Cureus
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Open Access Review Article

Selective Caries Removal Versus Complete Caries Excavation in Permanent Teeth: A Systematic Review and Meta-Analysis of Clinical Outcomes

Review began 10/30/2026
Review ended 11/09/2026
Published 11/12/2026

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DOI: 10.7759/cureus.119565

Abdulaziz Zailai [1, 2], Farid N. Ashi [3], Basmah Z. Alhawsawi [4], Mahmoud H. Shawli [5], Faris S. Alfawzan [6], Waleedah B. Almasri [7], Rawan S. Aldossari [8], Abdulrahman H. Aljohani [9], Nisrin I. Alnashar [10], Baseel M. Alghamdi [11], Monira AlHajri [12], Azizah Alatawi [13], Fahdah I. Alshumaymiri [10], Sara Z. Turki [14], Faisal N. Almukhallafi [15]

1. Restorative Dentistry, Jazan Specialized Dental Center, Jazan, SAU 2. Restorative Dentistry, Scientific Council, Saudi Board in Restorative Dentistry (SBRD), Jazan, SAU 3. General Dentistry, Al-Thager General Hospital, Jeddah, SAU 4. General Dentistry, Ram Clinics, Yanbu, SAU 5. General Dentistry, King Abdulaziz University, Jeddah, SAU 6. General Dentistry, Nebras Polyclinic, Riyadh, SAU 7. Dentistry, King Saud University, Riyadh, SAU 8. Restorative Dentistry, Armed Forces Hospital, Dhahran, SAU 9. General Dentistry, Dallah Hospital, Riyadh, SAU 10. Dentistry, Princess Nourah Bint Abdulrahman University, Riyadh, SAU 11. Dentistry, King Faisal University, Al Khobar, SAU 12. Dentistry, Imam Abdulrahman Bin Faisal University, Dammam, SAU 13. Dentistry, King Salman Armed Forces Hospital, Tabuk, SAU 14. Dentistry, Ram Clinics, Yanbu, SAU 15. General Dentistry, Ministry of Health, Madinah, SAU

Corresponding author: Abdulaziz Zailai, abdulaziz.zailai@outlook.com

Abstract

The management of deep carious lesions in permanent teeth has shifted from complete (non-selective) caries excavation (CCE), which carries a high risk of iatrogenic pulp exposure, toward selective approaches, including single-visit selective excavation (SE) and two-visit stepwise excavation (SW). This systematic review and meta-analysis compared the clinical outcomes of selective caries removal (SCR; SE or SW) with CCE in permanent teeth, using trial sequential analysis (TSA) and the GRADE framework. Electronic databases and trial registries were searched for randomized controlled trials (RCTs) comparing SCR with CCE in permanent teeth with deep carious lesions. Random-effects meta-analyses with Hartung-Knapp-Sidik-Jonkman adjustment were performed for pulp exposure, clinical success, need for endodontic treatment, and postoperative symptoms. Eight RCTs (nine reports; 875 analyzed teeth) were included. SCR was associated with a lower risk of intraoperative pulp exposure than CCE (risk ratio (RR) = 0.24; 95% CI: 0.07-0.83; number needed to treat = 5), but this estimate lost statistical significance in sensitivity analyses and in several leave-one-out analyses, and TSA showed that the required information size had not been reached. The reduction appeared larger with SE than with SW, but this comparison was indirect. Clinical success as defined by the trial authors (RR = 0.96; 95% CI: 0.74-1.25) and success among teeth not exposed during excavation (RR = 0.93; 95% CI: 0.84-1.03) did not differ between groups. An exploratory composite outcome that counted every intraoperative exposure as a failure favored SCR (RR = 1.20; 95% CI: 1.13-1.27), reflecting mainly the difference in exposure rates rather than improved long-term pulp or tooth survival. Estimates for the need for endodontic treatment and postoperative symptoms were very imprecise, and lower acute postoperative sensitivity after SE was reported by a single trial. The certainty of the evidence was low to very low. Selective caries removal may reduce the risk of pulp exposure compared with complete excavation in permanent teeth, but the evidence is very uncertain, and its effects on pulp survival and long-term outcomes remain unclear. Large, rigorously designed RCTs with long-term follow-up are needed.

Categories: Dentistry
Keywords: deep caries, dental pulp exposure, meta-analysis, minimally invasive dentistry, selective caries removal, stepwise excavation, vital pulp therapy

Introduction And Background

Dental caries is one of the most prevalent non-communicable diseases globally, constituting a burden on healthcare systems and negatively impacting patients' quality of life [1,2]. The disease is a biofilm-mediated, diet-modulated, multifactorial, and dynamic process that results in net mineral loss of dental hard tissues [1,3]. If left untreated, the carious process progresses into the dentin, endangering the dental pulp. Deep carious lesions can provoke pulpal inflammation, which, without timely and appropriate intervention, may culminate in irreversible pulpitis, pulp necrosis, and apical periodontitis [4,5].

The traditional management of deep carious lesions was governed by the principles established by G.V. Black, which mandated the complete (non-selective) caries excavation (CCE) of all demineralized and bacteria-contaminated dentin until hard, sound tissue was reached [2,6]. However, this conventional approach is considered unnecessarily invasive and outdated [1,7]. In deep lesions, non-selective CCE poses a high risk of accidental pulp exposure [6,8]. Pulpal exposure complicates the clinical scenario, necessitating direct pulp capping, which has a variable and often limited prognosis, or expensive and burdensome endodontic interventions such as root canal treatment, which weakens the tooth structure and reduces its

long-term survival [6,8,9].

A paradigm shift toward minimally invasive dentistry has transformed the management of deep carious lesions [3,10], supported by microbiological and histological evidence demonstrating that the complete removal of infected dentin is not a strict prerequisite for caries arrest [11,12]. When a carious lesion is hermetically sealed with a restorative material, the remaining cariogenic bacteria are deprived of dietary fermentable carbohydrates. This nutritional starvation reduces the bacterial load and shifts the microenvironment to arrest lesion progression, allowing the pulp-dentin complex to heal and form tertiary dentin [11,13].

Conservative excavation strategies, namely, two-visit stepwise excavation (SW) and single-visit selective excavation (SE), have been endorsed by major international organizations, including the International Caries Consensus Collaboration (ICCC) and the European Society of Endodontology (ESE) [2,14,15]. SW involves partial caries removal and temporary sealing, followed by re-entry after several months for final excavation to firm dentin [8,16]. Although SW reduces the incidence of pulp exposure compared to complete excavation, the requirement for a second visit increases costs, patient discomfort, and the risk of interim restoration failure or patient drop-out [6,8,16]. To overcome these drawbacks, single-visit SE (also referred to as partial caries removal) has gained prominence. This technique involves removing carious tissue from the peripheral walls to ensure an optimal adhesive seal while leaving soft or firm carious dentin over the pulpal wall, without subsequent re-entry [1,14,16].

Despite the biological rationale and updated clinical guidelines supporting selective caries removal (SCR), significant controversy persists among dental professionals globally [2,17]. Skeptics argue that leaving infected dentin behind may harbor anaerobic bacteria capable of degrading collagen and releasing endotoxins, which could perpetuate chronic subclinical pulpal inflammation or compromise the mechanical longevity of the adhesive restoration [17,18]. While multiple randomized controlled trials (RCTs) and systematic reviews have compared selective and CCE, the findings remain heterogeneous regarding key clinical outcomes, such as the maintenance of pulp vitality, restoration survival, and post-operative complications [1,8,19].

Several systematic reviews have addressed this question, but they differ from the present review in important respects. Earlier meta-analyses pooled primary and permanent teeth [10,12,19], although the two dentitions differ in pulpal volume, dentin thickness, histology, and regenerative capacity [13]. The consequences of treatment failure also differ: a primary tooth will exfoliate, whereas a permanent tooth must remain functional for decades, and a failed procedure usually leads to root canal treatment and an extensive restoration that weakens the tooth and shortens its expected survival [6,8,9]. Evidence from permanent teeth therefore needs to be synthesized separately. Of the reviews restricted to permanent teeth, one synthesized randomized trials qualitatively without meta-analysis [1], and the most recent combined pairwise, network, and trial sequential analyses [8]; additional randomized trials have been published since.

Three clinically relevant questions remain unresolved. First, previous syntheses have pooled "clinical success" outcomes whose definitions differ between trials, particularly in whether an intraoperative pulp exposure that is subsequently managed by vital pulp therapy is counted as a failure; it therefore remains unclear whether the lower risk of pulp exposure with selective approaches translates into better pulp survival. Second, it is uncertain whether single-visit selective removal and two-visit stepwise excavation differ in their protective effect. Third, it is unclear whether leaving carious dentin increases the later need for endodontic treatment or postoperative symptoms [17,18]. The aim of this systematic review and meta-analysis was to compare SCR (single-visit SE or two-visit SW) with CCE in permanent teeth with deep carious lesions, using only RCTs; to analyze clinical success separately according to how intraoperative pulp exposure was handled; to compare single-visit and stepwise approaches; and to assess the conclusiveness and certainty of the evidence using trial sequential analysis and the GRADE framework.

Review

Methods

Protocol Registration and Reporting Guidelines

This systematic review and meta-analysis was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement [20]. The protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO) on August 6, 2026 (registration number CRD420261305353). Compared with the registered protocol, analyses were performed in R (R Foundation for Statistical Computing, Vienna, Austria) rather than Review Manager; the Hartung-Knapp-Sidik-Jonkman (HKSJ) method and trial sequential analysis were added to account for the small number of trials; and clinical success was analyzed in three ways (as defined by the trial authors, among unexposed teeth, and as an additional exploratory composite outcome), as described below.

Eligibility Criteria

The eligibility criteria were structured using the Population, Intervention, Comparator, Outcomes, and Study Design (PICOS) framework [21]. The population included children, adolescents, and adults presenting with deep, cavitated dentinal carious lesions in permanent teeth. Eligible teeth included those diagnosed as vital asymptomatic or with reversible pulpitis, regardless of patient sex, ethnicity, or geographic location. The intervention was SCR (also termed partial caries removal, incomplete caries excavation, or minimally invasive dentistry), defined as the incomplete removal of carious dentin from the pulpal wall to avoid pulp exposure, while achieving firm dentin at the peripheral cavity margins, including both single-visit SE and two-stage SW. The comparator was non-selective CCE, defined as the complete excision of infected and affected carious dentin until hard dentin is reached on all cavity walls, prior to definitive restoration.

