REVIEW ARTICLE

Rotary versus Manual Glide Path Preparation in Root Canal Treatment: A Systematic Review and Meta-Analysis on Apically Extruded Debris

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ABSTRACT

Introduction: This systematic review and meta-analysis evaluated the influence of rotary and manual glide path preparation techniques on apically extruded debris during root canal treatment, addressing a critical aspect of endodontic treatment outcomes. **Methods:** Following PRISMA 2020 and COSMOS-E guidelines, a comprehensive search of Medline, Scopus, Embase, Epistemonikos, and grey literature identified *ex vivo* studies using human extracted teeth. Study quality was assessed with the RoBDEMAT tool, and meta-analysis (of four studies) used a random-effects inverse-variance model with a DerSimonian-Laird estimate. The level of evidence was evaluated using the DARE tool. A heat matrix was developed to map the confounding variables. **Results:** Eleven studies (2016–2024) met the inclusion criteria. Rotary systems, especially ProGlider, One G, and PathFile, showed significantly less debris extrusion compared to manual K-files. Meta-analysis revealed a standardized mean difference of 1.35 (95% CI: 0.82–1.87; $P < .01$), indicating greater apical debris with manual techniques. Newer rotary systems exhibited progressive improvements in debris reduction capabilities. **Conclusions:** This systematic review provides strong evidence that rotary glide path systems are more effective than manual techniques in minimizing apical debris extrusion during root canal treatment. These findings have significant clinical implications for reducing postoperative complications and improving treatment outcomes in endodontic practice. *(J Endod 2025;51:1021–1035.)*

KEY WORDS

Apical debris extrusion; manual glide path preparation; rotary glide path; root canal treatment; rotary instruments

SIGNIFICANCE

This systematic review provides compelling evidence that rotary glide path systems, particularly the ProGlider, significantly minimize apical debris extrusion compared to conventional manual K-file techniques in root canal treatment. By reducing extruded debris, these systems diminish the risk of postoperative complications such as pain and flare-ups, ultimately enhancing treatment outcomes and patient satisfaction. Endodontic practitioners are encouraged to adopt rotary glide path preparation as a routine clinical procedure to achieve improved therapeutic results.

Activated irrigants and hand or rotating tools are used in chemo-mechanical preparation. Apical instrumentation can force tissue remnants, dentin chips, and irrigants into periapical tissues[1–4], which can lead to postoperative discomfort and flare-ups[5–7] when the apical foramen is still patent. Canal curvature, irrigation method, file design, and cross-section all affect the amount of apically extruded debris (AED)[8,9].

Root canal procedures utilizing stainless steel instruments are associated with complications in curved radicular anatomies, manifesting as zipping, iatrogenic perforations, and canal transportation[10]. Contemporary nickel-titanium (NiTi) rotary systems demonstrate superior canal-centering capabilities[11]. While these systems significantly reduce operator fatigue, they possess an inherent vulnerability to torsional and flexural stresses[12]. This mechanical susceptibility may lead to instrument separation during clinical procedures. Clinical considerations further encompass heightened apical pressures and taper lock manifestations[13].

The initial establishment of guided pathways preceding NiTi rotary instrumentation constitutes a fundamental preparatory phase[14,15]. These pathways, characterized by uninterrupted channels extending from coronal access to apical terminus[16], traditionally employ instruments exhibiting 0.02 taper configurations with apical dimensions of 0.15 or 0.20 millimeters. Although conventional stainless steel K-file preparation demonstrates efficacy in reducing instrument fragmentation[15], this methodology exhibits

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limitations in negotiating curved canal architectures[17] and correlates with heightened postoperative discomfort relative to rotary protocols[18].

This investigation, through systematic literature examination and meta-analytical assessment, examines comparative outcomes between manual and rotary guided pathway methodologies regarding apically extruded debris (AED) within curved canal configurations, addressing current knowledge deficits in endodontic literature.

METHODS

Register and Protocol

This systematic review was registered in PROSPERO (CRD42024601182) and conducted in accordance with PRISMA 2020 guidelines[19] and Conducting Systematic Reviews and meta-analyses of Observational Studies of Etiology (COSMOS-E) standards for systematic reviews and meta-analyses of observational studies[20].

Search Strategy

Three calibrated reviewers (A.T., R.S., A.G.) conducted a systematic dual-assessment of rotary vs hand glide path effects on AED under expert supervision (D.A.). The search protocol encompassed six databases (Medline/PubMed, Scopus, Embase, Epistemonikos, Cochrane, EBSCOhost) through January 2025, utilizing MeSH/EMTREE terms:

((("rotaries"[All Fields] OR "rotary"[All Fields]) AND ("glide"[All Fields] OR "glided"[All Fields] OR "glides"[All Fields] OR "gliding"[All Fields]) AND "path"[All Fields]) OR (("hand"[MeSH Terms] OR "hand"[All Fields]) AND ("glide"[All Fields] OR "glided"[All Fields] OR "glides"[All Fields] OR "gliding"[All Fields]) AND "path"[All Fields])) AND (("apical"[All Fields] OR "apically"[All Fields] OR "apicals"[All Fields] OR "apices"[All Fields]) AND ("extrude"[Supplementary Concept] OR "extrude"[All Fields] OR "extrude"[All Fields] OR "extrudability"[All Fields] OR "extrudable"[All Fields] OR "extrudate"[All Fields] OR "extrudated"[All Fields] OR "extrudates"[All Fields] OR "extruded"[All Fields] OR "extruder"[All Fields] OR "extruders"[All Fields] OR "extrudes"[All Fields] OR "extruding"[All Fields]) AND "debris"[All Fields])

Supplementary searches included 20-year reference lists from major endodontic journals (International Endodontic Journal, Journal of Endodontics, Journal of Dental Research, Journal of Dentistry, Clinical Oral Investigation, International Journal of Oral Maxillofacial Surgery, Journal of Periodontal Research) and gray literature (Networked Digital Library, Shodh Ganga, Shodh Gangotri). The search concluded on February 15, 2025, with inter-reviewer reliability assessed via percentage agreement and kappa coefficient.

Selection Criteria

Only *ex vivo/in vitro* studies were considered. Specifically, studies were included if they utilized extracted human teeth (removed for orthodontic or periodontal reasons), employed the Myers and Montgomery method to quantify AED, compared manual (SS hand files #10–15) and rotary glide path preparation (with at least one group using rotary instruments), and ensured that final canal preparation was completed using rotary or reciprocating instrumentation in both groups. Studies were excluded if they involved animal models, alternative AED measurement methods lacked final rotary/reciprocating preparation in the manual group, were narrative reviews, editorials, or opinion pieces, or were published in languages other than English.

