the study was conducted by the same authors or institutions.

### Data Extraction

Two reviewers (A.M.E., N.L.R.) independently screened all titles, abstracts, and full texts of retrieved studies to determine eligibility. Disagreements were resolved by a discussion between the 2 authors, and if a consensus could not be reached, the senior reviewer (K.J.J.) resolved the discrepancy. The final decision on inclusion was made on the basis of the full-text article. Included studies were used to extract relevant data, including author, year of publication, sample size, study design, level of evidence, mean follow-up, surgical procedure (ie, knotless vs knot tying), initial tear size, preoperative fatty infiltration, repair integrity via the Sugaya classification,<sup>64</sup> failure rate, location of rotator cuff failure according to Cho et al,<sup>9</sup> and preoperative and postoperative Constant scores.

### Literature Quality Evaluation

The MINORS (Methodological Index for Non-Randomized Studies) criteria were used for grading the methodological quality of selected studies. The MINORS is a validated scoring tool to assess internal and external validity for nonrandomized studies.<sup>63</sup> Studies are assigned 0, 1, or 2, with a maximum of 24 for comparative studies and 16 for noncomparative studies. Although each included constituent study was scored, studies were not excluded from the systematic review on the basis of their MINORS score.

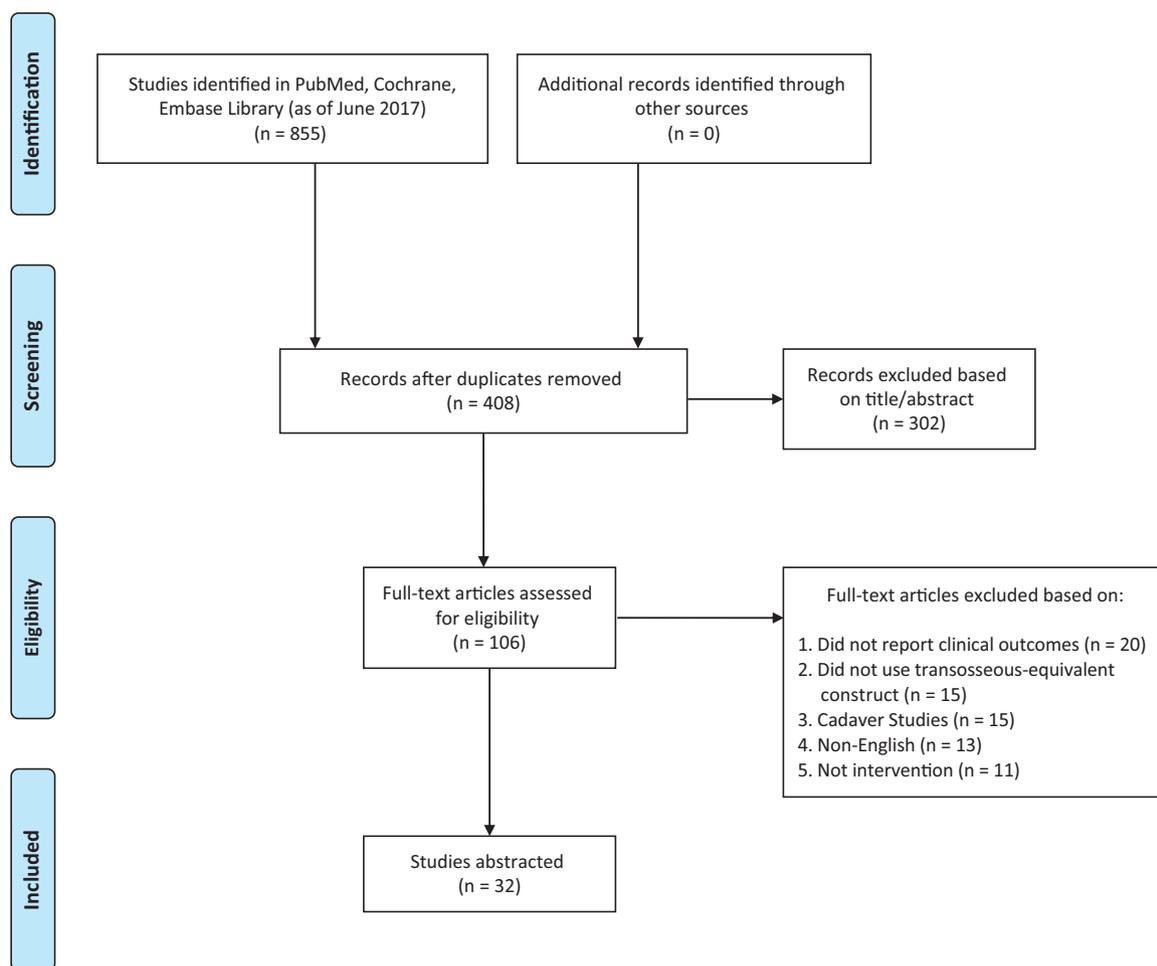
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**Figure 1.** PRISMA (Preferred Reporting Items for Systematic Meta-Analyses) flowchart of systematic search strategy.

