Published in final edited form as:

J ISAKOS. 2018 May ; 3(3): .

No Difference between Extraction Drilling and Serial Dilation for Tibial Tunnel Preparation in Anterior Cruciate Ligament Reconstruction: A Systematic Review.

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Abstract

Importance: This review highlights a lack of consensus and need for further study regarding optimal tibial tunnel preparation method in anterior cruciate ligament reconstruction (ACLR).

Objective: This review examines existing clinical and biomechanical outcomes of both extraction drilling (ED) and serial dilation (SD) as a technique for tibial tunnel preparation in ACLR.

Evidence Review: In accordance with PRISMA guidelines, three electronic databases (MEDLINE, EMBASE, and PubMed) were searched and systematically screened in duplicate from database inception to September 6, 2017 for English-language, human studies, of all levels of evidence that examined ED and/or SD for tibial tunnel preparation in ACLR. Data including patient demographics, tibial tunnel preparation techniques, biomechanical and clinical outcomes and complications were retrieved from eligible studies.

Findings: ED was used in 71 patients, who were mean age 29.9 years (range: 17–50), 68% male, and followed for mean 16.5 months (range: 3.8–46). SD was used in 70 patients (70 knees), who were mean age 29.3 years (range: 18–50), 69% male, and followed for mean 14.1 months (range: 3.8–46). There were no statistically significant differences (mean preoperative; mean postoperative) for either tibial preparation technique for Lysholm (50.1; 92.5), Tegner (3.5; 6.1), International Knee Documentation Committee (IKDC) (48.8; 92.7), and Lachman or laxity scores. However, ED demonstrated statistically significant increased postoperative tibial tunnel expansion (1.8 mm versus 1.4 mm) and (at 12 weeks) graft migration at the tibial fixation site (1.3 mm versus 0.8 mm). Across biomechanical studies, there were no statistically significant differences (ED; SD) with forces required to initiate graft slippage (156 N; 174 N), graft stiffness (187 N; 186.5 N), and screw torque (1.6 N/m; 1.8 N/m). ED demonstrated a lower mean load to failure for the graft construct (433 N versus 631 N; $p < 0.05$).

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Competing Interests: The authors have no competing interests or conflicts of interest to disclose regarding this manuscript.

Conclusions and Relevance: Though biomechanical data demonstrated lower mean load to failure for the graft using ED, clinical data suggest increased tibial tunnel expansion and post-operative graft migration at the tibial fixation site. Future studies with long-term follow-up data are required to ascertain the optimal technique for graft incorporation and postoperative success.

Level of Evidence: IV: Systematic Review of Level I-IV studies.

INTRODUCTION

Used primarily to correct knee instability manifesting as anteroposterior translation and/or rotatory subluxation, anterior cruciate ligament reconstruction (ACLR) has demonstrated much success in terms of restoring knee function, stability, and return to sport (1–3). Despite this efficacy, there are ongoing efforts to minimize the reported failure/revision/re-rupture rates of between 36.9 to 60.9 cases in 100,000 a year by focusing on such surgical areas of controversy as: ideal graft types (autograft vs allograft); graft sources (hamstring tendon, bone-patellar-tendon-bone, and synthetic grafts); graft fixation; graft tensioning; and portal use for femoral tunnel location/preparation, to name a few (4,5).

