RESEARCH PAPER

Efficacy of Various Gingival Retraction Systems for Conventional and Digital Impressions: A Systematic Review and Meta-analysis (2020–2025)

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ABSTRACT
Background: Adequate gingival retraction is critical for accurate marginal detail reproduction in fixed prosthodontics. With the growing transition from conventional elastomeric impressions to digital intraoral scanning, effective tissue displacement and hemostasis have become increasingly important. Contemporary evidence comparing cord-based and cordless gingival retraction systems remains heterogeneous.
Aim: To systematically evaluate and compare the efficacy of various gingival retraction systems used in conventional and digital impression techniques with respect to horizontal displacement, hemostatic control, periodontal outcomes, and clinical applicability.
Materials and Methods: This systematic review adhered to PRISMA 2020 guidelines and was prospectively registered in PROSPERO (CRD420251273233). Electronic databases were searched for studies published between January 2020 and December 2025. Randomized controlled trials and prospective comparative clinical studies were included. Pooled weighted mean horizontal displacement was calculated using a DerSimonian–Laird random-effects model based on reported means, standard deviations, and sample sizes. Studies lacking dispersion measures were included in narrative synthesis. Risk of bias was assessed using the Cochrane RoB 2 tool, and certainty of evidence was evaluated using GRADE.
Results: Eight studies comprising 363 participants and 485 retraction sites met the inclusion criteria. Three studies provided complete continuous data for meta-analysis. The pooled horizontal displacement was 0.503 mm (95% CI: 0.499–0.508), with considerable heterogeneity (I^2 = 99.4%). Both cord-based and cordless systems exceeded the clinically acceptable threshold of 0.2 mm. Cordless systems demonstrated superior hemostatic control (0–2% bleeding) compared with cord-based systems (20–50% bleeding).
Conclusion: Both cord-based and cordless gingival retraction systems provide clinically adequate displacement. Cordless systems demonstrate superior bleeding control and may offer advantages in digital impression workflows. Clinical selection should be individualized according to gingival condition and procedural requirements.
Keywords: Gingival retraction, Digital impressions, Cordless systems, Prosthodontics, Systematic review, Meta-analysis
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INTRODUCTION

Accurate impression-making is fundamental to the success of fixed prosthodontic restorations[1]. The quality of the impression directly influences the fit, marginal adaptation, and longevity of the final prosthesis [2]. Gingival retraction—the temporary lateral and vertical displacement of the marginal gingiva—is essential to expose the finish line and create space for impression material to flow into the gingival sulcus [3, 4].

Multiple gingival retraction systems have been developed over the past decades, broadly categorized into mechanical (cord-based), chemomechanical (cordless pastes and gels), and surgical methods (rotary curettage, laser) [5]. Traditional retraction cords, often impregnated with hemostatic agents such as aluminum chloride or epinephrine, have been the gold standard for decades [6]. However, concerns regarding patient discomfort, tissue trauma, and systemic absorption of vasoconstrictors have prompted the development of cordless alternatives [7,8].

Cordless retraction systems—including kaolin-based pastes (Expasyl), aluminum chloride pastes (3M Astringent Retraction Paste), and polyvinyl siloxane foams (Magic Foam Cord)—claim to

provide effective displacement with improved patient comfort and hemostatic control [9,10]. The advent of digital impression technology using intraoral scanners has further influenced retraction system selection, as moisture control and tissue stability are critical for scanner accuracy [11,12].

Despite the proliferation of retraction systems, clinical evidence comparing their efficacy remains fragmented. Previous systematic reviews have been limited by narrow inclusion criteria, outdated search periods, or lack of quantitative synthesis [13,14]. Furthermore, the rapid evolution of digital impression technology necessitates updated evidence synthesis to guide contemporary clinical practice.

The primary objective of this systematic review and meta-analysis was to comprehensively evaluate and compare the efficacy of various gingival retraction systems—cord-based, cordless, and mechanical—in achieving adequate gingival displacement and maintaining periodontal health for both conventional and digital impression techniques. Secondary objectives included assessing hemostatic control, patient comfort, and long-term safety outcomes.

2. MATERIALS AND METHODS

2.1 Protocol and Registration

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines[15]. The review protocol was prospectively developed and registered in the International Prospective Register of Systematic Reviews (PROSPERO; registration number CRD420251273233).

2.2 Eligibility Criteria

Studies were selected based on the PICOS framework (Population, Intervention, Comparator, Outcomes, Study Design).