Study Selection Process and Data Extraction

Three calibrated reviewers (A.T., R.S., A.G.) via a pre-established, piloted spreadsheet, conducted a systematic dual-assessment of the effects of rotary vs hand glide path preparation on AED, under the expert supervision of a fourth reviewer (D.A.). Postduplicate removal (Zotero), 2 reviewers (A.T. and R.S.) performed independent title/abstract screening and full-text analysis against the inclusion criteria. Disagreements during screening or selection were resolved through discussion or, when necessary, consultation with the third reviewer (A.G.). Following title/abstract screening and eligibility assessment, reference lists were manually reviewed. Data discrepancies were resolved through author correspondence and the fourth reviewer (D.A.) arbitration. Extracted parameters included: author, publication year, country, study design, root canal curvature, group allocation, sample size, hand/rotary glide path protocols, apical debris measurements, statistical analyses, and outcomes. For multi-arm or overlapping publications, only pertinent data were extracted.

Focused Question

The present systematic review was designed to answer the following PECOS question:

Does hand or rotary glide path preparation influence the amount of apically extruded debris in human-extracted teeth after root canal preparation?

- (P) Population: Human teeth extracted for orthodontic or periodontal reasons.
- (E) Exposure: Root canal preparation using reciprocating or rotary instrumentation after establishing a rotary glide path.
- (C) Comparison: Root canal preparation using reciprocating or rotary instrumentation after establishing a hand glide path.
- (O) Outcome measure: Amount of apically extruded debris measured using the Myers-Montgomery method.
- (S) Study type: *Ex vivo* studies

Risk of Bias Assessment

The risk of bias was independently evaluated by 2 reviewers (D.A. and R.S.) using the Risk of Bias tool for Pre-Clinical Dental Material Research (RoBDEMAT) tool, developed by Delgadi Af et al[21], which is the first tool specifically designed for preclinical dental materials research and validated by expert stakeholders. The tool assesses four domains—planning/allocation (D1), specimen preparation (D2), outcome assessment (D3), and data treatment/outcome reporting (D4) through nine items addressing various bias sources and directing signaling questions, with responses categorized as "sufficiently reported/adequate," "insufficiently reported," "not reported/not adequate," or "not applicable."

Evaluation of Control Statements for Possible Confounders and Bias Consideration and Assessment of Confounding Factors

Eligible studies underwent screening for explicit confounder adjustments, with dual independent critical appraisal (A.T., R.S.) and third-reviewer arbitration (D.A.). A Direct Acyclic Graph was generated via DAGitty based on Petersen et al[22], methodology, with 6 structured questions derived from prior research analyzing control statements and confounders[23]. The causal diagram depicts primary domains (blue nodes) and constituent variables (green nodes), with directional arrows indicating influence pathways (Supplementary Fig. S1).

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https://doi.org/10.1016/j.joen.2025.05.014

Assessment of Confounding Factors

The detailed review by JM Petersen et al[22] was further followed step by step. First, a list of possible confounding variables was identified through a thorough review of the studies. This was followed by grouping the confounding variables into domains. A comprehensive table was made where each study was assessed based on controlling these confounding variables, that were grouped into domains. Scoring Criteria for assessing how each study controlled the confounding variables are:0 = No Control: Variable not controlled or not mentioned. 1 = Partial Control: Basic measures implemented but not comprehensive, 2 = Full Control: Comprehensive control measures implemented and documented. A heat matrix was developed by the R Shiny app (https://malcolmbarrett.shinyapps.io/metaconfoundr/), which generated a heat matrix after the data were entered in the sample sheet provided and data exported in a.csv file.

Quantitative Analysis (Meta-Analysis)

Of the 11 studies that were included in the systematic review, only 4 studies had the rotary glide path and final root canal preparation common. Thus, for the meta-analysis, we considered only 4 studies[24-27]. An inverse-variance model with a DerSimonian-Laird estimate of tau was applied. Since the mean values among these studies varied, the standardized mean difference (SMD).

Quality Assessment

Quality assessment of included publications utilized the DARE tool[28,29], evaluating 5 criteria: inclusion/exclusion reporting, search adequacy, included studies' quality assessment, individual study detail sufficiency, and synthesis methodology. Two reviewers (D.A., R.S.) performed independent assessment, with supervisor (A.G.) arbitration when consensus was unattainable. Inter-examiner agreement was quantified via kappa coefficient analysis.

RESULTS

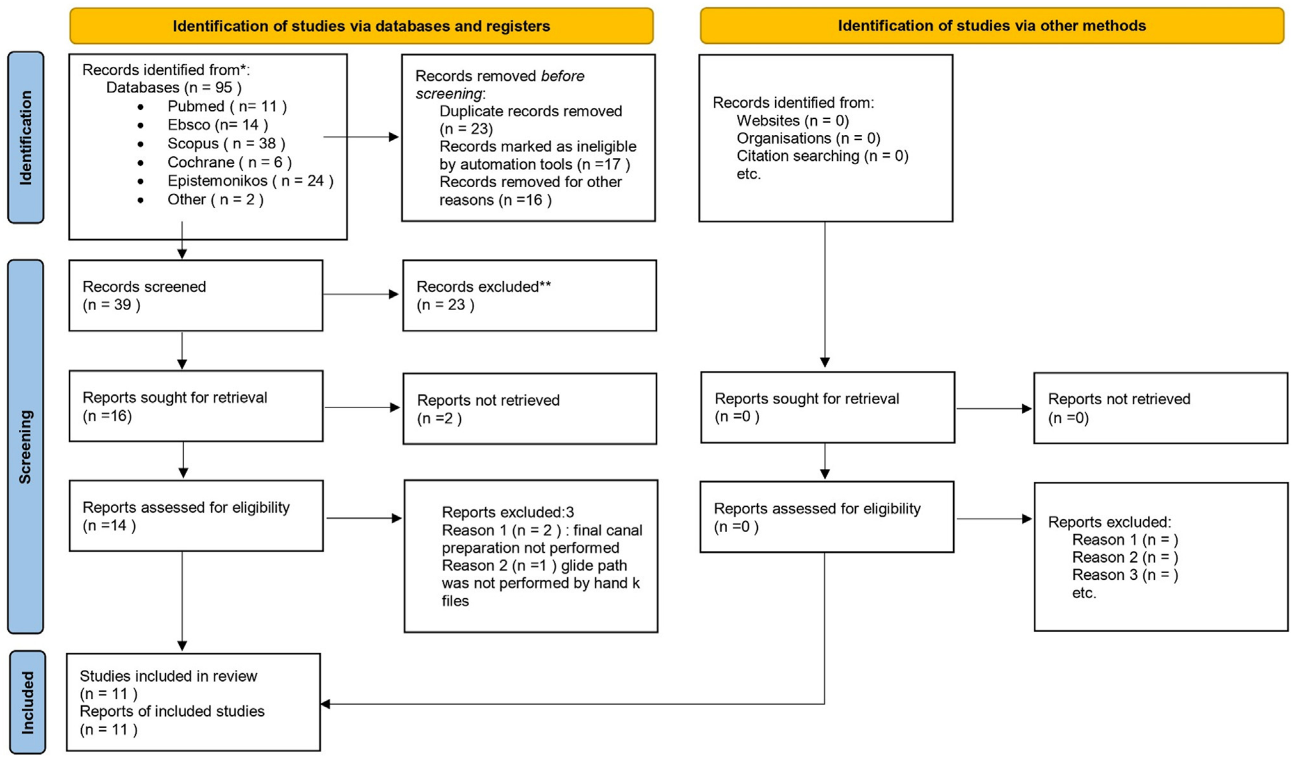
Characteristics of the Included Studies

After searching the database, we discovered 95 studies in total. Seventy-two remained after duplicates were eliminated. Thirty-nine articles were thoroughly reviewed after the remaining articles were excluded based on the abstract and title. Three items were later deleted due to their noncompliance with PECOS (Supplementary Table S1). Thus, as indicated by the revised PRISMA flow chart (Fig. 1), 11 research studies were included in the current systematic review. (The 27-point PRISMA checklist has been uploaded as Supplementary Table S2.