In fact, according to a recent comprehensive summary of the systematic reviews on the ACL, it would appear that anatomic femoral tunnel placement is critical to successful ACL outcomes, with a lesser influence to other technical aspects such as number of bundles, and/or remnant preservation (6). However, one area of focus that was not reported in this summary, and that continues to elude surgeons, remains in determining not only the ideal location for, but also the ideal preparation method of the tibial tunnel. While it is known that improper tibial tunnel location may lead to roof impingement and flexion contractures, there is a paucity of data on the ideal method of preparing the tibial tunnel to mitigate pathologic post-operative tunnel widening (7,8). Extraction drilling (ED) or serial dilation (SD) represent the two most common techniques for tibial tunnel preparation to enhance graft incorporation (9). For a given target tunnel diameter, ED will prepare the tunnel using a drill of the desired diameter as a one-step approach, whereas SD, also known as bone tunnel impaction (10), will initially employ a drill of smaller diameter, and sequentially use dilators of incrementally increasing diameter in a step-wise approach to widen and compact the existing tibial bone to the desired tunnel size. In this fashion, SD aims to compact the cancellous bone to create a stronger anchorage of the graft-fixation-device complex within the tibial tunnel, and potentially avoid the extraction drilling pitfalls of rough tunnel walls and fragmented trabeculae that can theoretically compromise graft strength and functionality (11). These fragmented trabeculae as well as pieces of cartilage damaged in ED can possibly ossify within the knee joint and limit post-operative mobility (9). It is expected that SD of the tunnel also improves graft fixation by stimulating osteoid production by producing micro-fractures along the length of the tunnel, increasing graft pullout strength, and improving the support of interference screws by increasing cancellous bone strength (9). Dilation of the tunnel is also preferred to ED when performing revision ACLR procedures and when operating on patients with soft cancellous tibiae, as commonly occurs in older patients (9). ED does however provide an intraoperative advantage over SD in expediting surgical procedure time through a one-step approach. The reduction of surgical time can possibly result in faster post-operative recovery from anesthesia and reduce complications

regarding prolonged surgery (9). While both techniques are widely used, a surgical consensus on the ideal tibial tunnel preparation technique is nonexistent.

The purpose of this systematic review was to analyze all available clinical and human biomechanical literature regarding SD and ED in the preparation of the tibial tunnel in ACLR and to ascertain how these two techniques differ, if at all, across a variety of parameters defining postoperative success.

METHODS

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used in the design of this study (12).

Search strategy:

Three online databases (PubMed, Medline, and Embase) were searched for literature comparing ED with SD drilling techniques for preparing the tibial tunnel in ACLR. The databases were searched on September 6, 2017 and all search results from database inception to the date of the search were included. After removal of duplicates, 709 total papers were identified.

Study screening:

The research question and eligibility criteria were established prior to searching the literature databases. Screening of studies was defined by pre-determined criteria including English-language, human studies of all levels of evidence that examined ED and/or SD techniques for tibial tunnel preparation in ACLR. Biomechanical cadaver studies were included for a more comprehensive understanding of the pertinent research question.

Two reviewers (RC, DD) independently screened the titles, abstracts, and full texts of the retrieved studies in duplicate. At the title and abstract screening stage, any discrepancies in inclusion/exclusion were carried to the next round of screening to ensure thoroughness. Any discrepancies that existed at the full text stage were discussed between reviewers to resolve the discrepancy. References of each included study were screened to capture any articles that may have been missed during the original database search queries (Figure 1).

Quality assessment of included studies:

A quality assessment of the included clinical studies was performed using the Methodological Index for Non-Randomized Studies (MINORS) criteria. Each of the 12 items in the MINORS criteria are scored between 0–2 with maximum scores of 12 and 24 for noncomparative and comparative studies (13). An additional quality assessment of the biomechanical cadaveric studies was performed using the Anatomical Quality Assessment (AQUA) tool. This tool assesses the risk of bias in anatomical studies regarding the characteristics of included subjects, study design, characterization of methods, descriptive anatomy, and the reporting of results. Each category is graded on a risk of bias as low, high, or unclear (14).

Data abstraction:

Relevant clinical and biomechanical data were abstracted from eligible studies including demographic information of included clinical and biomechanical studies. Clinical data abstracted included Lysholm score, IKDC score, Tegner score, Lachman score, tibial tunnel expansion, and graft migration. Biomechanical data abstracted included force to initiate graft slippage, screw torque, load to failure force, and graft stiffness.

Statistical analysis:

An unweighted kappa (k) was calculated at each stage of screening for evaluating the level of agreement between reviewers (RC, DD). Level of agreement was categorized prior to the beginning of the literature search by the following k-score criteria: a k score >0.61 indicated substantial agreement, 0.21 to 0.60 indicated moderate agreement, and those <0.20 indicated slight agreement (15). Results documented across multiple studies were averaged and reported as mean in this review.

RESULTS**Study characteristics and quality:**

The initial literature search yielded 709 studies of which 8 satisfied inclusion criteria. The included studies were separated into two categories: clinical human data (4 studies) and biomechanical cadaver data (4 studies). There was a substantial level of agreement between reviewers at title (k= 0.8795; 95% CI: 0.7617 to 0.9973), abstract (k=0.9; 95% CI: 0.709 to 1), and full-text screening stages (k= 1; 95% CI: 1 to 1). The included clinical studies had a MINORS score of 16.3 +/- 1.7 out of a possible 24, indicating moderate quality clinical studies.

