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Duration of canine retraction with fixed appliances: A systematic review and meta-analysis

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Introduction: Space closure is a challenging and time-consuming phase of orthodontic treatment with fixed appliances. This systematic review evaluated canine retraction duration using fixed appliances after maxillary first premolar extraction. **Methods:** Unrestricted systematic literature searches were conducted in 8 databases for randomized clinical trials, assessing the duration and rate of maxillary canine retraction using fixed appliances with or without treatment adjuncts published up to July 2021. Study selection, data extraction, and risk of bias evaluation were conducted independently and in duplicate. Random-effects meta-analyses of average rates or mean differences (MD) and 95% confidence intervals (CI) were conducted at α = 5%, followed by sensitivity and Grading of Recommendations Assessment, Development, and Evaluation analysis. **Results:** Fifty randomized clinical trials (6 parallel and 44 split-mouth designs) covering 811 participants (mean age 19.9 years; 34% male) were included. The estimated average pooled duration to achieve complete canine retraction was 4.98 months (2 trials; 95% CI, −2.9 to 12.88 months). Pooled average canine retraction was 0.97 mm at months 0-1 (23 trials; 95% CI, 0.79-1.16), 1.83 mm at months 0-2 (20 trials; 95% CI, 1.52-2.14), 2.44 mm at months 0-3 (23 trials; 95% CI, 2.10-2.79), 3.49 mm at months 0-4 (6 trials; 95% CI, 1.81-5.17) and 4.25 mm at months 0-5 (2 trials; 95% CI, 0.36-8.14). Surgically-assisted orthodontics was associated with greater canine retraction at all time points: months 0-1 (10 trials; MD, 0.52 mm; P = 0.004), months 0-2 (8 trials; MD, 0.53 mm; P = 0.04), months 0-3 (8 trials; MD, 0.67 mm; P = 0.01), and months 0-4 (3 trials; MD, 1.13 mm; P = 0.01), whereas subgroup analyses indicated significant effects of anchorage reinforcement method and bracket slot size on canine retraction. **Conclusions:** The average time to achieve complete retraction of the maxillary canine using fixed appliances was around 5.0 months. Most studies used split-mouth randomization to investigate canine retraction for around 1-3 months, with substantial heterogeneity across studies. At 3 months of treatment, high-quality evidence supported greater canine retraction with surgically-assisted orthodontics. (Am J Orthod Dentofacial Orthop 2022;■:■-■)

Orthodontic tooth movement represents the fundamental basis of orthodontic treatment and occurs through periodontal remodeling as a response to an external force applied to the tooth[1] through the activity of numerous host and treatment-related factors.[2] Comprehensive orthodontic treatment with fixed appliances is lengthy, with an average duration of 20-30 months.[3,4] This treatment burden can be associated with adverse clinical effects and reduced patient compliance, and there is interest among orthodontists and patients in methods to reduce treatment duration.[5,6]

In the last few decades, nonsurgical and surgically-assisted adjuncts have been advocated to enhance orthodontic tooth movement and reduce treatment duration. Nonsurgical adjuncts include variation in bracket design and force-delivery systems, low-level laser therapy (LLLT) (or photobiomodulation), vibration, pulsed electromagnetic fields, and low-intensity pulsed ultrasound. Surgically-assisted adjuncts include corticotomy, laser-assisted flapless corticotomy (LAFC), microosteoperforations (MOPs), piezocision, and local injection of

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platelet-rich fibrin or plasma products. However, evidence relating to how effective many of these interventions are in accelerating orthodontic tooth movement and, indeed, in reducing treatment time is generally poor.[6,7] The best available evidence relates to variation in fixed appliance design, which seems to have a minimal effect on treatment duration and efficiency[8-11]; interestingly, consensus regarding optimal force magnitude for orthodontic tooth movement is also lacking.[12]

Comprehensive orthodontic treatment with fixed appliances can be divided into distinct phases, including alignment and leveling, space management (either creation or closure), establishing interarch relationships, and finishing or detailing the occlusion. A previous systematic review reported that an average of 8.8 months (263.0 days) might be needed to complete the first phase of tooth alignment.[13] When orthodontic treatment with fixed appliances includes the extraction of teeth, space closure can represent one of the most challenging phases of treatment[14] and be associated with prolonged treatment duration.[3,15] In some circumstances, orthodontists undertake canine retraction mechanics as an isolated stage of treatment, which can help preserve anchorage during the establishment of interarch relationships. In addition, canine retraction represents a popular experimental model for investigating different variables during orthodontic tooth movement, and data relating to duration and rate of canine retraction is a useful metric when evaluating treatment progress and planning future research in this domain.

Although a recent systematic review investigated canine retraction rate in patients undergoing fixed orthodontic treatment, it did not assess complete duration of canine retraction, which is the most clinically relevant outcome for both patient and orthodontist. Furthermore, studies included in the review used surgical and nonsurgical adjuncts to increase rates of orthodontic tooth movement; however, those using conventional approaches were not included.[16] Therefore, the primary objective of this systematic review was to critically appraise evidence from randomized clinical trials (RCTs) assessing treatment duration to fully retract maxillary canines after maxillary first premolar extraction in adolescent and adult orthodontic patients using fixed appliances. The secondary objective was to evaluate the canine retraction rate measured as the amount of canine tooth movement per unit time and identify associated factors.

MATERIAL AND METHODS

Protocol and registration

The protocol for this review was made a priori and registered in the prospective register of systematic reviews (CRD42020198596). This review is performed and reported according to the Cochrane Handbook (version 6.3)[17] and Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020 statement,[18] respectively.

Eligibility criteria

According to the participants, intervention, comparison, outcome, and study design schema, studies meeting the following eligibility criteria were considered for inclusion: (participants) human participants of any age, sex, ethnicity, or malocclusion in need of maxillary first premolar extraction followed by individual canine retraction as a part of an orthodontic treatment plan with full-arch fixed appliances; (intervention) retraction of maxillary canines using full-arch fixed appliances with or without any treatment adjuncts; (comparison) any comparison involving different surgically-assisted or nonsurgical treatment techniques, appliances, or adjuncts; (outcome) assessing duration and or rate of maxillary canine retraction; and (study) parallel-group or split-mouth (within-patient randomized) RCTs. No limitations concerning language, publication year, or publication status were applied. Excluded were studies involving animals, case reports or series, cross-sectional studies, nonclinical and nonrandomized studies, studies using segmented arch mechanics or en masse retraction, studies including patients with any systematic disease, craniofacial abnormalities, studies without comprehensive orthodontic treatment or eligible outcomes, and studies involving patients who had undergone any previous treatment, multidisciplinary treatment, or growth modification.

The primary outcome of this review was the duration of maxillary canine retraction in months from the start to completion of retraction. The amount of canine retraction relative to the observation time (canine retraction rate) was evaluated as a secondary outcome.

Information sources, search strategy, and study selection

Eight electronic databases (MEDLINE, Embase, Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, Cochrane Database of Abstracts of Reviews of Effects, Scopus, Web of Science, and Latin American and Caribbean Health Sciences Literature) were searched systematically without restrictions for publication date, language or type from inception up to July 09, 2021 (Supplementary Appendix 1). This was supplemented with a search of the Directory of Open Access Journals, Digital Dissertations, metaRegister of Controlled Trials, and Google Scholar.

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The reference or citation lists of eligible articles and existing systematic reviews were manually searched for additional papers.

Study selection, data items, and collection

Two authors (F.W and J.S) independently screened titles, abstracts, and full texts to identify studies that meet the inclusion criteria. All discrepancies were resolved by discussion with a third author (M.T.C). Data extraction was performed independently by 2 authors (F.W and J.S), with similar discrepancy resolution using predefined and piloted forms covering: (1) study characteristics (design, clinical setting, country), (2) patient characteristics (age and sex), (3) malocclusion and treatment characteristics, (4) appliance type, (5) intervention and/or supplemental interventions, (6) follow-up period, and (7) outcome details.

Risk of bias in individual studies

The risk of bias in included trials was assessed according to Cochrane guidelines with the risk of bias 2.0 tool[19] independently by 2 authors (F.W and J.S) with the same mechanism of discrepancy resolution.

Data synthesis and summary measures

An effort was made to maximize data output from included studies, including missing data (Supplementary Appendix 2). Because orthodontic treatment outcome is inevitably affected by patient and treatment-related characteristics, a random-effects model was deemed appropriate to calculate the average distribution of true effects on the basis of clinical and statistical reasoning[20] with a restricted maximum likelihood variance-estimator, the Hartung-Knapp method adjustment for test statistics, and confidence intervals (CIs).[21] Mean differences (MD) for continuous outcomes and their corresponding 95% CIs were calculated as effect sizes. Initially, an indirect analysis of pooled averages was performed to calculate the average retraction duration or rate during treatment with 95% CIs. Then direct meta-analyses were performed comparing trial arms with different retraction methods or treatment adjuncts within each study and pooling the MDs across studies.

