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ORIGINAL RESEARCH

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Restorative interventions on permanent teeth after vital pulp therapy. A retrospective study on the 12-month success rates

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Abstract

Background: This retrospective study evaluated the 12-month success rates of two different restorative interventions for the management of first permanent molars that have undergone vital pulp therapy (VPT) and correlate the outcome with patient and tooth-related characteristics. **Methods**: Electronic records of all patients with one first permanent molar treated with VPT and restored at the Department of Pediatric dentistry (NKUA), were retrieved. Data regarding demographic characteristics, type of VPT performed, root developmental stage and type of final restoration were retrieved from patients' electronic records. Quality of restorations, reason for failure and need for re-treatment at 6 and 12-month post-treatment were evaluated through clinical photos using the Modified United States Public Health Service (USPHS) criteria. Significant correlations were investigated using Fisher's exact test and associations between development of a default and patient and tooth-related characteristics by multivariate regression analysis. **Results**: From the 42 molars included, majority were from the upper arch (55%), had undergone pulpotomy (74%) and were sealed with pre-formed metal crowns (PMC) (71%). Success rates were high (>75%) but slightly decreasing with time. PMCs showed overall a more favorable performance, with differences between and within the groups not being significant. Re-treatment was required in eight restorations (19%), with major defaults on marginal adaptation and proximal contact for PMCs and secondary caries and marginal discoloration for adhesive restorations. No significant associations were detected between failure and patient- or tooth-related characteristics ($p > 0.05$). **Conclusions**: PMCs and adhesive restorations are good restorative materials of teeth that have undergone VPT, demonstrating an excellent long-term performance and directly affecting the outcome of the pulp therapy.

Keywords

Vital pulp therapy; Preformed metal crowns; Adhesive restorations; Composite; Onlays; Child; Pediatric patients

1. Introduction

Vital pulp therapy (VPT) is the treatment of teeth with signs of reversible or partially irreversible pulpitis and involves removal of pulp tissue that has been compromised but not destroyed by caries, trauma, or restorative procedures. It involves a great variety of procedures from lining of the dentine close to or in contact with the pulp (direct and indirect pulp capping) to removal of part or all infected coronal pulp (full and partial pulpotomy).

A successful outcome is directly related to a good coronal seal of the cavity that prevents bacterial micro leakage [1, 2]. The choice of the appropriate material varies according to the remaining tooth structure, operator's skills and patient's compliance and expectations [1, 3, 4]. Clinicians tend to use conventional treatment techniques to seal permanent teeth following vital pulp therapy [5]. From a biomimetic perspective, the preservation and conservation of tooth structure is paramount in upholding the balance between biological, mechanical, adhesive, functional and esthetic properties [6].

Direct composite resin restorations have been widely used for the restoration of posterior teeth due to their good esthetic properties and clinically acceptable performance [3], while cavity preparation requires less healthy tissue removal, compared to indirect restorations [7]. Bonding techniques have undergone major improvements since their launch and studies indicate that adhesive restorations remain intact and clinically acceptable for up to 3 decades, with annual failure rates being as low as 2.4% [3, 4]. However, their polymerization shrinkage and abrasion tendency causing poor marginal adaptation and secondary caries formation, remain their major disadvantages [3, 4].

Preformed metal crowns (PMCs) have been extensively used for permanent teeth with caries involving multiple surfaces, developmental dental defects with post-eruptive enamel breakdown and teeth that have undergone VPT and endodontic treatment due to the extensive dental tissue loss [8]. They are preferred as they offer full coverage of the tooth and increased resistance to masticatory forces and fractures. However, it should be noted that they can compromise periodontal health, as well as the remaining tooth structure, if the crown is overcontoured or have poor marginal fit, leading to eventual failure of the restoration [8].

Indirect adhesive restorations, present ideal occlusal morphology, and wear compatibility with opposing natural dentition [4, 9]. Being fabricated outside the mouth, onlays allow for better marginal integrity, while material's degree of conversion and microhardness is enhanced [3]. However, they require extensive tooth preparation, more chair-side time and have a higher cost [3, 4].