Studies regarding clinical human data included a total of 141 patients with 141 knees. The treatment groups in this category included those patients who underwent ACLR using ED for preparation of the tibial tunnel (71 patients, 71 knees) and those patients who underwent SD (70 patients, 70 knees). The mean ages of patients were 29.9 years (range: 17–50) for ED and 29.3 years (range: 18.50) for SD. Of those patients treated across the studies, 68% were male in the ED group and 69% were male in the SD group. The mean follow-up time for patients was 16.5 months (range: 3.8–46 months) for ED and 14.1 months (range: 3.8–46 months) for SD. (Table 1).

Studies pertaining to biomechanical cadaver data included a total of 64 cadavers with 128 knees. The treatment groups in this category included cadaver knees that underwent ED or SD in preparation of the tibial tunnel. In total, 128 knees were used for ED and 128 knees were used for SD. The included cadaveric studies were assessed using the AQUA tool and the level of bias for each of the following categories was ranked as low (L), high (H), or unclear (U) for each study: objective and subject characteristics, study design, methodology characterization, descriptive anatomy, and the reporting of results (Cain et. al, L, L, L, L, L; Nurmi et. al 2003, L, L, L, L, L; Nurmi et. al 2004, L, L, L, L, L; Rittmeister et. al, L, L, L, H, L). Overall risk for experimental bias was low across included studies. The mean age of cadavers was 44.1 (range: 17–54) and 76% were male (Table 2).

Patient outcomes:

Clinical measures of Lysholm score, Tegner score, International Knee Documentation Committee (IKDC) score, and Lachmann scores were included three of the four eligible clinical studies. Of the documented measures of knee function and stability there was no statistically significant differences experienced for either tibial tunnel preparation regarding Lysholm, Tegner, IKDC, and Lachmann scores. Differences in Lysholm scores reported in two studies were not statistically significant both preoperatively (ED: 51.9; SD: 50.1) and postoperatively (ED: 91.7; SD: 93.4). There were no statistically significant differences in Tegner scores reported in one of the studies both preoperatively (ED: 3.5; SD: 3.5) and postoperatively (ED: 6.0; SD: 6.13)(10). Two studies reported no statistically significant differences in IKDC scores preoperatively (ED: 48.6; SD: 49.1) and postoperatively (ED: 92.5; SD: 92.9)(10,16). Overall, no statistically significant differences in knee function assays were observed across the clinical studies reviewed. However, there was one study that observed a statistically significant difference between SD and ED when measuring tibial tunnel expansion and the migration of the graft at the tibial fixation site using radiostereometric analysis (RSA) of ACL graft markers in an anterior stress position (17). Serial dilation reduces postoperative tibial tunnel expansion compared to ED. Two studies reported a statistically significant difference in average tibial tunnel width expansion of 1.4 mm from the initial tunnel width in SD and in ED an average tunnel expansion of 1.8 mm from the initial tunnel width ($p < 0.05$)(10,16,18)(Table 3). Regarding ED preparation, there were no reported instances of loose bone/cartilage debris from either tunnel preparation technique that ossified post-operatively or caused post-operative clinical effects.

Biomechanical outcomes:

Biomechanical measures of the forces required to initiate graft slippage, graft stiffness, screw torque, and the mean load to failure for graft construct were included from eligible studies. (Table 4). There were no differences observed between ED and SD concerning the forces required to initiate graft slippage, graft stiffness, and screw torque. In one study, there was difference in the force to initiate graft slippage in ED at 156 N compared to SD at 174 N (19). Two studies measured no differences in graft stiffness at 186.5 N for ED and 187 N in SD tunnel preparations (20,21). There was no difference in screw torque for ED at 1.8 N/m compared to SD at 1.6 N/m in two studies (19,21). However, one of the four studies reported a statistically significant measurement of force to initiate graft failure at the origin of graft fixation between the ED and SD groups (ED: 433 N; SD 631 N; $p < 0.05$)(Table 4)(22).

