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ORIGINAL ARTICLE

Efficacy of diode laser application versus silver diamine fluoride (SDF) as a modification of Hall technique in primary teeth

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KEYWORDS

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Abstract *Background:* The Hall technique is a new technique aimed at depriving bacteria of any substrate, thereby limiting the progression of caries. Silver diamine fluoride (SDF) and diode laser are documented to have an antibacterial effect on carious enamel and dentin by eradicating bacteria such as Streptococcus mutans.

Aim: The current study aimed to increase the success rate of the Hall technique in carious primary molars by eradicating bacteria present in carious lesions using SDF or diode laser in combination with the Hall technique.

Materials and methods: A total of 159 children aged 4–8 years were randomly divided into three equal groups: Group I, application of the Hall technique; Group II, SDF with Hall technique; Group III, diode laser with Hall technique. Children were recalled at regular intervals over a year. Results: At the end of the follow-up period, Group III showed the highest clinical success rate (94.3 %), followed by Group II (96.2 %), while Group I showed the lowest clinical and radiographic success rates (88.7 % and 86.8 %, respectively); however, these differences were statistically non-significant.

Conclusion: Treatment of carious lesions using SDF or Diode Laser increased the success rate of the Hall technique in primary teeth.

1. Introduction

Dental caries is a preventable oral disease that occurs worldwide in children and adults. It is a dynamic process that results in the loss of the hard tooth structure, ending with cavitation. Depending on the interplay between different pathological and protective factors, this process has different phases of demineralisation and remineralisation, which subsequently influence

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the initiation and progression of dental caries (Featherstone, 2008).

Proper management of primary teeth with deep carious lesions to preserve pulp vitality is considered a significant challenge for all dental practitioners, as deep caries may cause severe pulp inflammation, eventually leading to pulp necrosis. During the excavation of deep caries, it is highly likely that the dentin barrier can break, which interferes with pulp healing (Thompson et al., 2008).

Recently, the shift from classical restorative approaches to minimally invasive treatment modalities has dramatically increased. The Hall technique was first introduced in Scotland by Dr. Norna Hall as a minimally invasive approach without caries removal or even local anaesthesia (Elamin et al., 2019).

One of the most recent and effective materials that can be used in minimally invasive approaches is silver diamine fluoride (SDF), which has been documented to arrest the progress of dental caries and prevent new carious lesions (Desai et al., 2021). It has been especially used in deciduous teeth because of its significant impact in special conditions such as early childhood caries and patients with medical or behavioural problems where traditional treatment cannot be performed using local anaesthesia (Oliveira et al., 2019).

In clinical practice, SDF application controls active carious lesions and helps prevent their further propagation. The presence of fluoride and silver ions in SDF enhances its antibacterial properties and promotes the remineralisation of tooth structure (Horst et al., 2016).

Laser technology and its applications in the dental field have recently emerged as a non-invasive modality and are considered a less painful approach, making it a good alternative to conventional treatment, particularly in children (Nazemisalman et al., 2015). Diode laser have been shown to exhibit a significant antibacterial action against Streptococcus mutans; therefore, they can be highly effective, if coupled with the Hall technique, in treating carious primary teeth (Lee et al., 2006).

The null hypothesis of the present study was that there is an increase in the success rate of the Hall technique in treating carious primary molars by eradicating bacteria present in the carious lesions by combining it with either SDF or Diode laser.

2. Materials and methods

The current study was a three-arm, parallel-group, blinded, randomised controlled clinical trial. This study was approved by the Medical Research Ethics Committee of the National Research Center (approval number: 1434052021) and registered at https://www.clinicaltrial.gov (registration number: 05265104).

This study was conducted in the outpatient clinic of the National Research Centre of Egypt. from which, 159 children were recruited with the following inclusion criteria:

- Aged 4–8 years with no medical history.
- Presence of asymptomatic enamel and dentin caries in one or more primary molars without radiographic signs of periapical pathosis.
- Absence of any signs or symptoms of pulpal pathosis.