Between-study heterogeneity was assessed by inspecting forest plots and calculating τ^2 and I^2. We considered $I^2 > 75\%$ to represent considerable heterogeneity while also considering the localization of heterogeneity on the forest plot and the certainty around heterogeneity estimates. Ninety-five percent prediction intervals were calculated for meta-analyses of $\geq$3 studies to incorporate and visualize existing heterogeneity while also providing a range of probable effects in a future clinical setting.

Analyses were run in R (version 4.0.4) by 1 author (S.N.P), and the dataset is openly available.[22] All P values were 2-sided ($\alpha = 5\%$, except for heterogeneity tests in which the α value was set as 10%).

Additional analyses, risk of bias across studies, and quality of evidence

Sources of heterogeneity were planned a priori to be sought through mixed-effects subgroup analyses or meta-regressions in meta-analyses of at least 5 studies according to patient age, sex, anchorage type, force magnitude, bracket type, bracket slot size, and methods of canine retraction. Reporting biases (including the possibility of publication bias) were assessed for meta-analyses with $\geq$7 studies with contour-enhanced funnel plots and Egger's test.

The certainty and quality of evidence were rated using the Grades of Recommendations, Assessment, Development, Evaluation (GRADE) framework,[23] and GRADE summary of findings tables[24] were constructed for direct meta-analyses at 3 months of retraction, which was arbitrarily judged to be clinically relevant, as no canine could have been fully retracted yet. Forest plots were augmented with contours denoting the magnitude of observed effects to assess heterogeneity, imprecision, and clinical relevance.

Sensitivity analyses

Robustness of results was checked for meta-analyses of $\geq$3 studies with sensitivity analyses on the basis of (1) RCT design (parallel or split-mouth), (2) precision of studies mainly according to sample size (most precise half and least precise half), and (3) risk of bias (low or some concern or high).

RESULTS

Study selection and characteristics

The electronic literature search yielded 2253 results. After removing duplicates, 915 titles and abstracts were screened, and the full text of 167 publications was checked against eligibility criteria (Supplementary Table I), whereas 6 additional studies were found through hand-searching. Eventually, 50 publications reporting 50 RCTs were included, as depicted in the PRISMA flow diagram (Fig 1).

Out of the 50 included RCTs, 44 were split-mouth, and 6 were of parallel-group design. Included trials were conducted in university clinics (n = 37; 74%), private practice (n = 2; 4%), hospitals (n = 10; 20%), or both private practice and university (n = 1; 2%) and originated from 17 countries, including Australia, Brazil, China, Dominican Republic, Egypt, India, Iran, Japan,

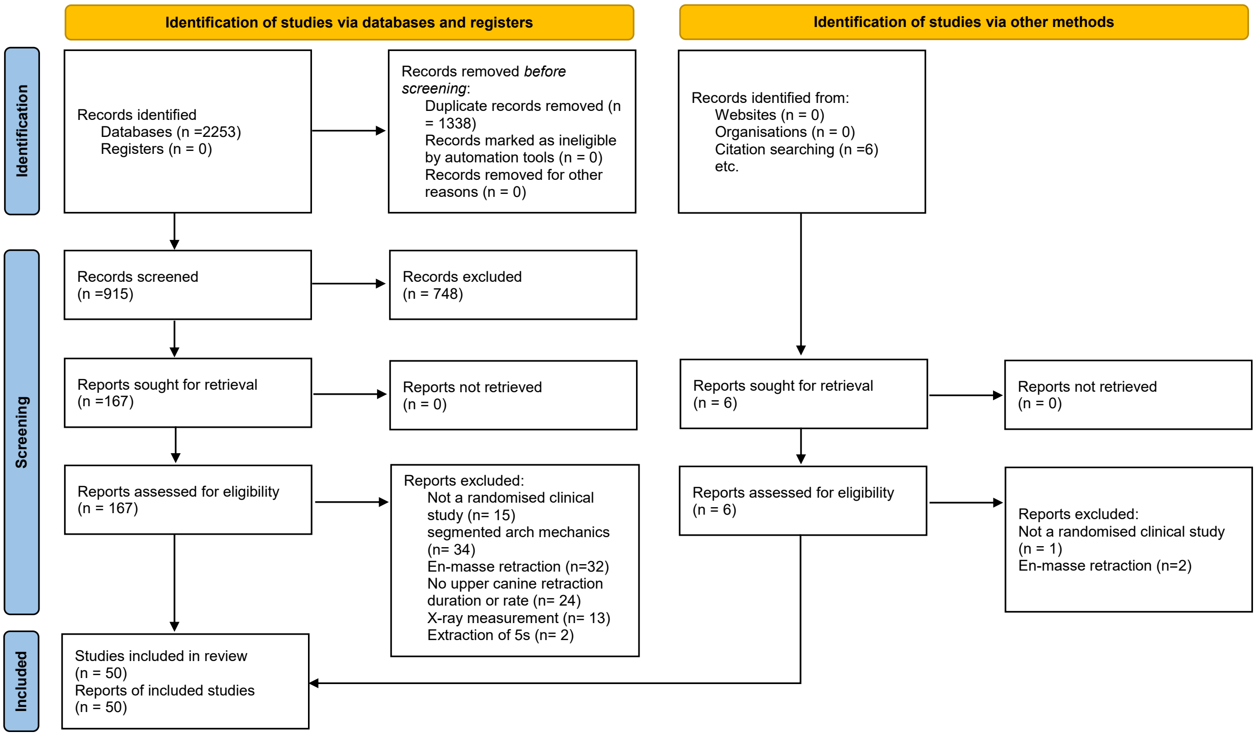

Fig 1. Preferred Reporting Items for Systematic reviews and Meta-Analyses diagram for the identification and selection of studies eligible in this review (reproduced from Page et al.[18] For more information, visit: http://www.prisma-statement.org).

Jordan, Malaysia, Pakistan, Saudi Arabia, Switzerland, Syria, Thailand, Turkey, and the United States. Of the 50 studies included, 48 trials (96%) were single-center, and 2 (4%) were multicenter (Table 1). The 50 trials included 811 participants with a mean age of 19.86 years (reported in 38 trials). Of the 40 studies reporting on patient gender, 561 (66%) participants were female and 283 (34%) were male.

Nineteen trials (38%) did not report malocclusion type, 14 (28%) included Class II Division 1 malocclusion, 3 (6%) included Class I malocclusion, 1 (2%) included Class II malocclusion, 6 (12%) included patients with either Class I or Class II Division 1 malocclusion, 3 (6%) included patients with either Class I or Class II malocclusion, 1 (2%) included patients with either Class II Division 1 malocclusion or crowding, 1 (2%) included patients with either Class II or bimaxillary protrusion, and 2 (4%) included patients with either severe crowding or protrusion requiring first premolars extractions.

Forty-six trials reported the amount of canine tooth movement measured at specific time intervals, and 4 reported the amount of canine tooth movement and duration. Canine retraction duration is measured as the time between the beginning of force application for canine retraction and the completion of full canine retraction. The amount of canine tooth movement was measured at a specific time interval by measuring the distance among several reference points. Canine tooth movement was measured, either from stone models (n = 13), scanned models (n = 19), intraorally (n = 8), intraoral scans (n = 2), on digital photocopies of models (n = 5), both intraorally and on scanned models (n = 2), or both intraorally and from stone models (n = 1). Time points used in this review were 0, 1, 2, 3, 4, and 5 months, and the amount of tooth movement was calculated for the following time intervals 0-1, 0-2, 0-3, 0-4, 0-5, 1-2, 2-3, 3-4, and 4-5 months, if possible.

