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Hall technique for primary teeth: A systematic review and meta-analysis

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ABSTRACT

Background: There has been a debate about the use of Hall Technique (HT), whether it can be considered as a standard technique for the management of carious primary molars.
Aim: To summarise the evidence on HT for managing dentine caries in primary teeth.
Design: MEDLINE, Embase, CENTRAL and Epistemonikos databases were searched for clinical studies conducted from 2007 to 2021 evaluating HT in primary teeth. Two reviewers independently screened, data extracted and quality assessed the studies.
Results: Eleven publications from eight unique studies were included. Four were of low risk of bias overall and five studies were included in a meta-analysis. Overall, HT was 49 % (RR 1.49 [95 % CI: 1.15–1.93], I^2 =89.5 %, p < 0.001) more likely to succeed. When compared to direct restorations, HT was 80 % more likely to succeed; while similar success was found when compared to conventional preformed metal crowns. HT was also over 6 times (RR 0.16 [95 %CI: 0.10–0.27], I^2 =0 %, p < 0.001) less likely to fail. Most of the studies included proximal or multi-surface lesions.
Conclusions: HT is successful option for the management of caries in primary teeth, particularly for proximal or multi-surface dentine lesions. It is well-tolerated by children and acceptable to parent, with mild adverse effects reported.

Contents

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1. Introduction

In recent years, there has been a paradigm shift in the restoration of carious primary teeth, with the increasing prominence of biological approaches over conventional surgical approaches [1]. Biological approaches are based on the preservation of tooth structure and maintaining function for as long as possible, and in the case of primary teeth, until these exfoliate naturally. Many of these approaches fall under the realm of minimal intervention dentistry (MID) [2]. Several MID techniques are conducted without any carious tissue removal, and thus can be carried out without the use of local anaesthesia even in deep lesions [3]. On the other hand, conventional surgical approaches involving removal of carious tissue can endanger the pulp vitality in primary teeth as a result of the thin enamel and dentine and relatively large pulp chambers. Consequently, these approaches often require the use of local anaesthesia, rubber dam isolation and can induce dental anxiety in young children [4].

Another aspect to consider when treating carious primary teeth is behaviour management of children, which can be challenging when delivering conventional dental caries treatments. Often times, dental general anaesthesia (DGA), which refers to dental treatment under general anaesthesia, may be the only treatment option available for treating anxious children with extensive lesions [5]. In addition, DGA involves greater risks, with adverse events occurring more frequently in very young children [6]. The rising costs and limited accessibility of surgical facilities means that alternative approaches to DGA are gaining in importance [7]. One such approach is the Hall Technique (HT) using preformed metal crowns (PMCs), in which, PMCs were cemented using glass-ionomer (luting) cement over carious primary molars. The technique was unique in that there was no carious tissue removal, no tooth preparation, and no local anaesthesia used [8]. Conventional PMCs have been shown to be the preferred treatment option with the best long-term success rate (< 90 %), especially when used to treat primary molars presenting with moderate to severe dentinal caries involving more than one surface [9]. However, conventional PMCs shares the same shortcomings with other conventional surgical approaches, and can be difficult to provide in young children. Conversely, the HT approach involves the placement of PMCs without local anaesthesia and the removal of caries tissue [8]. The success of this approach is predicated on the achieving of an effective marginal seal, which results in caries arrestment [10].

There has been a debate among clinicians and researchers about the use of HT over conventional surgical approaches, whether HT can be considered as a standard technique for the management of carious primary teeth. A study conducted using an online questionnaire surveyed 709 dentists from 65 countries and found that only half of the paediatric dentists surveyed have used the HT in their practice, with an even smaller proportion reporting HT as their primary techniques to manage carious primary molars [11]. Ultimately, this decision should be based on clinically relevant evidence from well-conducted randomised controlled trials (RCTs). Available evidence suggests that the HT is a cost-effective option [12], and has positive outcomes in terms of patient-reported acceptability and comfort [12,13].

The number of clinical studies, specifically RCTs, evaluating the effectiveness of HT for caries management in children has significantly increased in recent years; however, an updated review has yet been conducted. As such, the present systematic review aimed to examine the success rate, failure types and other clinical parameters of HT as used for caries management in children, and to provide recommendations to best translate the available evidence into practice.

2. Materials and methods

This systematic review followed the Cochrane methodology for the conduct of reviews in health care [14]. The protocol for this review was registered on PROSPERO (PROSPERO 2020 CRD42020202442) prior to conduct. The study was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [15].

This systematic review examined the following PICO question:

Do patients with dentine carious lesions in primary molars that are managed with Hall technique crowns compared with conventional restoration approaches, other MID techniques and no treatment have different outcomes, in terms of treatment success and failure?

2.1. Inclusion criteria

Studies included are limited to RCTs and controlled clinical trials (CCT) conducted from 2007 to 2021 and reported in the English language. The PICO question is as follows:

- Participants: Children with an untreated carious lesion(s) extending into dentine in primary molars that required intervention to limit caries progression. Only teeth without existing restorations were considered in order to exclude the possibility of the dental pulps being compromised by previous treatments.
- Intervention: In HT, a PMC is cemented over a primary molar to seal a dentine carious lesion, allowing for inactivation of carious lesion as well as the restoration of form and function.
- Comparator(s)/control: Conventional restoration approaches including non-selective caries removal to hard dentine (direct restorations, conventional PMCs), other MID techniques (Atraumatic Restorative Technique [ART], 38 % Silver Diammine Fluoride [SDF] application, Non-restorative Cavity Control [NRCC]), placebo and no treatment.

2.2. Treatment outcomes

The primary outcome of this systematic review was “success” as measured by:

- The tooth remaining symptom-free throughout the follow-up period characterised by the lack of pain, swelling, abscess, fistula, and pathological mobility.

- The lack of radiographic signs such as intraradicular or periapical radiolucency, and pathological root resorption.
- The restoration appearing satisfactory with no replacement required.