Results of Individual Studies

Multiple investigations have evaluated glide path preparation methodologies' influence on apical debris extrusion (Table 1). Gunes et al[24] demonstrated rotary systems' superiority (One G, G-Files, ProGlider, PathFile) over K-files when using WaveOne Gold. Ha JH et al,[25] established ProGlider's enhanced efficiency, while One G and ScoutRace showed intermediate effectiveness. Swarnakar et al[26] documented ProGlider's superior performance when combined with rotary NiTi systems. Zheng et al[27] confirmed ProGlider's efficacy in reducing canal transportation and debris extrusion compared to conventional methods.

Abdallah et al[33] and Keskin et al[32] demonstrated that the ProGlider instrument



*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).
**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

Source: Page MJ, et al. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

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FIGURE 1 – PRISMA flowchart.

TABLE 1 - Characteristics of the Studies Included

Author journal and year	Type of study	Type of teeth	Description of group	Curvature of root in degrees	Rotary glide path preparation	Manual glide path preparation	Final preparation of canal	Method to measure apical debris extrusion	Quantity of debris extruded in grams (g)	*P* value	Statistical analysis	Clinical implications	Inference
Pawar AM,et al J Conserv Dent 2017[30]	*In Vitro*	Lower Molar	Total sample size ($n = 60$)					Myers And Montgomery			One-Way ANOVA Tukey's Post Hoc Test ($P < .05$)	20/0.04 Glide Path Preparation Reduces Debris Extrusion	Glide Path Prepared To Size 20/0.04 And SAF 1.5 Mm Instrumentation Produce Less Debris In Curved Mesial Canals Of Mandibular Molars, Compared To Glide Path Established By 20/0.02 And Instrumentation By OS And WO Files.
			Group 1 (20/0.02 + One Shape) ($n = 20$)	20–40		NiTi 20/0.02 Hand K Files	OS (25/0.06)		Group 1 (20/0.02 + One Shape) = 0.000691 ± 0.000281	$P < .01$			
			Group 2 (20/0.02 + Wave one) ($n = 20$)	20–40		NiTi 20/0.02 Hand K Files	WO Primary (25/0.08)		Group 2 (20/0.02 + Wave one) 0.000723 ± 0.000319	$P < .01$			
			Group 3 (20/0.04+ Self Adjusting) ($n = 20$)	20–40	20/0.04 Rotary File		1.5 SAF		Group 3 (20/0.04+ Self Adjusting) = 0.000473 ± 0.000238	$P < .01$			
Gunes B, et al J Endod 2018[24]	*In Vitro*	Lower Molar	Total Sample Size ($n = 60$)					Myers And Montgomery			One-Way ANOVA Tukey's Post Hoc Test	Mechanical Glide Path Systems Reduce Debris Extrusion Compared To Manual Preparation	Manual K-Files Caused More Debris Extrusion Than One G Rotary Glide Path Files. Glide Path Preparation Had No Effect On Apical Debris Extrusion Before Root Canal Preparation Using A WOG File
			Group G-File: Rotary Glide Path ($n = 10$)	25–35	G1 (0.12 Taper) And G2 (0.17 Taper		Wave One Gold Primary Reciprocating File		0.00016 + 0.00013	$P < .05$			
			Group One G ($n = 10$)	25–35	Rotary Glide Path With 0.14 Taper		Wave One Gold Primary Reciprocating File		0.000088 ± 0.00005051	$P < .05$			
			Group ProGlider ($n = 10$)	25–35	Glide Path With Pro Glider 0.16 Taper		Wave One Gold Primary Reciprocating File		0.00028 ± 0.00020155	$P < .05$			
			Group Pathfile ($n = 10$)	25–35	Rotary Glide Path With 0.13 And 0.16 Taper		Wave One Gold Primary Reciprocating File		0.000137 ± 0.00007861	$P < .05$			
			Group K File ($n = 10$)	25–35		#10 And #15 Stainless Steel K Files For Glide Path Preparation	Wave One Gold Primary Reciprocating File		0.000326 ± 0.00021542	$P < .05$			
			Group without glide path ($n = 10$)	25–35			Wave One Gold Primary Reciprocating File		0.000182 ± 0.00012647	$P < .05$			

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TABLE 1 - Continued

Author journal and year	Type of study	Type of teeth	Description of group	Curvature of root in degrees	Rotary glide path preparation	Manual glide path preparation	Final preparation of canal	Method to measure apical debris extrusion	Quantity of debris extruded in grams (g)	*P* value	Statistical analysis	Clinical implications	Inference
Kurt O AEJ 2022[31]	*In Vitro*	Lower 1st Molar	Total sample size ($n = 96$)					Myers And Montgomery		$P < .05$	ANOVA AND Tukey Post-Hoc Test	Rotary Glide Path Systems Reduce Debris Extrusion	The Amount Of Apically Extruded Debris Was Higher In The Control Group (Without A Glide Path) Than In Glide Path Groups
			Without glide path ($n = 16$)	25–35			Rotate (25/0.04)		0.00587 ± 0.00018	$P < .05$			
			K File Group ($n = 16$)	25–35		#10 K And #15 K	Rotate (25/0.04)		0.003.79 ± 0.00014	$P < .05$			
			ProGlider Group ($n = 16$)	25–35	ProGlider File		Rotate (25/0.04)		0.00321 ± 0.00015	$P < .05$			
			R- Pilot Group ($n = 16$)	25–35	R - Pilot File		Rotate (25/0.04)		0.00276 ± 0.00019	$P < .05$			
			Trunatomy Glider Group ($n = 16$)	25–35	Trunatomy Glider File		Rotate (25/0.04)		0.00293 ± 0.00011	$P < .05$			
			Wave One Gold Glider Group ($n = 16$)	25–35	Wave One Gold		Rotate (25/0.04)		0.00339 ± 0.00015	$P < .05$			
Keskin C, et al Aust Endod J 2020[32]	*In Vitro*	Lower Molar	Total sample size ($n = 80$)					Myers And Montgomery			ANOVA and Tukey Post-Hoc Test	Rotary Glide Path Systems Recommended For Reducing Debris Extrusion	ProGlider, R-Pilot Or Waveone Gold Glider Instrument For Glide Path Preparation Prior To Further Enlargement With Reciproc Blue Excluded Less Amount Of Debris Compared To Manual Glide Path Preparation
			Rotary Proglider Group ($n = 20$)	25–35	ProGlider Instrument		Reciproc Blue R25		0.0022 ± 0.0010	$P < .05$			
			Reciprocating R – Pilot Group ($n = 20$)	25–35	R - Pilot		Reciproc Blue R25		0.0039 ± 0.0054	$P < .05$			
			Reciprocating Wave One Gold Glider Group ($n = 20$)	25–35	Wave One Gold Glider		Reciproc Blue R25		0.0036 ± 0.0025	$P < .05$			
			Hand K File Group ($n = 20$)	25–35		10 And 15 K Files	Reciproc Blue R25		0.0054 ± 0.0036	$P < .05$			
Swarnakar P, et al Endodontology 2023[26]	*In Vitro*	Lower Molar	Total sample size ($n = 80$)					Myers And Montgomery			ANOVA And Tukey's HSD Test ($P < .05$)	Rotary Niti Files Like PTG Result In Less Debris Extrusion Than Manual K-Files	• ProGlider Extruded The Least Amount Of Debris For Each Shaping File System. • All Rotary NiTi Glide Path Files Produced Less Debris Extrusion Than K-Files. Among

