Clinical Performance of 3D Printed Resin Composite Posterior Fixed Dental Prosthesis: A Permanent Solution?

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ABSTRACT

Objectives: This clinical trial aimed to evaluate the clinical outcomes of 3D-printed resin composite posterior fixed dental prosthesis (FDP) restorations. Materials and Methods: Between October 2020 and August 2022, 49 patients (33 females, 16 males, aged 19-60) received 68 3-unit 3D-printed resin composite posterior FDPs (ELS Even Stronger, Saremco, Switzerland). Follow-ups were conducted at baseline (2 weeks) by independent observers using modified FDI criteria, assessing anatomical form, marginal adaptation, surface roughness, color match, fracture, retention, and patient feedback. Fifty FDPs completed a 1-year follow-up, and 18 reached 2 years. Results: The mean observation period was 14.15 months. Failures were categorized as mechanical or biological, with 19 FDPs failing: 14 mechanical (12 cohesive fractures) and 5 biological (3 needing endodontic treatment, 2 periodontal issues). Two FDPs were recemented. Three FDPs showed surface luster loss, color mismatches, and staining. The survival rate based on mechanical failures was 69.5%, dropping to 61.0% when including biological complications. Conclusions: After 2 years, 3D-printed resin composite FDPs demonstrated acceptable performance, with most failures due to fractures in the connector region, suggesting the need for design revisions.

INTRODUCTION

Today's modern dentistry aims to restore the lost tooth function with new materials and technologies that are offered to dental clinicians' day to day, with the motivation to fulfill the increasing aesthetic expectations of the patients. Three-unit fixed dental prostheses (FDPs) are a frequent prosthetic treatment for the functional and aesthetic replacement of lost teeth[1-3]. Traditionally, full metal and/or ceramic FDPs have been successfully used in prosthetic dentistry for many decades. The introduction of metal-free FDPs allows dental clinicians to better reproduce natural tooth structures, avoiding the optical disadvantages of metal-ceramic restorations. With the introduction of digital technology "computer-aided design and computer-aided manufacturing (CAD/CAM)" to dentistry, ceramic and resin composites started to be preferred in the fabrication of FDPs using subtractive or additive technologies in routine clinical procedures[4-5]. Compared to traditional prosthetic treatments, CAD/CAM systems do not include error-prone procedures such as impression, casting, and wax modeling. CAD/CAM systems, based on subtractive manufacturing (milling)

principles that produce reliable restorations, work by cutting solid blocks into the desired shape, causing material waste and additional costs for milling tools. Considering the disadvantages related to the subtractive technique, additive manufacturing / three-dimensional (3D) printing techniques have gained popularity nowadays. Additive manufacturing (3D printing) is more economical and minimizes material waste resulting from the milling process. In addition, additive manufacturing can enable the production of more complex structures compared to subtractive milling systems[6]. This technique builds the object layer by layer with fewer restrictions for three-dimensional geometric shaping[7] and includes Stereolithography (SLA), Digital light processing (DLP), Selective Laser Sintering (SLS), and Fused Deposition Modelling (FDM) technologies[8]. 3D printable resin composite materials are typically built up layer by layer using DLP (digital light processing) technology[7]. The increasing invasiveness of digital technology in dentistry has led to 3D printing being preferred in different treatment processes such as orthodontic devices, surgical guides, implants, and restorative procedures[9]. These rapid developments in 3D printing technologies and materials have increased interest in new printable resin composites for the production of permanent indirect restorations[10].

Given the benefits of resin composites, including their lower brittleness compared to ceramics, reduced wear on opposing teeth, and ease of in-mouth repairs, the literature highlights their promising clinical performance[11]. Indirect resin composite restorations show great potential for adhering to biomimetic principles of tissue preservation.[12,13]. However, to date, CAD/CAM resin composite materials are generally limited to single-tooth restorations as a permanent treatment alternative[14]. There exists thus the question whether resin composite 3D printed restoration materials might be appropriate alternatives for the indication of three-unit FDPs. There are some studies in the literature evaluating the success of different prosthetic restorations under *in vitro* conditions[4,7,15] but the reports on the clinical performance of FDP materials are scarce.

This study aims to fill the gap in clinical research by evaluating the 2-year clinical success of 3D-printed resin composite posterior fixed dental prostheses (FDPs). Despite their potential advantages in routine restorative procedures, the clinical performance of 3D-printed resin composite FDPs has not been extensively studied. Therefore, this research specifically investigates their long-term suitability in posterior restorations.