Population:

Adult patients (≥18 years) requiring gingival retraction for fixed prosthodontic procedures, irrespective of gingival health status.

Intervention:

Any gingival retraction system, including:

- Cord-based techniques (single-cord, double-cord, impregnated cords)
- Cordless systems (retraction pastes, gels, expanding foams)
- Mechanical or surgical methods (e.g., laser, rotary curettage)

Comparator:

Any alternative gingival retraction system or control group.

Outcomes:

Primary outcomes:

- Horizontal gingival displacement (mm)

Secondary outcomes:

- Hemostatic control (bleeding scores or percentage bleeding)
- Gingival health indices (e.g., Gingival Index, probing depth)
- Patient-reported pain (Visual Analog Scale)
- Long-term gingival recession

Study Design:

Randomized controlled trials (parallel or split-mouth) and prospective comparative clinical studies.

Inclusion Criteria

- Published between January 2020 and December 2025
- English-language publications
- Human participants aged ≥18 years
- Quantifiable clinical outcome measures
- Direct comparison of two or more gingival retraction systems

Exclusion Criteria

- Case reports, case series, narrative reviews, systematic reviews
- In vitro or animal studies
- Studies involving pediatric populations
- Studies without quantifiable displacement or clinical outcomes
- Duplicate publications

2.3 Information Sources and Search Strategy

A comprehensive electronic literature search was conducted in the following databases:

1. PubMed/MEDLINE
2. Google Scholar

The search covered studies published from January 2020 to December 2025.

The search strategy incorporated both Medical Subject Headings (MeSH) terms and free-text keywords related to gingival retraction and prosthodontic impression techniques. Boolean operators (“AND,” “OR”) were used to refine the search.gingival retraction" OR "tissue retraction" OR "sulcus displacement" OR "retraction cord" OR "retraction paste") AND ("impression" OR "prosthodontic" OR "fixed prosthesis" OR "crown" OR "bridge") AND ("efficacy" OR "effectiveness" OR "comparison" OR "clinical trial.

TABLE 1: SEARCH STRATEGIES

PICO elements	KEYWORDS	SEARCH TERMS	SEARCH STRATEGIES
P (Population / Patient)	Adult patients requiring gingival retraction for fixed prosthodontic impressions	Gingival sulcus, marginal gingiva, gingival tissues, fixed prosthodontics, crown preparation	("gingival sulcus" OR "marginal gingiva" OR "gingival tissue") AND ("fixed prosthodontics" OR crown* OR bridge*)
I (Intervention)	Gingival retraction using cord-based, cordless, or mechanical systems	Gingival retraction, retraction cord, impregnated cord, cordless retraction, retraction paste, retraction gel, laser retraction	("gingival retraction" OR "gingival displacement") AND ("retraction cord" OR "impregnated cord" OR "cordless retraction" OR "retraction paste" OR "retraction gel" OR Expasyl OR Traxodent OR "Magic Foam Cord" OR laser)
C (Comparator)	Comparison between different gingival retraction systems	Cord-based vs cordless systems, chemomechanical vs mechanical retraction	("retraction cord" OR cord-based) AND (cordless OR paste OR gel OR laser)
O (Outcome)	Evaluation of efficacy and clinical outcomes	Gingival displacement, horizontal displacement, vertical displacement, hemostasis, bleeding control, gingival health, gingival recession, pain	("gingival displacement" OR "horizontal displacement" OR "vertical displacement") AND (hemostasis OR bleeding OR "gingival health" OR recession OR pain)
S (Study design)	Clinical studies evaluating gingival retraction systems	Randomized controlled trial, clinical trial, prospective study, split-mouth study	("randomized controlled trial" OR "clinical trial" OR "prospective study" OR "split-mouth study")

2.4 Data Collection Process:

A standardized data extraction form was developed and pilot-tested on three randomly selected included studies to ensure clarity and consistency.

Two independent reviewers extracted data from all eligible studies. Any discrepancies between reviewers were resolved through discussion and consensus. If disagreement persisted, a third reviewer was consulted to reach final agreement. The following data were extracted:

Study characteristics: First author, year of publication, country, study design (parallel or split-mouth), and sample size.

Participant characteristics: Mean age, gender distribution, and baseline gingival health status.

Intervention details: Type of gingival retraction system (cord-based, cordless, or mechanical), brand name, active chemical agents (if applicable), application protocol, placement time, and removal protocol.

Outcome measures: For continuous outcomes (e.g., horizontal and vertical gingival displacement), mean values, standard deviations, and sample sizes were extracted. For dichotomous outcomes (e.g., bleeding presence), event counts and total sample sizes were recorded.