Interventions were classified according to the procedure actually performed, irrespective of the terminology used by the trial authors (e.g., partial caries removal, incomplete excavation, or indirect pulp treatment). Single-visit SE was defined as removal of carious tissue to hard dentin at the cavity periphery and to soft or firm dentin over the pulp, followed by definitive restoration at the same visit, with no planned re-entry. SW was defined as a first-stage partial excavation with a provisional or intermediate restoration, followed by planned re-entry after an interval and further excavation before the definitive restoration. SE and SW together are referred to as SCR. Arms of multi-arm trials were classified separately using these definitions.

The primary outcomes included the incidence of pulp exposure during caries excavation and the maintenance of pulp vitality (overall clinical success) at the longest available follow-up, while the secondary outcomes encompassed restoration survival/failure rates, postoperative pain or sensitivity, incidence of secondary caries, and the need for endodontic treatment. Only RCTs, including parallel-group, split-mouth, cluster-randomized, and multicenter trials, were included. Studies involving primary teeth, non-carious lesions, previously endodontically treated teeth, teeth with irreversible pulpitis or necrosis, and non-randomized observational or in vitro studies were excluded.

Because trials differed in whether an intraoperative pulp exposure followed by vital pulp therapy was counted as a failure, clinical success was analyzed in three ways: (i) as defined by the trial authors; (ii) among teeth that were not exposed during excavation; and (iii) as an additional exploratory composite outcome, constructed by the reviewers from the reported data, in which a tooth was counted as a success only if the pulp was not exposed during excavation and the tooth was clinically and radiographically successful at the last follow-up. The composite outcome therefore counts every intraoperative exposure as a failure, irrespective of the outcome of subsequent vital pulp therapy; it is driven largely by the difference in exposure rates and does not measure long-term pulp or tooth survival.

Information Sources and Search Strategy

A systematic literature search was conducted in PubMed/MEDLINE, Embase, the Cochrane Central Register of Controlled Trials (CENTRAL), Scopus, and Web of Science from inception to September 10, 2026. To capture unpublished data and minimize publication bias, grey literature was searched via ClinicalTrials.gov, the WHO International Clinical Trials Registry Platform (WHO-ICTRP), OpenGrey, and ProQuest Dissertations & Theses. The search strategy combined Medical Subject Headings (MeSH), Emtree terms, and free-text keywords for three concepts (selective, partial, or stepwise caries removal; complete or non-selective caries removal; and permanent teeth), using Boolean operators and truncation. No restrictions on publication date or language were applied. The complete search strategy for each database is provided in the Appendices. Additionally, backward and forward citation searching (snowballing) of included studies and relevant prior reviews was conducted to identify any further eligible literature.

Study Selection and Data Extraction

Study selection was conducted in two phases using a dedicated systematic review software platform. Two reviewers independently screened titles and abstracts for relevance, followed by an independent full-text assessment of potentially eligible articles against the predefined inclusion and exclusion criteria; dual independent screening was used because single screening misses a substantially larger proportion of eligible studies [22]. Any disagreements between the reviewers were resolved through arbitration by a third independent reviewer.

Data extraction was independently performed by two reviewers using a standardized and piloted spreadsheet. The extracted data included study characteristics (author, year, country, design, setting), patient demographics, specifics of the interventions and comparators, follow-up durations, and clinical outcome metrics.

When a trial enrolled both primary and permanent teeth, it was eligible only if outcomes were reported separately for permanent teeth by treatment arm, and only the permanent-tooth data were extracted. When outcome counts were not reported directly, they were derived from reported percentages, participant flow, or the trials' failure definitions; derived or inferred values were checked by a second reviewer, flagged in the extraction form, and examined in a sensitivity analysis that excluded the trials contributing them.

Quality Assessment and Risk of Bias

The risk of bias of the included RCTs was assessed independently by two reviewers using the revised Cochrane Risk of Bias tool for randomized trials (RoB 2) [23]. Studies were evaluated across five domains: bias arising from the randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. Discrepancies were resolved by a third reviewer.

Data Synthesis and Statistical Analysis

Statistical analyses were performed using the R software environment for statistical computing, version 4.6.1 [24], utilizing the meta and metafor packages [25]. For dichotomous outcomes (e.g., pulp exposure, overall clinical success), the effect sizes were pooled and expressed as risk ratios (RR) with their corresponding 95% confidence intervals (CIs). For continuous outcomes, the mean difference (MD) or standardized mean difference (SMD) was utilized, as appropriate.

Recognizing the anticipated clinical and methodological heterogeneity across the included trials, a random-effects model was designated a priori as the primary analytical approach. The between-study variance (τ^2) was estimated using the restricted maximum likelihood (REML) estimator. Confidence intervals for pooled estimates were calculated with the HKSJ method, which uses a t-distribution with k − 1 degrees of freedom. This method was chosen because, when few trials are pooled, conventional Wald-type intervals are too narrow and inflate the type I error rate, whereas HKSJ intervals maintain coverage closer to the nominal level [26]. Because HKSJ intervals can be very wide when only two to four trials contribute, the main outcomes were also re-estimated using REML with Wald-type intervals and with a Mantel-Haenszel common-effect model as sensitivity analyses. Heterogeneity was assessed with Cochran's Q test and quantified with the I^2 statistic and τ^2, with I^2 values > 50% indicating substantial heterogeneity [27]; its clinical implications were summarized with 95% prediction intervals. A continuity correction of 0.5 was added to all cells of trials with zero events in one arm; trials with no events, or with all participants experiencing the event, in both arms were non-estimable for the risk ratio and contributed no weight. A treatment-arm continuity correction was applied in a sensitivity analysis.

The tooth was the unit of analysis, as in the included trials. For trials that included more than one tooth per patient, no cluster-adjusted estimates or intracluster correlation coefficients were reported, so within-patient correlation could not be accounted for; this is addressed as a limitation. For trials comparing SE and SW arms with a single complete-excavation arm, the SE and SW arms were combined for the main analyses. For the SE-versus-SW subgroup analysis, the events and participants of the shared control arm were divided equally between the two comparisons, so that no control participant was counted twice.

To explore sources of heterogeneity, predefined subgroup analyses were conducted (single-visit SE vs. two-stage SW, and short-term (⩽12 months) vs. long-term (>12 months) follow-up), and differences between subgroups were tested with the random-effects test for subgroup differences. Sensitivity analyses excluded trials at high overall risk of bias, trials contributing derived or inferred data, and the trial with a mixed-dentition sample; in addition, a leave-one-out analysis was performed to evaluate the influence of individual studies on the pooled effect size [28]. The number needed to treat (NNT) and number needed to harm (NNH) were calculated to translate the pooled estimates into absolute terms [29]. The absolute risk difference (ARD) was calculated as CR × (RR − 1), where CR is the pooled control-group risk (total events divided by total participants in the control arms of the trials contributing to the estimate), and NNT or NNH = 1/|ARD|; 95% CIs were obtained by applying the same calculation to the confidence limits of the RR.

Standard assessments for small-study effects and potential publication bias involve the visual inspection of contour-enhanced funnel plots [30] and formal statistical evaluation using Egger's regression test [31], complemented by the non-parametric trim-and-fill method for adjusting pooled estimates [32]. However, because fewer than 10 studies contributed to each meta-analysis, these analyses were not performed, as they lack adequate power to distinguish true asymmetry from chance [31]. To control the risk of random errors (type I and type II) resulting from sparse data and repeated significance testing, trial sequential analysis (TSA) was performed [33]. The required information size (RIS) was calculated as $RIS = 4(z_{1-\alpha/2} + z_{1-\beta})^2 \times \bar{p}(1 - \bar{p})/\delta^2 \times 1/(1 - D^2)$, where $\bar{p}$ is the mean of the control and anticipated intervention event proportions, δ is the anticipated absolute difference, and D^2 is the diversity estimated from the meta-analysis. A two-sided α of 5% and power of 80% were used, with the pooled control-group event proportion as the control event rate. The anticipated effects were a relative risk reduction (RRR) of 20% and 40% for pulp exposure and a 10% relative change for the clinical success outcomes. Trials were entered in chronological order, and Lan-DeMets O'Brien-Fleming alpha-spending monitoring boundaries were constructed using the ldbounds package in R. Statistical significance was established at a two-sided p-value of <0.05.

Certainty of Evidence

The certainty of the evidence for each outcome was evaluated using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) framework [34] and graded as high, moderate, low, or very low based on risk of bias, inconsistency, indirectness, imprecision, and publication bias. Risk of bias was downgraded when most of the weight came from trials with some concerns or high risk of bias; inconsistency when I^2 exceeded 50% or the prediction interval included effects in opposite directions; indirectness when outcome definitions differed across trials or the outcome had to be inferred; and imprecision by one level when the optimal information size (OIS) was not met, and by two levels when, in addition, the 95% CI included both appreciable benefit and appreciable harm (RR 0.75 and 1.25). Publication bias could not be assessed because fewer than 10 trials contributed to each outcome.

Results

Study Selection and Characteristics

A literature search across all databases and registers yielded 939 records. After removing 161 duplicates, 778 unique records underwent title and abstract screening, which resulted in the exclusion of 763 records. The remaining 15 reports were retrieved and subjected to full-text eligibility assessment. Of these, six reports were excluded for the following reasons: wrong study design (n = 3), wrong intervention (n = 2), and wrong population (n = 1). Nine reports corresponding to eight RCTs [35-43] fulfilled all eligibility criteria and were included in the final qualitative and quantitative syntheses (Figure *1*).