The secondary outcome of failure was categorised into:

- Minor failure: When initial treatment has failed via recurrent caries, caries progression, restoration loss but tooth was still restorable, and any reversible pulpitis could be managed by repair or replacement of the restoration.
- Major failure: When initial treatment has failed resulting in the need of extraction or pulp treatment, as result of pulpal exposure during treatment, signs or symptoms of irreversible pulpal damage such as dental abscess and spontaneous pain, or when the tooth is broken down and unrestorable.
- Overall failure: Restorations with either minor and/or major failures.

Other outcomes examined were:

- Time to treatment/restoration failure/retreatment measured by months
- Gingival and periodontal status (measured by reported indices)
- Occlusion changes post treatment
- Patient/carer perceptions and acceptance of treatment
- Cost effectiveness of treatment

2.3. Search strategy

An experienced information specialist (MM) conducted the searches. MEDLINE, Embase, Cochrane Library Central Register of Controlled Trials (CENTRAL) and Epistemonikos were searched from January 2007–29 th March 2021 and updated 1 August 2022. Searches were built around the following concepts: (Hall OR Seal caries/carious lesion OR Biological Prevention OR Preformed metal crown/Stainless steel crown) AND (Tooth, Deciduous OR Primary dentition OR Pediatric dentist). Searches were restricted to English language studies published between January 2007 and March 2021. Full search strategies can be found in Supplemental Table S1. Reference lists of the included studies were also screened. Search results were downloaded into a reference management software (Endnote, Version 9) and duplicates removed.

2.4. Study selection

Two reviewers (SH, SA) independently screened all titles and abstracts against the inclusion criteria with a third reviewer resolving any disagreements (ABH). Following this, 2 reviewers (SH, ABH) independently screened the full text of studies assessed to be relevant during the title and abstract screening, with another reviewer (SA) resolving any disagreements.

Data extraction was completed independently by 2 reviewers (SH, ABH) and the following data was extracted using a specifically designed data extraction form: study characteristics (author, year, country, setting and funding), population characteristics (age, type of teeth, x-rays taken, depth of lesion and surfaces), numbers included (intervention group, control group, lost to follow up), study outcomes (unit of randomisation, unit of analysis, primary and secondary outcomes), and outcome information including methods of assessment and information regarding risk of bias.

2.5. Risk of bias assessment

Risk of bias was conducted independently by 2 reviewers (SH, ABH) using version 2 of the Cochrane risk-of-bias tool for randomised trials (RoB 2) [16] to assess each study across 5 domains:

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

After which, an overall risk of bias was determined for each included study according to the guidance of the RoB2 tool. Any disagreement was discussed and resolved with the help of another reviewer (SA).

2.6. Data analysis and synthesis

Random-effects meta-analyses were conducted for success and failure (major/minor) rates of HT compared to control. Additionally, sub-analyses comparing HT to different categories of control restorations were conducted to elicit any differences. Results were reported as risk ratios (RR) with 95 % confidence intervals (CIs) and statistical heterogeneity was assessed using the I^2 statistic. Outcomes which were not amenable to meta-analysis due to clinical heterogeneity among the included studies were summarized in tables and described narratively across the studies.

3. Results

3.1. Selection of studies

The initial search in databases resulted in 789 records, of which 571 potentially eligible publications remained after duplicates were removed. After title and abstract screening, 535 publications were excluded, after removing a further 7 duplicates, 29 publications were left eligible for full-text review. After full-text review, 18 publications were excluded with reasons provided in Supplemental Table S2. That resulted in the final inclusion of 11 publications from 8 unique studies (2 studies had multiple publications but only 1 publication from each study was included in the analysis). Fig. 1 shows the PRISMA flow chart of the selection process.

3.2. Assessment of included studies' risk of bias

Four of the studies included were judged to be of low risk of bias overall [17–20], with the rest judged to be of high risk of bias [21–24]. The largest contribution of bias occurs with the randomisation process, with some studies randomising at subject level but reporting results at tooth level, introducing significant bias to the results. Fig. 2 presents a summary of the RoB 2 assessment across all included studies.

3.3. Characteristics of the studies

The study characteristics, primary and secondary outcomes presented in Table 1.

The eight included studies [8,17,18,20,22–24] examined children aged from 3 to 10 years over a period ranging from 12 to 60 months. The setting of the studies ranged from being conducted in classrooms without dental facility by dental students [17], primary care facilities by dental therapists [23], general practice units by general dentists [19,24], and University clinics conducted by paediatric

