Comparing the Use of Flexible and Rigid Reaming Systems Through an Anteromedial Portal for Femoral Tunnel Creation During Anterior Cruciate Ligament Reconstruction

A Systematic Review

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Background: Recent studies have suggested that femoral tunnel drilling during anterior cruciate ligament (ACL) reconstruction (ACLR) with the use of a flexible reaming system through a standard anteromedial portal (AM-FR) may result in a different tunnel geometry compared with a rigid reamer through an accessory anteromedial portal with hyperflexion (AM-RR).

Purpose: To summarize radiologic, anatomic, and clinical outcomes from available studies that directly compared the use of AM-FR versus AM-RR for independent femoral tunnel creation during ACLR.

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

Methods: A literature search was performed using the MEDLINE (PubMed) and Web of Science databases to identify all studies that directly compared radiologic, anatomic, and clinical outcomes between the use of AM-FR and AM-RR. The literature search, data recording, and methodological quality assessment was performed by 2 independent reviewers. The outcomes analyzed included resultant ACL graft positioning and graft bending angle; femoral tunnel positioning, aperture morphology, length, and widening; posterior wall breakage; and distance from various posterolateral knee structures.

Results: A total of 13 studies met the eligibility criteria for inclusion. There was no difference in femoral tunnel aperture location between techniques. There were conflicting findings among studies regarding which technique resulted in a more acute graft bending angle. One study reported greater femoral tunnel widening upon follow-up with the use of AM-FR. AM-FR produced longer and more anteverted femoral tunnels than did AM-RR. The difference in tunnel length was significant and more prominent in lesser degrees of knee flexion. With AM-FR, femoral tunnels were farther from the lateral collateral ligament and peroneal nerve, and 1 of 5 studies had fewer reports of posterior wall breakage. There has been no literature comparing the clinical or functional outcomes of these techniques.

Conclusion: Although no clinical studies exist comparing AM-FR and AM-RR for femoral tunnel creation during ACLR, both systems allow for reproducible positioning of an anatomic femoral tunnel aperture. The use of AM-FR results in longer and more anteverted femoral tunnels than using AM-RR, with exit points on the lateral femur that are different but safe. Surgeons should be aware of the technical differences with each method; however, further study is needed to identify any clinically important difference that results.

Keywords: anterior cruciate ligament; ligament reconstruction; femoral tunnel; reamer

The surgical technique for anterior cruciate ligament (ACL) reconstruction (ACLR) has evolved significantly since its inception, which has led to improved postoperative outcomes and an increased ability for patients to return to sports after ACL surgery.[12,21,26,29,34] Over the past decade, there has been an increased emphasis placed upon achieving an anatomic reconstruction of the ACL in order to more accurately restore native knee kinematics.[7,12,14,33,36] This focus on anatomic reconstruction of the ACL has led to many surgeons transitioning from transtibial (TT) femoral tunnel drilling to other less-constrained, or "independent," methods of creating the

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femoral tunnel, as TT drilling has been shown to result in nonanatomic, vertical graft positioning and poorer rotational stability by comparison.[1,3,12,33] Several other, less-constrained methods exist to create the femoral tunnel, including the use of an anteromedial (AM) portal, outside-in technique, and outside-in retrograde drilling technique.[12,14,28] Respective advantages and disadvantages have been reported for each of these other methods, but the choice of which technique to use is largely dependent upon surgeon preference and experience.[14,28]

The uses of an AM or accessory AM portal and rigid reamer (AM-RR) or flexible reamer (AM-FR) are typically grouped together in the literature when comparing outcomes between the use of independent femoral tunnel drilling and other techniques for femoral tunnel creation.[28] There are, however, several technical differences between these 2 techniques. Flexible reaming systems utilize flexible guide pins and reamers, whereas in rigid reaming systems these components are inflexible. AM-RR requires hyperflexion of the knee to 120°, which can be challenging in certain patients depending upon the patient's body habitus, musculature, or intrinsic flexibility.[27,28] The use of an inflexible guide and reamer is also limited based upon the anatomy of the patient's femoral notch and the placement of the AM portal; however, performing a notchplasty or moving the portal may provide better access in these instances.[14,27,28,33] There is recent evidence to suggest that these technical differences result in AM-RR being more "constrained" in comparison with AM-FR than was previously recognized.[14] Conversely, while flexible reamers require lesser degrees of knee flexion and allow for more forgiveness with a curved offset guide, they can anecdotally be challenging to aim and have the potential to break when drilling hard bone.[8]

This systematic review of the literature was conducted to summarize the currently available studies that directly compare radiologic, anatomic, and clinical outcomes between the use of AM-FR and AM-RR for independent femoral tunnel creation, with a focus upon determining differences in the ability of each technique to create an anatomic reconstruction of the ACL.

METHODS

Study Eligibility

Inclusion criteria for this study involved both retrospective and prospective studies of all levels of evidence that directly compared radiologic, anatomic, and clinical outcomes between the use of AM-FR and AM-RR techniques for femoral tunnel creation in ACLR. Cadaveric studies examining the distances to surrounding ligaments and neurovascular structures, femoral tunnel length, and posterior femoral cortical wall breakage were included because they reported anatomic findings relevant to surgical risk and clinical outcome.[15,16,20,21,30,33,36] Studies were excluded if they were not available in full-text through MEDLINE (PubMed) or were not available in the English language. Similarly, studies that only concentrated on describing surgical technique were excluded from this review. No restriction was made with regard to date of publication.