Up to date, available evidence regarding long-term success rates of adhesive restorations on permanent teeth is limited. Existing literature has shown favorable outcomes following pulpotomy in primary molars, indicating that no single factor significantly affects the success rates of VPT at 24 months of follow-up [10, 11]. The prospective study by Tan *et al.* [12], examining restorative outcomes following VPT on mature permanent teeth, suggested that secured coronal restoration is essential for long-term success. Furthermore, in a recent review, it was concluded that the provision and maintenance of a suitable permanent restoration should be considered an essential component of the pulpotomy procedure. However, there is currently no strong evidence to guide clinicians on optimal coronal restoration to promote the success of VPT procedures and more studies are necessary to clarify this issue [13]. In the most recent systematic review, it was concluded that the restorative material did not have a significant effect on the clinical and radiographic outcome [14].

Therefore, the aim of the present study was to compare the clinical and radiographic success rates of two different restorative interventions for the management of first permanent molars that have undergone vital pulp therapy (including pulp capping and pulpotomy). Secondary objectives were to assess the main reasons for failure, the need for restoration replacement, and the correlation of the outcome with specific patient and tooth-related characteristics.

2. Materials and methods

The study was conducted and reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guideline (**Supplementary material**), and the research protocol was approved by the Ethics Committee of the School of Dentistry, National and Kapodistrian University of Athens (NKUA), Greece (No 665/23.10.2024).

2.1 Sample and data collection

The sample was the most convenient and included all patients attending the Postgraduate Clinic of the Pediatric Dentistry Department (NKUA) for treatment between 2016 and May 2024 that met the following inclusion criteria:

- Patients with a noncontributory medical history;
- With at least one permanent molar treated with VPT;
- With full dental records (including clinical photos and radiographs);
- With at least 12 months' follow-ups.

Patients with compromised medical history, which have undergone non-vital pulp therapy or VPT in an anterior tooth, with unclear photographs or radiographs, and missing data through follow-ups or with follow-ups of less than 12 months were automatically excluded.

All treatments had been performed using strict protocols under local anesthesia and rubber dam isolation by three postgraduate students, constantly supervised by an assistant professor at the Department.

2.2 Data collection

For all eligible patients, information regarding demographic characteristics of the patients, type of VPT performed, root developmental stage and type of final restoration were retrieved from electronic records. Intra-oral photographs and radiographs were used to evaluate restoration quality and record reason for failure and need for re-treatment at 6 and 12-months post-treatment follow-ups. All evaluations were performed independently by two previously calibrated (Inter-examiner reliability: $k = 0.82$, intra-examiner reliability: Intra-class coefficient (ICC) = 0.93) qualified pediatric dentists that were blinded regarding patients' characteristics and VPT undertaken. Any discrepancies were resolved with discussion with a third pediatric dentist, an assistant professor in the clinic.

2.3 Assessment criteria of success

Restoration quality was evaluated using the Modified United States Public Health Service (USPHS) criteria, assessing marginal integrity and discoloration, secondary caries formation, gross fracture, color match, and anatomic form of each restoration. Each component was rated as ideal (Alpha), clinically acceptable with minor defaults (Bravo) or clinically unacceptable (Charlie). Overall success was considered if all components were rated as either A or B, while restorations with at least one C in any component were considered a failure. Radiographic success was evaluated using two additional criteria, proximal contact and alveolar bone resorption, as both are key indicators of caries risk and periodontal health [15].

2.4 Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 27.0 (IBM Corp., Armonk, NY, USA). The distribution of clinical and radiographic characteristics was investigated at baseline, and 6- and 12-months post-treatment. Continuous variables were presented as mean ± standard deviation (SD) and categorical variables as frequencies (n) and percentages (%). Significant correlations between characteristics at various time intervals were investigated by χ^2 and Fisher's exact test and associations between development of a minor or major default and patient and tooth-related

characteristics by multivariate regression analysis. A *p*-value of less than 0.05 was considered as statistically significant.

3. Results

3.1 Sample characteristics

Forty-two first permanent molars from 35 patients with a non-contributory medical history (15 males and 20 females) with a mean chronological age of 10.6 years were evaluated. Majority were from the upper arch (54%), had closed apices (64%), had undergone pulpotomy (74%) and were sealed with PMCs (71%) (Table 1).

TABLE 1. Descriptive statistics of sample characteristics at baseline (N = 42).