After the clinical and radiographic examination of the children, the parents were explained in detail about the study, and those who agreed to allow their child participate in the study were requested to sign a written consent form.

2.1. Sample size calculation:

By adopting an alpha level of 0.05, a beta of 0.2, that is, power = 80 %, and an effect size (ω) of (0.239) as calculated from the study by Rosenblatt (2008), the predicted sample size (n) was found to be 138 cases. The sample size was increased by 15 % to include 159 cases (53 per group) to compensate for possible dropouts during follow-ups. The sample size calculations were performed using PASS 2021 software for Windows.[1]

2.2. Randomization and grouping:

The children were randomly distributed into Groups I, II, or III. They were asked to pick up a folded paper from a box with numbers ranging from 1 to 159 and accordingly assigned to either of the three groups. The randomisation list was created using computer software. (https://www.random.org/).

In group I: Hall technique (N = 53).

In group II: SDF + Hall technique (N = 53).

In group III: Diode Laser + Hall technique (N = 53).

The examination and follow-up evaluations were performed by a single operator who was trained before conducting the study.

2.3. Clinical procedures:

2.3.1. Procedures of hall technique:

The Hall technique was performed, which did not require local anaesthesia or excavation of caries. A preoperative radiograph was obtained for every child, and orthodontic separators were inserted into the contact area and left in place for 5–7 days. Subsequently, in the second appointment, the separators were removed, and an appropriately sized stainless-steel crown, tight enough to give a feeling of 'spring back' during seating, was selected and cemented using glass ionomer cement.

2.3.2. Hall technique with SDF application

The same procedures as in the Hall technique were performed, but before cementation of the crown, 38 % SDF was placed on the carious lesion through the following steps: Petroleum jelly was applied to the lips and surrounding tissues to avoid staining. Cotton rolls and gauze were then used to completely isolate the teeth. The affected tooth was dried with a gentle blow of air, and one drop of the SDF was dropped on an applicator and applied to the carious lesion with a rubbing motion for 2–3 min. This was followed by cementation of the crown, as previously explained.

2.3.3. Hall technique with diode laser application

In this group, before cementation of the stainless-steel crown, a diode laser with a wavelength of 970 nm and output power

[1] PASS 2021 Power Analysis and Sample Size Software (2021). NCSS, LLC. Kaysville, Utah, USA, ncss.com/software/pass.

adjusted at 1 W (Sirona 970 nm +/- 15) in continuous wave and contact mode was used. The laser light was transferred through a 200 μm flexible fibre optic tip.

The fibre optic tip was inserted inside the cavity to a depth of 1 mm with a continuous clockwise spiral movement from the top to the bottom and anticlockwise in the reverse direction. Irradiation was performed for 15 s and applied five times for each cavity at intervals of 15 s.

2.4. Clinical and radiographic outcome

An immediate postoperative radiograph was taken for the patients, and they were recalled at 3 months, 6 months, and 1 year for clinical and radiographic evaluations. The patients in the follow-up were categorised as clinically or radiographically successful or showing minor or major clinical failure. (Table 1) (Sharaf et al., 2021).

2.5. Statistical analysis

Categorical data were expressed as frequency and percentage values. Intergroup comparisons were performed using Fisher's exact test, following which multiple pairwise comparisons utilising multiple z-tests with Bonferroni correction were used. Intragroup comparisons were analysed using Cochran's Q test, followed by pairwise comparisons using multiple McNemar tests with Bonferroni correction. Statistical significance was set at $p < 0.05$. Statistical analysis was performed using the R statistical analysis software, version 4.1.3, for Windows.[2]

3. Results

The results showed no statistically significant difference at different time intervals between the three groups ($p > 0.05$). With regard to the clinical outcomes, Group II showed the highest rate of clinical success (n = 51, 96.2 %), followed by Group III (94.3 %, n = 50), while Group I had the lowest success rate (88.7 %, n = 47). Following the intragroup comparison, no significant difference in all groups at different intervals ($p > 0.05$) was noted (Table 2).

