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CONTENTS / İÇİNDEKİLER

ORIGINAL ARTICLES / ARAŞTIRMA MAKALELERİ

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ORIGINAL ARTICLE / ARAŞTIRMA MAKALESİ

Evaluation of the Effect of Different Beverages on Microhardness of Single-Shade Universal Resin Composites

Farklı İçeceklerin Tek Renkli Üniversal Rezin Kompozitlerin Mikrosertliği Üzerine Etkilerinin İncelenmesi

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ÖZ

Amaç: Bu çalışmada farklı içeceklerin tek renkli üniversal rezin kompozitlerin mikrosertlik değerleri üzerindeki etkilerinin incelenmesi amaçlandı.

Gereç ve Yöntemler: Farklı üreticilere ait sekiz tek renkli üniversal rezin kompozitten (Admira Fusion X-tra, Voco; Charisma Diamond One, Kulzer; Charisma Topaz One, Kulzer; Essentia Universal, GC; Omnichroma, Tokuyama; Optishade, Kerr; Vittra APS Unique, FGM; Zenchroma, President Dental) toplam 432 disk şeklinde örnek (10x2 mm) hazırlandı. Örnekler, kontrol grubu olarak distile su (pH:7) ve deney grupları olarak kahve (pH:5), kırmızı şarap (pH:3.5), kola (pH:2.5), multivitamin (pH:3) ve yeşil çay (pH:6) içeceklerinde 6 aylık klinik kullanıma denk gelen sürede (37°C, 6 gün) bekletildi. Başlangıç (t_0), termal döngü (5-55°C, 5000 döngü) ve içecekte bekletme sonrası (t_1) Vickers mikrosertlik ölçümleri yapıldı. Elde edilen veriler ANOVA ve Bonferroni testi ($p<0,05$) ile analiz edildi.

Bulgular: Test edilen tek renkli üniversal rezin kompozitler ve içecekler arasında mikrosertlik değerleri açısından istatistiksel olarak anlamlı farklılıklar bulundu ($p<0,001$). Admira Fusion X-tra en yüksek mikrosertlik ortalama değerini gösterdi (74,3). Tüm içeceklerin mikrosertlik değerleri üzerinde anlamlı bir etkisi olduğu gözlendi ($p<0,001$). Kırmızı şarap test edilen kompozitlerin mikrosertlik değerlerinde en fazla değişime neden oldu. Kompozit tipi, içecek ve zaman arasındaki etkileşimler istatistiksel olarak anlamlı bulundu ($p=0,001$).

Sonuç: Asidik içecekler, tek renkli üniversal rezin kompozitlerin mikrosertlik değerlerinde belirgin düşüşlere neden oldu. Bu sonuçlara göre restoratif materyal seçiminde asidik içeceklere maruziyet göz önünde tutulmalıdır.

Anahtar Kelimeler: Asidik içecek, mikrosertlik, tek renkli üniversal rezin kompozit, termal döngü, Vickers.

ABSTRACT

Objective: The aim of this study was to investigate the effects of different beverages on the microhardness values of single-shade universal resin composites.

Materials and Methods: A total of 432 disk-shaped samples (10x2 mm) were prepared from eight single-shade universal resin composites produced by different manufacturers (Admira Fusion X-tra, Voco; Charisma Diamond One, Kulzer; Charisma Topaz One, Kulzer; Essentia Universal, GC; Omnichroma, Tokuyama; Optishade, Kerr; Vittra APS Unique, FGM; Zenchroma, President Dental). The samples were stored in distilled water (pH:7) as the control group and experimental groups were stored in coffee (pH:5), red wine (pH:3.5), coke (pH:2.5), multivitamin (pH:3), and green tea (pH:6) for a duration equivalent to 6 months of clinical use (37°C, 6 days). Vickers microhardness measurements were taken at the beginning (t_0), after thermal cycling (5-55°C, 5000 cycles), and following immersion in the beverages (t_1). The obtained data were analyzed using the Robust ANOVA and Bonferroni tests ($p<0.05$).

Results: There were statistically significant differences in microhardness values among tested single shade universal resin composites ($p<0.001$). Admira Fusion X-tra exhibited the highest mean microhardness value (74.3). A statistically significant decrease in microhardness values was observed after immersion in all beverages ($p<0.001$). Red wine caused the greatest reduction in microhardness among tested composites. Interactions between composite type, beverage, and time are statistically significant ($p=0.001$).

Conclusion: Acidic beverages cause significant reductions in the microhardness values of single-shade universal resin composites. Exposure to acidic beverages should be considered when selecting restorative materials.

Keywords: Acidic beverage, microhardness, single-shade universal resin composite, thermal cycling, Vickers.

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INTRODUCTION

Composite resins are widely used in dentistry due to their esthetic appearance and mechanical performance, providing functional restorations with improved longevity. In recent years, single-shade universal resin composites have emerged as innovative materials, offering simplified application techniques and enhanced shade-matching capabilities (Cruz da Silva et al., 2023; Pereira Sanchez et al., 2019). These materials eliminate the need for multiple shade options by relying on their optical blending properties, simplifying the selection process for clinicians.