## Qualitative Analysis

Because of the overall variation in study design (evidence levels 1-4) and outcome heterogeneity, a quantitative meta-analysis was deemed inappropriate. Therefore, a qualitative analysis was performed.

## RESULTS

### Studies Included

Our initial search strategy yielded 855 studies. After the removal of 447 duplicates, the individual titles and abstracts of the remaining 408 articles were reviewed and resulted in the exclusion of 302 articles that were not relevant to our study. The full text of the remaining 106 articles was thoroughly reviewed for eligibility, and 74 were eliminated on the basis of inclusion and exclusion criteria. No other studies were extracted from the reference lists of these studies (Figure 1). The reasons for exclusion were as follows: study did not report failure rates or clinical outcome scores (31%), study did not use a TOE construct (22%), cadaveric or biomechanical studies (21%), non-English

language (18%), and case reports (8%). The 32 included articles identified by the 2 independent reviewers were then evaluated by the senior reviewers to ensure that the strict eligibility criteria had been met.

### Study Quality

Of the 32 studies that were included, 1 study represented level 1 evidence, 5 studies represented level 2 evidence, 17 studies represented level 3 evidence, and 9 studies represented level 4 evidence. Noncomparative studies had a mean MINORS score of 13.3, and comparative studies had a mean MINORS score of 20.9, indicating moderate quality of evidence (Appendix Table A2). A summary of the included studies is shown in Table 1.

### Study Characteristics

The 32 studies included in the systematic review were published between 2008 and 2015 (Table 1). Of those studies, 7 utilized a knotless TOE construct in a total of 257 patients, and 27 studies utilized a knot-tying TOE construct in a total of 1701 patients. A total of 29 studies documented