In Group I, a major failure was recorded in two cases at the 6-month follow-up and in one case at 9 months; the failure was in the form of dental abscesses, while in Group II, no cases showed any failure, and in Group III, one case of minor failure due to crown loss was observed at the end of the follow-up.

The results of the inter- and intragroup comparisons in radiographic evaluation are presented in Table 3. There were no significant differences at any time interval between the three groups ($p > 0.05$). Regarding the final radiographic outcome at the end of the follow-up, Groups II and III showed the highest percentage of radiographic success (n = 51, 96.2 %), while Group I had the lowest value (n = 48, 86.8 %). The intragroup comparison showed no significant difference at the different intervals in all the groups ($p > 0.05$, Table 3).

Radiographic failure was seen in three patients in Group I (one showed widening in the periodontal ligament space and two had furcation radiolucency) at the 6-month follow-up, while at the 9-month follow-up, one more case in this group showed furcation radiolucency.

Table 1 Criteria of clinical and radiographic success and failure.

Clinical Success	Crowns were acceptable clinically. No signs or symptoms of any pulpal disease.
Minor Clinical Failure	Crown fracture or perforation Reversible pulpitis with no need for intervention
Major Clinical Failure	1. An abscess or irreversible pulpitis that need pulpotomy or extraction. 2. Crown loss and the tooth is non-restorable
Radiographic Success	1. No evidence of radicular radiolucency 2. No internal or external root resorption
Radiographic Failure	1. Periapical or furcation radiolucency 2. External or internal root resorption 3. Widening in the periodontal ligament space.

An overall evaluation was performed, where cases that showed both clinical and radiographic success were considered successful, while those that showed either minor or major clinical failure alone, radiographic failure alone, or both were all considered failures. Based on the previous categorisation of the overall outcome, Group II showed the highest percentage of successful cases (n = 51, 96.2 %), followed by Group III (94.3 %, n = 50), whereas Group I had the lowest value of overall success (86.8 %, n = 46), and there was no statistical difference between them ($p = 0.217$, Table 4, and Figs. 1 and 2).

4. Discussion

Conventional restorations with the use of high-speed handpieces and local anaesthesia tend to induce fear in children. A new approach for controlling the activity of cariogenic bacteria involves sealing it. The Hall technique was developed especially for uncooperative young children and was based on the principle of separating the carious lesion from the bacterial biofilm in situ and covering the tooth with a stainless-steel crown to limit the progression of caries (Innes et al., 2011; Oong et al., 2008).

Unfortunately, sealing the carious lesion does not lead to the complete eradication of the bacteria. Instead, stress due to nutrition depletion permits the development of a new ecology, especially when the lesion is closer to the pulp. Cariogenic bacteria can survive on the nutrients in the pulpal fluid inside the dentinal tubule. In contrast, carious lesions contain different bacterial species that can survive through cross-feeding. Therefore, the survival of bacteria within the sealed crown may lead to further demineralisation of dentine, subsequently leading to pulpal involvement (Knutsson et al., 1994). Accordingly, this study aimed to initially disinfect carious lesions using either SDF or a diode laser before performing the Hall technique.

SDF is a non-invasive treatment approach used across Asia since 1970, and its success has been reported, especially in young children with a greater incidence of caries, because of the high fluoride concentration (Quock et al., 2012; Peng et al., 2012). A single application of 38 % SDF was used in the current study and was found to be efficient in arresting car-

[2] R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Table 2 Inter and intragroup comparisons of clinical evaluation in all groups.