Canine retraction duration to completion and or amount of canine tooth movement was compared among different interventions, including different retraction methods (n = 1), different bracket types (n = 3), different ligation methods (n = 1) and different orthodontic forces (n = 1). The majority of trials used adjuncts to orthodontic treatment, including surgically-assisted orthodontics (n = 18), vibration (n = 4), LLLT (n = 14), low-intensity pulsed ultrasound (n = 1), both surgically-assisted orthodontics and LLLT (n = 3), both surgically-assisted orthodontics and local

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Table I. Characteristics of included studies

Study	*Design, setting, and country*†	*Patients (M/F), age, y*‡	*Malocclusion, Tx*	*Appliance*	*Intervention, supplemental*	*FU in wk (interval)*	*Outcome*
Abbas et al[58]	RCT (2 PA SMD), Uni, EGY	A: 10 (NR), 15-25 B: 10 (NR), 15-25 (SMD)	Cl II/1, Ex of maxillary 4s	Labial CLB (Roth)	A: Corticotomy B: Piezocision	0-(2)-12	RetractRate
Ahmad et al[25]	RCT (2 PA SMD), Uni, EGY	16 (0/16), 15-20	NR, Ex of maxillary 4s	Labial CLB (NR)	Mucoperiosteal flap, LLLT	0-2-6-14-16-end	RetractRate, RetractDur
Abdelhameed and Refai[59]	RCT (3 PA SMD), Uni, EGY	A: 10 (NR), 15-25 B: 10 (NR), 15-25 C: 10 (NR), 15-25	Cl II or Bimax Prot, Ex of maxillary 4s	Labial CLB (NR)	A: MOPs B: LLLT C: MOPs + LLLT	0-(2)-12	RetractRate
Aboalnaga et al[60]	RCT (SMD), Uni, EGY	18 (F), 20.50	NR, Ex of maxillary 4s	Labial CLB (Roth)	MOPs	0-(4)-16	RetractRate
Aboul-Ela et al[42]	RCT (SMD), Uni, EGY	13 (5/8), 19	Cl II/1, Ex of maxillary 4s	Labial CLB (NR)	Corticotomy	0-(4)-16	RetractRate
Alfawal et al[49]	RCT (2 PA SMD), Uni, SYR	A: 18 (7/11), 18.7 B: 18 (5/13), 17.47	Cl II/1, Ex of maxillary 4s	Labial CLB (MBT)	A: Piezocision B: LAFC	0-(4)-16	RetractRate, RetractDur
Alikhani et al[61]	RCT (2 PA SMD), Uni, USA	A: 10 (5/5), 26.8 B: 10 (3/7), 24.7	Cl II/1, Ex of maxillary 4s	Labial CLB (MBT)	A: MOPs B: CNT	0-(-)-4	RetractRate
Alkebsi et al[62]	RCT (SMD), Uni, JOR	32 (8/24), 19.26	Cl II/1, Ex of maxillary 4s	Labial CLB (MBT)	MOPs	0-(4)-12	RetractRate
Alqadasi et al[63]	RCT (SMD), Hosp, CHN	8 (NR), 15-40	Cl II/1, Ex of maxillary 4s	Labial CLB (MBT)	MOPs	0-2-4-8-12	RetractRate
Alqadasi et al[48]	RCT (2 PA SMD), Hosp, CHN	A: 10 (4/6), 20.89 B: 11 (5/6), 20.89	Cl II/1, Ex of maxillary 4s	Labial CLB (MBT)	A: MOPs B: Piezocision	0-2-4-8-12	RetractRate
Al-Naoum et al[64]	RCT (SMD), Uni, SYR	30 (15/15), 20.04	Cl II, Ex of maxillary 4s	Labial CLB (MBT)	Corticotomy	0-1-2-4-8-12	RetractRate
Al-Shafi et al[65]	RCT (SMD), Hosp, CHE	20 (10/10), 15.8	NR, Ex of maxillary 4s	Labial SLB	Light-emitting diode lights	0-(4)-12	RetractRate
Araghbidikashani et al[66]	RCT (SMD), Uni, IRN	15 (6/9), 14.3	NR, Ex of maxillary 4s	NR	Different retraction methods, none	0-(4)-16	RetractRate
Babanouri et al[67]	RCT (2 PA SMD), Uni, IRN	28 (NR), 16.3-35.2	Cl I-II/1, Ex of maxillary 4s	Labial CLB (MBT)	A: Buccal MOPs B: Buccal and palatal MOPs	0-(4)-12	RetractRate
Cruz et al[68]	RCT (SMD), Pract, BRA	11 (NR), 12-18	Crowding or Bimax Prot, Ex of maxillary 4s	Labial CLB (Roth)	LLLT	0-(4)-8	RetractRate
Dakshina et al[69]	RCT (SMD), Hosp, IND	24 (NR), > 18	NR/ Ex of maxillary 4s	NR	LLLT	0-(4)-12	RetractRate
Deguchi et al[70]	RCT (SMD), Uni, JPN	30 (6/24), 21.30	Cl I-II, Ex of maxillary 4s	Labial CLB (NR)	Use of clear snap	0-(4)-end	RetractRate, RetractDur
Doshi-Mehta Bhad-Patil[71]	RCT (SMD), Hosp, IND	20 (8/12), 12-23	NR, Ex of maxillary 4s	Labial CLB (MBT)	LLLT	0-(NR)-12-end	RetractRate
El-Timamy et al[72]	RCT (SMD), Uni, EGY	16 (0/16), 18	Crowding or Bimax Prot, Ex of maxillary 4s	Labial CLB (Roth)	Local injection of platelet-rich plasma	0-(4)-16	RetractRate
Ekizer et al[73]	RCT (SMD), Uni, TUR	20 (7/13), 16.77	NR, Ex of maxillary 4s	Labial CLB (Roth)	Light-emitting diode lights	0-(4)-12	RetractRate

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Table I. Continued

Study	*Design, setting, and country*†	*Patients (M/F), age, y*‡	*Malocclusion, Tx*	*Appliance*	*Intervention, supplemental*	*FU in wk (interval)*	*Outcome*
Farid et al[74]	RCT (SMD), Uni, EGY	16 (0/16), 21.5	Cl I-II, Ex of maxillary 4s	Labial CLB (Roth)	Combined corticotomy and LLLT	0-(4)-16	RetractRate
Feizbakhsh et al[75]	RCT (SMD), Uni, IRN	20 (12/8), 28	Cl. I, Ex of 4s	Labial CLB (Roth)	MOPs	0-(0)-4	RetractRate
Haliloglu-Ozkan et al[76]	RCT, Uni, TUR	EXP: 17 (10/7), 15.27 CNT: 15 (9/6), 16.13	NR, Ex of 4s	Labial CLB (MBT)	MOPs	0-(4)-8	RetractRate
Ozkan and Arici[77]	RCT (2 PA SMD), Uni, TUR	A: 12 (6/6), 17.27 B: 12 (6/6), 18.13	Cl I-II/I, Ex of maxillary 4s	Labial CLB (MBT)	A: MOPs B: CNT	0-(0)-4	RetractRate
Hassan et al[78]	RCT (SMD), Uni, SYR	15 (4/11), 20.99	NR, Ex of maxillary 4s	One side: labial CLB Other side: labial SLB	Different bracket types, none	0-(0)-12	RetractRate
Heravi et al[79]	RCT (SMD), Pract, IRN	20 (3/17), 22.1	NR, Ex of maxillary 4s ± Ex of mandibular 4s	Labial CLB (Roth)	LLLT	0-(4)-8	RetractRate
Jaber et al[80]	RCT (SMD), Uni, SYR	18 (7/11), 16.9	Cl II/I, Ex of maxillary 4s	Labial CLB (MBT)	LAFC	1-2-4-8-12	RetractRate
Jivrajani et al[26]	RCT (SMD), Hosp, IND	10 (3/7), 14-24	NR, Ex of maxillary 4s	Labial CLB (MBT)	LLLT	0-12-End	RetractRate, RetractDur
Kansal et al[81]	RCT (SMD), Uni, IND	10 (NR), NR	NR, Ex of maxillary 4s	Labial CLB (MBT)	LLLT	0-5-9	RetractRate
Karci and Baka[82]	RCT (2 PA SMD), Uni, TUR	A: 12 (5/7), 16.84 B: 12 (5/7), 16.45	Cl II/I, Ex of maxillary 4s	Labial CLB (MBT)	A: Piezocision B: Local injection of platelet-rich fibrin	1-(2)-12	RetractRate
Kundi et al[83]	RCT, Uni, SAU	EXP/CNT: 30 (14/16), 27.9	Cl II/I, Ex of maxillary 4s	Labial CLB (MBT)	MOPs	0-(0)-4	RetractRate
Liao et al[84]	RCT (SMD), Uni, TUR & AUS	13 (NR), 13.6	NR, Ex of maxillary 4s	Labial CLB (NR)	Vibration	0-(4)-12	RetractRate
Limpanichkul et al[85]	RCT (SMD), Uni, THA	12 (4/8), 20.11	NR, Ex of maxillary 4s	Labial CLB (Roth) (SLB on maxillary 3s)	LLLT	0-(4)-12	RetractRate
Mahmoudzadeh et al[86]	RCT (SMD), Uni & Pract, IRN	12 (3/9), 18.91	NR, Ex of maxillary 4s	Labial CLB (MBT)	LAFC	0-4	RetractRate
Mezomo et al[87]	RCT (SMD), Uni, BRA	15 (5/10), 18	Cl I-II, Ex of maxillary 4s	One side: labial CLB Other side: labial SLB	Different bracket types, none	0-(4)-12	RetractRate
Mistry et al[88]	RCT (SMD), Hosp, AUS	22 (7/15), 17.3	NR, Ex of maxillary 4s	Labial SLB (Hanson)	LLLT	0-(4)-12	RetractRate
Pacheco et al[89]	RCT (SMD), Uni, DOM	17 (5/12), 33	Cl I-II/I, Ex of maxillary 4s	Labial CLB (MBT)	Using leukocyte-platelet-rich fibrin membranes	0-(4)-20	RetractRate
Qamruddin et al[90]	RCT (SMD), Uni, PAK	22 (11/11), 19.8	Cl II/I, Ex of maxillary 4s	Labial SLB (MBT)	LLLT	0-(3)-9	RetractRate
Qamruddin et al[91]	RCT (SMD), Uni, PAK	22 (11/11), 19.18	Cl II/I, Ex of maxillary 4s	Labial CLB (MBT)	LIPUS	0-(3)-12	RetractRate
Sharma et al[92]	RCT (SMD), Uni, IND	17 (NR), 18.87	Cl I-II/I, Ex of maxillary 4s	Labial CLB (MBT)	Corticotomy	0-(3)-end	RetractRate

