SYSTEMATIC REVIEW

Canal Transportation Produced by Single-File Endodontic Systems: A Systematic Review of In Vitro Micro-CT and CBCT Studies

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Running title: Canal transportation with single-file systems

ABSTRACT

Background: Single-file nickel–titanium (NiTi) systems simplify root canal preparation, but whether they preserve the original canal path as well as multi-file sequences remains debated.

Objective: To systematically evaluate canal transportation produced by single-file endodontic systems in extracted human single-rooted permanent teeth.

Methods: The review followed PRISMA 2020 and a protocol registered in PROSPERO (CRD420261414848). PubMed/MEDLINE, Scopus and Google Scholar were searched without date limits for English-language in vitro studies that measured canal transportation with micro-computed tomography (micro-CT) or cone-beam computed tomography (CBCT) after preparation with a single-file system. Two reviewers independently screened records, extracted data and appraised risk of bias with a modified Joanna Briggs Institute (JBI) checklist. Meta-analysis was planned; because comparators, measurement levels and transportation formulas differed and means with standard deviations were inconsistently reported, findings were synthesised narratively by comparison and root level following SWiM guidance. Certainty was rated with an adapted GRADE approach.

Results: Twelve studies (702 teeth; 11 CBCT, 1 micro-CT) were included, testing WaveOne, WaveOne Gold, Reciproc, Reciproc Blue, OneShape, One Curve, HyFlex EDM and XP-endo Shaper. Against multi-file sequences, single-file systems produced less transportation at one or more levels in four of eight studies, similar transportation in three, and mixed results in one. Reciprocating WaveOne transported less than rotary OneShape in two studies, whereas WaveOne Gold transported more than rotary HyFlex EDM in one. Among reciprocating files, one study favoured WaveOne over Reciproc and two found no difference. A mechanical glide path and a traditional access cavity were each associated with less transportation. All studies carried a moderate risk of bias, and certainty of evidence was very low.

Conclusions: In single-rooted teeth, single-file systems produce canal transportation comparable to, and at times lower than, multi-file sequences, and no single-file system was consistently superior. Adequately powered, standardised micro-CT studies reporting level-specific means and standard deviations are needed.

Keywords: Canal transportation; Cone-beam computed tomography; Micro-computed tomography; Reciprocation; Root canal preparation; Single-file system

Registration: PROSPERO- CRD420261414848, registered 03 June 2026

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1. INTRODUCTION

Cleaning and shaping aim to produce a continuously tapering preparation that keeps the original canal path and the apical foramen in place [1,2]. Canal transportation is the removal of canal wall structure on the outside curve in the apical half of the canal, caused by the tendency of files to return to their straight form [3]. It can lead to ledging, zipping, strip perforation and residual infected tissue, and apical transportation above about 0.3 mm has been linked to poorer seal of the root filling [3,4].

Single-file NiTi systems followed Yared's 2008 report that one reciprocating instrument could prepare a canal to its final size [5]. Reciprocating files (WaveOne, WaveOne Gold, Reciproc, Reciproc Blue) and continuous-rotation files (OneShape, One Curve, HyFlex EDM, XP-endo Shaper, Neoniti) reduce instrument sequences, working time and cross-contamination [6]. Their alloys, heat treatments, tapers and cross-sections differ widely, so their shaping behaviour cannot be assumed to be equivalent.

Micro-CT and CBCT allow non-destructive superimposition of pre- and post-instrumentation scans and calculation of transportation by the method of Gambill et al. [7,8]. Many laboratory studies have used them to compare single-file systems with one another and with multi-file sequences, but their conclusions conflict [9–11]. Most were done in curved mesial canals of molars, where curvature dominates; evidence from single-rooted teeth, the most common anatomy in daily practice and the population of this review, has not been synthesised.

The objective of this systematic review was to evaluate and compare the canal transportation produced by single-file endodontic systems during preparation of extracted human single-rooted permanent teeth, as assessed by micro-CT or CBCT.

2. METHODS

2.1 Protocol and registration

The review was reported according to PRISMA 2020 [12]. The protocol was registered in PROSPERO on 03 June 2026 before data extraction began.

