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Book

3. Mueller HJ, Freeman D. FT-IR spectrometry in materiolography. 2nd Ed., Ohio: American Society for Metal 1994, p.51-56.

Chapter in a book

4. Alexander RG. Considerations in creating a beautiful smile. In: Romano R, editor. The art of the smile. London: Quintessence Publishing, 2005, p.187-210.
5. Hudson FB, Hawcroft J. Duration of treatment in phenylketonuria. In: Seakins J, Saunders R, editors. Treatment of inborn errors of metabolism. London: Churchill Livingstone, 1973, p.51-56.

Thesis

6. Maden I. Effect Of Nd:YAG Laser Treatment In Addition To Scaling And Root Planning. Doctoral Dissertation, Istanbul University Institute of Health Sciences Periodontology Department, 2009.

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Figure 1. Panoramic radiograph of the patient taken 6 months after surgery, note irregular borders of the lesion.

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	Control group (Mean % ± SD %)	First group (Mean % ± SD %)	Second group (Mean % ± SD %)
CTA	21.41 ± 4.2	2.5 ± 2.4	11.42 ± 4.2
NBA	11.48 ± 0.2	21.41 ± 14.22	11.41 ± 4.2

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Original research

Dimensional accuracy of vinyl polyether and polyvinyl siloxane impression materials in direct implant impression technique for multiple dental implants

Rohini Rajendran[1], N. Gopi Chander[1], Kuttae Vishwanathan Anitha[1], Balasubramanian Muthukumar[1]

Purpose
The present study compared the dimensional accuracy of vinyl polyether silicone (VPES) and polyvinyl siloxane (PVS) impression materials used for non-splinted (NS) and splinted (S) direct open-tray impression techniques for multiple implants inserted in simulated edentulous mandibles.

Materials and Methods
A mandibular stainless steel model with eight internal connections for implant analogs was fabricated to simulate a clinical scenario. The acrylic resin splinted and non-splinted direct impressions were obtained for both VPES and PVS materials. Seventy-two cast samples were divided into four groups based on the impression techniques and materials used. The dimensional accuracies of the casts were measured in three different axes using a computerized coordinate measuring machine (CMM), and were statistically compared.

Results
The differences in the distortion values between the VPES and PVS impression materials were not statistically significant. Similarly, the differences between the splinted and non-splinted groups among the VPES and PVS materials were not statistically significant.

Conclusion
The casts fabricated from VPS or PVS impression materials provide similar dimensional accuracy regardless of the implant splinting method.

Keywords: *Dental implants, Direct impressions, Polyvinyl siloxane, Vinyl polyether silicone, Dimensional accuracy*

Introduction

Implant-supported prostheses have become an essential treatment modality (1,2). The passive fit of the implant–supported superstructure is an important factor that determines the treatment success (3). The mismatch between osseous implants and their superstructures induces stresses in prostheses, implants, and peri-implant structures (4,5). Fit precision depends on many factors, among which the impression and an accurate master cast are vital components (6). The factors that influence the cast accuracy are the characteristics of the impression material, technique, type of tray, die material, implant angulation, and fit tolerance between the implant components and transfer copings (7-12). In the case of multiple implants, the quality of the final impression and transfer of the exact positions of the implants to the model are of utmost importance (13).

Various impression techniques have been considered for obtaining accurate master casts (14,15). Open and closed tray techniques are the most

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commonly used protocols. Previous studies have demonstrated that the open-tray technique is more accurate than the closed-tray method (16,17). Herbst *et al.* (18) observed no difference between splinted and non-splinted impression copings. Assuncao *et al*. (19) inferred that splinting impression copings with acrylic resin provided favourable results in angled implants. Papaspyridakos *et al.* (20) reported that the splinted technique produced master casts that were more accurate than the ones produced using the non-splinted method, for one-piece implant-supported fixed dental prostheses in edentulous jaws. Inconsistent findings have been reported in various studies regarding splinted or non-splinted impression copings (21,22).

Different materials have been considered for making implant impressions. Polyether (PE) and polyvinyl siloxane (PVS) have been selected as materials of choice (15,16,23). Studies have justified the use of PE as an impression material for multiunit implant-retained restorations in completely edentulous situations, because it has the property of low strain during compression, with the most advantageous Shore A hardness value (24,25). Further, the PVS impression material aids in easy removal of the set impression owing to its suitable modulus of elasticity; thus, it has been suggested as a preferred material for the direct implant impression technique (13). The advantages and limitations of these materials have led to the development of new-generation vinyl PE silicone (VPES) impression materials that combine the benefits of the PE and PVS materials. These novel materials are hydrophilic and combine the most desired properties of both materials (11,26). Limited research and evidence are available in the literature to recognize the dimensional accuracy of these novel materials over PVS in situations of multiple-implant impression making.

The present study aimed to evaluate and compare the dimensional accuracy of the VPES and PVS impression materials in direct tray splinted and non-splinted approaches to multiple-implant impressions. The null hypothesis tested is that no difference would be detected between the dimensional accuracies of the two impression materials and the splinted and non-splinted techniques.

Materials and methods

Model design

The study was approved by the Institutional Review Board (SRMDC/IRB/2015/MDS/NO:202). A standard mandibular stainless-steel reference model was milled to simulate the clinical scenario of the direct implant impression technique (26). A completely edentulous, die stone cast of the mandible was selected and three-dimensional (3D) scanning was performed using CAD CAM. A reference model was fabricated using CAD CAM with the grade 404 stainless steel material (Siva Shakthi Engineering Works, India). Eight sites with dimensions of 3.5 mm × 10 mm (Adin Dental Implant Systems Ltd, India) were selected at the lateral incisor, canine, second premolar, and molar regions on either side of the arch. A three-axis vertical milling machine (Denford VMC 1300, Denford Ltd., UK) was used to ensure parallelism among the implants. They were sequentially described by letters A to H from the left-most posterior to the right distal implant site. The tray thickness, spacer, positioning, and impression were performed as described previously (27). 2-mm-wide and 1-mm-deep grooves were made in three different places for effective positioning, stabilization of the tray during impression procedures and to obtain uniform thickness of impression materials. The two posterior grooves were placed between implants A and H, and the anterior groove was placed between implants D and E.

Impression taking

Two impression materials, VPES (Figure 2) (EXA'lence 370 regular set; GC, USA) (Product no: 137805, Lot no: 1510051, 1602081) and PVS (GC Flexceed, GC Dental, USA) (Lot no:1610191), were evaluated for their dimensional accuracy using both the splinted and non-splinted techniques. Eight square-shaped internal connection hexagonal transfer copings were used (Adin Dental Implant Systems Ltd, India) (Figure 1). Each transfer coping was internally secured into the analogue and tightened with a torque wrench calibrated to 10 Ncm. The copings were connected by dental floss (Oral B Company, Chennai, India) and wrapped around to act as a scaffold. A pattern resin with thickness of 2–3 mm (GC pattern resin, GC Ltd, India) (Lot no: 1608092) was applied around the impression copings and to the scaffoldings of the dental floss before making the impression, using an incremental application technique with a brush. The splint was cut using 0.17-mm-thick diamond discs (Acurata Manhardt Dental, Chennai, India). The bars were approximately 2–3 mm in diameter; they were sectioned into a length of approximately 5 mm and joined using the bead-brushing method after 24 h with the auto-polymerizing acrylic resin (27-30). Impressions were made immediately after the material was set. Seventy-two samples were analyzed, with 18 samples in each group, listed as follows. Group VPES (S): Direct splinted technique with VPES. Group VPES (NS): Direct non-splinted technique with VPES. Group PVS (S): Direct splinted technique with PVS. Group PVS (NS): Direct non-splinted technique with PVS.

A mandibular edentulous, perforated metal stock tray was used to make impressions. Eight perforations were created in the tray with a round bur (width, 2 mm) at the site of the implants, to provide access for the guide pins of the impression copings. The stock trays were coated with a tray adhesive (Universal VPS adhesive, GC India) and allowed to dry for 15 min before making impressions. Both the VPES and PVS impressions were made using a single-step double-mix putty wash impression technique, following the manufacturer's instructions. Impression of the reference stainless steel model was made, and the tray was fully seated on the three location marks of the model and maintained in position throughout the setting time. The stock tray was seated over the guide stops, and a circular piece of steel weighing 1 kg was placed on the impression tray to standardize the seating load. After the material was set, the tray was removed. One operator made all impressions to reduce inter-operator variability. Retrieved impressions were examined and repeated if any inaccuracies were found such as air voids or material residues between the analogue-impression coping interfaces, and if any separation from the tray was detected. Implant analogs were screwed to the impression copings (Figure 2), and type-

4 gypsum casts (Ultra Rock die stone, Shruti products, Upleta, India) (Batch no: 170603) were made (Figure 3) (29,30).

Dimensional stability measurements

The dimensional stability of the impression materials was evaluated for the linear and rotational distortions observed in the casts. A computerized coordinate measuring machine (CMM OL-3020, Opus Precision Instruments, India) with a mechanical probe (diameter, 0.5 mm; resolution, 0.0001 mm) was used for measuring the relative linear distortion in the X, Y, and Z coordinates of the centers of the implant platforms. The 3D or rotational distortion (r) was calculated from the linear displacements using the following formula:

$$r = \sqrt{x2 + y2 + z2}$$

Linear distortion was evaluated from the left-most posterior implant (implant A). The centroid of the implant A head was used as a reference from which measurements were made. Linear distortions were defined as absolute differences between the reference model values and the definitive cast in the X, Y, and Z directions, and are denoted as ΔX, ΔY, and ΔZ.

The reference planes were defined to measure the sample coordinates (ΔX, ΔY, and ΔZ).

The center of the implant positioned on the model was scanned using a machine. The Z plane was outlined on the anterior – posterior surface of the implant. The X-plane was expressed as a line transiting through two implant centers perpendicular to the Z plane. Perpendicular to these X and Z planes was the Y plane. The impression analogues were fastened on the implants, and the implants were circularly scanned around the center to establish the X, Y, and Z axes. The distances in the three axes were measured as AB, AC, AD, AE, AF, AG, and AH (between the implants) (Figure 4). A single operator that was blinded to the experimental setup recorded all measurements three times to avoid intra-operator-related errors, and the mean of the values was recorded. The differences in the values for all axes were tabulated and statistically analyzed.

Statistical analysis

The data was analyzed with SPPS 17.0 (SPSS Inc. Released 2008. SPSS Statistics for Windows, Version 17.0. Chicago, IL, USA) software. Based on the distribution characteristics of the data, the one-way analysis of variance (ANOVA) test was used for multiple comparisons among study groups.

Results

The mean differences, standard deviation, and statistical data of the various axes and groups are summarized in Table 1. The results suggest no statistically significant relationship pertaining to the axes, materials, and techniques. The 3D displacement (Table 1) suggests no statistically significant relationship between the techniques and materials. The ANOVA test results comparing the splinted and non-splinted groups of the VPES and PVS are listed in Table 2 and Table 3. The results suggest no statistically significant differences (f (1.27) = 3.490, p = 0.33).

Figure 1. *Impression coping attached to the reference model.*

Figure 2. *Direct Impression with attached lab analogues.*

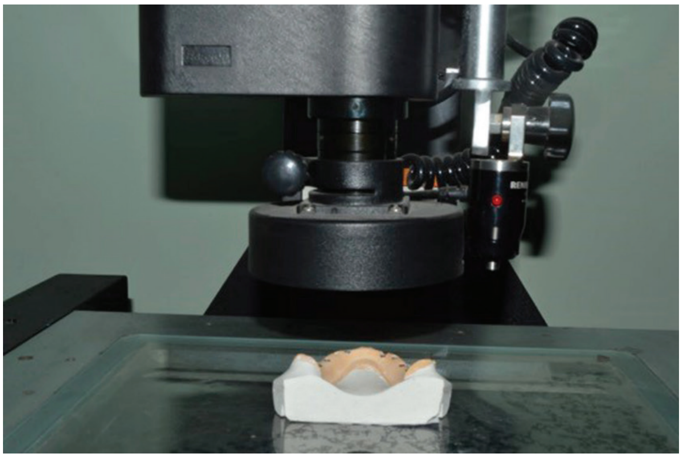

Figure 3. *Cast obtained from impression.*

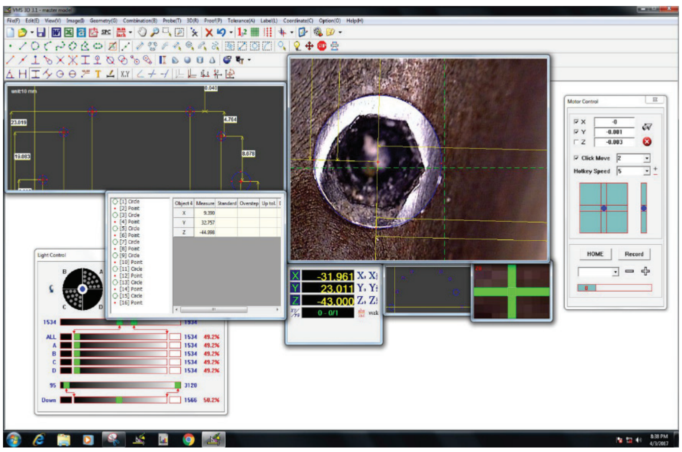

Figure 4. *Recorded measurements through the software of CMM.*

Table 1. *Mean, standard deviation, p and F values of the splinted and non-splinted impression materials in mm.*

Axis		VPES (S)	VPES (NS)	PVS (S)	PVS (NS)	P value	F value
X axis	Mean	0.11	0.18	0.15	0.16	0.29	1.32
	SD	0.08	0.07	0.05	0.07		
Y axis	Mean	0.10	0.13	0.10	0.11	0.10	2.30
	SD	0.02	0.08	0.07	0.07		
Z axis	Mean	0.08	0.11	0.09	0.10	0.18	1.76
	SD	0.04	0.05	0.04	0.05		
3 D	Mean	0.16	0.27	0.22	0.30	0.09	2.45
	SD	0.08	0.08	0.08	0.17		

Table 2. *ANOVA (Single factor) : Summary statistics between groups*.

Groups	Count	Sum	Average	Variance
VPES (S)	4	0.37542857	0.09385714	0.0015738
VPES (NS)	4	0.66457143	0.16614286	0.00781488
PVS (S)	4	0.53985714	0.13496429	0.00514211
PVS (NS)	4	0.708	0.177	0.00300307

Table 3. *ANOVA analysis.*

Source of Variation	SS	df	MS	F	P value	F crit
Between Groups	0.01668474	3	0.00556158	1.27	0.33	3.490
Within Groups	0.05260161	12	0.00438347			
Total	0.06928635	15				

Discussion

The results were statistically insignificant and failed to reject the null hypothesis about the relationship between materials and techniques. A marginal numerical advantage was observed for VPES over PVS. Siadat *et al.* (12,13) observed a smaller discrepancy for VPES and suggested it as a material of choice for direct and indirect impression techniques Higher tensile strength and better flow properties of VPES can make it more advantageous and preferred to other impression materials. Baig *et al.* (11) determined that the accuracy of the VPES impression material was comparable with that of PE for multi-implant abutment level. Kurtulmus *et al.* (17) and Vojdani *et al.* (32) compared the VPS, VPES, and PE impression materials' accuracy in angulated implants, and found no significant differences among the compared impression materials. The accuracy was marginally higher for PVS, owing to elastic recovery. This study determined that VPES exhibited less distortion compared with PVS impression materials. The differences observed can be attributed to the higher number of implants considered in the present study, and the superiority can be related to the elastic properties of the considered materials.

Only a few studies evaluated situations with more than six implants and the impact of distortion for scenarios with many implants. This study determined the influence of eight implants, different impression materials, and techniques. The higher number of implants engages the elastic recovery properties of the materials owing to the increase in linear and rotational forces. Unlike earlier studies, the results of this study can be impacted by the higher number of implants and the properties of the used impression materials.

The majority of the existing studies used reference models made of acrylic or simulated materials (11,28). These materials can affect the studies' outcomes, owing to their dimensional changes. This limitation was reduced in this study by using metallic reference models.

The present study found no statistically significant difference between the splinted and non-splinted impression techniques (f (1.27) = 3.490, p = 0.33). This is consistent with the findings reported by the majority of existing studies. Al-Quran *et al.,* Papaspyridakos *et al.,* Naconecy *et al.,* Ongul *et al*., Hariharan *et al.,* and Kim *et al*. showed that the splinted technique is better than the non-splinted implant impression technique (7,20,21,33-35). The variability in the observations reported in a few literature studies can be owing to different study designs, implant systems, different splinting materials, inaccurate repositioning of impression copings, different implant angulations, and expansion of stone materials.

In this study, a pattern resin was used as the splinting material. The splint was made prior to the impression making, to reduce polymerization shrinkage. The splint was sectioned and reconnected to the impression copings. The retentive design of the impression coping was an internal hexagonal connection that produced less vertical displacement. Machine intolerance was reduced by using novel analogues and impression copings. Significant evidence exists in literature suggesting that the PVS material is ideal for the direct impression technique, owing to its good rigidity and ability to prevent rotation of implant components. The VPES material is also an ideal impression material. It is hydrophilic and has properties comparable to those of the PVS material. The deviations found in the present study were within statistically acceptable limits, similar to the observations reported by Ebadian *et al.* (36). Extreme caution and standard recommendations were adhered to when making implant impressions using materials and techniques. The present study had some limitations. The present study used a stock impression tray. Additional studies using other techniques, different impression trays, and addressing a variety of realistic and clinically relevant scenarios are still required.

Conclusion

Irrespective of the technique and material, the linear and rotational distortion values were within the acceptable range. Therefore, it can be concluded that the casts fabricated from VPS or PVS impression materials provide similar dimensional accuracy regardless of the implant splinting method.

Türkçe Özet: *Vinil polieter ve polivinil siloksan ölçü materyallerinin çoklu implantlar için direk implant ölçü tekniğinde boyutsal doğruluğu. Amaç: Bu çalışma, simule edilmiş dişsiz alt çenelere yerleştirilen birden fazla implant için kullanılan splintlenmiş (S) ve splintlenmemiş (NS) direk açık ölçü tekniğinde polieter (VPES) ve polivinil siloksan (PVS) ölçü materyallerinin boyutsal doğruluğunu karşılaştırmıştır. Gereç ve Yöntem: Klinik durumu simule etmek için paslanmaz çelikten implant analogları için sekiz in-*

ternal bağlantıya sahip paslanmaz çelik bir alt çene modeli üretilmiştir. Akrilik reçine ile splintlenmiş vey splintlenmemiş direk ölçüler VPES ve PVS materyalleri kullanılarak alınmıştır. Yetmiş-iki örnek kullanılan ölçü tekniği ve materyallerine göre dört gruba ayrılmıştır. Modellerin boyutsal doğruluğu üç farklı eksende bilgisayarlı koordinat ölçüm makinesi (CMM) kullanılarak ölçülmüş ve istatistiksel olarak karşılaştırılmıştır. Bulgular: VPES ve PVS ölçü maddelerinin distorsiyon değerleri arasında anlamlı bir farklılık bulunmamıştır. Benzer şekilde, splintlenmiş ve splintlenmemiş gruplarda da VPES ve PVS ölçü maddelerinin distorsiyon değerleri arasında anlamlı bir farklılık bulunmamıştır. Sonuç: VPES ve PVS ölçü maddelerinden elde edilen modeller implant splintlenme metodu gözetmeksizin benzer doğruluk göstermektedir. Anahtar Kelimeler: dental implantlar; direk ölçü; polieter, polivinil siloksan, boyutsal doğruluk

Ethics Committee Approval: The study was approved by the institutional review board (SRMDC/IRB/2015/MDS/NO:202).

Informed Consent: Not required.

Peer-review: Externally peer-reviewed.

Author contributions: RR and NGC participated in generating the data fort he study. RR, NGC and KVA participated in gathering the data fort he study. RR, NGC and BM participated in the analysis of the data. RR and NGC wrote the majority of the original draft of the paper. RR, NGC, KVA and BM participated in writing the paper. RR, NGC and KVA have had access to all of the raw data of the study. All authors have reviewed the pertinent raw data on which the results and conclusions of this study are based. All authors have approved the final version of this paper. All authors guarantee that all individuals who meet the Journal's authorship criteria are included as authors of this paper. All authors participated in designing the study.

Conflict of Interest: The authors had no conflict of interest to declare.

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Original research

Adhesive strength of fiberglass posts treated with thio-urethane-based experimental silanes

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Purpose

The aim of this study was to evaluate the adhesive bond strength of fiberglass posts treated with experimental silanes based on thio-urethane and submitted to thermo and mechanical cycles.

Materials and Methods

Bovine roots were divided into six groups: RX-RU2 (RelyX CP + RelyX U200); PETMP-HDDI-RU2 (PETMP-HDDI + RelyX U200); PETMP-BDI-RU2 (PETMP-BDI + RelyX U200); RX-RU (RelyX CP + RelyX Ultimate); PETMP-HDDI-RU (PETMP-HDDI + RelyX Ultimate); PETMP-BDI-RU (PETMP-BDI + RelyX Ultimate). One slice from each root third (n=10) was submitted to the push-out test and the values evaluated with R Program statistical analysis, while the failure pattern assessed in percentage.

Results

Among root thirds, RX-RU2 promoted greater strength at the cervical and apical thirds; PETMP-HDDI-RU2 showed highest values at the three thirds; and PETMP-BDI-RU2 was strongest at the apical third. RX-RU presented higher strength at the apical third, and PETMP-HDDI-RU and PETMP-BDI-RU had similar values at the three thirds. In each root third, PETMP-HDDI-RU2 showed similar strength at all thirds, and similar strength at the apical third was observed for other associations. Mixed and adhesive failures predominated.

Conclusion

Experimental silanes promoted different bond strength values in the adhesion of fiberglass posts to the root thirds, with better results for PETMP-HDDI silane. The root region did not influence the failure pattern and most slices showed mixed (MCDP) or adhesive (ADP) failure.

Keywords: *Fiberglass post, Experimental silane, Resin cement, Adhesive strength, Failure pattern*

Introduction

The current concept of dentistry is a conservative proposal that preserves the largest amount of healthy tooth tissue when affected by caries disease or trauma. Treatment for severely affected teeth was previously extraction; however, protocols that are more conservative are now commonly used in dental clinics. Direct and indirect restorations with different materials, endodontic treatments with root retainers and prosthetic crowns are some examples of the conservative dentistry to rehabilitate the compromised dental structure.

Endodontic treatments with root retainers are procedures for teeth severely destroyed and that do not allow the reconstruction of the crown with direct restorative materials. Root retainers are available in different materials and shapes; however, studies have shown greater effectiveness with fiberglass posts (1,2). These retainers replaced metal posts because they offer better color similarity to natural tooth, they preserve the dentin

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of the root canal and they improve the flexibility as well as the mechanical properties of the restorations.

Fiberglass posts are associated to adhesive cementation, favoring protocol acceptance due to good clinical results (1). Resin cements are classified according to the activation system: chemical (conventional), physical (photo activation by light) or dual activation (chemical and physical). Dual activation cements show improved mechanical properties compared to chemical activation cements or photo activated only cements (3).

Dual activation cements also have chemical activation, and are used to fix fiberglass posts compensating the attenuation of the photo activation in deeper regions of the root canal. In addition, resin cements can interact with the root dentin substrate in different ways, depending on the adhesion protocol used. The classification of dual activation resin cements is based on conventional or self-adhesive cements and whether they are associated to bonding agents. Conventional cements are combinations of adhesive systems that can be etch-and-rinse or self-conditioning cements (4). Self-conditioning resin cements do not require prior dentin treatment, such as acid etching, primer and adhesive applications, since the organic matrix containing multifunctional methacrylate monomers interacts chemically with the hydroxyapatite of dental tissue (5,6). However, resin cements and the preparation of the root canal for installation of the retainer can promote failures in the interface post-adhesive-cement-dentin, being the main factor in the debonding of the fiberglass post from the root canal (7). Therefore, new materials had to be developed in order to improve the adhesive bonding technique to dentin and to decrease clinical failure. Thus, researchers have incorporated thio-urethane oligomers into resin materials, improving the resistance to fracture, reducing the polymerization shrinkage stress and increasing dentin adhesion (8,9).