Single-shade universal resin composites consist of organic matrices, inorganic fillers, and coupling agents. The organic matrix typically includes Bis-GMA, UDMA, and TEGDMA, which provide polymerization flexibility and strength. Inorganic fillers, improve wear resistance and mechanical durability (Turk et al., 2024). Nano-hybrid and nano-filled formulations enhance polishability and surface smoothness, contributing to esthetic outcomes and resistance to staining (Zhang et al., 2021). Their ability to adapt to the surrounding environment makes them suitable for both anterior and posterior restorations, addressing both functional and esthetic needs (Bektas et al., 2024).

Recent studies have evaluated the mechanical behavior and color stability of single-shade composites, emphasizing their optical blending effects and shade adaptation capabilities for esthetic outcomes (Korkut et al., 2023; Villalta et al., 2020; Gencer et al., 2023). Testing protocols, including ISO standards, are essential for assessing composite performance, while non-standardized *in vitro* tests complement these by offering insights into durability under simulated clinical conditions (Heintze & Zimmerli, 2011a,b). These emphasize the importance of assessing composite performance under realistic oral conditions to predict material reliability (Lucena et al., 2023). Microhardness testing, such as the Vickers method, is crucial for assessing the durability and wear resistance of resin composites.

Duratbegovic et al. (2023) highlighted that polymerization parameters, including light intensity, exposure time, and distance, significantly influence Vickers microhardness values and temperature rise during curing. Proper optimization of these variables is essential to achieving uniform polymerization and mechanical stability (Zhu et al., 2023). Hardness values reflect the material's ability to withstand mechanical forces and resist deformation, directly impacting clinical longevity (Sharma et al., 2021). Assessing these values helps to determine material suitability for functional restorations, particularly under varying oral conditions that involve thermal and mechanical stress (Szalewski et al., 2024). Evaluating hardness under simulated conditions, including solution immersion and thermal cycling, provides insight into material performance under stress (Bagheri et al., 2019). Such analyses help to predict how these materials behave in oral environment, guiding clinicians in material selection and improving restorative outcomes (Ren et al., 2023). Moreover, hardness measurements provide indirect information about the degree of conversion and polymerization quality, which are crucial for ensuring optimal physical properties and clinical performance (Yılmaz Atalı et al., 2023).

Single-shade universal resin composites are designed for use in both anterior and posterior regions, offering not only esthetic benefits but also notable mechanical strength (Dietschi & Fahl, 2016). However, their long-term clinical success depends on their resistance to external factors, such as environmental conditions and dietary habits (Beltrami et al., 2018). In the moist oral environment, composites exposed to temperature changes can absorb substances that contribute to restoration failure, leading to discoloration and patient dissatisfaction. Beverages commonly consumed in daily life -such as coffee, red wine, cola, and green tea- may negatively affect both the esthetic and mechanical properties of resin composites (Küden et al., 2023). Addressing this issue often requires restoration replacement, which may result in unnecessary loss of healthy tooth structure (Bozkaya et al., 2018).

The present study investigates the effects of different beverages on the microhardness values of single-shade universal resin composites using the Vickers hardness test. By evaluating mechanical changes, this research aims to provide valuable data for optimizing restorative material selection and application.

The null hypotheses of the study were as follows:

1. There is no difference in microhardness values among different universal resin composites immersed in same beverages.

2. There is no difference in microhardness values of universal resin composites immersed in different beverages.

MATERIALS AND METHODS

Eight single-shade universal resin composite materials from different manufacturers were used in this study: Admira Fusion X-tra (Voco), Charisma Diamond One (Kulzer), Charisma Topaz One (Kulzer), Essentia Universal (GC), Omnichroma (Tokuyama), Optishade (Kerr), Vittra APS Unique (FGM), and Zenchroma (President Dental). The details of these composites, including brand names, manufacturers, monomer compositions, filler types, filler loadings, and lot numbers, are provided in Table 1.

Table 1. The brand names, manufacturers, monomer compositions, filler types, filler loadings, and lot numbers of the single-shade universal resin composites used in the study.

Composite		Manufacturer	Type	Monomer	Filler Composition/Size	Filler by wt/vol%	Lot Number
Admira Fusion X-tra	AF	VOCO, Germany	Nanohybrid	ORMOCER	Silicon dioxide nanofillers (20–50 nm) and silicon oxide-based hybrid fillers	84/na	2418360
Charisma Diamond One	CD	Kulzer, Germany	Nanohybrid	UDMA TCD-U TEGDMA	B2O3-F-Al2O3-SiO2, silica, TiO2, fluorescent, metallic oxide, organic pigments,5 -20 µm	81/64	K010021
Charisma Topaz One	CT	Kulzer, Germany	Nanohybrid	UDMA, TCD-U TEGDMA	Ba−Al−B−F−Si glass, PPF, SiO2	75/59	K010204
Essentia Universal	GE	GC, Japan	Microhybrid	UDMA Bis-MEPP Bis-EMA Bis-GMA TEGDMA	PPF (17 µm): strontium glass (400 nm), lanthanide fluoride (100 nm), fumed silica (16 nm) FAlSi glass (850 nm)	81/na	2211181
Omnichroma	OC	Tokuyama, Japan	Supra-nanofiller	UDMA TEGDMA	Uniform sized supra-nano spherical filler (260 nm spherical SiO2-ZrO2) and CF	79/68	2652
Optishade	OP	Kerr, USA	Nanohybrid	Bis-EMA Bis-GMA TEGDMA	PPF, BaO-Al2O3-SiO2, silica, and F3Yb, organic fillers Smallest: 5 nm, Largest: 400 nm, average particle size: 50 nm	81/64.5	8242079
Vittra APS Unique	VU	FGM, Brasil	Nanohybrid	UDMA TEGDMA	Zirconia charge, silica (200 nm)	82/72	230921
Zenchroma	ZC	President, Germany	Microhybrid	UDMA Bis-GMA TEMDMA	Glass powder, silicon dioxide inorganic filler (0.005–3.0 µm).	75/53	2022003727

