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Economic Evaluation of ART and Hall in Primary Molars

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Abstract

Background This study reports an economic evaluation from the perspective of the Brazilian healthcare system. This is a secondary outcome of a three-year randomised controlled trial that compared Atraumatic Restorative Treatment (ART) to the Hall Technique (HT) for managing occluso-proximal caries lesions in primary molars. The primary outcome showed that the HT had a higher survival rate compared to ART and the economic evaluation was to test cost-effectiveness.

Methods Children (5–10 years old) in public schools of Tietê-SP/Brazil, were randomly allocated to either the ART or HT arm. Treatment survival was assessed using Kaplan-Meier analysis. The economic evaluation considered baseline and cumulative material and professional costs based on the Brazilian National Health System (SUS) perspective. For the economic analysis, direct and indirect costs were collected and calculated. When retreatment was necessary, an incremental cost of only one retreatment per child was considered for the analysis. All costs were collected in reais and converted and reported in euros. A discount rate of 5% was considered and a bootstrap regression was used to assess material costs' dynamics over time (α = 5%). Monte-Carlo simulation generated cost-effectiveness scatter plots.

Results The study included 131 participants (ART = 65; HT = 66) and 112 (85.5%) were followed up over three years. Survival was higher in HT compared to ART restorations (ART = 32.7%; HT = 93.4% $p < 0.001$). The HT (€13.02) cost less compared to ART (€16.79) ($p < 0.001$ 95% CI: -10.07 to -1.87) due to ART higher treatment failure and cumulative costs. Although baseline costs were lower in the ART group, the cumulative cost due to the need for restoration replacement was higher after 3 years.

Conclusion Hall Technique is a cost-effective strategy compared to Atraumatic Restorative Treatment for managing occluso-proximal carious lesions in primary molars in a school setting after 36 months, particularly from the perspective of the Brazilian public health system.

Trial registration This trial was registered in ClinicalTrials.gov (NCT02569047) on 2015-10-06.

Keywords Cost-effectiveness, Atraumatic restorative treatment, Dental caries, Hall technique, Health services research, Primary molars, Randomised controlled trial

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Introduction

Dental caries remains the predominant chronic disease affecting approximately 514 million children globally and ranking as the 10th most prevalent health condition over the past two decades [1, 2]. Identifying cost-effective management approaches is essential, given the ubiquity of this condition and its frequent treatment by dentists worldwide [3]. In light of these considerations, various techniques have emerged supported by robust evidence of their efficacy in treatments for deciduous teeth [4].

Atraumatic Restorative Treatment (ART) is one of the most widely used techniques for the definitive treatment of caries lesions in primary molars [5, 6]. It was originally designed for use in the field, but is now commonly applied in dental practices [7], recommended in guidelines [8, 9], and taught in many dental schools as a standard technique to manage dental caries. ART's viability as a treatment is due to its efficacy for occlusal lesions in both primary and permanent teeth, as well as its favourable patient acceptance [10–12].

In contrast, another technique that has been studied and can be strongly recommended due to its remarkable efficacy is the Hall Technique (HT) [13]. The HT emerged more than 15 years ago as a minimal intervention dentistry (MID) approach for addressing carious lesions, and is recognised globally [14, 15]. HT isolates the bacterial environment within the lesion substrate and promotes dentin remineralization, thus preventing acid-mediated degradation and lesion progression after exposure to the oral environment [16–18]. Moreover, clinical trials have consistently demonstrated the effectiveness of HT relative to conventional restorative interventions and non-restorative cavity management, which are conventional modalities in paediatric dental practice [19–21]. The detailed protocol and results of one of these trials, reported elsewhere [22, 23], showed a consistent outcome of 32.7% for ART and 93.4% for HT after a 3-year follow-up. These findings demonstrate a significant beneficial effect associated with this technique. However, although these studies have shown that HT is more effective than other techniques, there remains a gap in the evidence regarding its cost-effectiveness.

The concept of cost-effectiveness in dental care includes both the initial procedure costs and the effectiveness of the technique in maintaining restoration longevity without requiring further interventions such as additional restorations, pulp therapy, or tooth extraction. In 2010, global dental treatment costs averaged $442 billion, representing 4.6% of total global health expenditure [24, 25]. To date, no prospective randomised controlled trials have been undertaken in settings lacking conventional dental infrastructure to compare the cost-effectiveness of ART, a technique frequently used in underserved communities, with the HT. Accordingly, this article aims to present the results of a secondary outcome from an RCT [22, 23] assessing the cost-effectiveness of ART and the HT for managing occluso-proximal dentine carious lesions in primary molars within a school-based context over a 36-month period in Brazil.

Materials and methods

This study was registered on ClinicalTrials.gov (NCT02569047), approved by the local ethics committee of the University of São Paulo/Brazil (#1,293.935) [23], and is reported according to the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) guidelines [26].

Study design

Study population and subgroups

Children between 5 and 10 years old attending public schools of Tietê city, presenting at least one occluso-proximal dentine carious lesion on primary molars, with no signs or symptoms pulp involvement, presenting a cooperative behaviour and whose parents agreed with their participation via a consent form, were included in the study.