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Table I. Continued

Study	*Design, setting, and country*†	*Patients (M/F), age, y*‡	*Malocclusion, Tx*	*Appliance*	*Intervention, supplemental*	*FU in wk (interval)*	*Outcome*
Siriphan et al[93]	RCT, Uni, THA	EXP1: 20 (3/17), 21.6 EXP2: 20 (5/15), 22.1 CNT: 20 (5/15), 20.9	NR, Ex of maxillary 4s	Labial CLB (Roth)	Vibration	0-12	RetractRate
Taha et al[94]	RCT, Uni, USA	EXP: 10 (3/7), 15.9 CNT: 11 (4/7), 15.09	NR, Ex of maxillary 4s	Labial CLB (MBT)	Vibration	0-(4)-12	RetractRate
Telatar et al[95]	RCT (2 PA), Uni, TUR	EXP: 11 (5/6), 15.8 CNT: 8 (5/3), 15.9	Crowding or Cl II/I, Ex of 4s	Labial CLB (MBT)	Vibration	0-(4)-24	RetractRate
Thomas et al[96]	RCT (SMD), Hosp, IND	33 (9/24), 22.1	Cl I-II/I, Ex of maxillary 4s	Labial CLB (MBT)	MOPs	0-(2)-12	RetractRate
Varella et al[97]	RCT (SMD), Hosp, IND	10 (4/6), 17.7	Cl I, Ex of 4s	Labial CLB (MBT)	LLLT	0-(4)-8	RetractRate
Wahab et al[98]	RCT, Uni, MYS	EXP/CNT: 20 (NR), 14-30	Cl I-II/I, Ex of maxillary 4s	One side: labial CLB Other side: labial SLB	Different bracket types, none	0-(4)-12	RetractRate
Wahab et al[99]	RCT (SMD), Uni, MYS	19 (6/13), 21.3	Cl II/I, Ex of maxillary 4s	Labial SLB (MBT)	Different orthodontic forces, none	0-(1)-5	RetractRate
Yassaei et al[100]	RCT (SMD), Uni, IRN	11 (0/11), 19.0	Cl I, Ex of 4s	Labial CLB (NR)	LLLT	0-(4)-16	RetractRate
Zeitounlouian et al[101]	RCT (SMD), Uni, SYR	21 (6/15), 20.85	Cl II/I, Ex of maxillary 4s	Labial CLB (MBT)	Local injection of platelet-rich fibrin	0-(4)-20	RetractRate
Zheng et al[102]	RCT (SMD), Hosp, CHN	12 (4/8), 18-28	NR, Ex of maxillary 4s	Labial CLB (MBT)	LLLT	0-(1)-4	RetractRate

M, male; *F*, female; *Tx*, treatment; *FU*, follow-up; *PA*, parallel arms; *SMD*, split-mouth design; *Uni*, university clinic; *EGY*, Egypt; *NR*, not reported; *Cl*, Angle's Class; *Ex*, extraction; *CLB*, conventionally ligated bracket; *RetractRate*, retraction rate; *RetractDur*, retraction duration; *Bimax Prot*, bimaxillary protrusion; *SYR*, Syria; *USA*, United States; *JOR*, Jordan; *CNT*, control; *CHN*, China; *Hosp*, hospital; *CHE*, Switzerland; *IRN*, Iran; *BRA*, Brazil; *EXP*, experimental; *IND*, India; *JPN*, Japan; *TUR*, Turkey; *SAU*, Saudi Arabia; *AUS*, Australia; *THA*, Thailand; *Pract*, private practice/clinic; *DOM*, Dominican Republic; *PAK*, Pakistan; *LIPUS*, Low-intensity pulsed ultrasound; *MYS*, Malaysia.
†Countries given with their alpha-3 codes; ‡Patient age is given either as mean (1 value without parenthesis) or if the mean is not reported as a range (2 values in parenthesis).

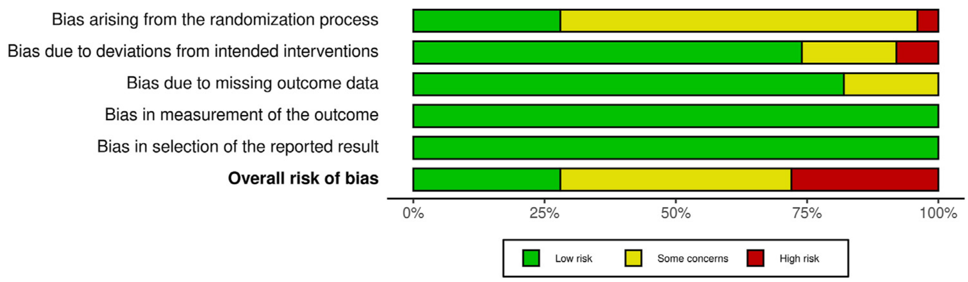

Fig 2. Overall risk of bias scores for the specific domains presented as percentages.

injection of platelet-rich fibrin (n = 1), and local injection of platelet-rich fibrin or platelet-rich plasma (n = 3).

Eighteen trials reported using temporary anchorage devices (TADs) to enhance posterior anchorage: 15 used a transpalatal arch (TPA, including Nance button), 1 used both TADs and TPA, 1 used both TPA and headgear, 2 used vertical stopped loops, 4 used ligation of second premolars and first molars together, 2 included the second molar in the anchor unit, and 7 trials did not report on anchorage reinforcement methods. In 46 trials, nickel-titanium (NiTi) closed coil springs were used to retract the canines, delivering 150 g of force in 36 trials, 100 g of force in 1 trial, 200 g of force in 3 trials, 120 g of force in 1 trial, 180 g of force in 1 trial, 61 g of force in 1 trial, both 100 g and 150 g of force in 1 trial, and 50 g, 100 g, and 150 g of force in 1 trial, with 1 study not reporting on force magnitude. Simultaneously, elastic chains were used in 4 trials delivering 150 g of force. Maxillary first premolars were extracted 0-6 weeks before fixed appliance placement in 22 trials, 6 months before retraction in 3 trials, 3 months before retraction in 2 trials, 0-4 weeks before retraction in 12 trials, with 11 trials not reporting on the timing of extraction.

Risk of bias within studies

The risk of bias assessment for the 50 included trials is shown in Figure 2, Supplementary Figure 1, and Supplementary Table II. A high risk of bias was found in 14 trials (28%), with each trial having at least one domain judged to have a high risk of bias (or multiple domains judged to have some concerns). Nine trials were at high risk of bias because of issues with the randomization process, deviations from intended interventions, and missing outcome data. Four trials were at high risk of bias because of issues with the randomization process (lack of information regarding the allocation concealment) and deviations from intended interventions. One trial was at high risk of bias because of a lack of random sequence generation and allocation concealment. Twenty trials (40%) presented concerns with the randomization process, mainly lack information regarding allocation concealment (n = 15), randomization sequence generation (n = 1), and both allocation concealment and randomization sequence generation (n = 4). The remaining 16 trials (32%) presented a low risk of bias except for the absence of a priori protocols, which would rule out selective reporting.