In addition, the association of 1,6 hexanediol dimethacrylate (HDDMA) cross-linking agent with thio-urethane in acrylic resin activated by microwave energy resulted in the thio-urethane chain breaking, forming a linear polymer harmful to the polymerization of poly methyl methacrylate. However, the HDDMA addition in up to 20% by weight, not associated with thio-urethane, significantly improved the properties studied (10). Based on this considerations, it would be timely and current to verify the effect of the thio-urethanes addition in experimental silanes and verify the effect on the bond strength of resin cements to fiberglass posts.

The aim of this study was to evaluate the adhesive bond strength of fiberglass posts treated with commercial or experimental silanes based on thio-urethane, fixed with resin cement in root canal, and submitted to thermo and mechanical cycles. The study null hypothesis was that there would be no differences in the bond strength values among the cements, silanes or root thirds.

Materials and methods

Synthesis of experimental silanes

The thio-urethanes utilized as silanes were prepared in the Oregon Health and Science University laboratories. Two oligomers were synthetized in solution with catalytic amounts of triethylamine. Multi-functional thiol-pentaerythritol tetra-3-mercaptopropionate (PETMP) was combined with two di-functional isocyanates: 1,6-hexanedioldiissocyante (HDDI - aliphatic) or 1,3-bis (1-isocyanato-1- methylethyl) benzene (BDI - aromatic), as shown in a previous study (11).

Experimental groups

Teeth were randomly divided into 6 groups (n=10): RX-RU2 (RelayX CP silane and RelyX U200 resin cement - Control); PETMP-HDDI-RU2 (PETMP-HDDI experimental silane and RelyX U200); PETMP-BDI-RU2 (PETMP-BDI experimental silane and RelyX U200); RX-RU (RelyX CP commercial silane and RelyX Ultimate resin cement - Control); PETMP-HDDI-RU (PETMP-HDDI experimental silane and RelyX Ultimate); PETMP-BDI-RU (PETMP-BDI experimental silane and RelyX Ultimate). RelyX Ceramic Primer - lot 1822100538; RelyX U200 - lot 5174278; RelyX Ultimate - lot 1906300185; Single Bond Universal - lot 1908600389; Filtek Z250 - lot 1820600456 and Vitrebond - lot 18100642 were manufactured by 3M ESPE (Nova Odessa, SP, Brazil).

Tooth preparation

Freshly extracted bovine lower incisors were kept in distilled water under refrigeration until use. The criterion of external anatomical similarity of the bovine teeth was considered for the selection of straight roots with cervical canal diameter of 2.0 mm and closed apices. The teeth were cleaned with a scalpel blade to remove the residual periodontal ligament. The root length with 16 mm was checked with a digital caliper (Isomet 1000; Buchler, Lake Bluff, IL, USA). The pulp was removed with a Kerr-type endodontic file (Maillefer - Dentsply, Petropolis, RJ, Brazil).

Endodontic treatment

Root canal treatment was performed with biomechanical preparation (step-back technique) and Kerr endodontic files (Maillefer - Dentsplay). The working length was at 1 mm before the foramen with an apical stop set at diameter 55. The canal was irrigated with 1% sodium hypochlorite (Asfer Chemical Industry; Sao Caetano, SP, Brazil), saline solution (ADV, Nova Odessa, SP, Brazil), final irrigation with 17% ethylene diamine tetra acetic acid (Formula & Action, Sao Paulo, SP, Brazil), washed with saline solution and dried with absorbent cones (Dentsply Malleifer, Germany). Canal filling was done by lateral condensation using Gutta Percha cones (Dentsply, Malleifer, Germany) and calcium hydroxide-based cement (Sealer 26; Dentsply Malleifer, Germany). The canal entrance was sealed with Vitrebond (3M-ESPE), and the teeth kept in relative humidity in microbiological greenhouse (Prolab; Sao Paulo, SP, Brazil) at 37^{o}C for 7 days.

Root canal preparation

After storage, the canal filling material was removed with a drill (#3 Exacto; Angelus, Londrina, PR, Brazil) obtaining a depth of 12 mm and preserving 4 mm apical endodontic treatment. Before cementation, the post was sectioned with a diamond disc (KG Sorensen) in a high speed rotating device (KaVo Industry; Joinville, SC, Brazil) cooled with water, establishing a 16-mm length. The length excess corresponding to coronary portion was 4 mm. The posts were cleaned with 70% alcohol for 30 s and air dried for 5 s. A layer of RelyX CP conventional silane (3M-ESPE) or experimental (PETMP-HDDI or PETMP-BDI) silanes was applied to the posts of each group with microbrushes (KG Brush; Sorensen) and dried with a light air jet for 5 s. The posts were fixed with RelyX U200 or RelyX Ultimate self-adhesive resin cements (3M-ESPE) applied to the canal with a Centrix syringe (DFL, Rio de Janeiro, RJ, Brazil). The cement application protocols recommended by the manufacturer were: RelyX U200: Canal washing for 30 s; excess moisture removal with absorbent cones keeping the dentin moist; cement manipulation mixing the base paste with the catalyst paste for 20 s until to obtain a homogeneous mixture; cement application from the apical to cervical region with a syringe. RelyX Ultimate: Canal conditioning with 37% phosphoric acid for 15 s; washing with water for 30 s; excess moisture removal with absorbent cones keeping the dentin moist; active application of the Single Bond Universal adhesive with a microbrush for 20 s; excess adhesive removal with absorbent paper; cement manipulation mixing the base paste with the catalyst paste for 20 s until to obtain a homogeneous mixture; and cement application from the apical to cervical region with a syringe.

The posts were inserted into the canal with light digital pressure. After removing the excess, the cement was photo activated for 40 s with the Bluephase G2 device (Ivoclar-Vivadent, Schaan, Liechtenstein - 1200 mW/cm^2 irradiance), according to the manufacturer's recommendations. A length of 20 mm of the post was fixed into the canal; the remaining 4 mm was used as a guide to standardize the distance between the photo activator tip and the cervical root. Periapical radiographs were taken to check the condition of the endodontic treatment and the fiberglass post fit.

Tooth crown preparation

Cores were filled with resin composite (Filtek Z250; 3M-ESPE) using the incremental technique. Etching was done with 37% phosphoric acid (Biodynamics, Ibipora, PR, Brazil) for 15 s, washing with distilled water, drying with cotton, and active application of the Single Bond Universal adhesive (3M-ESPE) with a microbrush (KG Sorensen) for 20 s. The adhesive was dried with a light air jet for 5 s, and photo activated for 20 s (Bluephase G2; Ivoclar Vivadent). Each resin composite increment was photo activated for 20 s (Bluephase G2; Ivoclar Vivadent), and the crown delimitation was achieved with a #2135 drill (KG Sorensen). Based on previous work (12), the crowns were made with self-curing acrylic resin (Vipi Cril; Vipi, Pirassununga, SP, Brazil) in a silicone molds (Zetalabor; Zhermack, Rovigo, Italy) obtained from a premolar tooth. After finishing and polishing, the crowns were fixed with RelyX U200 self-adhesive resin cement (3M-ESPE) manipulated according to the manufacturer's recommendations.

Mechanical cycling

The tooth root was embedded in rigid PVC tubes (Tigre, Osasco, SP, Brazil) with 2 mm in height by 2.5 mm in diameter containing acrylic resin (Vipi Cril; Vipi). The teeth were submitted to mechanical cycling with 1.2 x 10^6 cycles in a device for mechanical fatigue (ERIOS, ER 11000, Sao Paulo, SP, Brazil). Repetitive axial impacts with a load of 50 N at 2 Hz frequency were made by a metal piston on the crown immersed in distilled water at 37°C (13).

Thermal cycling

The teeth were subjected to 500 thermal cycles (M-TWS-1; Willytec, Munich, Germany) in alternate baths of distilled water at 5-55ºC (30 s at 5ºC + 5 s of transfer + 30 s at 55ºC + 5 s of transfer to the next cycle), according to the ISO/TS 11405:2000(E) standard (14).

Push-out bond strength

After thermal and mechanical cyclings, the roots separated from the crowns were fixed on acrylic plates with sticky wax (Kota; Sao Paulo, SP, Brazil), and positioned on the metallographic cutter (Isomet 1000; Buehler) for crosscuts. Slices with 1-mm thickness from each root third (n=10) were obtained and checked with a digital caliper (Mitutoyo; Suzano, SP, Brazil). The root slices (Figure 1) submitted to the push-out test in a universal testing machine (Instron 4411; Norwood, MA, USA) which was positioned to displace the fiberglass post portion in the apex-crown direction with a speed of 0.5 mm/min. Metallic pointers with active tips compatible with the canal diameter were used allowing the force to be executed only on the post portion without touching the canal wall. The load was recorded in N and the bond strength values calculated in MPa, dividing the force (N) by the adhesive area (mm^2) which was calculated with the formula:

$$AD = \pi (R + r) [(h^2 + (R - r)^2]^{0.5}$$

Where: π = constant 3.1416; R = canal coronal radius (mm); r = canal apical radius (mm); and h = root slice thickness.

Failure pattern

The failure pattern was analyzed with a stereoscopic 50x magnifying glass (Leica MZ75; Sao Paulo, SP, Brazil) and classified as ACP (Adhesive - at cement-post interface); ADP (Adhesive - at dentine-post interface), and MCDP (Mixed - at cement-dentine-post interfaces). Representative slices of each

Figure 1. *Root slices 1-mm thickness.*

failure pattern were covered with a gold-palladium layer in a metallizer (Bal-Tec SCD050; Sputter Coater, Sao Paulo, SP, Brazil) and observed with SEM (Jeol, JSM 5600LV; Tokyo, Japan).

Statistical analysis

The values of the bond strength were submitted to exploratory analyzes and the data did not meet the assumptions of an analysis of variance (ANOVA). After descriptive and exploratory data analysis, a generalized linear model was estimated since the study design was subdivided in plots. The R Program Core Team made the statistical analysis for push-out test values, (A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria; 2019), considering a significance of 5% (15).

Results

Shear bond strength

The means and standard deviations of the bond strength (MPa) for the cement, silane and root third factors are shown in Table 1. There was a triple interaction between the study factors. When the comparison was among root thirds (in row), RX-RU2 (control) showed significantly greater strength at the cervical and apical thirds; PETMP-HDDI-RU2 had similar values at the three thirds; and PETMP-BDI-RU2 had greater strength at the apical third. RX-RU (control) showed significantly greater resistance at the apical third; and PETMP-HDDI-RU and PETMP-BDI-RU had similar values at the three thirds. Comparing each root third (column), PETMP-HDDI-RU2 provided a similar strength at the three thirds, and similar values were found for the apical third at the RX-RU and PETMP-BID-RU groups.

Table 1. *Means (standard deviation) of the bond strength (Mpa) in relation to the factors cement, silane and root third. [1]Control. * It differs significantly from RelyX U200 cement in the same conditions as silane and third (p <0.05). Means followed by different letters (uppercase letters in row comparing thirds and lowercase letters in the column comparing silane in each cement type) differ from each other (p<0.05). P (cement) = 0.0010; p (silane) <0.0001; p (cement x silane) = 0.0005; p (third) = 0.0245; p (cement x third) = 0.0687; p (silane x third) = 0.1222.*

Cement	Silane	Root third		
		Cervical	Middle	Apical
RelyX U200	[1]RX	8.58 (3.57) Ab	6.71 (1.85) Bb	8.64 (3.63) Ab
	PETMP-HDDI	14.77 (4.60) Aa	15.64 (4.54) Aa	14.95 (4.33) Aa
	PETMP-BDI	2.64 (2.37) Bc	4.67 (4.29) ABb	9.17 (9.03) Ac
RelyX U	[1]RX	8.32 (4.86) Bb	*10.17(5.00) ABab	11.04 (5.17) Aa
	PETMP-HDDI	12.37 (3.20) Aa	12.59 (4.08) Aa	13.23 (4.30) Aa
	PETMP-BDI	*9.27 (4.92) Ab	9.48 (2.55) Ab	8.81 (5.43) Ab

Failure pattern

Table 2 shows the failure pattern as a function of the factors root third, cement and silane. The root region did not influence the failure pattern and most slices showed mixed (MCDP) or adhesive (ADP) failures. In the cervical third, the majority of failures was MCDP in the RX-RU2 group and ADP for the PETMP-HDDI-RU2 and PETMP-BDI-RU2 groups. Additionally, most of the failures was MCDP in all associations with RelyX Ultimate. In the middle and apical thirds, the majority of failures was MCDP or ADP in all associations with RelyX U200 or RelyX Ultimate.

Discussion

This study evaluated the *in vitro* the bond strength of fiberglass posts treated with commercial or experimental silanes

Table 2. *Failure pattern (number / %) in relation to the factors root third, cement and silane. ACP (Adhesive - at cement-post interface); ADP (Adhesive - at dentine-post interface); MCDP (Mixed - at cement-dentine-post interfaces). [1]Control.*

Root third	Cement	Silane	Failure pattern		
			ACP	ADP	MCDP
Cervical	RelyX U200	[1]RX	3 / 33.3%	1 / 11.1%	5 / 55.6%
		PETMP-HDDI	1 / 11.1%	5 / 55.6%	3 / 33.3%
		PETMEP-BDI	0 / 0.0%	5 / 55.6%	4 / 44.4%
	RelyX Ultimate	[1]RX	0 / 0,0%	4 / 40.0%	6 / 60%)
		PETMP-HDDI	0 / 0.0%	1 / 12.5%	7 / 87.5%
		PETMEP-BDI	0 / 0.0%	3 /(33.3%	6 / 66.7%
Middley	RelyX U200	[1]RX	0 / 0.0%	5 / 55.6%	4 / 44.4%
		PETMP-HDDI	1 / 10%	4 / 40.0%	5 / 50%
		PETMEP-BDI	2 / 22.2%	3 / 33.3%	4 / 44.4%
	RelyX Ultimate	[1]RX	0 / 0.0%	2 / 20%	8 / 80%
		PETMP-HDDI	0 / 0.0%	4 / 44.4%	5 / 55.6%
		PETMEP-BDI	0 / 0.0%	5 / 55.6%	4 / 44.4%
Apical	RelyX U200	[1]RX	0 / 0.0%	5 / 55.6%	4 / 44.4%
		PETMP-HDDI	2 / 20%	6 / 60%	2 / 20%
		PETMEP-BDI	0 / 0.0%	4 / 44.4%	5 / 55.6%
	RelyX Ultimate	[1]RX	0 / 0.0%	5 / 55.6%	4 / 44.4%
		PETMP-HDDI	1 / 11.1%	2 / 22.2%	6 / 66.7%
		PETMEP-BDI	0 / 0.0%	4 / 44.4%	5 / 55.6%

based on thio-urethane, fixed with resin cements on roots with conventional endodontic technique and subjected to thermal and mechanical cycling. The study hypothesis that there would be no difference in the bond strength values between cements, silanes or root thirds was rejected, since there was a statistically significant difference in the interaction between these factors.

The push-out test assesses *in vitro* the bond strength of the adhesive cementation interface in different protocols. In addition, the push-out test permits a more homogeneous stress distribution, less variability during the mechanical test, and reduction of premature failures (16). This desired methodological condition was obtained in the current study.

Investigations evaluating bonding methods of fiberglass posts to root dentin have shown different results in relation to canal regions. Higher bond strength values occurred in the cervical region, since the resin cement is submitted to photo and chemical activation intensities in this region, obtaining a better polymerization rate (17). After acid etching, the canal dentin area is responsible for the greatest adhesive strength of the bond, but not all areas exhibit similar responses to the acid etching (18). The types of root canal surface etching have different effects on the bond strength of fiberglass posts to root dentine; however, all evaluated surface treatment methods increased the adhesive strength when compared to the control samples (19).

Table 1 shows different values of bond strength in the interface between the fiberglass post and dentine in each root canal region. In addition to the other study factors, these differences seem to be dependent mainly on the interaction between silane and adhesive cement. In the comparison among root thirds, RX-RU2 (Control) provided significantly greater strength at the cervical and apical thirds; PETMP-HDDI-RU2 had similar values at the three thirds; and PETMP-BDI-RU2 presented the higher value at the apical third. RX-RU (Control) showed significantly greater strength at the apical third, and PETMP-HDDI-RU and PETMP-BDI-RU demonstrated similar values at the three thirds. Comparing each root third, PETMP-HDDI-RU2 showed similar strength at the three thirds, and similar values were observed at the apical third for the RX-RU and PETMP-HDDI-RU groups.

Besides the influence of the interaction between silane and adhesive cement on the fiberglass posts bond strength, the current study showed that the cement type and thermo-mechanical aging could also significantly affect the bond. Previous study showed that the pull-out bond strength was significantly affected by the cement type and ageing. RelyX ARC showed the highest bond strength before thermo-mechanical loading; however, the strength values decreased significantly after the procedure (20).

In this study, the interaction between silane and adhesive cement did not promote a similar behavior pattern that occurs by the difference of the photo activation intensity on the cervical portion compared to deeper regions of the root canal, and the consequent mechanical strength value related to polymerization rate. However, fiberglass posts are subjected to several other factors that can influence the cement-dentine-post bond quality. Among them, length, diameter, shape, surface structure and type of the post, cement layer thickness, application methods of the resin cement, and root canal treatment types (21).

Studies have shown a higher value of bond strength on the root apical region, and others have claimed that the bond strength on dentine close to the pulp is considered only 30 to 40% of the strength on peripheral dentine (22,23). A relationship exists between the dentine area available for bonding and the bond strength obtained. The smaller the dentine thickness near the pulp, the larger the dentinal tubule area (24). In addition, there are several structural differences between coronal and intra radicular dentine substrates (25). The literature reports differ between a study showing that the retention level improves with the increase of the length of the cemented post in the root canal, and other suggesting that the retention value of the fiberglass post to dentine worsens with the deepening of the canal (26,27).

In general, greater shear bond strength was observed for commercial cements associated with PETMP-HDDI experimental silane when compared to the RX silane and RX-PETMP-BDI associations, except at the apical region with the RU cement in all associations. On the other hand, the PETMP-HDDI silane associated to each cement type showed greater strength at all root thirds, while the RU cement showed the greatest strength at the cervical third.

Hyphrophobic silane compounds used to modify the surface of materials, whether based or not on silica, alter the bond quality between organic and inorganic materials (28). This fact could have a significant effect on the chemical and mechanical properties of experimental silanes in relation to adhesive interface strength. As such, different silane types were used to modify the surface of inorganic materials in order to improve the adhesion to organic materials (29). Maybe for that same reason, resin materials incorporated with thio-urethane additives have provided some advantages over the mechanical properties of non-additive materials (11).

The covalent interaction of thio-urethane with methacrylate occurs by transferring the pending functionality of the thiol in the oligomer chain. This chain transfer reaction delays the gelling or vitrification of the material, providing a higher level of monomer conversion, reducing polymerization stress, improving the network homogeneity and increasing the strength to fracture toughness (8,30,31). These effects have positive consequences for the chemical-mechanical properties of these experimental polymeric materials.

Highest adhesive strength was observed for PETMP-HDDI. Probably, this experimental silane imparted greater toughness and fracture toughness to posts adhesion, since the polymerization of resin materials added with thio-urethanes promote a more stable adhesive interface (32). Although this relationship probably exists with PETMP-BDI silane, the highest adhesive strength value for this material occurred only on the apical third with both commercial cements. The difference in composition between the PETMP-HDDI and PETMP-BDI silanes may have caused the difference in adhesion levels among the root thirds, although this assumption should be checked in other studies evaluating the physical-chemical behavior of these experimental silanes.

In this sense, the adhesive resin for fixing fiberglass posts also needs improved the mechanical properties, since endodontically treated teeth are subjected to repetitive impact forces of different intensities. Moreover, the polymerization shrinkage reduction and the lesser stress level occurred in resin materials modified by thio-urethane may significantly contribute to adhesive strength, especially at the bonding interface (9). Based on these considerations, it is possible that the improvement observed in the mechanical properties of commercial adhesive cements, when associated to PETMP-HDDI silane, can stabilize the bond strength of fiberglass posts to the root canal over long time.

Most of the root slices presented MCDP or ADP failures (Table 2), and the failure pattern was not similar among the different root regions. At the cervical third, the majority of failures was MCDP for RX-RU2 and ADP for PETMP-HDDI-RU2 and PETMP-BDI-RU2 groups; additionally, most of the failures was MCDP in all associations with RelyX Ultimate. At the middle and apical thirds, the majority of failures was MCDP or ADP for all associations with RelyX U200 or RelyX Ultimate.

A previous study showed that silane impaired, or generally had no effect on the bond strength of self-adhesive resin cements to fiberglass posts, and the bond strength was greater than for conventional cement when the posts were not silanized. There was also a predominance of adhesive failures in all groups, with a greater number of mixed failures when the posts were silanized (33). This fact seems similar to the result of the current study regarding the failure types.

Fiberglass posts without silane application showed a smoother surface, reducing the mechanical locking with adhesive cement (34). Therefore, as the PETMP-HDDI and PETMEP-BDI silanes were able to increase the bond strength, it is assumed that the greater the strength required for dislodging the fiberglass posts, the greater the occurrence of mixed or cohesive failures, as occurred in this investigation. Thus, further studies are needed with different methods of silane application to understand the adhesive mechanisms that could improve the bond strength.

Another factor that may be related to reduction of adhesive failures with PETMP-HDDI and PETMEP-BDI silanes is be the amount of polymerization stress occurring between the fiberglass post and root dentine. Since the modulus of elasticity of resin cements is less than for fiberglass posts and root dentin, a higher stress concentration would occur at the adhesive interface (35). In this sense, the reaction between low glass transition oligomer and the methacrylate network can increase the modulus of elasticity, toughness and fracture strength of resin cements, when compared to methacrylate without additive (9). In addition, a photo elastic study showed that the different endodontic retainer types influenced the stress distribution on the root canal, and that the fiberglass post is the best choice for restoring endodontically compromised teeth, since a smaller stress value may increase the longevity and reduce the possibility of failures (36).

Another interesting report was that the bond strength values were not similar between groups with fiberglass posts of different diameters and there was no significant difference between the root regions in all groups. The failures were predominantly adhesive between resin cement and the post; however, the post with the best adaptation to the root canal showed a higher bond strength value (21).

In the current study, the roots were submitted to thermal and mechanical cycles simulating *in vitro* conditions for endodontic treatment. It is possible that the aging of the interface formed between root canal and fiberglass post, when fixed with commercial cements associated with the PETMP-HDDI or PETMEP-BDI silanes, result in similar marginal microleakage in the long term. However, the failure pattern was not similar among the root regions, since most of the slices presented mixed or adhesive cement-post failure, a fact that would may justify the application of these materials in clinical endodontic procedures. Moreover, a previous study showed that thermal stress increased the marginal microleakage level mainly due to the difference in the coefficient of thermal expansion between the materials (37).

It is expected that the promising findings of the current study, discussed with results reported in previous investigations, may contribute to improve the adhesive bond between the fiberglass posts treated with experimental silanes and the root canal dentine, and possibly to predict the mechanical behavior of these associations in the oral environment when in use.

Conclusion

Based on findings of this study, the experimental silanes promoted different bond strength values in the adhesion of fiberglass posts to the root thirds, with better results for PETMP-HDDI silane. The root region did not influence the failure pattern and most slices showed mixed (MCDP) or adhesive (ADP) failures.