The sample size of the primary trial was calculated based on the primary outcome—restoration survival at 36 months—aiming to detect a 25% difference between groups with 80% power and a significance level of 5%. Accounting for a 20% loss to follow-up, the final sample size was set at 124 children (62 per group) [23]. This secondary analysis includes data from these participants.

Study setting

The study was carried out in eight schools of Tietê's municipality, located in the state of São Paulo, Brazil. Tietê has 42,500 inhabitants and the Gross Domestic Product (GDP) is around R$1.9 million, 48% of which comes from services, followed by industry (37.3%), public administration (11.3%) and agriculture (3.3%) [27]. The interventions were conducted in classrooms, with children lying on school desks, which is a common practice in Brazilian public schools where dental conventional equipment is not available. This approach allows dental care to be provided directly in the school setting for all children.

Payer's perspective.

The analysis was conducted from the perspective of the Brazilian public health system, considering only direct costs, including professional fees, materials, and procedures reimbursed by the public sector. Since treatments were carried out in public school classrooms—where conventional dental equipment is generally unavailable—this setting reflects the real-world conditions under which such interventions would be implemented within the public system.

Comparators and time horizon

ART restorations were compared to the HT. Participants were included upon parental consent for the study, and then they were assigned to one of the two arms through an electronically generated randomisation list. Randomisation was at the participant level and only one tooth was included per child.

Treatment for children in the ART group (control) included selective caries removal to soft dentine using hand instruments followed by restoration with an encapsulated glass ionomer cement (Equia Forte GC Corp., Leuven, BE).

For the HT group (experimental) no caries tissue removal or tooth preparation were performed. Before placing the preformed metal crown, an orthodontic separator was inserted between the tooth to be crowned and the adjacent tooth when tight proximal contact was present. The separator remained in place for one to seven days.

The preformed metal crowns (3 M/ESPE, St Paul, USA) were cemented with encapsulated glass ionomer cement (Fuji I, GC Corp., Leuven, BE).

Further details on the study methodology have already been published in the protocol [22] and in the study reporting the primary outcome results (treatment survival after 36 months) [23]. The 131 children included in the baseline were assessed after 1, 6, 12, 18, 24, 30, and 36 months by the same trained and calibrated evaluators. Failures reported in each evaluation period were considered for incremental cost determination.

Health outcomes

Restorations' survival was the primary outcome of the RCT, defined as the absence of complications that would require intervention, including new caries, restoration loss, or pulp pathology, as detailed in Table 1.

Currency, price date, discount rate and conversion

The time spent on each treatment was recorded by an external evaluator using a stopwatch, along with the type and quantity of materials used to restore the cavities. Utility costs such as water and electricity were not included in the analysis. A discount rate of 5% was applied, in accordance with recommendations for lower-middle-income countries [28].

The total cost of the treatments was considered as the sum of the professional costs (based on the time spent to perform each treatment considering the salaries of dentists and dental nurses in Brazil, following the Brazilian Federal Law 3991/61) and the cost of procedures (based on the depreciation of material and instruments). For the ART group, the total time spent performing a restoration was recorded from the time the child was lying on the table ready to receive treatment and the operator positioned until the restoration was finished and the child was instructed to stand up. For the HT group, the time spent was recorded at two different times: 1- when the child was lying on the table ready to have the orthodontic separators placed until being instructed to stand up; 2- second time, when the child was lying on the table and ready to remove the orthodontic separator and then to have the preformed metal crown placed until being told to stand up.

Direct costs included professional and material expenses. Professional costs were calculated by multiplying the time spent on each treatment by the average hourly income of dentists and dental nurses, including the legally mandated unhealthiness allowances—40% for dentists and 20% for dental nurses—due to occupational risk exposure. Material costs were based on the quantity and unit price of consumables used per treatment. Indirect costs referred to the depreciation of reusable instruments and equipment, calculated according to their estimated useful life and average usage time.

Table 1 Treatments evaluation criteria. (modified from Innes et al., 2007) [18]

Outcome	Outcome Criteria	
	ART	**Hall Technique**
Success	Satisfactory restoration, no intervention required No signs or symptoms of pulp damage Tooth exfoliated with no minor or major failures	Satisfactory crown, no intervention required No signs or symptoms of pulp damage Tooth exfoliated with no minor or major failures
Minor Failures	New carious lesions (around the restoration or in the tooth) Restoration fracture or wear– intervention is required (> 0.5 mm) Restoration loss– tooth can be re-restored Reversible pulpitis– can be managed without the need of pulpotomy or extraction	Crown perforation Crown loss– tooth can be re-restored Reversible pulpitis– can be managed without the need of pulpotomy or extraction
Major Failures	Irreversible pulpitis, dental abscess or fistula– requires pulpotomy or extraction Restoration loss– tooth cannot be re-restored Tooth fracture	Irreversible pulpitis, dental abscess or fistula– requires pulpotomy or extraction Crown loss– tooth cannot be re-restored Tooth fracture

Additional costs were considered for retreatments following minor failures, while major failures (e.g., requiring endodontic therapy or extraction) were valued using standard procedure costs from the Brazilian national public health service. All costs were initially calculated in Brazilian Reais (BRL) and converted into Euros using the October 2015 exchange rate (€1.00 = R$3.39).