Results of individual studies, indirect analyses of pooled averages across trials, direct comparisons within and across trials

The pooled average time to achieve complete retraction of the maxillary canines was estimated from indirect meta-analyses at 4.98 months (2 trials; 95% CI, −2.92 to 12.88 months) (Table II and Supplementary Figs 2-11). Pooled cumulative average canine tooth movement from baseline (beginning of canine retraction) was 0.97 mm at 1 month (23 trials; 95% CI, 0.79-1.16), 1.83 mm at 2 months (20 trials; 95% CI, 1.52-2.14), 2.44 mm at 3 months (23 trials; 95% CI, 2.10-2.79), 3.49 mm at 4 months (6 trials; 95% CI, 1.81-5.17), and 4.25 mm at 5 months (2 trials; 95% CI, 0.36-8.14). In addition, pooled average canine retraction for each separate month was 0.84 mm for months 1-2 (21 trials; 95% CI, 0.68-1.01), 0.73 mm for months 2-3 (17 trials; 95% CI, 0.55-0.90) and 0.69 mm for months 3-4 (4 trials; 95% CI, 0.08-1.31). As expected, substantial heterogeneity was seen for most indirect poolings (I^2 >95%); therefore, the 95% CIs and the 95% predictions might be more informative than the pooled point estimates.

Direct comparisons among different orthodontic forces, retraction methods, fixed appliances, or treatment adjuncts (including vibration, LLLT, surgically-assisted orthodontics, or local injection of platelet-rich fibrin or plasma) were performed both in individual single-studies (Supplementary Table III) and as meta-analyses of at least 2 studies (Table III and Supplementary Figs 12-29). Meta-analysis of 2 trial arms found a

Table II. Indirect meta-analyses of pooled averages across the control groups of all studies

Outcome	Trials	Pooled average (95% CI)	*P* value	tau^2 (95% CI)	I^2 (95% CI)	95% prediction
Total retraction duration (mm)	2	4.98 (−2.92 to 12.88)	0.08	0.74 (–)	96 (89-99)	–
Retraction mo 0-1	23	0.97 (0.79-1.16)	<0.001	0.16 (0.09-0.33)	99 (98-99)	0.11-1.83
Retraction mo 0-2	20	1.83 (1.52-2.14)	<0.001	0.39 (0.21-0.89)	98 (97-98)	0.48-3.17
Retraction mo 0-3	23	2.44 (2.10-2.79)	<0.001	0.60 (0.34-1.21)	99 (99-99)	0.80-4.08
Retraction mo 0-4	6	3.49 (1.81-5.17)	0.003	2.48 (0.89-14.98)	100 (100-100)	−1.25 to 8.23
Retraction mo 0-5	2	4.25 (0.36-8.14)	0.05	0.13 (–)	69 (0-93)	–
Retraction mo 1-2	21	0.84 (0.68-1.01)	<0.001	0.11 (0.06-0.25)	96 (95-97)	0.12-1.57
Retraction mo 2-3	17	0.73 (0.55-0.90)	<0.001	0.10 (0.05-0.25)	96 (95-97)	0.04-1.41
Retraction mo 3-4	4	0.69 (0.08-1.31)	0.04	0.15 (0.04-1.98)	99 (99-99)	−1.15 to 2.54
Retraction mo 0-3; mean (mm/mo)	4	0.92 (0.72-1.12)	<0.001	0.01 (0.00-0.25)	65 (0-88)	0.42-1.42

CI, confidence interval; *mo*, month.

significant reduction in canine retraction duration with surgically-assisted orthodontics (MD, 1.11 months less; 95% CI, −2.32 to 0.10; *P* = 0.05; Table III). Canine retraction was greater with surgically-assisted orthodontics (vs nonsurgical orthodontics) at months 0-1 (n = 10; MD, 0.52 mm; 95% CI, 0.21-0.84 mm; *P* = 0.004), months 0-2 (n = 8; MD, 0.53 mm; 95% CI, 0.06-0.97 mm; *P* = 0.04), months 0-3 (n = 8; MD, 0.67 mm; 95% CI, 0.20-1.13 mm; *P* = 0.01), and months 0-4 (n = 3; MD, 1.13 mm; 95% CI, 0.60-1.66 mm; *P* = 0.01) (Table III and Figs 3 and 4).

Apart from these meta-analyses, several outcomes were assessed only by single trials and are listed in Supplementary Table III. Single trials indicated that complete canine retraction duration was shorter using ClearSnap bracket attachments (vs none; MD, −2.43 months; 95% CI, −2.68 to −2.19 months; *P* <0.001), whereas a larger retraction force of 150 g was found from a single trial to be better both than a 100 g force (MD, −0.50 month; 95% CI, −0.98 to −0.02 month; *P* = 0.04) and a 50 g force (MD, −1.30 month; 95% CI, −1.99 to −0.61 mm; *P* <0.001). Canine retraction was greater with coil spring (vs laceback; 0-4 months; MD, 1.65 mm; 95% CI, 0.04-3.26 mm; *P* = 0.05) and with combined buccal or palatal MOPs (vs only buccal MOPs; 0-3 months; MD, 0.79 mm; 95% CI, 0.43-1.15 mm; *P* <0.001).

Additional analyses

Subgroup analyses and meta-regression analyses were used to investigate potential sources of heterogeneity. In the indirect analysis (Supplementary Table IV), treatment with 0.018-in slot brackets was associated with greater canine retraction than 0.022-in slot brackets for months 0-2 (2.24 vs 1.72 mm, respectively; *P* = 0.07), months 0-3 (3.41 vs 2.31 mm, respectively; *P* = 0.003) and months 2-3 (0.96 vs 0.66 mm, respectively; *P* = 0.06).

Subgroup analysis was likewise employed to explore sources of heterogeneity in the direct meta-analyses of MDs among the different modalities of surgically-assisted orthodontics (Table IV). Statistically, significant subgroup differences were found among the 4 techniques (corticotomy, LAFC, MOPs, and piezocision) for many time points. For total canine retraction in months 0-1, months 0-2, and months 0-3, consistent results indicated LAFC being the most effective, followed by piezocision and MOPs (P for subgroup differences <0.10 in all instances). Similar findings were found for the monthly rates of canine retraction at months 1-2 or months 2-3, in which LAFC or corticotomy proved most effective (*P* <0.001 among subgroups).

Subgroup and meta-regression analyses were used to investigate potential sources of heterogeneity for direct comparisons of MDs between different patient- or treatment-related characteristics (Supplementary Table V). Patient gender was significantly associated with the benefit of surgically-assisted orthodontics compared with conventional orthodontics (0.22 mm per extra 10% males in the sample; *P* = 0.03), which might indicate a gender-specific biological response to surgical insults (Supplementary Fig 30). Anchorage reinforcement with TADs was associated with lower benefits of added canine retraction because of surgically-assisted orthodontics compared with TPA-anchored mechanics for months 0-1 (0.33 vs 0.80 mm), months 0-2 (0.28 to 1.24 mm) and months 0-3 (0.43 to 1.36 mm) (*P* <0.001 in all instances). However, these differences might indicate a measurement artifact not necessarily because of increased absolute canine retraction but rather an anchorage loss of the posterior unit that might influence canine retraction measurement. Five indirect meta-analyses and 6 direct meta-analyses could be assessed for reporting biases, but Egger's test indicated no signs of funnel-plot asymmetry. Sensitivity analyses on the pooled

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Table III. Direct meta-analytical comparisons with MDs on canine retraction duration and rate

