

Pulpal survival and postoperative treatment needs following selective vs. total caries removal in mature permanent teeth with reversible pulpitis: A randomized clinical trial

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ABSTRACT

Objectives: To compare pulpal survival and treatment needs following selective and total caries removal in mature permanent teeth.

Methods: The design was a parallel double blind, randomized clinical trial. Mature teeth with caries radiographically extending $\geq 2/3$ of dentine and without spontaneous pulpitis were included. Teeth were allocated to either selective (SCR) or total caries removal (TCR) using block randomization technique. In the SCR group, caries removal to firm dentine was followed by placement of Biodentine and composite restoration. In TCR group caries removal was to hard dentine; with immediate management by vital pulp therapy (VPT) using Biodentine in case of pulp exposure. Preoperative pain levels were recorded. Teeth were followed up after 6 and 12 months. Data were analyzed using Chi square test and regression analysis.

Results: 124 teeth with a diagnosis of reversible pulpitis were treated (63 in SCR, 61 in TCR). 17/ 61 teeth (28%) in the TCR had pulp exposure, managed by VPT and were successful at recall. Pulp survival was significantly higher in TCR compared to SCR at 6 months (100 % vs 93.65%, $p=0.04$ respectively) and at 12 months (98.4% vs 82.5, $P= 0.003$ respectively). Multivariate analysis revealed the type of procedure (SCR vs TCR) and the preoperative pain levels (above or below 5/10) as significant prognostic factors. The odds of failure increased significantly for teeth treated with SCR (OR 27.6, 3.6–212.4, $p=0.001$) and if preoperative pain levels were $\geq 5/10$ (OR 0.2, 0.04–0.8, $P=0.024$).

Conclusion: Selective caries removal for deep carious lesions in mature teeth failed to reveal overt pulp exposures in more than one quarter of cases and led to significantly lower pulp survival over one year, when compared with complete caries removal and immediate VPT.

Clinical significance: In deep carious lesions of mature permanent teeth with reversible pulpitis, total caries removal to hard dentine is recommended for a predictable pulp survival.

Clinical trial registration: This trial was registered at ClinicalTrials.gov (NCT05144711).

1. Introduction

Dental caries is a multifactorial disease driven by biofilm formation and frequent supply of fermentable carbohydrates. Pulpitis accompanies the carious process throughout its progression, with increasing severity as the infection progresses through the dentine thickness [1]. Radiographically, extensive carious lesions are classified into two sub-categories: deep and extremely deep caries. Deep carious lesions reach the inner quarter of dentine, but a zone of dentine exists between the

lesion and the pulp. Whereas an extremely deep carious lesion penetrates the entire thickness of the dentine and exposes the pulp. Radiographically deep lesions tend to have bacteria only in the primary dentine, whereas extremely deep carious lesions have bacteria in contact with the pulpal tissue, with presence of inflammatory infiltrate [2].

To prevent overt pulp exposure in deep carious lesions of permanent teeth, some authors have favoured incomplete (“selective”) caries removal (SCR) by leaving soft or leathery dentine on the floor of the cavity rather than total caries removal (TCR) to hard dentine [3,4]. This

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approach was driven by previously reported negative outcomes for vital pulp therapy (VPT) in carious pulp exposures; those studies mostly used calcium hydroxide or did not pay attention to the quality of the coronal restoration [5-7]. However, the contemporary use of calcium silicate-based materials in the management of carious pulp exposure has resulted in the reemergence and broader acceptance among dental professionals of VPT procedures including direct pulp capping and pulpotomy. Clinical studies reported high success rate of 90–97.6% over 4- 9 years follow up [8-10].

The main drawback for leaving carious dentine in the cavity, is that it hinders direct observation of the state of the pulp underneath caries or even whether a carious exposure is already present. From a histopathological perspective Ricucci et al., [11] conducted a study on deep carious lesions and their histological features after selective caries excavation and adhesive cavity restoration. They reported that even in carious dentine that is classified as "leathery" or "firm," bacterial infection persisted, leading to subclinical inflammation of the pulp. The presence of potentially arrested caries did not guarantee the absence or control of bacterial infection in the affected teeth. This result formed the bases for the American Association of Endodontists recommendations which recognizes the importance of TCR removal for deep carious lesions [12]. This contrasts with the guidelines of the European Society of Endodontology, which states that the selective removal of carious tissue is recommended for teeth with reversible pulpitis, if caries has not extended beyond the pulpal quarter of dentine [13].

The aim of this study was to compare pulp survival and the need for further intervention after SCR and TCR including VPT in mature permanent teeth with deep carious lesions and a preoperative diagnosis of reversible pulpitis, and to study the potential effect of variables on the outcome of the two procedures. The null hypothesis of the study was, there is no difference in pulp survival after selective or total caries removal techniques in mature permanent teeth with deep carious lesions.

2. Materials and methods

This parallel double blind random randomized clinical trial followed the Consolidated Standards of Reporting Trials reporting guidelines (CONSORT).