MATERIALS AND METHODS

STUDY DESIGN

This clinical study was carried out in the Department of Prosthetics Dentistry, Medipol University, Dental School, Istanbul, Turkey, and approved by the Republic of Turkey Ministry of Health Turkish Medicines and Medical Devices Agency (Vote number of the Regulatory Ethical Committee No: 68869993-511.06-E.150622; Clinical Trials. Gov Identifier: NCT04600297). The properties, brands, and manufacturers of the materials used in this study are listed in Table 1. Between 10.10.2020 - 05.08.2022, 68 3D printed resin composite 3-unit posterior FDPs were performed in 49 patients aged between 19-60 years (33 females, 16 males, mean age: 42.5, with at least one 3-unit FDP indication) in the posterior region of the maxilla or mandible. This study adapts the principles of the Declaration of Helsinki.

PATIENT RECRUITMENT

The inclusion and exclusion criteria for this clinical observation are listed in Table 2. Two operators independent of the study's objectives agreed to recruit the patients who required an FDP. Before starting the treatment procedures, each patient included in the study was informed in detail about the alternative treatment procedures, and their informed consent was obtained. The preoperative properties of the supporting teeth and gingival tissues of the individuals included in the study were evaluated in detail based on certain criteria, and the viability and radiographic evaluations of the existing teeth for which prosthetic restorations were planned were completed.

Table 1. The brand, type, manufacturer and chemical composition of the main materials used in this study.

Brand	Type (Batch)	Manufacturer	Chemical Composition
ELS even stronger	3D printed resin composite	Saremco, Rebstein, Switzerland	bisphenol A diglycidyl methacrylate ethoxylated, Urethane-dimethacrylate, Trimethylbenzonyldiphenylphosphine oxide; anorganic fillers: dental glass silica
Variolink Esthetic DC	Resin cement	Ivoclar Vivadent, Schaan, Liechtenstein	bisphenol A diglycidyl methacrylate, urethane dimethacrylate, triethylene glycol dimethacrylate; inorganic fillers: barium glass, ytterbium trifluoride, Barium-Aliminium-fluorosilicate glass, spheroid mixed oxide, initiators, stabilizers, pigments. Syntac primer: triethyleneglycol methacrylate, polyethyleneglycol dimethacrylate, maleic acid, ketone; syntac adhesive: polyethyleneglycol dimethacrylate, glutaraldehyde. Heliobond: bis-GMA, triethyleneglycol dimethatcrylate, stabilizers, initiators

Table 2. The inclusion and exclusion criteria considered in the clinical trial.

Inclusion criteria	Exclusion criteria
Subjects had to be over the age of 18 and agree to keep the scheduled recall appointments for data collection and maintenance and plan to stay in the area for at least 3 years.	Subjects suffering from general health impairment or were pregnant during the duration of the study
Subjects had to agree to keep the scheduled recall appointments for data collection and maintenance and plan to stay in the area for at least 3 years.	Subjects who are known to be allergic to the ingredients of resin materials
Subjects withouth obvious untreated caries, dental health problems (regularly checked by a dentist)	Subjects who were restored with a removable partial dental prosthesis (RPDP), unless the RPDP replaced the tooth that was planned to be restored in the study
Subjects with good or moderate oral hygiene (plaque score of less than 30% in anterior region before treatment), No untreated periodontal disease (probing depth and attachment levels within normal limits, no furcation involvement, and no mobility)	Subjects who presented with severe wear facets and/ or reported parafunctional activities such as clenching or nocturnal bruxism. Patients who report parafunctional activities such as clenching or nocturnal bruxism after the delivery of the restoration will also be excluded
Subjects who need for a three-unit posterior FDP* with one missing tooth from the second premolar to the second molar	Subjects with considerable periodontal disease without treatment (DPSI3-,3+and4)
Only FDPs with opposing natural dentition (either intact or restored with intracoronal or extracoronal fixed restorations), and with a minimum of 20 teeth)	The abutment of FDPs with considerable horizontal and/or vertical mobility of teeth: tooth mobility index score 2 or 3,
Only FPDs with end abutments (No cantilever) and sufficient length of the clinical crown of abutments must be over 5 mm	The abutment of FDPs with extensive loss of tooth tissue due to endodontic treatment
Only FPDs with abutment teeth are vital or endodontically treated with a sealed root filling to the apical region, and have to be without apical periodontitis for the past 6 months.	