Time	Status	Group I		Group II		Group III		χ^2	p-value
		n	%	n	%	n	%		
Baseline	***Success***	53	100.0 %	53	100.0 %	53	100.0 %	**NA**	**NA**
	Minor failure	0	0.0 %	0	0.0 %	0	0.0 %		
	Major failure	0	0.0 %	0	0.0 %	0	0.0 %		
	Drop out	0	0.0 %	0	0.0 %	0	0.0 %		
3 months	***Success***	52	98.1 %	53	100.0 %	52	98.1 %	**1.01**	**0.603**
	Minor failure	0	0.0 %	0	0.0 %	0	0.0 %		
	Major failure	0	0.0 %	0	0.0 %	0	0.0 %		
	Drop out	1	1.9 %	0	0.0 %	1	1.9 %		
6 months	***Success***	49	94.2 %	53	100.0 %	51	98.1 %	**5.15**	**0.272**
	Minor failure	0	0.0 %	0	0.0 %	0	0.0 %		
	Major failure	2	3.8 %	0	0.0 %	0	0.0 %		
	Drop out	1	1.9 %	0	0.0 %	1	1.9 %		
9 months	***Success***	47	95.9 %	51	96.2 %	51	100.0 %	**4.07**	**0.397**
	Minor failure	0	0.0 %	0	0.0 %	0	0.0 %		
	Major failure	1	2.0 %	0	0.0 %	0	0.0 %		
	Drop out	1	2.0 %	2	3.8 %	0	0.0 %		
12 months	***Success***	47	100.0 %	51	100.0 %	50	98.0 %	**1.93**	**0.380**
	Minor failure	0	0.0 %	0	0.0 %	1	2.0 %		
	Major failure	0	0.0 %	0	0.0 %	0	0.0 %		
	Drop out	0	0.0 %	0	0.0 %	0	0.0 %		
χ^2		**7.33**		**7.99**		**7.07**			
p-value		**0.502**		**0.092**		**0.529**			
Final clinical results after 1 year	***Success***	47	88.7 %	51	96.2 %	50	94.3 %	**8.46**	**0.206**
	Minor failure	0	0.0 %	0	0.0 %	1	1.9 %		
	Major failure	3	5.7 %	0	0.0 %	0	0.0 %		
	Drop out	3	5.7 %	2	3.8 %	2	3.8 %		

Table 3 Inter and intragroup comparisons of radiographic evaluation.

Time	Status	Group I		Group II		Group III		χ^2	p-value
		N	%	n	%	n	%		
Baseline	***Success***	53	100.0 %	53	100.0 %	53	100.0 %	**NA**	**NA**
	Failure	0	0.0 %	0	0.0 %	0	0.0 %		
	Drop out	0	0.0 %	0	0.0 %	0	0.0 %		
3 months	***Success***	52	98.1 %	53	100.0 %	52	98.1 %	**1.01**	**0.603**
	Failure	0	0.0 %	0	0.0 %	0	0.0 %		
	Drop out	1	1.9 %	0	0.0 %	1	1.9 %		
6 months	***Success***	48	92.3 %	53	100.0 %	51	98.1 %	**7.25**	**0.123**
	Failure	3	5.8 %	0	0.0 %	0	0.0 %		
	Drop out	1	1.9 %	0	0.0 %	1	1.9 %		
9 months	***Success***	46	95.8 %	51	96.2 %	51	100.0 %	**4.10**	**0.392**
	Failure	1	2.1 %	0	0.0 %	0	0.0 %		
	Drop out	1	2.1 %	2	3.8 %	0	0.0 %		
12 months	***Success***	46	100.0 %	51	100.0 %	51	100.0 %	**NA**	**NA**
	Failure	0	0.0 %	0	0.0 %	0	0.0 %		
	Drop out	0	0.0 %	0	0.0 %	0	0.0 %		
χ^2		**10.39**		**7.99**		**2.98**			
p-value		**0.239**		**0.092**		**0.562**			
Final radiographic results after 1 year	***Success***	46	86.8 %	51	96.2 %	51	96.2 %	**8.62**	**0.071**
	Failure	4	7.5 %	0	0.0 %	0	0.0 %		
	Drop out	3	5.7 %	2	3.8 %	2	3.8 %		

ies, as previously documented (Chu and Lo, 2008). Chaurasiya and Gojanur (2021) compared the application of 38 % and 12 % SDF on anterior and posterior primary teeth and found 38 % SDF more efficient in arresting caries.

Diode laser is another disinfectant that can be used to eradicate cariogenic bacteria. The power used in laser application plays a fundamental role in cavity disinfection. Accordingly, in this study, the diode laser was applied for 15 s in five cycles

Table 4 Intergroup comparison of the overall evaluation.