2.2 Eligibility criteria (PICOS)

Element	Inclusion	Exclusion
Population	Extracted human single-rooted permanent teeth (single canal, mature apex)	Primary teeth; multi-rooted teeth; immature apices; root resorption; previously treated or fractured teeth; artificial blocks or 3D-printed replicas
Intervention	Root canal preparation with any commercially available single-file NiTi system, reciprocating or continuous rotation	Single files used only as glide path or retreatment instruments
Comparator	Another single-file system, a multi-file sequence, a different kinematic, or the same file with a different adjunct (glide path, access design)	No comparator group
Outcome	Canal transportation (mm) measured on pre- and post-instrumentation micro-CT, CBCT or another validated 3D imaging method	Transportation not reported; 2D radiographic or sectioning methods only
Study design	Randomised or non-randomised comparative in vitro studies	Reviews, case reports, abstracts without full text, non-English reports

2.3 Information sources and search

PubMed/MEDLINE, Scopus and Google Scholar were searched from inception to [insert date of final search], with no date restriction and an English-language limit. Only published studies were sought. The PubMed strategy, adapted for the other databases, was:

("canal transportation" OR "apical transportation" OR "centering ability" OR "shaping ability") AND ("single file" OR "single-file" OR WaveOne OR Reciproc OR OneShape OR "One Curve" OR "HyFlex EDM" OR "XP-endo Shaper" OR Neoniti OR "reciprocating") AND ("cone-beam computed tomography" OR CBCT OR "micro-computed tomography" OR "micro-CT") AND (premolar* OR incisor* OR canine* OR "single-rooted")

For Google Scholar, the first [insert number] records sorted by relevance were screened.

2.4 Study selection

Records were de-duplicated in [insert reference manager]. Two reviewers (KB, AC) independently screened titles and abstracts and then full texts against the eligibility criteria. Disagreements were resolved by discussion. Reasons for full-text exclusion were recorded.

2.5 Data collection

Two reviewers independently extracted data into a piloted form: author, year, country, tooth type and number, canal curvature (Schneider method [16]) and shape, single-file system(s) with size, taper and kinematics, comparator(s), glide path, imaging modality, measurement levels, transportation formula, statistical tests and main findings. Means and standard deviations of transportation at each level were extracted where reported. Missing data were requested from corresponding authors [insert whether any replied].

2.6 Risk of bias

Risk of bias was appraised independently by two reviewers using the JBI checklist for quasi-experimental studies [13], modified for laboratory endodontic research. Items were: Q1 clear cause and effect; Q2 groups similar at baseline (curvature, length or anatomical matching); Q3 groups treated alike apart from the intervention (single operator, standard irrigation and working length); Q4 comparator group; Q5 pre- and post-instrumentation measurements; Q6 complete specimen follow-up; Q7 outcome measured in the same way in all groups; Q8 reliable outcome measurement (calibrated or blinded examiner); Q9 appropriate statistics; Q10 sample size justification. Each item was rated yes, no or unclear. Studies with ≥8 yes ratings were judged low risk, 5–7 moderate and ≤4 high.

2.7 Synthesis methods

A random-effects meta-analysis of mean or standardised mean differences with 95% confidence intervals was planned where at least two studies compared the same systems at comparable levels. Heterogeneity was to be assessed with I^2. Because comparator pairs rarely repeated, levels ranged from 1 to 11 mm from the apex, transportation was reported as signed or absolute values, and level-specific means with standard deviations were unavailable for most studies, pooling was not appropriate. Results were therefore synthesised narratively following the Synthesis Without Meta-analysis (SWiM) guideline [15]. Studies were grouped by comparison: (a) single-file versus multi-file; (b) reciprocating versus continuous-rotation single files; (c) between reciprocating single files and alloy generations; (d) adjuncts (glide path and access cavity). The direction of effect was tabulated by apical, middle and coronal level and summarised by vote counting based on direction and statistical significance.