The quantity and specification of the materials used to calculate the cost were recorded in the clinical record of each participant. There was an additional 15.9% increase in the cost of materials due to the inflation rate from 2015 to 2018, the year the study was completed. The average value from three different material suppliers was considered for each material used in this study. Each material had the price divided by the number of available units contained in each package to get the price of an individual unit. The materials that could not be separated out as an individual unit had a predetermined measurement that was considered as a unit of the material referred to (e.g. 10 cm of dental floss).

Equipment depreciation (autoclave and light curing unit) was calculated considering a useful life of 5 years and a depreciation rate of 0.48 Euros/hour. Instrumental depreciation was calculated considering a useful life of 3 years for each instrument [29]. Considering instrument usage of 160 h per month, a depreciation rate of 0.012/hour was considered.

Analytical methods

Microsoft Excel 2013, Stata 13 (StataCorp LP, Texas, USA) and XLSTAT 2018 were used for data input and statistical analysis.

A Kaplan-Meier survival analysis and the Log-rank test were used to calculate survival rates. In order to compose the total cost of each technique used to treat children in this trial, a median cost related to professional and material costs was performed.

To obtain a sampling distribution of the mean costs and effects, Bootstrapping regression was used, adopting the 95% CI around the means.

A Monte-Carlo simulation was used to construct a cost-effectiveness plan using 10,000 simulated situations [30]. To explore the uncertainties related to cost-effectiveness analysis (CEA), a Bayesian inference was adopted. Costs and effects were described using statistical distributions (XLSTAT 2018 - Addinsoft SARL, Paris, France). Simulated values for effects and costs were plotted on a cost-effectiveness plot (X-axis = effect; Y-axis = cost). The plan is composed of four different areas: (1) the Northwest - NW (least effective, most expensive); (2) the Northeast - NE (most effective, most expensive); (3) the Southeast - SE (most effective, least expensive); and (4) the Southwest - SW (least effective, least expensive). When a new treatment is more effective and less expensive (SE), it is defined as dominating the given standard treatment. If the new treatment is less effective and more expensive (NW), it is defined as dominating the existing treatment (Fig. 1).

The proportion (in percentage) of dots in each quadrant was assessed visually to analyse the uncertainties related to the variables. Incremental cost (Δ) and effect (HT-ART) were calculated, as was the incremental cost-effectiveness ratio (ICER).

The difference in cost per effectiveness (lost or gained) was indicated using the incremental cost-effectiveness ratio (ICER). If ICER values are positive, an additional cost is attributed to additional effectiveness. However, an additional cost is attributed to an effective loss if the ICER is negative. Estimated costs (c) were calculated in Euros and effectiveness (e) in months. The ICER is calculated by dividing the incremental cost difference (Δcost = cost-experimental group - cost control group) by the effect difference (Δeffect = effect-experimental group - effect control group).

$$ICER = \frac{\Delta\ cost}{\Delta\ effect}$$

The treatment survival rate after 36 months was defined as the effect. If at any point in the follow-up time, a failure required reintervention (restoration/crown defect but not interfering with the health of the tooth, signs or symptoms of irreversible pulp damage, fistula/abscess, tooth fracture, or failures that cannot be repaired), it was then considered an event. A retreatment cost was assumed when the child presented restoration failure according to the necessary treatment to be performed (retreatment, pulp treatment or extraction), limited to only one retreatment cost per child.

Model structure and assumptions

The economic evaluation model was developed to simulate the costs and effectiveness of two treatment strategies—ART restorations and the Hall Technique for managing occluso-proximal caries in children aged 5 to 10 years. This model is based on individual-level data from an RCT and employs a Monte Carlo simulation to account for uncertainty and variability in costs and treatment outcomes over time.

Unlike decision-analytic models based on Markov state transitions—commonly used when relying on literature-based parameters or long-term extrapolations, such as in Schwendicke et al. [31], our approach leverages real-world, trial-based data. This allows a more empirical and context-specific assessment of cost-effectiveness within a fixed 36-month follow-up period.