Türkçe Özet: *Thio-Uretan esaslı deneysel silanlarla muamele edilmiş fiber postların adeziv dayanıklılığı Amaç: Bu çalışmanın amacı thio-Uretan esaslı deneysel silanlarla muamele edilmiş fiber postların adeziv yapışma gücünü termo ve mekanik sikluslar sonrası değerlendirmektir. Gereç ve Yöntem: Sığır dişleri altı gruba bölünmüştür: RX-RU2 (RelyX CP + RelyX U200); PETMP-HDDI-RU2 (PETMP-HDDI + RelyX U200); PETMP-BDI-RU2 (PETMP-BDI + RelyX U200); RX-RU (RelyX CP + RelyX Ultimate); PETMP-HDDI-RU (PETMP-HDDI + RelyX Ultimate); PETMP-BDI-RU (PETMP-BDI + RelyX Ultimate). Her kökün üçte birinden bir dilim (n=10) çekme testine tabi tutulmuş ve değerler R istatistiksel analiz programı kullanılarak değerlendirilirken, başarısızlık paternleri yüzde hesabı ile belirtilmiştir. Bulgular: Üçte bir köklerden RX-RU2servikal ve apikalde daha fazla dayanıklılık göstermiş, PETMP-HDDI-RU2 tüm bölümlerde en yüksek değerleri vermiş, PETMP-BDI-RU2 ise apikalde daha fazla dayanıklılık göstermiştir. RX-RU apikalde daha fazla dayanıklılık gösterirken, PETMP-HDDI-RU ve PETMP-BDI-RU tüm bölümlerde benzer dayanıklılık göstermiştir. Her üçte bir kökte PETMP-HDDI-RU2 tüm bölümlerde bölümlerde benzer dayanıklılık göstermiştir. Karışık ve adeziv başarısızlık daha çok olmuştur. Sonuç: Deneysel silanlar fiber postların üçte bir köklere yapışma kuvvetinde farklılıklar göstermiş, PETMP-HDDI silanı daha iyi sonuç vermiştir. Kök bölgesi başarısızlık paternini etkilememiş ve tüm dilimlerde karışık (MCDP) ya da adeziv (ADP) başarısızlık görülmüştür Anahtar kelimeler: Fiber post; Deneysel silan; Reçine siman; adeziv dayanıklılık; başarısızlık paterni*

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Author contributions: VMP, CSP, APPF and RLXC participated in designing the study. VMP and RLXC participated in generating the data for the study. VMP, MCP, RAPR and RLXC participated in gathering the data for the study. VMP, MCP, RAPR and RLXC participated in the analysis of the data. VMP and RLXC wrote the majority of the original draft of the paper. VMP and RLXC participated in writing the paper. VMP, MCP, RAPR and RLXC have had access to all of the raw data of the study. VMP and RLXC have reviewed the pertinent raw data on which the results and conclusions of this study are based. All authors have approved the final version of this paper. VMP and RLXC guarantee that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

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Original research

Reliability and validity of the Turkish version of oral health impact profile for edentulous subjects

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Purpose
The validated translations of the OHIP-EDENT exist in different languages; however, there is no reliable and validated Turkish translation. The present study was conducted to evaluate the reliability and to validate the Oral Health Impact Profile in edentulous subjects translated to Turkish (OHIP-EDENT-T).

Materials and Methods
The study sample included 104 conventional complete denture wearers (58 women and 46 men, mean age: 61.13 ± 9.43 years). The original English version of OHIP-EDENT was translated into Turkish using a forward-backward method and applied to the subjects. The reliability of the OHIP-EDENT-T was evaluated using internal consistency and the test–retest method. Validity was determined as construct and convergent validity. The construct validity of OHIP-EDENT-T was assessed using exploratory and confirmatory factor analysis.

Results
The Cronbach's alpha value for OHIP-EDENT-T was 0.890. The intraclass correlation coefficient (ICC) was 0.749 for the OHIP-EDENT-T total score, and ICCs for the subscales ranged from 0.630 (95% CI = 0.501-0.823) to 0.859 (95% CI = 0.531-0.897), indicating good to excellent agreement. The Kaiser-Meyer-Olkin value for sampling adequacy was 0.820 and results of Bartlett's sphericity test indicated statistical significance ($\chi 2$=1139.767; df=171, p=0.001). This showed that factorial analysis could be applied to the data set. The three-factor structure of the scale explained 81.1% of the observed variance. The agreement of the three-factor solution was further tested with confirmatory factor analysis, and the fit index was found to be acceptable (chi-square fit test=1.449, RMSEA=0.040, GFI=0.94, CFI=0.93).

Conclusion
Within the limitations of this study, it can be concluded that OHIP-EDENT-T is a valid and reliable instrument for evaluating the quality of life of edentulous patients.

Keywords: *Oral-health related quality of life, OHIP, OHIP-EDENT, Edentulous, Complete denture*

Introduction

The increase in the life expectancy has been associated with tooth loss (1). In Turkey, the prevalence of edentulism is on the rise (2) and this affects the main functional activities of edentulous patients (3). The Oral Health-Related Quality-of-Life (OHRQoL) is a multi-dimensional construct that aims to collect information concerning the patient's subjective assessment of his/ her oral health, including functional as well as psycho-social well-being, sense of self, expectations and treatment satisfaction (4). Although both fixed and removable implant-supported prostheses have been reported to increase OHRQoL and patient satisfaction when compared to complete dentures (CDs) (5), CDs continue to be the most common treatment option for edentulism (6).

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OHRQoL scales are score-based tools for evaluating the effect of dental treatment on oral health and quality-of-life (7-11). One of the most popular OHRQoL instruments, the Oral Health Impact Profile (OHIP) provides a detailed analysis of OHRQoL based on the conceptual model of oral health described by Locker that utilizes the World Health Organization (WHO) International Classification of Impairments, Disabilities and Handicaps (12-14). The OHIP comprises of 49 questions grouped under 7 subdomains, namely: functional limitation, physical pain, psychological discomfort, physical disability, psychological disability, social disability and handicap. OHIP is a realiable and valid instrument, however, it is also long and difficult to complete (15,16). A shorter, more patient-friendly 14-item version of the (OHIP-14), developed by Slade (14), covers the same 7 domains as the original OHIP. This version demonstrated acceptable validity, therefore, it is less time-consuming for researchers and easier to complete for patients. However, some parts of the OHIP-14 are inappropriate for CRDP wearers and the floor effect limits its ability to detect improvements in CRDP wearers following clinical intervention (16). To address these issues, Allen and Locker (16) implemented the OHIP-EDENT, a 19-statement version that covers the same domains as the OHIP, that can detect changes in OHRQoL before and after insertion of new CRDPs. Since the OHIP-EDENT can be used to evaluate negative impacts specifically related to edentulous patients, it can provide additional data that might be useful in developing effective interventions for edentulous patients (17).

Validated translations of the OHIP-EDENT exist in Portuguese, Japanese, Spanish, Chinese and Nepalese; however; there is no reliable and validated Turkish translation (17-21). Therefore, recent studies on the edentulous Turkish population have used the Turkish version of the OHIP-14, which has been noted as a limitation (22-26). Therefore, the aim of the present study was to translate the OHIP-EDENT into Turkish and to assess the reliability and validity of this translated version (OHIP-EDENT-T).

Patients and Methods

Participants and eligibility criteria

This study was approved by the Ethics Committee of the Istanbul University Faculty of Medicine (Approval No. 18205), and written informed consents were obtained from all participants. Based on a recommended minimum of 5-10 patients per item for instrument analysis (27) (i.e. 95 participants for the 19-item questionnaire), and adding 10% to account for possible drop-outs, 104 edentulous individuals (58 female, 46 male, age range: 39-87 years; mean age: 61.13 ± 9.43) were recruited consecutively among patients attending the Istanbul University, Faculty of Dentistry, Department of Prosthodontics for CD treatment. To be included in the current study, the subjects had to be adult, consent to participate, be born, raised and educated within the national borders of Turkey, and have the cognitive skills and literacy to complete the study forms. Individuals who were unable to understand the OHIP-EDENT-T questions were not invited to the study.

Complete dentures

Conventional maxillary and mandibular dentures were fabricated using standard prosthetic method that involved balanced articulation with anatomic acrylic resin teeth (Enigma; Davis Schottlander & Davis, Tonawanda, NY, USA) and maximal extension of the denture borders using functional impression methods by 5 prosthodontists who were blinded to the study protocol (28).

Translation

The original OHIP-EDENT questionnaire comprises of 19 items grouped under 7 domain as follows: 1-functional limitation (3 items), 2- physical pain (4 items), 3- psychological discomfort (2 items), 4-physical disability (3 items), 5-psychological disability (2 items), 6- social disability (3 items) and 7-handicap (2 items) (17). Participants rate the frequency with which their daily activities are affected by oral health-related problems associated with denture use on a scale of 0-4 (0: Never; 1: Hardly ever; 2: Occasionally; 3: Fairly often; 4: Very often). OHRQoL impairment is characterized by the the sum of the individual items that ranges from 0 to 76. Higher scores indicate greater impairment. The OHIP-EDENT was translated into Turkish by a dentist fluent in both English and Turkish. The translated version (OHIP-EDENT-T) was reviewed by six other dentists, and the conceptual equivalence between the original inventory and the translated version was checked by an independent, professional translator who has back-translated the scale (8).

Questionnaire administration

Following an average of 4-week of functional adaptation and adjustment period during which the subjects wore the same dentures, The OHIP-EDENT-T (Figure 1), the global question (see convergent validity section below) and a demographic form were handed out to the patients. Subjects filled the forms alone in a quiet room in the morning hours with no time restriction. 35 randomly selected participants were re-tested after two weeks.

Reliability

Internal consistency of the OHIP-EDENT-T was assessed by calculating Cronbach's alpha values. Test-retest reliability was evaluated by calculating intraclass correlation coefficients (ICC) and 95% confidence intervals (CI) for the OHIP-EDENT-T. Cronbach's alpha values range from 0.0-1.0, with a value of 0.7 or higher considered reliable (29). Intra-class correlation (ICC) scores that indicate varying levels of agreement were interpreted as follows: <0.40: poor to fair; 0.41-0.60: moderate; 0.61-0.80: good: >0.80: excellent (30).

Validity

Construct validity of the OHIP-EDENT-T was assessed using exploratory factorial analysis. Bartlett's sphericity and Kaiser-Meyer-Olkin (KMO) tests were conducted to explore possible significant correlations among the OHIP-EDENT-T items, with factor loadings of >0.40 considered significant (31).

1. Dişlerinizde, ağzınızda veya takma dişlerinizde bir sorun olduğu için yemek çiğnemekte zorluk çektiniz mi?
2. Dişlerinize veya takma dişlerinize yemek kaçtı mı?
3. Takma dişlerinizin yerine tam oturmadığını hissediyor musunuz?
4. Ağzınızda acı duydunuz mu?
5. Dişlerinizde, ağzınızda veya takma dişlerinizde bir sorun olduğu için yemek yerken rahatsızlık duydunuz mu?
6. Ağzınızda acıyan yerler var mı?
7. Takma dişleriniz rahatsızlık verdi mi?
8. Dişlerinizle ilgili sorununuz var mı?
9. Dişleriniz, ağzınız veya takma dişlerinizin farkında olarak mı yaşıyorsunuz?
10. Dişleriniz, ağzınız veya takma dişlerinizle ilgili bir sorun nedeniyle bazı yemekleri yemekten çekindiniz mi?
11. Takma dişlerinizle ilgili sorun nedeniyle yemek yiyemediğiniz oluyor mu?
12. Dişleriniz, ağzınız veya takma dişlerinizle ilgili bir sorun nedeniyle yemek yemeyi yarıda bıraktığınız oldu mu?
13. Dişleriniz, ağzınız veya takma dişlerinizle ilgili bir sorun nedeniyle üzülüyor musunuz?
14. Dişleriniz, ağzınız veya takma dişlerinizle ilgili bir sorun nedeniyle utanıyor musunuz?
15. Dişleriniz, ağzınız veya takma dişlerinizle ilgili bir sorun nedeniyle dışarı çıkmaktan kaçındığınız oldu mu?
16. Dişleriniz, ağzınız veya takma dişlerinizle ilgili bir sorun nedeniyle eşinize veya ailenize karşı daha az hoşgörülü müsünüz?
17. Dişleriniz, ağzınız veya takma dişlerinizle ilgili bir sorun nedeniyle başkalarını rahatsız ediyor musunuz?
18. Dişleriniz, ağzınız veya takma dişlerinizle ilgili bir sorun nedeniyle başkaları ile birlikte olmaktan zevk almadığınız oluyor mu?
19. Dişleriniz, ağzınız veya takma dişlerinizle ilgili bir sorun nedeniyle genelde hayatın daha az tatmin edici olduğunu düşünüyor musunuz?

Figure 1. *Turkish translation of the OHIP-EDENT (OHIP-EDENT-T). The rating scale for each item is as follows: 0: Hiç bir zaman, 1: Ender, 2: Bazen, 3: Sık, 4: Çok sık.*

Convergent validity

In line with previous studies, after responding to the OHIP-EDENT-T, participants were asked an extra-global question (“Are you satisfied with the use of complete dentures”) with 5 possible responses (1-“very satisfied”, 2-“ ‘satisfied,” 3-“fair,” 4-“dissatisfied”, 5-“very dissatisfied”) in order to examine convergent validity (17,21). The convergent validity was assessed by examining the correlation between OHIP-EDENT-T subscale scores and the global question, with correlation levels rated as follows: <0.20: poor; 0.21-0.40: fair; 0.41-0.60: good; 0.61-0.80: very good; >0.81: excellent (32).

Statistical analysis

Data analysis was performed using the Statistical Package for Social Sciences (SPSS Inc., Release 15.0 for Windows, Chicago, IL, USA). In addition, the factorial model according to the results of exploratory factor analysis was verified by confirmatory factor analysis (IBM SPSS Amos 21.0; IBM Corp, Armonk, NY, USA). The current study used the following fit indexes: chi-square fit test (acceptable value ≤ 3) , a root-meansquare error of approximation (RMSEA, acceptable value ≤ .08), goodness of fit index (GFI, acceptable value ≥ .85) and comparative fit index (CFI, acceptable value ≥ .90). The confidence level was set to 95% and $p<0.05$ was considered significant.

Results

Demographic data of participants was presented in Table 1.

Reliability

Table 2 shows the internal consistency of the multi-item scales. Cronbach’s alpha for the OHIP-EDENT-T total score was 0.890. Cronbach’s alpha values for the subscales ranged from 0.714 for “Physical pain” to 0.883 for “Psychological disability.” All subscales exceeded the minimum reliability standard of 0.70. The ICC was 0.749 for the OHIP-EDENT-T total score, and ICCs for the subscales ranged from 0.630 (95% CI = 0.501-0.823) to 0.859 (95% CI = 0.531-0.897), which indicates good to excellent agreement.

Validity

As KMO value for sampling adequacy was 0.820 and Bartlett's sphericity test indicated statistical significance ($\chi 2$=1139.767; df=171, p=0.001) factorial analysis could be applied to the data set. The results of factor analysis for all subscales are given in Table 3. Factor loadings were above 0.40 for all items. 81.1% of total variance was explained by three factors, namely: Physical impact (Functional limitation, Physical pain, Physical disability); Psychological impact (Psychological discomfort, Psychological disability); and Social impact (Social disability, Handicap). OHIP-EDENT-T total and subscale scores significantly correlated with the global question (rs: 0.645-0.742), demonstrating good to excellent convergent validity (Table 4).

When the fit index values were examined, the current study have found that the results were acceptable and in good agreement. The results from the fit indexes were; for chi-square fit test 1.449, for RMSEA 0.040, for GFI 0.94, for CFI 0.93.

Table 1. *The distribution of the demographic data of the participants.*

		n	%
Gender	Women	58	55.8
	Men	46	44.2
General Health	Poor	12	11.6
	Moderate	45	43.2
	Good	47	45,2
Marital status	Single	27	25.9
	Married	77	74.1
Living status	Alone	17	16.3
	With the family	87	83.7
Working status	Retired	83	79.8
	Working	21	20.2
Monthly income level	Low	23	22.1
	Moderate	30	28.9
	High	51	49.0
Educational level	University	15	14.4
	High school	34	32.7
	Middle school or under	55	52.9

Discussion

The OHIP-EDENT questionnaire has become the gold standard for reporting patient centered quality of life in edentulous patient (33). The questionnaire has been translated into Portuguese, Japanese, Spanish, Chinese and Nepalese and the reliability of these culturally-adapted versions have been evaluated (17-21). However, the present study is the first to examine the reliability and validity of a Turkish version of the OHIP-EDENT, the OHIP-EDENT-T.

Previous studies have reported that the Cronbach's alpha values for the OHIP-EDENT varied between 0.785 and 0.972 (17,21). This inconsistency, such as the one between Nepali as well as Chinese versions of the OHIP-EDENT, have been attributed to the differences in sample sizes (17, 21). Cronbach's coefficient alpha of OHIP-EDENT-T was 0.89, which indicates that this scale is able to measure a theoretical construct with good internal consistency and to reliably detect changes in the OHRQoL of edentulous subjects. The corrected item-total correlation coefficients were above 0.20 which shows the consistency of the items in the scale. Good internal consistency was further clarified by ICC values (0.749; (95% CI =0.567-0.896), indicating test-retest reliability remains stable over time.

Previous studies evaluating the OHRQoL of new denture wearers have reported OHIP-EDENT scores of 14.91 and 16.23. The present findings demonstrated that the mean OHIP-EDENT-T score was 14.59, which is in accordance with those reported previously (19,34). A systematic review and meta-analysis of the baseline OHIP-EDENT scores determined 28.63 (95% CI, range: 21.93-35.34) to be the pre-treat-

Table 2. *Cronbach's coefficient alpha values and test–retest reliability of the OHIP-EDENT-T.*

		OHIP EDENT-T Mean±Standard Deviation	Corrected item total correlation (n=104)	Test–retest (ICC) (n=35)	95 % CI
Physical impact	Functional limitation	3.65±2.88	0.813	0.793	0.453-0.815
	Physical pain	4.19±3.67	0.714	0.645	0.417-0.793
	Physical disability	2.37±2.84	0.819	0.630	0.501–0.823
Psychological impact	Psychological discomfort	2.16±2.22	0.765	0.684	0.449-0.804
	Psychological disability	1.01±1.71	0.883	0.859	0.531-0.897
Social impact	Social disability	0.64±1.79	0.841	0.724	0.597-0.876
	Handicap	0.57±1.42	0.839	0.786	0.550-0.861
	Total OHIP-EDENT-T	14.59±13.09	0.890	0.749	0.567–0.896

ment baseline for edentulous patients. Although the present study did not record pre-treatment scores, the enormous difference between the baseline OHIP-EDENT scores reported by meta-analysis and the post-treatment scores calculated in the present study suggest that improvements in OHRQoL related to prosthetic treatment were measurable by the OHIP-EDENT-T (33).

The current study measured both construct and convergent validity of the OHIP-EDENT-T. Previous studies evaluating the OHIP-EDENT used different methodologies for assessing validity, the exploratory factor analysis being the most common (17,20,21,35,36). The main purpose of factor analysis is to facilitate the understanding and interpretation of the relationships between numerous variables considered to be correlated by reducing them to smaller number of basic dimensions. However, even though OHRQoL is generally recognized by the scientific literature to be a multidimensional construct that includes physical and psychological factors as well as social well-being, there is no consensus regarding its specific factorial characteristics (37). Results of the exploratory factor analysis of OHIP-EDENT data varied among studies: Souza et al. (35) reported 4 relevant domains, He and Wang (17), Shrestha et al. (21) and Montero et al. (20) reported 5 relevant domains – with relevancy referring to factors with eigenvalues of >1. Possebon et al. (36) is the first study in the literature to report the confirmatory factorial analysis of the OHIP-EDENT instrument. Accordingly, a model was presented with 3 factors comprised of 19 sub-factors. Similarly, the present study found 3 relevant domains for the OHIP-EDENT-T.

This study has a number of strengths, first of which is the wide socio-demographic range of the study population. In addition, the simple language of the questionnaire and scale makes the survey easy to apply and easy to evaluate. In terms of limitations, de novo development was not conducted, so that the final translation could not be compared with previous versions. In addition, sensitivity and responsiveness of the OHIP-EDENT-T could not be evaluated, since this would require a longitudinal study.

Table 3. *Exploratory factor analysis of OHIP-EDENT-T.*

	Factor 1: Physical impact	Factor 2: Psychological impact	Factor 3: Social impact
Factor 1:			
Physical impact			
1. Chewing difficulty	0.651		
2. Food catching	0.455		
3. Dentures not fitting	0.515		
4. Aching sensation	0.586		
5. Uncomfortable to eat	0.782		
6. Sore spots	0.873		
7.Uncomfortable dentures	0.471		
10. Avoids eating	0.582		
11. Unable to eat	0.765		
12. Interrupts meals	0.503		
Factor 2:			
Psychological impact			
8. Worried		0.784	
9. Self-conscious		0.671	
13. Upset		0.717	
14.Been embarrassed		0.434	
Factor 3:			
Social impact			
15. Avoided going out			0.749
16. Less tolerant			0.724
17. Irritable			0.859
18.Unable to enjoy company			0.881
19.Life unsatisfying			0.481
% variance	45.5	25.4	10.2
Total variance (%)		81.1	

Table 4. *Convergent validity of the OHIP-EDENT-T: correlations between subscale scores with global oral health rating (Spearman's rank correlation coefficient. * p < 0.01).*

Subscale	Rs	95 % CI
Total Score	0.734	0.590 to 0.831*
Subscales		
Physical impact	0.711	0.560 to 0.820*
Psychological impact	0.742	0.650 to 0.816*
Social impact	0.645	0.541 to 0.735*

Conclusion

Within the limitations of this study, it may be concluded that the OHIP-EDENT-T is a valid and reliable instrument for evaluating the OHRQoL of edentulous patients.

Türkçe Özet: *Konik-ışınlı bilgisayarlı tomografi (kıbt) kullanılarak molar dişlerde kök kanal uzunluğu ölçümü: iki boyutlu ve üç boyutlu yöntemlerin karşılaştırılması. Amaç: Bu çalışmada amaç, büyük azı dişlerinin 2 boyutlu (2D) ve 3 boyutlu (3D) konik-ışınlı bilgisayarlı tomografik (KIBT) yöntemleri ile gerçekleştirilen kök kanal uzunluğu ölçümlerinin, gerçek kök kanal uzunluklarıyla uyumunun incelenmesidir. Gereç ve yöntem: 24 büyük azı dişe ait 70 kök kanalı KIBT ile tarandı ve kök kanalları eğimlerine göre "Düz", "Aşırı kurvatürlü" ve "Birden fazla kurvatüre sahip" olarak sınıflandırılmıştır. 2D ölçümler, uygun bir KIBT kesitinde, kök kanalının foramen apikalesi ile ilgili kanalın tüberkül tepesi referans alınarak yapılmıştır. 3D ölçümler, aynı referans noktaları arasında düzenli aralıklarla ilerleyen aksiyal kesitler içerisinde gerçekleştirilmiştir. KIBT ile ölçüm yöntemlerinin tekrarlanabilirlik ve güvenilirlik analizinde Sınıf İçi Korelasyon Katsayısı kullanılmıştır. Gerçek kök kanal uzunluğu ve KIBT ile kök kanal uzunluğu ölçümleri arasındaki farkların kabul edilebilir sınırlar dahilinde (± 0,5 mm) olup olmadığı ki-kare ve McNemar testleri ile değerlendirilmiştir. Bulgular: Her iki yöntemin de tekrarlanabilir olduğu ve mükemmel güvenilirlik sağladığı gözlemlendi. Bununla birlikte, 3D yöntemi ile elde edilen ölçümler % 85,7 oranla kabul edilebilir sınırlar dahilinde bulunmuştur ve 2D yöntemi ile arasındaki fark istatistiksel olarak anlamlı bulunmuştur (p <0.05). "Birden fazla kurvatüre sahip" kök kanallarında, 3D yöntemi ile yapılan kök kanal uzunluğu ölçümleri 2D metodundan daha güvenilir bulunmuş-*

tur. "Düz" kök kanalları için 2D yöntemi "Aşırı kurvatürlü"'kök kanallarına kıyasla gerçek kök kanal uzunluğuna önemli ölçüde yakın sonuçlar vermiştir (p <0.05). Sonuç: 3D yöntemi ile 2D yöntemine kıyasla daha doğru kök kanal uzunluğu ölçümleri elde edilebilinir. Hali hazırda mevcut bir KIBT görüntüsü varsa, büyük azı dişlerinde kök kanal uzunluklarının tedaviye başlamadan önce belirlenmesinde alternatif olarak kullanılabilinir. Anahtar Kelmeler: Konik-ışınlı bilgisayarlı tomografi, Kök kanalı, İki boyutlu, Üç boyutlu, Endodonti

Ethics Committee Approval: This study was approved by the Ethics Committee of Istanbul University Faculty of Medicine (Approval No. 18205).