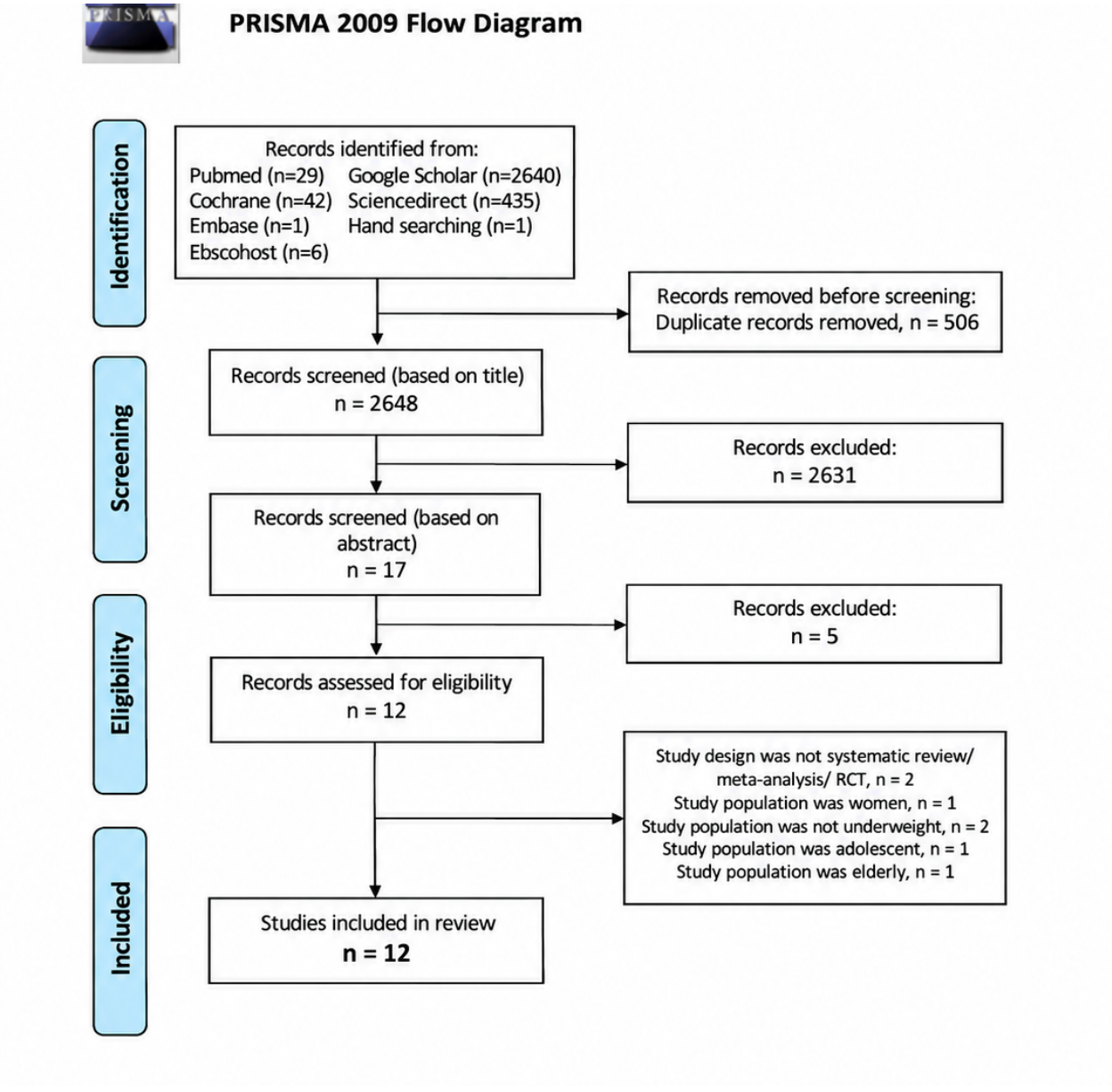
2.8 Reporting bias and certainty of evidence

Risk of bias due to missing results was judged qualitatively, since fewer than ten studies addressed any single comparison and funnel plots were not informative. Certainty for each comparison was rated with GRADE [14]. Laboratory evidence started at low certainty and was downgraded for risk of bias, inconsistency, indirectness (in vitro surrogate outcome) and imprecision (small samples).