Literature Search

A review of the literature was conducted using MEDLINE (PubMed) and Web of Science databases in May 2020. The search was performed using the following keywords: flexible, rigid, ACL, anterior cruciate ligament, and reconstruction. The keywords were combined with the Boolean terms "OR" and "AND" in the following manner: (flexible OR rigid) AND (ACL OR anterior cruciate ligament) AND reconstruction. After the initial keyword search, we searched all identified full-length manuscripts manually to identify additional relevant studies.

Study Selection and Data Abstraction

Two reviewers (T.E.M. and A.J.I.) independently evaluated all literature titles and abstracts resulting from the initial keyword search. In situations where the abstract did not provide sufficient information to either include or exclude the study, the full-text manuscript was accessed for further review. Any discrepancy regarding inclusion of studies between the initial 2 reviewers was arbitrated by the senior author (B.C.W.). The interrater reliability for study selection was tested between the 2 independent reviewers.

Relevant data were extracted and recorded by the same 2 independent reviewers using a structured methodology and predefined form. Information regarding sample size was recorded to allow for weighted comparison of included studies that compared the same outcomes. Reporting parameters, such as means, medians, and standard deviations, were also recorded for the same purpose. Key findings with regard to ACL graft positioning or femoral tunnel geometry were recorded to address the primary study question. Additional anatomic results, such as distance to critical posterolateral (PL) knee structures and resultant femoral tunnel length and widening, were also recorded.

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Risk-of-Bias Assessment

The studies included in this systematic review were assessed for methodological quality using the methodological index for non-randomized studies (MINORS) scale.[31] The global ideal score for comparative studies using the MINORS scale is 24.[31] Methodological quality was also assessed for 1 included randomized controlled trial (Kosy et al[20]) using the Jadad scale, which has an ideal score of 5.[13] Two independent reviewers (T.E.M., A.J.I.) scored the included studies, and discrepancies were arbitrated by the senior author. The scoring process was subsequently tested for interrater reliability.

Study selection and methodological quality scoring were assessed for interrater reliability between the independent reviewers. This was calculated using the intraclass correlation coefficient via SPSS software Version 25 (IBM Corp), and the strength of agreement was assessed based upon the criterion introduced by Cicchetti.[4] For the correlation coefficient, $P < .05$ was considered significant.

RESULTS

Figure 1 details the results of the literature search for this systematic review. Complete agreement was reached between the 2 reviewers after performing an independent screening of the 118 titles and abstracts identified via the MEDLINE (PubMed) literature search. Using this first database, 12 studies were found to meet the inclusion criteria. The most common reason for exclusion was that the study did not directly compare AM-FR and AM-RR for femoral tunnel creation in ACLR (n = 96). According to the predefined exclusion criteria, technical notes (n = 7) and editorial or author commentaries (n = 3) were also excluded. The 2 reviewers also performed a secondary search of the Web of Science database by using the bibliography of studies identified via the MEDLINE (PubMed) search and identifying the number of citations by other authors. One additional article was found to meet the inclusion criteria, resulting in a total of 13 studies[‡] being eligible for this review (Table 1).

The decision to include the study by Yoon et al[36] was made because this study compared results of ACLR using AM-FR with a historical control that used AM-RR and was also included in this review.[16] The mean MINORS score for the identified comparative studies was 19.33 (80.54% of the global ideal score). The mean Jadad score for the included randomized controlled trial was 5 (100% of the global ideal score). The intraclass correlation coefficient for the interrater MINORS score was excellent (0.977; 95% CI, 0.95-0.99; $P < .001$). There was 100% agreement in the evaluation of the included randomized controlled trial.

Radiologic Outcomes

ACL Graft Positioning. Four included studies[14,16,34,36] utilized advanced imaging modalities to objectively assess the effect of AM-FR versus AM-RR on ACL graft positioning. Jamsher et al[14] utilized magnetic resonance imaging (MRI) in the coronal and sagittal planes to compare ACL graft inclination angles in patients undergoing ACLR using AM-FR (n = 18) and AM-FR (n = 18) and compared these values with those of 18 healthy controls with intact, native ACLs to determine the ability of the respective technique to restore anatomic graft positioning. In comparison with the healthy controls' mean coronal (73.6° ± 3.4°) and sagittal (49.3° ± 4.2°) graft inclination, there was a statistically significant difference ($P < .01$) in mean sagittal graft inclination between the AM-RR group (56.0° ± 6.1°) and the AM-FR group (49.9° ± 5.0°). Additionally, the authors found no difference in mean coronal graft inclination between the AM-RR (69.5° ± 5.3°) and AM-FR (69.3° ± 4.5°) in comparison with the healthy control group.

Three studies[16,34,36] evaluated the femoral graft bending angle, illustrated in Figure 2. There were conflicting results regarding which technique created a more acute angle, as shown in Table 2.