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TABLE 1 - Continued

Author journal and year	Type of study	Type of teeth	Description of group	Curvature of root in degrees	Rotary glide path preparation	Manual glide path preparation	Final preparation of canal	Method to measure apical debris extrusion	Quantity of debris extruded in grams (g)	*P* value	Statistical analysis	Clinical implications	Inference
													• The Shaping Files, PTG Extruded Less Debris Apically than WOG.
			Group 1 (WOG + Hand K file (*n* = 10)	5–20	1 - Group	#10 And #15 Manual K Files	WOG Primary File In Reciprocation		0.3916 ± 0.1533	Vs Group 2 – .085 Vs Group 3 – .760 Vs Group 4 – .048 Vs Group 5 – .038 Vs Group 6 – .001 Vs Group 7 – .012 Vs Group 8. – .001			
			Group 2 (WOG = G files) (*n* = 10)	5–20	G1 (#0.12) And G2 (#0.17)		WOG Primary File In Reciprocation		0.2283 ± 0.0152	Vs Group 3 – .883 Vs Group 4 – 1.000 Vs Group 5 – 1.000 Vs Group 6 – .822 Vs Group 7 – .997 Vs Group 8. – .018			
			Group 3 (WOG + One G) (*n* = 10)	5–20	One G (#0.14)		WOG Primary File In Reciprocation		0.3030 ± 0.2500	Vs Group 4 – .774 Vs Group 5 – .720 Vs Group 6 – .111 Vs Group 7 – .470 Vs Group 8. – .000			
			Group 4 (WOG + Pro glider) (*n* = 10)	5–20	ProGlider (0.16)		WOG Primary File In Reciprocation		0.2158 ± 0.0194	Vs Group 5 – 1.000 Vs Group 6 – .916 Vs Group 7 – 1.000 Vs Group 8. – .034			
			Group 5 (PTG + Hand K file) (*n* = 10)	5–20	5- Group	#10 And #15 Manual K Files	PTG Rotary System		0.2107 ± 0.0297	Vs Group 6 – 1.000 Vs Group 7 – .942 Vs Group 8. – .044			
			Group 6 (PTG + G files) (*n* = 10)	5–20	G1 (#0.12) and G2 (#0.17)		PTG Rotary System		0.1461 ± 0.0506	Vs Group 7 – .994 Vs Group 8. – .479			
			Group 7 (PTG + One G file) (*n* = 10)	5–20	One G (#0.14)		PTG Rotary System		0.1893 ± 0.1857	Vs Group 8. – .115			
			Group 8 (PTG + ProGlider) (*n* = 10)	5–20	ProGlider (0.16)		PTG Rotary System		0.033 ± 0.0339				
Abdallah MA Alex Dent J 2017[33]	*In Vitro*	Lower 1st Molar	Total sample size (*n* = 30)					Myers And Montgomery		*P* < .05	ANOVA Test	Rotary Glide Path Preparation With One-Shape System May Reduce Post-Operative Complications	• Rotary Glide Path Files Showed Less Amount Of Apical Extruded Debris Than Hand Files. • Less Amount Of Debris Was Obtained With The ProGlider Glide Path File.
			Group 1 (K type manual files) (*n* = 10)	25–35	Group 1	K Type Manual Files (# 10, # 15, # 20)	One Shape Single File		0.007 ± 0.003	.001			
			Group 2 (G1 and G2 of the G file system) (*n* = 10)	25–35	G1 And G2 Of G - File System		One Shape Single File		0.006 ± 0.003	.001			
			Group 3 (Single ProGlider File (*n* = 10)	25–35	Single ProGlider File		One Shape Single File		0.003 ± 0.001				

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TABLE 1 - Continued

Author journal and year	Type of study	Type of teeth	Description of group	Curvature of root in degrees	Rotary glide path preparation	Manual glide path preparation	Final preparation of canal	Method to measure apical debris extrusion	Quantity of debris extruded in grams (g)	*P* value	Statistical analysis	Clinical implications	Inference
Shekh TM et al Int J of Life Sci, Biotech and Pharma Res 2024[34]	*In Vitro*	Lower 1st Molar	Total sample size (n = 30)					Myers And Montgomery		.01	ANOVA Post-Hoc Tukey Test ($P < .05$)	All Mechanical Systems Produced Significantly Less Debris Than Manual Technique	Authors Found That More Debris Was Extruded By Manual K-Files Than By One G Rotary Glide Path Files. Apical Debris Extrusion Was Unaffected By Glide Path Preparation Prior To Root Canal Preparation With A WOG file
			Group I (Glide path + One G + WOG) (n = 5)	Curvature Not Mentioned	One G		Wave One Gold Preparation		0.000081 ± 0.0001	.01			
			Group II (Glide path + ProGlider + WOG) (n = 5)	Curvature not mentioned	ProGlider		Wave One Gold Preparation		0.000241 ± 0.0002	.01			
			Group III (Glide Path + Path files + WOG) (n = 5)	Curvature not mentioned	Pathfiles		Wave One Gold Preparation		0.000185 ± 0.0001	.01			
			Group IV (Glide path + G files) (n = 5)	Curvature not mentioned	G files		Wave One Gold Preparation		0.000154 ± 0.0004	.01			
			Group V (Glide Path + Kfile + WOG) (n = 5)	Curvature not mentioned		k file	Wave One Gold Preparation		0.000323 ± 0.0003	.01			
			Group VI Without Glide Path (n = 5)	Curvature not mentioned			Wave One Gold Preparation		0.000192 ± 0.0002	.01			
Nayak G Bioinformation 2024[35]	*In Vitro*	Lower Molar	Total Sample Size (n = 120)					Myers And Montgomery		$P < .05$	ANOVA And Tukey's Post Hoc Test	Rotary Glide Path Systems Reduce Debris Extrusion	The G Files Produced Less Debris Than The Other File Systems. The V Glide Path 2 File System Exhibited The Greatest Extrusion Of Debris.
			Group I (Senseus profinder) (n = 20)	0–10		Sensus Profinder Files	Final Canal Preparation Was Done But File Name Was Not Mentioned		0.000072 ± 0.000003	$P < .05$			
			Group II (PathFile) (n = 20)	0–10	Pathfiles Niti Rotary		Final Canal Preparation Was Done But File Name Was Not Mentioned		0.000105 ± 0.000005	$P < .05$			
			Group III (G-Files) (n = 20)	0–10	G Files		Final Canal Preparation Was Done But File Name Was Not Mentioned		0.00007 ± 0.000002	$P < .05$			