Ethical approval was obtained from the Institutional Review Board, and the study was registered with clinical trials.gov. The unit of randomization and analysis was the tooth. Randomization was done using a block randomization system (block of 4), the randomization sequence was kept in concealed envelopes, that were opened by a research assistant not involved in the clinical procedure. The patient and the evaluator were blinded to the type of the treatment, and the operator was blinded until randomization was revealed by the research assistant after completion of peripheral caries excavation.

2.1. Patients' recruitment

The selection and treatment of the cases extended from June 2021 to May 2022. Patients attended the graduate dental clinics for management of carious posterior teeth were assessed for inclusion in the study according to preset criteria listed in Table 1. None of the included patients reported spontaneous lingering pain preoperatively, though some stated that the affected tooth was sensitive to cold stimuli. The presence of provoked pain of reversible pulpitis was not an exclusion criterion.

A written informed consent was obtained from every patient after explaining the treatment procedures and the need for follow-up.

2.2. Sample size

Based on the primary outcome of pulp survival which is judged by clinical and radiographic normalcy at 12 months follow up. The sample size was calculated using G power analysis at 5% significance. The minimum sample size required was 60 teeth in each group, for a difference of 20% in the outcome between the 2 treatment approaches (72% for SCR and 94% for TCR with VPT for teeth with reversible pulpitis [14,15], and accounting for 20% wear rate in the follow up

2.3. Clinical procedure

The patients were asked to score the intensity of any preoperative provoked pain on a scale from 0–10, where zero is no pain, and 10 is the maximum pain. Preoperative pulpal and periapical diagnosis were established after clinical examination, including soft tissue palpation, percussion, and cold testing using Endo-Ice (Hygienic Corp, Akron, OH, USA). Pain indicative of reversible pulpitis was defined as provoked short-duration pain that lasted for a few seconds and disappeared after removal of the stimulus [16].

Periapical and bitewing radiographs were taken. Baseline characteristics of the patient (age, gender) and the treated tooth (number, position, number of missing walls) were recorded.

One calibrated graduate student with 5 years clinical experience performed the clinical procedure. The study ran during his second- and third-year endodontic program. Calibration of the operator was done on non-study participants under supervision of an endodontist during his first year. The tooth was anesthetized with 4% Articaine with 1: 100.000 epinephrine (Septodont, France). A rubber dam was applied, and the tooth crown was disinfected with 5% NaOCl before caries excavation. The tooth was randomly assigned to one treatment group as below:

Selective caries removal group (SCR): The demineralized and undermined enamel was removed using a diamond fissure bur in a high-speed dental handpiece under copious water coolant to expose the underlying carious dentin. Caries excavation for the cavity walls was carried out until the walls and the dentin-enamel junction were free of caries, while keeping the leathery dentine in the pulpal floor (Fig. 2). Caries excavation was done using sequential sizes of sterile slow speed

Table 1

Inclusion and exclusion criteria.

Inclusion Criteria
The patient's age ≥ 17 years old
Non-contributory medical history (ASA1)
Deep caries extending ≥ 2/3 of dentine but not exposing the pulp on the bitewing radiograph
The tooth should give a positive response to cold testing
Clinical diagnosis of reversible pulpitis
The tooth is restorable via direct restoration, probing pocket depth and mobility are within normal limits
No signs of pulpal necrosis including sinus tract or swelling
No radiographic evidence of periapical changes indicative of apical periodontitis
Exclusion Criteria
Patient age <17, Immature teeth
Spontaneous pain, diagnosis of irreversible pulpitis, pulp necrosis, apical periodontitis
Tooth requires coronal coverage restoration
Caries exposing the pulp on bitewing radiograph

round burs and guided with the use of caries detector dye (Prevest Denpro, India) under magnification (microscope/ dental loupes 4–5x magnification), a sharp dental excavator was used to ensure no soft dentine remained in the cavity. Leathery dentin is described clinically as dentine that does not deform when an instrument is pressed onto it and has a slight tackiness [17].

The cavity was disinfected with a cotton pellet moistened with 2.5% NaOCl followed by dry pellet to remove excess NaOCl, then Biodentine (Septodont, France) was placed in a thickness of 2 mm over the pulpal floor, a thin layer of resin modified glass ionomer liner (Vitrebond, 3M, Germany) was placed on top and the cavity was restored with resin composite (Filtek Z250, 3M, Germany).

Total carious removal group (TCR): after removal of undermined and demineralized enamel, and clearing of the dentine enamel junction as described in the SCR group. Total caries removal to hard dentine was done with the aid of caries detector dye on the pulpal floor.