3. RESULTS

3.1 Study selection

The searches identified [n] records (PubMed/MEDLINE [n], Scopus [n], Google Scholar [n]). After removal of [n] duplicates, [n] titles and abstracts were screened and [n] full texts were assessed. Twelve studies met the eligibility criteria [17–28] (Figure 1). The most frequent reasons for exclusion were use of molar mesial roots or other multi-rooted teeth (for example [31]), simulated resin canals or 3D-printed replicas, no single-file arm, and no transportation outcome despite micro-CT analysis of single-rooted teeth [29,30].



PRISMA 2020 flow · 12 studies included

Bracketed counts are to be completed from the database exports of the final search.

3.2 Study characteristics

The twelve studies, published between 2014 and 2025, evaluated 702 teeth (Table 1). Seven were conducted in India, two in Brazil and one each in Lebanon, France and Egypt. Premolars were used in ten studies, canines in one and mandibular incisors in one; three studies selected oval canals [23,27,28]. Eleven studies used CBCT and one used micro-CT [23]. Measurement levels ranged from 1 to 11 mm from the apex, and all studies that reported their formula used the method of Gambill et al. [7].

Table 1. Characteristics of included studies

Study	Country	Teeth (n)	Single-file system (kinematics)	Comparator(s)	Imaging; levels	Main transportation finding
Tambe et al., 2014 [17]	India	Curved premolars ≥10° (30; 10/group)	WaveOne (R); OneShape (C)	ProTaper Universal	CBCT; 3 levels	WaveOne transported least, less than OneShape and ProTaper
Jain et al., 2016 [18]	India	Single-rooted premolars, 10–24° (40; 20/group)	WaveOne (R)	ProTaper Universal	CBCT; 3, 6, 9 mm	WaveOne less at 3 and 6 mm; no difference at 9 mm
Mamede-Neto et al., 2017 [19]	Brazil	Mandibular premolars (128; 16/group)	WaveOne, WaveOne Gold, Reciproc (R)	ProTaper Next, ProTaper Gold, Mtwo, BioRaCe, RaCe	CBCT; [levels: verify]	No significant difference among the eight systems
Jain et al., 2018 [20]	India	Single-rooted mandibular premolars (40; 20/group)	WaveOne (R); OneShape (C)	Head-to-head	CBCT; 1, 3, 5 mm	WaveOne less; OneShape transported at 1 and 3 mm
Jain & Gupta, 2019 [21]	India	Single-rooted mandibular premolars (40; 20/group)	WaveOne; Reciproc (R)	Head-to-head	CBCT; 3, 6, 9 mm	WaveOne less than Reciproc
Hage et al., 2020 [22]	Lebanon	Curved single-rooted premolars (120; 30/group)	Reciproc R25; Reciproc Blue RB25 (R)	With or without PathFile glide path	CBCT; [levels: verify]	Reciproc Blue did not reduce transportation versus Reciproc; PathFile improved centring
Xavier et al., 2020 [23]	Brazil	Oval single-canal canines (40; 20/group, paired)	XP-endo Shaper (C)	Mtwo	Micro-CT at 37 °C; 3, 5, 7 mm	No difference
Antony et al., 2020 [24]	India	Single-rooted mandibular premolars, 0–10° (30; 10/group)	One Curve (C)	ProFit S3, ProTaper Gold	CBCT; 3, 6, 9 mm	No difference
Majumdar et al., 2022 [25]	India	Single-rooted premolars, 10–20° (60; 20/group)	XP-endo Shaper (C)	ProTaper Gold, EdgeFile X7	CBCT; 2, 4, 6 mm	XP-endo Shaper less than ProTaper Gold
Richard et al., 2022 [26]	France	Mandibular incisors, <35° (54; 18/group)	WaveOne Gold (R)	Manual, ProGlider or WaveOne Gold Glider glide path	CBCT; 4, 7, 11 mm	Mechanical glide paths less than manual at 7 mm
Saurabh et al., 2025 [27]	India	Oval mandibular premolars (60; 20/group)	One Curve (C)	Jizai, HyFlex CM	CBCT; 3, 6, 9 mm (MD, BL)	No difference at 3 and 6 mm; HyFlex CM highest at 9 mm MD
Sherif & Attia, 2025 [28]	Egypt	Single-canal premolars (60; 10/group)	HyFlex EDM (C); WaveOne Gold (R)	TruNatomy; traditional vs conservative access	CBCT; apical, middle, coronal	WaveOne Gold highest; HyFlex EDM similar to TruNatomy; conservative access increased apical and middle transportation

R, reciprocation; C, continuous rotation; MD, mesiodistal; BL, buccolingual.