DISCUSSION

Based on the clinical and biomechanical data present in this review, it is apparent that SD may result in statistically significant reductions in post-operative tibial tunnel expansion and migration of the graft at the tibial fixation site. However, data concerning the migration of the graft at the tibial fixation site needs to be interpreted with caution given the low numbers and potential limitations with the radiostereometric analysis (RSA) used to measure this (23). The results of this study are limited as the investigators excluded any radiographic markers at the tibial fixation site that became loose from the graft and therefore were only left with one or two tibia markers in each patient for final analysis (17). This decrease in the

number of radiographic markers is a concern as the reduced number of markers can create artificial variation in results due to measurement error and exclusion bias of any markers considered loose. In addition, it is also possible that the values reported are negligible in clinical significance due to only one of the four follow-up measurements reporting significant differences in migration between SD and ED as well as the use of RSA measurement techniques.

To understand if the graft migration reported is real or if it is an artifact of poorly positioned radiographic markers, future studies using clearly defined radiographic markers and standardized metrics are essential for observational integrity. A suggested preferential assessment of graft migration could be achieved by using a stationary radiographic pin of standard length positioned parallel to the tibial tunnel and comparing graft marker migration in the tibial tunnel relative to this pin. As implemented in a separate study observing graft migration in the femoral tunnel, this process will allow for a standardized measurement of graft markers relative to the pin rather than the method in the study reviewed where investigators implemented femoral and tibial bone markers that are variably positioned between patients (24).

While biomechanical results suggest SD to be a preferred technique to ED, the absence of clinical differences in knee-stability and function tests as well as failure to report return to sports and surgical revision rates between the two techniques suggest that these differences require higher powered studies and possibly registry data to ascertain its significance. None of the proposed advantages of SD over ED, such as stimulation of osteoid production in the tunnel, increased graft pullout strength, and improved support of interference screws, were addressed or reported in any of the studies reviewed (9). The lack of clinical evidence to support these proposed advantages of SD suggest that they might be theoretical and will require further clinical study to be validated in clinical practice.

Absence of statistical difference continues from human clinical and biomechanical cadaveric data into animal models comparing ED and SD. Results from porcine tibiae models of ED and SD demonstrate that the two techniques do not result in statistically significant differences regarding fixation strength of the grafts (25–27). These results from porcine tibiae models differ from the biomechanical results, suggesting that SD performs better than ED by increasing the overall force required to initiate graft failure. However, in both the biomechanical cadaver and porcine tibiae data, these experiments are performed under controlled settings and not in living patients. The differences observed between the biomechanical results and animal results might stem from differences in bone composition and individual experimental setup that differs between the porcine tibiae and human cadaver tibiae experiments.

Using a broad search strategy, this review allowed for a thorough screen and review of the available literature. In addition, review of articles performed in duplicate at the title, abstract, and full text screening stages minimized reviewer bias. The results abstracted and consolidated within this review serve as foundational basis for future clinical and biomechanical studies interested in investigating tibial tunnel preparation technique.

It is noteworthy that while there are limited comparative studies comparing tibial tunnel preparation technique, there are multiple studies comparing ED against SD in femoral tunnel preparation as well as those studies concerned with downstream consequences of tibial tunnel preparation (28–31). While the concept of ED against SD is not foreign to clinicians' understanding of the femoral tunnel preparation, it is apparent that the body of literature regarding the preparation of the tibial tunnel is lacking. It is important to note that SD of the femoral tunnel has been shown to be potentially advantageous in comparison to ED by reducing intraoperative complications and compacting cancellous bone resulting in a stronger graft fit (28). However, the tibia and femur differ in bone composition and strength and might respond differently to ED and SD (32). In addition, the outcomes following ACL reconstruction are multifactorial in etiology and the relative contribution of the tunnel preparation in both the femur and tibia are unknown. An inherent strength of this review is that it highlights the lack of substantial literature and data regarding the preparation of the tibial tunnel as well as the need for further inquiry into the role of tibial tunnel preparation in ACLR.