The cavity was disinfected with 2.5% NaOCl, and inspected under the microscope or using dental loops to identify pulp exposures. If no pulp exposure is evident, Biodentine was placed in a thickness of 2 mm over the pulpal floor, and the cavity was restored with Vitrebond liner and resin composite. In case of pulp exposure, visual inspection was done to ensure the pulp was bleeding normally and uniformly red with no zones of degeneration or necrosis, then direct pulp capping was the treatment of choice otherwise partial or full pulpotomy was done using previously defined clinical guidelines [18]. The bleeding was controlled via gentle pressure with a cotton pellet soaked with 2.5% NaOCl over the pulpal wound for 2 minutes and repeated twice if required (total 4 minutes). If no hemostasis was achieved, the procedure was modified to partial pulpotomy and again if the bleeding was not controlled then full pulpotomy was performed (Fig. 2). After that, 2–3 mm of Biodentine was placed over the pulp and a rim of surrounding dentine, and the cavity was restored with Vitrebond and resin composite.

A postoperative periapical radiograph was taken. The patients were advised to attend the clinic in case of symptoms at any time following the treatment. Patients were phone called after one week to score the pain levels on a scale from 0–10.

2.4. Recall protocol

Patients were contacted by phone to attend for evaluations at 6- and 12-months following treatment, clinical evaluation was done by one endodontist. The outcome (pulp survival) was considered successful if (1) no clinical signs and symptoms of pulpal pathosis including pain, tenderness to percussion, mobility, sinus tract, and swelling were detected; and (2) no pathosis was visible on the recall radiograph, such as resorption or rarefaction. (3) The tooth gives a normal response to cold sensibility testing compared to that of a control contralateral tooth. Restoration integrity was also checked clinically and radiographically at follow up.

In case of pain, loss of vitality, or periapical lesion development the procedure was considered as failure and further intervention was done. Two experienced endodontists evaluated the radiographs at two separate occasions (NT, ZA), previous calibration of the evaluators was done on radiographs of 20 cases not related to the study.

3. Data analysis

Data were analyzed using (SPSS) version 25. Data were described using means, standard deviations, and percentages. The Chi-Square test was used to compare proportions. The Generalized Estimating Equations (GEE) procedure was used to assess the difference in the odds of success between the two procedures after adjusting for other factors (preoperative pain levels, multiple teeth in the same patient). The GEE extends the generalized linear model to allow for analysis of correlated observations. Kappa statistics was used for intra and inter observers' agreement. A p-value < 0.05 was considered statistically significant.

4. Results

The level of interobserver and intraobserver agreement on radiographic outcome was 0.98, and 0.96. A consort flow chart of the included patients and teeth is presented in Fig. 1. One hundred thirty-four teeth from 105 patients were evaluated for inclusion in the study, 10 teeth were excluded as not meeting inclusion criteria (caries exposing the pulp on radiograph, young patients <17 years). The final study sample included 124 teeth from 95 individuals aged 17 to 62 years (mean=31.52±12.21). Sixty-one teeth received TCR and 63 teeth received SCR. No pulp exposure occurred in the SCR group, while 17 out of the 61 teeth (28%) in the TCR had pulp exposure; 12 teeth received a direct pulp cap, 1 tooth received partial pulpotomy, and 4 teeth received full pulpotomy. These 17 teeth within the TCR group were successful at 6 and 12 months follow up.

The mean (SD) preoperative pain levels were 3.8 (1.82) in the TCR and 5.3 (1.68) in the SCR ($p<0.001$). Significant reduction in the pain levels occurred at one-week post treatment in both groups; the mean (SD) pain levels were 0.46 (0.76) and 1.73 (1.28) respectively, $p<0.001$. Baseline characteristics of the patients and teeth included in the 2 groups are presented in Table 2.

4.1. Follow up

No patients required emergency intervention before or between the scheduled recalls. At 6 months follow up the recall rate was 100% (124/124). In the TCR group pulp survival was 100%, all teeth (n=61) were asymptomatic, gave normal response to cold testing, palpation, percussion, and normal findings on the periapical radiograph. In the SCR group pulp survival was 93.65%, 4/63 patients reported pain in their teeth, diagnosed with necrotic pulp and normal periapical status, and managed with root canal therapy. The difference in pulp survival between SCR and TCR at 6 months was statistically significant (100% vs 93.65%, $P=0.045$).

At 12 months follow up all patients attended recall (total of 120 teeth excluding the 4 teeth that failed at 6 months). For the TCR group 1/61 patients reported pain, the pulp was found necrotic and root canal treatment was initiated. For the SCR group, 7 patients reported pain (6 teeth diagnosed with necrotic pulp and normal periapical status; and were treated with root canal therapy, 1 tooth was diagnosed with irreversible pulpitis and was treated with full pulpotomy).

In total over the 12 months follow up, further intervention was needed in 1 tooth without VPT in the TCR group, compared to 11 teeth in the SCR group. The overall pulp survival was 98.4% (60/61) for the TCR compared to 82.5% (52/63) for the SCR group, with statistically significant difference ($p=0.003$). All restorations were adequate, and no repair or replacement was needed.