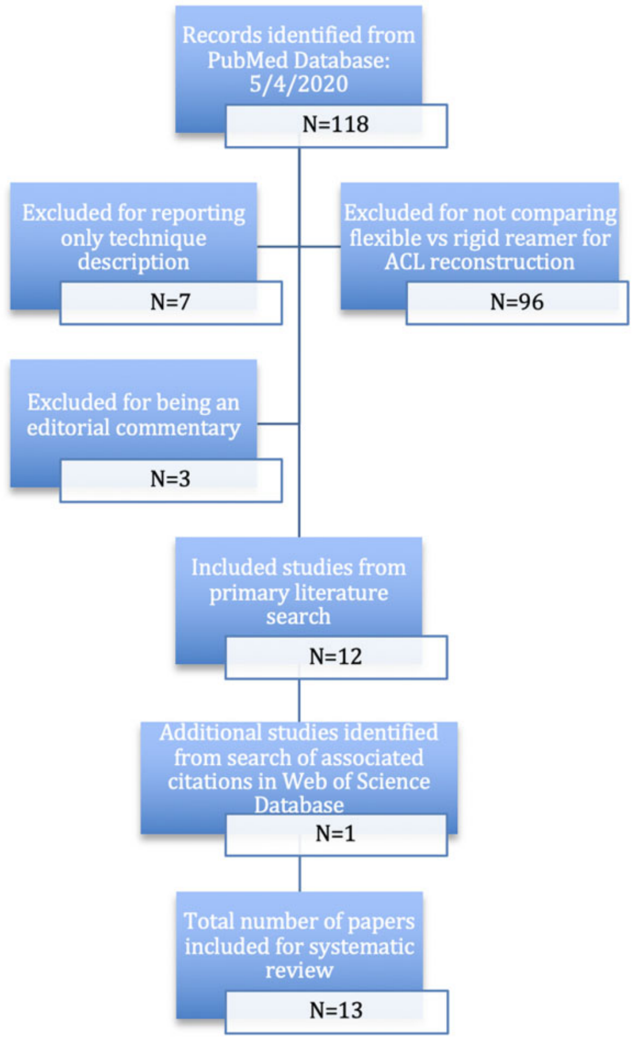

Figure 1. Flowchart of the literature screening process for this review. ACL, anterior cruciate ligament.

[‡]References 5, 9, 14–16, 20, 21, 23, 30, 33–36.

TABLE 1
Details of the Included Studies[a]

Lead Author (year)	LOE (Study Design)	Graft Type	Knee Flexion	Group, n	Mean Age, y	Imaging	Outcomes
Yoon[36] (2020)	4 (retrospective, case series)	Hamstring or tibialis	F: 95°-100°	F: 30	F: 30	3-D CT	Femoral tunnel length, femoral graft bending angle, femoral tunnel position, posterior wall breakage
Jamsher[14] (2020)	2 (prospective, comparative)	Hamstring	F: 90° R: 120°	F: 18 R: 18 Native ACL: 18	F: 33.4 R: 27.5	MRI	Sagittal and coronal graft inclination
Kosy[20] (2020)	1 (RCT)	Hamstring	F: 100° R: >120°	F: 25 R: 25	F: 29 (med) R: 29 (med)	3-D CT	Femoral tunnel length, femoral tunnel position and angles, aperture shape, exit point
Wein[35] (2019)	4 (retrospective, cohort)	PT	F: 90° R: 120°	F: 43 R: 37	—	XR	Femoral tunnel anteversion and length
Tashiro[34] (2017)	3 (retrospective, comparative)	Quadriceps tendon	F: 100-110° R: max	F: 31 R: 18	F and R: 21	3-D CT	Graft bending angle, tibiofemoral kinematics, femoral tunnel widening
Forsythe[9] (2017)	4 (3-D virtual cadaveric)	—	F: 90°, 110°, 125°, max R: 90°, 110°, 125°, max	F: 6 R: 6	F and R: 47	3-D CT	Femoral tunnel length and dimensions, distance from posterior cortex
Kadija[15] (2017)	3 (prospective, cohort)	Hamstring or PT	F: 100-110° R: max	F: 18 R: 82	F: 26.3 R: 25.1	XR	Femoral tunnel length, femoral tunnel position
Kim[16] (2015)	3 (retrospective, comparative)	Hamstring	F: 110° R: max	F: 27 R: 27	F: 30.1 R: 34.0	3-D CT	Femoral tunnel length, graft bending angle, posterior wall breakage, femoral tunnel aperture and angle, femoral tunnel position
Muller[23] (2015)	4 (retrospective, cohort)	Hamstring or PT	F: <120° R: 120°	F: 50 R: 50	—	XR	Femoral tunnel angle
Dave[5] (2012)	4 (cadaveric)	—	F: 90°, 120° R: 90°, 120°	F: 8 R: 8	F and R: 53	—	Femoral tunnel length, distance from posterior femoral cortex
Larson[21] (2012)	4 (cadaveric)	—	F: 110° R: 110°	F: 5 R: 5	F and R: 71	3-D CT	Femoral tunnel length, aperture, femoral placement
Silver[30] (2010)	4 (cadaveric)	—	F: 120° R: 120°	F: 10 R: 10	F and R: 82	—	Femoral tunnel length, distance to lateral anatomic structures
Steiner[33] (2012)	4 (cadaveric)	—	F: 110° R: 110°	F: 6 R: 6	F and R: 64	XR	Femoral tunnel length, femoral exit locations, femoral tunnel alignment

[a]Dashes indicate that this is not described or present in the study. 3-D, 3-dimensional; ACL, anterior cruciate ligament; CT, computed tomography; F, flexible reamer; LOE, level of evidence; max, maximum; med, median; MRI, magnetic resonance imaging; PT, patellar tendon; R, rigid reamer; RCT, randomized controlled trial; XR, radiograph.