TABLE 1  
Included Studies<sup>a</sup>

Author (Year)	Study Design	LOE	Follow-up, Mean $\pm$ SD, mo	No. of Patients	Initial Rotator Cuff Tear Size, <sup>b</sup> cm	Degree of Fatty Infiltration <sup>c</sup>	Repair Integrity via Sugaya Classification	Retears, n (%)	Location of Rotator Cuff Failure, Type 1/Type 2	Imaging Modality <sup>d</sup>	Time From Surgery to Imaging, mo
<i>Knotless TOE</i>											
Boyer et al <sup>5</sup> (2015)	Pro	3	21	35	13 B1, 17 B2, 5 B3	$\leq$ G1	Y	6 (17)	6/0	MRI, CT	13
Ide et al <sup>26</sup> (2015)	Retro	3	81	36	2.1 $\pm$ 0.9 (1.0-3.5)	$\leq$ G2	—	5 (14)	—	MRI	12.8
Hug et al <sup>25</sup> (2015)	Retro	3	24.4 $\pm$ 4.7	22	1-5	1.40 $\pm$ 0.34	Y	5 (23)	3/2	MRI	24.4
Kim et al <sup>30</sup> (2014)	Retro	3	6.21	61	1-4	—	Y	22 (36)	12/9 <sup>e</sup>	MRI	6.2
Werthel et al <sup>73</sup> (2014)	Retro	3	19.0 $\pm$ 4.2	32	14 B1, 17 B2, 1 B3	$\leq$ G2	Y	2 (6)	—	MRI	19
Rhee et al <sup>57</sup> (2012)	Pro	2	21.2	51	1-3	G0-G4	—	3 (6)	—	MRI	6.8
El-Azab et al <sup>17</sup> (2010)	Pro	2	14	20	—	G1-G3	—	4 (20)	—	MRI	14
<i>Knot-tying TOE</i>											
Boyer et al <sup>5</sup> (2015)	Pro	3	29	38	12 B1, 22 B2, 4 B3	$\leq$ G1	Y	9 (24)	7/2	MRI, CT	13
Shin et al <sup>61</sup> (2015)	Retro	3	34.1 $\pm$ 8.9	37	1.67 $\pm$ 0.42	—	—	3 (8)	—	MRI	6
Wang et al <sup>72</sup> (2015)	RCT	1	4	30	13.70 $\pm$ 3.27	—	Y	9 (30)	—	MRI	4
Choi et al <sup>11</sup> (2014)	Retro	3	31.2	147	94 (63.9%) D2, 38 (25.9%) D3, 15 (10.2%) D4	G0-G4	Y	25 (17)	5/20	MRI	23.4
Hug et al <sup>25</sup> (2015)	Retro	3	24.4 $\pm$ 4.7	20	1-5	—	Y	5 (25)	1/4	MRI	24.4
Kim et al <sup>31</sup> (2014) <sup>f</sup>	Retro	3	36	21	—	—	—	2 (10)	—	US, MRI	32.4
Kim et al <sup>31</sup> (2014) <sup>f</sup>	Retro	3	35.3	16	—	—	—	0 (0)	—	US, MRI	21.9
McCormick et al <sup>44</sup> (2014)	Retro	3	48	19	3.30 $\pm$ 0.74	$\leq$ G2	Y	2 (11)	—	MRI	48.8
Park et al <sup>47</sup> (2014) <sup>g</sup>	Retro	3	24	42	3.87 $\pm$ 0.64	1.6 $\pm$ 0.7	—	8 (19)	4/4	US	24
Park et al <sup>47</sup> (2014) <sup>g</sup>	Retro	3	24	53	3.44 $\pm$ 0.52	0.8 $\pm$ 0.7	—	9 (17)	2/7	US	24
Park et al <sup>53</sup> (2014)	Retro	3	5.7	103	1-5	—	—	7 (7)	—	MRI	6
Ryu et al <sup>58</sup> (2015)	Pro	2	58	34	2.91 $\pm$ 1.46	0.69 $\pm$ 0.40	Y	8 (24)	—	MRI	8.2
Anakwenze et al <sup>1</sup> (2013)	Retro	3	13.3	69	3-5	$\leq$ G2	—	4 (6)	—	—	N/A
Haneveld et al <sup>24</sup> (2013)	Retro	3	28.4 $\pm$ 8.9	36	1-5	—	Y	13 (36)	—	MRI	28.4
Kim et al <sup>29</sup> (2013)	Pro	2	31	26	2.15 (1.2-4.0)	—	Y	3 (12)	2/1	US, MRI	27.9
Kim et al <sup>33</sup> (2013)	Pro	2	26.6	32	>3	0.97 $\pm$ 0.48	Y	2 (6)	—	MRI	26.6
Lee et al <sup>36</sup> (2013)	Retro	3	27.4	62	11 D1, 47 D2, 4 D3	0.73 $\pm$ 0.57	Y	30 (48)	—	MRI	27.4
Neyton et al <sup>46</sup> (2013)	CS	4	16.1	107	<3	$\leq$ G2	Y	11 (10)	10/1	MRI	16.1
Park et al <sup>48</sup> (2013)	Retro	3	25.1	119	68 D2, 51 D3	—	—	—	—	—	N/A
Park et al <sup>49</sup> (2013)	CS	4	37.6 $\pm$ 8.9	36	>5	1.3 $\pm$ 0.6 (0.3-2.7)	—	9 (25)	—	US	24
Tudisco et al <sup>68</sup> (2013)	Retro	3	38.9 $\pm$ 2.3	20	1-3	—	—	5 (25)	0/5	MRI	38.9
Choi et al <sup>10</sup> (2012)	CS	4	28	41	3 D1, 23 D2, 11 D3, 4 D4	33 G1-G2, 6 G3-G4	—	8 (20)	5/3	US	28
Gerhardt et al <sup>23</sup> (2012)	Retro	3	23.4 $\pm$ 2.9	20	16 (80%) B2, 4 (20%) B3	1.15 $\pm$ 0.50	Y	5 (25)	—	MRI	23.4
Cho et al <sup>8</sup> (2011)	CS	4	25.2	87	7 (8%) D1, 41 (47%) D2, 32 (37%) D3, 7 (8%) D4	G0-G4	—	29 (33)	12/17	MRI	8.5
Mihata et al <sup>45</sup> (2011)	Retro	3	38.5	107	67 D1-D2 (1.8 $\pm$ 0.5), 40 D3-D4 (4.2 $\pm$ 1.2)	G0-G4	Y	5 (5)	—	MRI	32.9
Toussaint et al <sup>66</sup> (2011)	CS	4	15	154	47 (30.3%) P1, 88 (57.4%) P2, 19 (12.3%) P3	$\leq$ G2	—	22 (14)	—	MRI, CT	15