CLINICAL PROCEDURES

The treatments were carried out by two operators (P.H., T.O.) who have experience in prosthetic dentistry. Preparation of the teeth was carried out according to the manufacturer's recommendations. The preparation guidelines were applied to the abutment teeth for replacing missing tooth with the 3D printed resin composite posterior FDP where the tooth preparation allowed 1.5 mm thickness overall with chamfer finish lines. The distance difference between the centers of the abutment teeth was applied as maximum of 20 mm. The minimum occlusal thickness was 1.5 mm, and the mesial and distal connector sizes were prepared as minimum 16 mm^2. The connector size dictates the pontic design and is designed as a modified ridge-lap per the request of the patients. The supragingival or slightly subgingival margins of the preparations respected the biologic width. Digital impressions were acquired using an intraoral scanner (TRIOS 3, 3Shape, Copenhagen, Denmark). The intraoral scanning procedure was performed according to the manual. Resin composite FDPs ELS Even Stronger (Saremco, Rebstein, Switzerland) were designed using Trios Design Studio and sent to the printer (MAX UV, Asiga, Michigan, USA) via a software (Asiga Composer Software). All resin composite FDPs were checked for marginal fit, inter-proximal contact, and occlusion before cementation. They were then steam-cleaned, dried, washed with isopropanol, and polished according to the manufacturer's recommendations. Photo-polymerization was performed with a polymerization device (Otoflash G171, Nk Optic, Baierbrunn, Germany) according to the manufacturer's recommendations. The resin composite FDPs were cemented using an adhesive resin cement (Variolink Esthetic DC, Ivoclar Vivadent, Schaan, Liechtenstein). Cotton rolls were used to manage salivation and gingival fluid during adhesive placement. Adhesive pre-treatment of the teeth was applied using 37% orthophosphoric acid (Ivoclar Vivadent) and a dental bonding system (Adhese Universal, Ivoclar Vivadent). After air-abrasion with aluminum oxide (grain size: 50 µm, pressure: 2.5 bar), silane (Monobond Plus, Ivoclar Vivadent) was applied to the intaglio. The resin composite FDP was adhesively placed. Excess luting material was removed and the margins of the resin composite FDPs were covered with a protective layer (Liquid Strip, Ivoclar Vivadent) for 8 min. After polymerization, excess luting material was completely removed.

CLINICAL EVALUATION

Two independent, calibrated clinicians with more than 15 to 20 years of clinical experience performed the baseline evaluations 15 days after the cementation of the FDPs. The e-calib system (www.e-calib.info) was used for calibration between observers in this research and was accepted as a minimum of 80% intra-agreement[16,17]. The follow-up of FDPs were done 2 weeks (baseline), 1 year and 2 years after placement by two independent calibrated observers using modified FDI criteria for anatomical form, secondary caries, marginal adaptation, surface roughness, colour match, fracture of material, staining surface, staining margin, approximate anatomical form, retention, gingival health, and patient's view. After the controls were completed, the patients were asked whether they were satisfied with the aesthetic result and functionality of their FDPs, and patient responses (yes/no) were recorded. The patients were informed to call in case of any complaints about the performed restorations. Failure types were categorized as mechanical and biological ones.

STATISTICAL METHODS

Data were statistically analyzed with a statistical software (IBM SPSS Statistics for Windows, version 25.0, NY, USA). Qualitative data were recorded in scores and their frequency in percentage. Comparisons of data were performed using Mc Nemar and marginal homogeneity tests and two-tailed significance level was considered as 0.05. Survival analyses were performed using Kaplan-Meier. Log Rank (Mantel-Cox) tests were used to obtain the cumulative survival rates in relation to observation time.

RESULTS

Both operators performed similar numbers of 3D printed resin composite 3-unit posterior FDPs (P.H. n=33; T.O, n= 35). Sixty-eight, 3D FDPs were cemented in 49 patients. The distribution of the FDPs per location according to the FDI numbering system is presented in Table 3. The mean observation period was 14.15 months (min: 11.20; max: 32.03 months). During this observational study, 18 FDPs completed the 2-year follow-up period, whereas 50 FDPs completed the 1-year control period *(Figures 1 a-e)*. In the evaluations, a total of 19 FDPs were found

Table 3. Distribution of the 68 FDPs regarding location of the replaced teeth according to FDI numbering system.

Replaced tooth	16	15	25	26
Number of FDPs	5	7	4	2
Replaced tooth	46	45	35	36
Number of FDPs	19	2	4	25