No.	Experimental	Reference	Outcome, mm	Trial arms	MD (95% CI)	*P* value	tau^2 (95% CI)	I^2 (95% CI)	95% prediction
1	150 g of retraction force	100 g retraction force	Retraction mo 0-1	2	0.03 (−0.15 to 0.22)	0.75	0 (–)	0 (–)	–
2	PRP/PRF injection	Control/saline injection	Retraction mo 0-1	2	−0.06 (3.42 to 3.31)	0.87	0 (–)	69 (0-93)	–
3	PRP/PRF injection	Control/saline injection	Retraction mo 0-2	2	0.18 (−0.84 to 1.19)	0.27	0 (–)	0 (–)	–
4	PRP/PRF injection	Control/saline injection	Retraction mo 0-3	3	0.54 (−0.56 to 1.63)	0.17	0.12 (0.00-8.93)	49 (0-85)	−4.97 to 6.04
5	PRP/PRF injection	Control/saline injection	Retraction mo 0-4	2	0.24 (−3.66 to 4.14)	0.58	0 (–)	0 (–)	–
6	PRP/PRF injection	Control/saline injection	Retraction mo 0-5	2	−0.64 (−7.98 to 6.71)	0.47	0.58 (–)	86 (46-97)	–
7	PRP/PRF injection	Control/saline injection	Retraction mo 1-2	2	0.26 (−2.08 to 2.60)	0.39	0.02 (–)	36 (–)	–
8	PRP/PRF injection	Control/saline injection	Retraction mo 2-3	2	−0.02 (−4.77 to 4.73)	0.97	0.24 (–)	84 (32-96)	–
9	PRP/PRF injection	Control/saline injection	Retraction mo 3-4	2	0.23 (−0.27 to 0.73)	0.11	0 (–)	0 (–)	–
10	LLLT	Control	Retraction mo 0-1	9	0.22 (−0.04 to 0.48)	0.09	0.11 (0.04-0.37)	97 (96-98)	−0.60 to 1.04
11	LLLT	Control	Retraction mo 0-2	9	0.51 (−0.13 to 1.15)	0.10	0.67 (0.27-2.37)	98 (98-99)	−1.53 to 2.56
12	LLLT	Control	Retraction mo 0-3	8	0.53 (0.01-1.05)	0.05	0.36 (0.14-1.56)	99 (98-99)	−1.04 to 2.10
13	LLLT	Control	Retraction mo 1-2	9	0.32 (−0.08 to 0.72)	0.11	0.27 (0.11-0.95)	98 (97-99)	−0.97 to 1.61
14	LLLT	Control	Retraction mo 2-3	6	0.19 (−0.08 to 0.45)	0.13	0.06 (0.02-0.36)	97 (96-98)	−0.57 to 0.94
15	Self-ligating bracket	Conventional bracket	Retraction mo 0-3	3	0.59 (−0.45 to 1.64)	0.13	0.15 (0.01-5.73)	77 (24-93)	−5.25 to 6.44
16	Adjunct vibration	Control	Retraction mo 0-3	3	0.31 (−1.11 to 1.73)	0.45	0.25 (0.01-12.81)	77 (26-93)	−7.29 to 7.91
17	Surgically-assisted orthodontics	Control	Retraction mo 0-1	10	0.52 (0.21-0.84)	0.004	0.17 (0.07-0.61)	95 (93-97)	−0.47 to 1.51
18	Surgically-assisted orthodontics	Control	Retraction mo 0-2	8	0.53 (0.06-0.97)	0.04	0.27 (0.10-1.23)	91 (85-95)	−0.84 to 1.90
19	Surgically-assisted orthodontics	Control	Retraction mo 0-3	8	0.67 (0.20-1.13)	0.01	0.28 (0.10-1.22)	94 (90-96)	−0.71 to 2.05
20	Surgically-assisted orthodontics	Control	Retraction mo 0-4	3	1.13 (0.60-1.66)	0.01	0 (0.00-16.90)	46 (0-84)	−0.50 to 2.75
21	Surgically-assisted orthodontics	Control	Retraction mo 1-2	9	0.25 (−0.01 to 0.50)	0.05	0.06 (0.02-0.51)	82 (68-90)	−0.40 to 0.89
22	Surgically-assisted orthodontics	Control	Retraction mo 2-3	8	0.19 (−0.02 to 0.40)	0.06	0.05 (0.02-0.22)	90 (83-94)	−0.41 to 0.80
23	Surgically-assisted orthodontics	Control	Retraction mo 3-4	2	−0.04 (−0.17 to 0.08)	0.15	0 (–)	0 (–)	–
24	Surgically-assisted orthodontics	Control	Total retraction duration (mo)	2	−1.11 (−2.32 to 0.10)	0.05	0 (–)	0 (–)	–

CI, confidence interval; *MD*, mean difference; mo, month; *PRF*, platelet-rich fibrin; *PRP*, platelet-rich plasma.

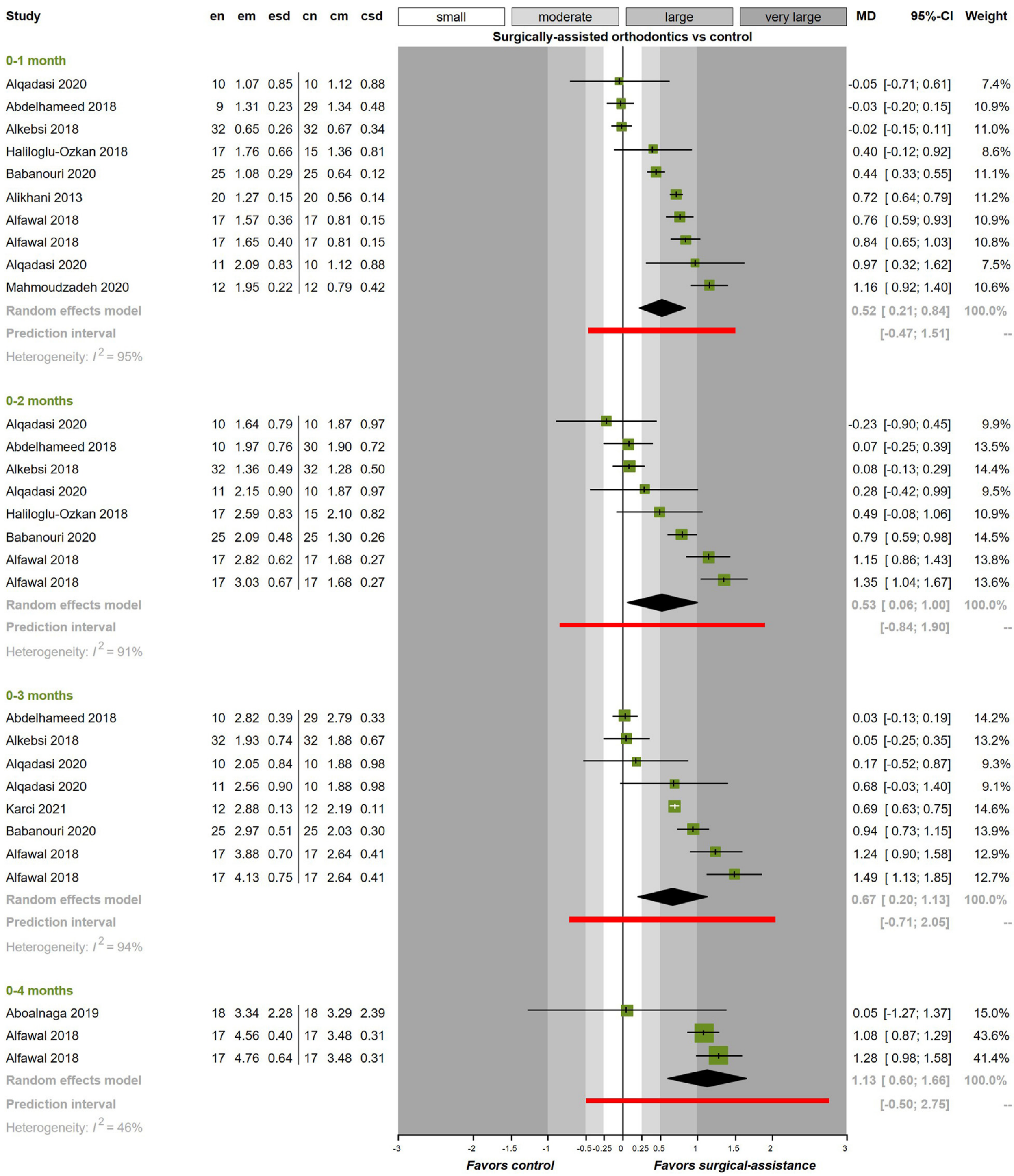

Fig 3. Forest plots depicting the effect of surgically-assisted orthodontics vs nonsurgically assisted orthodontics on the amount of canine tooth movement at months 0-1, 0-2, 0-3, 0-4 (in millimeters). *en*, experimental number; *em*, experimental mean; *esd,* experimental standard deviation; *cn,* control mean; *cm,* control mean; *csd,* control standard deviation.