3.3 Risk of bias

All twelve studies were judged at moderate risk of bias (Table 2). Every study had pre- and post-instrumentation scans with an identical protocol and a comparator group. None reported a sample size calculation in the accessed report, and none stated that the examiner was calibrated or blinded to group allocation. Anatomical matching before allocation was explicit only in the micro-CT study [23]; other studies relied on curvature ranges or length standardisation.

Table 2. Risk of bias (modified JBI checklist)

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Yes (n/10)	Overall
Tambe 2014	Y	U	U	Y	Y	U	Y	U	Y	U	5	Moderate
Jain 2016	Y	Y	U	Y	Y	Y	Y	U	Y	N	7	Moderate
Mamede-Neto 2017	Y	U	U	Y	Y	U	Y	U	Y	U	5	Moderate
Jain 2018	Y	Y	U	Y	Y	U	Y	U	Y	U	6	Moderate
Jain & Gupta 2019	Y	Y	U	Y	Y	U	Y	U	Y	U	6	Moderate
Hage 2020	Y	Y	Y	Y	Y	U	Y	U	Y	U	7	Moderate
Xavier 2020	Y	Y	U	Y	Y	U	Y	U	Y	U	6	Moderate
Antony 2020	Y	Y	U	Y	Y	Y	Y	U	Y	N	7	Moderate
Majumdar 2022	Y	Y	U	Y	Y	U	Y	U	Y	U	6	Moderate
Richard 2022	Y	Y	U	Y	Y	U	Y	U	Y	U	6	Moderate
Saurabh 2025	Y	U	U	Y	Y	Y	Y	U	Y	N	6	Moderate
Sherif 2025	Y	U	U	Y	Y	U	Y	U	Y	U	5	Moderate

Y, yes; N, no; U, unclear. Q1–Q10 as defined in Section 2.6.

3.4 Synthesis of results

Quantitative pooling was not possible (Section 2.7). Table 3 shows the direction of effect for each comparison and root level.

Table 3. Direction of effect on canal transportation by comparison and level

Comparison	Study	Apical	Middle	Coronal
(a) Single-file vs multi-file	Tambe 2014: WaveOne, OneShape vs ProTaper	WaveOne lower (level-specific data not reported)	—	—
	Jain 2016: WaveOne vs ProTaper	SF lower	SF lower	No difference
	Mamede-Neto 2017: WaveOne, WaveOne Gold, Reciproc vs five multi-file	No difference	No difference	No difference
	Xavier 2020: XP-endo Shaper vs Mtwo	No difference	No difference	No difference
	Antony 2020: One Curve vs ProTaper Gold, ProFit S3	No difference	No difference	No difference
	Majumdar 2022: XP-endo Shaper vs ProTaper Gold	SF lower	SF lower	Not measured
	Saurabh 2025: One Curve vs Jizai, HyFlex CM	No difference	No difference	SF lower than HyFlex CM (MD)
	Sherif 2025: WaveOne Gold, HyFlex EDM vs TruNatomy	WaveOne Gold higher; HyFlex EDM no difference	Same	Same
(b) Reciprocating vs rotary single-file	Tambe 2014: WaveOne vs OneShape	Reciprocating lower	—	—
	Jain 2018: WaveOne vs OneShape	Reciprocating lower at 1 and 3 mm; no difference at 5 mm	Not measured	Not measured
	Sherif 2025: WaveOne Gold vs HyFlex EDM	Reciprocating higher	Reciprocating higher	Reciprocating higher
(c) Between reciprocating files and alloys	Jain & Gupta 2019: WaveOne vs Reciproc	WaveOne lower	WaveOne lower	WaveOne lower
	Mamede-Neto 2017: WaveOne vs WaveOne Gold vs Reciproc	No difference	No difference	No difference
	Hage 2020: Reciproc Blue vs Reciproc	No difference	No difference	No difference
(d) Adjuncts	Richard 2022: mechanical vs manual glide path (WaveOne Gold)	No difference	Mechanical lower	No difference
	Hage 2020: PathFile vs no glide path (Reciproc, Reciproc Blue)	Centring improved; transportation [verify]	—	—
	Sherif 2025: traditional vs conservative access	Traditional lower	Traditional lower	No difference