Characteristics	Descriptive measure
Age (yr) (mean (SD))	10.6 (2.23)
Gender (boy: n (%))	21 (50%)
Dental arch (n (%))	
Upper	23 (55%)
Lower	19 (45%)
Root developmental stage (n (%))	
Closed apex	27 (64%)
Open apex	15 (36%)
Vital pulp therapy (n (%))	
Direct pulp capping	11 (26%)
Pulpotomy	31 (74%)
Final restoration (n (%))	
Composite resin	8 (19%)
Onlay	4 (10%)
Pre-formed metal crowns	30 (71%)

SD: standard deviation.

3.2 Treatment outcome

All restorations demonstrated a favorable performance (Fig. 1), with success rates exceeding 75% at all time intervals (Table 2). Success rates of PMCs and adhesive restorations (including both composite resin restorations and onlays) were 90% and 83% respectively, 6-months post-treatment, difference that was not considered significant. At 12-month success rates decreased slightly but non significantly ($p = 0.4$) or both types of restorations (83% *vs.* 75%, respectively). The overall good performance of the materials is also demonstrated by the flatter slope of the Kaplan-Meier curve (Fig. 2).

Table 3 presents clinical performance of all different parameters assessed for each restoration at 6 and 12 months. A trend towards higher performance of PMCs across most parameters was evident, with the differences though not reaching statistical significance. PMCs showed major defaults regarding marginal adaptation and proximal contact while adhesive restorations also regarding secondary caries formation and marginal discoloration.

3.3 Need for retreatment

Retreatment was required in eight restorations overall (19%). In most cases a repeat or repair of the same type of restoration was performed, while in only case an adhesive restoration had to be replaced by a PMC. Specifically, at 6 months two PMCs had to be replaced due to poor fit and adaptation (Fig. 3) and two adhesive restorations due to secondary caries formation, which in one case lead to pulp necrosis (Fig. 4). The tooth was then endodontically treated and restored with a PMC. At 12 months, another two PMCs and two adhesive restorations required replacement due to clinically unacceptable proximal contacts.

3.4 Correlation with patient- and tooth-related characteristics

Tables 4 and 5 present the effect of different patient and tooth-related factors on the development of any default at 6 and 12-month post-treatment, respectively. None of the factors seem to significantly affect the outcome at any time point.

4. Discussion

The present study compared the success rates of different restorative interventions in posterior permanent teeth that had previously undergone VPT. In an attempt to compare longevity of materials that do not fully cover the tooth and depend on chemical substances for adhesion with those that compensate for the extensive tooth loss the study tried to highlight the importance of a good coronal seal for the outcome of VPT.

Overall, both types of restorations performed equally well, with PMCs showing slightly higher success rates over time compared to adhesive restorations, with differences not being statistically significant. Failure of adhesive restorations was primarily linked to loss of marginal integrity and secondary caries formation, with the latter being the only statistically significant factor. Finally, none of patient- and tooth-related factors showed a direct influence on the outcome even 12-months post-treatment.

The demonstrated preference of PMC has been previously highlighted, as they are commonly used in severely compromised permanent molars due to their full coverage and mechanical properties [16]. This is further supported by their high success rates as a sealing material after VPT, with results of the present study being in accordance with previous ones indicating success rates exceeding 85% [8, 16]. Chaipattanawan *et al.* [17], supported their suitability, however their longevity is limited and may necessitate replacement long-term. According to a recent systematic review and meta-analysis of the American Dental Association Council regarding the effect of different direct restorative materials used to treat cavitated caries lesions on vital permanent teeth, it was concluded that there is limited evidence and of moderate to very low quality to support significant differences between direct restorative materials used in practice [18].

Similarly, the high overall success rate of adhesive materials reported in the present study is supported by the results of a recent systematic review showing that bonded partial indirect posterior restorations had better survival rates over vital teeth