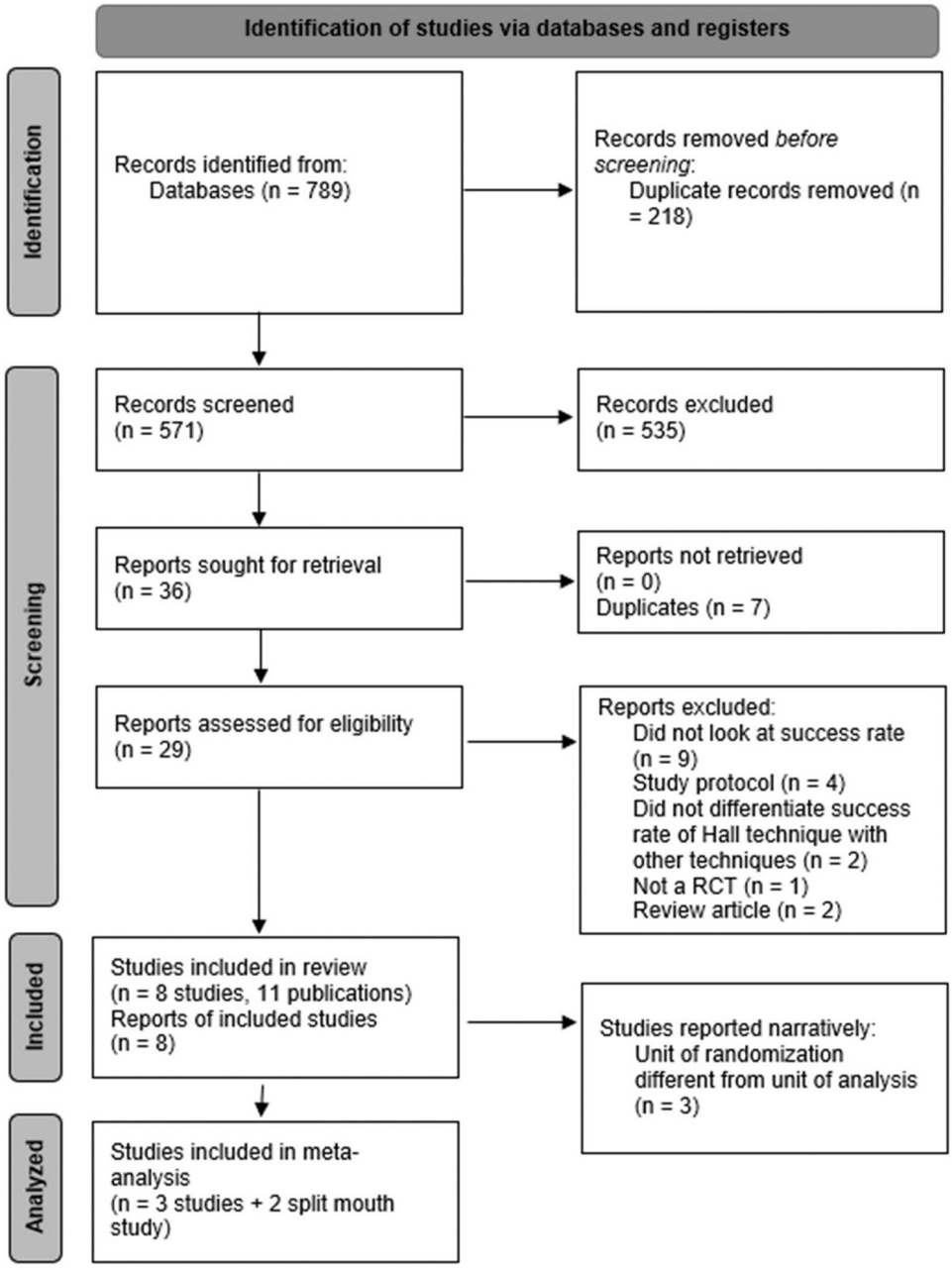

Fig. 1. PRISMA flow diagram.

dentists/residents [18,20–22]. Most included only teeth with multisurface lesions into dentine, with the exception of two studies including some teeth with enamel lesions [21,23] and three studies including some teeth with single surface (occlusal) lesions [19,21,24]. Most of the studies had pre-operative radiographic assessment with the exception of 3 studies [17,20,22]. As the definitions of success, minor failure and major failure across the included studies were sufficiently similar to the current study, the results were grouped and analysed together.

The control groups had interventions such as conventional PMCs, conventional restorations, ART restorations, and NRCC with two studies having two different control groups [18,20].

All of the studies reported success and major/minor failure rates at the tooth level. Three of the studies randomised and analysed one tooth per subject [17,18,20]. Two studies randomised at subject level and included one or more teeth per subject [23,24], while the other three studies were split mouth studies with two including two teeth (control and intervention) per subject [19,21] and the other including two or more teeth per subject [22]. Due to these differences in the unit of randomisation and the unit of analysis reported, only five studies were included in meta-analyses, the three studies with unit of randomization at tooth level with one included tooth per subject [17,18,20] and the two spilt mouth studies with only two teeth per subject [19,21].

Meta-analyses were conducted for success rate and failure rates of HT compared to control techniques: ART [17,18], conventional PMCs [18,21], conventional restoration [19,20], and NRCC [20]. The pooled analysis of the five studies assumes no clustering effect in the split-mouth study (i.e. that the two teeth per subject can be assumed to be independent in terms of success and failure rate), as the teeth are independently assessed and randomised at the patient level. However, if clustering has occurred, this assumption of independence may result in overestimation of variance (i.e. 95 % confidence intervals around the pooled result which are too wide).

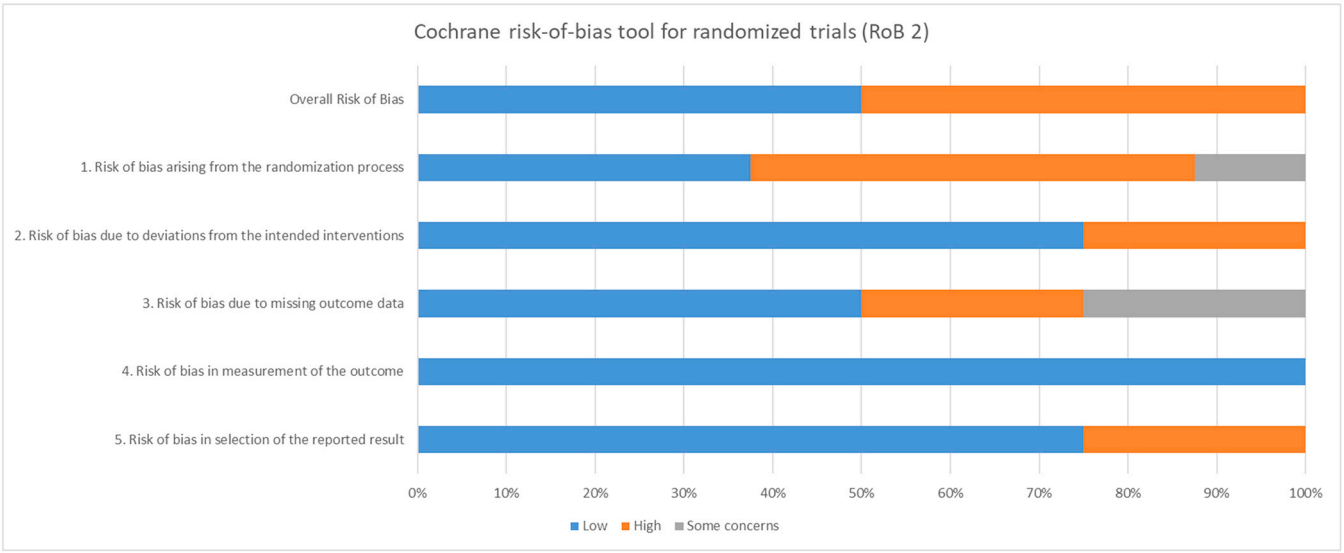

Fig. 2. Summary of risk of bias across all included studies (Rob 2).