SF, single-file. “Lower” and “higher” denote statistically significant differences ($P < 0.05$) as reported by the study.

(a) Single-file versus multi-file sequences. Eight studies addressed this comparison. Four found less transportation with the single-file system at one or more levels: WaveOne against ProTaper Universal [17,18], XP-endo Shaper against ProTaper Gold [25], and One Curve against HyFlex CM at 9 mm [27]. Three found no difference: WaveOne, WaveOne Gold and Reciproc against five multi-file systems [19], XP-endo Shaper against Mtwo [23], and One Curve against ProTaper Gold and ProFit S3 [24]. One gave mixed results: WaveOne Gold transported more than TruNatomy, while HyFlex EDM did not differ from it [28]. Where differences favoured single files, the comparator was usually a progressively tapered ProTaper file [17,18,25].

(b) Reciprocating versus continuous-rotation single files. WaveOne transported less than OneShape in two premolar studies [17,20], with the difference concentrated within 3 mm of the apex [20]. In contrast, WaveOne Gold transported more than HyFlex EDM in the only study that compared heat-treated files of both kinematics [28]. Kinematics alone therefore did not predict transportation.

(c) Between reciprocating files and alloy generations. One study found less transportation with WaveOne than Reciproc at 3, 6 and 9 mm [21]. Another found no difference among WaveOne, WaveOne Gold and Reciproc [19]. The heat-treated Reciproc Blue did not reduce transportation compared with M-Wire Reciproc in 120 premolar canals [22].

(d) Adjuncts. With WaveOne Gold, a mechanical glide path (ProGlider or WaveOne Gold Glider) produced less transportation and better centring than manual files at the middle level, with no difference between rotary and reciprocating glide path files [26]. A PathFile glide path improved centring of Reciproc and Reciproc Blue [22]. Conservative access cavities increased apical and middle-third transportation regardless of the file system [28].

Magnitude. Few accessed reports gave level-specific means with standard deviations. In the study that did, mean absolute transportation with One Curve and Jizai stayed within 0.5 mm at all levels, while HyFlex CM reached 0.94 ± 0.35 mm at 9 mm mesiodistally [27]. Whether the differences reported elsewhere exceed the 0.3 mm threshold associated with impaired apical seal [4] could not be determined.

3.5 Reporting bias and certainty of evidence

Only published, English-language studies were sought, and seven of twelve came from Indian centres, three from one author group [18,20,21]. Small studies with positive findings for a newer system are more likely to be published, so reporting bias is possible. Certainty of evidence was very low for every comparison (Table 4).

Table 4. Certainty of evidence (adapted GRADE)

Comparison	Studies (teeth)	Risk of bias	Inconsistency	Indirectness	Imprecision	Certainty
(a) Single-file vs multi-file	8 (448)	Serious	Serious	Serious	Serious	Very low
(b) Reciprocating vs rotary single-file	3 (130)	Serious	Serious	Serious	Serious	Very low
(c) Between reciprocating files and alloys	3 (288)	Serious	Serious	Serious	Serious	Very low
(d) Glide path and access design	3 (234)	Serious	Not serious	Serious	Serious	Very low

Evidence started at low certainty because all studies were laboratory studies; indirectness reflects the in vitro surrogate outcome. Teeth counts include all arms of contributing studies.

4. DISCUSSION

This review found that, in single-rooted permanent teeth, single-file systems produced canal transportation equal to or lower than multi-file sequences in seven of eight comparisons, and that no single-file system or kinematic was consistently superior. The evidence comes from small laboratory studies at moderate risk of bias, so certainty is very low.