(continued)

TABLE 1 (continued)

Author (Year)	Study Design	LOE	Follow-up,		Initial Rotator Cuff Tear Size, <sup>b</sup> cm	Degree of Fatty Infiltration <sup>c</sup>	Repair Integrity via Sugaya Classification	Retears, n (%)	Location of Rotator Cuff Failure, Type 1/Type 2		Imaging Modality <sup>d</sup>	Time From Surgery to Imaging, mo
			Mean ± SD, mo	No. of Patients								
Park et al <sup>50</sup> (2010)	CS	4	12	78	11 D1, 32 D2, 18 D3, 17 D4	G0-G4	—	7 (9)	—	US	12	
Pennington et al <sup>55</sup> (2010)	Retro	3	24	37	3.40 ± 0.95	—	Y	12 (32)	—	MRI	21	
Sethi et al <sup>60</sup> (2010)	CS	4	16.1	40	2.9 (2.5-5.1)	0.45 ± 0.66	—	7 (18)	—	MRI	16.1	
Voigt et al <sup>70</sup> (2010)	CS	4	24	45	—	G0-G4	Y	13 (29)	7/6	MRI	12	
Frank et al <sup>18</sup> (2008)	CS	4	14.6	25	—	G0-G4	—	3 (12)	—	MRI	14.6	

<sup>a</sup>Dashes indicate data not reported. CS, case series; CT, computed tomography; LOE, level of evidence; MRI, magnetic resonance imaging; N/A, not applicable; Pro, prospective study; RCT, randomized controlled trial; Retro, retrospective study; TOE, transosseous-equivalent; US, ultrasound; Y, yes.

<sup>b</sup>Initial rotator cuff tear size in the anteroposterior dimension, reported as No., mean ± SD (range), range, mean ± SD, n (%), mean (range), or mean. B, Bateman classification<sup>2</sup> (grade 1 [B1]: <1 cm; grade 2 [B2]: 1-3 cm; grade 3 [B3]: 3-5 cm); D, DeOrio and Cofield classification<sup>15</sup> (small [D1]: <1 cm; medium [D2]: 1-3 cm; large [D3]: 3-5 cm; massive [D4]: >5 cm); P, Patte classification<sup>54</sup> (type 1 [P1]: “small tears” or retraction of the tendon to the articular surface margin on the humerus; type 2 [P2]: “large tears” or retraction of the tendon between the articular margin of the humerus to the glenoid; type 3 [P3]: “massive tears” or retraction of the tendon to the glenoid or more medial).

<sup>c</sup>Degree of fatty infiltration, as defined by the 5-stage Goutallier Classification<sup>49</sup> (G0, no fatty deposits; G1, some fatty streaks; G2, more muscle than fat; G3, as much muscle as fat; and G4, muscle < fat), or reported as global fatty degeneration index mean ±SD, which is the mean value of 3 muscles’ (supraspinatus, infraspinatus, and subscapularis) degree of fatty infiltration.<sup>49</sup>

<sup>d</sup>When 2 imaging modalities were indicated, the primary modality is listed first.

<sup>e</sup>1/22 was unable to be classified.

<sup>f</sup>Kim et al<sup>31</sup> (2014) listed twice to differentiate between 21 patients with bursal-side lesions and 16 patients with articular-side lesions.

<sup>g</sup>Park et al<sup>47</sup> (2014) listed twice to differentiate between 42 patients with U-shaped tears and 53 patients with L-shaped tears.

initial tear size, either with mean tear size, range of tear sizes, or DeOrio and Cofield classification<sup>15</sup> or Bateman classification,<sup>2</sup> and 1 study classified size according to Patte.<sup>54</sup> A total of 24 studies evaluated patients’ preoperative rotator cuff fatty infiltration, and 33 studies (n = 1839 patients) evaluated patients for full-thickness retears at or before final follow-up. The mean follow-up was 26.7 and 27.6 months in the knotless and knot-tying groups, respectively. Overall, 17 studies evaluated repair integrity via magnetic resonance imaging (MRI) according to the Sugaya classification, in which Sugaya types 1 and 2 (intact repair) and Sugaya types 4 and 5 (not intact repair) were interpreted universally across all studies.<sup>64</sup> The interpretation of Sugaya type 3, however, was not uniform across studies regarding the integrity of rotator cuff repair. A total of 11 studies specified the location of retears according to Cho et al,<sup>9</sup> with type 1 retears located at the tendon-bone interface (original repair site) and type 2 retears located medially with the original repair intact. We found 24 studies (n = 1432 patients) that reported preoperative and postoperative Constant scores (Table 2).