Therefore, meta-analyses were also stratified by the number of included teeth per subject (one tooth included per subject and two teeth per subject in the split-mouth study).

The results of the other studies are reported narratively.

3.4. Primary outcome: success rate

Overall, HT was 49 % (RR 1.49 [95 % CI: 1.15–1.93], I^2 =89.5 %, p < 0.001) more likely to succeed when compared with control techniques (Fig. 3A). Without the split-mouth studies, HT was more than 50 % (RR 1.55 [95 % CI: 1.16–2.07], I^2 =84.0 %, p < 0.003) more likely to succeed. Statistical heterogeneity was substantial in both meta-analyses of success rate (I^2 > 80 %), which seems to originate from the success rate in the control group of the Araujo et al., 2020 study, which is much lower than the other studies (34 % compared to 50–72 %). This may be the result of the higher failure rate of ART in multi-surface restorations. For the studies not included in the meta-analysis, [22–24] HT had a success rate ranging from 85 % to 93 %.

When compared only against direct restorations (Conventional restorations, ART, mART) [17–20], HT was more than 80 % (RR 1.80 [95 % CI: 1.37–2.36], I^2 =79.9 %, p = 0.002) more likely to succeed. (Fig. 3B) This was supported by the other studies not included in the meta-analysis [22,23]. However, when compared only against conventional PMCs [18,21], HT showed similar success rates (RR 1.02 [95 % CI: 0.90–1.15], I^2 =52.3 %, p = 0.148). (Fig. 3C) Similar outcome was seen in the studies not included in the meta-analysis [23,24].

3.5. Secondary outcome: failure types and rates

Meta-analysis shows that, HT is over 6 times (RR 0.16 [95 %CI: 0.10–0.27], I^2 =0 %, p < 0.001) less likely to fail when compared to control techniques (Fig. 4A). Both minor failure (RR 0.13 [95 % CI: 0.07–0.25], I^2 =0 %, p < 0.001) and major failure (RR 0.21 [95 % CI: 0.10–0.45], I_2 =0 %, p < 0.001) (Fig. 4B, Fig. 4C) are less likely with HT compared to control techniques. Results were similar without the split-mouth studies.

For the studies not included in the meta-analysis, HT had a minor failure rate ranging from 2 % to 10 % and a major failure rate ranging from 2 % to 6 %. HT had very similar failure types and rates when compared to conventional PMCs [23,24]. When compared to conventional restorations, specifically with GIC restorations, HT was shown to have significantly lower minor failure rates [22,23]. With regards to major failures, HT was found to have similar rates when compared to conventional restorations [22,23].

3.6. Other clinical outcomes, parental and patient acceptance

Details of the other outcomes were presented in Table 2.

Occlusal vertical dimension (OVD) was examined in four studies [8,17,18,24]; however, there was a lot of heterogeneity over the method of measuring change in OVD. Overall, HT resulted in increase in OVD immediately post-treatment in almost all children when compared to conventional PMCs/restorations. However, this increase resolved over time and was no longer detectable at 12 months [8,18,24].

Gingival index (GI) was not found to be different in three studies between HT and control groups [20,22,24]. However, GI was found to be significantly better in both HT and control groups after treatment in one study [22] and plaque index was found to be significantly better in all groups after treatment in another study [20].

Treatment time was found to be similar for HT and conventional restorations [8,18], but was found to be significantly less when compared to conventional PMCs [18,21,24].

The scales used to evaluate treatment discomfort were different for all three studies reporting that measure. Overall, HT was found to show higher discomfort scores when compared to ART for the stages of orthodontic separator placement and crown cementation [17]. However, HT was found to be more comfortable and less anxiety inducing than conventional PMCs [18,24].

The majority of parents and children were accepting of the HT with significant increase in quality of life as measured by the OHRQoL [17,18]. Children, parents and dentists preferred the HT over conventional restorations in one study [8]. However, parents preferred the appearance of ART over PMCs [17] but were more dissatisfied with ART at follow up [18].

In one study, HT crowns were found to be more cost-effective than conventional PMCs. It was found to be almost one-third cheaper than conventional PMCs, thus the incremental cost-effectiveness ratio (ICER) was US$136.56 more for each PMC placed conventionally [24].

4. Discussion

Even though HT has become one of the accepted techniques for the management of caries in primary teeth, the amount of pre-

Table 1
Study characteristics, success and failure rates of Hall Technique crowns Vs Control techniques.