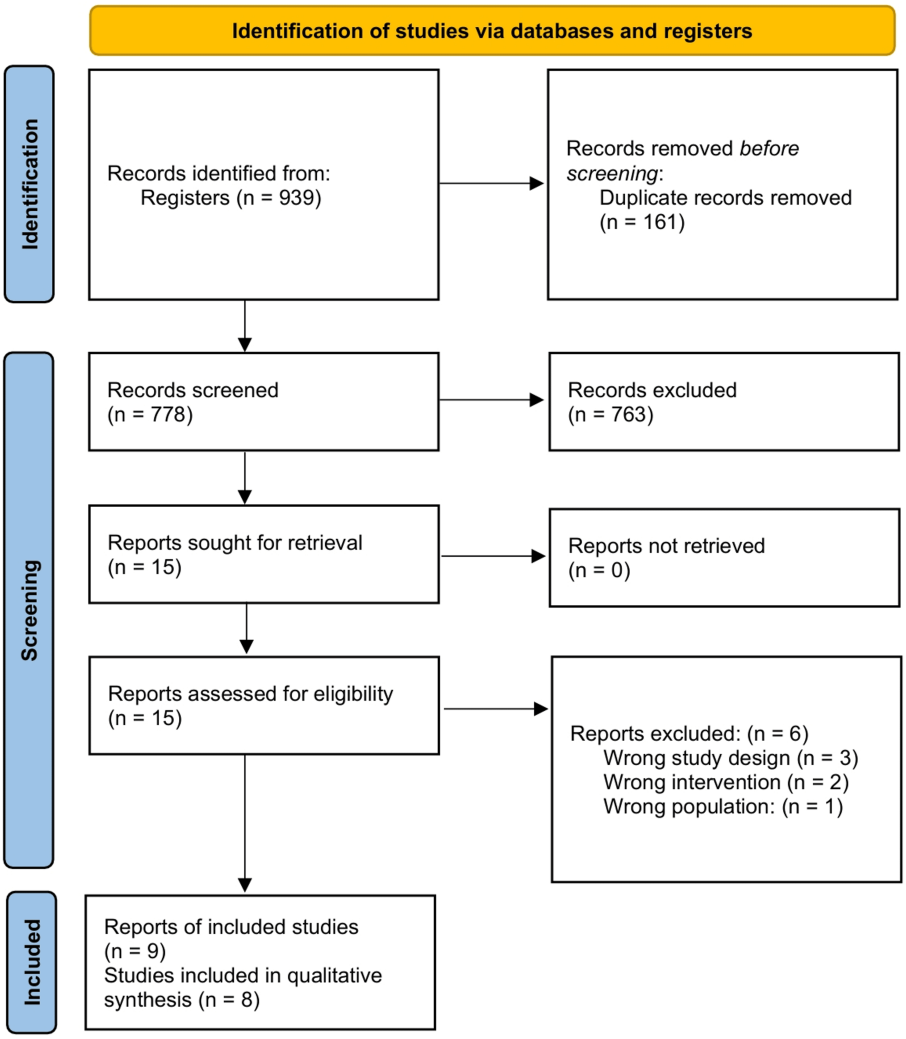


FIGURE 1: PRISMA 2020 flow diagram.

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

The baseline characteristics of the included studies and participants are summarized in Table *1*. The trials were conducted across various geographical regions, including Sweden, Turkey, Denmark, Brazil, India, Pakistan, and Jordan. The study populations comprised children, adolescents, and adults (mean age ranging

from 8.7 to 29 years) presenting with deep carious lesions extending into the middle or pulpal third of the dentin (1/2 to 75% dentin thickness). All included teeth were diagnosed as vital, with no clinical or radiographic signs of irreversible pulpitis or necrosis.

Study	Country	Design	Setting	Unit of analysis	Randomized SCR/CCE	Analyzed SCR/CCE	Age	Population	Pulp status	Lesion depth
Leksell et al. (1996) [35]	Sweden	RCT, parallel (134 teeth/116 patients)	University + 2 public district clinics; 6 pediatric dentists	Tooth	64/70	57/70	6-16 years (mean 10.2)	Young permanent posterior teeth (126 molars, 8 premolars); 31 immature roots	Vital; no persistent pain (14 transient provoked pain)	Radiographic depth with expected exposure if DCE
Orhan et al. (2010) [36]	Turkey	RCT, 3-arm, tooth-level (mixed dentition; permanent subgroup extracted)	University pediatric clinic; single operator	Tooth	36 (SE 19 + SW 17)/24	36/24	4-15 years (mean 8.7, whole sample)	Young permanent mandibular first molars (60 of 154 teeth)	Vital; no irreversible pulpitis	≥3/4 dentin thickness
Bjørndal et al. (2010) [37]; (2017) [38]	Denmark & Sweden	Multicenter RCT, parallel, patient-blinded (1 tooth/patient)	6 centers (dental schools + public dental service)	Patient	156/158	143 (1 year), 118 (5 years)/149 (1 year), 121 (5 years)	≥18 y (median 29)	Adults; premolars, molars, incisors; ~96% approximal	Vital; mild-to-moderate pretreatment pain allowed (reversible)	≥75% dentin with radiodense zone
Rando-Meirelles et al. (2013) [39]	Brazil	RCT (preliminary), tooth-level; teeth of same patient in both arms	University clinic; single operator	Tooth	9-Sep	8-Aug	12-17 years (mean 15.8)	Adolescents; occlusal lesions in permanent molars	Vital; no spontaneous pain	≥ middle third of dentin
Khokhar et al. (2018) [40]	India	RCT, parallel	Postgraduate institute; single operator	Tooth/patient	70/73	67/69	14-54 years (mean 25.2)	Mature permanent mandibular molars	Vital (EPT + cold); no irreversible pulpitis	≥1/2 dentin
Ahmed et al. (2021) [41]	Pakistan	RCT, parallel (lottery)	Nishtar Institute of Dentistry, Multan	Tooth	35/35	30/30	Mean 23.4 (CCR)/25.6 (PCR) y	Permanent molars (occlusal/occluso-proximal)	Vital (cold + EPT)	≥1/2 dentin
Taha et al. (2024) [42]	Jordan	RCT, parallel, double-blind, block randomization	Jordan University of Science and Technology	Tooth	63/61	63/61	NR (abstract)	Mature permanent teeth	Reversible pulpitis (clinical diagnosis)	≥2/3 dentin
Shah et al. (2026) [43]	Pakistan	RCT, parallel, 1:1, computer-generated, sealed opaque envelopes	Outpatient dental clinics (Sindh)	Patient	30/30	30/30	18-45 years (mean 28.4)	Adults; occlusal/occluso-proximal deep caries in molars	No irreversible pulpitis	Deep (not quantified)

TABLE 1: Design, setting, and participants of the eight included randomized controlled trials (nine reports).

SCR: selective caries removal (experimental arm), CCE: complete caries excavation (control arm), SE: single-visit selective excavation, SW: two-visit stepwise excavation, DCE: direct complete excavation, CCR: complete caries removal, PCR: partial caries removal, EPT: electric pulp test, NR: not reported.

Table *2* details the intervention protocols, restorative materials, and follow-up durations. The experimental arms utilized either single-visit SE [36,39-43] or two-visit SW [35,37,38]. The control arms uniformly employed complete (non-selective) caries excavation (CCE) to hard dentin. Follow-up periods varied widely, ranging from 7 days for short-term postoperative sensitivity [43] to 60 months for long-term clinical and radiographic outcomes [38].

Study	SCR arm	CCE arm	Liner/restoration	Maximum follow-up (months)
Leksell et al. (1996) [35]	SW: bulk removal, $Ca(OH)_2$ + ZOE 8-24 weeks, re-entry	Direct complete excavation (hard dentin)	$Ca(OH)_2$ + ZOE; GIC/resin or amalgam	43 (mean; range 12-132; unexposed teeth only)
Orhan et al. (2010) [36]	SE: 1-visit IPT (soft dentin left) and SW: 2-visit IPT (3-month re-entry); $Ca(OH)_2$ liner	DCE to hard dentin	$Ca(OH)_2$ + GIC base + composite	12
Bjørndal et al. (2010) [37]/(2017) [38]	SW: selective to soft, $Ca(OH)_2$ + GIC, re-entry 8-12 weeks	Direct complete (non-selective) excavation in one visit	$Ca(OH)_2$ base; OptiBond Solo Plus + Herculite XRV	60 (5-year report)
Rando-Meirelles et al. (2013) [39]	SE: partial removal (pulpal soft dentin left), GIC liner, composite; no re-entry	Complete removal to hard dentin; $Ca(OH)_2$ + GIC; composite	GIC (SE) vs $Ca(OH)_2$ + GIC (CCE); resin composite	24 (mean 18.7 SE / 21 CCE)
Khokhar et al. (2018) [40]	SE (partial): soft wet dentin left on pulpal wall; single visit	CCR guided by caries-detector dye	RMGIC base + Tetric N-Ceram composite	18
Ahmed et al. (2021) [41]	SE (partial) by visual-tactile criteria	CCR confirmed with caries-detector dye	RMGIC + composite	18
Taha et al. (2024) [42]	SE to firm dentin + Biodentine + composite	Total caries removal to hard dentin; VPT (Biodentine) if exposed	Biodentine + composite	12
Shah et al. (2026) [43]	SE: firm periphery, affected dentin preserved on pulpal floor; single visit	Complete excavation to firm dentin incl. pulpal floor	RMGIC (immediate)	0.23 (7 days)

TABLE 2: Interventions, restorative protocol, and follow-up.

SCR: selective caries removal (experimental arm), CCE: complete caries excavation (control arm), SE: single-visit selective excavation, SW: two-visit stepwise excavation, DCE: direct complete excavation, CCR: complete caries removal, $Ca(OH)_2$: calcium hydroxide, ZOE: zinc oxide-eugenol, GIC: glass-ionomer cement, RMGIC: resin-modified GIC, IPT: indirect pulp treatment, VPT: vital pulp therapy.

Several trial-specific decisions were required. Orhan et al. [36] randomized 154 teeth (94 primary and 60 young permanent molars) from 123 patients to one-visit indirect pulp treatment, two-visit indirect pulp treatment, or direct complete excavation; outcomes were reported separately by dentition and treatment arm, and only the 60 permanent molars (19 SE, 17 SW, and 24 controls) were extracted. Because allocation was not reported to be stratified by dentition, the permanent-tooth data represent a subgroup of the randomized sample, and the effect of excluding this trial was examined in a sensitivity analysis. Bjørndal et al. [37,38] and Shah et al. [43] included one tooth per patient. Leksell et al. [35] (134 teeth in 116 patients), Orhan et al. [36] (154 teeth in 123 patients), and Rando-Meirelles et al. [39] (18 randomized teeth in 11 patients, with teeth of the same patient allocated to both arms) included more than one tooth per patient, and Khokhar et al. [40], Ahmed et al. [41], and Taha et al. [42] did not report the number of teeth per patient; none of these trials reported a cluster-adjusted analysis. Some counts were derived rather than reported directly: pulp exposures in the complete-excavation arm of Ahmed et al. [41] were calculated from the reported percentage; the number of pulp exposures in the SCR arm of Taha et al. [42] was not stated in the available report and was assumed to be zero; and the need for endodontic treatment was inferred from the trials' failure definitions in three trials [40-42].