Abbreviations: Bis-GMA = Bisphenol A-glycidyl methacrylate; TEGDMA = triethylene glycol dimethacrylate; UDMA = urethane dimethacrylate; TCD-U: Tricyclodecane-urethane dimethacrylate; PPF = pre-polymerized filler; SiO2 = silicon oxide (silica); ZrO2 = zirconium oxide; BaO-Al2O3-SiO2 = Barium aluminosilicate glass; TiO2 = Titanium dioxide, YbF3 = Ytterbium trifluoride; B2O3-F-Al2O3-SiO2 = Boro-fluoro-aluminosilicate; CF = Composite filler; Bis-EMA = Ethoxylated bisphenol-A Di methacrylate; Bis-MEPP = Bisphenol-A ethoxylate Di methacrylate; TEMDMA = Tetra-ethylen Di methacrylate; fAlSi = fluoroaluminosilicate; na: not available. * The data were provided by the manufacturers.

Power analysis was performed using G*Power 3.1.9.6 software (Heinrich Heine University, Germany) to determine the appropriate sample size. Despite the large effect sizes reported in the literature, a high effect size (f = 0.4) defined by Cohen (1988) was adopted to ensure the reliability of the study and avoid overpowered results. The analysis indicated that a minimum of 7 samples per group was required for 48 groups, with a 95% confidence level (α = 0.05) and 95% power (1-β = 0.95). Considering potential sample loss (drop-out), 9 samples per group were planned. In this context, a total of 432 samples were prepared (n=9) and were divided into a control group stored in distilled water (DW) and experimental groups immersed in coffee (CO), red wine (WN), coke (CC), multivitamin (MV), and green tea (GT). The brand names, manufacturers, pH of the beverages used in this study are presented in Table 2.

Table 2. The brand names, manufacturers and pH of the beverages used in the study.

Beverage	Manufacturer	pH
Distilled Water	N/A	7.0
Coffee	Nestle, Switzerland	5.0
Red Wine	Anycra, Türkiye	3.5
Coke	The Coca Cola Company, USA	2.5
Multivitamin	Redoxon, Germany	3.0
Green Tea	Lipton, UK	6.0

Samples were prepared using metal molds with a diameter of 10 mm and a thickness of 2 mm. Restorative materials were placed in the molds using a Teflon spatula, covered with a transparent polyester strip, and pressed with a glass slide to ensure a smooth surface.

Polymerization was performed using a VALO LED curing unit (Ultradent, USA) at 1000 mW/cm^2, following the manufacturer's instructions, ensuring light exposure on both top and bottom surfaces. To remove the oxygen-inhibited layer, samples were polished using Sof-Lex polishing disks (3M ESPE, USA) in coarse, medium, fine, and superfine grits, as recommended by the manufacturer. Each step lasted 15 seconds and samples were further polished using Eve Diacomp system (Eve Ernst Vetter GmbH, Germany) to achieve a uniform and smooth surface.

All samples were stored in distilled water at 37°C for 24 hours before baseline measurements (t_0). Three random Vickers indentations were performed on each sample using INNOVATEST 412A Vickers Hardness Tester (INNOVATEST Europe, Netherlands). The indentations were made with a 0.49N/g load and a dwell time of 15 seconds. The average of the three measurements was calculated and recorded as the initial microhardness value for each sample.

Samples underwent 5000 thermal cycles between 5-55°C, with a dwell time of 30 seconds in each bath and a transfer time of 10 seconds between baths, simulating 6 months

of clinical use as recommended by ISO:11405 standards for thermocycling protocols. This process was designed to replicate the thermal stresses experienced in the oral cavity due to consumption of hot and cold beverages (Morresi et al., 2014).

Following thermal cycling, samples were immersed in prepared solutions at 37°C for a duration of 6 days simulating 6 months of clinical use (Schneider et al., 2024), with daily replacement to ensure consistency and stability throughout the experimental period. Samples were vertically immersed in the beverages to ensure complete and uniform contact with all surfaces. Distilled water (pH 7.0) was stored at room temperature. Multivitamin (pH 4.0) was formulated by dissolving one effervescent tablet in 200 ml of distilled water, also stored at room temperature to mimic clinical conditions. Coke (pH 2.5) and red wine (pH 3.5) were refrigerated at 4°C; green tea (pH 6.0) and coffee (pH 5.0) were freshly prepared using hot water (80°C) prior to use to reflect their typical consumption temperatures.