Author, year	Country (study location)	Study setting	Funding	Study duration	Subject age range	Pre-op x-ray taken	Depth of carious lesion in study	Carious surfaces involved	Unit of randomi-zation	Unit of analysis	Intervention (Hall technique crown)				Control group treatment	Control			
											Number of subjects	Lost to follow up	†Success (Total)	‡Failure (Major/ minor)		Number of subjects	Lost to follow up	†Success (Total)	‡Failure (Major/ minor)
Ayedun, 2021	Nigeria	University clinic by Post graduate student	No funding received	12 months	3–8	Yes	Enamel or dentine caries on BW radiograph	Single surface (proximal/ occlusal)	Tooth (2 teeth per subject analysed), Split mouth	Tooth	25 subjects, 25 teeth	2 subjects	23 (23)	0/0	Conventional PMCs	25 subjects, 25 teeth	2 subjects	21 (23)	1/1
Kaptan, 2021	Turkey	University clinic by dentist	No funding received	12 months	4–8	No	Dentine lesions	Multisurface	Not stated (2 or more teeth per subject analysed), Split mouth	Tooth	33 subjects, 45 teeth	2 subjects	42 (45)	1/2	Conventional restorations using compomer	33 subjects, 39 teeth	2 subjects	29 (39)	1/9
Boyd, 2021	New Zealand	Dental therapists in primary care	Cure Kids New Zealand grant	24 months	3–8	Yes	< 0.5 mm into dentine to > 0.5 mm into dentine but confined to dentine's outer half. 1.1 % enamel caries	Single surface (proximal)	Subject (1 or more teeth per subject analysed)	Tooth	149 subjects, 273 teeth	18 subjects, 32 teeth	189 (222)	10/23	Selective carious tissue removal Restoration of PMCs (59.6 %), amalgam (5.4 %), composite (6.7 %), GIC (28.3 %) restorations	146 subject, 297 teeth	8 subjects, 14 teeth	196 (252)	16/40
Araujo, 2020	Brazil	School class room with no dental facility by dental students	São Paulo Research Foundation	36 months	5–10	No	Dentinal cavitated lesion with no signs and symptoms of pulp involvement	Multisurface	Tooth (1 tooth per subject analysed)	Tooth	66 subjects/ teeth	10 subjects/ teeth	54 (56)	1/1	ART with high viscosity GIC	65 subjects/ teeth	9 subjects/ teeth	23 (56)	5/28
Ebrahimi, 2020	Iran	University clinic by Post graduate student	Not stated	12 months	4–9	Yes	Did not state	multisurface	Tooth (1 tooth per subject analysed)	Tooth	42 subjects/ teeth	8 subjects/ teeth	33 (34)	1/0	modified ART (handpieces) with high viscosity GIC, Conventional PMCs	mART: 42 PMC: 39 Total: 81	mART: 10 PMC: 9 Total: 19	mART: 15 PMC: 30 Total: 45 (62)	mART: 11/6 PMC: 0/0
Elamin, 2019	Sudan	General dentistry practice. HT by dental therapist and Conventio-nal PMCs by dentist	No funding received	24 months	5–8	Yes	Extending into dentine ICDAS 4 and 5	Single and multisurface	Subject (1 or more teeth per subject analysed)	Tooth	86 subjects, 109 teeth	25 teeth	99 (109)	7/3	Conventional PMCs	78 patients, 103 teeth (excluded 2 teeth with required pulp therapy at preparation stage)	22 teeth	91 (103)	6/6
Santamaria, 2014;	Germany	University clinic by 7 Paediatric dentists	Paediatric Dentistry Department of	30 months	3–8	No	Extending into dentine ICDAS 3–5	Multisurface	Tooth (1 tooth per subject analysed)	Tooth	52 subjects/ teeth	12 subjects/ teeth	37 (40)	1/2	Non-restorative caries treatment,	NRCC: 52 Conventional restoration: 65	NRCC: 8 Conventional restoration: 7	NRCC: 31 CR: 39	NRCC: 4/9 CR: 5/14

(*continued on next page*)

Table 1 (*continued*)

Author, year	Country (study location)	Study setting	Funding	Study duration	Subject age range	Pre-op x-ray taken	Depth of carious lesion in study	Carious surfaces involved	Unit of randomization	Unit of analysis	Intervention (Hall technique crown)				Control group treatment	Control			
											Number of subjects	Lost to follow up	†Success (Total)	‡Failure (Major/ minor)		Number of subjects	Lost to follow up	†Success (Total)	‡Failure (Major/ minor)
Santa-maria, 2017		and 5 Post graduate residents	Greifswald University, Germany.												Complete caries removal and conventional restorations (CR) using compomer			Total: 70 (102)	
Innes, 2007; Innes, 2011; Innes, 2015[a] [a]Chart review on com-pleted RCT	Scotland	17 General dental practices.	University of Dundee, UK	(1–60 months) data analysed at 48 months [a]until exfoliation of teeth	4–9	Yes (31 had no radio-graph-s)	Carious into dentine (≤ or > halfway into dentine radiographi-cally	Single and multi-surface	Tooth (2 teeth per subject analysed), Split mouth	Tooth	132 subjects/ teeth	37 subjects/ teeth	84 (91) [a]88 (97)	3/4 [a]4/5	Conventional restoration (different materials/ some under LA) complete caries removal in 78 % and incomplete caries removal in 22 %	132 subjects/ teeth	37 subjects/ teeth	47 (91) [a]48 (96)	15/38 8 control teeth initially experi-enced a 'Minor' failure and a subsequent 'Major' failure 1 control tooth experi-enced a 'Major' failure and a subsequent 'Minor' failure." [a]48 overall failure 20/ 40 (mul-tiple failures in some teeth)

†Success is measured by:
•The tooth remaining symptom-free throughout the follow-up period characterised by the lack of pain, swelling, abscess, fistula, and pathological mobility.
•The lack of radiographic signs such as intraradicular or periapical radiolucency, and pathological root resorption.
•The restoration appearing satisfactory with no replacement required.
‡Failure is measured by:
•Minor failure: When initial treatment has failed via recurrent caries, caries progression, restoration loss but tooth was still restorable, and any reversible pulpitis could be managed by repair or replacement of the restoration.
•Major failure: When initial treatment has failed resulting in the need of extraction or pulp treatment, as result of pulpal exposure during treatment, signs or symptoms of irreversible pulpal damage such as dental abscess and spontaneous pain, or when the tooth is broken down and unrestorable.
•Overall failure: Restorations with either minor and/or major failures.