Informed Consent: Informed consent was obtained from all participants.

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Author contributions: CB and OG participated in designing the study. ÖE and KBK participated in generating the data for the study. ÖE participated in gathering the data for the study. SÇD participated in the analysis of the data. CB, OG, KBK and SÇD wrote the majority of the original draft of the paper. KBK participated in writing the paper. CB, OG, SÇD have had access to all of the raw data of the study. CB has reviewed the pertinent raw data on which the results and conclusions of this study are based. CB, OG, ÖE, KBK and SÇD have approved the final version of this paper. SÇD guarantees that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

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Original research

The retreatment abilities of ProTaper Next and F6 Skytaper: a micro-computed tomography study

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Purpose
The aim of this study was to evaluate the retreatment abilities of the ProTaper Next (PTN) and F6 SkyTaper (F6) systems by using micro-computed tomography (micro-ct), radiographic and microscopic imaging techniques.

Materials and Methods
The root canals of twenty-six extracted mandibular premolar teeth were prepared and obturated. For the retreatment procedure, the teeth were randomly divided into two equal groups according to endodontic instruments: PTN (X4) and F6 (#40/.06). Pre- and post-operative filling material volumes were measured with micro-ct, and areas were measured with radiographic and microscopic imaging techniques. The percentages of residual material were calculated, and then statistically compared. The significance level was set at $p<0.05$.

Results
There was no statistically significant difference between F6 and PTN for retreatment efficacy in the micro-ct and radiographic imaging techniques ($p>0.05$). PTN demonstrated better cleaning ability when evaluated by microscopic imaging. ($p<0.05$). The correlation was moderate between micro-ct and radiographic, and micro-ct and microscopic imaging groups; however, it was strong between radiographic and microscopic imaging methods.

Conclusion
The PTN and F6 files had similar effects in the removal of filling material with micro-ct evaluation. The radiographic imaging method gave similar results with micro-ct imaging.

Keywords: *Micro-computed tomography, Microscopy, ProTaper next, Radiography, Retreatment*

Introduction

Non-surgical retreatment is the treatment of choice for teeth that have undergone failed root canal treatment. This procedure includes the total removal of previous root canal filling material, disinfection, reshaping and refilling (1). Remnant filling material on the root canal surface might cause the persistence of microorganisms and prevent the monobloc structure formation of new filling material with dentin (2). Therefore, the efficacy of the instruments used for retreatment procedures is important for the successful removal of the gutta-percha.

There are several techniques for the removal of gutta-percha, such as hand-files, rotary instruments, heated instruments, ultrasonic instruments, and lasers. The ProTaper Next (PTN) (Dentsply Maillefer, Ballaigues, Switzerland) produced from M-Wire alloy is a multi-file system, and the F6 SkyTaper (F6) (Komet, Lemgo, Germany) is a single-file NiTi system. These rotary systems are originally manufactured for endodontic treatment and proved to be efficient for retreatment procedures in previous studies (3-11).

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Micro-ct evaluation has been widely used to evaluate the amount of residual root filling material in recent studies (3-5, 12-14). It is accepted as the gold standard for being a reproducible and non-destructive method that provides a detailed evaluation of the three-dimensional morphological features of the observed object and also provides quantitative data (9). There are several other methods to evaluate remnant filling material, such as longitudinally dividing the roots to evaluate the canal walls microscopically or radiographically (11, 15-24). Evaluating residual material radiographically is a method based on detecting the radiopacity of filling material. Previous studies have compared microscopic and radiographic methods for evaluating retreatment procedures (19-21).

Until recently, there has been no study comparing PTN and F6 for retreatment efficacy or comparing microscopic and radiographic evaluation with micro-ct for retreatment. The aim of this study is to compare PTN and F6 in their ability to clean gutta-percha and as methods for retreatment evaluation. The null hypothesis is that there is no difference between PTN and F6 for gutta-percha removal and that there is no difference between the methods for retreatment evaluation.

Materials and Methods

Study design

The Ethical approval was obtained from the Ethics Committee of the Ankara Yildirim Beyazit University (research ID: 2018-242, decision date and number: 28.06.2018-11). Twenty-six mandibular premolar teeth extracted for periodontal or orthodontic reasons were stored in 0.1% thymol until the beginning of the experiment. The teeth were confirmed to have a single root and root canal, complete apex formation, and no internal calcifications/resorptions via radiographic and visual examinations.

Root canal filling

The teeth were decoronated by using diamond disks to standardize the root lengths at 17 mm. After decoronation procedure, the coronal openings of the root canals were examined under a dental operation microscope (Leica M320, Leica Microsystems, Wetzlar, Germany) to confirm to have a round shape at horizontal section. The working lengths were established as 16 mm. Root canal preparation was performed with PTN system instruments with the size of X3 (Dentsply Maillefer, Ballaigues, Switzerland). The root canals were irrigated with 2 mL of 17% EDTA and 2 mL 2.5% NaOCl solution. Apical patency was performed with #10 K-file. Then, the root canals were dried by paper-points. The root canals were obturated by lateral condensation technique using #30 master and #25 accessory gutta-percha cones. As root canal paste, AH Plus (Dentsply, Detrey, Konstanz, Germany) was used. The access cavity was sealed temporarily with CavitG (3M ESPE, Seefeld, Germany). The teeth were stored at 37°C and 100% humidity for four weeks.

Retreatment procedure

After the removal of the temporary sealing material, 2 mm of gutta-percha at the coronal part was removed with a #3 gates-glidden drill. A few drops of chloroform were used at this created space. After 30 seconds, the retreatment procedure was performed. The teeth were randomly divided into two groups for retreatment procedure as follows:

The PTN group (n=13): The root canal fillings were removed with X3 and X4 ProTaper Next instruments. In each instrument change, 3 mL of 2.5% NaOCl solution was used for irrigation procedure.

The F6 group (n=13): #30, #35 and #40 sizes of F6 SkyTaper instruments were used respectively for filling material removal. In each instrument change, 2 mL of 2.5% NaOCl solution was used for irrigation procedure.

A total of 6 mL 2.5% NaOCl solution was used for each tooth during the retreatment process. The instruments were used respectively with an electric torque-controlled motor (EndoTouch TC2; SybronEndo, Glendora, USA) at a speed of 300 rpm and a torque of 2.0 N/cm in brushing motion until reaching the working length. After the apical foramen was reached, a size 15 K-file was inserted 1 mm beyond the apical foramen to maintain apical patency. Each file was used once, and no instrument separation was observed during the procedure. The retreatment procedure was performed by a single operator.

Micro-ct Evaluation

For volumetric analysis of the filling materials, the teeth were scanned using micro-ct (SkyScan 1174, Bruker Micro-ct, Kontich, Belgium) before and after retreatment procedures with following scanning parameters: 50 kVp, 800 µA, a pixel size of 33 um, a beam hardening correction of 30%, a smoothing of 2 and a ring artifact correction of 6. Scanning was performed by 180° rotation around the vertical axis, a camera exposure time of 2.700 ms, a rotation step of 0.4°, and frame averaging of 3. Flat field correction and geometric correction for random movement were performed in all scans. The scanning procedure took approximately one hour per sample. Three-dimensional reconstruction data were obtained by NRecon software (version 1.6.9.4, Bruker micro-CT). For the calculation of the volume of the filling material, CTAn software (version 1.17.7.2, Bruker micro-CT) was used. Three-dimensional visualization and qualitative evaluation of the filling material were performed with CTVox software (version 3.3.0, Bruker Micro-ct). The examination of the images was performed by a blinded observer. Pre- and post-operative volumes of filling material were measured in mm^3, and then the percentage volumes were calculated (Figure 1, A-D).

Radiographic evaluation

The roots were digitally radiographed in approximal directions (Figure 1-E). The radiographic procedure was performed using a dental X-ray unit (Planmeca ProX, Helsinki, Finland) at 50 kVp, 8 mA and 0.01 s exposure time with a digital sensor (MPS, Progeny Dental, Buffalo Grove, USA). The digital software used was Soredex, Digora Optime (Kavo, Brea, CA, USA), which allowed the researchers to use all the options available such as brightness, contrast adjustment and magnification. The areas of remaining material and total root canal surface were measured using a software (ImageJ;

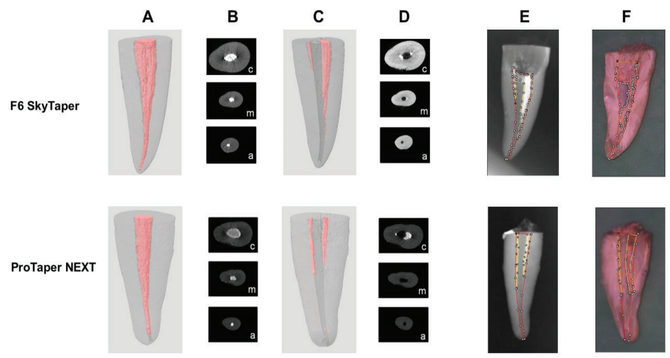

***Figure 1.** Images obtained with different observational methods: (A) pre-treatment and (C) post-treatment 3D images observed with micro-ct 3D imaging. (B) pre-treatment and (D) post-treatment cross-sectioning images with micro-ct; c = coronal, m = middle, a = apical. (E) radiographic, (F) microscopic images. Yellow lines mean filling material borders and red lines mean root canal borders at (E) and (F).*

Wayne Rasband, NIH, MD, USA). The percentage value calculation was obtained by dividing these two values. The percentage values were recorded for each sample.

Microscopic evaluation

The roots were longitudinally separated by using a diamond disk. The root halves with more remaining material for each tooth were chosen for analysis. The root halves were photographed under a dental operation microscope (Leica M320, Leica Microsystems, Wetzlar, Germany) at 25x magnification (Figure 1-F). By using the software (ImageJ), the areas of remnant material and total root surface were measured, and the ratio between the values was recorded as a percentage value.

The obtained percentages of PTN and F6 were compared with the methods of micro-ct, radiography and microscopy separately. The correlations for the three observational methods were analyzed.

Statistical analysis

The Shapiro-Wilk test was used to evaluate the assumption of normality. The percentage volumes of the remnant material for each file were normally distributed for micro-ct, while radiographic and microscopic techniques were distributed non-normally ($p<0.05$). For statistical comparison of the files with micro-ct, the independent sample t-test was used. The Mann-Whitney U test was used to compare the systems with radiography and microscopy. The Spearman correlation test was performed in order to evaluate the correlation between the observational methods. The significance level was set to $p< 0.05$ (SPSS v22.0 for Windows; SPSS Inc, Chicago, IL, USA).

Results

Comparison of files for retreatment efficacy

There was no significant difference between F6 and PTN for retreatment efficacy when the analysis was performed by micro-ct (P = 0.08) or radiographically (P = 0.057), while PTN proved to have better cleaning ability when evaluated by microscopy (P = 0.039) (Table-1). The study was completed with a statistical power of 50% (effect size = 0.80, α = 0.05) (G*Power 3.1.9.4 software; Heinrich Heine University, Dusseldorf, Germany)

Table 1. *Comparing remnant material percentages after instrumentation with ProTaper Next and F6 SkyTaper using different observational methods PTN: ProTaper Next, F6: F6 SkyTaper, SD: Standard deviation. [a] t value for t-test (normally distributed data), [b] Z value for Mann Whitney U test (non- normally distributed data).*

Imaging Methods	Instruments (n=13)	Residual material (%)		Test	P
		Mean ± SD	Median		
Micro-ct	PTN	0.14±0.09	0.13	0.031[a]	0.08
	F6	0.22±0.11	0.20		
Radiography	PTN	0.14±0.13	0.09	1.923[b]	0.057
	F6	0.27±0.21	0.22		
Microscopy	PTN	0.12±0.19	0.05	2.08[b]	0.039*
	F6	0.26±0.20	0.20		

Correlations among the evaluation techniques

The correlation (Spearman test) of the results obtained by radiography and microscopy was strong (rho = 0.744; P = 0.000), while the correlation was moderate for micro-ct and microscopy (rho = 0.466; P = 0.016), as well as the micro-ct and radiography groups (rho = 0.568; P = 0.002).

Discussion

This study investigated the filling material cleaning ability of F6 and PTN and compared them with three observational methods: micro-CT (the gold standard), radiography and microscopy. For the analysis and evaluation of filling material removal from the root canal space, the results obtained from micro-ct were accepted as the gold standard and the other observational methods were compared with micro-ct. When files were compared with micro-ct and radiography, there was no significant difference between the tested instruments in their ability of to remove gutta-percha. The tested null hypotheses were accepted when a comparison was made with micro-ct and radiographic techniques, but they were rejected for microscopy because PTN was found to be more effective with this method.

F6 and PTN files are both single-file systems and used in continuous rotation motion (25, 26). The differences between the systems are their cross-sections and the alloy type from which they were produced. F6 is a nickel-titanium system has an S-shaped section with two sharp cutting edges, and greater chip space, while PTN has a rectangular cross section with two cutting edges, and manufactured from M-Wire (25, 26). The rectangular cross-section design of the PTN system and greater chip space of F6 could be a facilitating factor for debris removal in the coronal direction, and may also remove filling material efficiently (26).

Although the mean percentage of remnant material for F6 was higher, there was no significant difference between the instruments statistically. A previous study comparing the F6 SkyTaper, Reciproc and Mtwo for residual material on the root canal walls filled with gutta-percha and AH Plus found no difference between them (11). There is no other study evaluating F6 for retreatment ability. Studies evaluating PTN and Reciproc systems for gutta-percha removal found similar results for these techniques (5, 9). Another study comparing WaveOne, PTN and RaCe also found no difference for retreatment ability (3). In all these studies, the final apical sizes of the groups were kept similar. In this study, initial enlargement was finished with PTN X3 file, and root canal filling was performed with lateral condensation technique with #30 master and #25 accessory cones in two groups. Lateral condensation technique with AH Plus was performed for the filling technique for its common usage (27-30). Apical preparation size after retreatment was set two sizes beyond the initial preparation size to reduce remnant material (31, 32). The retreatment procedure was finished with X4 file for the PTN group and #40 file for the F6 group; therefore, the final apical sizes and tapers for the groups were equal (#40/.06). It could be said, for the retreatment procedure, that the initial and final preparation enlargements were similar for the groups. The similarity for the percentages of the remnant material of the groups could be related to this methodological similarity between groups.

Total irrigant volume for groups during the retreatment procedure were equal to avoid a possible difference in remaining filling material depending on the different volumes of solution. Chloroform was used to solve gutta-percha to simulate clinical conditions, although it has been claimed that this pushes the softened gutta-percha into irregularities of the root canal walls and prevents the cleaning procedure (20).

When the groups were compared by micro-ct or radiography, there was no significant difference between them. But with microscopic evaluation, PTN proved to have better cleaning ability. One study comparing microscopic and radiographic methods for retreatment evaluation found radiographic evaluation more reliable because microscopic evaluation requires splitting the tooth and material removal might exist during the cutting procedure (33). Some other previous studies have claimed microscopy to be superior to radiographic evaluation, as regarding magnification and distortion possibility during radiographic imaging, small volumes of remnant material may not be visualized as detailed as in microscopic evaluation (19, 21, 34). In this study, some totally cleaned samples were detected only in microscopic evaluation groups, but residual filling material could be seen in these samples when evaluated with radiography or micro-ct. Although the correlation between radiography and microscopy was strong, the comparisons of the two files with these methods were different. Radiography gave similar results in the retreatment efficacy comparison of files with micro-ct.

Radiography gives two-dimensional information about a three-dimensional structure, while micro-ct is a non-invasive technique that provides qualitative and quantitative three-dimensional data for retreatment procedures (21, 35, 36). In this study, there was no significant difference when PTN and F6 were compared by micro-ct and radiography, but the correlation between micro-ct and radiographic techniques was moderate.

For radiographic and microscopic evaluation, the values were calculated as pixels and for micro-ct the values were calculated as mm^3. For all observational methods, the cleaning ability evaluation was made with percentages. Values were obtained by dividing pre- and post-operative values, to overcome the differences.

The option to use the radiographic method to assess the removal of filling material simulates clinical procedures as radiographs are used to detect the presence of remnant material on the root canal space for retreatment procedures (19, 23). Its clinical reliability was supported with the present study, as radiography gave similar results as micro-ct.

Conclusion

The efficencies of ProTaper Next and F6 SkyTaper files had similar effects in the removal of residual filling material from root canal space when evaluated with micro-ct. The radiographic method gave similar results with micro-ct, while the microscopic technique found the ProTaper Next to be more effective.

Türkçe Özet: *Protaper Next ve F6 Skytaper Sistemlerinin Tekrarlayan Kanal Tedavisindeki Yeteneği Açısından Farklı Görüntüleme Yöntemleriyle Karşılaştırılması: Mikro-Bilgisayarlı Tomografi Çalışması. Amaç: Bu çalışmanın amacı, mikro-bilgisayarlı tomografi (mikro-bt), radyografik ve mikroskobik görüntüleme tekniklerini kullanarak ve karşılaştırarak ProTaper Next (PTN) ve F6 SkyTaper (F6) sistemlerini tekrarlayan kök kanal tedavisindeki etkinlikleri açısından değerlendirmektir. Gereç ve Yöntemler: Yirmi altı adet çekilmiş alt çene küçük azı dişinin kök kanalları endodontik olarak genişletildi ve dolduruldu. Tekrarlayan kök kanal tedavisi prosedürü için dişler kullanılan eğelere göre rastgele iki eşit gruba ayrıldı: PTN (X4) ve F6 (# 40 / .06). İşlem öncesi ve sonrası kanal içi dolgu materyali hacimleri micro-ct ile, alanları ise radyografik ve mikroskobik görüntüleme teknikleriyle ölçüldü. Artık materyal yüzdeleri, iki enstrümantasyon sistemi için mikro-bt, radyografik ve mikroskobik görüntüleme yöntemleriyle karşılaştırıldı. Eğelerin etkinliğini istatistiksel açıdan karşılaştırmak amacıyla t-testi ve Mann-Whitney U testi kullanıldı. Görüntüleme yöntemleri arasındaki korelasyonu değerlendirmek için Spearman korelasyon testi yapıldı. Anlamlılık seviyesi $P < 0.05$ olarak belirlendi. Bulgular: Analiz mikro-bt ve radyografik görüntüleme teknikleriyle yapıldığında tekrarlayan kanal tedavisi etkinliği için F6 ve PTN arasında istatistiksel olarak anlamlı bir fark yoktu ($P > 0.05$), ancak mikroskobik görüntüleme ile değerlendirildiğinde PTN'nin daha iyi temizleme etkinliğine sahip olduğu görüldü ($P < 0.05$). Mikro-bt ve radyografik, ve mikro-ct ve mikroskobik görüntüleme teknikleri arası korelasyon orta düzeyde olup; radyografik ve mikroskobik görüntüleme teknikleri arasında yüksek düzeyde idi. Sonuç: PTN ve F6 sistem eğelerinin, mikro-bt ile değerlendirmede kanal dolgu materyalinin uzaklaştırılmasında benzer etkili olduğu görüldü. Radyografik görüntüleme yöntemi mikro-bt görüntüleme yöntemiyle benzer sonuçlar verdi. Anahtar Kelimeler: Mikro-bilgisayarlı tomografi, Mikroskop, ProTaper next, Radyograf, Tekrarlayan kanal tedavisi*

Ethics Committee Approval: Ethical approval was obtained from the Ethics Committee of the Ankara Yildirim Beyazit University (research ID: 2018-242, decision date and number: 28.06.2018-11).

Informed Consent: Participants provided informed constent.

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Author contributions: ES participated in designing of the study. ES and SİY participated in generating the data for the study. ES, SİY, MO and HHC participated in gathering the data for the study. ES, SİY, MO and FG participated in the analysis of the data. ES wrote the majority of the original draft of the paper. ES participated in writing the paper.

ES, SİY, MO, FG and HHC have had access to all of the raw data of the study. ES, SİY, MO, FG and HHC have reviewed the pertinent raw data on which the results and conclusions of this study are based. ES, SİY, MO, FG and HHC have approved the final version of this paper. ES guarantees that all individuals who meet the journal's authorship criteria are included as authors of this paper.

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Original research

In vitro accuracies of 3D printed models manufactured by two different printing technologies

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Purpose
This study aims to compare the accuracies of full-arch models printed by two different 3D printing technologies.

Materials and Methods
A mandibular horseshoe-shaped master model was designed with RapidForm XOR2 software The master model was printed 10 times with 3D printers using direct light processing (DLP) and PolyJet technology (n=20). The printed models were then scanned with an industrial scanner and saved in STL file. All digital models superimposed with the master model STL file and comparison of the trueness was performed using Geomagic Control 3D analysis software. The precision was calculated by superimposing combinations of the 10 data sets in each group.

Results
The trueness of printed models was 46 µm for the DLP printer and 51 µm for PolyJet printer; however, this difference was not statistically significant (p=0.155). The precision of printed models was 43 µm for the DLP printer and 54 µm for PolyJet printer. DLP printed models were more precise than the PolyJet printed models (p<0.001).

Conclusion
The 3D printing technologies showed significant differences in the trueness of full-arch measurements. Although DLP printed models had better trueness than PolyJet printed models, all of the 3D printed models were clinically acceptable and might be used for the production of fixed restorations.

Keywords: *3D printing, Direct light processing, Polyjet, Trueness, Precision*

Introduction

The introduction of dental CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) systems has considerable effects on the fabrication process of dental prostheses. As a result, advanced physical model requirement has been eliminated in most dental applications (1-3). With the recent development of dental scanners, patient's intraoral topography can be transferred to digital environment. There is no need for physical storage, and replication of models is easy and fast (2,4,5).

3D printing has the advantages of fast production, minimum waste of materials, complex geometry production, and multiple product manufacturing (4). 3D printing technology is currently used for the production of fixed prostheses, guides for implant surgery, models for orthodontic as well as maxillofacial surgery planning (2,6-9).

Currently, different techniques and technologies are available for producing dental models with 3D printers. Stereolithography (SLA), direct light processing (DLP), material jetting (PolyJet) 3D printing technologies are commonly used in dentistry (4,10). The DLP technology uses a high power LED,

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a digital projector, and a photopolymer liquid resin to produce objects layer-by-layer. DLP printers can cure the entire surface of the photopolymer resin in a single pass, and this leads to shorter printing times (4,11). The PolyJet technology has a similar mechanism of an inkjet printer, using liquid photopolymers rather than ink. PolyJet printers disperse the photopolymer over the workspace, and cure them with UV light source (6,12).

The accuracy term includes trueness and precision parameters. The deviation of the printed object from its actual dimensions is described as the trueness of a 3D printer (13). Higher trueness means that the dimension of the printed object is similar or equivalent to the reference object (14). On the other hand, the 3D printer's precision defined with the difference between repeated prints (13).

In the field of prosthetics, the accuracy evaluation of 3D printed dental models is limited (12,14,15). Therefore, this study aimed to compare the accuracies of models used for the production of fixed prostheses, printed with DLP and PolyJet printing technologies. The null hypothesis was that there is no statistical difference in the accuracy and trueness of models fabricated with two different 3D printers.