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TABLE 1 - Continued

Author journal and year	Type of study	Type of teeth	Description of group	Curvature of root in degrees	Rotary glide path preparation	Manual glide path preparation	Final preparation of canal	Method to measure apical debris extrusion	Quantity of debris extruded in grams (g)	*P* value	Statistical analysis	Clinical implications	Inference
			Group IV (Scout-RaCe files) (*n* = 20)	0–10	Scoutrace Files		Final Canal Preparation Was Done But File Name Was Not Mentioned		0.00008 ± 0.000002	$P < .05$			
			Group V (Hyflex glidepath files) (*n* = 20)	0–10	Hyflex Glidepath Files		Final Canal Preparation Was Done But File Name Was Not Mentioned		0.000078 ± 0.000003	$P < .05$			
			Group VI (V glide-path 2 file system (*n* = 20)	0–10	V Glide Path 2 File System		Final Canal Preparation Was Done But File Name Was Not Mentioned		0.000110 ± 0.000004	$P < .05$			
Ha JH J Dent Sci 2016[25]	*In Vitro*	Lower Incisor	Total sample size (*n* = 40)					Myers And Montgomery			One-Way ANOVA With Tukey's Test	Rotary Glide Path Systems Are Preferable To Manual Preparation	Creating The Glide-Path Using Nickel-Titanium Rotary Files Produced Lower Amounts Of Debris Extrusion Than Using Manual Stainless-Steel Files.
			Group ProGlider (*n* = 10)	Less Than 10	ProGlider (16 Progressive Taper)		Final Canal Preparation Was Done But File Name Was Not Mentioned		ProGlider = 0.000061 ± 0.000036	$P < .05$			
			Group One G (*n* = 10)	Less Than 10	One G (14/0.03 Taper)		Final Canal Preparation Was Done But File Name Was Not Mentioned		One G = 0.000118 ± 0.000041	$P < .05$			
			Group Scoutrace (*n* = 10)	Less than 10	Scoutrace (15/0.02 Taper)		Final Canal Preparation Was Done But File Name Was Not Mentioned		Scoutrace = 0.000117 ± 0.000068	$P < .05$			
			Group hand files (*n* = 10)	Less than 10		Ss Hand K File Group (15/0.02 Taper)	Final Canal Preparation Was Done But File Name Was Not Mentioned		Hand K File = 0.000177 ± 0.000078	$P < .05$			
Zheng, et al BMC Oral Health 2018[27]	*In Vitro*	Lower 1st Molar	Total sample size (*n* = 60)								One-Way ANOVA With Tukey's Test	Both The PG And PF Niti Glide Path File Groups Produced Significantly Less Apical Extruded Debris Than The KF Group	ProGlider File And Pathfiles Showed Reduced Apical Extruded Debris Compared To The K-Files.
			Group K Files (*n* = 20)	25–40		Stainless Steel K-Files (15#, 0.02 And 20#, 0.02),	Wave One Primary	Myers And Montgomery	K Files = 0.00144 ± 0.00045	$P < .05$			
			Group Path File (*n* = 20)	25–40	Pathfiles (13#, 0.02, 16#, 0.02, 19#, 0.02),		Wave One Primary		Pathfiles = 0.00049 ± 0.00022	$P < .05$			
			Group ProGlider (*n* = 20)	25–40	ProGlider Single File (16#, 0.02 To 0.085),		Wave One Primary		ProGlider = 0.00043 ± 0.00017	$P < .05$			

(*continued on next page*)

TABLE 1 - Continued

Author journal and year	Type of study	Type of teeth	Description of group	Curvature of root in degrees	Rotary glide path preparation	Manual glide path preparation	Final preparation of canal	Method to measure apical debris extrusion	Quantity of debris extruded in grams (g)	*P* value	Statistical analysis	Clinical implications	Inference
Pawar AM, et al Endod Practice Today 2017[36]	*In Vitro*	Lower Molar	Total sample size (*n* = 80)					Myers And Montgomery			One-Way ANOVA With Tukey's Test	The Universal Protaper Rotary Files Were Associated With Significantly Less Debris Extrusion In Spite Of Glide Path Preparation Using Both Files; 20/0.02 And 20/0.04 Compared With Waveone's Single Reciprocating File System ($P < .01$)	A Glide Path Prepared With A 20/0.04 Rotary File Decreased Debris Extrusion, Com Pared With A Glide Path Established By The 20/0.02
			Group Hand K Files + PTU (*n* = 20)	20–40		20/0.02 Hand K File	PTU		0.000769 ± 0.000446	$P < .01$			
			Group Hand K Files + Wave One (*n* = 20)	20–40		20/0.02 Hand K File	WOG		0.001028 ± 0.000614	$P < .01$			
			Group Rotary File + PTU (*n* = 20)	20–40	20/0.04		PTU		0.000489 ± 0.000651	$P < .01$			
			Group Rotary File + Wave One (*n* = 20)	20–40	20/0.04		WOG		0.000862 ± 0.000501	$P < .01$			

significantly reduced apical debris, particularly in curved canals. In contrast, Khatri et al[34] reported that K-files extruded more debris compared to mechanical systems. Kurt et al[31] found that the R-Pilot system was more effective in minimizing debris extrusion than other glide path techniques. Furthermore, Nayak et al[35], in a study involving 120 mandibular molars, concluded that the G file system extruded the least apical debris, whereas the newly introduced V file system resulted in the highest debris extrusion. Additionally, Pawar et al[30] compared 20/0.04 rotary and 20/0.02 manual preparation protocols using OneShape and WaveOne systems They concluded that 20/0.04 + Self-adjusting files instrumentation of the mesial canals of mandibular molars resulted in the least debris extrusion compared to the other groups. Pawar et al,[36] confirmed that the Protaper Universal system produced minimal apical debris relative to WaveOne instrumentation.

This comprehensive analysis (2016–2024) establishes mechanical systems' clinical superiority over manual techniques, despite *in vitro* limitations regarding periapical tissue simulation. The evidence demonstrates progressive improvement in mechanical systems' capability to minimize debris extrusion while maintaining canal integrity.

Quality Assessment and Risk of Bias

The RoBDEMAT tool was used to assess the risk of bias for the included studies (Table 2). A moderate Risk of bias was seen in 81.8% (9 studies) of the studies while a high risk was observed in 2 studies[26,34]. None of the studies reported adequate control groups.

Sample randomization was largely not reported, and blinding was not adequately reported in any of the studies. However, most studies (81.8%) adequately reported standardization procedures, testing procedures, statistical analysis, and study outcomes.