### Failure Rates and Clinical Outcomes

Rotator cuff healing and repair integrity can be assessed using various imaging modalities, including ultrasound, MRI, or computed tomography (CT) arthrography. Imaging modalities used among the studies were as follows: MRI (78%), ultrasound (17%), and CT arthrography (5%).

Several studies used both ultrasound and MRI depending on patient preference and ability to pay. When 2 imaging modalities were used in a study, the one that was used primarily is listed first in Table 1. Time from surgery to imaging varied among studies, with some performing imaging at mean final follow-up and others at shorter intervals (Table 1). When analyzed by surgical technique, the knotless studies reported a retear rate ranging from 6% to 36%. In comparison, the retear rate in the knot-tying group ranged from 0% to 48% (Table 1).

The preoperative and postoperative Constant scores for both repair techniques were used to determine functional improvement at final follow-up. All included studies reported an increase in the mean preoperative to postoperative Constant score. The knotless studies reported a preoperative Constant score ranging from 38 to 65 and a postoperative range from 73 to 83. The preoperative Constant score range in the knot-tying group was from 42 to 64, and postoperative scores ranged from 55 to 96 (Table 2).

### DISCUSSION

Although prior evidence has shown improved biomechanics and a lower risk for medial retears in all-knotless repair, the results of this study do not support our initial hypothesis that clinical results of knotless repair demonstrate superiority over knot-tying repair. Our study found that both TOE techniques demonstrated a considerable increase in the Constant score from baseline to 2 years

TABLE 2  
Constant Scores<sup>a</sup>

Author (Year)	Preoperative	Postoperative
<b>Knotless TOE</b>		
Boyer et al <sup>5</sup> (2015)	49.7 ± 13.2	82.6 ± 8.3
Ide et al <sup>26</sup> (2015)	—	—
Hug et al <sup>25</sup> (2015)	—	78.2 ± 13.2
Kim et al <sup>30</sup> (2014)	—	—
Werthel et al <sup>73</sup> (2014)	38 ± 11	73 ± 11
Rhee et al <sup>57</sup> (2012)	65.2	79.1
El-Azab et al <sup>17</sup> (2010)	46 ± 26	80 ± 16
<b>Knot-tying TOE</b>		
Boyer et al <sup>5</sup> (2015)	48.2 ± 13.9	81.3 ± 9.9
Shin et al <sup>61</sup> (2015)	62.8 ± 2.4	89.4 ± 1.8
Wang et al <sup>72</sup> (2015)	—	—
Choi et al <sup>11</sup> (2014)	53.3	84.3
Hug et al <sup>25</sup> (2015)	—	77.0 ± 8.6
Kim et al <sup>31</sup> (2014) <sup>b</sup>	51.0 ± 20.5	75.9 ± 10.6
Kim et al <sup>31</sup> (2014) <sup>b</sup>	57.4 ± 18.0	83.0 ± 11.8
McCormick et al <sup>44</sup> (2014)	—	76.0 ± 16.9
Park et al <sup>47</sup> (2014) <sup>c</sup>	50.9 ± 12.2	75.8 ± 12.2
Park et al <sup>47</sup> (2014) <sup>c</sup>	52.4 ± 11.5	77.6 ± 10.8
Park et al <sup>53</sup> (2014)	50.5 ± 14.0	55.3 ± 11.4
Ryu et al <sup>58</sup> (2015)	53.8 ± 15.9	73.4 ± 10.3
Anakwenze et al <sup>1</sup> (2013)	—	—
Haneveld et al <sup>24</sup> (2013)	—	—
Kim et al <sup>29</sup> (2013)	58.6 ± 17.7	75.4 ± 10.9
Kim et al <sup>33</sup> (2013)	—	—
Lee et al <sup>36</sup> (2013)	63.6	74.9
Neyton et al <sup>46</sup> (2013)	54.5 ± 12.5	80.0 ± 12.1
Park et al <sup>48</sup> (2013)	48.8 ± 12.3	76.9 ± 7.0
Park et al <sup>49</sup> (2013)	44.8 ± 12.3	75.3 ± 9.9
Tudisco et al <sup>68</sup> (2013)	42 ± 12	67 ± 15
Choi et al <sup>10</sup> (2012)	58	91
Gerhardt et al <sup>23</sup> (2012)	—	77.0 ± 8.6
Cho et al <sup>8</sup> (2011)	48.0	80.3
Mihata et al <sup>45</sup> (2011)	—	—
Toussaint et al <sup>66</sup> (2011)	44.4 ± 8.9	80.5 ± 9.3
Park et al <sup>50</sup> (2010)	—	—
Pennington et al <sup>55</sup> (2010)	—	—
Sethi et al <sup>60</sup> (2010)	—	—
Voigt et al <sup>70</sup> (2010)	64	96
Frank et al <sup>18</sup> (2008)	—	84.3