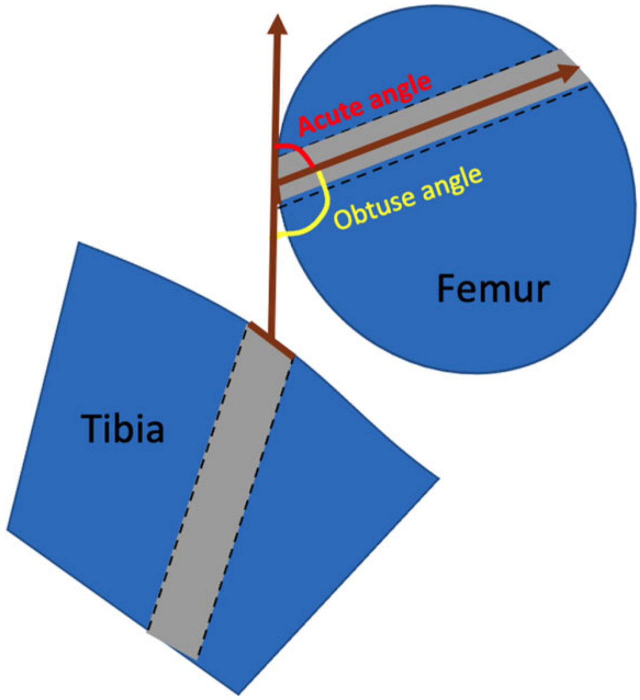

Figure 2. Illustration of the assessment of graft bending angle in the included studies.

Femoral Tunnel Geometry. Eight included studies[9,15,16,20,21,23,33,35] quantified femoral tunnel positioning by utilizing radiologic parameters. No studies reported any significant difference in the intra-articular femoral tunnel aperture location.[15,16,20,36] Table 3 illustrates a comparison of 6 studies that reported femoral tunnel positioning in the frontal, coronal, sagittal, or axial plane.[15,20,21,23,33,35] Two out of 3 studies[15,33,35] reported a significant difference in tunnel positioning in the sagittal plane, with AM-FR resulting in greater tunnel anteversion in these studies (Figure 3).[33,35] One out of 5 studies[15,20,21,23,33] reported a significant difference in tunnel positioning in the frontal or coronal plane, with AM-FR resulting in a less vertically oriented tunnel in this instance (Figure 3).[15]

Four studies described femoral tunnel aperture morphology.[16,20,21,34] Kim et al[16] found that the AM and PL femoral tunnel apertures were larger (more elliptical) in the AM-RR group compared with the AM-FR group. Kosy et al,[20] Larson et al,[21] and Forsythe et al[9] all found no difference in tunnel aperture dimensions (Table 4).

Femoral Tunnel Length. Ten studies reported outcomes on maximal possible femoral tunnel length that resulted from utilizing AM-FR versus AM-RR for femoral tunnel creation during ACLR.[§] In all studies, the reamer size used corresponded with the respective graft diameters. Table 5 details the included studies that reported femoral tunnel length.

Posterior Wall Breakage. Resultant posterior wall breakage during femoral tunnel creation was reported by 5 studies.[9,15,16,20,36] AM-FR demonstrated fewer reports of posterior wall breakage. These data can be found in Table 6.

Several studies in this review also evaluated the location of the femoral tunnel exit point relative to anatomic structures (Table 7). Dave et al[5] performed a cadaveric study and used digital calipers to compare the distance of femoral interosseous guidewire "tunnels" from the posterior femoral cortex depending upon when AM-FR or AM-RR was used with the knee in both 90° and 120° of flexion. The authors found a significant difference in the distance from the posterior femoral cortex at both 90° (AM-FR, 12.6 ± 3.3 mm; AM-RR, 5.0 ± 3.3 mm) and 120° (AM-FR, 19.0 ± 5.3 mm; AM-RR, 12.9 ± 4.5 mm). Forsythe et al[9] also found a significant difference in mean distance from the posterior femoral cortex between systems with the knee in 90° (AM-FR, 0.9 mm; AM-RR, −0.6 mm) and 110° (AM-FR, 2.3 mm; AM-RR, −0.1 mm), with AM-RR on average resulting in breach of the posterior femoral cortex in both circumstances. There was no significant difference between the use of AM-FR and AM-RR at greater degrees of knee flexion (AM-FR: 125°, 4.4 mm; maximum flexion, 6.7 mm; AM-RR: 125°, 3.9 mm; maximum flexion, 8.3 mm).

Femoral Tunnel Widening. Tashiro et al[34] correlated their dynamic graft bending angle with femoral tunnel widening ($r = 0.48$; $P < .001$) 6 months postoperatively. The authors found that the greater graft bending angle seen with the use of AM-FR than AM-RR was correlated with significantly greater femoral tunnel widening (AM-FR, 113.9% ± 17.6%; AM-RR, 97.7% ± 17.5%), which was expressed as a percentage of the tunnel area relative to the instruments used to create it.