Evaluation of the Control Statements for Possible Confounders

None of the studies mentioned the word "bias" and confounders in the abstracts, discussion, or results based on the prior research analyzing control statements and confounders[23].

Assessment of Confounding Variables

A total of 26 confounding variables across 7 domains were identified (Supplementary Table

TABLE 2 - RoBDEMAT Tool

Domains	D1			D2		D3		D4		
Study reference	**Q1. Control group**	**Q2. Randomization of samples**	**Q3. Sample size rationale and reporting**	**Q4. Standardization of samples and materials**	**Q5. Identical experimental conditions across groups**	**Q6. Adequate and standardized testing procedures**	**Q7. Blinding of test operator**	**Q8. Statistical analysis**	**Q9. Reporting study outcomes**	**Overall risk**
Abdallah MA Alex Dent J 2017[33]	Not Reported	Insufficiently reported	Insufficiently reported	Adequate	Adequate	Adequate	Not Reported	Adequate	Adequate	Moderate
Gunes B et al J Endod 2018[24]	Reported	Insufficiently reported	Insufficiently reported	Adequate	Adequate	Adequate	Not Reported	Adequate	Adequate	Moderate
Ha JH J Dent Sci 2016[25]	Not Reported	Insufficiently reported	Insufficiently reported	Adequate	Adequate	Insufficiently reported	Not Reported	Adequate	Adequate	Moderate
Keskin C Aust Endod J 2020[32]	Not Reported	Insufficiently reported	Insufficiently reported	Adequate	Adequate	Adequate	Not Reported	Adequate	Adequate	Moderate
Khatri M Int J life Sci 2024[34]	Reported	Insufficiently reported	Insufficiently reported	Adequate	Insufficiently reported	Insufficiently reported	Not Reported	Adequate	Adequate	High
Kurt O Aust Endod J 2022[31]	Reported	Insufficiently reported	Insufficiently reported	Adequate	Adequate	Adequate	Not Reported	Adequate	Adequate	Moderate
Nayak G Bioinformation 2024[35]	Not Reported	Insufficiently reported	Insufficiently reported	Adequate	Adequate	Insufficiently reported	Not Reported	Adequate	Adequate	Moderate
Pawar AM Endod Practice Today[36]	Not reported	Insufficiently reported	Insufficiently reported	Adequate	Insufficiently reported	Adequate	Not Reported	Adequate	Adequate	Moderate
Pawar et al J Conserv Dent 2017[30]	Not Reported	Insufficiently reported	Insufficiently reported	Reported/ Adequate	Reported/ Adequate	Adequate	Not Reported	Reported/ Adequate	Reported/ Adequate	Moderate
Swarnakar P Endodontology 2023[26]	Not Reported	Insufficiently reported	Insufficiently reported	Adequate	Adequate	Adequate	Not Reported	Adequate	Adequate	High
Zheng L et al BMC Oral Health[27]	Not Reported	Insufficiently reported	Insufficiently reported	Adequate	Adequate	Adequate	Not Reported	Adequate	Adequate	Moderate

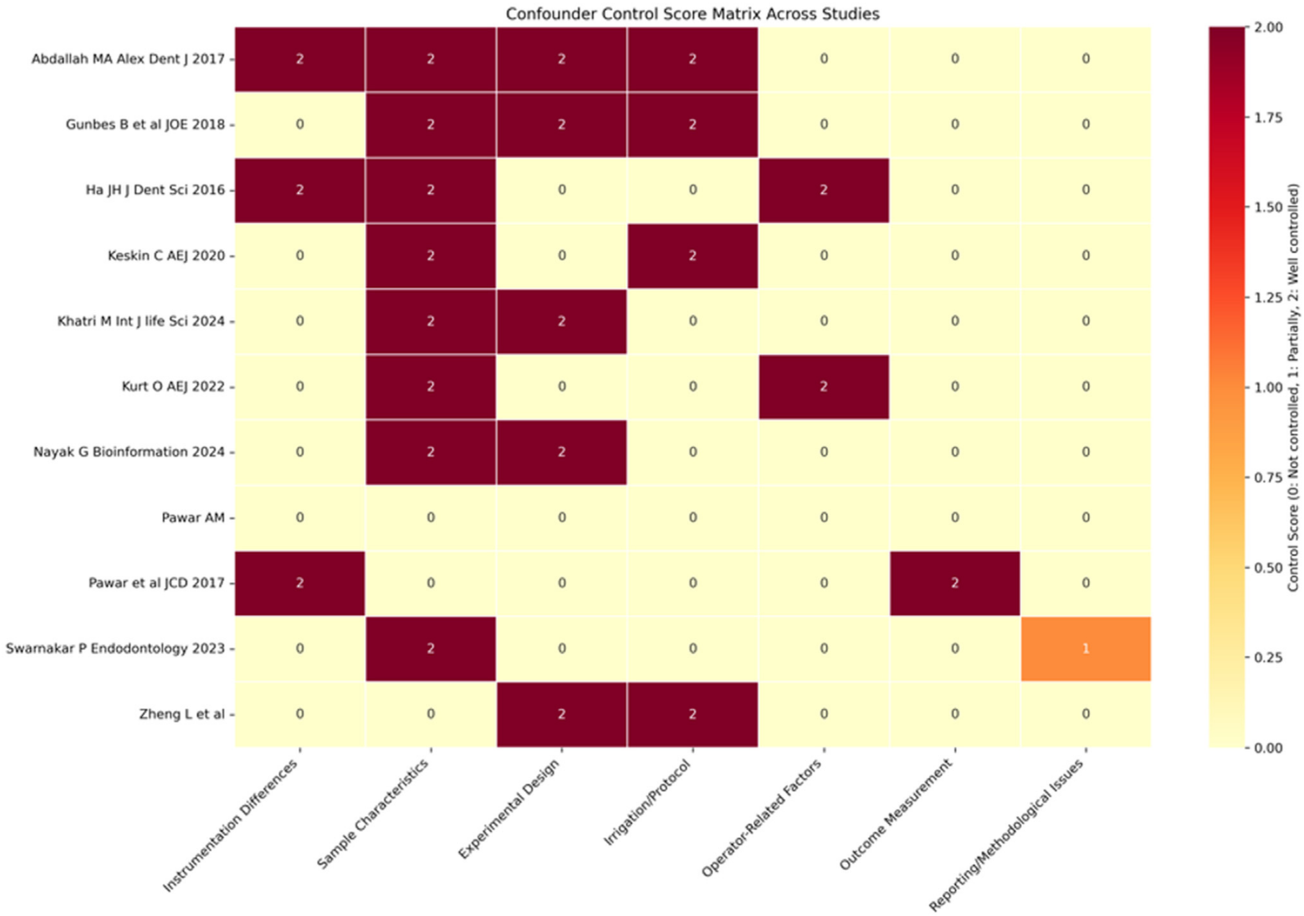

FIGURE 2 – Heatmatrix for control of confounders.