Using GEE, the univariate analysis revealed that the odds of pulp survival at the 12-month follow-up were significantly higher for the TCR compared to the SCR (OR = 12.7; 95% CI: 1.6, 102.3; p -value = 0.017). This significant difference persisted even after adjusting for age, gender, and different preoperative pain (OR = 27.6; 95% CI: 3.6, 212.4; p -value = 0.001) (Table 3). Furthermore, for teeth with preoperative pain levels $\geq 5/10$, the odds of pulp survival were significantly lower when treated with SCR. Detailed information about the failed cases is presented in Table 4, and representative radiographs in Figs. 3–5.

5. Discussion

The main treatment objective for carious teeth requiring intervention is complete removal of the infected dentine followed by placement of a sealing, long-lasting restoration in order to preserve the pulpal health. Based on evidence that dental demineralization, at the advancing front of dental caries, precedes bacterial invasion, Fusayama et al. [19] promoted only selective caries removal in deep carious lesions, they used tactile judgment to differentiate between

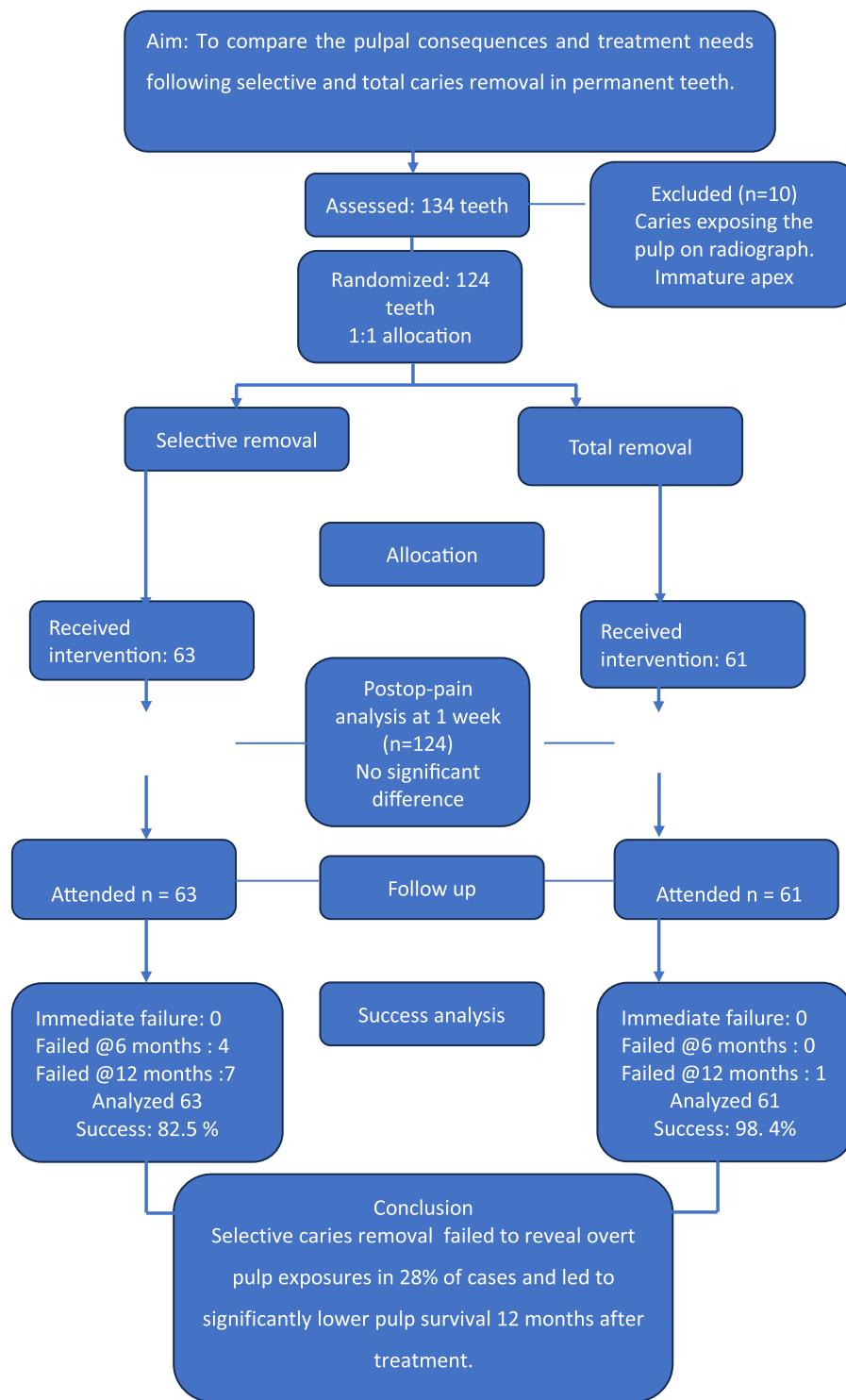


Fig. 1. Consolidated Standard of Reporting Trials flowchart of the study participants.

heavily infected outer carious dentine, and the demineralized, inner affected dentine. This technique has been widely recommended since that time [3,4,7,17].