Following the immersion period, Vickers microhardness testing was conducted again under identical conditions to assess post-immersion changes. Measurements taken after immersion and thermal cycling were recorded as t_1 values, which were compared to the baseline (t_0) to evaluate changes in hardness.

Data were analyzed using Jamovi 2.5.6. Normal distribution was analyzed using the Shapiro-Wilk test. Since the microhardness values were not normally distributed by composite, beverage, and time, robust ANOVA was performed using the Walrus package. Multiple comparisons were analyzed using the Bonferroni test. Quantitative data were presented as trimmed mean±standard error, and statistical significance was set at p<0.05.

RESULTS

Statistical analysis revealed that composite type, beverage type, and immersion time had a significant effect on the microhardness of single-shade universal resin composites (p<0.001). Furthermore, all interactions among these three variables were also found to be statistically significant (p=0.001) (Table 3).

Table 3. Comparison of microhardness values according to composite, beverage, and time.

	Test Statistics	p*
Composite	267514.000	**<0.001**
Beverage	178.000	**<0.001**
Time	134.000	**0.001**
Composite x Beverage	420.000	**0.001**
Composite x Time	521.000	**0.001**
Beverage x Time	205.000	**0.001**
Composite x Beverage x Time	347.000	**0.001**

*Robust ANOVA, p<0.05

Baseline microhardness values (t_0; mean=65.0) were slightly higher than post-immersion values (t_1; mean =64.0). Based on the composites, the initial microhardness values (t_0) from highest to lowest, were as follows: AF: 74.6, ZC: 71.3, CD: 71, CT: 70.2, VU: 64.9, OP: 64.7, OC: 57.5, GE: 40.3. The microhardness values of composites following immersion in solution are listed in descending order as follows: AF: 73.5, CD: 70.8, ZC: 70.3, CT: 64.9, VU: 64.4, OP: 64.3, OC: 58.8, and GE: 40.2 (Table 4).

The main effect of composite type, beverage, and the interaction between composite type and beverage were statistically significant on change in microhardness values (p<0.001) (Table 5).

Table 4. Descriptive statistics and multiple comparisons of microhardness values according to composite, beverage, and time.

Time	Composite	Beverages						Main effect*
		CO	CC	DW	GT	MV	RW	
t0	AF	75 ± 0.136	74.5 ± 0.291	74.7 ± 0.237	74.1 ± 0.455	74.2 ± 0.335	74.6 ± 0.338	74.6 ± 0.125
	CD	71.3 ± 0.344	71.5 ± 0.224	70.4 ± 0.226	70.8 ± 0.327	71.1 ± 0.222	70.6 ± 0.236	71 ± 0.116
	CT	70.1 ± 0.478	70.2 ± 0.398	69.4 ± 0.713	70.5 ± 0.319	70.7 ± 0.508	70.3 ± 0.447	70.2 ± 0.175
	GE	40.3 ± 0.169	40.3 ± 0.169	40.4 ± 0.23	40.1 ± 0.171	40.2 ± 0.22	40.3 ± 0.078	40.3 ± 0.064
	OC	57.1 ± 0.566	58.3 ± 0.617	58 ± 0.633	59 ± 0.564	55.5 ± 1.083	56.9 ± 0.588	57.5 ± 0.295
	OP	65.1 ± 0.227	65.2 ± 0.328	64.8 ± 0.256	64.1 ± 0.441	64.6 ± 0.398	64.5 ± 0.098	64.7 ± 0.128
	VU	64.1 ± 0.413	63.4 ± 1.416	65.2 ± 0.227	65.2 ± 0.208	64.6 ± 0.355	65.2 ± 0.282	64.9 ± 0.15
	ZC	71.1 ± 0.298	71.7 ± 0.221	70.8 ± 0.19	69.8 ± 0.887	71.7 ± 0.152	72.1 ± 0.21	71.3 ± 0.149
	Total	64.9 ± 1.38	65 ± 1.37	64.8 ± 1.34	64.8 ± 1.34	64.7 ± 1.39	64.9 ± 1.38	65 ± 0.554
t1	AF	74.8 ± 0.174	74.9 ± 0.091	74.8 ± 0.135	74.6 ± 0.122	74.8 ± 0.116	64.9 ± 0.962	73.5 ± 0.544
	CD	71.3 ± 0.664	71.1 ± 0.155	70.9 ± 0.408	70.4 ± 0.235	70.6 ± 0.189	70.5 ± 0.228	70.8 ± 0.129
	CT	64.3 ± 0.188	64.8 ± 0.352	68.5 ± 0.763	64.4 ± 0.221	64.3 ± 0.176	63.9 ± 0.114	64.9 ± 0.26
	GE	40.2 ± 0.075	40.1 ± 0.132	40.4 ± 0.129	40.5 ± 0.128	40.1 ± 0.197	40 ± 0.155	40.2 ± 0.059
	OC	58.6 ± 0.309	58.4 ± 0.15	59.5 ± 0.185	59.6 ± 0.227	59.5 ± 0.339	56.9 ± 0.227	58.8 ± 0.168
	OP	65 ± 0.17	65 ± 0.131	64.9 ± 0.156	65 ± 0.176	64.7 ± 0.119	60.2 ± 0.257	64.3 ± 0.269
	VU	65.9 ± 1.316	64.5 ± 0.164	64.3 ± 0.273	63.6 ± 1.235	64 ± 0.507	64.1 ± 0.229	64.4 ± 0.124
	ZC	70.6 ± 0.259	70.5 ± 0.232	70.7 ± 0.294	70.3 ± 0.161	69.9 ± 0.14	70.1 ± 0.245	70.3 ± 0.09
	Main effect**	64.4 ± 1.34	64.2 ± 1.33	64.8 ± 1.32	64.1 ± 1.3	64 ± 1.3	61.9 ± 1.2	64 ± 0.53