Anatomic Outcomes

Distance to Critical Structures. Silver et al[30] performed a cadaveric study comparing the mean distance from a guide pin placed using AM-FR (n = 10) or AM-RR (n = 10) during femoral tunnel creation, as well as both the peroneal nerve and the femoral origin of the lateral collateral ligament (LCL). The authors found the distance from the peroneal nerve to be 42.3 mm with the use of AM-FR and 37.8 mm with the use of AM-RR. Additionally, pins placed via AM-FR were significantly farther from the femoral origin of the LCL (26.1 mm vs 13.4 mm). Kosy et al,[20] Wein et al,[35] Dave et al,[5] Steiner and Smart,[33] and Tashiro et al[34] all found more anterior femoral tunnel exit points with the use of AM-FR compared with AM-RR. Larson et al[21] found no difference with regard to femoral tunnel exit point (Table 7).

Clinical Outcomes

No studies were identified that reported clinical outcomes between the use of AM-FR versus AM-RR for femoral tunnel creation during ACLR.

DISCUSSION

Although no clinical studies exist comparing AM-FR and AM-RR for femoral tunnel creation during ACLR, both systems allow for reproducible positioning of an anatomic

[§]References 5, 9, 15, 16, 18, 20, 21, 30, 33, 35, 36.

TABLE 2
Femoral Graft Bending Angle in the Included Studies[a]

Study	Reamer System	Femoral Graft Bending Angle, deg	Sagittal Inclination, deg	Coronal Inclination, deg
Yoon et al[36]	Flexible	108.4 ± 6.9	—	—
Jamsher et al[14]	Flexible	—	49.9 ± 5.0	69.3 ± 4.5
	Rigid	—	56.0 ± 6.1[b]	69.5 ± 5.3
	Native ACL	—	49.3 ± 4.2	73.6 ± 3.4
Tashiro et al[34]	Flexible	Walking: 99.4 ± 7.8[b] Running: 99.5 ± 9.0[b]	—	—
	Rigid	Walking: 112.5 ± 9.3 Running: 105.9 ± 9.6	—	—
Kim et al[16]	Flexible - AM	115.5 ± 5.5[b]	—	—
	Flexible - PL	117.3 ± 9.7[b]	—	—
	Rigid - AM	108.4 ± 7.4	—	—
	Rigid - PL	109.3 ± 9.2	—	—

[a]Data are reported as mean ± SD. Dashes indicate that this information is not evaluated in the respective studies. Note, Tashiro et al[34] utilized the acute angle formed by the graft and the femoral tunnel vector, whereas Kim et al[16] and Yoon et al[36] utilized the obtuse angle. ACL, anterior cruciate ligament; AM, anteromedial; PL, posterolateral.
[b]Statistical significance between flexible and rigid reamer groups.

TABLE 3
Femoral Tunnel Positioning in Different Planes[a]

Study	Reamer System	Frontal, deg	Coronal, deg	Sagittal, deg	Axial, deg
Kosy et al[20]	Flexible	—	44.1 ± 5.8	—	40.0 ± 6.8
	Rigid	—	42.8 ± 5.3	—	37.4 ± 7.5
Wein et al[35]	Flexible	—	—	40.3 ± 1.7[b]	—
	Rigid			18.6 ± 6.0	—
Kadija et al[15]	Flexible	43 ± 7[b]	—	44 ± 10	—
	Rigid	53 ± 6	—	43 ± 15	—
Muller et al[23]	Flexible	44.7 ± 7.0	—	—	—
	Rigid	42.0 ± 7.2	—	—	—
Larson et al[21]	Flexible	—	51.77	—	—
	Rigid	—	61.22	—	—
Steiner and Smart[33]	Flexible	44.6 ± 11.4	49.1 ± 5.5	44.2 ± 10.2[b]	—
	Rigid	40.0 ± 4.5	45.3 ± 4.1	28.7 ± 5.0	—

[a]Data are reported as mean ± SD. Single decimal values refer to the results listed in the respective papers for each measurement (when included a decimal value indicates a fraction of a degree, based on what was reported in the respective papers). When SD was not reported by the respective paper, this value was not included. Dashes indicate that this information is not evaluated in the respective studies.
[b]Statistical significance between flexible and rigid reamer groups.

femoral tunnel aperture. The use of AM-FR results in longer and more anteverted femoral tunnels, with exit points on the lateral femur that are safe, but different in location from those created using AM-RR. Although there are technical differences between the use of either method and some evidence of radiologic and anatomic differences that result from their use, further study is warranted to identify any clinically important difference that results. Historically, the AM-FR and AM-RR techniques have not been subdivided when comparing different methods for independent femoral tunnel creation during ACLR.[28] However, several important technical differences between their use exists, which result in the AM-FR technique's being less constrained by notch anatomy, AM portal placement, or the degree of knee flexion during tunnel creation.[14,27,28,33] To our knowledge, this study is the first systematic review of the literature that compiles outcomes of studies directly comparing radiologic, anatomic, and clinical outcomes using the 2 techniques. As neither technique is currently considered the gold standard, there is a need for further examination of their effect on ACLR.