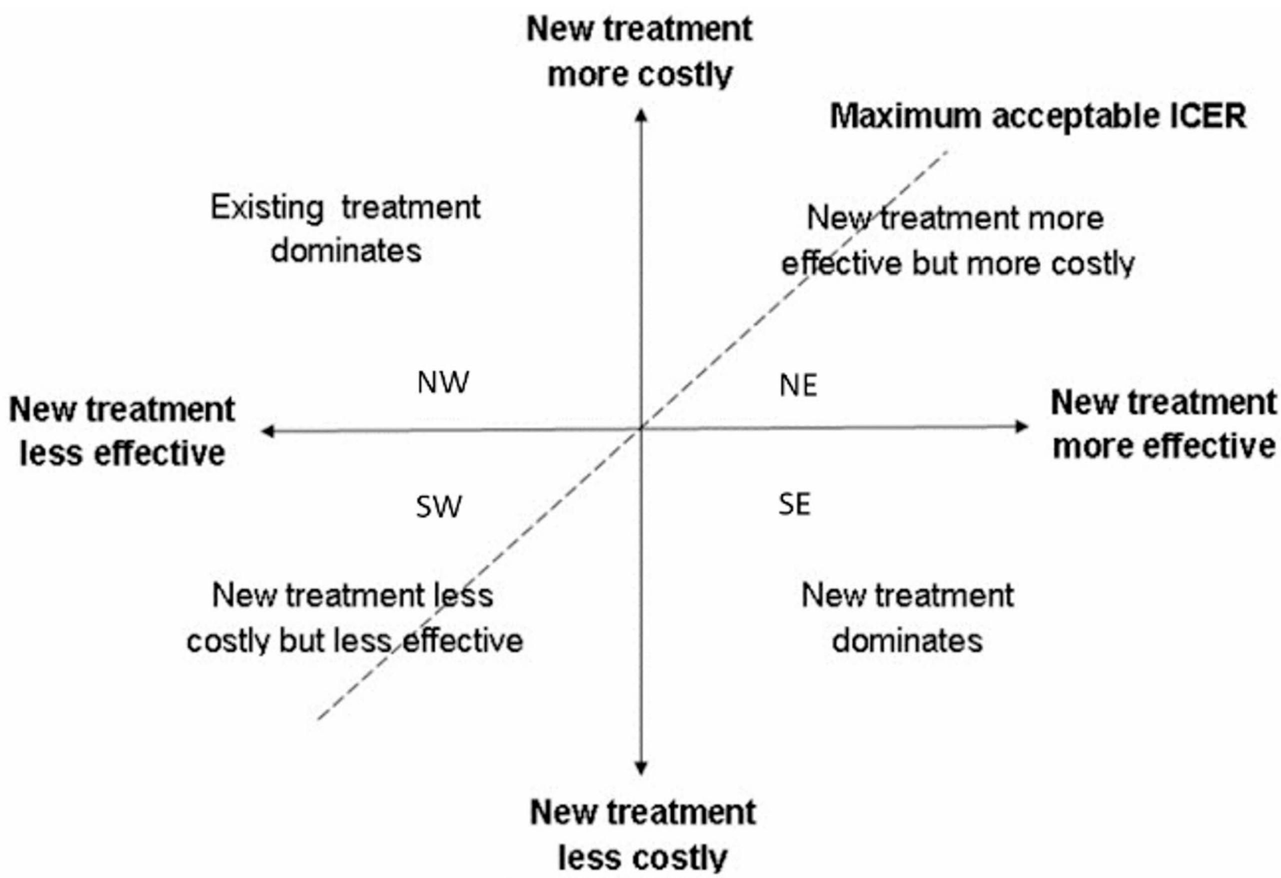

Fig. 1 Cost-effectiveness plan– adapted from Hounton and Newlands [32]

The model structure is presented in Fig. 2, summarizing the flow of participants, treatment assignment, and cost components considered in the simulation.

Assumptions and structure

- Children were randomized 1:1 to receive either ART or HT, with one treated tooth per child.
- Treatment survival was evaluated at multiple follow-up points over 36 months. Failure was defined as the occurrence of any event requiring retreatment (e.g., new caries, restoration loss, pulp involvement).
- For failed cases, only one retreatment was assumed per child.
- Direct costs included professional time (based on Brazilian public health wages), material costs, and depreciation of instruments.
- Cost and effectiveness data were analysed using Monte Carlo simulation with 10,000 iterations, generating a probabilistic cost-effectiveness plane.

This modelling strategy provided a robust estimation of incremental cost-effectiveness ratios (ICERs), capturing uncertainty while remaining grounded in trial-observed clinical pathways.

Results

Effectiveness

The HT presented a significantly higher survival rate in comparison to ART (HT = 93.4%; ART = 32.7%; Fig. 3). This difference was both statistically significant ($p < 0.001$) and clinically meaningful, with HT demonstrating nearly three times the survival rate of ART restorations.

Costs

Initially, the material cost was higher for HT compared to ART ($p = 0.042$), see Table 2. When assuming a retreatment cost due to failure (incremental cost), ART exceeded the HT costs at the end of 3 years. The 6-month follow-up was the period when the highest incremental cost was recorded for the ART group and corresponds to a period where the highest number of failures occurred (Fig. 4). The different components of the total cost for each treatment and the average time to perform the restorations for both groups is shown in Table 2.