*Fixed Dental Prothesis

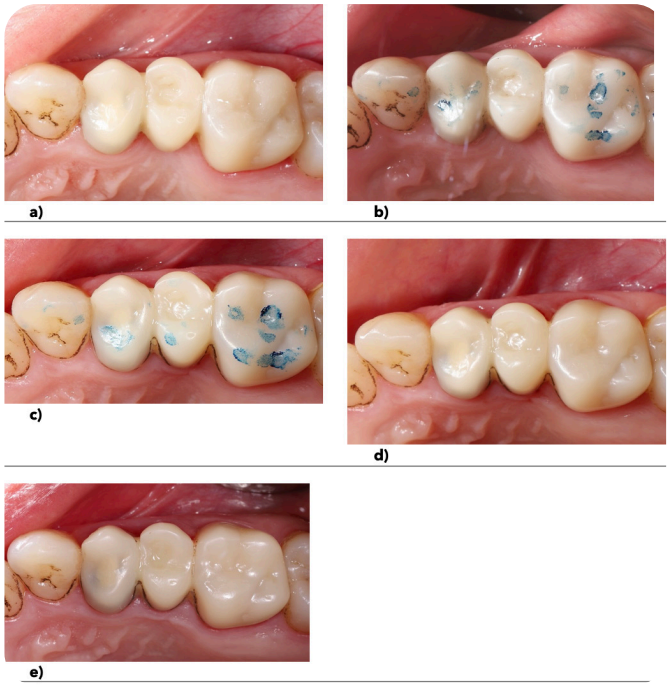

Figure 1a-e: Representative clinical photos of a 3-unit resin composite FDP between 14-16 a) at cementation, b) at baseline, c) at 6 months d) at 1 year, e) at 2 years.

to be clinically unsuccessful. When the failures were classified as biological and mechanical, 5 biological failures and 14 mechanical failures were encountered *(Table 4)*. The observed biological failures occurred within the first six months with the need for root canal treatment and gingival tissue damage. Three patients complained with pain and diagnosed with irreversible pulpits at 2-, 4- and 9-months following treatment. The restorations were removed, and root canal treatment was performed on those teeth. The restorations were adhesively fractured during the removal, and as a result, new FDPs were fabricated. Two of the resin composite FDPs presented gingival problems that could not be accepted as clinically successful and needed replacement. In the intraoral evaluation of the patients, bleeding was observed in the gingiva along with gingival recession buccally *(Table 5)*. Mechanical failures were generally observed as connector fractures. Twelve FDPs showed cohesive fractures of which 11 were in one connector either in mesial or distal site only and 1 in the pontic itself *(Figures 2 a-d)*. Eight of these fractures were observed during the 6-month follow-up period, 3 were detected during the 1-year follow-up period and 1 was observed after 2 years in clinical service. Failure types mainly associated with fractures in the connector region require revision of design parameters. Two FDPs showed loss of retention within the 6-month and 1-year control periods. Based on mechanical failures, the survival rate was 69.5% (95% CI: 46.6% -92.4%) and when biological complications were included, the survival rate corresponded to 61.0% (95% CI: 40.0% -83.9%) (Kaplan-Meier) *(Figures 3 a-b)*.

Considering the anatomic forms of the resin composite FDPs, it was determined that almost all restorations were in normal anatomical contour during the follow-up period with

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Table 4. Clinical criteria according to the modified FDI criteria.

	Anatomical form	Approximal anatomical form (contact point)	Secondary Caries	Marginal Adaptation	Surface Luster	Colour Match	Fracture of material	Gingival Health (Mesial/ Facial/ Distal)	Staining Surface	Staining Margin	Retention	Patients view
1- Clinically very good/ excellent	Normal contour	Normal contact point (floss or 25 mm, metal blade can pass)	No secondary or primary caries	Harmonious outline, no gaps, no white or discolored lines	Luster comparable to enamel	Good color match	No fracture	No plaque, No inflammation, No pockets	No surface staining	No marginal staining	Retentive	Entirely satisfied with esthetics and function
2-Clinically good	Slightly deficient contour	Contact slightly too strong but no disadvantage (floss or 25 mm metal blade can only pass with pressure)	Small and localized	Marginal gap (<150 mm), white lines	Slightly dull, not noticeable from speaking distance	Minor deviations in shade	Small hairline crack	Little plaque no inflammation (gingivitis), no pocket development	Minor surface staining, easily removable by polishing	Minor marginal staining, easily removable by polishing		Satisfied esthetic and function
3- Clinically sufficient / satisfactory	Visibly deficient contour	Somewhat weak contact, no indication of damage to tooth, gingiva or periodontal structures; 50 mm metal blade can pass	Larger areas Only preventive measures necessary	Gap< 250 mm	Dull surface but acceptable if covered with film of saliva	Distinct deviation but acceptable. Does not affect esthetics	Two or more or larger hairline cracks and/or material chip fracture not affecting the marginal integrity of approximal contact	Difference up to one grade in severity of PBI compared to baseline and compared to control tooth	Moderate surface staining that may also present on other teeth, not esthetically unacceptable	Moderate marginal staining, not esthetically unacceptable		Minor criticism but no adverts clinical effects a-Esthetic shortcomings b-Some lack of chewing comfort c-Unpleasant treatment procedure
4- Clinically unsatisfactory (but reparable)	Inadequate contour. Repair possible	Too weak and possible damage due to food impaction; 100 mm metal blade can pass	Caries with cavitation. Localized and accessible. Can be repaired	Gap> 250 mm	Rough surface cannot be masked by saliva film, simple polishing is not sufficient. Further intervention necessary	Localized clinical deviation that can be corrected by repair	Material chip fractures which damage marginal quality or approximal contacts	Difference of more than one grade of PBI in comparison to control tooth or increase in pocket depth > 1mm requiring intervention	Unacceptable surface staining on the restoration and major intervention necessary	Pronounced marginal staining; major intervention necessary for improvement		Desire for improvement a-Esthetics b-Function e.g. Tongue irritation. Reshaping of anatomic form or refurbishing is possible
5-Clinicallv poor (replacement necessary)	Inadequate contour Requires replacement	Too weak and/ or clear damage due to food impaction and/ or pain/gingivitis	Deep caries that is not accessible for repair of restoration	Generalized major gaps or irregularities	Very rough, unacceptable plaque retentive surface	Unacceptable. Replacement necessary	(Partial or complete) loss of restoration or multiple fractures	Severe/ acute gingivitis or periodontitis	Severe surface staining and/ or subsurface staining, generalized or localized, not acceptable for intervention	Deep marginal staining, not accessible for intervention	Decementation	Completely dissatisfied and/or adverse effects, including pain