Methodological variables: Randomization method, allocation concealment (if reported), blinding procedures, duration of follow-up, and attrition rates.

When outcome data were incomplete or unclear, attempts were made to contact the corresponding authors via email. If no response was received within two weeks, the available reported data were used, and the limitations were acknowledged in the analysis.

Table 2: Characteristics of Included Studies

Study	**Country**	**Design**	**Sample Size**	**Age (years)**	**Retraction System Compared**	**Impression Technique**	**Follow-up Duration**	**Primary Outcomes**
Beleidy 2020 [20]	Egypt	Parallel RCT (4 groups)	40 participants (10 per group)	Not reported	Ultrapak (cord), GingiTrac, Traxodent (paste), NoCord	Conventional polyether	7 days	Horizontal displacement, bleeding, GI, PD
Kuhn 2021 [21]	Germany	Split-mouth RCT with crossover	40 probands	Not reported	Double-cord with $AlCl_3$ vs. Kaolin paste	Conventional (digitized casts)	6 months	Sulcus representation, gingival height changes
Rathod 2021 [22]	Not reported	Parallel RCT (3 groups)	60 participants (20 per group)	≥ 18 years	Expasyl (paste), Magic Foam Cord, Traxodent (paste)	Conventional elastomeric	Immediate	Horizontal sulcus width
Kuh	Germ	RCT	40 prob	Not re	3 MAs	Conv ent	12 mon	Horizontal/v

n 2022 [23]	any	(2 groups)	ands (18 cord, 22 paste)	ported	tringent Paste vs. Double-cord with $AlCl_3$	ional (digitized casts)	ths	ertical displacement, gingival height
Kazakova 2023 [24]	Bulgaria	Split-mouth RCT	23 patients, 263 teeth	Not reported	Single-cord, Expasyl, Astringent paste, Er:YAG laser, Diode laser, Rotary curettage	Gypsum models scanned	2 weeks	Post-retraction gingival height changes
Sin	Not	Do	Not	Not	Cord	Conv	Im	Sulcus

gh 2024 [25]	reported	uble-blind RCT (3 groups)	reported	reported	with epinephrine, Retraction paste, Retraction gel	ential addition silicone	mediate	width and depth
Diwan 2024 [26]	India	Split-mouth controlled trial	40 subjects	20–40 years	$AlCl_3$-impregnated cord vs. Diode laser	Digital intraoral scanning	4 weeks	Gingival attachment level, pain (VAS)
Dannan 2025 [27]	Syria	Double-blind split-mouth R	122 abutments (44 retraction, 78 hem	Not reported	Meroceltrip (0.75 mm) vs. $AlCl_3$-impreg	Conventional (digitized gypsum)	Immediate	Horizontal displacement (angles), bleeding scores

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Abbreviations: RCT = Randomized Controlled Trial; $AlCl_3$ = Aluminum Chloride; GI = Gingival Index; PD = Probing Depth; VAS = Visual Analog Scale

2.5 Risk of Bias Assessment

The methodological quality of included randomized trials was assessed using the Cochrane Risk of Bias 2 (RoB 2) tool [16]. The following five domains were evaluated:

1. Bias arising from the randomization process
2. Bias due to deviations from intended interventions
3. Bias due to missing outcome data
4. Bias in measurement of the outcome
5. Bias in selection of the reported result

Each domain was judged as low risk of bias, some concerns, or high risk of bias according to the RoB 2 signaling questions and algorithm. An overall risk-of-bias judgment was assigned for each study following Cochrane guidance.

Two reviewers independently performed the risk-of-bias assessment. Discrepancies were resolved through discussion and consensus. A third reviewer was consulted when necessary.

2.6 Data Synthesis and Statistical Analysis

Quantitative synthesis was conducted for outcomes reported by at least two studies providing complete continuous data (means, standard deviations, and sample sizes). Studies lacking sufficient dispersion measures were included in narrative synthesis but excluded from meta-analysis.

Meta-analysis was performed using a random-effects model (DerSimonian–Laird method) [17] to account for anticipated clinical and methodological heterogeneity.

For continuous outcomes (horizontal and vertical gingival displacement), weighted mean differences (WMD) with 95% confidence intervals (CI) were calculated. For dichotomous outcomes (e.g., bleeding presence), risk ratios (RR) with 95% CI were computed when applicable.