Material and Methods

Study model

An horse-shoe shaped master model simulating the mandibular arch was designed with CAD software (RapidForm XOR2, 3D Systems Inc, USA). Six abutments (10,15 mm height) with a 6º total angle of convergence and 1 mm at circumferential shoulder finish lines, mimicking prepared teeth (right mandibular second molar, right mandibular second premolar, right mandibular canine, left mandibular canine, left mandibular second premolar and left mandibular second molar) were positioned on the arch.

3D printing

The digital master model was then saved in Standard Tessellation Language (STL) file format and was transferred to each of the 3D printers. Ten models were manufactured for each printer by using two different printing technologies; DLP technology (Perfactory Vida, EnvisionTEC Inc., Dearborn, Michigan, US), and PolyJet technology (Objet30 Orthodesk, Stratasys Ltd., Eden Prairie, Minn, and Rehovot, Israel) (Figure 1). DLP printer used E-Model and PolyJet Printer used VeroDentPlus materials while printing. 20 models were printed in total. Corresponding numbers were given to the 10 models in each group. According to the manufacturer's recommendations, printed DLP models were soaked into isopropyl alcohol for post-process and waited 3 minutes for post-cure. The models printed with PolyJet printer were cleaned with a waterjet for 2 minutes and no additional post-cure process was required for PolyJet. The technical data of 3D printers are summarized in Table 1.

Digitization process of the models

An industrial structured blue LED light 3D scanner (ATOS Core 200 5M, GOM GmbH, Braunschweig, Germany), was selected as the reference scanner. According to VDI/VDIE 2634 Part 3 (VDI e.V.; Düsseldorf, Germany) maximum deviations were: 0,002 mm probing error form (Sigma), 0,004 mm probing error (size), 0.007 mm sphere spacing error and 0,008 mm length measurement error. The reference scanner was calibrated and was tested. Then, all printed models were scanned with the reference scanner, and each digital model was saved in STL file format.

3D comparison

Printed models were superimposed over the master model by using the best-fit alignment method of the 3D analysis software (Geomagic Control, 3D Systems, Rock Hill, SC, USA). Same method was used for each sample. A sample size of 15.000 points with a tolerance of 0.001 mm was used in 3D analysis. Root Mean Square (RMS) values were used for the trueness and precision comparisons. Trueness was assessed, in each case, by the superimposition of the master model data over the data sets obtained from the DLP and PolyJet models. Precision was determined by superimposing the combinations of the 10 data sets in each group (45 pairs for each printer technology). Color maps were also used to evaluate the distribution of 3-dimensional deviations which were spread over the complete surface of each printed model. In the color-coded maps, yellow-to-red fields indicated printed models which were larger than master model; and light blue-to-dark blue fields indicated printed models which were smaller than master model (Figure 2).

Statistical analysis

The statistical analysis was done with a significance level of 95% using statistical software (SPSS v20 for Macintosh; IBM Corp., Chicago, IL, USA). According to Kolmogorov–Smirnov test with Lilliefors Significance correction, variances were found to be normally distributed in trueness group ($p = 0.194$). Therefore, independent-sample *t*-test was used to analyze trueness values ($p=0.155$). Kolmogorov–Smirnov with Lilliefors adjustment test was conducted for testing normality ($p=0.009$) of the precision group. The normality assumption was not met, therefore, Mann-Whitney U test was used to evaluate the significant differences between groups ($p<0.001$).

Results

Trueness and precision

The mean trueness of DLP printed models was 46±9.86 µm, and for PolyJet printed models it was 51±5.11 µm (Figure 3). No significant differences were found between DLP and PolyJet printed models ($p=0.155$) in the comparison of trueness measurements. However, significant differences were found in the precision of the printed models. The mean precision of DLP printed models was 43±13.77 µm, and PolyJet printed models was 54±8.65 µm (Figure 3). DLP printed models were significantly more precise than PolyJet printed models. ($p<0.001$).

Color map evaluation

In the color maps, acceptable deviations were set in the range of ±30 µm (green areas) (Figure 3). In the trueness com-

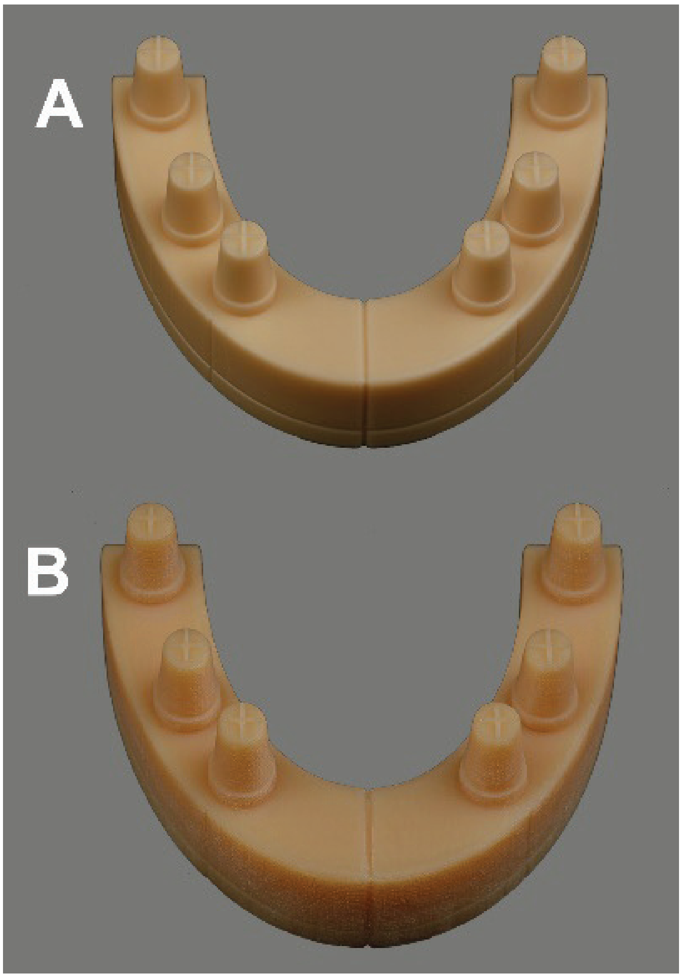

Figure 1. *The 3D printed models using DLP technology (A) and PolyJet technology (B).*

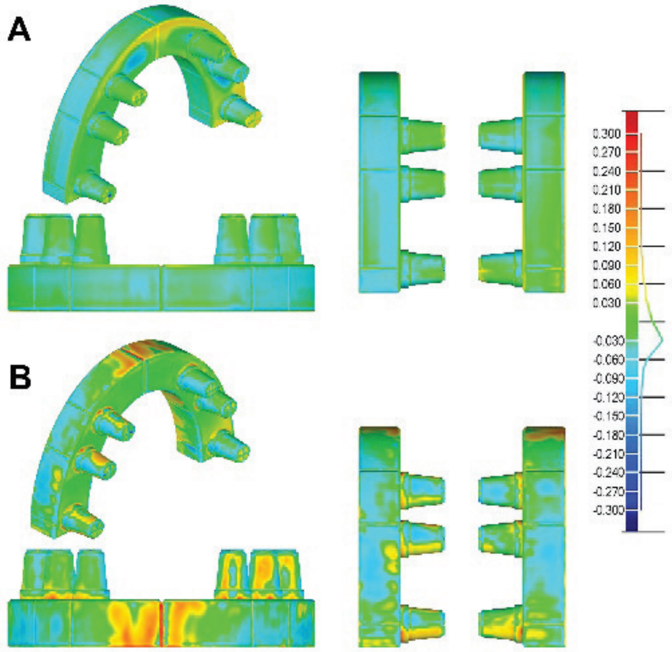

Figure 2. The color maps display the discrepancy between the printed models and the master model. The scale bar ranges from -300 to 300 µm. Light blue through dark blue color (-30 to -300 µm) indicates the printed model is smaller than the master model; green color shows difference ±30 µm between printed model and master model; yellow to red color (+30 to +300 µm) indicates printed model is larger than the master model. A: DLP, B: PolyJet.

parison, DLP printed models displayed a more homogenous pattern of green surfaces than PolyJet printed models. Lingual section of the arch showed a slight contraction. In the posterior region and the buccal of the posterior abutments, a slight expansion was observed on DLP printed models. On the other hand, PolyJet printed models displayed a slight expansion in the midline of the arch. Posterior abutments showed uneven deviations (mostly contraction). In some models, the circumferential expansion was observed in the posterior abutments (Figure 3).

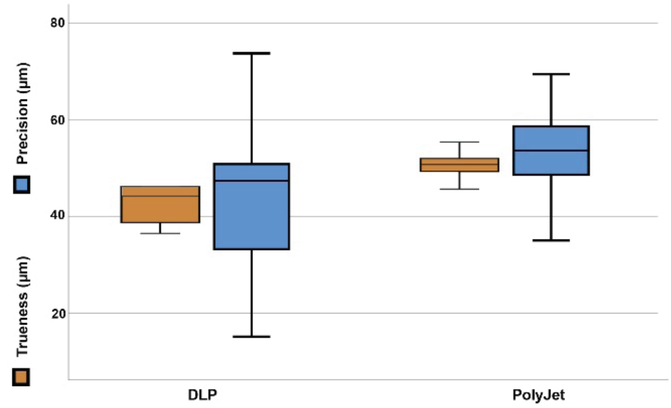

Figure 3. *Trueness and precision for DLP and PolyJet models. Orange color presents "trueness" and blue color presents "precision".*

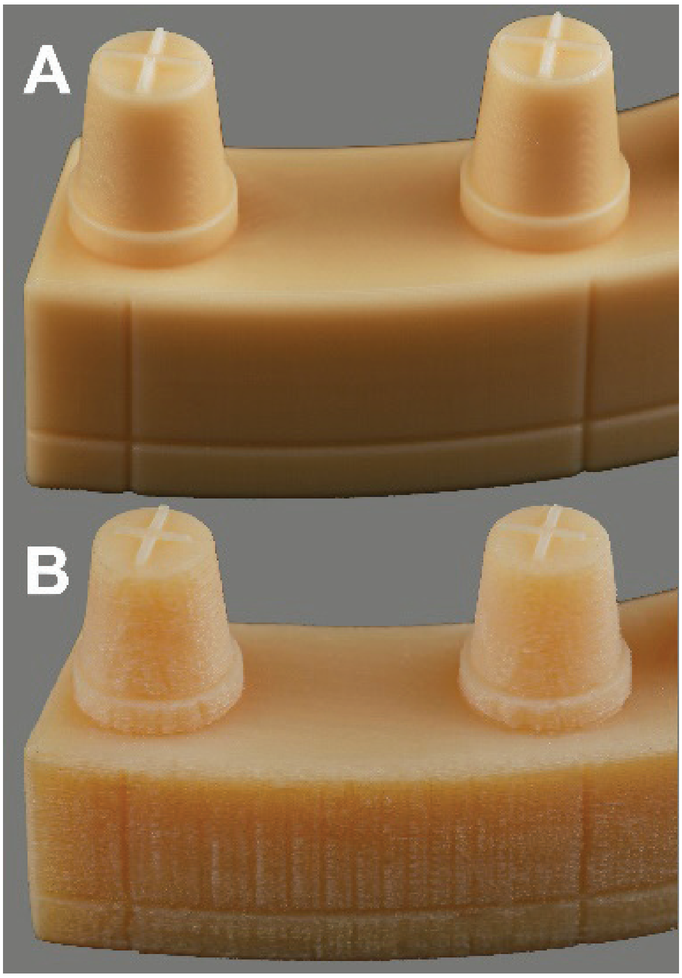

Figure 4. *The surface quality of 3D printed models. DLP printer used E-Model material, and PolyJet printer used VeroDentPlus material during the production of the models. DLP model has a smooth surface, and in contrast to DLP, PolyJet model has a rough surface. A:DLP, B:PolyJet.*

Table 1. *Technical data of tested DLP and PolyJet printers.*

Printer	Manufacturer	Technology	Material	Layer Thickness	Resolution (x-,y- and z-axis)
Perfactory Vida	envisionTEC	DLP (Direct light processing)	E-Model	50 µm	X&Y - 73 µm Z - 25 to 150 µm
Objet30 *Orthodesk*	Stratasys	PolyJet	VeroDentPlus	28 µm	X-axis: 600 dpi Y-axis: 600 dpi Z-axis: 900 dpi

Table 2. *Printing time and costs of models manufactured by DLP and PolyJet printers.*

Printer	Support Material	Post-cure	Post-process	Printing time	Cost of one model
Perfactory Vida	No need	3 min	2 min (isopropanol alcohol bath)	4 models in 1 hour	$ 2-9
Objet30 Orthodesk	SUP705	No need	2 min (waterjet)	2 hr, 30 min (one model)	$ 6,5

Discussion

According to the results of the present study, regarding the trueness and precision of two different printed models, the null hypothesis stating that the DLP printed models had no significant differences than PolyJet printed models was accepted. However, the null hypothesis on the precision variable was rejected.

The accuracy of the physical models might affect the misfit of fixed prostheses, which could lead to larger marginal or internal discrepancies before the prosthesis delivery (3,12). In the literature, the clinically acceptable range for the production of fixed prosthesis varies from 100 to 200 µm (16-18). In this study, the trueness of all printed working models found below 100 µm and therefore they were considered to be acceptable for clinical use.

The layer thickness, building direction, angle, intensity, laser speed, curing process, different printing technologies are influencing factors for the accuracy of printed models (19-23). When comparer to previous studies, the present one reveal inconsistencies because the accuracy of reference scanners, printer technology, print materials, the geometry of printed models, printing parameters and analysis methodology used in these studies vary. The accuracy of the scanner also affects the quality of the measurements. The scanner used in this study is an industrial scanner with an accuracy of 2 µm and might not have a significant effect on the results of this study.

In the current study mean RMS trueness values of DLP models were 46 µm and PolyJet models were 51 µm. Precision values were 43 µm for DLP models and 54 µm for PolyJet models. Some authors stated that there was no significant difference between SLA and DLP printers. They used a complete-arch model, and RMS trueness values were 85 µm and 105 µm for SLA and DLP printers, respectively. Furthermore, the precision of SLA printer was 49 µm, and DLP printer was 52 µm (14). The precision of their DLP printer was close to the one used in the present study; however, the trueness of DLP printer in our study was more accurate. Although the layer thickness was the same as the printer used in this study, photopolymer resin materials and printers' brands were different. These differences might have led to dimensional differences in printed models. According to Jin *et al*., mean trueness (RMS) of complete-arch SLA models was 114.3 µm, and PolyJet was 124 µm (12). Mean RMS precision values were 59 µm for SLA and 41 µm for PolyJet models. Kim *et al*. found the accuracy of complete-arch models 74 µm for DLP, and 69 µm for PolyJet and 176 µm for SLA printers (24). Besides, PolyJet and DLP models were found to be more precise than SLA. However, the layer thickness and X-Y resolution values of SLA and DLP printers were different from the current study. Dietrich *et al*. found trueness of two complete-arch models for PolyJet as 66 µm and 62 µm, for SLA models as 109 µm and 92 µm (25). Regarding precision, SLA models were found as 20 µm and 23 µm, PolyJet models were found as 46 µm and 38 µm. These values were close to the precision values calculatedin this study, and slight differences can occur among different printing materials and technologies. In the current study, DLP models showed better trueness values than the PolyJet models, and the reason for this might be the lower level of photopolymer shrinkage during photocuring. Jin *et al*. stated that more evaporation and contraction may occur on PolyJet models during the printing process (12). According to Rebong *et al*., expansion and/or shrinking of resin materials may occur during the printing process, and this could explain the trend of dimensional increase and decrease (26).

In our study, the layer thickness of PolyJet models was 28 µm, and DLP models was 50 µm. Although the layer thickness value of PolyJet printer was lower than DLP printer, PolyJet models were not more accurate than DLP models. According to Favero *et al*., this could be explained by the increased number of layers (20). Higher amounts of layers during the production of objects might increase the potential for errors and artifacts. Besides, Favero *et al*. stated that as the layer thickness decreases, the deviation value increases (20).

Regarding to the color maps, homogeneous green areas was observed in DLP models. The posterior region and the upper surface of the arch showed a slight expansion. Lingual region of the arch displayed a slight contraction (Figure 2). The lingual region of the arch had a smooth surface, and this causes polymers to contact evenly (4). PolyJet models displayed a localized expansion on the buccal of the arch, especially in the anterior region (Figure 2). The reason for this might be the expansion of the resin material during the printing process. In some models, the contraction was observed in the posterior region and abutments (Figure 2). This shrinkage pattern might be due to the higher photopolymer density in the posterior than the anterior (4).

The cost of one model and printing times varied among different printing technologies (Table 2). Perfactory Vida (DLP) prints four models in 1 hour, and Objet30 Orthodesk (PolyJet) prints one model in 2 hours 30 minutes. DLP printer needs less time to print models because of the high-resolution projector, which cures entire layers at once. Besides, DLP models can be printed with a smooth surface finish. However, the surface quality of PolyJet models was lower than DLP models (Figure 4). PolyJet printer used VeroDentPlus material, and a rougher surface finish was observed. This may be associated with the VeroDentPlus photopolymer material because smooth surface quality can be obtained using other photopolymer resins like VeroClear. In contrast to DLP models, the post-curing process is not necessary for PolyJet models.

In this study, only two different printers and printing materials were compared. Future studies should evaluate different printers, the role of layer thickness, new printing materials, the effect of building angle, and printing parameters to guide clinicians and dental laboratories for selecting appropriate printers.

Conclusion

3D models printed with DLP printer (46 µm) showed better trueness than models printed with Polyjet printer (51 µm), but this difference was not significant. On the other hand, DLP printed models (43 µm) showed better statistical precision of the complete-arch than the PolyJet printed models (54 µm) (p<.001). The current study demonstrated that physical working models manufactured with tested 3D printers are within the clinical tolerance, and both DLP and PolyJet printed models are suitable for the production of fixed prostheses.

Türkçe Özet: *İki Farklı Baskı Teknolojisi ile Üretilen 3 Boyutlu Modellerin Doğruluğu: In Vitro Üç Boyutlu Değerlendirme. Amaç: Bu çalışma, iki farklı 3 boyutlu baskı teknolojisi ile üretilen tam ark modellerin doğruluğunu karşılaştırmayı amaçlamaktadır. Gereç ve Yöntem: Mandibuler at nalı şeklindeki ana modeller RapidForm XOR2 yazılımı ile tasarlanmış ve tasarlanan ana modeller doğrudan ışık işleme (DLP) ve PolyJet teknolojisi kullanılarak 3 boyutlu yazıcılarla üretilmiştir (n=20). Üretilen modeller daha sonra endüstriyel bir tarayıcı ile taranarak STL dosyası şeklinde kaydedilmiştir. Elde edilen tüm dijital modeller, ana model STL dosyası ile üst üste çakıştırılmış ve doğruluğunun karşılaştırması Geomagic Control 3D analiz yazılımı kullanılarak gerçekleştirilmiştir. Doğruluk, her gruptaki 10 veri seti kombinasyonunun üst üste çakıştırılması ile hesaplanmıştır. Bulgular: Üretilen modellerin doğruluğu DLP yazıcı için 46 µm ve PolyJet yazıcı için 51 µm olarak bulunmuştur; fakat bu fark istatistiksel olarak anlamlı değildir (p=0.155). Üretilen modellerin hassasiyeti DLP yazıcı için 43 µm ve PolyJet yazıcı için 54 µm' dir. DLP yazıcı ile üretilen modeller PolyJet ile üretilen modellere göre daha hassastır (p<0.001). Sonuç: 3 boyutlu baskı teknolojileri, tam ark ölçümlerinin doğruluğunda önemli farklılıklar göstermiştir. DLP ile üretilmiş modellerin PolyJet ile üretilmiş modellere göre doğruluğu daha yüksek olmasına rağmen, tüm 3 boyutlu üretilmiş modeller klinik olarak kabul edilebilirdir ve sabit restorasyonların üretimi için kullanılabilir. Anahtar Kelimeler: 3 Boyutlu baskı, Direkt ışık işleme, Polyjet, Doğruluk, hassasiyet*

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Author contributions: FA and SA participated in designing the study. FA and SA participated in generating the data for the study. FA, SA, and GC participated in gathering the data for the study. FA SA, and GC participated in the analysis of the data. FA and GC wrote the majority of the original draft of the paper. SA participated in writing the paper. All authors have had access to all of the raw data of the study. All authors have reviewed the pertinent raw data on which the results and conclusions of this study are based. All authors approved the final version of this paper. All authors guarantee that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

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Original research

The in-vitro effects of white henna addition on the *Candida albicans* adhesion and physical properties of denture base resin

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Purpose
This *in-vitro* study evaluated and compared the effect of white henna (WH) and natural henna (NH) addition on *Candida albicans* adhesion and physical properties of the denture base material.

Materials and Methods
A total of 243 acrylic resin specimens (9 per group) were divided as follows: 81 for flexural strength, 81 for *Candida albicans* adherence test, and 81 for surface roughness, translucency, and hardness. Heat-polymerized acrylic resin specimens were prepared by adding 0.5, 1.0, 1.5, or 2.0 wt% of WH or NH. *Candida albicans* adhesion was determined using direct culture and slide count methods. Flexural strength, surface roughness, hardness, and translucency were measured using the three-point bending test, profilometer, Vickers hardness test, and spectrophotometer, respectively. ANOVA and post hoc Tukey's tests were performed for data analysis.

Results
Addition of 0.5% WH, 1% WH, and 0.5% NH to denture base resin significantly decreased *Candida albicans* adhesion ($p<0.05$). WH and NH significantly decreased the flexural strength and translucency, except 0.5% WH, and significantly increased surface roughness, except 0.5% WH and 0.5% NH. WH addition showed non-significant differences in the hardness, while NH addition significantly decreased hardness ($p<0.05$).

Conclusion
Addition of WH and NH decreased *C. albicans* adhesion to PMMA denture base resin. However, flexural strength, translucency, and surface roughness were adversely affected, particularly at higher concentrations. Hardness was reduced with NH only.

Keywords: *Antifungal agent, Candida albicans; Dental prosthesis, Henna, Physical properties*

Introduction

Polymethylmethacrylate (PMMA) was introduced as a denture base material due to its ease of fabrication, low cost, esthetics, ease of repair, and relatively low toxicity (1). However, the use of the denture intra-orally changes the bio-environment and paves the way for the deposition of biofilms (2). The porous and irregular surfaces of acrylic resins favor microbial adhesion, accumulation, and colonization, which are determining factors in the majority of oral diseases such as candidiasis, sore/burning mouth, and glossodynia (3). Moreover, improper denture hygiene results in debris accumulation and biofilm formation. This leads to inflammatory changes in the underlying mucosa and causes denture-related stomatitis (DS) (4). The role of *Candida albicans* (*C. albicans*) in the development of DS is associated with pathogenic overgrowth of *Candida* on denture sur-

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faces and the oral mucosa, which is widely accepted as an etiological factor (5,6).

The therapeutic strategies currently used to overcome these fungal infections are topical and/or systemic antifungal agents, topical antiseptics, and disinfectants (5). A commonly used antifungal agent known to be an effective treatment of DS is nystatin. However, nystatin is toxic and assists in the development of resistant strains of *C. albicans* (7). Unfortunately, the recurrence of DS may happen due to the short-acting effects of antifungal medications and the low salivary flow rate, making careful cleaning and disinfection of the denture post antifungal treatment crucial (7,8). This led researchers to adopt more incorporative approaches of natural extract-based antifungal agents into the acrylic resin of the denture base (9).

Several natural extract-based antifungal agents products could prevent DS (10-15). These products were found to be less costly, less toxic, and had reduced ability to produce resistant strains compared to pharmaceuticals (10,11). One of these natural antimicrobial products that could be incorporated into denture base is henna (12,13). Many studies have found that henna has an antifungal effect and could be used to treat fungal infections as a substitute to pharmaceuticals (16,17). Henna has been used in many cultures for the health and wellness of skin and hair, and for the treatment of body lesions caused by fungal infections for thousands of years. However, allergic reactions were found to be one of its side effects. Although few cases have been reported, it was declared that henna carries no genotoxic risk, as confirmed by Yusuf *et al.* (18-20).