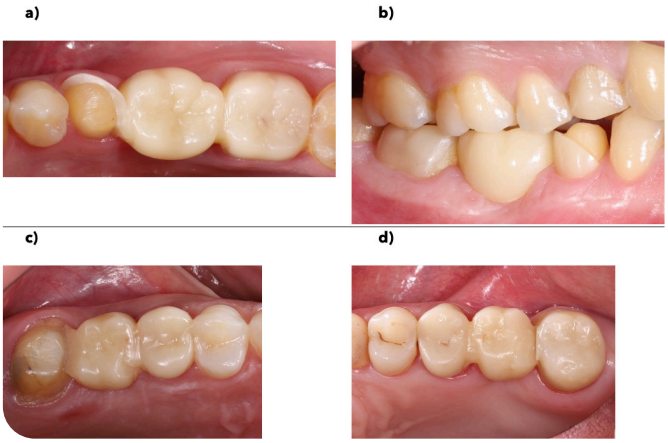

Figure 2a-d: Representative clinical photos from failures of 3-unit resin composite FDPs. a) occlusal view of the cohesive within material failure, b) buccal view of the cohesive within material failure, c) occlusal view of the connector failure, d) occlusal view of the connector failure.

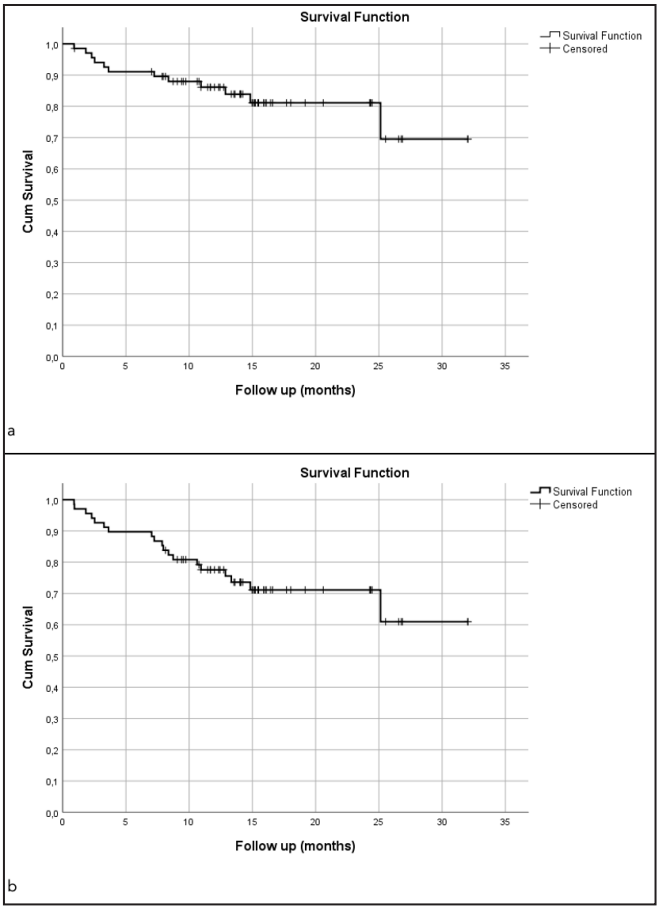

Figure 3a-b: Event-free survival rates of 3-unit resin composite restorations FDPs (n=68) with a) 69.5% (95% CI : 46.6% -92.4%) based on mechanical complications only, b) 61.0% (95% CI: 40.0% -83.9%) based on combined mechanical and biological complications.