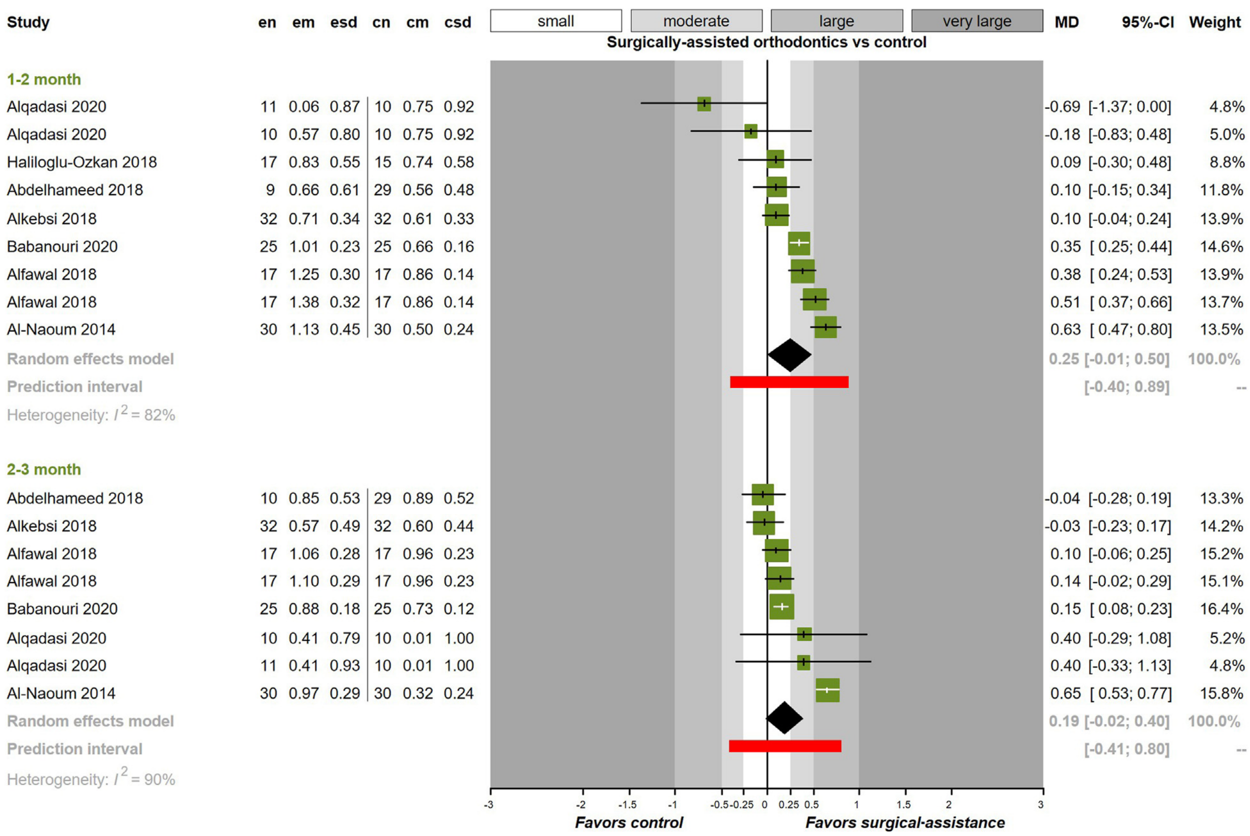

Fig 4. Forest plots depicting the effect of surgically-assisted orthodontics vs nonsurgically assisted orthodontics on the amount of canine tooth movement at months 1-2 and 2-3 (in millimeters). *en*, experimental number; *em*, experimental mean; *esd,* experimental standard deviation; *cn,* control mean; *cm,* control mean; *csd,* control standard deviation.

average canine retraction amounts (Supplementary Table VI) found that RCTs with parallel groups tended to report different canine retraction amounts than split-mouth RCTs, which might indicate artifacts because of different intraarch configurations. No direct association between risk of bias and amounts of canine retraction was seen. Finally, evidence of imprecision was seen for the indirect analyses, in which the most precise studies (ie, those with probably larger sample sizes) showed considerably more conservative amounts of retraction than more imprecise (smaller) studies.

For direct meta-analyses of MDs (Supplementary Table VII), no differences were seen between parallel and split-mouth RCTs or between studies with high risk and low risk of bias/some concerns. Similarly, Egger's test saw no considerable hints of reporting biases. Sensitivity analyses according to study precision also did not find any consistent overestimation from imprecise studies (small study effects). In the 2 instances with $P < 0.10$, the most precise studies indicated greater treatment benefits from surgically-assisted surgery orthodontics.

According to the GRADE analysis (Table V), high quality of evidence supported increased canine retraction with surgically-assisted orthodontics and a lack of effect for self-ligating brackets or platelet-rich plasma or fibrin. Moderate quality of evidence supported the finding of no benefit from adjunct use of vibration because of the high risk associated with bias of one of the included RCTs.

DISCUSSION

Summary of evidence

This systematic review summarizes evidence from RCTs on canine retraction duration and rate following maxillary first premolar extraction using full-arch fixed appliances. From the initially identified 2259 studies, 50 were included (n = 811 participants). Canine retraction duration was assessed in terms of the time required to complete retraction of the maxillary

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Table IV. Subgroup analyses for the various surgically-assisted orthodontics approaches compared with control groups

Outcome (mm)	Mean difference with 95% CI				
	Corticotomy	LAFC	MOPs	Piezocision	*P* value
Retraction mo 0-1	-	n = 2; 0.95 (−1.59 to 3.49)	n = 6; 0.27 (−0.08 to 0.61)	n = 2; 0.85 (0.41-1.29)	<0.001
Retraction mo 0-2	-	n = 1; 1.15 (0.86-1.43)	n = 5; 0.27 (−0.21 to 0.76)	n = 2; 0.87 (−5.90 to 7.64)	<0.001
Retraction mo 0-3	-	n = 1; 1.24 (0.90-1.58)	n = 4; 0.31 (−0.41 to 1.03)	n = 3; 0.97 (−0.20 to 2.13)	0.005
Retraction mo 0-4	-	n = 1; 1.08 (0.87-1.29)	n = 1; 0.05 (−1.27 to 1.37)	n = 1; 1.28 (0.98-1.58)	0.16
Retraction mo 1-2	n = 1; 0.63 (0.47-0.80)	n = 1; 0.39 (0.24-0.53)	n = 5; 0.17 (−0.03 to 0.36)	n = 2; −0.04 (−7.65 to 7.57)	<0.001
Retraction mo 2-3	n = 1; 0.65 (0.53-0.77)	n = 1; 0.10 (−0.06 to 0.25)	n = 4; 0.07 (−0.13 to 0.28)	n = 2; 0.15 (−0.53 to 0.82)	<0.001
Retraction mo 3-4	-	n = 1; −0.03 (−0.12 to 0.06)	-	n = 1; −0.05 (−0.12 to 0.02)	0.72
Total retraction duration (mo)	-	n = 1; −1.20 (−1.76 to −0.64)	-	n = 1; −1.01 (−1.56 to −0.46)	0.63

CI, confidence interval; *LAFC*, laser-assisted flapless corticotomy; *mo*, month; *MOP*, micro-osteoperforation.

canines, and canine retraction rate was determined as the amount of canine tooth movement for the various periods.

This review found limited research assessing the prespecified primary outcome of canine retraction duration, with only 4 studies assessing this metric. Clinical trials have focused on canine retraction rate as a primary outcome of their interventions, but useful clinical data on complete retraction duration is lacking (2 studies were also excluded from data synthesis because of missing data).[25,26] The overall pooled average for complete canine retraction duration was 4.98 months. The canine retraction phase is one of the most time-consuming stages of orthodontic treatment, and shortening this period may lead to shorter overall treatment duration (although choosing to retract the maxillary canine teeth as a separate stage of treatment might be regarded as de novo, a more time-consuming treatment process when compared with a single stage of en masse retraction). This review found that surgically-assisted orthodontics resulted in a shorter retraction duration than control groups (1.11 months less). This agrees with 2 recent reviews demonstrating that corticotomy-facilitated orthodontics results in a shorter treatment duration than conventional treatment.[27,28] However, these findings need to be interpreted cautiously because only 2 studies were included in data synthesis, and they might not be representative.

Substantial variation was seen in the amount of canine retraction reported at various treatment time points. There was extreme heterogeneity across studies, explained by differences in clinical settings, patient demographics, malocclusion, anchorage enhancement, fixed appliance type, treatment adjuncts, orthodontic mechanics, and appointment intervals.[15,29-32] Moreover, the timing of canine retraction initiation after premolar extraction differed among included studies. There is limited evidence available relating to retraction timing; however, greater tooth movement at recent extraction sites has been reported previously,[33] which could be related to reduced resistance to tooth movement, the immediate tissue inflammatory response after extraction, and supposed regional acceleratory phenomenon.[34] In addition, subgroup analysis indicated that 0.018-in bracket slot size was associated with greater tooth movement than 0.022-in. This agrees with previous findings that treatment duration is significantly shorter for 0.018-in bracket slot size.[35] However, the relationship between bracket slot size and treatment duration is inconsistent, with further high-quality evidence suggesting that treatment duration is independent of bracket slot size[32,36] and 1 trial (albeit with multiple variables) reporting faster tooth movement with 0.022-in slot size.[37]