Status	Group I		Group II		Group III		χ^2	p-value
	n	%	n	%	n	%		
Success	46	86.8 %	51	96.2 %	50	94.3 %	**5.77**	**0.217**
Failure	4	7.5 %	0	0.0 %	1	1.9 %		
Drop out	3	5.7 %	2	3.8 %	2	3.8 %		

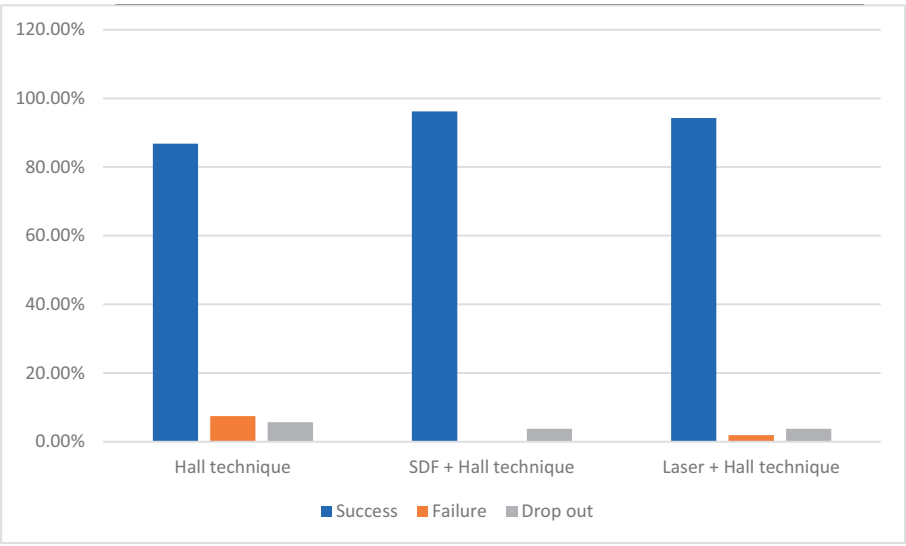

Fig. 1 Bar chart showing the overall evaluation of different groups.

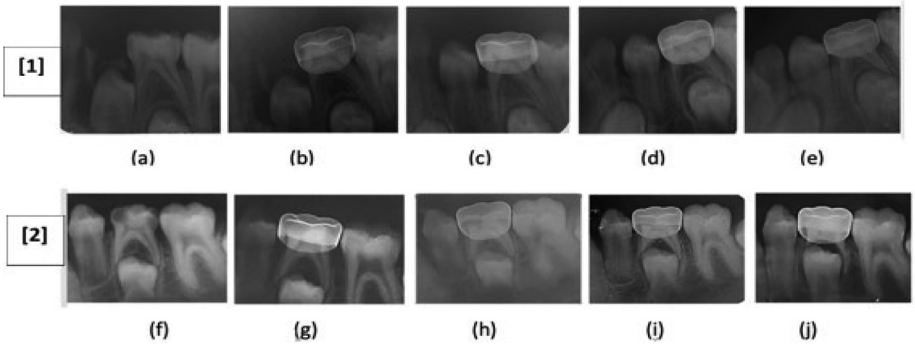

Fig. 2 [1]: Radiographic follow up for a lower 2nd primary molar treated with SDF + hall technique, (a) Pre-operative radiograph, (b) immediate post-operative radiograph, (c) 3 months follow up, (d) 6 months follow up, (e) 1 year follow up, and [2]: radiographic follow-up for a child with lower 2nd primary molar treated with laser + hall technique, (f) pre-operative radiograph, (g) immediate post-operative, (h) 3 months follow up, (i) 6 months follow up, (j) 1 year follow up.

with 1 W output power, which is highly effective for disinfecting the cavity. This was consistent with earlier studies. (Gutknecht et al., 2004).

Castro et al. (2006) concluded that the use of a diode laser with a power output of 1 W may significantly reduce the number of S. mutans in the carious cavities. In contrast, the use of five cycles with 15 s of application in each cycle was found to be more efficient than one cycle, as it penetrated a deeper layer of infected dentin (Vinothkumar et al., 2020). In addition, the direction of application of the laser, in a clockwise direction from top to bottom, followed by an anticlockwise direction, achieved better penetration within the cavity.