3 restorations being acceptable and just 2 restorations being scored as "visibly deficient contour" according to modified FDI criteria, and all restorations had normal contact points. Dull surfaces were observed in 3 of the FDPs that completed two years clinically, and it was determined that two of them needed intervention by polishing intraorally and slightly dull surfaces were observed in 4 FDPs. Considering the color match of the resin composite FDPs with the existing hard dental tissues, localized clinical deviations were observed in 2 FDPs after 1 year, and 1 FDP after 2 years, due to the patients' smoking habit. According to the surface staining parameter, 2 resin composite FDPs at the end of 1 year, and 1 FDP after 2 years were observed stained as requiring intervention by polishing. However, these stains were also present in other teeth and the patients were satisfied with the aesthetic and function of their resin composite FDPs. Thus, the discolorations did not require intervention *(Table 6)*.

DISCUSSION

The idea that developments in resin composites, which are frequently applied in direct posterior restorations, create materials with improved mechanical properties day by day, has led to the question of whether resin composite 3D-printed restoration materials will be suitable alternatives for the indication of three-unit FDPs[16]. There are numerous *in vitro* studies testing the different properties of these materials however, no clinical publications are available in the literature[4,7,18]. Thus, this research aims to find an answer to the question of whether 3D-printed resin composite FDPs with their improved properties can provide a successful prognosis in the permanent treatment of single tooth deficiencies.

The failures encountered in this clinical study can be classified as mechanical and biological. According to the mechanical failures, the most common reason is the fractures observed in FDPs. When the clinical follow-ups were considered, 8 FDPs showed fractures after six months, 3 FDPs after one year, and 1 FDP after 2 years of clinical observation. Fractures were observed in 11 FDPs in just one connector on the mesial or distal side. In line with the findings of the present investigation, laboratory studies in the literature revealed that the cracks and fractures observed in FDPs originate from the gingival surface of the connector because the weak point under tensile load is towards the pontic[19]. In different clinical studies, it is observed that the most important reason for fracture of FDPs applied with CAD/CAM technology is associated with connector area dimensions[18,20].

In an *in vitro* study testing the fracture strength of ceramic and composite three-unit FDPs produced with subtractive and additive CAD/CAM technologies, ELS Even Stronger fabricated FDPs tested in the present study had the lowest fracture load[4]. In this aspect, the importance of connector thickness can be emphasized, and it is stated that the minimum connector cross-sectional area required to prevent fracture failures

Table 5. Life table of mechanical and biological failure types observed in the FDPs.

No	Failure type	Failure time	Failure reason	Failure case	Replacement tooth
1	Biological Failure	6 months	Gingival failure	45-47 FDP	Molar
2			Gingival failure	35-37 FDP	
3			Endodontic treatment	45-47 FDP	
4			Endodontic treatment	35-37 FDP	
5			Endodontic treatment	34-36 FDP	Premolar
6	Mechanical failure	6 months	Fracture (connector)	45-47 FDP	Molar
7			Fracture (connector)	45-47 FDP	
8			Fracture (connector)	35-37 FDP	
9			Fracture (connector)	45-47 FDP	
10			Fracture (connector)	35-37 FDP	
11			Fracture (Pontic)	45-47 FDP	
12			Fracture (connector)	35-37 FDP	
13			Fracture (connector)	35-37 FDP	
14			Retention loss	35-37 FDP	
15		1 year	Fracture (connector)	45-47 FDP	
16			Fracture (connector)	45-47 FDP	
17			Fracture (connector)	15-17 FDP	
18			Retention loss	45-47 FDP	
19		2 year	Fracture (connector)	34-36 FDP	Premolar

should be in the range of 12-16 mm^2 [1]. Such failures observed in the current study are cohesive fractures in the connector cross-sectional area. When the failures were considered in this study, it was determined that the replaced teeth were molars in 83.3% and premolars in 16.7% of the cases. These percentages can be associated with the information in the literature that molars are exposed to more occlusal forces than premolars. Because the average bite force applied to molars is around 800 N[20].

Another reason for mechanical failures observed in the present clinical study is the loss of retention. The reasons for the loss of retention mentioned in the literature are short clinical crowns, the luting agents, and the high technical sensitivity of adhesive procedures[21,22]. This type of failure, observed in two resin composite FDPs, can be associated with the larger taper angle in the old preparations in the present study.