Risk of Bias in Included Studies

The methodological quality and risk of bias of the included trials, assessed using the RoB 2 tool, are visually represented in Figure *2*. Overall, only one trial [37,38] was judged to be at a low risk of bias. Five trials had some concerns [36,39,40,42,43] due to issues related to the randomization process (Domain 1) or deviations from intended interventions resulting from the lack of operator blinding (Domain 2). Two trials [35,41] were classified as having a high risk of bias due to methodological flaws, including inadequate randomization sequence generation, compromised allocation concealment, and inconsistencies in outcome reporting.

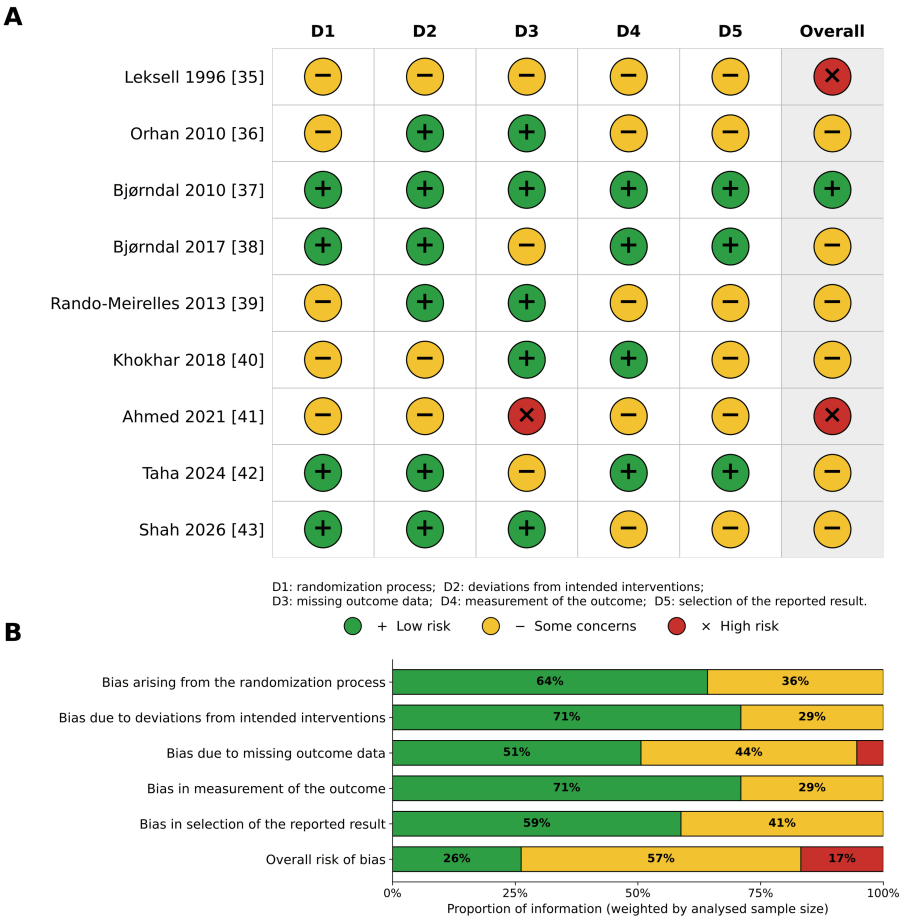


FIGURE 2: Risk-of-bias assessment of included trials (Cochrane RoB 2).

(A) Traffic-light plot of domain-level and overall judgments for each of the eight included trials (nine reports) [35-43]. (B) Weighted summary bar plot showing the proportion of information (weighted by analyzed sample size) at each risk level for each domain and overall.

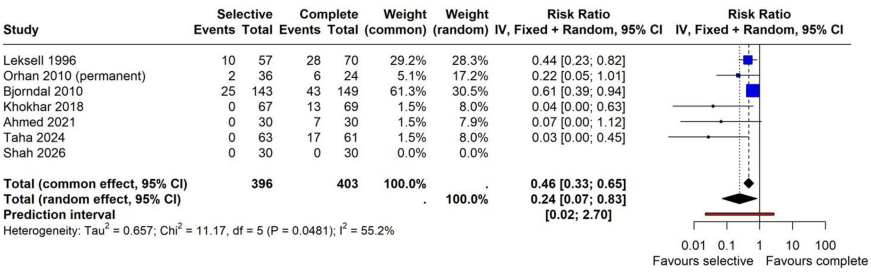
D1: randomization process, D2: deviations from intended interventions, D3: missing outcome data, D4: measurement of the outcome, D5: selection of the reported result.

Green (+): low risk, yellow (−): some concerns, red (×): high risk.

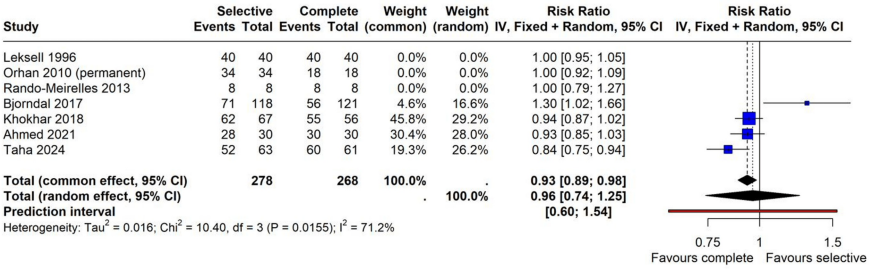
Primary Outcomes

Pulp exposure: The incidence of intraoperative pulp exposure was reported in seven trials (859 teeth) [35-37,40-43], of which six (799 teeth) contributed to the pooled estimate; Shah et al. [43] reported no exposures in either arm and was therefore non-estimable. Selective caries removal was associated with a lower risk of pulp exposure than CCE (RR = 0.24; 95% CI: 0.07-0.83; p = 0.032) (Figure *3A*). Based on a pooled control-group risk of 283 per 1,000, the absolute risk difference was -214 per 1,000 (95% CI: -263 to -47), corresponding to an NNT of 5 (95% CI: 4-22) to prevent one pulp exposure. Heterogeneity was moderate (I^2 = 55.2%; τ^2 = 0.657), and the 95% prediction interval (0.02-2.70) included no effect.

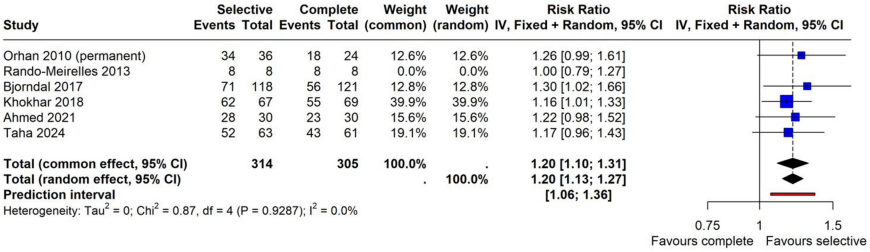
A



B



C



D

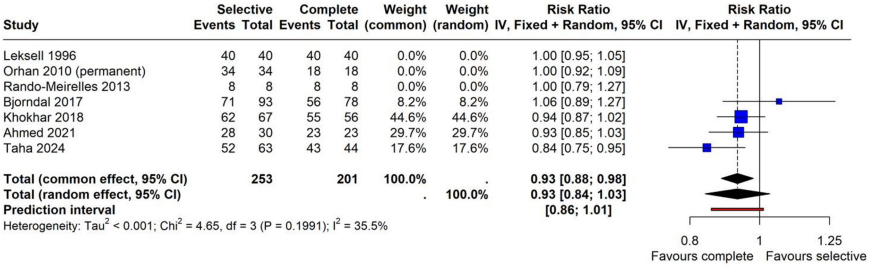


FIGURE 3: Forest plots of the primary outcomes, selective caries removal (SCR) versus complete caries excavation (CCE).

(A) Pulp exposure [35-37,40-43]. (B) Clinical success as defined by trial authors, longest follow-up [35,36,38-42]. (C) Exploratory composite success in which every intraoperative pulp exposure is counted as failure [36,38-42]. (D) Success restricted to teeth not exposed during excavation [35,36,38-42].

Studies with 0% or 100% events in both arms are shown but non-estimable (weight 0%).

Squares: study risk ratios (size proportional to weight), horizontal lines: 95% CIs, diamonds: pooled common-effect and random-effects (REML, Hartung-Knapp) estimates, red bar: 95% prediction interval.

In the subgroup analysis by approach (Figure *4A*), the reduction in pulp exposure was larger with single-visit SE (RR = 0.07; 95% CI: 0.02-0.35; I^2 = 0%) than with two-visit SW (RR = 0.53; 95% CI: 0.29-0.99; I^2 = 0%) (test for subgroup differences, random-effects model: $p < 0.001$). This comparison is indirect, made between trials

rather than within them, and may be confounded by differences in patient age, lesion depth and location, excavation endpoints, and liner materials; in addition, exposures occurring at the re-entry visit were counted in the SW trials. It should therefore be interpreted as hypothesis-generating.