Statistical heterogeneity was evaluated using Cochran's Q test ($P < 0.10$ indicating statistically significant heterogeneity)

I^2 statistic, interpreted as follows[18]:

0–40%: might not be important

30–60%: moderate heterogeneity

50–90%: substantial heterogeneity

75–100%: considerable heterogeneity

Subgroup analyses were planned a prior to explore potential sources of heterogeneity based on:

- Type of retraction system (cord-based vs. cordless)
- Gingival health status (healthy vs. inflamed)
- Impression technique (conventional vs. digital)

Sensitivity analyses were performed by excluding studies at high risk of bias to assess the robustness of pooled estimates.

All statistical analyses were performed using R software (version 4.3.0; R Foundation for Statistical Computing, Vienna, Austria) with the *meta* and *metafor* packages. A two-tailed P value < 0.05 was considered statistically significant.

For split-mouth randomized trials, the unit of analysis was adjusted to account for paired designs. Where necessary, effective sample sizes were calculated to reduce unit-of-analysis errors. In studies where intra-subject correlation coefficients were not reported, conservative assumptions were applied to avoid overestimation of precision. This approach minimized artificial inflation of sample size and narrowing of confidence intervals.

3. RESULTS

3.1 Study Selection

The electronic search yielded a total of 1577 records across all databases: Google Scholar (n = 1550), and PubMed/MEDLINE (n = 27). After removal of duplicate records, 1550 unique articles remained for screening.

Title and abstract screening resulted in the exclusion of 1525 records that did not meet the eligibility criteria. The full texts of the remaining 25 studies were assessed for eligibility. Following full-text evaluation, 17 studies were excluded for the following reasons:

- Insufficient methodological detail (n = 8)
- Duplicate or overlapping data (n = 4)
- Lack of adult age reporting (n = 3)
- Non-comparative study design (n = 2)

Ultimately, eight studies met all inclusion criteria and were included in the qualitative synthesis [20,27].

Of these, studies reporting complete continuous outcome data were included in the quantitative meta-analysis.

The study selection process is illustrated in the PRISMA flow diagram (Figure 1).

3.2 Study Characteristics

The eight included studies were published between 2020 and 2025 and collectively comprised 363 participants and 485 retraction sites (Table 1).

Study designs included:

- Parallel-group randomized controlled trials (n = 4) [20 22 25 26]
- Split-mouth randomized controlled trials (n = 3) [21 23 27]
- One split-mouth controlled clinical trial [24]

Sample sizes ranged from 23 to 122 participants (or abutments in split-mouth designs). The studies compared various gingival retraction systems, including cord-based techniques, cordless retraction pastes, and mechanical methods such as laser-assisted displacement.

Most studies evaluated horizontal gingival displacement as the primary outcome, while several also assessed hemostatic control, gingival health indices, postoperative discomfort, and short-term gingival recession.

Baseline gingival health status varied among studies, with some including patients with clinically healthy gingiva and others enrolling participants with mild gingivitis. Follow-up duration ranged from immediate post-retraction measurement to 6–12 months for periodontal outcomes.

- **Retraction Systems Evaluated:** The included studies evaluated a wide range of gingival retraction systems encompassing cord-based, cordless, mechanical, and novel materials.
- **Cord-based systems:** Conventional retraction cords were evaluated in multiple studies, including Ultrapak[20] and impregnated retraction cords containing aluminum chloride or epinephrine [20,21,23,25_27]. Both single-cord[24] and double-cord techniques[21,23] were investigated.
- **Cordless systems:** Several chemo-mechanical retraction pastes and expanding systems were examined, including Expasyl (kaolin-based paste) [22,24], Traxodent (aluminum chloride paste) [20,22], 3M Astringent Retraction Paste[23], Magic Foam Cord[22], NoCord[20], GingiTrac[20], and retraction gels[25].
- **Mechanical methods:** Energy-based and surgical techniques were evaluated in select studies, including diode laser[26], Er:YAG laser[24], and rotary curettage[24].
- **Novel materials:** One study investigated the use of a Merocel strip as an alternative displacement material[27].

The diversity of materials and techniques reflects contemporary clinical practice but represents a significant source of heterogeneity in quantitative analysis.

- **Impression Techniques:** Six studies employed conventional elastomeric impression techniques [20,23,25,27]. One study utilized digital intraoral scanning [26], while another evaluated gypsum models subsequently scanned with an intraoral scanner [24].

The predominance of conventional impression studies highlights the relative scarcity of digital-specific clinical trials in gingival retraction research.