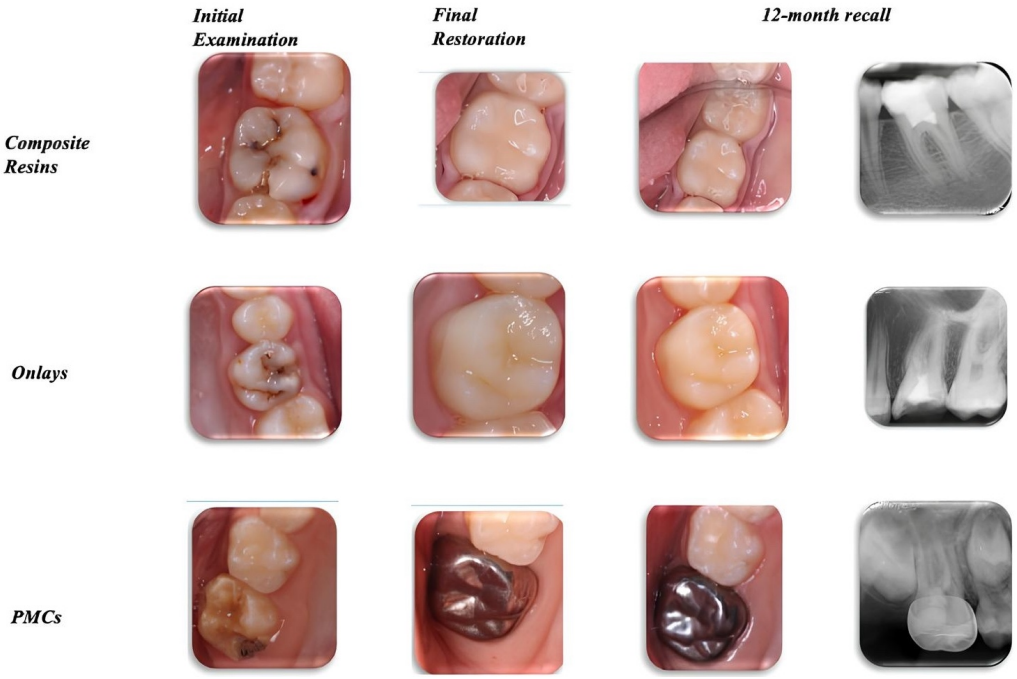

FIGURE 1. Initial clinical pictures confirming deep caries, followed by clinical pictures and radiographs following restorative interventions and at 12-months follow-up. PMCs: Preformed metal crowns.

TABLE 2. Clinical success after 6 and 12 months, by restoration.

	Preformed metal crowns n (%)	Adhesive restorations n (%)	*p* value*
6-months			
Success	27 (90%)	10 (83%)	0.7
Failure	3 (10%)	2 (17%)	
12-months			
Success	25 (83%)	9 (75%)	0.4
Failure	5 (17%)	3 (25%)	

*χ^2 *and fisher's exact test.*

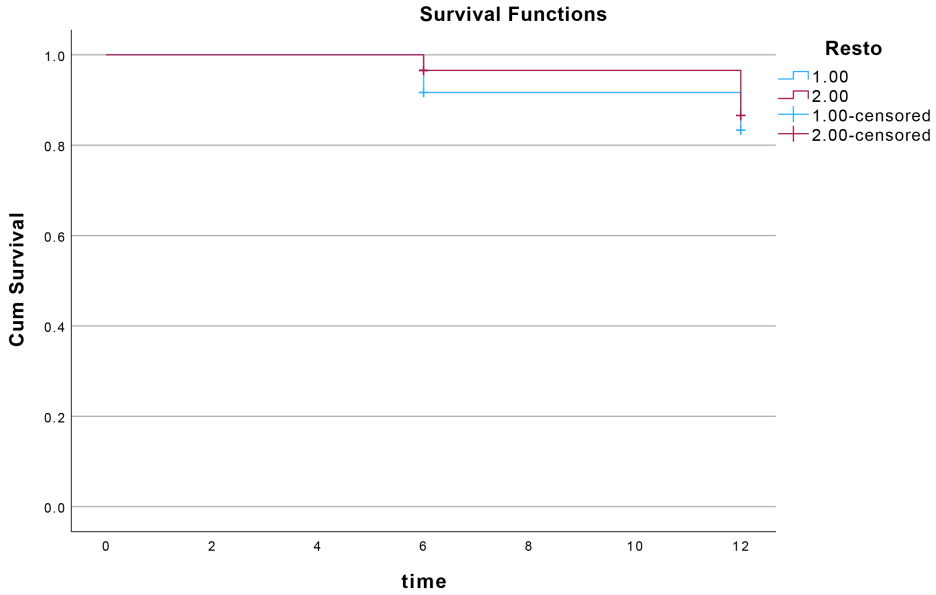

FIGURE 2. Kaplan-Meier survival analysis.

TABLE 3. Pairwise comparison between adhesive restorations and PMCs at follow-up.