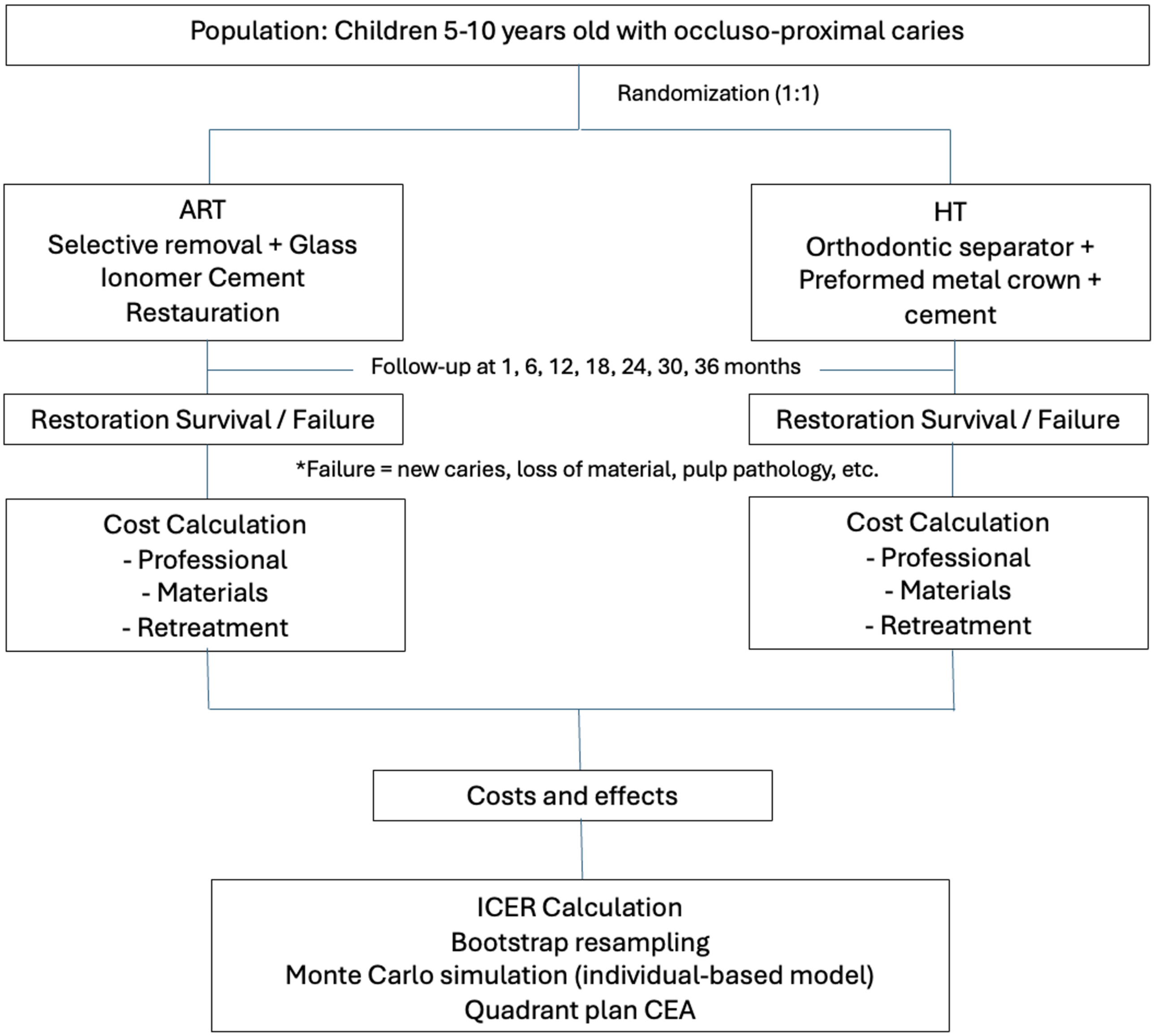

Fig. 2 Flowchart of the economic evaluation model based on Monte Carlo simulation

Cost-effectiveness

Considering the sample size of this trial, HT was less expensive and more effective than ART, with an average ICER of 0.03 Euros spent additionally while gaining 1% survival of restorations using the HT after 3 years of follow-up. The cost-effectiveness plan (Fig. 5) shows the proportion of points in each quadrant considering 10000 simulated situations. The probabilities of HT represented in the plan are: 1) most effective and most expensive (NE) = 35%; most effective and least expensive (SE) = 40%; least effective and most expensive (NW) = 10%; and least effective and least expensive (SW) = 15%. This trial is also represented in the cost-effectiveness plan and is located in the SE quadrant (new treatment dominated existing treatment). The evaluation of the cost between materials over time using Bootstrap regression analysis (10,000 repetitions) is presented in Table 3.

Discussion

Although HT has been more effective than ART for restorations of primary teeth considering their longevity with a higher survival rate for HT (93.4%) compared to ART (32.7%) [23], it is still unclear whether the technique is also in the brazilian context. Therefore, although this represents a secondary analysis using data from a previously published clinical trial, the present study was specifically designed to evaluate the costs and cost-effectiveness of HT compared to ART in the management of cavitated caries lesions in primary molars.