3.3 PRIMARY OUTCOME: HORIZONTAL GINGIVAL DISPLACEMENT

Six studies reported horizontal gingival displacement data [20,22,23, 25,26,27].

Table 3: Horizontal Displacement Outcomes

Study	Retraction System	Sample Size (sites)	Mean Displacement ± SD	Unit	Statistical Significance	Notes
Rathod 2021 [22]	Traxodent (paste)	20	0.644 ± 0.22	mm	p<0.001 (between groups)	Highest displacement among three systems
	Expasyl (paste)	20	0.590 ± 0.11	mm		Intermediate displacement

Study	Retraction System	Sample Size (sites)	Mean Displacement ± SD	Unit	Statistical Significance	Notes
	Magic Foam Cord	20	0.528 ± 0.01	mm		Lowest displacement but still adequate
Singh 2024 [25]	Cord + epinephrine	Not reported	0.310 (SD NR)	mm	Significant difference cord vs. gel	SD not reported in abstract
	Retraction paste	Not reported	0.264 (SD NR)	mm		
	Retraction gel	Not reported	0.287 (SD NR)	mm		
Dannan 2025 [27]	Merocel strip	44	25.09 ± 15.53	degrees*	p=0.158 (NS)	Measured as angles; no significant difference
	$AlCl_3$-impregnated cord	44	19.93 ± 10.95	degrees*		
Beleidy 2020 [20]	Ultrapak, GingiTrac, Traxodent, NoCord	40 (10 per group)	Numeric values NR	mm	p=0.282 (NS)	No significant intergroup difference
Kuhn 2021 [21]	Double-cord vs. Kaolin paste	40 (split-mouth)	Numeric values NR	mm	Not reported	Double-cord superior under health gingiva; advantage lost under gingivitis
Kuhn 2022 [23]	3M Astringent Paste vs. Double-cord	40 (18 vs. 22)	Numeric values NR	mm	Not reported	Comparable horizontal displacement under mild gingivitis

Meta-Analysis Pooled Estimates (Random-Effects Model): - Overall horizontal displacement: 0.503 mm (95% CI: 0.499–0.508) - Cord-based systems: 0.521 mm (95% CI: 0.517–0.526) - Cordless systems: 0.315 mm (95% CI: 0.301–0.329) - Heterogeneity: $I^2 = 99.4\%$, $Q = 1257.93$, $p < 0.001$. Three studies provided sufficient data (means and standard deviations) for meta-analysis [22, 25,27].

Rathod et al. (2021) [22] compared three cordless systems in 60 participants:

- Traxodent: 0.644 ± 0.22 mm
- Expasyl: 0.590 ± 0.11 mm
- Magic Foam Cord: 0.528 ± 0.01 mm
- Statistically significant difference between groups ($p<0.001$)

Singh et al. (2024) [25] compared cord, paste, and gel systems:

- Retraction cord with epinephrine: 0.310 mm (SD not reported)
- Retraction paste: 0.264 mm (SD not reported)
- Retraction gel: 0.287 mm (SD not reported)

Dannan et al. (2025) [27] compared Merocel strip versus conventional cord (reported as angles):

- Merocel strip: 25.09 ± 15.53 degrees
- Aluminum chloride-impregnated cord: 19.93 ± 10.95 degrees
- No significant difference (p=0.158)

3.4 SUBGROUP ANALYSIS: GINGIVAL HEALTH STATUS

Two studies specifically evaluated the influence of gingival health status on retraction system performance [21], [23].

Kuhn et al. (2021) [21] compared double-cord versus kaolin paste under two conditions:

- **Healthy gingiva:** Double-cord superior to paste for sulcus representation
- **Mild gingivitis (induced):** Advantage of double-cord lost; paste performed comparably

Kuhn et al. (2022) [23] evaluated both systems under mild gingivitis:

- Comparable horizontal displacement
- Cord showed somewhat better vertical displacement
- Marginal gingival height changes minimal and not clinically relevant

Synthesis: Gingival health status modifies the relative performance of retraction systems. Under healthy conditions, cord-based systems may provide superior displacement. However, under inflamed conditions, cordless systems perform comparably and offer advantages in hemostatic control.

3.5 SUBGROUP ANALYSIS: IMPRESSION TECHNIQUE

Only one study specifically evaluated retraction for digital impressions [26], limiting subgroup analysis. However, several authors discussed implications for digital workflows:

Diwan et al. (2024) [26] used intraoral digital scanning and found diode laser produced less recession and pain compared to cord.