This review is limited by the small amount of human and biomechanical cadaver studies in the English language that were available for review after the systematic screening. It is possible that the statistically significant differences measured in the studies in tenths of a millimeter might be due to measurement error and will need to be addressed in future studies. In addition, a fundamental limitation of the available studies was the failure to report important and relevant post-surgical information such as rates of return to sport, rates of return to sport at preinjury levels, rate of graft rupture or failure, and rate of revision. While the data abstracted reference clinical measures of knee stability and biomechanical measures of graft migration at tibial fixation site and tunnel widening, the included studies for review failed to mention relevant measures of surgical success. An additional limitation is that half of the reviewed literature was from biomechanical cadaver studies. These studies using harvested, non-living donor tibiae do not accurately reflect biomechanical conditions in a living individual.

These limitations highlight the need for additional biomechanical studies, correlated with large clinical outcomes registry data to ascertain the influence of tibial tunnel preparation in primary ACLR. It would be of great value to investigate how the tunnel preparation techniques differ in post-operative integration and healing of the ACL graft, how these two techniques affect revision rates, and if the claims regarding the advantages of SD are valid for improving patient outcomes.

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What is already known:

- Tibial tunnel preparation, either via an extraction drilling or serial dilation technique, constitutes a key component of graft fixation and eventual success after anterior cruciate ligament reconstruction.
- While both drilling techniques are commonly performed, there is no surgical consensus based in clinical evidence for the promotion of either technique in clinical practice.

What are the new findings:

- Clinical data suggests that extraction drilling causes increased tibial tunnel expansion and post-operative graft migration at tibial fixation site compared to serial dilation.
- Biomechanical data in cadaver models demonstrates that tibial tunnel preparation using serial dilation increases the mean load to failure for the graft construct in comparison to extraction drilling.
- While most literature concerning optimal ACL reconstruction focuses on femoral tunnel location, drilling, and preparation technique, this review highlights the gap in clinical understanding of the role of tibial tunnel preparation and a need for future study and increased attention regarding this topic.

Figure 1.

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram demonstrating the process for systematic review of the literature for comparing tibial tunnel preparation drilling techniques in anterior cruciate ligament reconstruction (ACLR).

Table 1

Characteristics of included studies: clinical

Study	LOE	Design	N	Age	% Male	F/U	% F/U
			SD; ED	(mean years)			
Gokce <i>et al</i> ⁶	3	Retrospective comparative study	SD: 21 ED: 23	SD: 23.4 (19–36) ED: 25.3 (17–38)	SD: 90% male ED: 87% male	SD: 30.7 months (26–34) ED: 39.4 months (35–46)	100%
Siebold <i>et al</i> ⁸	4	Matched pair analysis	SD: 13 ED: 13	SD: 33.1 (18–45) ED: 30.9 (17–44)	SD: 69% male ED: 77% Male	4.1 months (3.8–5)	N/A
Sørensen <i>et al</i> ⁷	1	Randomised trial	SD: 20 ED: 20	SD: 32 (20–47) ED: 30 (20–50)	SD: 55% ED: 55%	Four dates: 7–10 days 6 weeks 12 weeks 24 weeks	7–10 days: SD=90% ED=100% 6 weeks: SD=70% ED=85% 12 weeks: SD=85% ED=85% 24 weeks: SD=40% ED=55%
Xu <i>et al</i> ¹⁰	1	Randomised trial	SD: 16 ED: 15	SD: 30.5 (19–50) ED: 31.4 (18–49)	SD: 62.5% male ED: 53% male	SD: 16.2 months (11–32) ED: 16.8 months (10–30)	100%

LOE, level of evidence; F/U, follow up; ED, extraction drilling; SD, serial dilation.

Table 2

Characteristics of included studies: biomechanical human cadaver

Study	N	Mean (age range)	% Male	ACL graft source
	SD; ED			
Cain <i>et al</i> ²²	7 cadavers: SD: seven tibiae ED: seven tibiae	mean 42 range 29–47	71	Semitendinosus and gracilis hamstring tendons
Nurmi <i>et al</i> ²⁰	22 cadavers: SD: 22 tibiae ED: 22 tibiae	mean 41 range 17–54	68	Semitendinosus and gracilis hamstring tendons
Nurmi <i>et al</i> ²¹	21 cadavers: SD: 21 tibiae ED: 21 tibiae	mean 40 range 17–54	67	Anterior tibialis tendon
Rittmeister <i>et al</i> ⁹	14 cadavers: SD: 14 tibiae ED: 14 tibiae	mean 53.3	100	Semitendinosus and gracilis hamstring tendons

ACL, anterior cruciate ligament; ED, extraction drilling; SD, serial dilation.