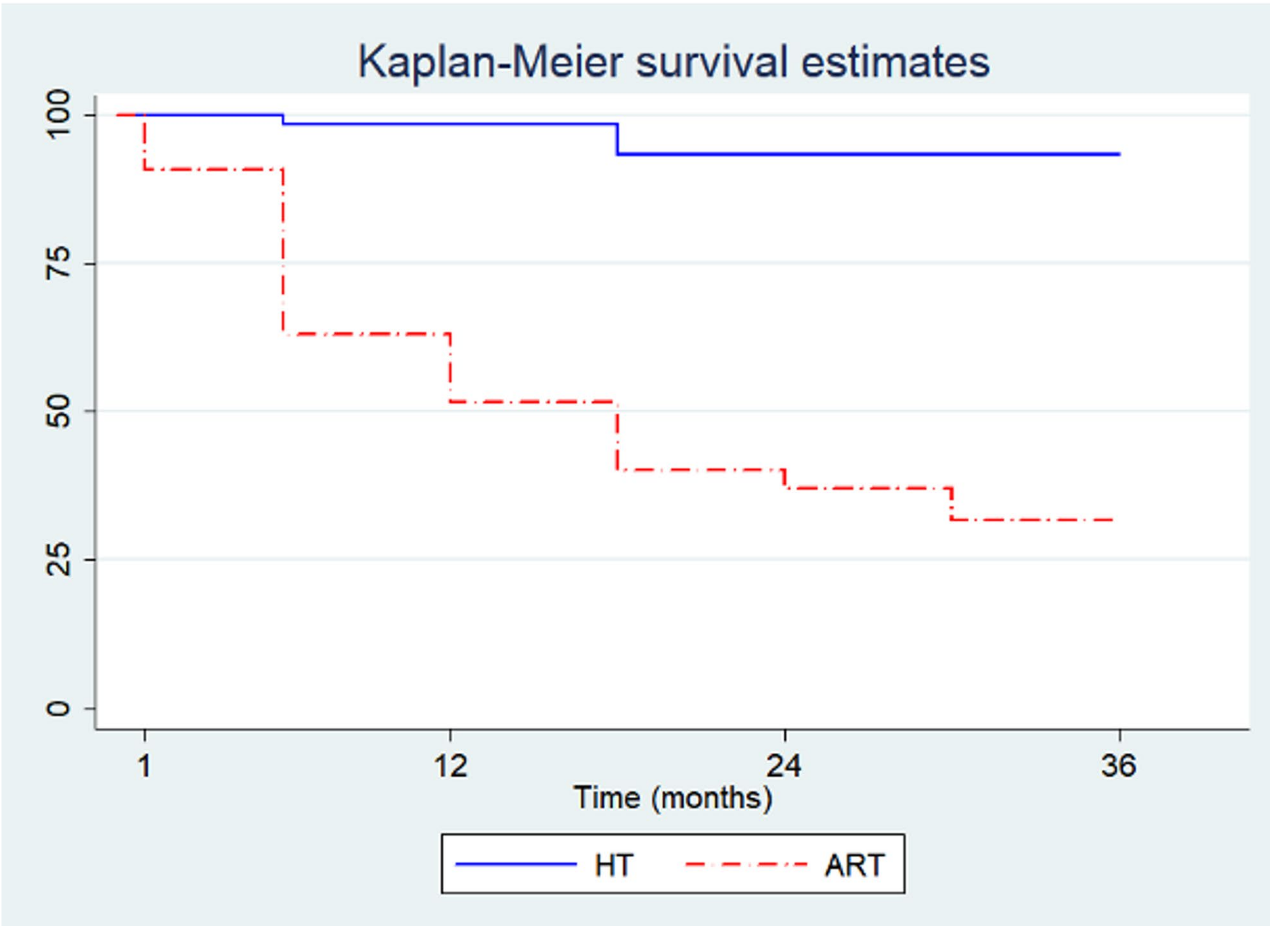

Fig. 3 Kaplan-Meier survival estimates after 36 months follow up ($n = 131$)

Table 2 Initial mean cost and mean time to perform ART restorations and HT

	Mean Cost (95%CI)			Mean time▲ (95%CI)
	Professional	Material	Total	
ART	€5.84 (5.30–6.38)	€4.59 (4.39–4.78)	€10.43 (9.76–11.09)	17.58 (15.90-19.27)
HT	€3.30 (2.95–3.65)	€9.12 (8.76–9.48)	€12.42 (11.85–12.98)	9.92 (8.89–10.96)
p-value †	< 0.001*	< 0.001*	0.042*	< 0.001*

† Calculated using Bootstrapped quantile regression

▲ mean time spent to perform the treatments measured in minutes

* Difference statistically significant

Though the HT initially incurred higher costs, primarily due to material expenses (73.4%), by the 36-month time frame, the cumulative costs associated with ART had surpassed those of the HT. This shift in cost dynamics was attributed to incremental expenditures related to restorations and retreatments necessitated by instances of failure. However, a limitation of this trial pertains to the precise quantification of retreatments required, as we have assumed only one retreatment cost upon failure observation in both intervention groups. Notably, in the context of ART costs, the predominant component comprised professional fees (56%). In this sense, the costs for the ART arm might be underestimated.

Despite ART being deemed less intricate in comparison to conventional treatment (CT), operators required comparatively more time to execute ART procedures compared to the HT. It is imperative to note that this trial exclusively accounted for direct costs associated with both treatments (professional and material), conducted within public school settings during regular