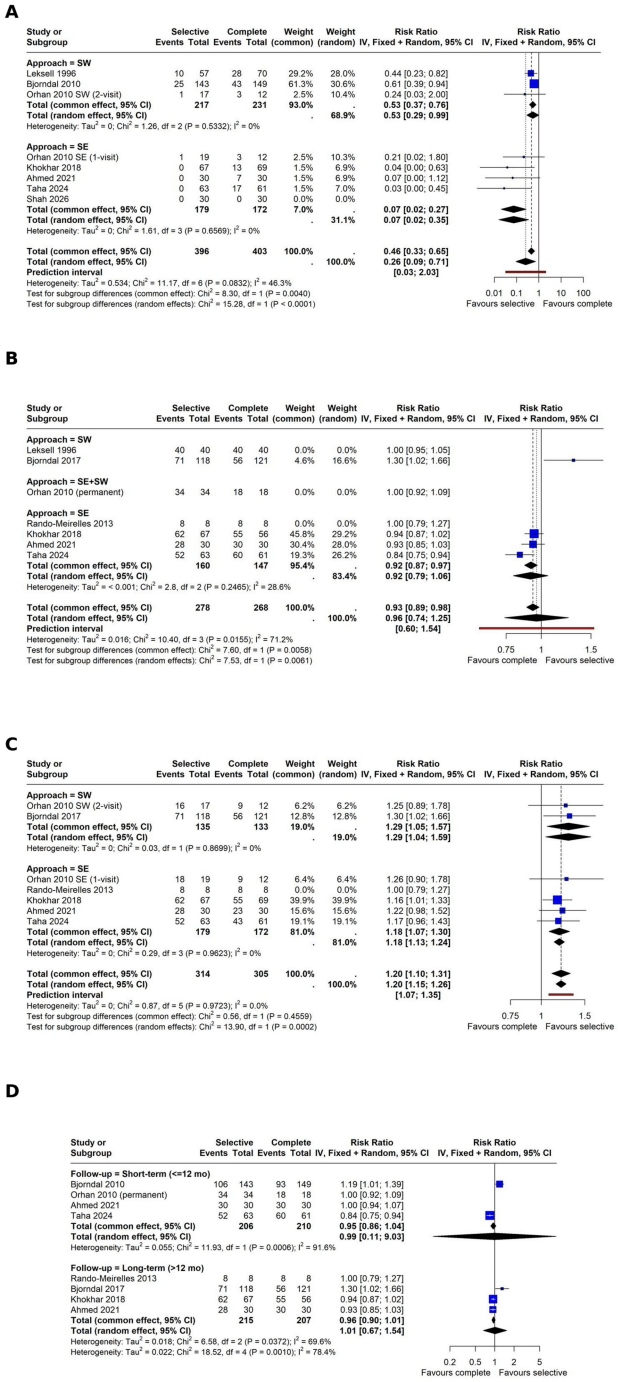


FIGURE 4: Subgroup forest plots.

(A) Pulp exposure by approach, SW vs. SE [35-37,40-43]. (B) Author-defined clinical success by approach [35,36,38-42]. (C) Composite success (exposure = failure) by approach [36,38-42]. (D) Success by follow-up window, short term (≤12 months) vs. long term (>12 months) [36-42]; overall estimate suppressed because studies contribute to both windows. Orhan et al. [36] enters as separate SE and SW comparisons with a halved shared control.

Clinical success: Clinical success was analyzed in three ways because trials defined it differently. Seven trials reported clinical success as defined by the trial authors [35,36,38-42]. Definitions differed: some trials counted an exposed pulp that was successfully managed by vital pulp therapy as a success [41,42], some

excluded exposed teeth from the success analysis [35,36,40], and one counted exposure as a failure [38]. Leksell et al. [35], Orhan et al. [36], and Rando-Meirelles et al. [39] reported 100% success in both arms and were non-estimable; the pooled estimate from the four estimable trials (546 teeth) showed no statistically significant difference between SCR and CCE (RR = 0.96; 95% CI: 0.74-1.25; p = 0.669; I^2 = 71.2%; 95% prediction interval: 0.60 to 1.54) (Figure *3B*).

When the analysis was restricted to teeth that were not exposed during excavation, success did not differ between groups (RR = 0.93; 95% CI: 0.84-1.03; p = 0.116; I^2 = 35.5%; follow-up 12 to 60 months) (Figure *3D*). Clinical success analyzed by follow-up window (Figure *4D*) showed no significant pooled difference at ⩽12 months (RR = 0.99; 95% CI: 0.11-9.03; I^2 = 91.6%) or at >12 months (RR = 1.01; 95% CI: 0.67-1.54; I^2 = 69.6%); because several trials contributed to both windows, no overall estimate was calculated.

Secondary Outcomes

Need for endodontic treatment: Four trials (336 teeth) [39-42] reported the need for endodontic treatment after the initial procedure; Rando-Meirelles et al. [39] reported no events in either arm, so three trials (320 teeth) contributed to the pooled estimate. In these three trials, the outcome was partly inferred from the trials' failure definitions (e.g., pulp necrosis, irreversible pulpitis, or periapical changes assumed to require endodontic treatment). The pooled RR was 2.58 (95% CI: 0.05-123.20; p = 0.402; I^2 = 69.8%) (Figure *5A*), and adding the unexposed teeth of Bjørndal et al. [38] gave a similarly imprecise estimate (RR = 1.80; 95% CI: 0.25-12.74) (Figure *5B*). These CIs are compatible with both a large reduction and a large increase in risk, so the analysis cannot determine whether SCR changes the need for endodontic treatment.

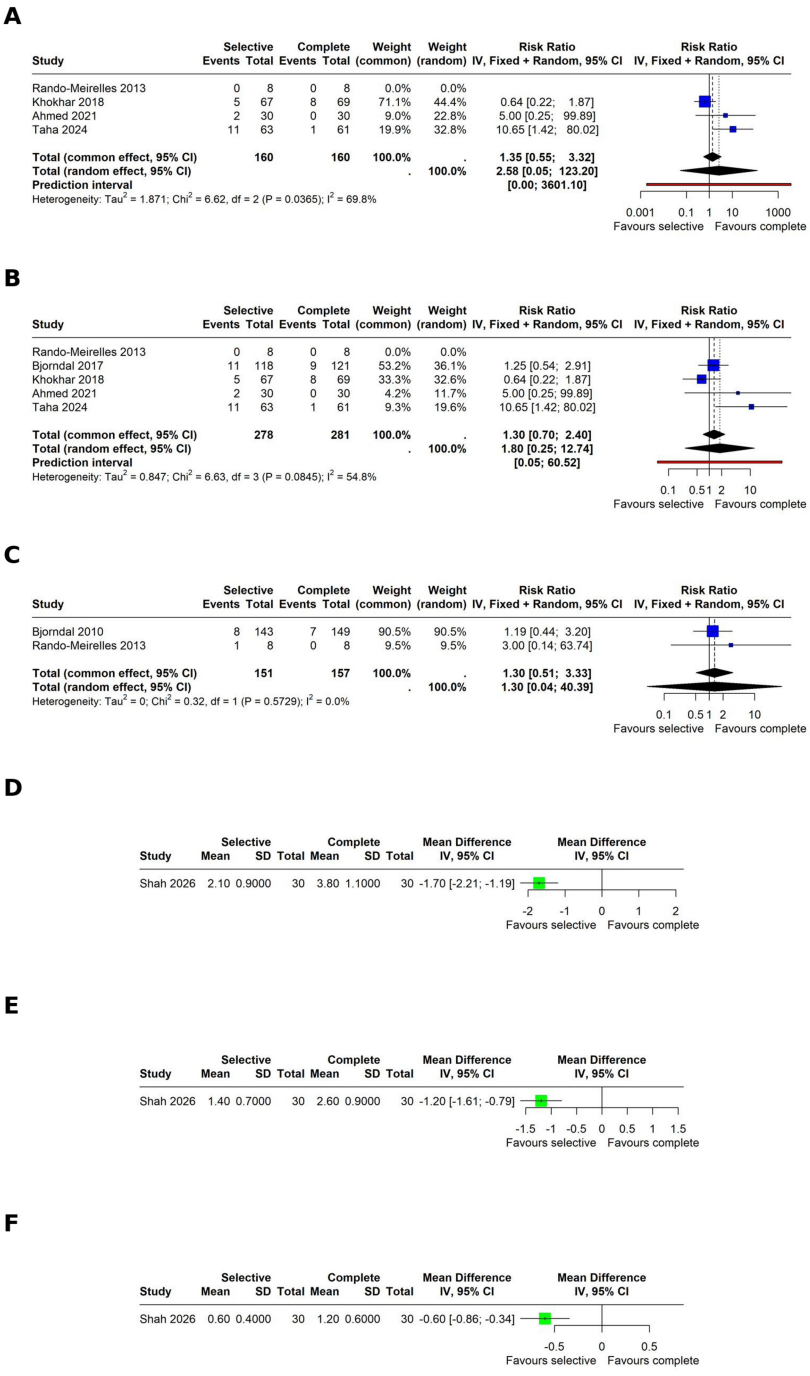


FIGURE 5: Forest plots of secondary outcomes.

(A) Need for endodontic treatment [39-42]. (B) Need for endodontic treatment including Bjørndal et al., unexposed teeth only [38-42]. (C) Postoperative pain or symptoms during follow-up [37,39]. (D-F) Postoperative sensitivity on VAS at 24 h, 72 h, and 7 days (mean difference) [43]. RR < 1 and negative MD favor SCR.

Postoperative pain and sensitivity: Delayed postoperative pain or symptoms during follow-up were reported by two trials (308 teeth) [37,39], with no significant difference between groups (RR = 1.30; 95% CI: 0.04-40.39; p = 0.510; I^2 = 0%) (Figure *5C*). Acute postoperative sensitivity on a visual analogue scale (VAS, 0-10) was reported by a single trial of 60 patients [43], in which scores were lower after single-visit SE than after CCE at 24 hours (MD = -1.70; 95% CI: -2.21 to -1.19), 72 hours (MD = -1.20; 95% CI: -1.61 to -0.79), and 7 days (MD = -0.60; 95% CI: -0.86 to -0.34) (Figure *5D*-*5F*). Because these data come from one small trial with seven days of follow-up, they cannot be generalized.

Additional Exploratory Outcome: Composite Success

In the exploratory composite outcome, a tooth was counted as a success only if the pulp was not exposed during excavation and the tooth was successful at the last follow-up, so every intraoperative exposure was counted as a failure, even when the exposed pulp was subsequently managed successfully by vital pulp therapy. Six trials contributed [36,38-42], five of which were estimable (619 teeth). The composite favored SCR (RR = 1.20; 95% CI: 1.13-1.27; $p < 0.001$; $I^2 = 0\%$; NNT 8; 95% CI: 6-12) (Figure *3C*), with point estimates in the same direction for SW (RR = 1.29; 95% CI: 1.04-1.59) and SE (RR = 1.18; 95% CI: 1.13-1.24) (Figure *4C*). Because success did not differ among unexposed teeth, this result is driven mainly by the difference in pulp exposure rates and should not be interpreted as independent evidence of improved pulp survival or long-term tooth survival.