Criteria	Time interval 6 months (n (%))		Time interval 12 months (n (%))	
	Adhesive Restoration	Preformed metal crowns	Adhesive Restoration	Preformed metal crowns
Marginal integrity/Adaptation				
Alpha	5 (42%)	18 (60%)	5 (42%)	18 (60%)
Bravo	6 (50%)	10 (33%)	5 (42%)	9 (30%)
Charlie	1 (8%)	2 (7%)	2 (16%)	3 (10%)
p-value*	0.39		0.45	
Gross fracture				
Alpha	10 (83%)	30 (100%)	10 (83%)	30 (100%)
Bravo	2 (17%)	0 (0%)	2 (17%)	0 (0%)
Charlie	0 (0%)	0 (0%)	0 (0%)	0 (0%)
p-value*	0.42		0.29	
Secondary caries				
Alpha	10 (84%)	30 (100%)	9 (75%)	30 (100%)
Bravo	1 (8%)	0 (0%)	2 (17%)	0 (0%)
Charlie	1 (8%)	0 (0%)	1 (8%)	0 (0%)
p-value*	0.35		0.08	
Color match				
Alpha	7 (58%)		7 (58%)	
Bravo	5 (42%)	N/A	5 (42%)	N/A
Charlie	0 (0%)		0 (0%)	
p-value	-		-	
Anatomic contour				
Alpha	11 (92%)		9 (75%)	
Bravo	1 (8%)	N/A	3 (25%)	N/A
Charlie	0 (0%)		0 (0%)	
p-value	-		-	
Marginal discoloration				
Alpha	8 (67%)		7 (58%)	
Bravo	4 (33%)	N/A	3 (25%)	N/A
Charlie	0 (0%)		2 (17%)	
p-value	-		-	
Proximal contact				
Alpha	12 (100%)	25 (84%)	11 (92%)	24 (80%)
Bravo	0 (0%)	4 (13%)	1 (8%)	4 (13%)
Charlie	0 (0%)	1 (3%)	0 (0%)	2 (7%)
p-value*	0.32		0.71	

χ^2 and Fisher's exact test. N/A: non-applicable.

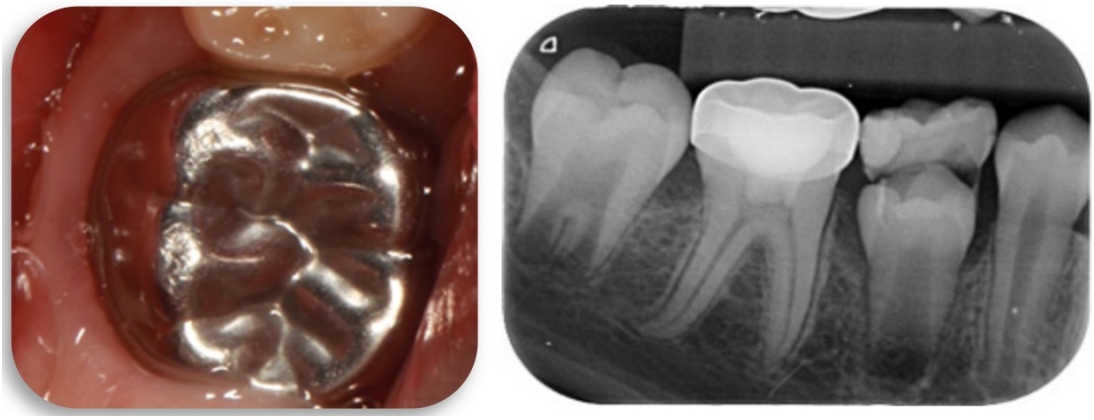

FIGURE 3. Clinical and radiographic pictures at 6-months follow-up, indicating a failure of the intervention due to poor fitting and adaptation of a PMC.