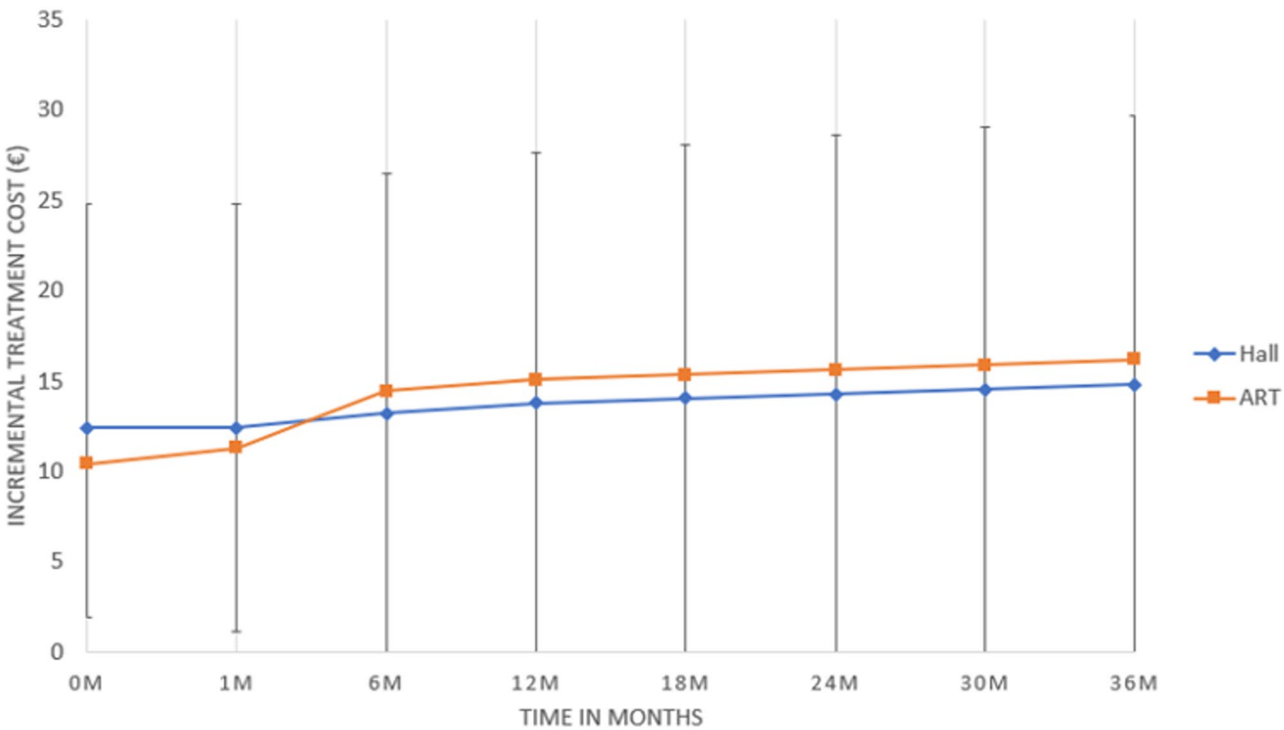

Fig. 4 Incremental cost curves for ART and HT over 36 months

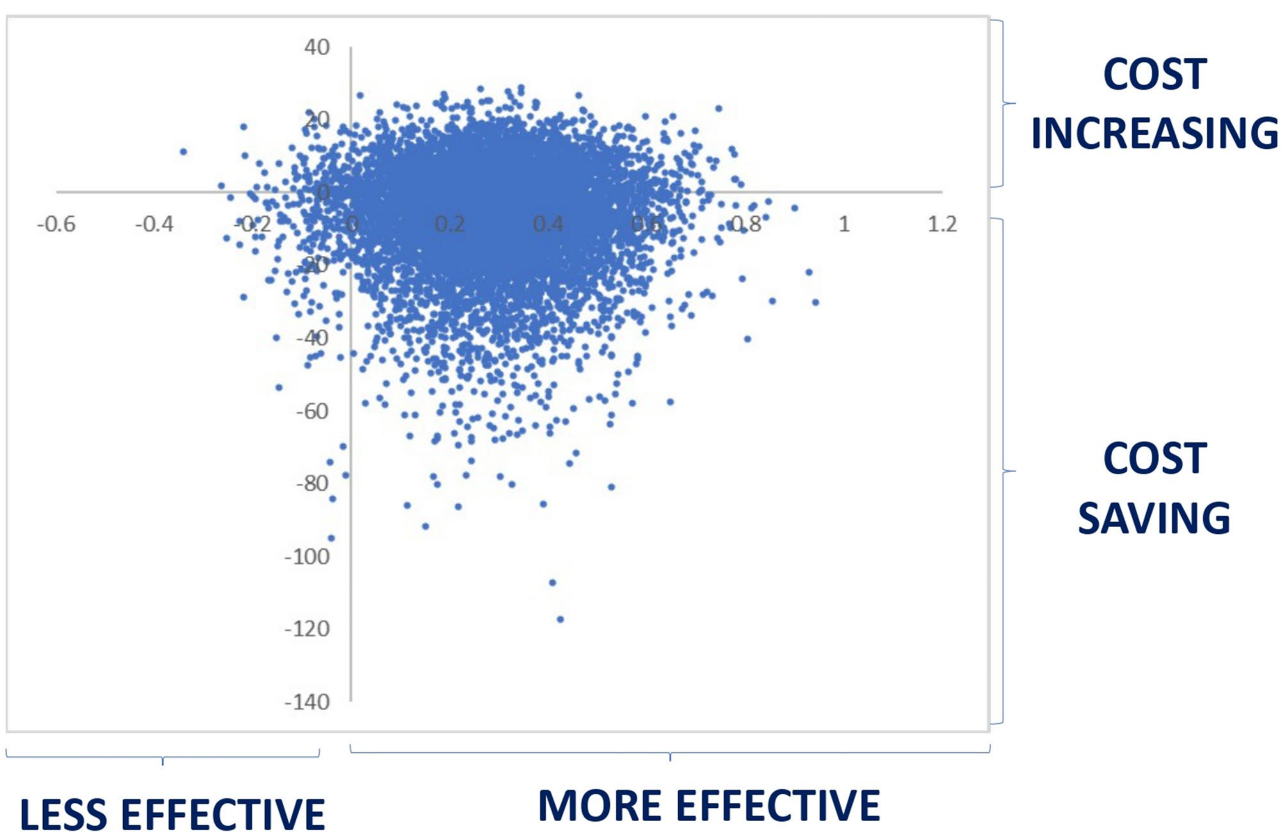

Fig. 5 Cost-effectiveness plane of HT compared to ART

Table 3 Evaluation of the cost between materials over time using bootstrap regression analysis