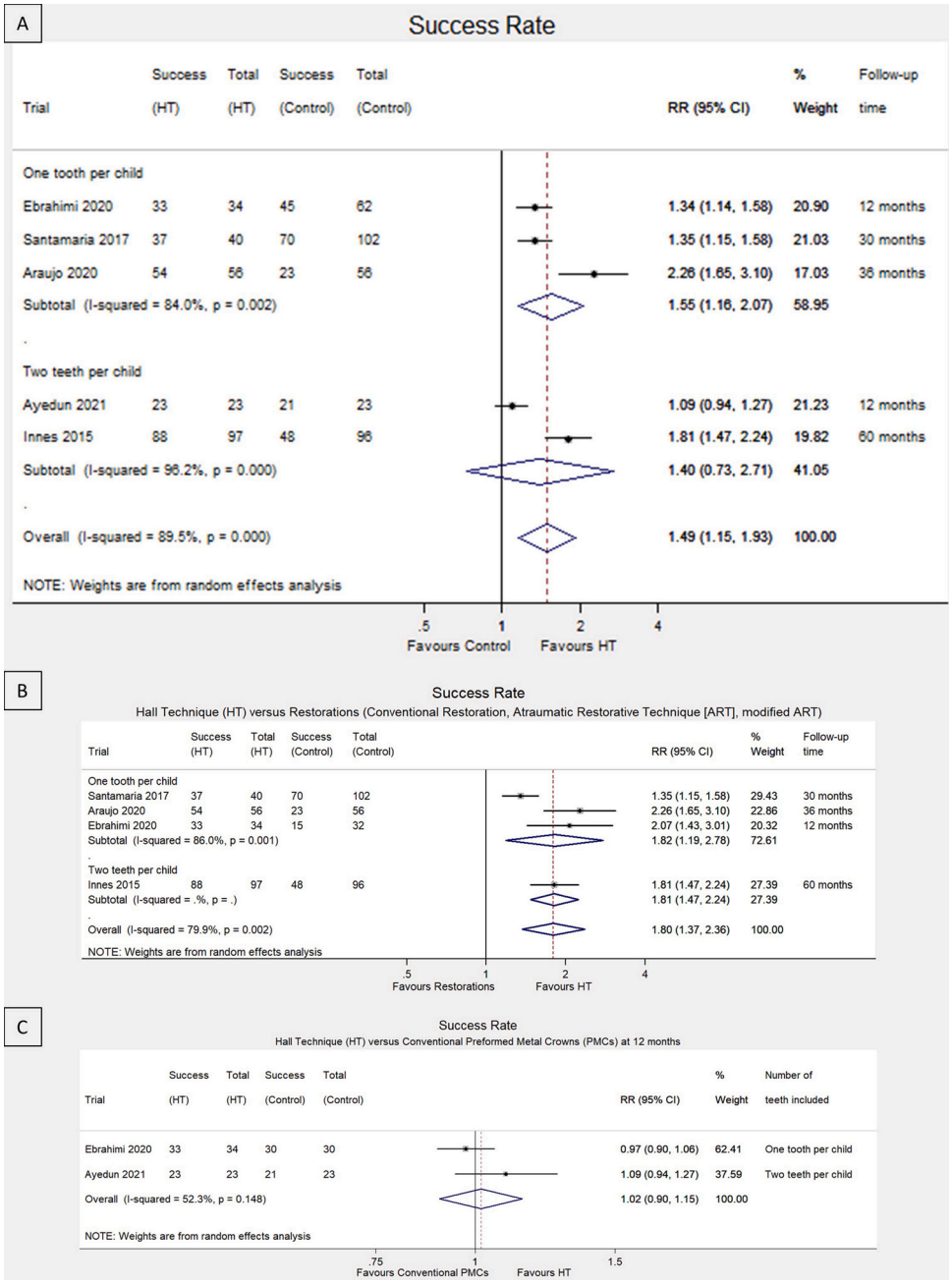

Fig. 3. Meta-analysis for success of HT. A: Overall success rate. B: Success rate of HT versus Restorations (Conventional restorations, Atraumatic Restorative Technique [ART], modified ART). C: Success rate of HT versus Conventional PMCs.

appraised literature (systematic reviews) remains scarce. The most recent systematic reviews suggested that HT may be superior to conventional restorations [19,25,26]. However, additional RCTs since published may affect the conclusions of these reviews. The publication of recent RCTs examining HT against a greater variety of controls such as conventional PMCs, ART and NRCC necessitates a review of the literature in order to appraise the currently available evidence.

This review found that HT is overall 49 % more likely to succeed when compared with other caries management techniques. Interestingly, it is 80 % more likely to succeed when compared with restorations; however, HT has a similar success rate when compared to conventional PMCs.

Although a previous systematic review showed that HT may be more than five times more successful than control techniques [26], the studies included in that meta-analysis did not include conventional PMCs which are traditionally considered to be the most successful restoration type in primary teeth [19]. Moreover, that meta-analysis included studies that were very heterogeneous in their protocols including a split mouth study, a child-level randomization, and a tooth-level randomization. As such, the actual clinical advantage of HT is likely to be closer to the findings of the current study. The process of this systematic review made it clear there is a need for more standardised approach when conducting and reporting interventional studies, to ensure clear randomisation at patient level with ideally one tooth included per patient or with suitable adjustment for clustering performed in spilt-mouth designs. This will allow for more studies to be included in future meta-analyses.

In addition, HT reduces the risk of failure when compared to other caries management techniques. When examining the types of