*Composite main effect regardless of solution. **Main effect of solution regardless of composite. Trimmed mean±standard error (trimming rate=0.05).

Table 5. Comparison of change in microhardness values (ΔVHN) according to composite and solution.

	Test Statistics	p*
Composite	30.800	**<0.001**
Beverage	12.300	**<0.001**
Composite x Beverage	131.600	**<0.001**

*Robust ANOVA, p<0.05

The mean ΔVHN values of the single-shade universal resin composites, ranked from highest to lowest, were as follows: CT: 5.73; ZC: 1.22; OC: 0.92; VU: 0.68; CD: 0.38; OP: 0.31; AF: 0.06; and GE: 0.06. According to the findings, the CT composite showed the highest mean ΔVHN value (5.73), indicating a significantly greater microhardness change than all other composites. In contrast, AF and GE exhibited the lowest values (0.06), with AF forming a distinct statistical group, suggesting superior resistance to surface hardness alteration. The other materials (ZC, OC, VU, OP, CD) demonstrated intermediate values with overlapping statistical groups, implying no significant differences among some of them (Table 6).

The average ΔVHN values based on beverage type, ranked from highest to lowest, were as follows: RW: 1.7; MV: 0.5; CC: 0.48; DW: 0.19; GT: 0.15; and CO: 0.09. RW exhibited a statistically significantly higher microhardness change value compared to all other beverages, whereas no significant difference was observed among CO, CC, GT, and MV. When the interaction of resin composites with beverages was examined, AF showed the highest average ΔVHN (Table 6)(Figure 1).

DISCUSSION

The results of this study demonstrated that single-shade universal resin composites exhibit different levels of microhardness. This variability among the composites underscores the role of filler composition, resin matrix properties, and polymerization techniques. The composite formulation plays a significant role in hardness retention and structural stability, emphasizing the importance of material composition in clinical performance.

Table 6. Descriptive statistics and multiple comprasions of microhardness change (ΔVHN) values according to composite and beverage.

Composite	Beverage						
	CO	CC	DW	GT	MV	RW	Main effect*
AF	0.09(-1.01-1)	-0.38(-1.78-0.8)	-0.24(-1.27-0.9)	-0.61(-2.3-0.92)	-0.74(-1.48-0.59)	9.15(5.55-13.47)	0.06(-2.3-13.47)^{a}
CD	0.08(-2.44-3.37)	0.54(-0.7-1.69)	-0.49(-2.63-1.38)	0.56(-1.08-1.54)	0.59(-1.29-1.4)	0.12(-0.77-1.18)	0.38(-2.63-3.37)^{bc}
CT	5.52(3.38-8)	5.35(3.49-6.31)	0.49(-1.98-3.56)	6.13(4.63-7.29)	7.01(3.85-8.34)	6.5(4.79-8.19)	5.73(-1.98-8.34)^{d}
GE	0.07(-0.87-0.81)	0.11(-0.47-1.2)	0.18(-1.82-1.06)	-0.23(-1.19-0.68)	-0.02(-0.61-1.63)	0.37(-0.34-1.06)	0.06(-1.82-1.63)^{b}
OC	-1.7(-3.89-0.51)	-0.24(-2.26-3.95)	-1.25(-4.01-1.08)	-0.85(-3-2.54)	-3.38(-8.79-1.06)	0.43(-3.53-2.93)	-0.92(-8.79-3.95)^{e}
OP	0.06(-0.7-1.35)	0.58(-1.69-0.9)	0.31(-1.37-1.07)	-0.6(-3.4-1)	-0.43(-2.04-1.89)	4.39(3.01-5.48)	0.31(-3.4-5.48)^{cf}
VU	-0.41(-13.07-1.22)	0.37(-10.22-1.91)	0.97(-1.28-2.69)	0.81(-0.37-9.34)	0.65(-1.25-3.74)	0.88(0.21-2.66)	0.68(-13.07-9.34)^{cf}
ZC	0.26(-0.72-2.44)	1.55(-0.46-2.1)	-0.02(-2.44-1.47)	-0.4(-5.83-2.46)	1.73(1.18-2.52)	1.78(1.1-3.43)	1.22(-5.83-3.43)^{f}
Main effect**	0.09(-13.07-8)^{A}	0.48(-10.22-6.31)^{A}	0.19(-4.01-3.56)^{B}	0.15(-5.83-9.34)^{A}	0.5(-8.79-8.34)^{A}	1.7(-3.53-13.47)^{C}	0.43(-13.07-13.47)

*Main effect of composite regardless of solution. **Main effect of solution regardless of composite. Median (minimum-maximum); $^{A-C}$: No significant difference between solutions sharing the same capital letter in the same row. a-f: No significant difference between composites sharing the same lowercase letter in the same comparisons.