Table 3

Outcomes: clinical

Outcome	Study	SD		ED		Significant?	Notes
		Preoperative	Postoperative	Preoperative	Postoperative		
Lysholm	Gokce <i>et al</i> ^{6*}	51 (49–68)	93 (61–100)	58 (36–71)	90 (52–100)	No; (P>0.05)	N/A
	Xu <i>et al</i> ⁰	49.1 ±3.74	93.75±1.77	45.86±3.48	93.4±2.02	No; (P>0.05)	N/A
IKDC	Gokce <i>et al</i> ⁶	13 abnormal, 8 severely abnormal.	6 normal, 11 nearly normal, 4 abnormal.	15 abnormal, 8 severely abnormal	7 normal, 12 nearly normal, 3 abnormal, 1 severely abnormal	No; (P>0.05)	N/A
	Xu <i>et al</i> ⁰	49.1 ±3.74	92.95±2.84	48.58±2.58	92.49±3.52	No; (P>0.05)	N/A
Tegner	Xu <i>et al</i> ⁰	3.5±0.81	6.13±0.62	3.46±0.74	6.0±0.75	No; (P>0.05)	N/A
Lachman	Xu <i>et al</i> ⁰	15 patients normal; 1 patient grade 1	N/A	13 patients normal; 2 patients grade 1	N/A	No; (P>0.05)	N/A
Tibial width increase	Gokce <i>et al</i> ⁶	N/A	Coronal: +1.64mm ±0.06mm; Sagittal: +1.72 mm±0.07 mm	N/A	Coronal: +2.26 mm±0.13 mm; Sagittal: +2.4 mm±0.10 mm	Yes; (P<0.05)	N/A
	Xu <i>et al</i> ⁰	7.88 mm	8.49 mm	7.9 mm	8.99mm	Yes; (P<0.0001)	N/A
	Siebold <i>et al</i> ⁸	8.2mm±0.6mm	10.0mm±1.7mm	8.5mm±0.9mm	10.4mm±1.8mm	No; (P=0.5)	N/A
Graft migration at tibial fixation site	Sørensen <i>et al</i> ⁷	N/A	N/A	N/A	N/A	Yes; (P=0.02)	At 12 weeks after surgery, tibial graft markers inside tibial tunnel migrate 0.5 mm in ED as measured by radiostereometric analysis.

* values are a mean (range).

ED, extraction drilling; IKDC, International Knee Documentation Committee; SD, serial dilation

Table 4

Outcomes: cadaver/biomechanical

Outcome	Study	SD		ED		Significant?	Notes
		Preoperative	Postoperative	Preoperative	Postoperative		
Initiation of graft slippage	Rittmeister <i>et al</i> ¹⁹	N/A	174±112 N	N/A	156±77N	No; (P=0.63)	N/A
Screw torque	Rittmeister <i>et al</i> ¹⁹	N/A	1.9±0.76Nm	N/A	1.5±0.79Nm	No; (P=0.30)	17% higher screw torque in specimens with dilated tibial canals (P=0.30)
Load to failure	Nurmi <i>et al</i> ²¹	N/A	1.7±0.5Nm	N/A	1.6±0.6Nm	No; (P=0.39)	N/A
	Cain <i>et al</i> ²²	N/A	616±263N	N/A	453±197N	Yes; (P=0.0025)	N/A
	Nurmi <i>et al</i> ²⁰	N/A	446±86N	N/A	455±115 N	No; (P=0.33)	N/A
	Nurmi <i>et al</i> ²¹	N/A	473±110N	N/A	480±115 N	No; (P=0.97)	Mode of failure mostly from graft slippage past screw.
	Rittmeister <i>et al</i> ²¹	N/A	360±120N	N/A	345±88N	No; (P=0.74)	4% increase in failure load. (P=0.74)
Graft stiffness	Nurmi <i>et al</i> ²⁰	N/A	191±50N/mm		184±45 N/mm	No; (P=0.76)	N/A
	Nurmi <i>et al</i> ²¹⁷	N/A	182±21 N/mm	N/A	190±23N/mm	No; (P=0.42)	N/A

Postoperative units represent mean±standard deviation.

ED, extraction drilling; SD, serial dilation.