	Prospected mean € Euro (SD)	Coefficient (Bootstrap SE)	*p*-value	95% Confidence Interval
Baseline Total Cost				
ART	10.43 (4.31)			
Hall Technique	12.42 (3.72)	3.16 (0.66)	< 0.001*	1.87 to 4.45
12-months Total Cost				
ART	15.35 (12.36)			
Hall Technique	12.81 (6.05)	-4.01 (1.66)	0.016*	-7.25 to -0.76
24-months Total Cost				
ART	16.13 (12.37)			
Hall Technique	13.02 (6.62)	-4.91 (1.74)	0.005*	-8.32 to -1.51
36-months Total Cost				
ART	16.79 (15.42)			
Hall Technique	13.02 (6.62)	-5.97 (2.09)	0.004*	-10.07 to -1.87

academic terms. It is important to emphasise that within a controlled clinical study, we still underestimate the cost of the procedures carried out as the attendants are trained and calibrated, reducing the chance of failure, the patients are motivated to take care of themselves, and the whole treatment is highly controlled. Under normal conditions, the cost of ART re-interventions, for example, would result in an even higher cost compared to the cost of HT.

The cost-effectiveness of interventions can vary in different contexts [33]. In two separate studies [19, 20] that evaluated the cost-effectiveness of the HT compared to CT and non-restorative cavity control (NRCC) at 2- and 5-year follow-ups, respectively, in a European public health context, concluded that the HT represents a cost-effective approach, regardless of the setting or perspective in which it was implemented (e.g. primary/secondary care, dental clinics or community/school settings). The findings of our study, encompassing cost-effectiveness, hold significant implications for public health services, dental professionals, and parents/caregivers, given its execution without formal dental facilities and its favourable cost-effectiveness relative to ART, a prevalent approach within the Brazilian public health system for managing carious lesions in children, especially in places lacking conventional dental care.

While costs were assessed from the viewpoint of the public health service, encompassing operator salaries, additional expenses such as travel costs and the potential loss of working hours for parents/guardians were excluded due to the school-based nature of the trial. Furthermore, expenses related to electricity and running water were not factored into the treatment costs, albeit assumed to be negligible and uniform across both interventions, thereby presumed to have minimal impact on the cost-effectiveness of the HT. Additionally, uniform time assumptions for restoration following initial treatment loss may not accurately reflect real-world scenarios where restoration times could vary. The inability to blind participants, operators, and outcome assessors due to the distinct techniques and materials employed in each strategy represents another notable limitation. It is pertinent to acknowledge that our study's trial-based design imposes inherent limitations on the generalizability of cost outcomes, particularly concerning external validity and generalisability, while acknowledging that modelling approaches utilised in other studies may mitigate some of these limitations.

The assessment of cost-effectiveness serves as a relevant metric for discerning the economic viability of diverse intervention strategies for managing carious lesions. However, the lack of studies investigating the cost-effectiveness of interventions targeting primary dentition is conspicuous [34]. Given the dental caries is a public health concern, with disproportionately higher prevalence among individuals from low-income countries, the cost of treatment could significantly influence the selection of strategies for managing caries lesions in paediatric populations.

Therefore, cost analysis should be integrated into evaluations of interventions for managing dental caries in children. This includes ancillary costs such as transportation and opportunity costs, including the time children and their parents may spend away from school or work. These factors, along with the number of required appointments for both initial treatments and retreatments, can significantly impact the overall cost of care. The findings of this study support the potential adoption of the Hall Technique in the Brazilian public health system, given its superior cost-effectiveness compared to ART approach.

Conclusion

The Hall Technique proves to be a cost-effective strategy compared to the Atraumatic Restorative Treatment for managing occluso-proximal carious lesions in primary molars within a school setting after 36 months, from the perspective of the Brazilian public health system.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12903-025-06528-8.

Supplementary Material 1

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Author contributions

DPR, NPI, CCB, DH and FMM designed this trial. DPR was the Chief Investigator. MPA was the study director, responsible for participant's recruitment, data collection and monitoring the trial. JRG drafted this article. ICO and FMM were responsible for statistical analysis. All authors read and approved the final manuscript.

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Data availability

Data is provided within the supplementary information files.

Declarations

Ethics approval and consent to participate

This trial was approved by the Research Ethics Committee of the School of Dentistry, University of São Paulo in October 2015 (protocol number 1.293.935). The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants' parents or legal guardians prior to their enrolment in the trial. Additionally, all child participants signed a written assent form before initiating their treatment. Participants who chose not to take part were excluded from the study and did not receive any treatment.

Consent for publication

Not applicable as there are no participants' identifiable data, pictures or illustrations that require consent to publish in this manuscript.

Competing interests

The authors declare no competing interests.

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