S3): instrumentation differences, irrigation protocols, sample characteristics, outcome measurements, experimental design, operator-related factors, and reporting/methodological issues. The investigation by Abdallah MA et al[33] demonstrated superior methodological control through four key variables: standardized instrumentation protocols, specimen pre-screening/matching, operator techniques, and irrigation protocols. In comparison, the study by Pawar AM et al[36] showed limited control with inadequate methodological documentation. Technical aspects of instrumentation received optimal attention in select investigations[25,30,33,36]. Four studies[24,27,33,35] exhibited excellent experimental design control, though only 3 implemented adequate irrigation protocols[24,27,33]. Operator-related variables received comprehensive consideration in two studies[25,31], and robust outcome measurement was evident solely in Pawar et al[30]. One study[26] incorporated partial measures for reporting and methodological control, though these aspects generally lacked rigorous implementation across the literature. A customized heat map (Fig. 2) based on Peterson JM et al.[22] illustrates that sample characteristics were most commonly controlled, whereas reporting/methodological issues were least addressed, emphasizing the need for standardized approaches particularly as demonstrated by Abdallah MA et al,[33].

Results of the Meta-Analysis

Four out of 11 trials that shared final root canal preparation techniques could be meta-analyzed. Several combinations of rotary and hand glide paths were assessed in studies by Gunbes B et al[24], Swarnakar P et al[26], Zheng et al,[27] and Khatri M et al[34]. Hand glide compared to G1/G2 WaveOne Gold comparison[24,26,34] showed no heterogeneity ($I^2 = 0.0\%$; $P > .05$) and considerably more debris in the manual group (SMD = 1.12; 95% CI: 0.51–1.73; $P < .001$). The comparison of One G Rotary + WaveOne Gold[24,26,34] revealed mild heterogeneity ($I^2 = 42.4\%$; $P > .05$) and significantly more debris with hand files (SMD = 1.04; 95% CI: 0.22–1.85; $P < .05$). Comparisons of ProGlider and WaveOne Gold[24,26,27,34] showed high heterogeneity ($I^2 = 82.3\%$; $P < .001$) and no significant difference (SMD = 1.27; 95% CI: 0.09–2.44; $P < .05$). PathFiles + WaveOne Gold comparison[24,26,27] showed a significant difference (SMD = 1.98; 95% CI: 0.66–3.33; $P < .05$) with moderate heterogeneity ($I^2 = 76.9\%$; $P < .05$). Forest plot analysis (Fig. 3) indicated increased apical extrusion in manual glide path groups across these analyses.

Level of Evidence (DARE)

High quality studies were 3 in number (Tables 3). Abdallah MA et al.[33] demonstrated comprehensive reporting and robust methodology across all DARE criteria. Gunbes B et al[24] exhibited strong adherence to all DARE criteria with clear reporting, while Ha JH et al[25] showed excellent compliance with all DARE criteria. The moderate quality studies were seven in number. Keskin C et al[32] revealed good synthesis but partial compliance in inclusion criteria and quality assessment. Khatri M et al[34] showed limitations in search methodology but partial reporting details. Kurt O et al,[31] demonstrated well-synthesized with some limitations in search methodology.

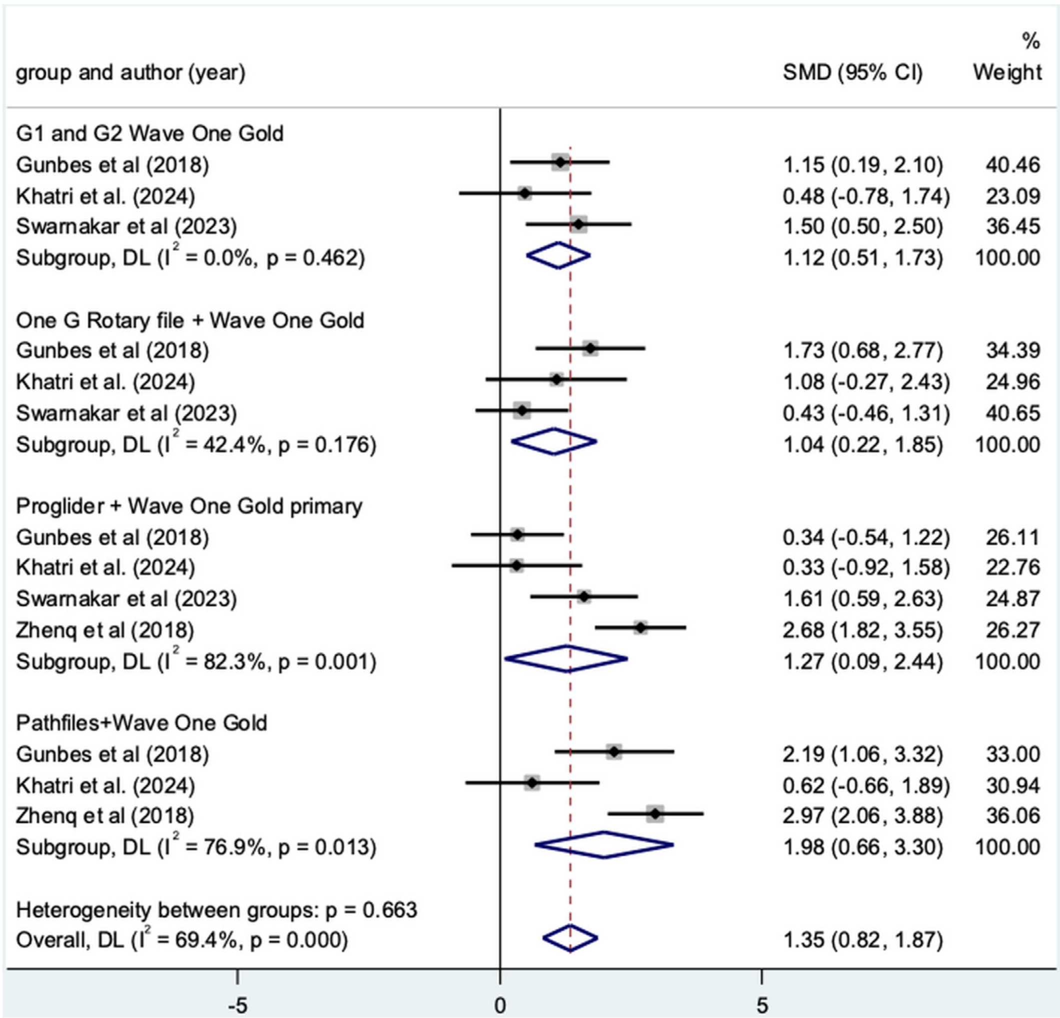

FIGURE 3 – Forest plot showing the comparison between hand glide files and various rotary glide files. SMD, standard mean difference.

Nayak G et al[35] showed adequate search but partial reporting of inclusion criteria. Pawar et al[30] also showed good synthesis but limitations in quality assessment. However, Swarnakar P et al[26] showed partial compliance with the search methodology. Zheng L et al[27] showed some limitations in quality assessment. The low-quality study was Pawar AM et al[36] who showed significant deficiencies across most DARE criteria, indicating substantial methodological and reporting limitations. The inter-rater reliability analysis for DARE Tool Assessment presents the inter-rater reliability between four independent reviewers for each of the five DARE tool questions. The assessment used Cohen's kappa to measure agreement between two reviewers (D.A. and R.S.). The interagreement score was 0.58 which was classified as a substantial agreement based on the table of Landis & Koch (1977), which was used as a guide.