<sup>a</sup>Data are reported as mean or mean ± SD. Dashes indicate data not reported. TOE, transosseous-equivalent.

<sup>b</sup>Kim et al<sup>31</sup> (2014) listed twice to differentiate between 21 patients with bursal-side lesions and 16 patients with articular-side lesions.

<sup>c</sup>Park et al<sup>47</sup> (2014) listed twice to differentiate between 42 patients with U-shaped tears and 53 patients with L-shaped tears.

postoperatively. Prior studies, however, have shown that postoperative clinical outcomes do not necessarily correlate with rotator cuff retears. Our study did support a narrower range of re-tear rates in knotless studies (6%-36%) compared with knot-tying studies (0%-48%). As studies with evidence levels 3 to 4 were primarily analyzed in this systematic review, we were unable to provide any direct quantitative comparison of technique outcomes.

The ideal rotator cuff repair should allow for easy and quick arthroscopic application while still achieving

adequate biomechanical stability to facilitate tendon-to-bone contact and eventual healing.<sup>22,43</sup> The development of knot-tying TOE repair has provided a more anatomic configuration of the rotator cuff footprint, but recent evidence has suggested concerns of overtensioning of tissue and potential strangulation with medial knots, which has been shown to impede blood flow and long-term healing.<sup>12,32,37</sup> The importance of structurally healed rotator cuffs has also been shown to affect clinical outcomes, which can affect patient satisfaction after the procedure.<sup>62</sup> Despite the technical improvements and mechanical advantages of knot-tying TOE repair, it must be weighed against the importance of optimizing the healing environment and long-term tissue quality. In turn, arthroscopic rotator cuff repair utilizing knotless suture anchor fixation has become increasingly popular. Knotless repair allows for a technically facile and reliable operative procedure. In addition to the theoretical benefits of efficient suture limb management and the monetary and patient-derived benefits from reduced operative time, knotless repair allows surgeons to achieve compression and mechanical stability without reducing perfusion to the tendon.<sup>32</sup> A biomechanical study by Burkhart et al<sup>7</sup> found that knotless repair had yield load, ultimate load, and cyclic displacement that were statistically equivalent to classic double-row repair.

Given the potential decrease in tendon perfusion with knot-tying TOE repair, we hypothesized that eliminating medial knot impingements with knotless techniques could reduce medial strangulation and perforation, thereby leading to fewer repair failures. Studies have associated blood flow with healing and structural integrity of the rotator cuff, which has been shown to affect postoperative clinical results.<sup>62</sup> Although knot tying the medial row increases the biomechanical properties of the TOE construct, Park et al<sup>52</sup> revealed that medial knots inhibit self-reinforcement and adversely affect rotator cuff biomechanics, potentially leading to increased rotator cuff failure; however, their study did not specifically investigate clinical outcomes. Furthermore, an in vivo human study using laser Doppler flowmetry found a nearly 50% reduction in tendon blood flow after lateral anchor fixation.<sup>12</sup> Considering the relative impact of blood supply on tendon healing, the Christoforetti et al<sup>12</sup> study indicated that a decrease in intratendinous blood flow from this construct could result in worse outcomes for tissue repair. A recent study by Kim et al<sup>32</sup> used indocyanine green fluorescence to assess the perfusion status of the compressed tendon with the knot-tying TOE construct compared with parallel-type transosseous repair in rabbits. Their study showed that knot tying hindered blood supply to the tendon in the compressed region near the tuberosity. The authors reported that medial-row failure of the construct may be related to interruption in the blood supply caused by overcompression in the closed-circuit configuration.