Sensitivity and Leave-One-Out Analyses

Sensitivity and leave-one-out analyses are shown in Figure *6* and Figure *7*. For pulp exposure, the point estimate favored SCR in every analysis, but the CI included no effect after excluding the two trials at high risk of bias [35,41] (four estimable trials, 612 teeth; RR = 0.18; 95% CI: 0.02-1.74; $I^2 = 67.5\%$) (Figure *6A*), trials contributing derived or inferred data [41,42] (RR = 0.47; 95% CI: 0.20-1.12) (Figure *6B*), or Orhan et al. [36] (RR = 0.20; 95% CI: 0.04-1.15) (Figure *6C*). The loss of significance after excluding the high-risk trials reflects a wider CI and greater heterogeneity with fewer trials rather than a change in the direction of effect; nevertheless, it shows that the statistical significance of the pooled result depends partly on trials at high risk of bias. With a Mantel-Haenszel common-effect model (RR = 0.35; 95% CI: 0.25-0.49) or REML with Wald-type intervals (RR = 0.24; 95% CI: 0.10-0.61), the reduction remained significant, so the conclusion also depends on the choice of CI method; a treatment-arm continuity correction gave the same result as the main analysis. In the leave-one-out analyses, the pulp-exposure estimate ranged from RR 0.16 to 0.40 and lost statistical significance when Orhan et al. [36], Khokhar et al. [40], Ahmed et al. [41], or Taha et al. [42] was omitted (Figure *7A*). For author-defined clinical success, no sensitivity analysis changed the null finding (RR range 0.96-1.01; Figure *6D*-*6F*; Mantel-Haenszel RR = 1.01, 95% CI: 0.92-1.10; REML-Wald RR = 0.96, 95% CI: 0.83-1.11), and leave-one-out estimates ranged from 0.92 to 1.01 (Figure *7B*). The exploratory composite outcome remained significant in every leave-one-out iteration (RR range 1.19-1.23) (Figure *7C*).

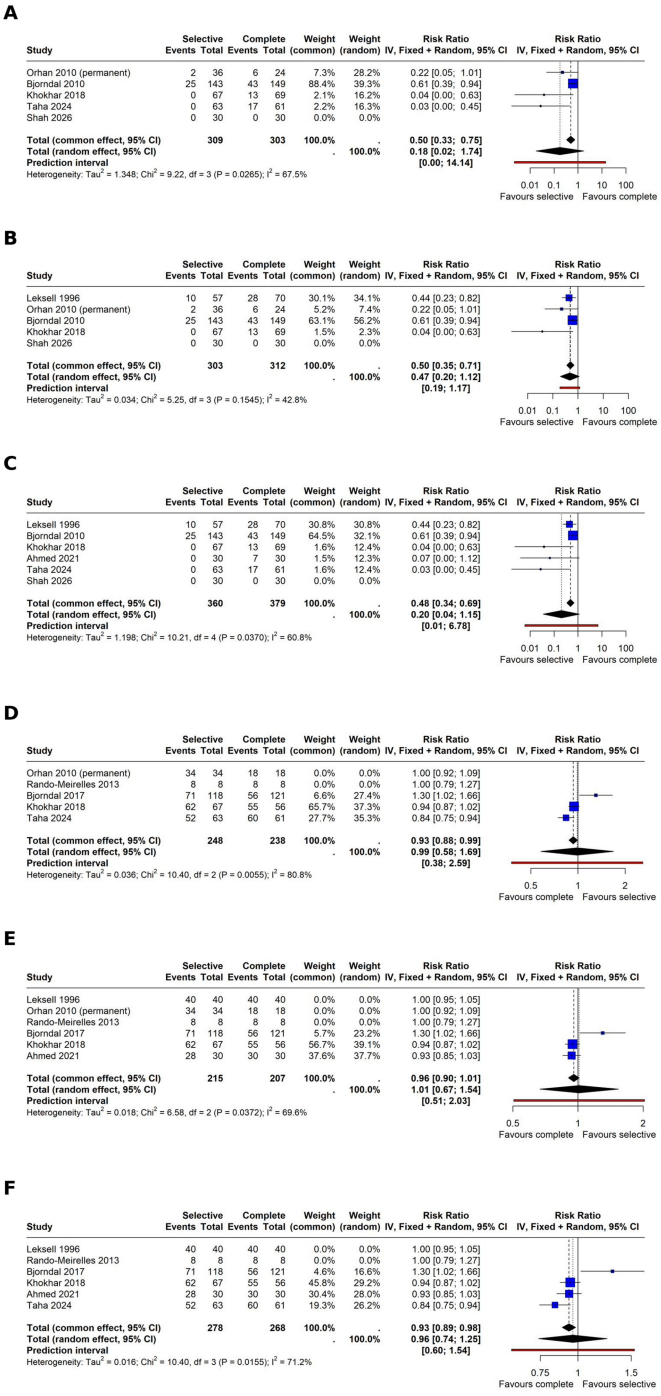


FIGURE 6: Sensitivity forest plots.

Pulp exposure: (A) excluding high-risk-of-bias trials [36,37,40,42,43]; (B) excluding derived/inferred data [35-37,40,43]; (C) excluding Orhan et al. [35,37,40-43]. Author-defined clinical success: (D) excluding high-risk-of-bias trials [36,38-40,42]; (E) excluding derived/inferred data [35,36,38-41]; (F) excluding Orhan et al. [35,38-42].

Studies with 0% or 100% events in both arms are shown but are non-estimable (weight 0%).

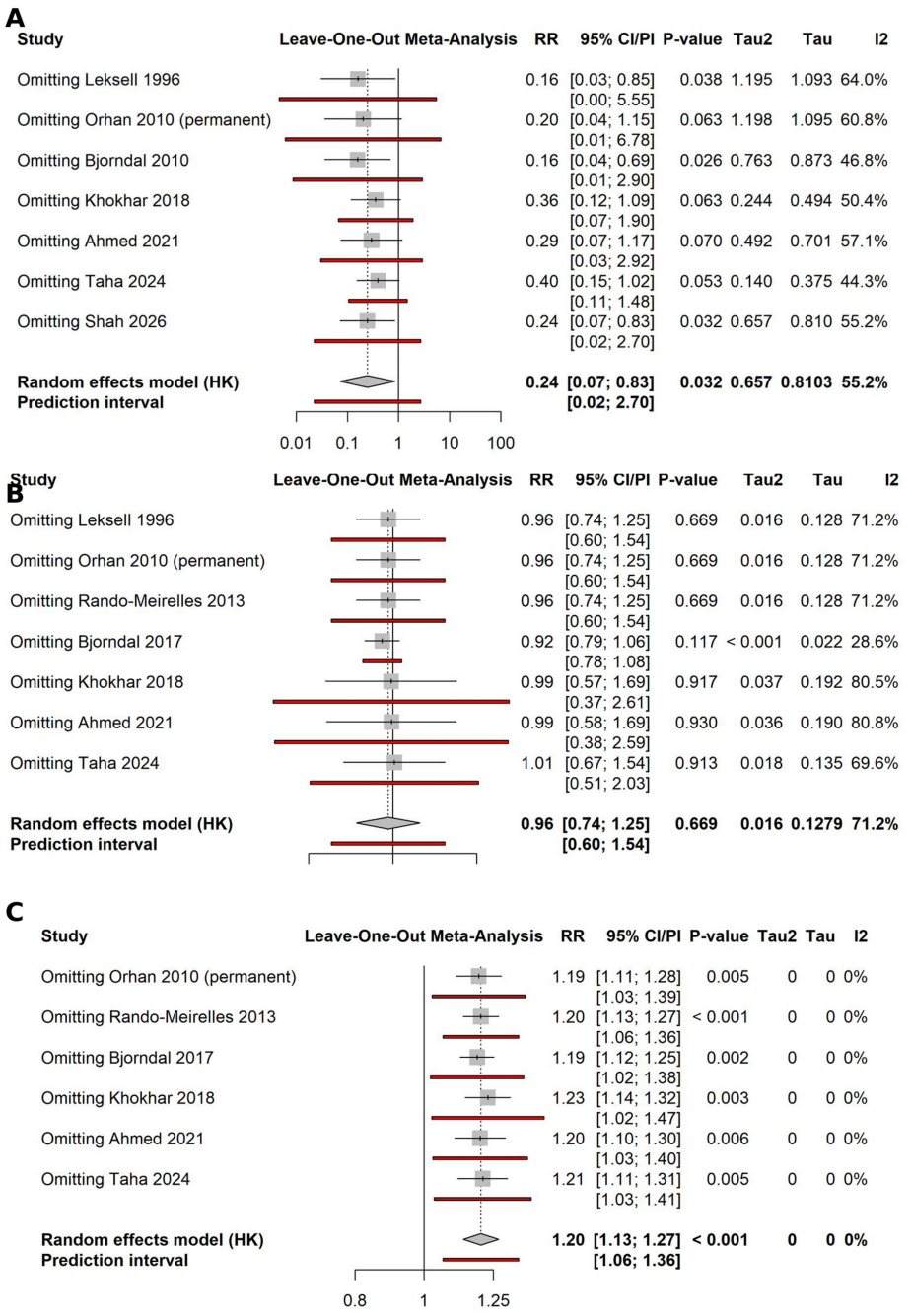


FIGURE 7: Leave-one-out influence analyses.

(A) Pulp exposure [35-37,40-43]. (B) Author-defined clinical success [35,36,38-42]. (C) Composite success (exposure = failure) [36,38-42].

Each row shows the pooled random-effects RR (95% CI) after omitting the named study [35-43]; the bottom row gives the full-sample estimate.

Trial Sequential Analysis (TSA)

TSA results are shown in Figure *8*. For pulp exposure, with a control event proportion of 28.3%, α = 5%, power = 80%, and D^2 = 86.7%, the RIS was 13,989 teeth for an RRR of 20% and 3,227 teeth for an RRR of 40%. With 799 teeth accrued (6% and 25% of the RIS, respectively), the cumulative Z-curve (final Z = -3.03) crossed the conventional significance threshold, but not the trial sequential monitoring boundaries (Figure *8A*, *8B*); the evidence for pulp exposure is therefore inconclusive. For author-defined clinical success (control event proportion 75.0%, 10% relative change, D^2 = 89.7%), the RIS was 9,030 teeth; 546 teeth (6%)

had accrued, and the Z-curve crossed neither the conventional threshold nor the monitoring boundaries (Figure *8C*). For the exploratory composite outcome (control event proportion 63.9%, 10% relative change, D^2 = 0%), the RIS was 1,695 teeth; with 619 teeth accrued (37%), the Z-curve (final Z = 4.14) crossed the O'Brien-Fleming monitoring boundary (Figure *8D*). This indicates that the difference in the composite outcome is unlikely to be due to random error; however, because the composite is driven by exposure rates, it does not provide conclusive evidence of improved long-term pulp or tooth survival.