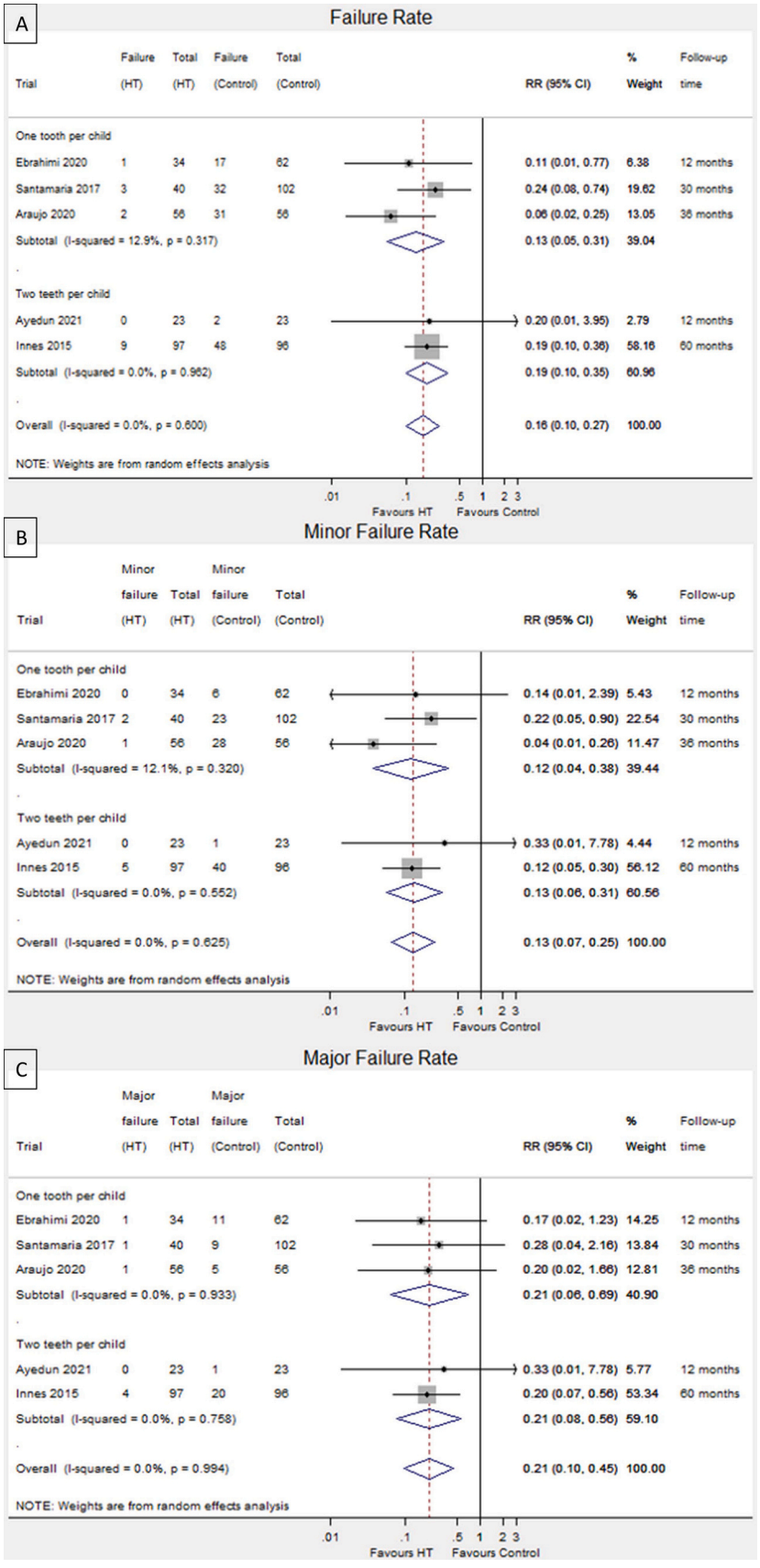

Fig. 4. Meta-analysis for failure rates and types. A: Overall failure rate. B: Minor failure rate. C: Major failure rate.

Table 2
Additional clinical outcomes, Subject discomfort, Parental and Subject acceptance, Cost effectiveness of Hall Technique crowns Vs Control techniques.

Author, year	Number of subjects	Method of Assessment	Results
Occlusal vertical dimension (OVD)			
Araujo, 2020	112	OVD measured at canine	HT: Baseline 3.80 mm (SD ± 1.17 mm); Immediately after crown placement 5.25 mm (SD ± 1.20), increase of 1.45 mm (SD ± 0.87 mm); OVD returned to its pre-crown measurements within four weeks after treatment. There was no difference at baseline and four weeks after treatment (p = 0.057).
Ebrahimi, 2020	96	Overbite	Mean post-treatment overbite decreased by 2.4 mm compared to the baseline. After six and 12 months, the mean change decreased to 1.40 mm and 0.31 mm, respectively.
Elamin, 2019	165	OVD measured by contact at contra-lateral tooth	HT: nearly all the children had raised occlusions immediately after placement but only 4 % of the children in conventional treatment group. At 6 months, nearly all the children returned to normal occlusal contacts except 3 % in HT group. By 12 months, all the children had normal occlusion.
Innes, 2011	132	OVD measured at incisor	HT group: mean reported value increase for all teeth was 2.4 mm (SD 0.13, range 0–4 mm). Even occlusal contact was recorded on both sides of the arch for all 129 children at the one year recall appointment.
Periodontal health			
Kaptan, 2021	33	Gingival index	There was a significant decrease in gingival scores in HT and conventional treatment teeth at baseline-6 months and baseline-1 year (P < 0.05).
Elamin, 2019	165	Gingival index Plaque index	No significant relationship between PMCs placement method (HT or conventional) with plaque index and gingival index.
Santamaria, 2017	142	Gingival index Plaque index	GI did not show significant variation in any of the arms during the study period. The amount of plaque-free children increased significantly after 1 yr. The majority of patients (n = 24 of 29, 83 %) who presented with failures had a Plaque Index > 0 at the time of examination compared to successful cases (n = 28 of 119, 24 %;p < 0.000).
Treatment time			
Ayedun, 2021	23	Treatment time	Significantly (p = 0.01) more time was spent during the conventional treatment (28.2 ± 17.0 min) than HT (4.5 ± 1.5 min)
Ebrahimi, 2020	96	Treatment time	Mean treatment time for the HT, mART, and conventional PMCs groups were 8.4 ± 4.9, 11.1 ± 5–2, and 17.3 ± 5.1 min, significantly longer in PMCs P < 0.001
Elamin, 2019	165	Treatment time	The mean procedure time for the conventional PMCs group (33.9 min; SD = 10.61) was significantly higher (p < 0.001) than that in the HT group (9.1 min; SD = 2.87)
Innes, 2011	132	Treatment time	Conventional restorations: mean time of 11.3 min (range 4–32 min; SD 5.5) HT: mean time of 12.2 min (range 2–40 min; SD 8.3)
Treatment discomfort			
Araujo, 2020	131	The Wong-Baker Faces Pain Scale (WBFPS)	HT has higher discomfort scores compared to ART p: < 0.001, adjusted OR= 3.67 (1.79–7.49). 34 children (51.5 %) reported the same discomfort score for separator placement and crown cementation, 11 children (16.7 %) reported a higher level of discomfort after the orthodontic separator and 18 children (27.3 %) reported a higher level of discomfort after the crown cementation.
Ebrahimi, 2020	115	Faces Pain Scale-Revised	Patients in the HT group showed slightly lower-than-average FPS-R scores, and patients in the PMCs group showed slightly higher-than-average FPS-R scores, difference is not significant
Elamin, 2019	212	Self-reported Facial Image Scale (FIS)	HT subjects were less likely to report anxiety than CT immediately $\chi 2$ (4, N = 212) = 21.04, p < 0.001 or at 12 months $\chi 2$ (4, N = 212) = 52.74, p < 0.001.
Parental and subject acceptance			
Araujo, 2020	131 subject 92 parents	Questionnaire OHRQoL	Subjects: 70 % positive, 85 % neutral and positive Parents: 70 % positive No difference between groups except more parents disliked the appearance of the PMC (23.4 %) compared to ART (4.5 %). Significant improvement in OHRQoL for both total score and domains at 6 months, no difference between groups
Ebrahimi, 2020	96	Questionnaire	All parents were satisfied with HT (4) and PMCs (4) treatments. But there was a significant dissatisfaction for mART 3.19 ± 1.195
Innes, 2011	Not stated	Question post treatment	For 77 % of the subjects, 83 % of carers and 81 % of dentists, the preference was for HT.
Cost effectiveness of HT			
Elamin, 2019	212	Incremental cost-effectiveness ratio (ICER)	The calculated mean cost per unit for HT was US$2.45 (SD = 0.14), almost one-third cheaper than the cost of US $7.81 (SD = 0.14) for the CT. The ICER (incremental cost-effectiveness ratio) was US$136.56 more for each PMC placed by CT compared to that placed by HT per life year.