The historical consensus that the pulp should be regarded as irreversibly inflamed whenever a carious exposure occurs in mature permanent teeth regardless of the symptoms has been based on clinical outcomes of direct pulp capping with calcium hydroxide and mostly related to coronal leakage. The biological rationale for this conclusion is that underlying pulpal inflammation has spread throughout the pulp and that the blood supply through a mature apex is insufficient to

but its still bleeding on pulpotomy procedure

promote healing even after the insult is removed. Significant improvement has occurred in the understanding of pulp biology and the response of the pulp to the carious process; furthermore, the availability of newer materials based on hydrated calcium silicates has transformed the outcomes for vital pulp therapy of carious exposures even in mature teeth in adults. As a result, the concept of selective caries removal for pulp protection needs to be reconsidered.

Few systematic reviews were published on the clinical approaches for management of carious lesions. Li et al., [20] reported that the efficacy of selective caries removal appears comparable to that of

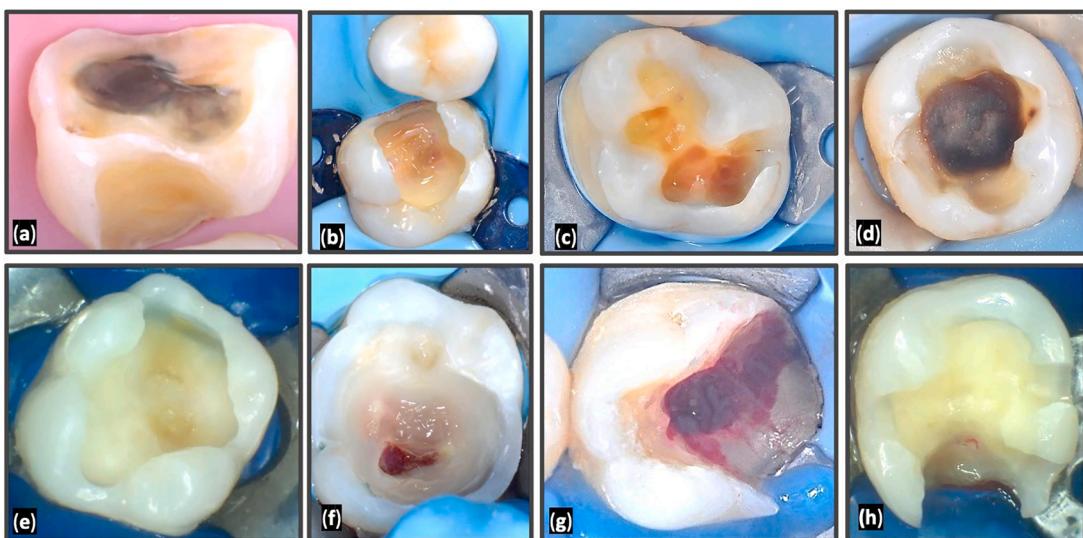


Fig. 2. (a-d) Clinical photographs representative of selective caries removal. Caries was selectively excavated, leaving the deepest leathery stained dentine over the pulp, but ensuring that the cavity walls and the dentine enamel junction are left hard and resistant to scratching with a dental probe. (e-h) Clinical photographs representative of total caries removal. Caries was completely removed from the cavity to hard dentine. In some cases, pulp exposure occurred and could be managed with direct pulp capping (e), partial pulpotomy (f), and full pulpotomy (g).

Table 2
Baseline characteristics of the study participants and included teeth in the selective removal (SCR) and the TOTAL removal (TCR) groups.

Variable	SCR N (63)	TCR N (61)	P-value
Gender	F 35 M 28	F 24 M 37	0.57
Age	<30 36 >30 27	<30 33 >30 28	0.80
Jaw	U 27 L 36	U 34 L 27	0.15
Tooth	Molar 39 Premolar 24	Molar 43 Premolar 18	0.31
Cavity	CI I 14 CI II 41 MOD 8	CI I 10 CI II 45 MOD 6	0.51
Mean (SD) preoperative pain level	5.3(1.68)	3.8 (1.8)	0.001

Table 3
Logistic regression predicting the likelihood of success at 12 months follow up for teeth included in the study (n=124).

	OR	95% Confidence Interval		P-value
Procedure: Selective vs. Total removal	27.6	3.6	212.4	.001
Preoperative pain \geq 5 vs. < 5	0.2	.04	.8	.024
Gender (male vs. female)	1.3	.4	4.7	.650
Age (<30 year vs. \geq 30 year)	1.9	.4	8.0	.379

nonselective caries removal in children, but selective caries removal may result in a lower incidence of pulp exposure. While a subsequent systematic review in 2020 reported that selective carious tissue removal presented higher success in maintaining pulpal health [21]. Schwendicke et al., [22] systematic review and meta-analysis on interventions for treating cavitated or dentine carious lesions, concluded that the included studies showed high risk of bias and limited precision of estimates due to small sample size and limited number of failures. Resulting in assessments of low or very low certainty for most comparisons.