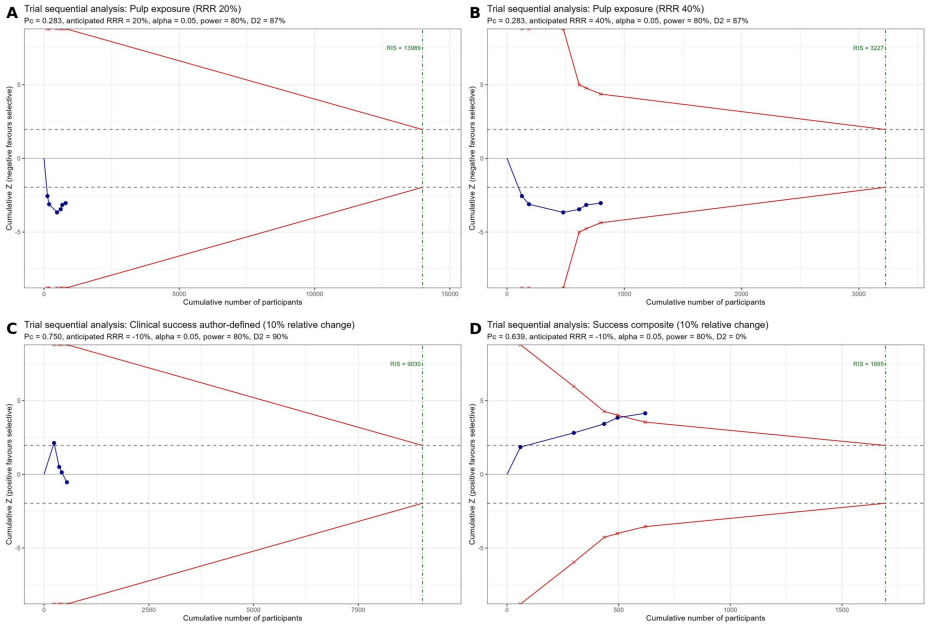


FIGURE 8: Trial sequential analysis plots.

(A) Pulp exposure, anticipated RRR 20% [35-37,40-42]. (B) Pulp exposure, anticipated RRR 40% [35-37,40-42]. (C) Author-defined clinical success, 10% relative change [38,40-42]. (D) Exploratory composite success (exposure = failure), 10% relative change [36,38,40-42].

All analyses used a two-sided α of 5%, power of 80%, the pooled control-group event proportion (Pc) and the diversity (D^2) shown in each panel heading, and Lan-DeMets O'Brien-Fleming alpha-spending boundaries. Trials with no events or with all events in both arms contribute no information to the cumulative Z-curve and are not plotted (pulp exposure [43]; author-defined success [35,36,39]; and composite success [39]).

Blue line and points = cumulative Z-curve as trials accrue (chronological order); red lines with crosses = O'Brien-Fleming monitoring boundaries; gray dashed lines = conventional significance thresholds (Z = ±1.96); green dash-dot vertical line = required information size (RIS).

Certainty of Evidence (GRADE)

The certainty of the evidence was evaluated using the GRADE framework (Table *3*). For pulp exposure, certainty was very low: it was downgraded for risk of bias (about 70% of the weight came from trials with some concerns or high risk of bias, and pulp exposure was judged by unblinded operators), inconsistency (I^2 = 55.2%, with a 95% prediction interval of 0.02 to 2.70), and imprecision (799 teeth, below the OIS of 1,170, with loss of significance in sensitivity analyses). Author-defined clinical success was rated very low because of risk of bias, inconsistency (I^2 = 71.2%), indirectness (success definitions differed across trials), and very serious imprecision (the 95% CI included both appreciable benefit and appreciable harm). The need for endodontic treatment was rated very low because of risk of bias, inconsistency (I^2 = 69.8%), indirectness (the outcome was partly inferred from failure definitions), and very serious imprecision. Postoperative pain or symptoms were rated very low because of indirectness (different symptom constructs) and very serious imprecision. The exploratory composite outcome was rated low because of risk of bias and imprecision (619 teeth, below the OIS of 831). Large, well-designed RCTs are therefore likely to change these estimates.

Outcome	Studies (participants)	RR (95% CI)	Risk with CCE (per 1000)	Risk with SCR (per 1000, 95% CI)	OIS	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Certainty	Comments
Pulp exposure [35-37,40-43]	7 RCTs; 6 pooled (799)	0.24 (0.07-0.83)	283	69 (20-236)	1,170	Serious	Serious	Not serious	Serious	Not assessable (k < 10)	⊕◯◯◯ Very low	–
Clinical success, author-defined [35,36,38-42]	7 RCTs; 4 pooled (546)	0.96 (0.74-1.25)	750	721 (555-937)	1,374	Serious	Serious	Serious	Very serious	Not assessable (k < 10)	⊕◯◯◯ Very low	Success definitions differ across trials
Need for endodontic treatment [39-42]	4 RCTs; 3 pooled (320)	2.58 (0.05-123.20)	56	145 (3-1000)	7,430	Serious	Serious	Serious	Very serious	Not assessable (k < 10)	⊕◯◯◯ Very low	Endodontic need partly inferred from failure definitions
Postoperative pain/symptoms [37,39]	2 RCTs (308)	1.30 (0.04-40.39)	45	58 (2-1000)	9,474	Not serious	Not serious	Serious	Very serious	Not assessable (k < 10)	⊕◯◯◯ Very low	Heterogeneous symptom constructs
Composite success (exposure = failure) [36,38-42]	6 RCTs; 5 pooled (619)	1.20 (1.13-1.27)	639	767 (722-812)	831	Serious	Not serious	Not serious	Serious	Not assessable (k < 10)	⊕⊕◯◯ Low	Reviewer-constructed outcome; effect driven mainly by the difference in pulp exposure

TABLE 3: Summary of findings: selective caries removal compared with complete caries excavation for deep carious lesions in vital permanent teeth (provisional GRADE ratings).

Ratings are provisional pending full-text verification of Taha et al. [42]. The first number in the "Trials reporting; trials pooled (participants)" column is the number of trials that reported the outcome (all cited in the Outcome column); the second is the number of trials that contributed to the pooled estimate, with their participants in parentheses. Trials with no events, or with all participants experiencing the event, in both arms are non-estimable for the risk ratio and carry zero weight: Shah et al. [43] for pulp exposure; Leksell et al. [35], Orhan et al. [36], and Rando-Meirelles et al. [39] for author-defined clinical success; and Rando-Meirelles et al. [39] for need for endodontic treatment. Risk with SCR = assumed control risk × RR. Optimal information size (OIS): participants needed for adequate power. Grading of Recommendations Assessment, Development, and Evaluation (GRADE) certainty: very low = the true effect is likely to be substantially different from the estimate. Publication bias was not assessed because fewer than 10 trials contributed to each outcome.

Discussion

This systematic review and meta-analysis of eight RCTs in permanent teeth found that selective caries removal was associated with a lower risk of intraoperative pulp exposure than complete excavation (RR = 0.24; NNT = 5) [35-37,40-43]. However, this estimate is based on very low-certainty evidence: it lost statistical significance in all three exclusion-based sensitivity analyses and in four of seven leave-one-out iterations, and the required information size had not been reached in the TSA. Clinical success as defined by the trial authors did not differ between approaches, and among teeth that were not exposed during excavation, success at 12 to 60 months was similar (RR = 0.93) [35,36,38-42]. The exploratory composite outcome, which counted every exposure as a failure, favored SCR (RR = 1.20), but because success among unexposed teeth was similar, this result largely reflects the difference in exposure rates. Taken together, the data suggest that the main potential advantage of SCR lies in avoiding pulp exposure; whether this translates into better long-term pulp or tooth survival could not be established from the available trials.

These findings are consistent with the recommendations of the ICCC and ESE [3,5,14] and with previous systematic reviews that reported fewer exposures after incomplete excavation [10,12,16]. Restricting inclusion to permanent teeth avoided combining dentitions that differ in pulpal histology, dentinal permeability, and regenerative potential [13], although it also limited the number of eligible trials.

The subgroup analysis suggested a larger reduction in pulp exposure with single-visit SE (RR = 0.07) than with two-visit SW (RR = 0.53). This comparison is indirect and potentially confounded by differences in patient age, lesion depth, excavation endpoints, and liner materials between trials [15], and should be regarded as hypothesis-generating. It is plausible that the re-entry and final excavation required in SW add a further opportunity for exposure [6,9,16], but head-to-head trials comparing the two approaches [6,9] are more appropriate evidence for this question. The pooled estimate for subsequent endodontic treatment was extremely imprecise (RR = 2.58; 95% CI: 0.05 to 123.20) and partly inferred from failure definitions [39-42], so it neither excludes a reduction nor an increase in endodontic treatment needs after SCR; notably, the most recent trial, conducted in teeth with reversible pulpitis, reported lower pulp survival after selective than after total caries removal [42]. Similarly, the lower acute postoperative sensitivity after SE came from a single trial of 60 patients with 7 days of follow-up [43] and should not be generalized as an established advantage.

Concerns persist that residual bacteria and their products may sustain subclinical pulpal inflammation beneath selectively excavated dentin [17,18]. Clinical and microbiological studies indicate that sealing reduces the viable bacterial load and arrests lesion progression [11,16,19], but histological evidence shows that inflammation may persist beneath residual carious dentin in some teeth [18], and the trials included here could not resolve this question. Laboratory studies provide additional biological context. Cariogenic biofilms can be targeted by bioactive delivery systems that combine antibacterial and remineralizing effects [44], and biofilm development involves a changing balance between bacterial proliferation, viability, and extracellular polymeric substance production that influences susceptibility to antimicrobial agents [45]. Pulp preservation also depends on controlling pulpal inflammation and on the behavior of pulp-protective materials: host-defense peptides have shown antibacterial, anti-inflammatory, and pro-reparative effects in models of the inflamed dental pulp [46], and the physicochemical properties of calcium silicate-based materials are impaired under acidic conditions such as those found in carious cavities [47]. These are in vitro and animal findings and do not constitute clinical evidence comparing selective and complete caries removal; however, they suggest that the quality of the seal, residual biofilm activity, and the choice of liner may influence outcomes and could contribute to the heterogeneity observed between trials.