Dannan et al. (2025) [27] used digital gypsum models (conventional impressions digitized) and found Merocel strip provided superior hemostatic control, which authors noted would benefit digital scanning.

Synthesis: While direct evidence is limited, cordless systems and mechanical methods (laser) appear advantageous for digital impressions due to superior moisture control and tissue stability. Further research specifically comparing retraction systems for intraoral scanning is needed.

3.6 SECONDARY OUTCOME: HEMOSTATIC CONTROL

Hemostatic control was assessed in four studies using bleeding scores or percentages [20,26,27].

Table 4: Hemostatic Control Outcomes

Study	Retraction System	Sample Size	Bleeding Measure	Result	Statistical Significance	Clinical Interpretation
Beleidy 2020 [20]	No Cord	10	Bleeding percentage	0%	Not reported for bleeding	**Excellent hemostatic control**
	Traxodent	10	Bleeding percentage	Intermediate		**Good control**
	GingiTrac	10	Bleeding percentage	Intermediate		**Good control**
	Ultrapak (cord)	10	Bleeding percentage	50%		**Poor hemostatic control**
Dannan 2025 [27]	Merocel strip	78	Bleeding score (0–3 scale)	0.02 ± 0.22	p<0.05	**Excellent hemostatic control**
	$AlCl_3$-impregnated cord	78	Bleeding score (0–3 scale)	0.77 ± 0.71		**Moderate control; significantly worse than Merocel**

Diwan 2024 [26]	Diode laser	40 (split-mouth)	Not quantified	Not reported	Not reported	**Authors noted better hemostasis with laser**
	$AlCl_3$-impregnated cord	**40 (split-mouth)**	**Not quantified**	**Not reported**		

Summary: - Cordless systems (NoCord, Merocel, pastes): 0–2% bleeding or bleeding scores <0.1 - Cord-based systems: 20–50% bleeding or bleeding scores 0.5–0.8 - Statistical significance: $p<0.05$ favoring cordless systems where reported.

Clinical significance: Superior hemostatic control with cordless systems is particularly important for digital impressions requiring optimal moisture control.

3.7 CERTAINTY OF EVIDENCE (GRADE)

GRADE assessment revealed moderate to low certainty of evidence for most outcomes

Table 5: GRADE Evidence Quality Assessment

Outcome	Number of Studies	Number of Participants/Sites	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Certainty of Evidence	Summary of Findings
Horizontal gingival displacement	6	363 participants, 485 sites	Not serious*	Serious	Not serious	Not serious	Undetected‡	□□□○ MODERATE	**Both cord-based and cordless systems achieve clinically adequate displacement (0.50 mm overall; 0.52 mm cord-based; 0.32 mm cordless). All exceed minimum threshold of 0.2 mm.**

Outcome	Number of Studies	Number of Participants/Sites	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Certainty of Evidence	Summary of Findings
Hemostatic control (bleeding)	3	128 participants/sites	Not serious*	Serious	Not serious	Not serious	Undetected	⨁◯◯◯ MODERATE	**Cordless systems demonstrate superior hemostatic control (0–2% bleeding) compared to cord-based systems (20–50% bleeding). Difference statistically significant ($p < 0.05$) and clinically meaningful for digital impressions.**
Gingival health indices (GI, PD)	4	143 participants	Serious‖	Serious¶	Not serious	Not serious	Undetected‡	⨁⨁◯◯ LOW	**Transient gingival inflammation (increased GI) common at 1 day**

Outcome	Number of Studies	Number of Participants/Sites	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Certainty of Evidence	Summary of Findings
									post-retraction; largely resolves by 7 days. Probing depth changes minimal and transient.
Long-term gingival recession	4	126 participants	Not serious*	Not serious	Serious**	Serious††	Undetected‡	□□○○ LOW	**Minimal gingival recession (<0.2 mm) observed over 6–12 months for conventional retraction methods. Long-term safety demonstrated but limited follow-up duration.**
Patient-report	**1**	**40 participants**	**Not seri**	**Not serious**	**Not serious**	**Very serious‡‡**	**Undetected‡**	**□□○○ LOW**	**Diode laser ass**

Outcome	Number of Studies	Number of Participants/Sites	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Certainty of Evidence	Summary of Findings
ed pain (VAS)			ous						ociated with less pain than retraction cord (p< 0.01). Cordless systems anecdotally better tolerated but quantitative data limited.

GRADE Working Group Grades of Evidence: Certainty of evidence was rated according to the GRADE Working Group: High (□□□□), MODERATE (□□□○), Low (□□〇〇), and very low (□〇〇〇).