Although 1 study[15] that examined ACL graft positioning found that the use of AM-FR better recreated the native anatomy of the ACL, the remainder of studies identified no significant difference in the intra-articular femoral tunnel aperture location.[14,16,20,36] This finding suggests that both flexible and rigid reaming systems allow for reproducible positioning of an anatomic intra-articular femoral

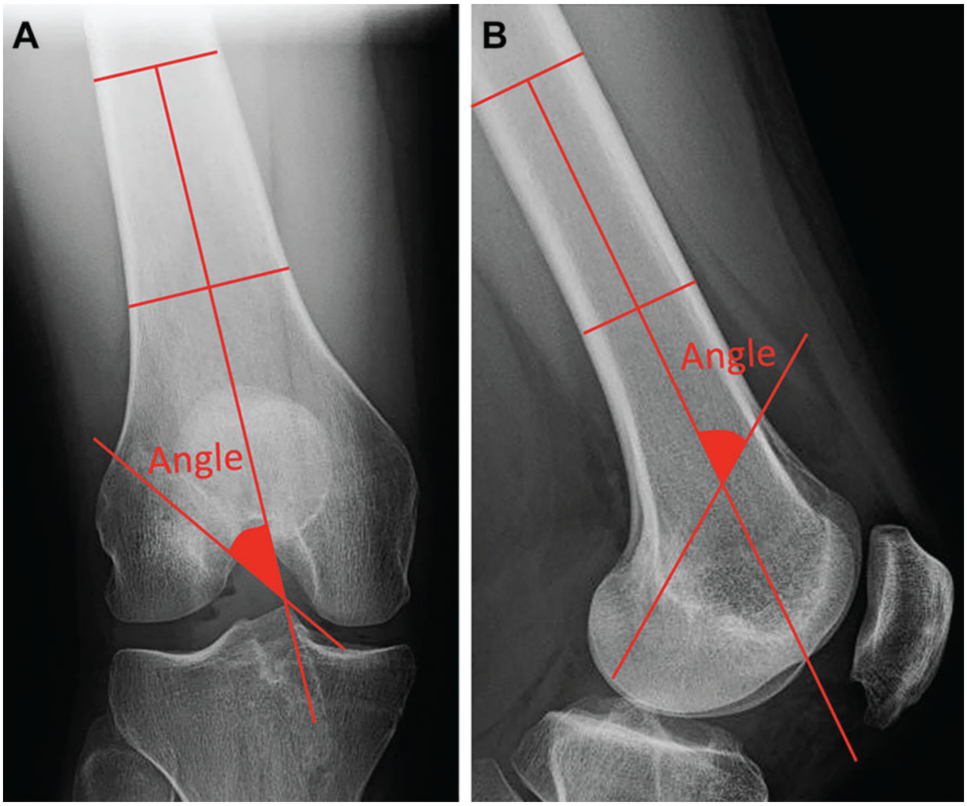

Figure 3. Measurement of femoral tunnel position on (A) the frontal or coronal plane on anteroposterior radiographs and (B) the sagittal plane on lateral radiographs of the knee.

TABLE 4
Femoral Tunnel Aperture Morphology[a]

Study	Reamer System	Height, mm	Width, mm	Ratio	Area, mm^2
Kosy et al[20]	Flexible	10.1 ± 1.0	12.4 ± 1.9	(W:H) 1.2 ± 0.2	—
	Rigid	10.4 ± 1.4	12.8 ± 2.5	(W:H) 1.2 ± 0.2	—
Kim et al[16]	Flexible - AM	—	—	(H:W) 1.18 ± 0.12[b]	—
	Flexible - PL	—	—	(H:W) 1.18 ± 0.10[b]	—
	Rigid - AM	—	—	(H:W) 1.35 ± 0.16	—
	Rigid - PL	—	—	(H:W) 1.32 ± 0.23	—
Larson et al[21]	Flexible	9.42	9.25	—	68.74
	Rigid	11.19	8.58	—	75.90
Forsythe et al[9]	Flexible - 90°	—	—	—	63 (51.9-74.2)
	Flexible - 110°	—	—	—	54.2 (47.4-61.1)
	Flexible - 125°	—	—	—	48.9 (40.8-57.1)
	Flexible - max	—	—	—	47.9 (43.2-52.6)
	Rigid - 90°	—	—	—	60.7 (43.9-77.5)
	Rigid - 110°	—	—	—	70.6 (33.9-107.2)
	Rigid - 125°	—	—	—	50.8 (38.6-62.9)
	Rigid - max	—	—	—	48.9 (43.7-54.0)

[a]Data are reported as mean ± SD or mean (range). Single decimal values refer to the results listed in the respective papers for each measurement (when included a decimal value indicates a fraction of a degree, based on what was reported in the respective papers). When SD was not reported by the respective paper, this value was not included. AM, anteromedial; H, height; max, maximum; PL, posterolateral; W, width.

[b]Statistical significance between flexible and rigid reamer groups.

tunnel aperture location despite the technical differences that exist between their use. Restoration of the native ACL footprint and anatomic tunnel placement has become the gold standard, as this has been shown to result in improved

TABLE 5
Reported Femoral Tunnel Length[a]