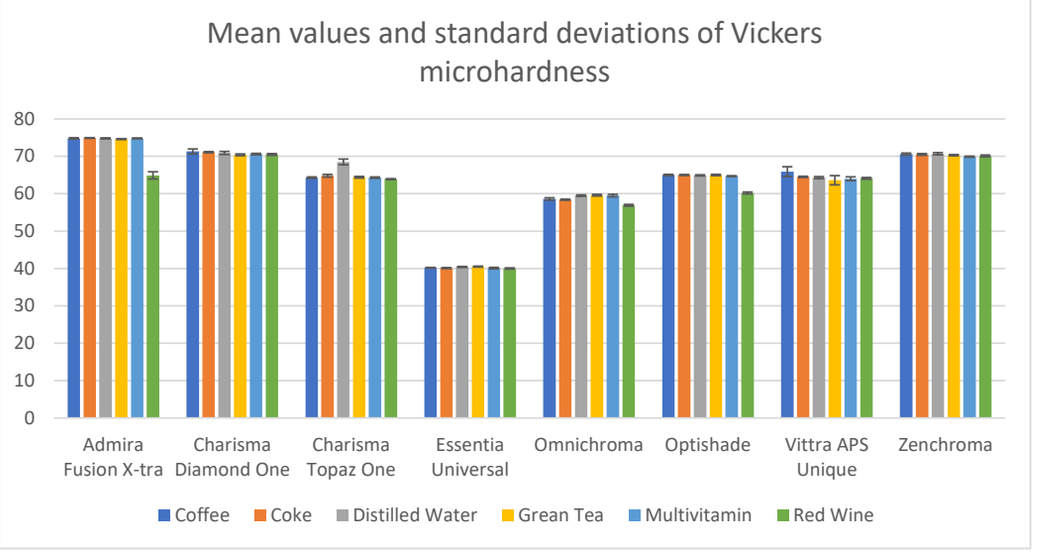

Figure 1. Mean and standard deviation of Vickers microhardness of resin composites after immersion in different beverages (t_1).

Studies reported nano-hybrid formulations, such as Charisma Topaz, exhibited higher hardness values due to improved filler structure, while composites with larger pre-polymerized particles, like Essentia Universal, demonstrated lower hardness values (Sarıalioğlu Güngör et al., 2023). Similarly, in our study, Charisma Topaz showed a mean microhardness value of 70.2, significantly higher than Essentia Universal, which exhibited a mean value of 40.3. These results suggest that composites with higher filler loads may demonstrate better resistance to degradation (Abreu et al., 2023).

In this study, Charisma Diamond, with a superior mean value of 71, displays the advantages of its nanohybrid filler structure, which significantly enhances mechanical strength and resilience. Omnichroma had a mean microhardness value of 57.5, which reflects moderate performance due to its spherical filler composition that balances esthetics and durability. Vittra APS Unique also performed favorably, with a mean value of 64.9, supported by advanced polymerization technology, contributing to its structural stability. These findings are consistent with those of Alharbi et al. (2024), who highlighted the critical roles of filler type and polymerization efficiency in determining the clinical performance and longevity of composite materials.

These findings led to the rejection of the first null hypothesis, which stated that there would be no statistically significant difference in microhardness values of different single-shade universal resin composites immersed in the same beverage. Similarly, the second null hypothesis was also rejected, indicating a statistically significant difference in microhardness values of universal resin composites when immersed in different beverages.

Acidic beverages, including coke, multivitamin, and particularly red wine, significantly reduced the microhardness values of composite resins, consistent with recent findings (AlSheikh et al., 2023; Vejendla et al., 2024). These beverages exert erosive effects by softening the resin matrix (Karatas et al., 2023) and weakening the filler–resin interface, leading to increased hardness degradation, roughness, and solubility (Kedici Alp et al., 2023; Hamouda, 2023).

The comparatively lower reductions in hardness values observed in samples stored in distilled water and green tea indicate that neutral and slightly alkaline environments provide better protection against structural degradation. This supports the notion that pH–neutral conditions are less aggressive toward resin composites, preserving their physical properties (Poggio et al., 2021).

The interaction effects between composite and beverage underscore the importance of evaluating materials not only in isolated conditions but also in simulated clinical environments involving multiple stressors. The highest interaction value was observed with Admira Fusion X-tra composite immersed in coffee, reaching 74.9, reflecting its superior resistance under these conditions. Conversely, the lowest interaction value of 40.1 was recorded for Essentia Universal composite immersed in multivitamin, highlighting vulnerability to environmental stressors. These observations highlight the importance of evaluating the performance of resin composites under acidic and thermally stressed conditions to ensure long-term clinical reliability.