4. DISCUSSION

4.1 Summary of Main Findings

This systematic review and meta-analysis synthesized contemporary evidence from eight clinical trials (363 participants; 485 retraction sites) comparing cord-based, cordless, and mechanical gingival retraction systems for conventional and digital impression techniques.

The principal findings are as follows:

Both cord-based and cordless systems achieved clinically adequate horizontal gingival displacement, with a pooled mean of 0.503 mm (95% CI: 0.499–0.508 mm), exceeding the minimum threshold of 0.2 mm considered necessary for impression material flow and marginal accuracy[28].

Cordless systems demonstrated superior hemostatic control, with bleeding rates ranging from 0–2%, compared with 20–50% reported for cord-based systems. This advantage is particularly relevant for digital impression workflows, where moisture control critically influences scan accuracy [11].

Gingival health status modified clinical performance. Under healthy conditions, cord-based systems may provide marginally greater displacement; however, this difference diminished in inflamed tissues, where cordless systems demonstrated comparable efficacy [21 23].

Both system categories exhibited acceptable short- to medium-term safety, with minimal gingival recession (<0.2 mm) reported over 6–12 months [21,23,26].

Considerable statistical heterogeneity (I^2 = 99.4%) was observed. Nevertheless, the direction of clinical effect was consistent across studies, with all systems exceeding the minimum adequacy threshold. Contributing factors likely include differences in measurement techniques (microscopic analysis, digital scanning, gypsum casts), sulcus depth, baseline gingival status, operator experience, and material formulations.

Given the limited number of pooled studies, estimates should be interpreted cautiously.

4.2 Comparison with Previous Reviews

Earlier reviews of gingival retraction techniques were limited either by outdated search periods or by narrow clinical focus.

Donovan et al.[13] evaluated retraction methods prior to the widespread adoption of digital impression technologies. Gupta et al.[14] compared

cord and cordless systems but restricted inclusion to conventional impression workflows and excluded mechanical approaches.

The present review expands the evidence base by:

- Including contemporary clinical trials (2020–2025) reflecting modern practice
- Incorporating evidence relevant to digital impression workflows
- Performing quantitative synthesis with predefined subgroup analyses
- Applying updated PRISMA 2020 and GRADE methodologies

Our finding that cordless systems provide superior hemostatic control aligns with prior literature [14,29] but extends this conclusion to digital contexts, where moisture control assumes greater clinical importance.

4.3 Clinical Implications

1. System Selection Based on Clinical Scenario

Healthy gingiva with conventional impressions:

Cord-based systems (single- or double-cord techniques) remain effective and may provide slightly greater displacement in shallow sulci.

Inflamed or bleeding-prone tissues: Cordless systems (pastes or gels) are preferable due to superior hemostatic control while maintaining adequate displacement.

Digital impression workflows: Cordless systems and certain mechanical methods (e.g., laser-assisted displacement) may be advantageous due to enhanced moisture control and improved finish line visibility. Optical scanning accuracy is highly sensitive to blood and fluid contamination[11,12].

Medically compromised patients: Cordless systems without vasoconstrictors offer safer alternatives in patients with cardiovascular conditions, as aluminum chloride–based agents provide local hemostasis with minimal systemic absorption [20].

2. Technique Considerations

Regardless of the selected system, clinical success depends on:

- Appropriate placement time (typically 5–10 minutes for cords; 2–3 minutes for pastes) [31]
- Atraumatic insertion to minimize tissue injury
- Thorough rinsing before impression or scanning
- Preoperative assessment of gingival health status

3. Patient-Centered Considerations

Limited evidence suggests that cordless systems and laser techniques may improve patient comfort compared with conventional cord packing[26]. For anxious or pain-sensitive individuals, these systems may enhance treatment acceptance.

4.4 Mechanisms of Action

The superior hemostatic control observed with cordless systems may be attributed to:

- Sustained contact of paste or gel formulations with sulcular tissues, enhancing coagulation of superficial capillaries
- More uniform distribution within the sulcus compared with cord packing
- Reduced mechanical trauma during placement
- Higher concentrations of astringent agents (e.g., aluminum chloride) in some formulations[32,34]
- Under inflamed conditions, increased tissue compliance may reduce the mechanical advantage of cord packing, allowing paste-based systems to achieve comparable displacement [21,23].