Single-file versus multi-file. Single files performed best against progressively tapered, conventionally treated ProTaper instruments [17,18,25]. A progressive taper and a stiffer core raise the restoring force of the file in a curve, which favours straightening [3,18]. When the comparators were heat-treated or constant-taper files such as ProTaper Gold, Mtwo, ProFit S3 or the RaCe family, differences disappeared [19,23,24]. This pattern suggests that alloy and design, more than the number of files, govern transportation. It agrees with molar studies in which WaveOne, Reciproc and OneShape shaped curved mesial canals with similar transportation [10] and with an early comparison of Reciproc and WaveOne against Mtwo and ProTaper [6].

Kinematics. Reciprocation is thought to reduce taper lock and torsional stress and so keep the file centred [5]. WaveOne did outperform the older, conventionally treated OneShape in two premolar studies [17,20]. However, the heat-treated rotary HyFlex EDM transported less than WaveOne Gold [28], whereas in molar mesial canals WaveOne Gold transported less than HyFlex EDM, Reciproc Blue and OneShape at the apical level [9]. Kinematics therefore appears to interact with alloy, cross-section and taper rather than act alone.

Alloy generations. Heat treatment improves flexibility and fatigue resistance, but it did not translate into less transportation in single-rooted teeth: Reciproc Blue matched Reciproc [22], and WaveOne Gold matched WaveOne [19]. In straight or moderately curved premolar canals, older alloys may already be flexible enough for the difference to be undetectable with CBCT.

Adjuncts. A mechanical glide path reduced transportation with WaveOne Gold [26] and improved centring with Reciproc files [22]. Conservative access cavities increased transportation in premolars [28], probably because coronal interference bends the file before it reaches the curve. These factors may influence transportation as much as the choice of file.

Measurement and anatomy. Eleven of twelve studies used CBCT. Clinical CBCT voxels of 75–200 µm are close to the size of the differences being measured, which reduces precision and may hide small effects; micro-CT is the preferred laboratory reference [8]. Studies also used different levels, signed or absolute values and mesiodistal or buccolingual planes. Oval canals, common in premolars and mandibular incisors [32], add a second source of variation that only three studies addressed [23,27,28].

4.1 Strengths and limitations

The review was prospectively registered, restricted to one anatomical group to reduce heterogeneity, and used duplicate screening, extraction and appraisal. Its limitations are those of the evidence: small samples (10–30 teeth per group), unreported sample size calculations and examiner blinding, frequent use of CBCT, and inconsistent reporting of dispersion data that prevented meta-analysis. Searching was limited to three databases and English-language publications, grey literature was not sought, and seven studies came from Indian centres, three from one group. Transportation is a surrogate outcome; its link to healing has not been established.

4.2 Implications for research

Future studies should use micro-CT, anatomically matched groups, calculated sample sizes and blinded, calibrated examiners. They should report signed and absolute transportation as mean ± SD at standard levels (for example 1, 3, 5 and 7 mm from the apex) in both planes, and state canal curvature and shape. Comparisons should include contemporary heat-treated multi-file sequences and control glide path and access design.

5. CONCLUSIONS

Within the limits of very low-certainty laboratory evidence:

1. Single-file systems shape single-rooted permanent teeth with canal transportation comparable to, and sometimes lower than, multi-file sequences; advantages were seen mainly against conventionally treated ProTaper instruments.
2. Neither reciprocating nor continuous-rotation kinematics, nor a newer heat-treated alloy, consistently reduced transportation.
3. A mechanical glide path and a traditional access cavity were associated with less transportation.

4. Standardised, adequately powered micro-CT studies that report level-specific means and standard deviations are needed before any single-file system can be recommended over another.

DECLARATIONS

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Conflicts of interest: None declared.

Author contributions: KB conceived the review, designed the search, screened studies, extracted data and drafted the manuscript. AC screened studies, extracted data, assessed risk of bias and revised the manuscript. All authors approved the final version. [Edit as appropriate]

Data availability: Extraction forms and risk-of-bias judgements are available from the corresponding author on reasonable request.

Ethics: Not required for a systematic review of published laboratory studies.

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