Study (Imaging)	Reamer System	Knee Flexion, deg	Femoral Tunnel Length, mm
Yoon et al[36] (3-D CT)	Flexible	95-100	32.8 ± 4.5
Kosy et al[20] (3-D CT)	Flexible	100	37.8 ± 3.7[b]
	Rigid	>120	35.0 ± 4.4
Wein et al[35] (XR)	Flexible	90	41.1 ± 3.6[b]
	Rigid	120	33.6 ± 2.9
Forsythe et al[9] (3-D CT)	Flexible	90	25.0 ± 8.4[b]
	Rigid	90	12.0 ± 4.5
	Flexible	110	31.0 ± 4.0[b]
	Rigid	110	28.6 ± 3.6
	Flexible	125	33.8 ± 3.5[b]
	Rigid	125	31.1 ± 4.1
	Flexible	Max (135-140)	35.0 ± 0.9[b]
	Rigid	Max (135-140)	35.5 ± 1.2
Kadija et al[15] (XR)	Flexible	100-110	41 ± 3[b]
	Rigid	Max	32 ± 5
Kim et al[16] (3-D CT)	Flexible - AM	110	35.8 ± 6.4[b]
	Flexible - PL	110	35.8 ± 3.9
	Rigid - AM	Max	31.4 ± 3.1
	Rigid - PL	Max	34.1 ± 4.3
Dave et al[5] (cadaveric)	Flexible	90	38.3 ± 5.4
	Rigid	90	34.4 ± 4.7
	Flexible	120	39.9 ± 5.3
	Rigid	120	39.3 ± 5.1
Larson et al[21] (cadaveric)	Flexible	110	28.92
	Rigid	110	37.73
Silver et al[30] (cadaveric)	Flexible	120	43.5[b]
	Rigid	120	37.1
Steiner and Smart[33] (cadaveric)	Flexible	110	42.0 ± 7.2[b]
	Rigid	110	32.5 ± 7.1

[a]Data are reported as mean ± SD. Single decimal values refer to the results listed in the respective papers for each measurement (when included a decimal value indicates a fraction of a degree, based on what was reported in the respective papers). When SD was not reported by the respective paper, this value was not included. 3-D, 3-dimensional; AM, anteromedial; CT, computed tomography; Max, maximum; PL, posterolateral; XR, radiograph.

[b]Statistical significance between flexible and rigid reamer groups.

knee kinematics; range of motion; and theoretically, decreased graft failure.[11,12,19,32,37] The focus on creating an anatomic reconstruction has led to a decrease in the performance of TT ACLR in favor of independent femoral tunnel techniques, as TT reconstruction has been shown to result in less anatomic femoral tunnels, a more vertically oriented graft, and poorer rotational stability.[12] Despite

TABLE 6
Reported Posterior Wall Breakage

Study	Reamer System	Posterior Wall Breakage, %
Yoon et al[36]	Flexible	6.6
Kosy et al[20]	Flexible	4
	Rigid	4
Kadija et al[15]	Flexible	0
	Rigid	0
Kim et al[16]	Flexible	14.8
	Rigid	14.8
Forsythe et al[9]	Flexible - 90°	16.6
	Flexible - 110°	0
	Rigid - 90°	33.3
	Rigid - 110°	50

these purported advantages, conflicting evidence exists in the literature to determine whether anatomic ACLR improves clinical outcomes. A prospective comparative study of the Danish Knee Ligament Reconstruction Registry including 1945 AM and 6430 TT primary ACL procedures demonstrated a greater risk of revision ACL surgery in the AM cohort.[25] Similar results were reported by Desai et al[6] using the Swedish National Knee Ligament Register. It is possible that the difference in graft bending angle and increased femoral tunnel widening seen in the study by Tashiro et al[34] are indicative of increased stress that could contribute to these clinical findings. The findings of Tashiro et al of a more acute femoral graft bending angle with the use of AM-FR is, however, contradicted by the findings of Kim et al.[16] Further large prospective and randomized study is needed to better understand the implication of these techniques on clinical outcome.

This systematic review also found that AM-FR resulted in longer femoral tunnels compared with when AM-RR was used for tunnel creation. Adequate tunnel length is important for femoral-sided graft fixation and healing, particularly with the use of suspensory devices. Tunnel length determines how much tunnel area remains for graft-to-bone healing after accounting for the length of the suspensory device.[30] Although the minimal length of graft in a tunnel needed for healing has not been determined, a length of 25 mm and 35 mm has been suggested for interference screw and suspensory-type fixation, respectively.[2] While AM-RR allows for adequate femoral tunnel length to be created when knee hyperflexion is able to be obtained, the study by Forsythe et al[9] highlights the risk of inadequate tunnel length with the use of AM-RR in patients in whom hyperflexion is unable to be achieved. This theoretical risk of inadequate tunnel length bears the potential for clinical relevance, especially when deep flexion is unable to be achieved because of a patient's body habitus, musculature, or intrinsic flexibility. While this suggests a potential technical advantage with the use of AM-FR, a previous study by Guglielmetti et al[10] did not observe a difference in rerupture rates between patients with <1.5 cm versus >2.5 cm of graft within the femoral tunnel. The theoretical risk of insufficient tunnel size has also not been investigated in clinical studies comparing AM-FR and AM-RR to

TABLE 7
Femoral Tunnel Exit Point and Distance to Critical Posterolateral Knee Structures[a]