failure, it was found that HT reduces both major failures (pulp treatment or extraction needed) as well as minor failures (worn or lost restorations, secondary caries and reversible pulpitis). The reduction of pulpal involvement in HT could be related to the non-removal of carious tissue, supported by a recent systematic review that concluded that less invasive caries management approaches such as selective- or non-caries removal is advantageous for vital, symptom-free carious primary teeth compared to complete caries removal [27]. The reduction in minor failures could be related to the durability of PMCs which is less prone to wear and tear damage, unlike GIC restorations [23].

In general, MID techniques such as ART and SDF have shown very respectable success rates when compared with conventional restorations, particularly for single surface occlusal carious lesions [28]. Moreover, with the development of new materials, conventional restorative techniques may lead to improved clinical outcomes over time [29]. However, when it comes to proximal or multi-surface lesions, the success rate of ART suffers. With a recent systematic review finding that ART has a lower success rate when compared to conventional restorations for proximal lesions [28,30]. Most of the RCTs in the current review included proximal or multi-surface lesions, suggesting that HT should be the MID technique of choice in these situations.

The main disadvantage of HT has been suggested to be an increase in OVD, resulting in discomfort post-operatively. However, the present review found that this increase in OVD resolves over time and tend not to be detectable after 12 months. Moreover, HT was found to be more comfortable to place than conventional PMCs [24] and conventional restorations [13]. Although there is evidence to show that it may result in more discomfort than ART [17]. HT was also found to be acceptable to children and parents, and is faster to place when compared to conventional PMCs, a finding supported by

a previous study [12]. A secondary publication on one of the included studies [20] found that dentists reported less negative behaviour in the HT group when compared to conventional restoration [13]. While cost-effectiveness studies on two of the included studies [8,20] found that HT was more cost-effective, with longer survival and less complications at lower costs compared to conventional restorations and NRCC [31]. The aforementioned clinical advantages of HT when compared to conventional PMCs and restorations, coupled with the high success rates makes HT a viable management technique for carious lesions in primary teeth.

The strengths of the current review include the robustness of methods, the sensitive database searches, the use of two reviewers throughout to screen, data extraction and assessment of bias. While one limitation is the study design inclusion criteria may have resulted in not capturing studies that report on patient acceptability/cost exist. Other limitations are the comparison of HT to a group of different interventions as the control, as well as the different follow-up periods of the included studies. This heterogeneity may reduce the generalizability of the meta-analysis results, which this paper attempted to address with secondary analyses comparing HT to individual categories of controls.

Additionally, the small number of studies comparing HT to conventional PMC means that the finding that it has a similar success rate should be interpreted with caution. Moreover, the success of HT in pulp-treated teeth was not evaluated in any of the included studies. This is a typical indication of conventional PMCs, when used in pulp-treated teeth to provide a good coronal seal [32].

5. Conclusion

HT is a successful technique for the management of dentine caries in primary molars, particularly for proximal or multi-surface lesions. It is well-tolerated by children and acceptable to parent, with very mild adverse effects. Future interventional studies (RCTs) should adopt a standardised approach with clear randomisation at patient level, allowing for more studies to be included in future meta-analyses.

CRediT authorship contribution statement

SH: Contributed to conception, design, data acquisition and interpretation, drafted and critically revised the manuscript. AB, SA: Contributed to conception, design, data acquisition and interpretation, and critically revised the manuscript. SN: Contributed to data acquisition and interpretation, performed all statistical analyses, and critically revised the manuscript. MM: Contributed to design, data acquisition and critically revised the manuscript. RMS: Contributed to conception, design, and critically revised the manuscript.

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Conflict of Interest

The authors declare no conflict of interest. All authors have made substantive contribution to this study and/or manuscript, and all have reviewed the final paper prior to its submission.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jdsr.2022.09.003.

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