Table 5. Summary of findings according to the GRADE approach for the months 0-3

	Anticipated absolute effects (95% CI)				
	*Control group**	*Experimental group*	*Difference in experimental group*		
Outcome, studies (patients)	*Control*	*PRP/PRF*		*Quality of the evidence (GRADE)†*	*What happens with experimental treatment*
Retraction in 3 mo, 3 trials (48)	2.96 mm	–	0.5 mm more (0.5 less to 1.6 more)	⊕⊕⊕⊕ high	Little to no difference in canine retraction
	Control brackets	Self-ligating brackets			
Retraction in 3 mo, 3 trials (50)	2.66 mm	–	0.6 mm more (0.5 less to 1.6 more)	⊕⊕⊕⊕ high	Little to no difference in canine retraction
	Control	Adjunct vibration			
Retraction in 3 mo, 3 trials (94)	2.66 mm	–	0.3 mm more (1.1 less to 1.7 more)	⊕⊕⊕○ moderate‡	Little to no difference in complete alignment duration
	Control	Surgically-assisted orthodontics			
Retraction in 3 mo, 8 trials (152)	2.28 mm	–	0.7 mm more (0.2 to 1.1 more)	⊕⊕⊕⊕ high§	Greater canine retraction

Note. Intervention: orthodontic treatment with fixed appliances with extractions including canine retraction and with/without adjuncts; Population: adolescent and adult patients with crowding; Setting: university clinics, hospitals and private practice (Australia, Brazil, China, Egypt, Iran, Jordan, Malaysia, Syria, Thailand, Turkey, United States).
mo, month; *PRF*, platelet-rich fibrin; *PRP*, platelet-rich plasma.
*Response in the control group is based on random-effects meta-analysis duration among the control groups; †Starts from "high."; ‡Downgraded by 1 level for bias because of the inclusion of 1 trial with high risk of bias; §Considerable inconsistency observed ($tau^2 = 0.28; I^2 = 94\%$), but this does not affect our decision about surgical-assisted orthodontics, as the majority of trials were on the same side of the forest plot. However, caution is warranted by the quantification of the actual reduction in alignment duration.

Direct meta-analyses indicated that surgically-assisted orthodontics was associated with greater canine tooth movement than conventional orthodontics, which has previously been suggested.[7,38] At 3 months of treatment, high-quality evidence supported greater canine retraction with surgically-assisted orthodontics (8 trials; 152 patients). Subgroup analyses for the various surgically-assisted procedures indicated significant differences. Among LAFC, MOPs, and piezocision at months (0-1, 0-2, and 0-3), the LAFC subgroup seemed to be the most efficient, followed by piezocision and MOPs. Among the 4 subgroups at months 1-3, corticotomy was the most efficient. Corticotomy is an invasive procedure involving raising a full-thickness mucoperiosteal flap and causing direct trauma to the bone. This implies a scenario in which bone injury accelerates all processes involved in healing, inflammation, bone modeling and remodeling—hence accelerating orthodontic tooth movement.[34,39,40] Previously, it has been reported that corticotomy results in shorter treatment duration[27,41] and faster tooth movement.[42-46] However, MOPs, LAFC, and piezocision are more minimally invasive procedures with potentially greater patient acceptance, although there is more limited evidence that these adjuncts may accelerate orthodontic tooth movement.[47] The abovementioned results agree with previous findings reporting that corticotomy resulted in a greater rate of canine tooth movement compared with piezocision[43] and piezocision was associated with greater tooth movement than MOPs in a single study.[48] Moreover, piezocision and LAFC were associated in a single trial with greater tooth movement than in control groups.[49] Furthermore, after the first month, a reduced amount of tooth movement was evident with time, which could be explained by the transient influence of these procedures when carried out only once during treatment.[34]

Subgroup analyses for the direct meta-analyses indicated that anchorage reinforcement methods were associated with the amount of canine retraction. Treatment without TADs or TPA was associated with greater tooth movement than with TADs or TPA, and treatment with TPA was associated with greater tooth movement than TADs. This could be due to differences in tooth movement, whether tipping or bodily. In studies that used TADs to enhance anchorage, NiTi closed coil springs were placed between TADs and power arms; hence, the force passes through the center of resistance, so more bodily movement is expected. However, in other studies, NiTi closed coil springs were placed at the bracket level between the first molar and canine hooks, and some tipping is inevitable. It has been reported that tipping movements are associated with faster tooth movement rates than bodily movement[50-52]; nevertheless, the duration required to fully retract the canine was longer because of the need for root uprighting canines to retract with tipping movement.[52] In addition, it is worth noting that most of the included studies followed patients for 3 months after canine retraction, so the greater amount of tooth movement in those studies that did not use TADs might be due to tipping. Moreover, different reference points were used to measure the amount of canine tooth movement among the included studies, and some of these points are not stable, which might have affected the estimates.

Finally, parallel-group RCTs tended to report more tooth movement than trials with a split-mouth design. Although a split-mouth study design can remove intersubject variability from the estimated treatment effect, cross-over effects, spilling of the effects, or contamination of one intervention to another are known disadvantages of this design.[53] Furthermore, many trials had a small sample size, and most precise studies showed different results than the least precise studies indicating a small study effect that might introduce bias and affect the precision of the estimates.[54]

Considerations for future research

It is disappointing that most trials investigating canine retraction use a split-mouth design as their preferred experimental model. This assumes baseline equivalence between opposite sides of the dental arch and independence to different bilateral interventions, which reduces sample size requirements. Although experimentally convenient, split-mouth designs should be avoided and randomization be carried out at the level of the individual, not the dental arch. Of equal concern is that many of these trials only report over the short-term, often failing to follow-up patients beyond 1 or a few months and rarely to the completion of canine retraction (only 2 trials out of 50 even included data to completion of retraction). As a model for understanding the effectiveness of different adjuncts in reducing orthodontic treatment time, this is not useful. Even for those studies following canine retraction to completion, this represents only 1 component of treatment in extraction patients and, although anchorage-conserving as previously stated, it is highly likely to be more time-consuming to retract the maxillary canines first and then the remainder of the labial segment when compared with direct en masse retraction of the maxillary 6 anterior teeth together with sliding mechanics. Indeed, many of these studies use canine retraction against absolute anchorage, which represents a sensible experimental model but will rarely be carried out in normal treatment (with fixed anchorage, why would you not do en masse retraction?). Another issue is the frequent reporting of percentage differences in tooth movement rates, which are largely clinically meaningless. Future investigations should ideally focus on the overall duration of treatment, the influence of adjuncts over this period, and the potential need for repeating them during the treatment journey. If canine retraction studies are conducted, they should investigate complete retraction of the canines and avoid split-mouth designs. Our pooled duration of 5.0 months to achieve complete canine retraction provides useful guidance for future sample size calculations. We suggest that intervention would need to induce a minimum of 2 months reduction in this time to be considered clinically significant.

Strengths and limitations

This review's strengths include a priori registered protocol,[55] comprehensive literature searching,[56,57] inclusion of RCTs,[21] use of modern statistics, assessing the quality of evidence according to GRADE,[20] and transparent provision of open datasets.[22]

Limitations include methodological issues with the conduct of included trials and the high heterogeneity levels among studies that might affect conclusions. Moreover, the limited number of studies with relatively small sample sizes that reported on the primary outcome and relatively short follow-up period after retraction might affect the precision of the effect. In addition, most meta-analyses were based primarily on studies with split-mouth design and small sample sizes, which might affect the precision of the estimated effects.[54] Finally, because of the small number of included trials and incomplete reporting, all preplanned subgroup and meta-regression analyses could not be undertaken to identify factors related to the outcome of interest.

CONCLUSIONS

This systematic review included 50 trials (covering 811 patients with a mean age of 19.9 years) with limited data indicating a pooled duration to achieve complete retraction of the maxillary canines of 5.0 months, with substantial heterogeneity across studies. Part of this heterogeneity could be explained by the patient or treatment-related characteristics and differences in the design of included studies. At 3 months of treatment, high-quality evidence supported greater canine retraction on average with surgically-assisted orthodontics, whereas no benefit was seen for platelet-rich plasma or fibrin (high-quality evidence), self-ligating brackets (high-quality evidence) or adjunct vibration (moderate-quality evidence). Future well-conducted, adequately powered and transparently reported parallel-group RCTs assessing clinically relevant outcomes will help identify methods to accelerate canine retraction. The findings of this systematic review should be used to inform power calculations for future research.

AUTHOR CREDIT STATEMENT

Fidaa Wazwaz contributed to conceptualization, data curation, formal analysis, original draft preparation, and manuscript review and editing; Jadbinder Seehra contributed conceptualization, data curation, formal analysis, original draft preparation, and manuscript review and editing; Guy H. Carpenter contributed to formal analysis and manuscript review and editing; Spyridon N. Papageorgiou contributed to conceptualization, formal analysis, original draft preparation, and manuscript review and editing; and Martyn T. Cobourne contributed to conceptualization, formal analysis, original draft preparation, and manuscript review and editing.

SUPPLEMENTARY DATA

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ajodo.2022.08.009.

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