In a study conducted by Nawasrah *et al.* (14), henna was used as an antifungal agent to prevent the occurrence of DS. This study recommended the use of henna in low concentrations, as high concentrations had an adverse effect on the denture's physical properties, namely color changes (21). Its incorporation in acrylic resin has provided a denture base with antifungal efficacy to control *C. albicans* proliferation (14). However, discoloration of the final product has limited its use. White henna (WH) is a completely synthetic material that originated in the 1970s. According to the manufacturer, WH is a dust powder and is composed of talcum, titanium dioxide, calcium carbonate, and menthol. The product is synthesized to bleach body hair and skin complexion. It is also used as a scrub to remove dead/damaged skin cells. The material also has the ability to withstand temperatures above 200 ºC (22). To the best of our knowledge, the effect of WH on denture base resin has not been investigated in the literature. We aimed to investigate the effect of WH on *C. albicans* adhesion as well as the physical properties of PMMA denture base material in comparison to a PMMA/NH composite. First, we propose that WH addition has antifungal effect. Second, we postulate that WH addition has no effect on the physical properties of PMMA and can be used as an alternative to NH for DS prevention.

Materials and Methods

Study design

A prior power analysis revealed that a total of 243 specimens (n = 9) were needed to adequately detect the differences between WH and NH at different concentrations and quantify their effect on the tested properties of modified denture base resin. In accordance with ADA specification No. 12 for denture base polymer, metal molds were prepared in dimensions of 65 × 10 × 2.5 mm for the assessment of flexural strength (n = 81) (23). For *C. albicans* adherence test (n = 81), surface roughness, hardness, and translucency (n = 81), the dimensions of the specimens were 10 × 20 × 2.5 mm. This resulted in a total of 243 specimens of heat-polymerized acrylic resin. The specimens were divided into 9 groups (n = 9) according to filler concentration (Table 1). The control group consisted of unmodified acrylic resin, while the other eight tested groups were prepared by addition of either type of henna at different concentrations (0.5%, 1.0%, 1.5 %, or 2.0 wt%) to acrylic powder (Major base 20, Major Prodotti Dentari, SPA, Italy).

White henna addition

WH (white henna, facial bleaching for face and neck, small size - 8850748038009) is a product that has obtained proper registration by the Ministry of Health. Licensed by FDA under registration number por 3/2541 and through por 4/2541. Natural extract of NH (Yamani henna powder, Harazi), was also used in the current study (14,24). An electronic scale was used to weigh the WH or NH, which were added separately to the PMMA powder in plastic beakers and mixed for 1 min. Next, they were mixed with PMMA powder and stirred in a blender at a rotating speed of 400 rpm for 30 min to achieve an equal distribution of henna within the acrylic powder.

Denture base resin preparation

Polymerization was carried out according to the method specified by the manufacturer and as prescribed in a previous study (25). After complete polymerization, the specimens were retrieved and finished by using a tungsten carbide bur (HM 79GX-040 HP; Meisinger) at 18,000 rpm followed by progressively finer cylindrical silicon resin burs (FINOPOL Polishers, 64830, LABOSHOP GmbH, Germany). Similar to the conventional method of denture polishing, only the cameo surfaces were polished by using a polishing cloth disc (TexMet C10in, 42-3210, Buehler GmbH, Germany) on a polishing machine (Metaserve 250 grinder-polisher, Buehler, Germany) at 100 rpm for five minutes under wet conditions (26,27). After ultrasonic cleaning, the specimens were stored for one week at 37 °C in distilled water that was changed daily to reduce residual monomers (28).

For the *C. albicans* adherence assay, specimens were sterilized with 70% alcohol then cleaned ultrasonically with sterilized distilled water. They were then incubated at 37 °C for two days in artificial saliva containing 2,000,000 *C. albicans* cells (ATCC 10231). The specimens were later washed and evaluated for attached and proliferated *C. albicans*. The specimens were incubated in a broth at 37 °C for 48 h after washing each specimen three times with phosphate-buffered saline (PBS). The broth was vibrated using a vortex followed by centrifugation of the tubes containing the specimens to yield a concentrated pellet of *C. albicans*. Later, two methods to count the number of adhered *C. albicans* to acrylic resin sample were used for each specimen.

Direct culture method - colony forming unit (CFU)

A 10 ml amount of each pellet was taken, serially diluted, and spread on a petri dish. The petri dish was incubated at 37 °C for 48 h. Colonies of *C. albicans* were counted using a marker pen counter (colony counter "Scienceware- bel-art products," Wayne, NJ, USA) in the quadrant where acceptable growth was noted and corrected for the dilution factor (14).

Slide count method

The collected candida pellets were placed on a slide count (Nebauer Slide Counter "Chambers-Marienfeld") after adding 2.5 ml of 0.4% solution of trypan blue in phosphate (MP-Biomedicals) to 7.5 ml of each sample for microscopic evaluation. The trypan blue stain can differentiate between dead and living *C. albicans*; dead cells usually appear blue in color while living cells appear transparent with a blue border. Using light microscope at low magnification (10X), the number of *C. albicans* was counted. The slide count usually contained four main squares; each is divided into 16 squares. *C. albicans* was counted in two main squares and multiplied by two to get the total number of *Candida* on the slide.

Physical properties

To determine the flexural strength, fracture load was measured using a three-point bending test on a universal testing machine (Instron, Model 2519-106, Norwood, MA, USA). Each specimen was placed on a 3-point flexure apparatus where the support span was 50 mm. Load was applied at the midpoint of the prepared area with a crosshead speed of 5 mm/min until the specimen fractured, and the maximum load at fracture was recorded. In order to calculate the flexural strength value of each specimen, the following formula was used: $FS = 3WL/2bd^2$ where FS is the flexural strength (MPa), b is the fracture load (N), W is the distance between the two supports, d is the specimen width, and L is the specimen thickness.

The surface roughness value (R_a, mm) was determined using a non-contact optical profilometer (Contour GT, Bruker Nano gmbH, Berlin, Germany). A linear variable differential transformer was installed to measure the surface morphology, while the numerical values of the surface profile were calculated on a computer to obtain the R_a. Three readings per specimen surface were measured (one at a midpoint and two at the margins) on each of the nine specimens per group, and the average R_a was recorded.

The hardness test was conducted using its corresponding tester (Wilson Hardness, ITW Test & Measurement GmbH, Shanghai, China) equipped with a Vickers diamond. An indenter (25-gf load) was applied for 30 s per specimen; the hardness values were digitally recorded for each specimen.

A reflectance value was measured using a spectrophotometer. A small size (10 × 7.5 mm) of aperture viewing area was selected. The spectrophotometer was calibrated using the provided white tile and black trap following the manufacturer's recommendations. Each specimen was stabilized against the port, supported at the back by a white or black reference material with the support arm closed. Color measurements of the coordinates (L*, a*, b*) of the CIE system were made for every disc against each background. Three readings were made for each specimen and the average was automatically presented by the software. Data was tabulated and translucency was calculated using the following equation $TR = [(L^*white - L^*black)^2 + (a^*white - a^*black)^2 + (b^*white - b^*black)^2]^{1/2}$ (26).

Statistical analysis

Normality in the data set was checked using a Shapiro-Wilk test. The test outcome provided insignificant p-values, proving that the data were normally distributed. Hence, statistical tests used for further analysis were parametric tests. One-way Analysis of variance (ANOVA) was conducted to determine the effects of white henna and natural henna on *C. albicans* adhesion, flexural strength, surface roughness, hardness, and translucency of the modified PMMA denture base resin. Tukey's honestly significant difference (HSD) post hoc test was used to determine differences in measurements between the different denture base materials. The correlation between measurements was tested using Pearson correlation analysis. For all comparisons, statistical significance difference was accepted to be $p<0.05$.

Results

ANOVA was used to test the overall significance of all properties between all groups (Table 2). After obtaining significant *p*-values from both WH and NH, pairwise comparisons were done using Tukey's HSD post hoc test (Table 3 and 4). Means, standard deviations, and statistical significances of *Candida* adhesion are summarized in Table 3. The results showed that the amount of *C. albicans* adhesion varied depending on the type of henna and their concentrations according to the variance analysis ($p < 0.05$) (Table 3).

In the direct culture method (Figures 1 and 2), Figure 2 showed that the addition of 0.5% NH and 0.5% WH significantly decreased *C. albicans* adhesion in comparison to the control group ($p < 0.001$) and had a value of (1007.2 ± 44.1) and (561.1 ± 17.0), respectively. However, henna concentrations of more than 0.5%, significantly increased *Candida* adhesion in comparison to the control group ($p < 0.001$). When utilizing the slide count method, it was noted that concentrations of 0.5% and 1.0% of the NH groups and 0.5% of the WH groups significantly decreased the *C. albicans* adhesion compared to the control group ($p < 0.001$), ($p < 0.001$), and ($p < 0.001$) by values of (2268 ± 139.7), (3207 ± 132.5) and (1920.2 ± 69.5), respectively. Other concentration groups (more than 0.5% NH & 1.0% WH) showed a significant increase in *C. albicans* adhesion compared to the control group ($p < 0.01$).

Between the NH and WH groups, a significant difference ($p < 0.001$) was found between all concentration groups except between 1.0% NH and 1.5% WH ($p = 0.18$) groups in terms of direct count. In addition, no significant differences were noted between 0.5% NH and 1.5% NH ($p = 0.994$) as well as 0.5% NH and 1.5% WH ($p = 0.999$), or between 1.5% NH and 1.5% WH ($p = 0.827$) in terms of slide count.

One-way ANOVA revealed NH and WH addition affected flexural strength (Table 2). The results showed that addition of NH and WH showed a statistically significant decrease in the flexural strength in comparison to the control group ($p<0.001$), except for the 0.5% WH group as it showed the highest FS value (83.09±0.98 MPa) (Table 4). Comparing NH groups, a significant decrease in FS was found between all groups ($p<0.001$). FS decreased as NH concentration increased where 2.0% NH had the lowest FS value (57.61 ± 1.20 MPa). Similarly, a significant decrease in FS was found between all groups of WH addition ($p < 0.0001$). FS decreased as WH concentration increased where 2.0% WH had the lowest FS value (59.5 ± 1.02 MPa). When comparing the NH and WH groups the NH and WH groups, significant differences were found between all groups except 0.5% NH and 1.0% WH ($p \approx 1.0$) and between 1.0% NH and 2.0% WH ($p = 0.993$).

One-way ANOVA revealed that NH and WH addition significantly affected surface hardness ($F = 12.978$, $p < 0.001$) (Table 2). The mean surface hardness and standard deviation of tested groups are summarized in Table 4. In comparison to the control group, the results showed a significant decrease in the hardness of all NH groups and 2.0% WH addition ($p < 0.001$) while there was no statistical significant difference at 0.5% WH ($p = 0.601$), 1.0% WH ($p = 0.416$) and 1.5% WH ($p = 0.221$). Additionally, the highest hardness value was reported in the control group (38.67 ± 1.33 VHN). The results showed that the addition of NH to PMMA denture base resin significantly decreased the hardness values in comparison to the control group ($p < 0.001$) while WH addition showed no significant difference in hardness values ($p > 0.05$), except the 2% NH group ($p = 0.022$).

Comparing NH groups, insignificant differences in hardness were found between all groups. The hardness value was lowest in the 1.0% NH group (31.05 ± 2.03 VHN). In between WH groups, insignificant differences in hardness was found between all groups ($p > 0.05$). The lowest hardness value was observed in the 2.0% WH group (35.39± 2.28 VHN). In comparison, between the NH and WH groups, insignificant differences were found between the 0.5% NH and 2.00% WH ($p = 0.352$) and the 0.5% NH and all NH groups, where the p-values were: 1.0% NH ($p = 0.334$), 1.5% NH ($p = 1.00$), and 2.0% NH ($p = 0.809$). Also, insignificant differences were found between 1.00% NH and 1.5% NH ($p = 413$), 1.5% NH and 2.0% NH ($p = 0.744$), and 1.5% NH and 2.0% WH ($p = 0.289$). There were insignificant differences found between 2.0% NH and all WH groups, where the values were: 0.5%WH ($p = 0.601$), 1.0% WH ($p = 0.416$), 1.5% WH ($p = 0.221$), and 2.0% ($p = 0.998$).

One-way ANOVA results showed that NH and WH additions significantly increased surface roughness ($F = 177.283$, $p = 0.000$) (Table 2). In comparison to the control group, Tukey results (Table 4) showed a significant increase in R_a with NH and WH addition ($p < 0.001$) in all percentages, except for 0.5% NH ($p = 1.00$) and 0.5% WH ($p = 0.999$) addition groups. Addition of 2.0% NH had the highest R_a value (0.51 ± 0.03 µm). When comparing NH groups, a significant increase in R_a in all groups was observed ($p < 0.001$). Similarly, between WH groups, a significant increase in R_a in all groups ($p < 0.001$) was noted. R_a increased as the concentration of NH and WH increased where 2.0% NH had the highest value (0.51 ± 0.03 mm). Non-significant differences were found when NH and WH were compared at 0.5% NH and 0.5% WH ($p = 1.00$), 1.0% NH and 1.0% WH ($p = 0.999$), and at 1.5% NH and 1.5% WH ($p= 0.989$).

One-way ANOVA proved NH and WH addition significantly affected translucency ($F = 370.890$, $p < 0.001$) (Table 2). As shown in Table 4, a significant decrease in the translucency was found with NH and WH additions in comparison to the control group ($p < 0.001$), except for 0.5% WH ($p \approx 1.00$); the control group had the highest translucency value (15.82). Comparing NH groups, a significant decrease in translucency was found between all groups ($p < 0.001$). The translucency value decreased as NH concentration increased and 0.5% NH showed the highest translucency (12.79 ± 0.61) while 2.0% NH showed the lowest translucency value (4.82 ± 0.29). In between the WH groups, in between WH groups, a significant decrease in translucency was noted between all groups, except for 0.5% WH ($p \approx 1.00$). The translucency value decreased as WH concentration increased where 2.0% WH had the lowest translucency value (8.17 ± 0.33). Also, non-significant differences were found between NH and WH for 0.5% NH and 1.0% WH ($p = 0.093$) and 1.0% NH and 1.5% WH ($p = 0.342$).

Discussion

The incorporation of antifungal agents in polymeric materials is considered a good alternative for slow and prolonged

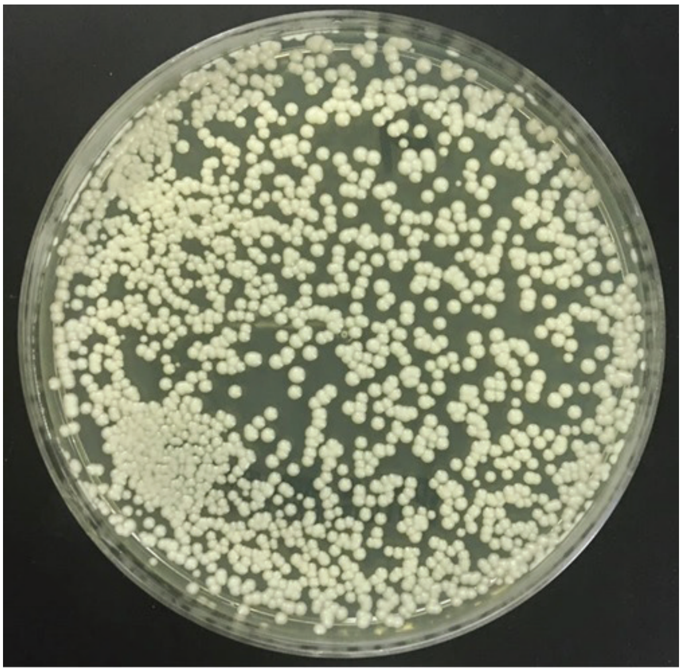

Figure 1. *Direct culture method for Candida count - control group (unmodified group).*

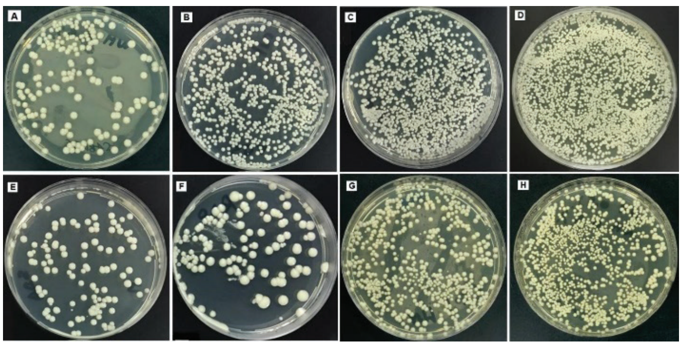

Figure 2. *Direct culture method for Candida count - Henna modified groups A-D NH group; E-H WH group.*

drug release in the mouth and may be therapeutically useful against *C. albicans* since it does not depend on patient cooperation (7,11,12). Moreover, it would maintain constant and prolonged contact of the antifungal agent with the oral tissues. It has been reported that a large portion of topical drugs used in fighting DS are lost from the oral cavity during the first three hours due to the diluting effect of saliva, and the cleaning effect generated by movement of the oral musculature that results in possible reduction of the therapeutic effect (6,8). Consequently, henna addition was suggested to be incorporated into denture base materials (21). This study hypothesized that henna has antifungal effects that may aid in the prevention of DS without compromising the denture base's physical and mechanical properties. This was confirmed through our results, which suggest low concentrations of henna can offer an antifungal activity preventing DS; however, it compromises the physical and mechanical properties of the denture base to some extent.

Henna is a readily available and cheap powder that has been proven to have some antifungal properties (17). It can be incorporated into the denture's base material in certain concentrations, making it cost effective and able to prevent recurring DS. This method results in what has been called a potential antimicrobial denture base; however, concerns of alterations to the mechanical and physical properties of the denture base rise with such procedure (14,29).

The results of this study have shown that a 0.5% concentration of either WH or NH as well as 1.0% WH reduced *C.*

Table 1. *Grouping of the specimens according to NH and WH concentrations.*

Group	Specifications
Control	Unmodified acrylic resin
I Natural Henna (NH)	Acrylic resin modified with 0.5% NH
	Acrylic resin modified with 1.0% NH
	Acrylic resin modified with 1.5% NH
	Acrylic resin modified with 2.0% NH
II White henna (WH)	Acrylic resin modified with 0.5% WH
	Acrylic resin modified with 1.0% WH
	Acrylic resin modified with 1.5% WH
	Acrylic resin modified with 2.0% WH

Table 3. *Mean (SD) and significant differences of C. albicans adhesion count (CFU/mL) according to henna type and concentration. Same lowercase letter in respective column indicated insignificant differences between tested groups whereas the level of significance was 0.05.*

Group	%	Mean(SD)	
		Direct culture method	Slide Count method
Control	0	1348.0(23.8)	3265.0(135.3)
NH	0.5%NH	1007.2(44.1)	2268.0(139.7) [a,b]
	1.0%NH	2061.4(31.1) [a]	3207.0(132.5)
	1.5%NH	2313.0(167.3)	5462.0(92.2) [a,c]
	2.0%NH	3207.0(132.5)	7357(296.4)
WH	0.5%WH	561.1(17.0)	1920.2(69.5)
	1.0%WH	1107.1(12.8)	3311.5(105.1)
	1.5%WH	1565.2(31.6) [a]	4618.5(140.1) [b,c]
	2.0%WH	2746.1(114.6)	6706.0(128.9)

Table 2. *ANOVA of direct culture, and slide count tests for Candida adhesion, flexural strength test, hardness test, surface roughness test, and translucency.*

			Sum of Squares	df	Mean Square	F	Sig.
Candida Adhesion	*Direct culture*	Between Groups	60995760.422	8	7624470.053	1079.225	.000
		Within Groups	572245.900	81	7064.764		
		Total	61568006.322	89			
	Slide count	Between Groups	295844993.622	8	36980624.203	1632.860	.000
		Within Groups	1834468.200	81	22647.756		
		Total	297679461.822	89			
Flexural Strength		Between Groups	6763.106	8	845.388	628.953	.000
		Within Groups	95.432	71	1.344		
		Total	6858.538	79			
Hardness		Between Groups	411.141	8	51.393	12.978	.000
		Within Groups	285.116	72	3.960		
		Total	696.257	80			
Surface roughness (Ra)		Between Groups	1.069	8	.134	177.283	.000
		Within Groups	.054	72	.001		
		Total	1.124	80			
Translucency		Between Groups	1150.665	8	143.833	370.890	.000
		Within Groups	27.922	72	.388		
		Total	1178.587	80			

Table 4. *Mean (SD) and significant differences of flexural strength, hardness, surface roughness, and translucency of tested specimens according to henna type and concentration.*

Group	%	Mean(SD)			
		Flexural strength (MPa)	Hardness (VHN)	Surface roughness (µm)	Translucency
Control	**0**	82.79(1.78) [a]	38.67(1.33) [a]	0.19(0.012) [a]	15.82(1.1) [a]
NH	**0.5%NH**	79.67(0.68) [b]	33.23(2.20) [b]	0.19(0.01) [a,b]	12.79(0.61) [b]
	1.0%NH	70.80(0.64) [d]	31.05(2.03) [b,c]	0.35(0.04) [c]	10.65(0.65) [c]
	1.5%NH	62.57(1.10) [c]	33.12(3.04) [b,c,d]	0.41(0.02) [d]	5.91(0.52)
	2.0%NH	57.61(1.20)	34.72(1.02) [b,d,e]	0.51(0.03)	4.82(0.29)
WH	**0.5%WH**	83.09(0.98) [a]	36.52(2.79) [a,e,f]	0.20(0.01) [a,b]	15.69(0.51) [a]
	1.0%WH	77.77(1.54) [b]	36.78(0.99) [a,e,f]	0.35(0.02) [c]	13.65(0.61) [b]
	1.5%WH	71.32(1.10) [d]	37.12(0.81) [a,e,f]	0.40(0.02) [d]	11.33(0.69) [c]
	2.0%WH	59.95(1.02) [c]	35.39(2.28) [b,d,e,f]	0.46(0.03)	8.17(0.33)

Same lowercase letter in respective column indicated insignificant differences between tested groups whereas the level of significance was 0.05.

albicans adhesion and subsequently, DS, in accordance with previous studies (14,16). While naphthoquinones are considered to be the main active molecules that give natural henna this antifungal property, the antifungal activity of WH is gained from its ingredients: talcum, titanium dioxide, calcium carbonate, and menthol (22). These chemicals were able to withstand the high temperatures PMMA is subjected to during curing (22). Further investigations are still required as WH showed over one-fold greater (55.7%) antifungal activity than NH at the same concentrations (0.5%).

A correlation between surface roughness and *C. albicans* adhesion and colonization has been reported (30). Surface roughness is an important property of the denture base material that influences plaque and microbial adhesion (31,32). A rough denture surface provides more area for microbial adhesion. In addition, it protects entrapped microorganisms from shearing forces during denture cleaning, making their removal difficult even when using antimicrobial agents (33). According to the findings of the current study, as NH and WH concentrations increased, *C. albicans* colonies increased, and this increase in colonies was proportional to the increase in surface roughness reported with modified groups.

The present study has shown that the addition of WH or NH decreases the FS of modified denture base in a direct relation to the filler concentration compared to non-modified denture base. Regardless, the decrease observed in some concentration groups remained above the minimally accepted FS value according to ISO: 1567 standard requirements (65 MPa) (23,34). The groups that met the standard requirement were 0.5%, 1.0%, and 1.5% of WH as well as the 0.5% and 1.0% NH groups. In alignment with previous reports, the addition of low concentrations (0.5%, 1.0%) of thymoquinone antifungal agent did not affect the FS of PMMA denture base material (25).