Randomized clinical trials are considered the gold standard in research methodology for evaluating the effectiveness of interventions. This study aimed to compare the SCR and the TCR approach in mature

permanent teeth with symptoms of reversible pulpitis. Based on the results, the null hypothesis of the study was rejected. Over 1 year follow up, the TCR approach accompanied by immediate VPT with a contemporary material led to a successful outcome of 98%. In contrast the SCR resulted in progressive pulp inflammation and pulp necrosis in 17.5% of the cases, requiring root canal treatment ($p= 0.003$).

The incidence of pulp exposure following TCR was 28% (17/61). Following pulp exposure, an intraoperative assessment approach based on the appearance of the exposed pulp tissue and the ability to achieve hemostasis was employed in the decision making for the management of pulp exposure [18]. Starting with the least invasive treatment based on these criteria, direct pulp capping in 12 cases, partial pulpotomy in 1 case and full pulpotomy in 4 cases. At follow up all 17 cases were successful and no further intervention was needed. The use of rubber dam isolation, magnification, intraoperative assessment of the exposed pulp tissue, a contemporary capping material (Biodentine), and the placement of a permanent restoration in the same visit have contributed to this success. Generally, the success rate for VPT for carious pulp exposure in teeth with clinical diagnosis of reversible pulpitis and using calcium silicate-based materials was reported to be in the range of 90–100% in several prospective clinical studies in both children and adults [9,10,23,24]. Hence pulp exposure during deep caries excavation is no longer considered a negative prognostic factor for pulp survival, nor is parallel with the diagnosis of asymptomatic irreversible pulpitis.

On the other hand, pulp survival after SCR approach over 1 year was 82.5%, and 17.5% required further intervention via root canal treatment. Since in TCR 28% of the teeth had pulp exposure, presumably the incomplete SCR group would have had a similar proportion, with residual caries obscuring the exposure. These results were in the range that was reported by previous studies [4,25], but lower than the 97% reported by Maltz et al. [3]. This difference may be attributed to variation in the characteristics of included patients and teeth, the remaining dentine thickness over the pulp and the liner material; for example, in the study by Maltz et al., the depth of caries was within the outer quarter of dentine, mostly class I cavities and in young patients less than 23 years old, where the chance of carious pulp exposure would have been low [3].

This study included teeth with caries extending into the inner quarter, mostly class II cavities (78%) and in an older age group up to 62 years. This was comparable to the protocol of Chua et al. [25] who compared the outcome of SCR to full pulpotomy using Biodentine. They

Table 4

Details of the failed cases in the selective caries removal (SCR) and total caries removal groups (TCR) over 12 months follow up.

Case	Age	Gender	Tooth type	Cavity	Procedure	Preop pain	Failure time	Further intervention
44	59	Male	Upper premolar	MOD	TCR	0	12 months	RCT
77	52	Female	Upper premolar	CII	SCR	7	6 months	RCT
86	18	Male	Upper premolar	CII	SCR	4	12 months	RCT
87	21	Female	Upper premolar	MOD	SCR	4	12 months	RCT
91	55	Female	Upper Molar	CII	SCR	4	6 months	RCT
95	22	Female	Lower Molar	CII	SCR	7	12 months	Pulpotomy
96	43	Female	Upper Molar	MOD	SCR	3	6 months	RCT
101	19	Female	Upper Molar	CI	SCR	6	12 months	RCT
103	37	Male	Upper premolar	CII	SCR	7	6 months	RCT
109	27	Male	Lower Molar	CI	SCR	5	12 months	RCT
110	30	Female	Lower Molar	CI	SCR	2	12 months	RCT
114	22	Male	Lower premolar	CII	SCR	2	12 months	RCT