The thermal cycling used in this study effectively mimicked intraoral temperature fluctuations, demonstrating its relevance for predicting long-term performance. Expansion and contraction induced by thermal stress can increase micro-cracks, emphasizing the need for combined thermal and chemical testing (Tüter Bayraktar et al., 2023). Accelerated aging processes and thermal cycling significantly affect microhardness and surface stability, emphasizing the relevance of Vickers hardness testing in evaluating structural changes (Fidan, 2023; Abouelmagd & Basheer, 2023).

Polymerization parameters, such as light intensity and exposure duration, influence conversion, hardness, and stability. In this study, polymerization was performed using a VALO LED curing unit (Ultradent, USA) at 1000 mW/cm^2 in standard power mode, ensuring uniform curing on both the top and bottom surfaces, as recommended by the manufacturer. This approach minimized the risk of incomplete polymerization, enhancing mechanical durability and performance (Korkut et al., 2023).

It is well known that, proper finishing and polishing enhance surface quality, reduce bacterial adhesion, and support long-term performance (Atalay et al., 2023; Bernaldo-Faustino et al., 2023; Chowdhury et al., 2023). In this study, finishing was performed using Sof-Lex disks in sequential grits, followed by the Eve Diacomp polishing system, as recommended by the manufacturer. This multi-step approach ensured a smooth and uniform surface, which is essential for minimizing surface irregularities that could compromise mechanical properties and durability.

This study underscores the importance of durability assessment for single-shade universal resin composites, as all materials tested exhibited microhardness values in accordance with ISO standards, confirming their clinical viability. Additionally, the observed decrease in microhardness values post-immersion highlights the need for regular maintenance and polishing to prolong the esthetic and functional lifespan of composites.

However, this study has several limitations. Since it was conducted *in vitro*, it could not fully replicate the dynamic oral environment, including saliva flow, pH fluctuations, biofilm formation, and mechanical forces. The immersion protocol involved continuous exposure, which does not reflect the intermittent consumption of beverages in real life. Additionally, maintaining beverages at 37°C does not simulate varying drinking temperatures. Although 5000 thermal cycles were applied to simulate 6 months of clinical use, this may be insufficient to assess long-term stability. The absence of simulated chewing forces and wear also limits the evaluation of microhardness and surface properties.

CONCLUSION

Within the limitations of this *in vitro* study, it can be concluded that environmental factors, including immersion in beverages and thermal cycling, significantly affect the micro hardness of single-shade universal resin composites. Key findings are summarized as follows:

1. Acidic solutions, particularly coke and red wine, caused the greatest reductions in microhardness values, potentially compromising structural integrity.
2. Neutral and slightly alkaline solutions, such as distilled water and green tea, preserved microhardness values more effectively, offering better resistance to degradation.
3. Composite formulation plays a crucial role in hardness retention, with nano-filled and advanced polymer matrix composites showing superior performance.
4. All tested composites met ISO:4049 standards for microhardness, confirming their clinical suitability despite variations in performance.
5. Thermal cycling and chemical exposure influenced material behavior, underscoring the need for durability testing under simulated oral conditions.

These results emphasize the importance of selecting restorative materials based on their resistance to environmental factors. Future studies should explore long-term effects involving mechanical fatigue, dynamic loading, and advanced surface treatments to enhance material performance and clinical reliability.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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ORIGINAL ARTICLE / ARAŞTIRMA MAKALESİ

Effects of Orthognathic Surgery on Posterior Airway Volume and Development of Obstructive Sleep Apnea

Ortognatik Cerrahinin Posterior Hava Yolu Hacmi ve Obstrüktif Uyku Apnesi Gelişimi Üzerine Etkileri

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ABSTRACT

Objectives: This study aimed to compare preoperative and postoperative polysomnography (PSG) measurements and evaluated the changes in posterior airway space (PAS) volume according to the movements performed in orthognathic surgery.

Materials and Methods: The mean age of the 14 patients included in this prospective observational study was 29.57 ± 8.05 years, 9 were female and 5 were male. Patients scheduled to undergo bimaxillary surgery, underwent overnight PSG in the sleep laboratory 1 week before and 3 months after the operation. PSG included the following: Apnea – Hypopnea Index (AHI) (/h), sleep onset (min), sleep efficiency (%), sleep stages (SS) 1 (%) - 2 (%) - 3 (%), rapid eye movement sleep (REM) (%) and oxygen saturation. For all patients, 3D cone beam computed tomography (CBCT) images were acquired 1 week before and 3 months after surgery. The pharyngeal airway was divided into two regions, the nasopharynx (NPV) and oropharynx (OPV). These regions were defined using the posterior nasal spine, posterior part of the ala of vomer and cervical vertebra. Preoperative and postoperative data obtained from CBCT and PSG were compared.

Results: In the comparison between AHI changes; the rate of decrease in NPV score was higher in patients with high AHI scores compared to others (p: 0,006). In patients with decreased AHI, the change in REM % was higher than the other groups (p: 0,019).

Conclusions: Orthognathic surgery causes changes in posterior airway volume and these changes cause changes in polysomonography data. In this study, it was concluded that NPV decreased more in patients with increased AHI values.