According to the biological parameters, two resin composite FDPs needed to be renewed for gingival reasons and were considered as failures. The scoring of these restorations was made based on the Papillary Bleeding Index (PBI). Regarding the evaluation criteria, restorations that are scored with a difference of more than one grade in the Papillary Bleeding Index (PBI) compared to the control tooth, with an increase in pocket depth over than 1 mm, or representing severe/acute gingivitis or periodontitis required intervention. In the failed cases in this study, bleeding in the gums and gingival recession in the buccal regions were observed in the intraoral examinations of the patients. These failures may be related to the deep preparation protocol. It is possible to observe such problems due to the necessity of taking the old preparation as a basis in these FDPs, performed to renew old metal-ceramic prostheses. As a result, the observed gingival failures are related to the deep margin preparation for metal-ceramic replacements rather than the new FDPs applied. Apart from the subgingival finishing line, another factor that can cause plaque accumulation and indirectly gingival problems is the surface roughness of the restoration. Rough surfaces increase the initial attachment of bacteria to the provisional restorative materials by protecting them from saliva and masticatory forces[23].

Table 6. Distribution and percentage (%) of scores for resin composite FDPs (N=68) according to the FDI criteria that could be evaluated at 1 and 2 years.

	Criteria									
	1 year (50 FDPs)					2 years (18 FDPs)				
	1	2	3	4	5	1	2	3	4	5
Anatomical Form	45 (90%)	3 (6%)	2 (4%)	0 (0%)	0 (0%)	16 (88,8%)	1 (5,6%)	1 (5,6%)	0 (0%)	0 (0%)
Approximal anatomical form (contact point)	50 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	18 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Secondary Caries	50 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	18 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Marginal Adaptation	44 (88%)	5 (10%)	1 (2%)	0 (0%)	0 (0%)	16 (88,8%)	1 (5,6%)	1 (5,6%)	0 (0%)	0 (0%)
Surface Luster	43 (86%)	4 (8%)	1 (2%)	2 (4%)	0 (0%)	15 (83,3%)	1 (5,6%)	0 (0%)	2 (11,1%)	0 (0%)
Colour Match	42 (84%)	1 (2%)	0 (0%)	2 (4%)	0 (0%)	16 (88,8%)	1 (5,6%)	0 (0%)	1 (5,6%)	0 (0%)
Fracture of material	47 (94%)	0 (0%)	0 (0%)	0 (0%)	3 (6 %)	17 (94,4%)	0 (0%)	0 (0%)	0 (0%)	1 (5,6%)
Gingival Health	33 (66%)	11 (22%)	5 (10%)	1 (2%)	0 (0%)	13 (72,2%)	2 (11,1%)	2 (11,1%)	1 (5,6%)	0 (0%)
Staining Surface	46 (92 %)	2 (4%)	0 (0%)	2 (4%)	0 (0%)	16 (88,8%)	1 (5,6%)	0 (0%)	1 (5,6%)	0 (0%)
Staining Margin	43 (86%)	6 (12%)	1 (2%)	0 (0%)	0 (0%)	16 (88,9%)	2 (11,1%)	0 (0%)	0 (0%)	0 (0%)
Retention	49 (98%)	0 (0%)	0 (0%)	0 (0%)	1 (2%)	18 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Patients view	50 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	18 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

The production of resin composite FDPs with different thickness polymerization with the automatically selected parameters during the printing process DLP technology results in various mechanical characteristics such as different conversion degrees and related surface properties[23]. Since the emission of light on the incrementally added layers of monomer can influence the quality of the printed part, a lower thickness layering will be concluded with a better conversion degree and better mechanical and biological properties with a lower amount of plaque accumulation. In the present study, layers of 50-micron thickness were polymerized. In a different laboratory study, it was emphasized that 25-micron thickness produced more successful results[23]. Yet, 3D printers today are programmed so that the transition between the layers is smoothened, and the surface properties are significantly affected by the subsequent cleaning and post-polymerization processes. Thus, this aspect needs further investigation.

Apart from DLP technology, the monomer content of the resin composite material is also effective in the degree of conversion. The preferred ELS even stronger in this research contains bis-EMA as organic content. In the literature, it was mentioned that this monomer positively affected the degree of conversion of resin composites[24]. *In vitro* investigations showed mechanical and chemical degradations for CAD/CAM composite materials due to higher water uptake and thermal expansion compared with ceramic ones[25]. In total, three FDPs required polishing due to the surface roughness and surface staining after 1 year in clinical service. The discolorations were related to the patients' smoking habits but did not interfere with patients' satisfaction and thereby replacement of the FDPs.