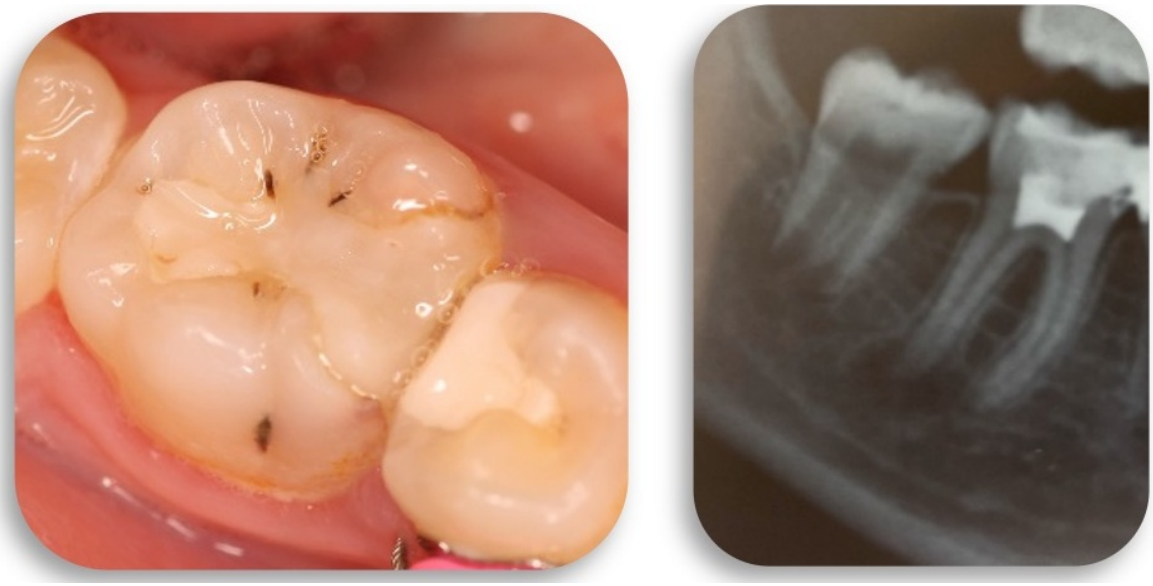

FIGURE 4. Clinical picture of a resin restoration that failed at 12-months post-treatment due to poor marginal adaptation and secondary caries formation, further underlined by a periapical radiolucency in the distal root seen radiographically.

TABLE 4. Results of multivariate regression analysis for developing any default at 6-months post-treatment.

	Unstandardized Coefficients		Standardized Coefficients		*p*-value	Collinearity Statistics	
	B	SE	Beta	*t*		Tolerance	VIF
(constant)	0.046	0.225		0.205	0.84		
Age	0.013	0.102	0.022	0.127	0.90	0.913	1.095
Gender	0.006	0.102	0.010	0.056	0.96	0.914	1.094
Dental arch	0.020	0.107	0.034	0.189	0.85	0.847	1.180
Vital pulp therapy	−0.011	0.130	−0.016	−0.085	0.93	0.734	1.362
Restoration	0.023	0.120	0.035	0.189	0.85	0.809	1.236

B: exponential value of B; SE: standard error; VIF: Variance Inflation Factor.

TABLE 5. Results of multivariate regression analysis for developing any default at 12-months post-treatment.

	Unstandardized Coefficients		Standardized Coefficients		*p*-value	Collinearity Statistics	
	B	SE	Beta	*t*		Tolerance	VIF
(constant)	4.313	0.225		0.204	0.82		
Age	1.085	0.102	0.026	0.126	0.89	0.813	1.093
Gender	1.577	0.102	0.014	0.054	0.94	0.910	1.095
Dental arch	2.095	0.107	0.041	0.186	0.83	0.857	1.179
Vital pulp therapy	−1.891	0.130	−0.018	−0.084	0.65	0.764	1.354
Restoration	2.665	0.120	0.034	0.189	0.34	0.819	1.246

B: exponential value of B; SE: standard error; VIF: Variance Inflation Factor.

compared to non-vital teeth [19]. The insignificant decrease in success rates overtime though has been previously suggested by Burke *et al.* [20], who concluded that adhesive restorations had lower performance rate long-term with the main reasons for failure, being fractures and secondary caries formation. In vital teeth, despite the higher dentin moisture and resilience that can improve bonding effectiveness of adhesion; however, inadequate coronal seal may still cause marginal degradation, fractures, or secondary caries [21].

The insignificant difference in the success rates found between the groups shown is partly in agreement with previous studies. A recent systematic review with meta-analysis showed no differences in the longevity between indirect and direct adhesive restorations 36 months post-treatment regarding sec-

ondary caries formation, marginal integrity, and discoloration [4]. On the other hand, other studies have reported slight marginal discoloration following direct composite restorations [22], attributed mainly to the restorative materials and the adhesion protocols that vary among studies increasing their heterogeneity.