This review used TSA and HKSJ-adjusted intervals to address the small number of trials. TSA showed that the cumulative sample for pulp exposure (799 teeth) was well below the RIS (3,227 teeth for an RRR of 40% and 13,989 for an RRR of 20%), so the conventional statistical significance of this outcome may reflect random error [33]. For author-defined clinical success, only 6% of the RIS had accrued. For the composite outcome, the cumulative Z-curve crossed the monitoring boundary, indicating that the observed difference in this exposure-driven outcome is unlikely to be due to chance; this does not establish an effect on long-term pulp or tooth survival, which the composite does not measure. The HKSJ adjustment reduces the risk of falsely narrow CIs when few studies are pooled [26], but with only three to six contributing trials, between-study variance was estimated imprecisely.

Limitations

This review has several limitations. First, the evidence base was small (eight RCTs, seven with fewer than 150 teeth), so heterogeneity was estimated imprecisely, and publication bias could not be assessed ($k < 10$) [31]; the certainty of evidence was low to very low [34]. Second, the reduction in pulp exposure was not robust: it lost statistical significance in all three exclusion-based sensitivity analyses and in four of seven leave-one-out iterations, and TSA showed that the required information size had not been reached. Third, success definitions differed across trials, and the composite outcome was constructed by the reviewers; its favorable result reflects mainly the difference in exposure rates rather than long-term pulp or tooth survival. Fourth, the SE-versus-SW comparison was indirect and potentially confounded by differences in population, lesion depth, and liner materials [15], and Orhan et al. [36] contributed a permanent-tooth subgroup of a mixed-dentition trial and two comparisons sharing a halved control group. Fifth, three trials included more than one tooth per patient [35,36,39], and three did not report the number of teeth per patient [40-42]; because no trial reported a cluster-adjusted analysis or an intracluster correlation coefficient, within-patient correlation could not be accounted for, which may have underestimated standard errors and overstated the precision of the pooled estimates. Sixth, several counts were derived or inferred rather than reported directly, particularly for the need for endodontic treatment. Finally, operators could not be blinded and judged pulp exposure themselves [23], only two trials reported registration [37,38,42], and evidence beyond two years came from a single trial [38], so long-term restorative outcomes could not be evaluated.

Within these limitations, the available evidence suggests that selective caries removal reduces the risk of pulp exposure compared with complete excavation in deep carious lesions of vital permanent teeth, which is consistent with current consensus recommendations and clinical guidelines [3,4,14]. However, the certainty of this evidence is very low, and the effects on pulp survival, endodontic treatment needs, and long-term restoration survival remain uncertain. Whether single-visit SE should be preferred over SW cannot be established from indirect subgroup comparisons; evidence from head-to-head trials [6,9] and practical considerations, such as the need for a second visit and patient compliance, should inform this choice.

Future research should prioritize large, rigorously designed RCTs with blinded outcome assessment, follow-up of more than five years, and analyses that account for multiple teeth per patient. Trials should report outcomes separately for exposed and unexposed teeth and state how exposures managed by vital pulp therapy are classified, so that pulp survival and long-term restoration survival can be evaluated directly. The adoption of standardized core outcome sets would help harmonize trial endpoints and reduce reporting inconsistencies.

Conclusions

Within the limitations of the available evidence, SCR was associated with a lower risk of pulp exposure than non-selective CCE in permanent teeth with deep carious lesions. However, this finding is based on very low-certainty evidence, was sensitive to the exclusion of individual trials, and had not reached the required information size. Clinical success as defined by the trial authors, and success among teeth not exposed during excavation, did not differ between the approaches. The exploratory composite outcome favored selective removal, but this mainly reflects the difference in exposure rates and does not demonstrate

improved long-term pulp or tooth survival. The apparent advantage of single-visit SE over SW is based on indirect comparisons. Large, well-designed RCTs with blinded outcome assessment, appropriate handling of multiple teeth per patient, and follow-up beyond five years are needed.

Appendices

Search strategies

All databases were searched from inception to September 10, 2026, with no date or language restrictions. Each strategy combined three concepts: (1) selective, partial, or stepwise caries removal; (2) complete or non-selective caries removal; and (3) permanent teeth.

PubMed/MEDLINE

#1 "selective caries removal"[tiab] OR "selective removal"[tiab] OR "selective excavation"[tiab] OR "partial caries removal"[tiab] OR "partial removal of carious"[tiab] OR "stepwise excavation"[tiab] OR "step-wise excavation"[tiab] OR "stepwise caries removal"[tiab] OR "incomplete caries removal"[tiab] OR "incomplete excavation"[tiab] OR "indirect pulp treatment"[tiab] OR "indirect pulp therapy"[tiab] OR "indirect pulp capping"[tiab]

#2 "Dental Caries/therapy"[Mesh] OR "Dental Cavity Preparation"[Mesh] OR "complete caries removal"[tiab] OR "complete caries excavation"[tiab] OR "complete excavation"[tiab] OR "total caries removal"[tiab] OR "non-selective"[tiab] OR "nonselective"[tiab] OR "direct complete excavation"[tiab] OR "conventional excavation"[tiab]

#3 "Dentition, Permanent"[Mesh] OR "permanent teeth"[tiab] OR "permanent tooth"[tiab] OR "permanent dentition"[tiab] OR "permanent molar*"[tiab] OR "young permanent"[tiab] OR "mature teeth"[tiab]

#4 #1 AND #2 AND #3

Embase (Embase.com)

#1 ('selective caries removal' OR 'selective removal' OR 'selective excavation' OR 'partial caries removal' OR 'stepwise excavation' OR 'step-wise excavation' OR 'stepwise caries removal' OR 'incomplete caries removal' OR 'incomplete excavation' OR 'indirect pulp treatment' OR 'indirect pulp therapy' OR 'indirect pulp capping'):ti,ab,kw

#2 'dental caries'/exp/dm_th OR 'cavity preparation'/exp OR ('complete caries removal' OR 'complete caries excavation' OR 'complete excavation' OR 'total caries removal' OR 'non-selective' OR nonselective OR 'direct complete excavation'):ti,ab,kw

#3 'permanent tooth'/exp OR ('permanent teeth' OR 'permanent tooth' OR 'permanent dentition' OR 'permanent molar*' OR 'young permanent' OR 'mature teeth'):ti,ab,kw

#4 #1 AND #2 AND #3

Cochrane Central Register of Controlled Trials (CENTRAL)

#1 ("selective caries removal" OR "selective removal" OR "selective excavation" OR "partial caries removal" OR "stepwise excavation" OR "step-wise excavation" OR "stepwise caries removal" OR "incomplete caries removal" OR "incomplete excavation" OR "indirect pulp treatment" OR "indirect pulp therapy" OR "indirect pulp capping"):ti,ab,kw

#2 MeSH descriptor: [Dental Caries] explode all trees and with qualifier(s): [therapy - TH] OR MeSH descriptor: [Dental Cavity Preparation] explode all trees OR ("complete caries removal" OR "complete caries excavation" OR "complete excavation" OR "total caries removal" OR "non-selective" OR nonselective OR "direct complete excavation"):ti,ab,kw

#3 MeSH descriptor: [Dentition, Permanent] explode all trees OR ("permanent teeth" OR "permanent tooth" OR "permanent dentition" OR "permanent molar*" OR "young permanent" OR "mature teeth"):ti,ab,kw

#4 #1 AND #2 AND #3

Scopus

TITLE-ABS-KEY ("selective caries removal" OR "selective removal" OR "selective excavation" OR "partial caries removal" OR "stepwise excavation" OR "step-wise excavation" OR "stepwise caries removal" OR

"incomplete caries removal" OR "incomplete excavation" OR "indirect pulp treatment" OR "indirect pulp therapy" OR "indirect pulp capping") AND TITLE-ABS-KEY ("complete caries removal" OR "complete caries excavation" OR "complete excavation" OR "total caries removal" OR "non-selective" OR nonselective OR "direct complete excavation" OR "conventional excavation") AND TITLE-ABS-KEY ("permanent teeth" OR "permanent tooth" OR "permanent dentition" OR "permanent molar*" OR "young permanent" OR "mature teeth")

Web of Science Core Collection

TS=("selective caries removal" OR "selective removal" OR "selective excavation" OR "partial caries removal" OR "stepwise excavation" OR "step-wise excavation" OR "stepwise caries removal" OR "incomplete caries removal" OR "incomplete excavation" OR "indirect pulp treatment" OR "indirect pulp therapy" OR "indirect pulp capping") AND TS=("complete caries removal" OR "complete caries excavation" OR "complete excavation" OR "total caries removal" OR "non-selective" OR nonselective OR "direct complete excavation" OR "conventional excavation") AND TS=("permanent teeth" OR "permanent tooth" OR "permanent dentition" OR "permanent molar*" OR "young permanent" OR "mature teeth")

Trial registries and grey literature

ClinicalTrials.gov: Condition/disease: dental caries; Intervention/treatment: selective caries removal OR partial caries removal OR stepwise excavation OR indirect pulp treatment.

WHO-ICTRP: (selective caries removal OR partial caries removal OR stepwise excavation OR incomplete caries removal) AND (complete caries removal OR non-selective).

OpenGrey and ProQuest Dissertations & Theses: (selective OR partial OR stepwise OR incomplete) AND (caries removal OR caries excavation) AND permanent.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Abdulaziz Zailai

Critical review of the manuscript for important intellectual content: Abdulaziz Zailai, Farid N. Ashi, Basmah Z. Alhawsawi, Faris S. Alfawzan, Rawan S. Aldossari, Abdulrahman H. Aljohani, Azizah Alatawi, Sara Z. Turki

Supervision: Abdulaziz Zailai

Acquisition, analysis, or interpretation of data: Farid N. Ashi, Basmah Z. Alhawsawi, Mahmoud H. Shawli, Faris S. Alfawzan, Waleedah B. Almasri, Rawan S. Aldossari, Abdulrahman H. Aljohani, Nisrin I. Alnashar, Baseel M. Alghamdi, Monira AlHajri, Azizah Alatawi, Fahdah I. Alshumaymiri, Sara Z. Turki, Faisal N. Almukhallafi

Drafting of the manuscript: Mahmoud H. Shawli, Waleedah B. Almasri, Nisrin I. Alnashar, Baseel M. Alghamdi, Monira AlHajri, Fahdah I. Alshumaymiri, Faisal N. Almukhallafi

Disclosures

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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