Biomechanical studies have also examined the mechanical integrity of anchor fixation on the rotator cuff. A study by Mazzocca et al<sup>43</sup> reported that cyclic loading of double-row repair resulted in failure of the medial row first, with tension overload causing mattress sutures to pull through the tendon medial to the repair site. Although medial knots

increase initial fixation strength, studies have shown that repeated loading over time can lead to loosening or slippage of the knot and eventual gap formation.<sup>13,40</sup> Rhee et al<sup>57</sup> reported no retears with the knotless technique, but nearly 75% of retears for the knot-tying TOE group occurred at the medial row. Furthermore, although limited by their number of patients, Hug et al<sup>25</sup> reported that the pattern of retears was medial rotator cuff failure in 4 of 5 cases for knot-tying repair and only 2 of 5 cases for knotless TOE repair. Therefore, medial rotator cuff failure has been shown to have a higher tendency after knot-tying TOE repair. Each of these studies raises the concern of medial strangulation and ultimate failure as a result of knot tying the medial row. However, even with similar failure rates among TOE techniques, the knotless application still allows for a relatively easier and more efficient procedure, resulting in a decreased length of surgery.<sup>6,56,69,71</sup>

Our study also analyzed clinical differences using the Constant score, a measure of function of the shoulder. Studies have shown that functional assessment scores can often be correlated with postoperative repair integrity, in which superior results have been reported in patients with intact repair.<sup>27</sup> Given these findings, we hypothesized lower Constant scores for knot-tying TOE repair based on the effect of strangulation and overtensioning on rotator cuff integrity. However, we found that both groups showed considerable improvement from preoperative to 2-year postoperative Constant scores. These results were also supported by Hug et al,<sup>25</sup> who evaluated the clinical and radiological results of the knotless anchor technique in 22 patients. Despite finding a reduction in the frequency of medial rotator cuff failure compared with knot-tying TOE repair, they reported no significant difference in the Constant score, subjective shoulder value (SSV), or Western Ontario Rotator Cuff Index (WORC) between the groups.<sup>25</sup> This highlights the possibility that postoperative clinical outcomes do not necessarily correlate with rotator cuff retears. In the study by Rhee et al,<sup>57</sup> the authors found a statistically significant improvement in clinical assessments within the knotless group using the Constant and University of California, Los Angeles (UCLA) scores. However, the difference between the knotless and knot-tying groups was nonsignificant. After a minimum follow-up of 12 months, Boyer et al<sup>5</sup> showed that the Constant score significantly improved in the postoperative period in both groups, but there was no statistical difference between groups. Their study reported no significant difference in retear rates between the knot-tying (24%) and knotless groups (17%).<sup>5</sup>

A review of the literature supports our findings that both TOE repair techniques achieve successful functional outcomes, but longer follow-up studies are needed to confirm these results and the role of knot tying in medial rotator cuff failure. The main strength of this study was our ability to identify a substantial number of overall patients by using an extensive search strategy with broad inclusion criteria to capture all related literature. However, there are several limitations in our study. First, our analysis is limited by the paucity of clinical outcome data regarding the newer knotless technique. Second, the majority of studies included in our analysis were observational, which further reduces the

quality of evidence provided by our conclusions. Third, our analysis could not control for potentially confounding variables such as tear size and tissue quality, which could have affected both the choice of surgical technique and the postoperative outcomes. Last, the lack of a standardized imaging protocol to evaluate repair integrity in the constituent studies could possibly have led to variations in the reporting of rotator cuff failure.

## CONCLUSION

This study supports previous literature that both knotless and knot-tying TOE techniques improve functional outcomes after rotator cuff repair. Although medial fixation has been shown as a mechanism of tendon failure, there is not sufficient evidence to support that knot-tying techniques contribute to medial-row failure of rotator cuff repair. Future studies should focus on conducting more robust comparative studies to improve our understanding of the medial row as a mode of rotator cuff failure. Further clinical and biomechanical research is needed to determine the optimal suture technique for long-term repair integrity.

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## APPENDIX

TABLE A1  
Search Criteria<sup>a</sup>

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1. Double-row rotator cuff repair
  2. Rotator cuff suture bridge
  3. Rotator cuff speed bridge
  4. Rotator cuff knot tying
  5. Rotator cuff knotless
  6. Transosseous-equivalent
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<sup>a</sup>Search engines used: PubMed, Cochrane, and Embase.TABLE A2  
MINORS Scores<sup>a</sup>