Regarding the main reason for failure, secondary caries formation and poor marginal adaptation were reported in the present study. This can be attributed to several factors, including polymerization shrinkage during adhesive technique, size of restoration, as well as isolation challenges, especially in the pediatric population [22]. Shrinkage stain and stress along with cavity design (C-factor) of the composite materials are still major parameters affecting marginal adaptation (internal and external) of the restoration. This is clearly indicated by the currently released materials with additional-fragmentation monomers to compensate for shrinkage. This problem exists even with bulk-fill liners/restorative materials for which improved adaptation has been observed when placed incrementally [23, 24].

The findings though are supported by the results of the study by Chaipattanawan *et al.* [25], showing that marginal ridge was the most common fracture location of permanent molars restored with composite resins, following VPT. Similarly, an increased risk of adhesive restoration failure, in high-caries risk individuals and especially in those with a greater number of restored surfaces has been reported [26, 27]. This underlines the decreased resistance to masticatory forces of teeth following increased tissue removal and decreased amount of available tissue for adhesion and strong bonding.

Regarding reasons for failure of PMCs, several studies suggest cementation of oversized crowns in adolescent permanent molars that compromised adaptation and produced eruption interference [25, 28]. In children choosing and adapting the right PMC might be further compromised given limited cooperation and restricted access especially in the posterior region of first permanent molars. Poor marginal adaptation creates space for bacterial microleakage which can further cause pulpal inflammation directly affecting the longevity of the restoration [29]. These findings collectively support the notion that early identification of clinical and radiographic signs such as marginal breakdown, crown misfit, or interproximal bone loss are pivotal in minimizing the risk of irreversible pulpal complications [28, 30].

In terms of correlation between patient and tooth-related factors there was no significant association detected. Evidence in the literature is limited, with some studies suggesting a positive influence on the survival of restoration due to the high healing potential of the pulp [5, 21, 31]. Although other studies report higher failure rates in older children, suggesting that increased occlusal forces, increased structural loss, or delayed treatment may adversely affect the likelihood of achieving a successful outcome [25].

5. Strengths and limitations

Up to date, majority of the studies focus on the long-term survival of restorations in endodontically treated teeth, while this retrospective study is one of the first evaluating the success rate of PMCs and adhesive restorations in permanent teeth that have undergone VPT. However, there are a few limitations, with the main being selection bias and the relatively small sample size due to predefined strict inclusion criteria. Accurate and complete documentation was used to create the database, limiting the sample size. A notable limitation of this study is the absence of detailed information on the materials used for pulpotomy or pulp capping, which may affect treatment outcomes and constrain the generalizability of the findings. Another limitation is the unequal distribution of cases between treatment groups, reflecting the high caries prevalence in our country and the increased tooth structure loss in affected teeth and supports the choice of PMCs. The smaller number of adhesive restorations may have limited the ability to detect statistically significant differences between groups. Moreover, due to its retrospective nature, there is difficulty in controlling other cofounding variables, such as diet, oral hygiene, and caries risk assessment factors, that can affect the outcome. Further investigations through prospective studies with larger sample sizes, extended follow-up periods, and control of potential confounding factors (*e.g.*, diet, oral hygiene, caries risk) are warranted to more accurately determine the long-term success of different restorative treatment protocols in permanent teeth following VPT.

6. Conclusions

Within the limitations of the present study, both types of restorative interventions demonstrated a favorable performance at the 6-months post treatment, with a slight but non-significant decrease in that of adhesive restorations at 12-month. The only significant reason for failure was secondary caries formation for adhesive restorations, while none of the patient- and tooth-related factors seemed to significantly affect the outcome. Therefore, results are promising for long-term success of both restorative interventions, although they should be confirmed by further prospective studies.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

KS and SG—designed the research study. AG, KC, PTK and KS—performed the research; wrote the manuscript. KS and SG—provided help and advice on the conduction of the study. AG, KC, KS—analyzed the data. All authors contributed to editorial changes in the manuscript. All authors read and approved of the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The research protocol was approved by the Ethics Committee of the School of Dentistry, National and Kapodistrian University of Athens (NKUA), Greece (No. 665/23.10.2024). In the

decision and given the retrospective design of the study it was stated that the need for patient consent has been waived.

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CONFLICT OF INTEREST

The authors declare no conflict of interest. Sotiria Gizani is serving as one of the Editorial Board members of this journal. We declare that Sotiria Gizani was not involved in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to MP.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jocpd.com/files/article/2028735812890181632/attachment/Supplementary%20material.docx.

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