A significant decrease was also noted in the modified denture base hardness value in all NH groups, which was in agreement with Nawasrah *et al*., and only the 2.0% concentration of WH groups (24). Unaffected WH groups may be attributed to the synesthetic constituents of WH, where particles were well distributed and bonded to PMMA. This effect is observed up to 1.5% concentration, above which resin saturation is attained and hardness is decreased.

The decrease in FS and hardness values may be attributed to the additive in the PMMA denture base material since it interferes with the integrity of the polymer matrix (30). These added particles could be aggregate-forming clusters acting as stress-concentration areas within the matrix (22,24). The weak bond between NH and the PMMA resin matrix makes the added henna act as an impurity, which resulted in an adverse effect on the degree of conversion. This, in turn, led to an increase in the level of residual unreacted monomer that acted as a plasticizer (22,35).

The oral tissue conditions under the denture base are affected by the surface properties of the denture base. Previous studies have suggested that surface roughness was found to be directly proportional to microorganism attachment to the denture base (24,32). The results of present study showed that that the specimens' R_a values significantly increased as the NH and WH concentrations increased. The increase in R_a values with high henna concentrations might be explained by the presence of some loosely attached particles of NH and WH on the resin surface which could easily be removed during the finishing and polishing phases, leaving voids (22).

The maximum acceptable R_a of removable prostheses for clinical use is 0.2 µm (31). In this study, both NH and WH at 0.5% concentration had lower R_a values (0.19 µm), which is considered clinically acceptable. This suggests that the limit for addition in relation to R_a is 0.5% for both henna types. Nawasrah *et al*., studied the effect of NH addition to PMMA denture base and noted that surface roughness increased as the percentage of henna increased, in consensus with this study (24).

The success of a removable prosthesis relies on the appearance of the denture base in relation to that of the patient's oral mucosa, and the translucency of the material itself. To offer prosthesis with a natural look, the level of translucency is critical. Therefore, it is important to create a harmonious optical property between the removable prosthesis and the underlying mucosa giving a "chameleon" effect, allowing the underlying soft tissues to show through the PMMA denture base (26). A significant decrease in translucency was noted with NH and translucency decreased as the concentrations of NH increased. On the other hand, 0.5% WH did not change the translucency in comparison to the control group, yet slight changes in translucency were found in 1.0% and 1.5% WH. The difference in the results may be attributed to henna color, where NH was found to be grey and WH was white. This resulted in different color absorption or reflection ability. Specimens with high concentrations of NH seemed black in color, while specimens containing high concentrations of WH appeared white.

White henna showed promising results that might help in the prevention of DS even with the alterations of the physical and mechanical properties of PMMA. This can be achieved when adding WH at 0.5% and 1.0% concentrations. An acceptable concentration of NH was found to be 0.5%, while higher concentrations lead to poor physical and mechanical properties of PMMA. It is recommended that future studies test the antifungal activity of WH at lower concentrations and its effect on the physical and mechanical properties of PMMA. Further investigation including aging effects such as water immersion, thermal cycling, and the longevity of the antifungal effect would also be very interesting and highly beneficial.

Despite some key foundational successes from which to build on, this *in-vitro* study also suffered some limitations. We noted the lack of use of other types of denture base materials; the lack of proper simulation of the oral environment, precluding dynamic movements; thermal changes; saliva with prospective pH; and the presence of other microorganisms that may affect the denture base properties and *C. albicans* adhesion.

Conclusion

Within the limitations of this study, the following conclusions can be drawn: the addition of 0.5%, 1.0% WH, and 0.5% NH to denture base material decreased *C. albicans* adhesion. However, increased concentrations of either type of henna yielded higher *C. albicans* adhesion. The addition of either type of henna decreased the flexural strength, especially at high concentrations. NH addition decreased the hardness, while no change in hardness with WH addition was observed. The addition of 0.5% WH or NH did not affect surface roughness, while higher concentration produced rougher surfaces. NH addition decreased translucency, while 0.5% WH addition did not show any changes in translucency.

Türkçe Özet: *Beyaz henna ilavesinin protez kaidesi reçinelerine candida albicans tutunması ve fiziksel özelliklerine in vitro etkisi. Amaç: Bu in-vitro çalışmada, protez kaide materyaline beyaz henna (BH) ya da doğal henna ilavesinin (DH) Candida albicans tutunması incelenmiştir. Ayrıca, bu akrilik materyalinin fiziksel özellikleri de değerlendirilmiştir. Gereç ve Yöntem: Toplam 243 akrilik Reçine örneğin (grup başına 9 örnek), 81'i bükülme dayanımını, 81'i Candida albicans tutunumunu, 81'i yüzey pürüzlülüğünü, geçirgenliğini ve sertliğini test etmek için kullanılmıştır. Isı ile polimerime olan akrilikten yapılmış olan örnekler, % ağırlıkça 0.5, 1.0, 1.5, or 2.0 BH ya da NH içerecek şekilde hazırlanmıştır. Candida albicans tutunumu, direkt kültür ve koloni sayma yöntemleri uygulanarak ölçülmüştür. Bükülme dayanumı, yüzey pürüzlülüğü, sertliği ve geçirgenliği sırası ile üç-nokta bükme testi, profilometre, Vickers sertlik testi, ve spektrofotometre ile ölçülmüştür. Veri analizi için ANOVA ve post hoc Tukey's testleri kullanılmıştır ($\alpha = 0.05$). Bulgular: Protez kaide reçinesine 0.5% BH, 1% BH, ya da 0.5% DH ilavesi Candida albicans tutunumunu anlamlı şekilde düşürmüştür ($p < 0.05$). BH ve DH, 0.5% lik BH hariç bükülme dayanımı ve geçirgenliği anlamlı şekilde düşürmüş, 0.5% BH ve 0.5% DH haricinde de yüzey pürüzlülüğünü arttırmıştır ($p < 0.05$). BH ilavesi, sertlikte istatistiksel olarak anlamlı olmayan değişiklikler gösterirken, DH ilavesi sertliği anlamlı olarak azaltmıştır ($p < 0.05$). Sonuç: BH ve DH ilavesi akrilik protez kaide reçinesine C. albicans tutunumunu azaltmaktadır. Fakat, bükülme dayanımı, geçirgenlik ve yüzey pürüzlülüğü üzerinde özellikle yüksek konsantrasyonlarda tam ters etki göstermiştir. Sertlik sadece NH ile azalmıştır. Anahtar Kelimeler: Antifungal ajan, Candida albicans, Dental protez, Henna, Fiziksel özellikler*

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Author contributions: MA, RA and MMG participated in designing the study. AA and RA participated in generating the data for the study. MA, AA,RA and ZA participated in gathering the data for the study. ZA and SQK participated in the analysis of the data. MA, AA and ZA wrote the majority of the original draft of the paper. MA, RA, ZA, MFE and MMG participated in writing the paper. MA, SQK and MMG have had access to all of the raw data of the study. MA, AA, RA, MFE and MMG have reviewed the pertinent raw data on which the results and conclusions of this study are based. All authors have approved the final version of this paper. MA and MMG guarantee that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

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Original research

Root canal length measurement of molar teeth using cone-beam computed tomography (CBCT): comparison of two-dimensional versus three-dimensional methods

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Purpose
This study aimed to evaluate the validity of 2-dimensional (2D) and 3-dimensional (3D) cone-beam computed tomographic (CBCT) root canal length measurements of molar teeth compared with actual root canal lengths and the influence of canal curvature on the accuracy of CBCT measurements.

Materials and Methods
Seventy root canals of 24 molar teeth were scanned using CBCT, and the root canals were categorized as; 'straight/curved,' 'highly curved,' and 'multiple curved.' The 2D measurements were performed within a suitable slice between the major foramen and the corresponding cusp. The 3D measurements were performed within the slices in regular intervals of axial planes in between the same reference points. The reproducibility and reliability of the methods were analyzed by intraclass correlation coefficient. Differences between the actual and CBCT root canal lengths were evaluated by chi-square and McNemar tests if the measurements were within acceptable limits of ±0.5 mm.

Results
Both methods were found to be reproducible and presented excellent reliability. However, the 3D method was significantly more accurate, with an 85.7% frequency of measurements within acceptable limits ($p<0.05$). In 'multiple curved' root canals, the 3D method presented more reliable measurements than the 2D method. For 'straight/curved' root canals, the 2D method gave results significantly closer to the actual root canal length in comparison with 'highly curved' root canals ($p<0.05$).

Conclusion
The 3D measurements are more accurate than 2D measurements. If an already existing CBCT is present, it could be an alternative method for predetermination of root canal lengths in molar teeth.

Keywords: *Cone-beam computed tomography, Root canal, Two-dimensional, Three-dimensional, Endodontics*

Introduction

The cone-beam computed tomography (CBCT) is a diagnostic imaging modality that provides a 3-dimensional (3D) visualization of the maxillofacial region. Because CBCT has the advantage of lower radiation dose compared with computed tomography (CT), it has become a useful method for treatment planning in various dental specialties, including endodontics (1-3). Currently, CBCT has an essential role in endodontic research for detecting apical periodontitis in both pre- or post-endodontic treatment, root fractures, perforations, internal/external root resorption, treatment planning in apical surgery or dental trauma cases, as well as exploration of root canal anatomy (4-11).

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CBCT has many advantages over periapical or panoramic radiography such as the absence of image distortion, magnification, and superimposition but the radiation dose is significantly higher (12-14). In endodontics, the application of CBCT should be preferred when the third dimension is needed to perform an accurate diagnosis. However, it should not be used routinely (14). Furthermore, already existing CBCT data should be analyzed to obtain additional information within the FOV for details outside the region of interest. This may decrease the need for additional periapical radiographs (15, 16).

CBCT images of the scanned area could be visualized in mesio-distal, bucco-lingual, coronal planes, as well as in three orthogonal planes at the same time. This enables the observer to examine the root canal curvatures and the position of the major foramen location, which is not always possible using periapical radiography (3). Some investigators reported in in-vitro, in situ , and in-vivo studies that the improved visualization of root canal morphology with CBCT could increase the accuracy of root canal length determination (17-25). In most of these studies, single-rooted teeth with straight single root canals were preferred in a vertical position to visualize, whenever possible, the whole length of the canal in a single slice (17, 20, 21, 23-25). Some of these studies concerned the accuracy of root canal length determination with CBCT in multi-rooted or curved root canals (18, 19, 22, 26, 27). Few studies compared 3D and 2D measurements (19, 21). Therefore, the aims of the present study were; first to compare the validity of 2D and 3D CBCT root canal length measurements and second, to evaluate the influence of root canal curvature on the accuracy of both CBCT root canal length measurement methods.

Materials and Methods

Study sample

Approval to use extracted human teeth in this study was granted by the Ethics Committee (Project No: D-KA 17/12). A priori power analysis revealed that the minimum sample size should be 70 root canals for α= 0.05 and to reach the power of 80%. Freshly extracted lower molar teeth were collected. Teeth with cracks, resorption, fractures, immature apexes, previous root canal treatment, amalgam, or crown restorations, extensive coronal caries resulting in loss of cusp structure/ points of reference, signs of hypercementosis, were excluded. Finally, a total of 70 root canals of 24 lower molar teeth were included. The teeth were kept in 10% formalin solution. After cleaning the calculus and soft tissue remnants, each tooth was numbered on the buccal surface and embedded into rectangular models with a height of 3.5 cm and a length of 4 cm, made from silicone putty (Zetaplus, Zhermack, Marl, Germany). A total of 6 silicone models with 4 teeth embedded in each were obtained. Also, a thin metal rod was placed on the front surface of each silicone model to determine the buccal surfaces of the teeth.

Imaging protocols

Preoperatively, teeth were scanned with a CBCT device (Carestream Kodak 9300 C; Rochester, New York, USA) at 80 kV and 10 mA, 8.01 s exposure time, (100x100 mm FOV) and 180 µm voxel size. CS 3D Viewer Software (Carestream Kodak 9300 C; Rochester, New York, USA) was used for the reconstruction of the images and the measurements of the root canal curvatures. If the root canal had one curvature and measured <25°, it was classified as 'straight/curved,' otherwise it was considered 'highly curved' (18). If the root canal had more than one curvature, it was classified as 'multiple curved' The open source software OsiriX-Lite DICOM Viewer (Pixmeo, SARL, Switzerland) was used for the measurements of the root canal lengths. A single experienced investigator performed all measurements in the CBCT images.

2D measurements

The 2D measurements of the root canal lengths on CBCT images were performed as described by Janner et al. (23). For the measurement of each root canal length, the coronal reference point was taken as the corresponding/adjacent cusp (buccal cusp for buccal root canal) and the apical reference point was taken as the major foramen. Firstly, the tooth was rotated by the operator to adjust the coronal and axial planes until the long axis of the root canal, the coronal reference, pulp chamber, major foramen, and, if possible, the whole length of the canal in one single slice made visible. The selection of the most suitable slice, either the sagittal or coronal one, was dependent on the curvature of the root and location of the major foramen. In highly curved and multiple curved root canals, the polyline tracing tool was used, following each visible canal curvature in the respective CBCT slice (24). The measurements obtained were recorded as 2D CBCT root canal length (Figure 1). Except for the rotation procedures and saturation/contrast adjustments, the images were not manipulated.

3D measurements

The 3D measurements of the root canal lengths on CBCT images were performed as described by Tchorz et al. (19). The major foramen, as the most apical reference point, was detected in the sagittal and axial planes. The center of the root canal in all following axial slices were pointed in regular intervals until the coronal reference point is reached. The coordinates of all points were documented and the 3D CBCT root canal length measurements were obtained by adding the distances between adjacent points (Figure 2). The 3D measurements were performed 2 weeks after the 2D measurements are completed. Reproducibility of all CBCT measurements was determined by repeating the measurement procedures after 1 month.

Actual root canal length measurements

The specimens were removed from their models, and the endodontic access cavities were prepared. The pulp tissues were removed using barbed broaches. After controlling the patency with the #8 K-File (Dentsply Maillefer), coronal flaring was performed using SX rotary files (ProTaper, Dentsply Maillefer, Ballaigues, Switzerland) to gain straight-line access. The actual root canal lengths were determined by a different blinded investigator, by inserting the 10 K-file into the root canal until the file tip became visible at the apical foramen under 4x magnification using an operating microscope (Leica Microsystems, Wetzlar, Germany). The rubber stop was placed at the predefined coronal reference point, and the actual root canal length was measured using an electronic digital caliper with a resolution of 0.01 mm (Allendale Electronics Ltd, New Scotland, Canada). After repeating the measurements, the average of two measurements was recorded as the actual root canal length.

Statistical analysis

IBM SPSS Statistics 22 (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp, USA) software was used for statistical evaluation. Intraclass correlation coefficients (ICCs) were used to analyze the reproducibility of both 2D and 3D CBCT root canal length measurements, and also to assess the reliability of CBCT in measuring root canal length. In addition, chi-squared and McNemar tests were used to evaluate the differences between the actual and CBCT root canal lengths if the CBCT measurements were within acceptable limits of ±0.5 mm. Significance was assessed at $p < 0.05$ level.

Results

According to the root canal curvature classification; 35 (50%) of the root canals were 'straight/curved,' 24 (34.3%) were 'highly curved,' and 11 were (15.7%) 'multiple curved' root canals (Figure 3). Since an excellent reliability was observed between the first and second values of the CBCT 3D (ICC =0.992; CI 95%: 0.988-0.995, p: 0.000) and 2D measurements (ICC = 0.965; CI 95%: 0.944-0.978; p: 0.000), the first measurements were used in the other comparisons of the study.

Mean variation between measurements of actual root canal lengths and 2D CBCT root canal lengths was 0.5 mm (ICC = 0.943; CI 95%: 0.910-0.964; p: 0.000) and for 3D CBCT root canal lengths it was 0.28 mm (ICC = 0.979; CI 95%: 0.968-0.986; p: 0.000). In 60 root canals (85.7%), measurements of 3D CBCT root canal length were within acceptable limits (±0.5 mm); in 10 root canals (14.3%), 3D CBCT measurements were short. In 46 root canals (65.7%), measurements of 2D CBCT root canal length were within acceptable limits; in 5 root canals (7.1%), 2D CBCT measurements were long, while in 19 root canals (%27.1) 2D CBCT measurements were short. According to these findings, measurements of 3D CBCT root canal length were significantly more accurate than the measurements of 2D CBCT (p:0.005; $p<0.05$; Mc Nemar Test).

In 'straight/curved' and 'highly curved' root canals, both 2D and 3D CBCT root canal length measurements presented strong, positive, and significant correlations with actual root canal lengths (p: 0.000, $p<0.05$). In 'multiple curved' root canals, 3D CBCT root canal length measurements presented excellent reliability (ICC= 0.930; CI 95%: 0.867-0.964; p: 0.000) with actual root canal lengths, whereas 2D CBCT root canal length measurements presented substantial reliability (ICC= 0.698; CI 95%: 0.204-0.909; p: 0.006). Between the subgroups of curvature classification, in comparisons according to acceptable limits, 2D CBCT measurements showed a significant difference (Table 1), unlike 3D CBCT measurements (Table 2). In two-paired comparisons, the differences between 'straight/curved' and 'highly curved' root canals were found to be significant (p:0.006; $p<0.05$).

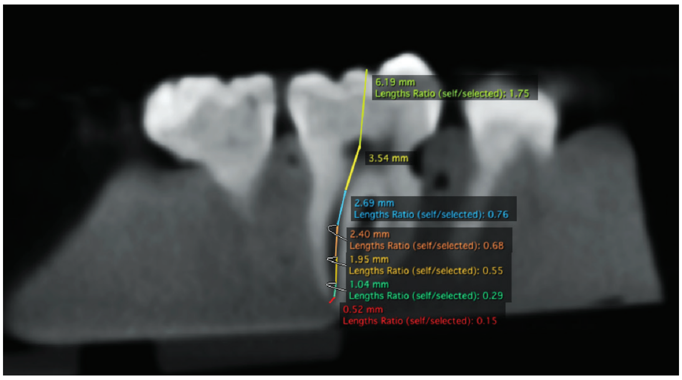

Figure 1. *Representative illustration of a two-dimensional cone-beam computed tomographic measurements of root canal length.*

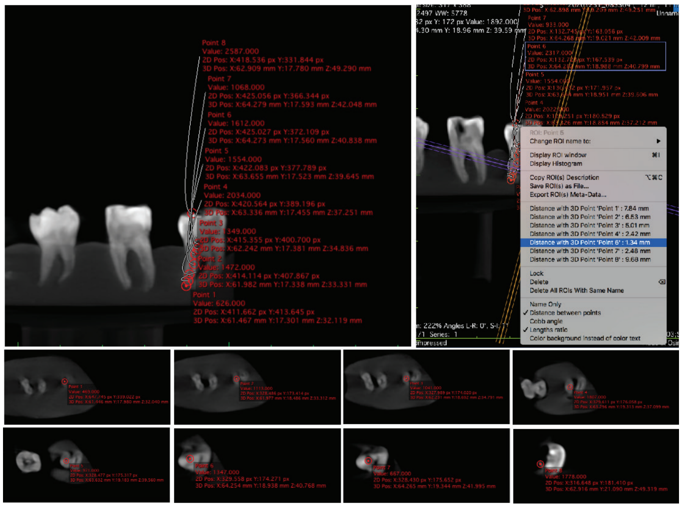

Figure 2. *Representative illustration of a three-dimensional cone-beam computed tomographic measurements of root canal length.*

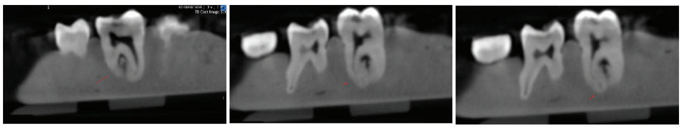

Figure 3. *Sagittal slices of a root canal with multiple curves.*

Table 1. *Evaluation of the accuracy (±0.5 mm) between the measurements of actual and 2D CBCT root canal lengths according to curvature classification Chi-Square test (*p<0.05).*

	CBCT 2D			
	Within acceptable limits (±0.5 mm)	**Longer than actual root canal lengths (>0.5 mm)**	**Shorter than actual root canal lengths (<0.5 mm)**	**p**
	n (%)	**n (%)**	**n (%)**	
Straight Curved	27 (77.1%)	4 (11.4%)	4 (11.4%)	0.039*
Highly Curved	13 (54.2%)	0 (0%)	11 (45.7%)	
Multiple Curved	6 (54.5%)	1 (9.1%)	4 (36.4%)	

Table 2. *Evaluation of the accuracy (±0.5 mm) between the measurements of actual and 3D CBCT root canal lengths according to curvature classification (Chi-Square test).*

	CBCT 3D			
	Within acceptable limits (±0.5 mm)	Longer than actual root canal lengths (>0.5 mm)	Shorter than actual root canal lengths (<0.5 mm)	p
	n (%)	n (%)	n (%)	
Straight/ Curved	30 (85.7%)	0 (0%)	5 (14.3%)	0.237
Highly Curved	21 (87.5%)	0 (0%)	3 (14.2%)	
Multiple Curved	9 (81.8%)	0 (0%)	2 (18.2%)	

Discussion

Our results suggest that 2D and 3D CBCT measurements are both reproducible and successful methods for predetermination of root canal length in molar teeth. However, the 3D method displayed significantly more accurate root canal length determination, and excellent reliability compared to the 2D method. In 'multiple curved' root canals, the 3D method presented more reliable measurements than the 2D method. The 2D method showed a tendency for underestimation of the 'highly curved' root canals compared to 'straight/curved' root canals (Table 1).

In most of the previous studies on the predetermination of root canal length using CBCT, teeth with straight and single root canals have been used, and 2D measurements have been performed in 3D environment (17, 20, 23-25). Only one study compared 2D and 3D CBCT approaches for predetermination of root canal length in molar teeth (19). According to the findings of that one, which are in agreement with ours, differences between actual root canal lengths and 3D measurements were significantly less than those seen with 2D measurements. Mean discrepancies were 0.32 and 0.58 mm, respectively. A high correlation was found between the actual root canal length and 3D measurements, and 80% of the 3D measurements were within acceptable limits.

In previous in-vitro studies using the 2D approach, Lucena *et al.* (18), Connert *et al.* (22), and Metska *et al.* (26) (in-situ) reported the mean discrepancies of 0.59 mm, 0.41 mm, and 0.74 mm for anterior, 0.51 mm for posterior teeth between the measurements of CBCT and actual root canal lengths, respectively. On the other hand, in a very recent in-vitro study, Yilmaz et *al.* (20) have found that measurement of root canal length with CBCT at different voxel sizes resulted in underestimation of between 1.16 and 1.63 mm. In addition, in clinical studies that used the 2D approach, Janner *et al.* (23) and Jeger *et al.* (24) reported a mean discrepancy of 0.4 mm and 0.51 mm between the measurements of CBCT and electronic apex locator, respectively. Similarly, Ustun *et al.* (25) found no significant difference between CBCT measurements and electronic apex locator (25). These researchers commonly concluded that existing CBCT images might be useful for endodontic working length determination.

Since CBCT became popular in endodontics as the imaging modality for treatment planning in complex cases, most patients who apply for root canal treatment might already have an existing CBCT (14). The incidental appearance of the endodontic treatment planned tooth in the field of view (FOV) would provide valuable information about the complexities such as curvatures, confluences and predetermination of the root canal length (15, 16, 20, 22). While most of the CBCT software currently in use can measure 2D root canal length with the linear measurement tool, it is impossible to measure 3D root canal length with the same practicality. Drawing a point-route by following the canal trajectory from axial sections and measuring each point›s distance will be very difficult and time-consuming when considering the clinical reality. Besides, measurements with non-automated programs can be affected by the skills and experience of the operator. Based on this fact, a new CBCT software that presents automated functions for preoperative root canal length measurement has been developed and the predetermination of the root canal lengths was found to be reliable (21, 27, 28).

Based on the results obtained from both previous studies and the present study, an already existing CBCT image can be useful in predetermining the working length in endodontic clinics and may result in the need for fewer periapical radiographs, which will support the 'as low as reasonably achievable' (ALARA) principle of radiology (15, 17-28).