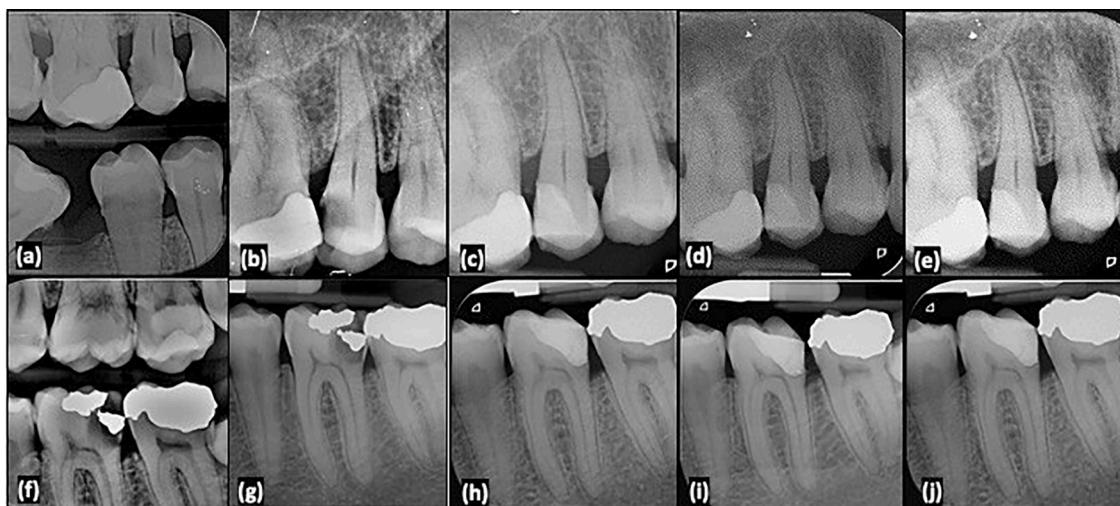


Fig. 3. Representative radiographs of treated teeth in the selective caries removal group. (a-e) preoperative bitewing and periapical radiographs (PA), immediate postoperative, 6 and 12 months follow up PAs for tooth 15 in a 43 years old female. (f-j) Radiographs for tooth 36 in a 30 years old male. The teeth were asymptomatic and gave positive response to cold sensibility testing at follow up.

concluded that selective excavation was inferior to full pulpotomy at 12 months follow up (84.5, 96.4% respectively). Despite these reported favourable results for full pulpotomy over selective removal, full pulpotomy may be considered an over treatment for teeth with clinical diagnosis of reversible pulpitis considering our evidence base knowledge on the histology of teeth with reversible pulpitis [26]. Following pulp exposure in a TCR approach, an intraoperative assessment approach based on the appearance of the exposed pulp tissue and the ability to achieve hemostasis should be employed in the decision making for the management of the pulp exposure. Starting with the least invasive treatment which is direct pulp capping shifting to partial and full pulpotomy and finally to the most invasive root canal treatment.

Although a bitewing radiograph was used to assess the caries extension as an inclusion criterion, the two-dimensional nature is a limitation for accurate assessment of lesion penetration which highlights the need for 3-dimensional assessment of caries extension via CBCT. The high failure rate in the SCR group may be partly explained by the fact

what's the limit of natural healing of infected pulp

why believing so

that the deeper the lesion the more likely to be associated with advanced pulpal inflammation and bacterial invasion of dentine and pulp tissue [2], that may not be managed via the partial excavation. Lesion activity and open environment were also related to bacterial penetration which may result in variation in the achieved outcome [2]. In addition to the fact that what appears to be firm clinically and resistant to excavation by a sharp instrument, is actually infected histologically [18], and these remaining bacteria may flourish and cause failure over time despite good marginal seal. In the study by Hashem et al., [27] the success rate of selective excavation dropped from 84% at 1 year to 72 % at 2 years. Therefore, the importance of longer-term follow-up for teeth treated with the selective removal approach is highlighted despite the accepted minimum of 1 year follow up.

This is the first study to directly compare selective caries removal to total caries removal with immediate VPT in a randomized clinical trial design, the results of this study cannot therefore be directly compared to other studies on caries removal approaches. The outcome assessment will "caries detector dye" help on removal of any infected material

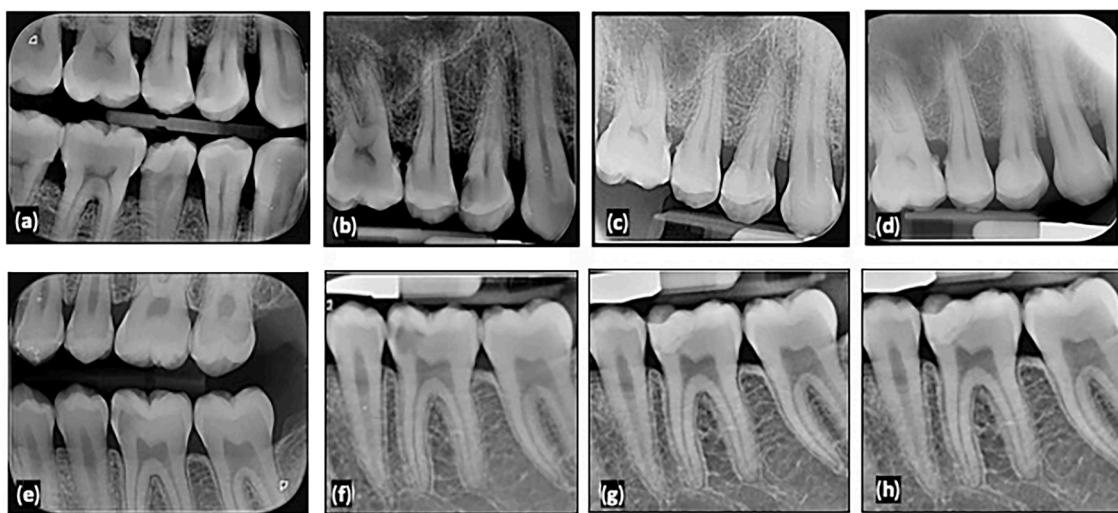


Fig. 4. Representative radiographs of treated teeth in the total caries removal group. (a-d) preoperative bitewing and periapical radiographs (PA), immediate postoperative and 12 months follow up PAs for tooth 14 in a 39 years old male, (e-h) PAs for tooth 36 in a 19 years old male. The teeth were asymptomatic and gave positive response to cold sensibility testing at follow up.