Author (Year)	Clearly Stated Aim	Inclusion of Consecutive Patients	Prospective Data Collection	Endpoints Appropriate to Study Aim	Unbiased Assessment of Study Endpoint	Follow-up Period Appropriate to Study Aim	% Lost to Follow-up	Prospective Calculation of Study Size	Adequate Control Group	Contemporary Groups	Baseline Equivalence of Groups	Adequate Statistical Analyses	Total
Anakwenze et al <sup>1</sup> (2013)	2	2	2	1	1	2	2	0	2	2	2	2	20/24
Boyer et al <sup>5</sup> (2015)	2	2	2	2	2	2	2	0	2	2	2	2	22/24
Cho et al <sup>8</sup> (2011)	2	2	2	1	1	2	2	0	2	2	1	2	19/24
Choi et al <sup>10</sup> (2012)	2	2	2	2	2	2	1	0	N/A	N/A	N/A	N/A	13/16
Choi et al <sup>11</sup> (2014)	2	2	2	2	2	2	2	0	N/A	N/A	N/A	N/A	14/16
El-Azab et al <sup>17</sup> (2010)	2	2	2	2	2	2	2	0	N/A	N/A	N/A	N/A	14/16
Frank et al <sup>18</sup> (2008)	2	2	2	1	1	1	2	0	N/A	N/A	N/A	N/A	11/16
Gerhardt et al <sup>23</sup> (2012)	2	2	2	2	2	2	2	0	2	2	2	2	22/24
Haneveldt et al <sup>24</sup> (2013)	2	1	2	2	1	2	2	0	2	2	2	2	20/24
Hug et al <sup>25</sup> (2015)	2	2	2	2	2	2	2	0	1	2	2	2	21/24
Ide et al <sup>26</sup> (2015)	2	1	2	2	2	2	2	0	2	2	1	2	20/24
Kim et al <sup>30</sup> (2014)	2	1	1	2	2	1	2	0	2	2	2	2	19/24
Kim et al <sup>29</sup> (2013)	2	2	2	2	2	2	2	0	2	2	2	2	22/24
Kim et al <sup>31</sup> (2014)	2	2	2	2	2	2	2	0	2	2	2	2	22/24
Kim et al <sup>33</sup> (2013)	2	1	1	2	2	2	1	0	2	2	1	2	18/24
Lee et al <sup>36</sup> (2013)	2	1	2	2	2	2	2	0	N/A	N/A	N/A	N/A	13/16
McCormick et al <sup>44</sup> (2014)	2	2	2	2	2	2	1	2	2	2	2	2	23/24
Mihata et al <sup>45</sup> (2011)	2	1	2	2	2	2	2	0	2	2	2	2	21/24
Neyton et al <sup>46</sup> (2013)	2	2	2	2	2	2	2	0	N/A	N/A	N/A	N/A	14/16
Park et al <sup>47</sup> (2014)	2	2	2	2	2	2	2	0	1	1	2	2	20/24
Park et al <sup>48</sup> (2013)	2	2	2	2	2	2	2	0	2	2	2	2	22/24
Park et al <sup>49</sup> (2013)	2	1	2	2	2	2	1	0	N/A	N/A	N/A	N/A	12/16
Park et al <sup>50</sup> (2010)	2	2	2	2	2	2	2	0	N/A	N/A	N/A	N/A	14/16
Park et al <sup>53</sup> (2014)	2	1	2	2	2	2	1	0	1	2	2	2	19/24
Pennington et al <sup>55</sup> (2010)	2	2	2	2	2	2	1	0	2	2	2	2	21/24
Rhee et al <sup>57</sup> (2012)	2	2	2	2	2	2	2	0	2	2	2	2	22/24
Ryu et al <sup>58</sup> (2015)	2	2	2	1	2	1	2	0	2	2	2	2	20/24
Sethi et al <sup>60</sup> (2010)	2	2	2	2	2	2	1	0	N/A	N/A	N/A	N/A	13/16
Shin et al <sup>61</sup> (2015)	2	2	2	2	2	2	2	0	2	2	2	2	22/24
Toussaint et al <sup>66</sup> (2011)	2	2	2	2	2	2	2	0	N/A	N/A	N/A	N/A	14/16
Tudisco et al <sup>68</sup> (2013)	2	1	2	2	2	2	1	0	2	2	2	2	20/24
Voigt et al <sup>70</sup> (2010)	2	2	2	2	2	2	2	0	N/A	N/A	N/A	N/A	14/16
Wang et al <sup>72</sup> (2015)	2	2	2	2	2	2	2	2	2	2	2	2	24/24
Werthel et al <sup>73</sup> (2014)	2	2	2	2	1	2	2	0	N/A	N/A	N/A	N/A	13/16

<sup>a</sup>MINORS, Methodological Index for Non-Randomized Studies; N/A, not applicable.