Study	Reamer System	Exit Point Relative to Lateral Condyle			Distance From Exit Point		
		Anterior	Superior	Medial	Distal Femur	Posterior Wall	LCL
Kosy et al[20]	Flexible	14.1 ± 5.7[b]	20.6 ± 3.9	—	—	—	—
	Rigid	10.4 ± 5.6	19.8 ± 4.4	—	—	—	—
Tashiro et al[34c]	Flexible Rigid	Flexible significantly more anterior	No difference	Rigid significantly more medial	—	—	—
Larson et al[21]	Flexible	—	—	—	36.96	4.37	—
	Rigid	—	—	—	45.94	6.15	—
Steiner and Smart[33]	Flexible	Flexible more anterior	—	—	45.8 ± 6.9	15.0 ± 7.9[b]	25.0 ± 6.2
	Rigid		—	—	49.7 ± 5.5	3.5 ± 4.2	24.7 ± 6.6
Silver et al[30]	Flexible	—	—	—	—	—	26.1[b]
	Rigid	—	—	—	—	—	13.4
Dave et al[5]	Flexible - 90°	—	—	—	—	12.6 ± 3.3[b]	—
	Flexible - 120°	—	—	—	—	19.0 ± 5.3[b]	—
	Rigid - 90°	—	—	—	—	5.0 ± 3.3	—
	Rigid - 120°	—	—	—	—	12.9 ± 4.5	—
Forsythe et al[9]	Flexible - 90°	—	—	—	—	0.9 ± 2.3[b]	—
	Flexible - 110°	—	—	—	—	2.3 ± 2.4[b]	—
	Flexible - 125°	—	—	—	—	4.4 ± 1.5	—
	Flexible - max	—	—	—	—	6.7 ± 0.5	—
	Rigid - 90°	—	—	—	—	–0.6 ± 1.6	—
	Rigid - 110°	—	—	—	—	–0.1 ± 2.2	—
	Rigid - 125°	—	—	—	—	3.9 ± 1.9	—
	Rigid - max	—	—	—	—	8.3 ± 2.1	—

[a]Data are reported as mean ± SD. Single decimal values refer to the results listed in the respective papers for each measurement (when included a decimal value indicates a fraction of a degree, based on what was reported in the respective papers). When SD was not reported by the respective paper, this value was not included. Dashes indicate that this information is not evaluated in the respective studies.LCL, lateral collateral ligament; max, maximum.
[b]Statistical significance between flexible and rigid reamer groups.
[c]Tashiro et al[34] did not report mean values, so a descriptor of the results has been used.

determine the clinical importance of these suggested differences.

The allowance for consistently longer femoral tunnel length and increased anteversion is possibly related to why 1 included study observed a decreased incidence of posterior wall breakage with the use of AM-FR.[9] Posterior wall breakage can lead to loss of graft fixation and early failure and is considered one of the disadvantages of independent femoral tunnel creation during ACLR because of the drilling angle provided relative to the shape of the distal femur.[22] Although the exact incidence of posterior wall breakage is unknown, it ranged from 0% to 16.6% within the studies included in this review and, in some limited reports, has even been as high as 23.8% to 33.3%.[17,24] Resultant posterior wall breakage during femoral tunnel creation was reported by 5 studies[9,15,16,20,36] in this review, with only 1 study[9] showing a difference between techniques. Although this review observed a small potential for increased risk of posterior wall breakage with the use of AM-RR, especially in lesser degrees of knee flexion, further study should be undertaken with a larger cohort of patients in order to better characterize this risk.

Limitations

Since AM-FR and AM-RR have historically not been subdivided when comparing different methods for femoral tunnel creation, relatively few studies exist in the literature that directly compare outcomes of their use. Additionally, many of the studies directly comparing the use of AM-FR and AM-RR have contained a low level of evidence and differed in the radiographic modality used for assessment. Specifically, several included studies[15,23,33,35] utilized radiographs for evaluation of tunnel positioning and measurement, which may be less accurate than other modalities of advanced imaging (see Table 1). Therefore, further study is required to more clearly define the anatomic or radiologic differences that result from the use of these 2 methods. Finally, this systematic review of the literature did not identify any studies that reported measures of functional outcome, rerupture rates, and rates of revision surgery. Further examination is needed to understand the clinical implications of these techniques. For example, there was a statistical difference reported in the distance of tunnels from PL knee structures between the use of AM-FR and AM-RR, although this is less likely to represent any significant clinical difference. Kosy et al[20] performed a randomized controlled trial comparing the use of AM-FR and AM-RR and suggested that the radiologic differences they found were likely not clinically important. However, the radiologic differences observed in their study were much smaller than those seen in other studies, and the authors made no direct comparison of resultant knee stability, functional performance, risk of graft rupture, and need for revision surgery. A study directly comparing these outcomes with regard to the use of AM-FR and AM-RR would appear to be novel in the literature and would be of high clinical importance.

Other limitations from this systematic review are primarily related to individual study methodology and technical differences. Included studies utilized different imaging modalities to make measurements, and the potential for poor interrater reliability among studies exists. Comparing various measurements from studies with small sample sizes to those with larger sample sizes may also not have been equivocal, as the presence of an outlier can skew measurements of central distribution. Other studies, such as the one by Jamsher et al,[14] that only had 1 surgeon using either AM-FR or AM-RR could be subject to operator bias. Additionally, there existed the possibility for numerous technical differences among studies, including what degree of knee flexion was present during tunnel creation. Despite these limitations, this study identified several radiologic and anatomic differences in outcome between the use of AM-FR and AM-RR for femoral tunnel creation during ACLR that suggest a need for future clinical study to evaluate whether these differences manifest in clinically important differences for patients.

CONCLUSION

Although no clinical studies exist comparing AM-FR and AM-RR for femoral tunnel creation during ACLR, both systems allow for reproducible positioning of an anatomic femoral tunnel aperture. The use of AM-FR results in longer and more anteverted femoral tunnels than the use of AM-RR, with exit points on the lateral femur that are different but safe. Surgeons should be aware of the technical differences with each method; however, further study is needed to identify any clinically important difference that results.

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