The main purpose of dentistry is to keep the tooth alive, therefore minimally invasive restorations are considered a priority even in prosthetic approaches because maximum preservation of tooth tissues is very important in maintaining tooth vitality and reducing possible postoperative sensitivity. In the current study, endodontic treatment was applied to 3 abutment teeth due to postoperative pain complaints in the first six-month period. The restorations were removed, and root canal treatment was performed on those teeth. The restorations were adhesively fractured during the removal, and as a result, new FDPs were fabricated. Root canal treatment was required in two of the three cases, both of which involved renewing previous restorations to accommodate new 3D-printed FDPs. It has been reported in the literature that approximately 63% and 72% of the coronal tooth structure is removed during all-ceramic and metal-ceramic crown preparation[26]. However, it is also emphasized that 2 mm

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or more residual dentine protecting the pulp after preparation is a very important threshold[27]. In these two cases, the old preparations were corrected rather than the new preparation applied. However, it is known that the CAD/CAM technology, of which the method applied in this study, can be considered favorable for clinical practice as it prevents unnecessary tooth tissue removal[4]. Therefore, such a complication is likely to occur after revisions of preparations for metal-supported FDPs, and this may be considered as a result of repeated preparation of dental tissues rather than a failure of the new resin composite FDPs.

Adhesive procedures can be considered as one of the biggest challenges in FDPs where material loss is high, and the adherent surface is limited to dentin tissue. Luting resin cements used in these procedures are classified as etch-and-rinse, self-etch, and self-adhesive according to the tooth tissue pretreatment[28]. The acid-etch technique applied in the present study and the removal of the smear layer with this technique can be associated with post-operative sensitivity. In addition to the etch and rinse adhesive technique preferred in this study, the luting resin cement preferred in the current research is a dual cure system, and in the literature these types of cement show lower rates of failure when compared with the chemical cure ones[29]. Therefore, it can be anticipated that endodontic complications are more likely to result from old preparations than from adhesive strategies.

While there are studies on metal-supported FDPs in the literature, the indications of resin composite FDPs are generally limited to temporary restorations. It is not a distant future that resin composites, which are offered to dentists with their improved properties every day, are preferred for permanent FDPs. However, there is still no clinical observation of resin composite FDPs in the dental literature. A systemic review[2] of metal-supported prosthetic approaches estimated the clinical survival and described the failure characteristics for CAD/CAM tooth-supported zirconia- and lithium disilicate-based FDPs. In this review, failures observed for all-ceramic bridge restorations fabricated by the CAD/CAM procedure are associated with specific problems such as technical (chipping, loss of retention) or biological (secondary caries) complications, unlike the present study[2].

The frequency of failures observed in this study was evaluated in two categories. Among the fracture and retention loss criteria summarized as mechanical failure, only fracture can be directly associated with resin composite FDPs. Loss of retention and the biological failures explained by gingival problems and endodontic complications may be associated with other parameters in the treatment procedure rather than resin composite FDPs. The question of whether it is correct to directly associate these retention loss, endodontic complications, or gingival problems with the failure of 3D printed resin composite FDPs can be considered as a limitation of this research.

The results of this clinical investigation revealed that gingival failures are mainly associated with the deep margin preparation rather than the new FDPs. The inclusion of old prosthetic restoration renewal procedures in the study is a limitation in this regard. Different polishing techniques could potentially yield better results regarding plaque accumulation and gingival health, warranting further research in this area.

Further development of resin composite CAD/CAM materials will enhance the long-term clinical success of the prosthetic restorations and expand the application range. Current research sheds light on the question of whether these materials, or their possible improved forms, could be an alternative in permanent fixed prosthetic approaches. Long-term clinical follow up of the present study will indicate whether the tested resin composite material may serve as long-term provisional or even permanent restorative material for three-unit FDPs.

CONCLUSIONS

From this clinical study, the following conclusions could be drawn:

1. 3D printed resin composite FDPs with the tested resin composite material after a mean observation time of 14.15 months represent the failure types mainly associated with fractures in the connector region which requires revision of design parameters.
2. The 3D resin composite FDPs evaluated in this study exceeded the expectations from a temporary material and thus be considered as mid-term provisional restorations.
3. More prospective studies focusing on long-term performance of 3D printed resin composite FDPs are needed to strengthen the evidence currently available in the literature in order to find out whether they may serve as permanent FDP alternatives.

DECLARATIONS

AUTHOR CONTRIBUTION

PH, TO, AM and MÖ contributed to the conceptualization and methodology of the study. PH, TO and AM applied the restorations. FOB and TTA evaluated the restorations. PH took photos of the cases and prepared the figures. TTA and PH performed the literature research, interpretation of the data, and draft writing. The study design and manuscript writing were supervised by MÖ. All authors revised, validated, and edited the work. All authors agree to be accountable for all aspects of the study design and its content. All authors approved the final submitted version.

Ethics Approval and Consent to Participate
The study was approved by the Republic of Turkey Ministry of Health Turkish Medicines and Medical Devices Agency (Vote number of the Regulatory Ethical Committee No: 68869993-511.06-E.150622; Clinical Trials. Gov Identifier: NCT04600297). All participants provided written informed consent.

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CONFLICT OF INTERESTS

The authors declare no competing interests.

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