Fig. 5. Representative radiographs of 6 failed cases. Five teeth treated with SCR developed symptoms and were diagnosed with pulp necrosis and subsequently treated with root canal therapy: tooth 14 (a-c), tooth 25 (d-f), tooth 26 (g-i), tooth 36 (j-l), tooth 45 (m-o). Tooth 37 treated with SCR developed symptoms of irreversible pulpitis and was treated with full pulpotomy using Biobondine (p-r).

criteria employed were strict. Positive response to sensibility testing was a success criterion, for all teeth except those that were treated with full pulpotomy. All failed cases were symptomatic, had negative response to sensibility test or an exaggerated response and therefore required intervention. All treated teeth were included in the analysis.

One of the highly quoted studies in this context is the randomized clinical trial by Bjorndal et al [7], this study compared stepwise caries removal in 2 visits versus total caries removal. Their outcome evaluation criteria were different; success was defined as unexposed pulp with sustained pulp vitality without periapical radiolucency. The incidence of pulp exposure in the total caries removal was 28.9% (which is comparable to this study, 28%), and significantly higher than the 17.5% for the

Stepwise removal, according to their evaluation criteria pulp exposure is a failure so they reported stepwise excavation to be more successful than total caries removal. However, going to the details of their results there was no significant difference between the 2 procedures in terms of loss of pulp vitality which is what actually matters in terms of outcome. Furthermore, when cases of pulp exposure were excluded from the analysis the success rate of the 2 procedures was comparable (89.8% vs 87.7% for stepwise and total removal respectively) and therefore no justification for the superiority of stepwise removal.

In the same study [7], 58 teeth with pulp exposure were randomized to either direct pulp capping or shallow partial pulpotomy (1–1.5mm), they reported poor outcome of the 2 procedures at 1 year follow up

31.8% & 34.5 respectively. Multiple factors may explain this surprisingly low success rate of VPT; caries excavation was completed with hand instruments after pulp exposure without rubber dam which may leave caries behind and results in contamination of the exposed pulp, placement of rubber dam late in the procedure after pulp exposure and hand excavation rather than at the start of caries excavation, the use of saline rather than NaOCl for pulp lavage, the use of calcium hydroxide as a capping material, delay in permanent restoration placement with risk for coronal leakage and dissolution of the calcium hydroxide, and multiple operators at 6 different sites. However, they concluded that stepwise excavation reduced the risk of pulp exposure and in view of the poor prognosis of VPT a step wise approach is recommended.

what is their logic

The findings of the above study are not supported by recent studies and systematic reviews on direct pulp capping and partial pulpotomy in adult teeth using strict protocols with calcium silicate-based capping materials, which reported a success rate range from 85–95 % [9,28–30]. These studies highlight the predictable outcome of capping carious exposures with contemporary treatment protocols and therefore leaving carious dentine as a routine practice to avoid pulp exposure is not justified.

Multivariate analysis was further used to investigate factors that might have affected the outcome. Gender, age, tooth location (lower, upper), tooth type (Premolar, Molar), and cavity classification (CI, CII, MOD) did not have an impact on pulp survival. While after adjusting for the confounders there was a significant association between treatment type and provoked pain levels, subjects that had pain levels $\geq 5/10$ had higher odds of failure (0.2 times) when treated with SCR compared to cases with lower pain levels which is in accordance with findings of Bjorndal et al. [7] where cases with preoperative pain had 0.48 times odds of failure. However, the multivariate regression analysis revealed that the most significant factor that affected pulp survival was the procedure itself, the odds of failure for the SCR approach were 27.6 times higher than the TCR approach. This highlight the importance of total caries removal to hard dentine for a more predictable outcome in mature permanent teeth with reversible pulpitis, particularly those presenting with symptoms.

6. Conclusion

Selective incomplete caries removal when managing deep carious lesions in mature teeth with reversible pulpitis failed to reveal overt pulp exposures in more than one quarter of cases and led to significantly lower pulp survival one year after treatment, when compared with complete caries removal and immediate VPT.

Ethics statement

The study protocol for this clinical trial was approved by the institutional review board, human ethics and research committee at Jordan University of Science and Technology (Approval Number 53/143/2021), and conformed to the Helsinki Declaration of 1975.

Patient consent statement

Informed consent was obtained from all individual participants included in the study.

CRediT authorship contribution statement

Nessrin A Taha: Writing – original draft, Validation, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Motaz M Ali:** Investigation, Data curation. **Imran Zainal Abidin:** Writing – review & editing, Data curation. **Yousef S Khader:** Writing – review & editing, Validation, Formal analysis.

Declaration of competing interest

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

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Data availability

The data that support the findings of this study are available upon reasonable request from the corresponding author. The data are not available publicly for privacy and ethical restrictions.

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