DISCUSSION

The present discussion synthesizes the findings from 11 studies[24-27,30-36] investigating the effect of hand and rotary glide paths on apically extruded debris. The integration of various combinations of rotary and hand glide path systems provides insight into the amount of debris extruded apically. Only studies that evaluated the effect of hand and rotary glide path in human extracted teeth and completion of canal preparation by either rotary or reciprocating motion were included in this review. The main focus was on the creation of a glide path with hand SS files # 10 and 15 to glide path by rotary system. Studies were stratified by canal curvature, system type, and sample size. In groups using rotary systems, AED ranged from 0.000061 g[25] to 0.006 g[33], while manual glide path approaches reported AED values from 0.000177 g[34] to 0.007 g[33] in studies with fewer than 50 teeth. In investigations involving 50–100 teeth, AED in the manual groups spanned from 0.000326 g[24] to 0.3916 g[26], compared to 0.000088 g[24] to 0.3030 g[26] for the rotary groups. A single study comprising more than 100 teeth recorded an AED of 0.00007 g in the manual arm and 0.000110 g in the rotary arm[35].

All 11 investigations employed K-files for manual glide path creation, with the exception of Nayak et al[35], who utilized the Senseus Profinder. Consistently, manual methods produced higher mean debris extrusion than rotary approaches. Additionally, three studies featuring a no-glide path control (Kurt et al[31], Gunes B et al[24], and Khatri M et al[34]) reported increased debris extrusion in the control group relative to the K-file group in only one instance (Kurt et al[31]). Among rotary systems, the Pro Glider was most frequently applied, with the G1 and G2 systems following closely, while the V Glide-Path 2 system introduced by Nayak

TABLE 3 - DARE Tool

Study	Q1: Inclusion/Exclusion criteria reported	Q2: Search adequate	Q3: Studies synthesized	Q4: Quality of included studies assessed	Q5: Sufficient details of included studies
Abdallah MA Alex Dent J 2017[33]	Yes	Yes	Yes	Yes	Yes
Gunes B et al J Endod 2018[24]	Yes	Yes	Yes	Yes	Yes
Ha JH J Dent Sci 2016[25]	Yes	Yes	Yes	Yes	Yes
Keskin C Aust Endod J 2020[32]	Partial	Partial	Yes	Partial	Yes
Khatri M Int J life Sci 2024[34]	Inadequate	Yes	Yes	Partial	Partial
Kurt O AEJ 2022[31]	Partial	Partial	Yes	Partial	Yes
Nayak G Bioinformation 2024[35]	Partial	Yes	Yes	Partial	Partial
Pawar AM Endod Practice Today[36]	Partial	yes	yes	yes	Partial
Pawar et al J Conserv Dent 2017[30]	Partial	Yes	Yes	Partial	Partial
Swarnakar P Endodontology 2023[26]	Yes	Partial	Yes	Partial	Yes
Zheng L et al BMC Oral Health[27]	Partial	Yes	Yes	Partial	Yes

DARE question	Kappa score	Agreement level
Q1: Inclusion/Exclusion	0.309	Fair
Q2: Search Adequate	0.309	Fair
Q3: Studies Synthesized	0.309	Fair
Q4: Quality Assessment	0.309	Fair
Q5: Sufficient Details	0.309	Fair

Kappa Score Interpretation.
<0: Poor agreement.
0.01–0.20: Slight agreement.
0.21–0.40: Fair agreement.
0.41–0.60: Moderate agreement.
0.61–0.80: Substantial agreement.
0.81–1.00: Almost perfect agreement.

et al[35] yielded the highest debris extrusion. Swarnakar P et al[26] provided a comparative assessment of different glide path methodologies using both the WOG and PTG systems.

For canals with intermediate curvature (0°–20°), manual AED ranged from 0.000072 g[35] to 0.3916 g[26], whereas rotary AED ranged from 0.000061 g[25] to 0.3030 g[26]. For teeth with curvatures between 20° and 40°, manual AED varied from 0.000326 g[24] to 0.007 g[33], compared with rotary AED ranging from 0.000088 g[24] to 0.006 g[33].

Quantitative assessment of canal curvature demonstrates direct proportionality with debris displacement magnitude, wherein rotary instrumentation exhibits superior regulation of AED. Meta-analytical examination of 11 investigations substantiates enhanced procedural outcomes with rotary systems, particularly ProGlider and R-Pilot configurations. Methodological progression from fundamental mechanical-manual comparisons to advanced rotary implementations reflects substantial technical refinement. Recent investigations[26,34,35] establish optimized protocols based on canal curvature severity, validating contemporary procedural guidelines. These advancements yield diminished AED measurements, reduced preparation intervals, and preserved canal architecture.

Subsequent research necessitates an examination of protocol standardization parameters, anatomical variation assessment, procedural efficiency quantification, and longitudinal outcome documentation. Economic feasibility analyses of rotary instrumentation systems, healing trajectory documentation, treatment success indices, and complication frequency measurements warrant systematic investigation. Material characterization protocols, irrigation methodology assessment, instrument design specifications, and operator expertise quantification remain fundamental for performance validation across anatomical configurations, advancing evidence-based therapeutic protocols in endodontic practice.

CONCLUSION

The systematic evaluation demonstrates the superior efficacy of rotary glide path systems compared to manual K-file techniques in minimizing apical debris extrusion during endodontic treatment. Contemporary rotary systems, particularly ProGlider, achieve a statistically significant reduction in extruded debris, suggesting enhanced clinical predictability. The synergistic integration of manual and mechanical systems demonstrates optimal debris control, especially in canals with moderate curvature. While the progression from basic mechanical-manual comparisons to sophisticated combined-system approaches represents a significant technological advancement in endodontics, the predominance of *in vitro* analyses necessitates further investigation of long-term clinical implications. This evidence supports the adoption of rotary systems while acknowledging the need for prospective clinical validation.

RELEVANT REPORTING GUIDELINES PAPERWORK

This systematic review was registered on the PROSPERO CRD42024601182 website, which is in charge of keeping records and organizing systematic reviews, with the number. This systematic study followed the Preferred Report Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 and Conducting Systematic Reviews and Meta-Analyses of Observational Studies of Etiology (COSMOS-E) guidelines.

DATA AVAILABILITY STATEMENT

All the pertaining data are with the corresponding author and can be made available with a requisition mail to daxabraham.sds@mrei.ac.in.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Adinath Walmik Talekar: Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing. **Dax Abraham:** Conceptualization, Data curation, Writing – original draft, Validation, Formal analysis, Visualization, Supervision, Project administration. **Rajat Sharma:** Visualization, Investigation, Visualization, Supervision, Project administration. **Alpa Gupta:** Supervision, Visualization, Supervision, Project administration. **Rajeev Kumar Malhotra:** Software, Formal analysis, Validation, Data curation, Visualization.

ACKNOWLEDGMENTS

The authors deny any conflicts of interest related to this study.

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