In this study, although there was a non-significant difference in the clinical and radiographic success between the three groups after one year of follow-up, all findings were indicative of major clinical failure in Group I. This supports the theory

that the trapped bacteria could survive under the crown and could proceed to the dental pulp, causing inflammation and subsequent pulpal death.

The overall success rate of the Hall technique after one year of follow-up was 86.8 %. This result is in agreement with those of previous studies (Innes et al., 2007, 2009). Later, when the authors performed a clinical and radiographic comparison between the Hall technique and the conventional method with an extended follow-up of 5 years, the success rate of the Hall technique was reported as 92 %, with 5 % minor and 2 % major failures (Innes et al., 2011).

In a randomised control trial undertaken in Scotland by Dean et al. (2011), wherein the follow-up was for 2 years, the minor failure rate of the Hall technique was reported as 2 % and the major failure rate was 5 % at the end of the follow-up. Elamin et al. (2019) stated that the success rate of the Hall technique after one year was 94.5 %, with 2.7 % minor and 6.4 % major failures.

When SDF was used in combination with the Hall technique, it increased the overall success rate (96.2 %), with no minor or major failures recorded in this group, which demonstrates the utility of SDF in arresting the growth of the cariogenic bacteria before proceeding with the Hall technique.

Both silver and fluoride ions in SDF seem to have a toxic effect on cariogenic bacteria. Silver ions, in particular, have significant antibacterial action on cariogenic bacteria. They can inhibit the formation of glucan. Glucan is not only responsible for the bulk of bacterial biofilms but also enhances the adhesion of bacteria to the tooth structure (Tamesada et al., 2004). Simultaneously, a high concentration of fluoride can inhibit the formation of cariogenic bacteria by activating other enzymes, such as enolase and ATPase, which affect bacterial carbohydrate metabolism (Koo, 2008).

Further, SDF enhances the occlusion of dentinal tubules by precipitating several compounds such as silver protein, silver phosphate, and calcium fluoride on the orifice of dentinal tubules. These compounds enhance the formation of an insoluble layer considered a protective layer to prevent further decay (Yu et al., 2001).

The SDF solution should be applied every 6 months to obtain the maximum benefit of treatment. However, this exposes children to a high concentration of toxic fluoride (Evans and Dennison, 2009). In the current study, a single application of SDF, followed by the placement of the crown, exposed the child to a minimal amount of fluoride with maximum benefit.

In the laser group, a diode laser was used in combination with the Hall technique, and the overall success rate was 94.3 %. The diode laser has a significant antibacterial effect, as exposure to the laser alters bacterial cell wall integrity, arresting bacterial growth (Gutknecht et al., 2004). However, 15 s of exposure to a diode laser can melt the superficial layer of dentin that occludes the dentinal tubule (Parirokh et al., 2007).

Mohan et al. (2016) compared the disinfecting effects of propolis, APF gel, chlorhexidine, and diode laser in primary teeth and found diode laser to be superior to the other disinfectants. In contrast, Lee et al. (2006) demonstrated that 810 nm diode lasers with 1 W power could kill 32.5 % of S. mutants present in the carious dentin.

As the Hall technique is non-invasive and involves no drilling or anaesthesia, it may be the best choice for young, uncooperative children with carious primary molars The use of SDF or iodide laser before placement of a stainless-steel crown could eradicate the cariogenic bacteria present in the carious lesion and prevent its progression into the pulpal tissue, thus increasing the success rate of the Hall technique in primary teeth.

5. Conclusion

The Hall technique is a non-invasive technique that can successfully treat carious primary molars; however, the application of SDF or diode laser in combination with this technique can improve the clinical and radiographic outcomes.

Ethical approval

The research was conducted following the World Medical Association Declaration of Helsinki. It was approved by the Medical Research Ethics Committee of the National Research Centre with approval number (1434052021).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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