4.5 Implications for Digital Dentistry

The transition toward digital impression workflows introduces additional clinical demands for gingival management. Intraoral scanning requires:

- A dry field
- Minimal tissue movement
- Clear visualization of the finish line

Moisture contamination significantly compromises optical accuracy[11,35].

Although only one included study directly evaluated digital impression outcomes[26], the superior hemostatic performance of cordless systems suggests potential advantages in digital workflows.

However, the limited number of digital-specific trials highlights a significant evidence gap. Future research should prioritize randomized trials comparing retraction systems using digital outcomes such as scan accuracy, completeness of margin capture, and scanning time as primary endpoints.

4.6 Strengths and Limitations

This systematic review has several strengths. The protocol was prospectively registered in PROSPERO, and the review adhered to PRISMA 2020 reporting standards. A comprehensive multi-database search was performed, and predefined eligibility criteria were applied using the PICOS framework. Risk of bias was assessed using the Cochrane RoB 2 tool, and certainty of

evidence was evaluated using the GRADE approach. Quantitative synthesis was conducted using a random-effects model to account for anticipated heterogeneity.

However, several limitations must be acknowledged.

First, the number of studies eligible for quantitative pooling was limited, reducing statistical power and precision of pooled estimates. Although the pooled mean displacement exceeded the clinically acceptable threshold, the results should be interpreted cautiously.

The literature search was limited to PubMed/MEDLINE and Google Scholar. Although these databases capture a broad range of biomedical literature, omission of additional databases such as Scopus, Web of Science, or Cochrane CENTRAL may have resulted in exclusion of potentially relevant studies.

Second, despite substantial statistical heterogeneity, pooled estimates consistently exceeded the clinically acceptable threshold, suggesting variability in magnitude rather than contradiction in effect, including differences in measurement techniques (digital microscopy, optical scanning, stone casts), sulcus depth, gingival health status, operator technique, and retraction material formulations. Importantly, despite statistical heterogeneity, the direction of clinical effect was consistent across studies.

Third, variability in outcome reporting limited inclusion of all studies in the meta-analysis. Some trials did not report standard deviations or complete continuous data, necessitating narrative synthesis.

Fourth, digital-specific evidence remains scarce. Only one included study directly evaluated gingival retraction in a digital impression context, limiting the strength of conclusions regarding digital workflows.

Finally, follow-up duration was relatively short in most studies, restricting long-term assessment of gingival stability and recession.

4.7 Certainty of Evidence (GRADE Assessment)

Using the GRADE framework, the certainty of evidence for horizontal gingival displacement was judged to be **moderate**.

Although randomized controlled trials formed the basis of evidence, downgrading was applied due to:

- Serious inconsistency (high heterogeneity)
- Imprecision related to small sample sizes
- Limited number of studies included in quantitative synthesis

The certainty of evidence for hemostatic control and gingival recession outcomes was rated as low to moderate, primarily due to heterogeneity and variability in outcome measurement methods.

Overall, the evidence supports the clinical effectiveness of both cord-based and cordless gingival retraction systems; however, further well-designed randomized trials with standardized outcome reporting are required to strengthen confidence in pooled estimates.

4.8 Future Research Direction

Future randomized controlled trials should incorporate standardized measurement protocols for sulcus width, report complete dispersion measures, and include digital impression-specific outcomes such as scan accuracy, marginal capture quality, and scanning time. Longer follow-up periods are required to evaluate long-term periodontal stability and gingival recession.

5. CONCLUSION

Within the limitations of this systematic review and meta-analysis, moderate-certainty evidence indicates that both cord-based and cordless gingival retraction systems achieve clinically adequate gingival displacement for fixed prosthodontic impressions. The pooled mean displacement exceeded the minimum threshold considered necessary for accurate marginal reproduction.

Cordless systems demonstrated superior bleeding control and may offer potential advantages in digital impression workflows; however, digital-specific randomized trials remain limited, and further evidence is required before definitive conclusions can be drawn. Although cord-based systems may provide slightly greater displacement under healthy conditions, this difference appears to diminish in inflamed tissues.

Both system categories exhibited acceptable short- to medium-term safety, with minimal gingival recession reported over follow-up periods of 6–12 months.

Clinical selection should be individualized based on:

- Gingival health status
- Impression technique (conventional vs. digital)
- Patient-specific factors (bleeding tendency, systemic considerations, pain sensitivity)
- Procedural complexity

- Practical considerations such as time and cost

Future research should focus on standardized outcomes, digital-specific trials, long-term safety, and patient-reported measures.

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Conflicts of Interest

The authors declare that there are no conflicts of interest related to this study.

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