Conclusion

3D measurements of root canal length in molar teeth are more accurate than 2D measurements and already available CBCT scans could be an alternative method for predetermination of root canal length in molar teeth. Further clinical studies using the 3D method will also contribute to clarifying this issue.

Türkçe Özet: *Konik-ışınlı bilgisayarlı tomografi (kıbt) kullanılarak molar dişlerde kök kanal uzunluğu ölçümü: iki boyutlu ve üç boyutlu yöntemlerin karşılaştırılması. Amaç: Bu çalışmada amaç, büyük azı dişlerinin 2 boyutlu (2D) ve 3 boyutlu (3D) konik-ışınlı bilgisayarlı tomografik (KIBT) yöntemleri ile gerçekleştirilen kök kanal uzunluğu ölçümlerinin, gerçek kök kanal uzunluklarıyla uyumunun incelenmesidir. Gereç ve yöntem: 24 büyük azı dişe ait 70 kök kanalı KIBT ile tarandı ve kök kanalları eğimlerine göre "Düz", "Aşırı kurvatürlü" ve "Birden fazla kurvatüre sahip" olarak sınıflandırılmıştır. 2D ölçümler, uygun bir KIBT kesitinde, kök kanalının foramen apikalesi ile ilgili kanalın tüberkül tepesi referans alınarak yapılmıştır. 3D ölçümler, aynı referans noktaları arasında düzenli aralıklarla ilerleyen aksiyal kesitler içerisinde gerçekleştirilmiştir. KIBT ile ölçüm yöntemlerinin tekrarlanabilirlik ve güvenilirlik analizinde Sınıf İçi Korelasyon Katsayısı kullanılmıştır. Gerçek kök kanal uzunluğu ve KIBT ile kök kanal uzunluğu ölçümleri arasındaki farkların kabul edilebilir sınırlar dahilinde (± 0,5 mm) olup olmadığı ki-kare ve McNemar testleri ile değerlendirilmiştir. Bulgular: Her iki yöntemin de tekrarlanabilir olduğu ve mükemmel güvenilirlik sağladığı gözlemlendi. Bununla birlikte, 3D yöntemi ile elde edilen ölçümler % 85,7 oranla kabul edilebilir sınırlar dahilinde bulunmuştur ve 2D yöntemi ile arasındaki fark istatistiksel olarak anlamlı bulunmuştur (p <0.05). "Birden fazla kurvatüre sahip" kök kanallarında, 3D yöntemi ile yapılan kök kanal uzunluğu ölçümleri 2D metodundan daha güvenilir bulunmuştur. "Düz" kök kanalları için 2D yöntemi "Aşırı kurvatürlü""kök kanallarına kıyasla gerçek kök kanal uzunluğuna önemli ölçüde yakın sonuçlar vermiştir (p <0.05). Sonuç: 3D yöntemi ile 2D yöntemine kıyasla daha doğru kök kanal uzunluğu ölçümleri elde edilebilinir. Hali hazırda mevcut bir KIBT görüntüsü varsa, büyük azı dişlerinde kök kanal uzunluklarının tedaviye başlamadan önce belirlenmesinde alternatif olarak kullanılabilinir.*

Anahtar Kelimeler: Konik-ışınlı bilgisayarlı tomografi, Kök kanalı, İki boyutlu, Üç boyutlu, Endodonti

Ethics Committee Approval: This study was approved by Baskent University Institutional Review Board (Project No: D-KA 17/12).
Informed Consent: Participants provided informed consent.

Peer-review: Externally peer-reviewed.

Author contributions: SNS and OG participated in generating the data for the study. SNS and OG participated in gathering the data for the study. SNS and OG participated in the analysis of the data. SNS wrote the majority of the original draft of the paper. SNS and OG participated in writing the paper. SNS has had access to all of the raw data of the study. SNS has reviewed the pertinent raw data on which the results and conclusions of this study are based. SNS and OG have approved the final version of this paper. SNS guarantees that all individuals who meet the Journal's authorship criteria are included as authors of this paper. SNS and OG participated in designing the study.

Conflict of Interest: Authors had no conflict of interest to declare.

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Original research

Evaluation of the distance between the central teeth after frenectomy: a randomized clinical study

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Purpose

The present study aimed to evaluate the periodontal status and the distance between the teeth one year after frenectomy in patients with abnormal frenums in the maxillary and mandibular midline.

Materials and Methods

This study included 50 patients (24 men and 26 women) between the ages of 13 and 53 who have frenum-induced diastemas between the incisors. The abnormal frenums were removed via conventional frenectomy. The distances between the teeth before and one year after the surgery were measured with a caliper. To determine the periodontal status, the pocket depth, plaque index, and bleeding on probing were measured from four surfaces. In addition, the amount of attached gingiva and degree of gingival recession were recorded and were statistically analysed.

Results

A significant decrease in the distance between teeth before and after frenectomy was observed ($p<0.05$). There was a statistically significant difference in the amount of gingival attachment, pocket depth, degree of gingival recession, plaque index, and bleeding on probing ($p<0.05$).

Conclusion

The removal of abnormal frenums with frenectomy can contribute to the reduction in the distance between the teeth. In addition, frenectomy increases the amount of gingiva and decreases the depth of the pocket, gingival recession, amount of plaque, and bleeding.

Keywords: *Abnormal frenum, Frenectomy, Diastema, Mucogingival surgery, Muscle attachment*

Introduction

The frenum is a folded anatomical structure that consist of mucous membrane, connective tissue, and occasionally of myofibers. The labial frenum is triangular in shape, connecting the cheek and lips to the alveolar mucosa/gingiva and the periosteum (1). Frenum-related problems are common in the canine, premolars, and sublingual regions (2). When the frenum attachment point is on the edge of the gingiva, it can cause several problems. Stress caused by this type of high frenum attachment can cause the free gingiva to shift in the apical direction. Frenums decrease the vestibule sulcus depth and increase plaque accumulation due to gingival recession as a result of the stress they create, making it difficult to practice good oral hygiene (3,4).

Frenums have been classified as mucosal, gingival, papillary, or papillary penetrating according to their attachment level and location (5). Based on morphology, frenums are classified as long-thin or short-thick

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(6). Abnormal frenums, often seen between the incisors, can cause gingival inflammation, loss of papillae, gingival pocket formation, and diastemas. Thus, they may lead to psychological problems due to aesthetic reasons (4,7). Accordingly, frenums may require surgical removal.

Frenectomy is the surgical removal of an entire frenum with its attachment to the underlying alveolar bone. This procedure separates the structure of the frenum with an incision. There are three techniques to surgically remove a frenum. These periodontal surgical operations are conventionally performed using a scalpel, electrosurgery, or soft tissue lasers (8,9). Each technique has certain advantages and disadvantages. Many surgical techniques, such as classic frenectomy, Miller's technique, V-Y plasty, and Z plasty, are used in conventional frenectomy (8).

The current studies on frenums mostly regard wound healing after the operation (1,2,9). Thus, data in the literature on measuring the distance between teeth after frenectomy are limited. This study aims to measure the distance between the teeth of patients one year after classical frenectomy. The null hypothesis tested is that the frenectomy procedure does not affect the periodontal variables and the distance between the teeth.

Patients and Methods

Participants and study design

This was a cross-sectional randomized clinical study that was approved by the Ethics Committee of the Adıyaman University Faculty of Medicine (protocol no: 2019-3). The study group consisted of patients who were randomly selected between 18 March 2019 and 18 March 2020. 50 participants (26 female, 24 male) scheduled to undergo frenectomy procedure whose age ranged between 13 and 53 years were enrolled in the present study. Before the procedure, the objectives of the study were explained to the patients, and informed consent forms that clearly stated that participation in the study was voluntary were collected. This study was conducted in patients who were admitted to the Periodontology Clinic of the Adıyaman University Faculty of Dentistry. The patients were systemically healthy, did not use any drugs, and had good oral hygiene habits.

The study was conducted by a single periodontist (AT) to standardize oral examinations, measurements, and surgical operations. Patients with abnormal frenums in the gingiva, papilla, and papillary penetration site between the central incisors of the maxilla and mandible and patients with a diastema equal to or greater than 1 mm between the central incisors were included in the study. The frenums were cut and completely removed with a pair of haemostats and a scalpel no. 15. Then, the tissues with fibrous muscle attachments under the periosteum were released, and the wound edges were primarily sutured with silk sutures. Healing was uneventful. Their appearance before and after frenectomy is shown in Figure 1.

Measuring the distance between the teeth

One year after the surgery, the distance between the teeth in the relevant areas were measured on plaster models fab-

Figure 1. *a. Clinical view of a patient before frenectomy b. Sutures in place c. Post-operative view.*

ricated before and after the operation from three points of patients' teeth with a digital stainless steel caliper (Mitutoyo, Kanagawa, Japan) (measuring range 0-150 mm/6 inches, and sensitivity of 0.01 mm). The first measurement was the distance between the horizontal plane passing through the incisal edges of the teeth and the points where the long axes of the teeth intersect the passing plane. The second measurement was the distance between the horizontal plane passing through the midpoints of the clinical crowns of the teeth and the plane passing through the long axes of the teeth and the points intersecting the plane passing through the midpoint of the teeth. The third measurement was the distance between the horizontal plane passing through the cement-enamel junction in the cervical region of the teeth and the intersections of the plane parallel to the long axes passing through the midpoints of the teeth.

Periodontal examination

In our research, periodontal examinations of the teeth of individuals in the area where frenectomy were performed on the four surfaces of each tooth. The gingival index, plaque index, amount of gingival attachment, and pocket depth of teeth were measured (10). The pocket depth was measured by a calibrated periodontist (AT) using a periodontal probe (Williams probe) (Hu Friedy, Chicago, USA) that provided millimetric measurements. Gingival attachment was measured by the distance between the fold created in the mucosa and gingival edge using dental tweezers according to the Wrinkle method (11).

Statistical analysis

Statistical analysis of the data was performed with SPSS Statistics 15.0 for Windows (SPSS Inc., Chicago, IL, USA). Parametric tests were used to compare normally distributed continuous variables. The measurements were evaluated as the arithmetic mean ± standard deviation (SD). A dependent t-test was used to compare binary variables obtained from intra-group measurements. An independent t-test for binary variables between groups and a one-way ANOVA test for more than two variables were used. To compare more than two inter-group variables, the Tukey test for post-hoc analysis was employed. The level of significance for was set to $p<0.05$.

Results

Of the 50 participants, 24 (48.0%) were male and 26 (52.0%) were female. Their age range was 13 to 53 years (average age: 25.80±13.41 years). The distribution of the gender, average age, frenum morphology, frenum location, frenum attachment location, and recurrence rate after frenectomy are presented in Table 1. Measurements of the distance between the teeth before and after frenectomy are shown in Table 2. A statistically significant difference was found among the average distance measurements and three other points of the teeth (p<0.05). In particular, the decrease in the distance between the midpoints of the teeth was remarkable (p=0.005). Periodontal measurements of the teeth and gingiva in the relevant region before and after frenectomy are shown in Table 3. There was a statistically significant decrease in periodontal measurements in the area where frenectomy was performed (p<0.001).

Comparisons of the differences in the distance between the teeth of individuals who underwent frenectomy in the lower jaw and upper jaw and the differences between these groups in the periodontal measurements and the locations of the frenums are shown in Table 4. The average pocket depth and bleeding around the teeth in the regions where frenectomy was performed significantly decreased in the maxilla (p=0.001 and p=0.006, respectively), and the average degree of gingival recession decreased in the mandible (p=0.010).

The difference in the distance of the teeth in individuals who underwent frenectomy according to frenum type and the difference in the periodontal measurements and the attachment site of frenums according to frenum type are shown in Table 5. A one-way ANOVA showed a statistically significant difference in the mean pocket depth, degree of gingival recession, and bleeding (p<0.05). The post-hoc Tukey test of periodontal measurements in the regions where frenectomy was performed revealed a significant difference in the mean pocket depth between the groups with gingival-papillary penetration (p=0.049). A significant difference was also found in the attachment sites of the frenums between gingival and papillary frenums and between gingival and papillary penetrating frenums (p=0.007 and p<0.001, respectively). There was a statistically significant decrease in the mean bleeding between gingival and papillary penetrating frenums only (p=0.017).

Table 1. *Demographic characteristics of the patients.*

Variables		Number of Individuals (n)	Percentage (%)
Total number of individuals		50	100.0
Female		26	52.0
Male		24	48.0
Frenum morphology	Short-thick	18	36.0
	Long-thin	32	64.0
Frenum location	Lower jaw	16	32.0
	Upper jaw	34	68.0
Frenum attachment level	Gingival	10	20.0
	Papillary	18	36.0
	Papillary penetrating	22	44.0
Occurrence of relapse	Absent	32	64.0
	Available	6	12.0
	Partially available	12	24.0
Attachment level of frenum after recurrence	Mucosal	28	56.0
	Gingival	18	36.0
	Papillary	4	8.0

Table 2. *Measurements of the distance of teeth at baseline and one year after frenectomy. Values are expressed as the arithmetic mean ± standard deviation. * P<0.05, significance between groups P, dependent t-test.*

	Baseline (n=50)	One year after (n=50)	P Value
Total distance between teeth	3.71±1.81	3.39±1.50	0.013*
Distance between the cervical margins of the teeth	4.27±1.85	3.93±1.58	0.049*
Distance between the midpoints of the teeth	3.66±1.97	3.20±1.44	0.005*
Distance between the incisal edges of the teeth	3.33±1.98	3.04±1.77	0.021*

Table 3. *The periodontal measurements of teeth and gingiva in the relevant region of individuals at baseline and one year after frenectomy. Values are expressed as the arithmetic mean ± standard deviation.**P<0.001, significance between groups, P, dependent t-test.*

	Baseline (n=50)	After one year (n=50)	P Value
Attached gingiva width	4.38±2.06	5.29±1.79	P<0.001**
Pocket depth	2.20±1.18	1.7±0.93	P<0.001**
Gingival recession	0.94±1.46	0.56±1.06	P<0.001**
Plaque index	1.10±0.76	0.40±0.70	P<0.001**
Gingival index	0.56±0.64	0.18±0.37	P<0.001**

Table 4. *Comparison of the change in the distance of teeth, periodontal measurements, and the location of frenums in individuals who underwent frenectomy in the lower and upper jaw * P<0.05, significance between groups** P≤0.001, high significance between groups P, independent t-test.*

Frenum Location	Lower Jaw	Upper Jaw	P Value
Total distance between teeth	-0.30±1.07	-0.33±0.79	0.919
Distance between the cervical margins of the teeth	-0.48±1.71	-0.26±0.84	0.537
Distance between the midpoints of the teeth	-0.46±0.92	-0.45±1.17	0.977
Distance between the incisal edges of the teeth	-0.35±0.35	-0.26±1.01	0.729
Degree of gingival attachment	0.90±1.57	0.91±0.89	0.978
Pocket depth	-0.06±0.48	-0.70±0.74	0.001*
Degree of gingival recession	-0.68±0.57	-0.23±0.43	0.010*
Amount of plaque	-0.81±0.81	-0.65±0.69	0.459
Amount of bleeding	-0.24±0.55	-0.68±0.44	0.006*

Table 5. *Comparison of the changes in the distance of teeth and periodontal measurements according to the attachment areas of frenums in individuals who underwent frenectomy. *P<0.05, significance between groups ** P<0.001, high significance between groups P, one-way ANOVA; P_{1-2}, P_{2-3}, and P_{1-3}, Tukey test.*

Frenum Attachment Level	Gingival (1)	Papillary (2)	Papillary Penetrating (3)	P Value	P1-2	P1-3	P2-3
Total distance between teeth	-0.68±0.83	-0.19±0.79	-0.25±0.96	0.353	0.358	0.421	0.979
Distance between the cervical margins of the teeth	-0.92±1.59	-0.12±1.17	-0.25±0.91	0.205	0.200	0.289	0.940
Distance between the midpoints of the teeth	-0.64±0.77	-0.19±0.78	-0.59±1.38	0.432	0.549	0.992	0.481
Distance between the incisal edges of the teeth	-0.50±0.29	-0.28±0.95	-0.20±0.95	0.663	0.793	0.638	0.957
Degree of gingival attachment	1.00±1.89	0.78±1.06	0.97±0.75	0.836	0.878	0.998	0.857
Pocket depth	-0.02±0.47	-0.61±0.80	-0.64±0.69	0.047*	0.078	0.049*	0.993
Degree of gingival recession	-0.90±0.52	-0.33±0.49	-0.18±0.39	0.001*	0.007*	P<0.001**	0.549
Amount of plaque	-1.00±0.67	-0.67±0.49	-0.59±0.89	0.335	0.481	0.311	0.942
Amount of bleeding	-0.80±0.42	-0.33±0.48	-0.23±0.59	0.021*	0.073	0.017*	0.801

Discussion

The size of two adjacent teeth on the same arc, the gap in the arc, and differences between the size of teeth cause diastemas. The prevalence of diastemas ranges from 3.7% to 16.2% in the young population. The aetiology of diastemas is often related to factors such as dental size, labial frenum, shape anomalies, parafunctional habits, tongue position, and periodontal diseases. The most important aetiological factor of diastemas is the maxillary labial frenum type (6,12).

It may be necessary to surgically remove a maxillary midline frenum to prevent a midline diastema and recurrence after orthodontic treatment, to facilitate oral hygiene practices, and to prevent plaque accumulation and gingival recession (13). Clinically, papillary and papillary penetrating frenums are considered pathological and are referred to as abnormal frenums. Abnormal frenums cause the loss of papillae, diastemas, difficulty in brushing teeth, misalignment, and some psychological disorders. Abnormal frenums are visually detected through movement of the papillary tip by applying tension to the lip or detected through pallor due to ischemia in the relevant region (14,15).

Individuals with a distance of 1 mm or greater between the central teeth were included in our study because the diastemas caused by frenums attached to the gingiva were larger than 1 mm and smaller than 2 mm in the frenum attachment classification, and the measurements were made on plaster models in the laboratory to increase objectivity (12).

A study by Boutsi *et al.* (16) included 226 children and demonstrated that frenums had 46.6% gingival attachment, 22.1% papillary attachment rate of and 26.1% papillary penetration. However, the frenums in our study had 20% gingival attachment, 36% papillary attachment , and 44% papillary penetration. The increased values in our study may have been due to the small sample size.

Delli *et al.* (13) reported that the distance between the teeth decreases after frenectomy, and in patients with diastemas of less than 2 mm, closure of the diastema occurred after 6 months. They also stated that the distance between the teeth of patients with diastemas of greater than 2 mm did not usually close. Suter *et al.* (17) reported that there was a decrease in diastemas 2–12 weeks after frenectomy, but no diastemas closed in any patient. However, they also reported that some patients had diastema closure after 4–19 months. In addition, they stated that after frenectomy, at least six months were required for diastema closure. Bergström *et al.* (18) studied patients with maxillary midline frenums and stated that there was a statistically significant decrease in the distance between central teeth after frenectomy; however, this decrease was no longer statistically significant two years after frenectomy.

In our study, similar to studies in the literature, the decrease in the distance between teeth was statistically significant one year after frenectomy. However, this decrease was smaller between the cervical margins of the teeth and larger between the midpoints. Therefore, the teeth might have moved after frenectomy. Since the average distance between teeth was 2–4 mm, a smaller diastema closure with frenectomy than that in the study by Suter *et al.* (17) higher diastema closure success may be achieved with orthodontic treatment with frenectomy.

When frenums make daily hygiene practices difficult, they may cause plaque formation, bleeding, periodontal pocket formation, and gingival recession (4,6,19). Similar to the findings in the literature, the increase in the degree of gingival attachment and decrease in the pocket depth, degree of gingival recession, amount of plaque, and bleeding significantly differed between the groups.

Frenum problems are more common between the central teeth in the maxilla and the buccal side of the mandible. Abnormal frenums are less visible in the mandible than in the maxilla but manifest more dramatically in the mandible (4,20). Mandibular frenums are responsible for 5% of gingival recession (20). According to the frenum location, the differences in the mean pocket depth and bleeding were significant in the maxilla, and the difference in the mean gingival recession was significant in the mandible. If a frenum clings to free gingiva, it causes displacement in the gingiva as a result of lip movement. Thus, the deepening of periodontal pockets and gingival recession occurs. One of the most important problems encountered in the clinic is that frenums attached to the gingiva through papilla and papillary penetration. As a result of this type of frenum clinging, movement of the lip, cheek, and facial muscles and movement of the free gingiva occur (20,21).

In our study, consistent with previous articles, there was a significant decrease in the mean pocket depth and bleeding between gingival and papillary penetrating frenums. There was a statistically significant decrease in the gingival recession between gingival and papillary frenums and between gingival and papillary penetrating frenums.

When frenums are surgically removed, it is necessary to carefully cut and completely remove muscle attachments and fibres. When muscle attachments and fibres are not completely removed, frenums regenerate after frenectomy. Our study showed that 12% of frenums recurred after frenectomy.

Conclusion

The removal of abnormal frenums with frenectomy can contribute to the reduction of the interdental distance between the incisor teeth. In addition, frenectomy increases the amount of gingiva and decreases the depth of the pocket, gingival recession, amount of plaque, and bleeding.

Türkçe Özet: *Frenektomi Operasyonu Sonrasında Santral Dişler Arasındaki Mesafenin Değerlendirilmesi: Bir Randomize Klinik Çalışma. Amaç: Bu çalışmada maksiller ve mandibular orta hatta anormal frenulumu olan hastaların frenektomi operasyonundan 1 yıl sonrasında ilgili bölgedeki periodontal durum ile dişler arasındaki mesafenin değerlendirilmesi amaçlanmıştır. Gereç ve Yöntem: Çalışmaya santral dişler arasında frenuluma bağlı diastema oluşan 13-53 yaş aralığında 50 hasta (24 erkek ve 26 kadın) dahil edildi. Anormal frenulum, klasik frenektomi operasyonuyla uzaklaştırıldı. Başlangıçta ve 1 yıl sonrasında ilgili dişler arasındaki mesafe kumpasla ölçüldü. Periodontal durumun tespiti için çalışmaya katılan bütün hastaların ilgili dişlerin 4 yüzeyinden cep derinliği, plak miktarı, kanama miktarı ölçüldü. Ayrıca yapışık diş eti ve diş eti çekilmesi miktarının da ölçümü yapıldı. Tüm veriler istatistiksel olarak değerlendirildi. Bulgular: Frenektomi operasyonu öncesi ve sonrasında dişler arası mesafe ölçümünde anlamlı bir azalma gözlemlendi(p<0.05). Periodontal bulgularda ise yapışık diş eti miktarında, cep derinliğinde, diş eti çekilmesinde, plak ve kanama miktarında istatistiksel olarak anlamlı bir fark olduğu bulunmuştur (p<0.05). Sonuç: Anormal frenulumları frenektomi operasyonu ile uzaklaştırmak dişler arasındaki mesafenin kapanmasına katkıda bulunabilir. Ayrıca frenektomi işlemi periodontal olarak yapışık diş eti miktarında artma, cep derinliğinde, diş eti çekilmesinde, plak ve kanama miktarının azalmasını sağlamaktadır. Anahtar Kelimeler: Anormal frenulum, Frenektomi, Diastema, Mukogingival cerrahi, Kas tutulumu*

Ethics Committee Approval: The study protocol was approved by the Ethics Committee of the Adıyaman University Faculty of Medicine (protocol no: 2019-3).

Informed Consent: Participants provided informed constent.

Peer-review: Externally peer-reviewed.

Author contributions: AT participated in designing the study. AT participated in generating the data for the study. AT participated in gathering the data for the study. AT and YC participated in the analysis of the data. AT wrote the majority of the original draft of the paper. AT participated in writing the paper. AT and YC have had access to all of the raw data of the study. AT and YC have reviewed the pertinent raw data on which the results and conclusions of this study are based. AT and YC have approved the final version of this paper. AT and YC guarantee that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

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