Keywords: Obstructive sleep apnea, polysomnography, orthognathic surgery

ÖZ

Amaç: Bu çalışmada, ortognatik cerrahide uygulanan hareketlere göre posterior hava yolu hacmindeki (PAS) değişikliklerin değerlendirilmesi ve preoperatif ve postoperatif polisomnografi (PSG) ölçümlerinin karşılaştırılması amaçlanmıştır.

Gereç ve Yöntemler: Bu prospektif gözlemsel çalışmaya dahil edilen 14 hastanın yaş ortalaması 29.57 ± 8.05 yıl olup, 9'u kadın ve 5'i erkekti. Bimaksiller cerrahi planlanan hastalara operasyondan 1 hafta önce ve 3 ay sonra uyku laboratuvarında gece boyu PSG uygulanmıştır. PSG'de, Apne-Hipopne İndeksi (AHİ) (/saat), uyku başlangıcı (dk), uyku etkinliği (%), uyku evreleri (SS) 1 (%) - 2 (%) - 3 (%), hızlı göz hareketi uykusu (REM) (%) ve oksijen satürasyonu parametreleri ölçülmüştür. Tüm hastalardan ameliyattan 1 hafta önce ve 3 ay sonra 3D konik ışınlı bilgisayarlı tomografi (CIBT) görüntüleri elde edilmiştir. Faringeal hava yolu nazofarenks (NPV) ve orofarenks (OPV) olmak üzere iki bölgeye ayrılmıştır. Bu bölgeler posterior nazal spine, ala vomerin posterior kısmı ve servikal vertebra kullanılarak tanımlanmıştır. CBCT ve PSG'den elde edilen preoperatif ve postoperatif veriler karşılaştırılmıştır.

Bulgular: AHİ değişiklikleri arasındaki karşılaştırmada; AHİ skoru yüksek olan hastalarda NPV skorundaki azalma oranı diğerlerine göre daha yüksekti (p: 0,006). AHİ'si düşük olan hastalarda REM % değişim oranı diğer gruplara göre daha yüksekti (p: 0,019).

Sonuç: Ortognatik cerrahi posterior hava yolu hacminde ve polisomonografi verilerinde değişikliklere neden olmaktadır. Bu çalışmada AHİ değerleri yüksek olan hastalarda NPV'nin daha fazla azaldığı sonucuna varılmıştır.

Anahtar Kelimeler: Obstrüktif uyku apnesi, polisomnografi, ortognatik cerrahi

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INTRODUCTION

Orthognathic surgery has effects such as causing changes in the surrounding soft tissues, tongue, hyoid bone, soft palate, adjacent muscles and volume of the posterior airway (Qahtani, 2016 ; Lee et al., 2019 ; Achilleos et al., 2000). Orthognathic surgery may lead to direct or indirect changes in the volume of the posterior airway and affect the patients breathing positively or negatively (Shin et al.,2015; Yamashita et al., 2017). Adequate airway volume is important in maintaining healthy vital functions. Decreased airway volume caused by various etiologic factors is among the causes that may lead to systemic diseases with high morbidity and mortality risk and predispose to obstructive sleep apnea syndrome (OSAS)(Achilleos et al., 2000). Polysomnographic (PSG) measurement remains the gold standard in the diagnosis of OSAS (Madani et al., 2007).

Many methods have been used to evaluate changes in airway volume. Some studies have performed two dimensional (2D) measurements with lateral cephalometric films, but volumetric changes in the airway, which is a three dimensional (3D) structure, cannot be adequately detected with lateral cephalometric radiographs (Pereira-Filho et al., 2011; Gokce et al., 2012; Burkhard et al., 2014). Airway volume can be measured more clearly with 3D cone-beam computed tomography (CBCT); however, few studies have investigated the relationship between volume measurements using CBCT and PSG respiratory parameters(Canellas et al., 2016a; Canellas et al., 2016b; Yajima et al., 2017).

In this study, we compared preoperative and postoperative polysomnography measurements and evaluated the changes in posterior airway space (PAS) volume according to the movements performed in orthognathic surgery.

MATERIALS AND METHODS

Patients

Approval for the study was obtained from the Marmara University Faculty of Medicine Clinical Research Ethics Committee (decision number 09.2022.1034 dated 29.11.2022). In the power analysis of this study, the required sample size was determined as 14 patient. This prospective observational study included patients with dentofacial deformities who were admitted to the Marmara University Faculty of Dentistry, Oral and Maxillofacial Surgery Clinic for bimaxillary orthognathic surgery between February 2023 and March 2024. A consent to participate form was obtained from all patients. The study included 14 patients aged between 21 and 44 years. Nine of the patients were female and five were male.

Patients scheduled to undergo bimaxillary surgery underwent overnight PSG in the sleep laboratory 1 week before and 3 months after the operation. For all patients, 3D CBCT images were acquired 1 week before (T0) and 3 months after surgery (T1).

The inclusion criteria for the study were that the patients were admitted to our clinic with the indication of orthognathic surgery, had a follow-up of at least 3 months postoperatively, and had pre – and postoperative polysomnographic measurements. Patients with congenital or syndromic deformities, a history of trauma, respiratory problems or without preoperative and postoperative evaluation with CBCT and PSG were excluded from the study.

Surgery

All the operations were performed under general anesthesia with nasotracheal intubation in the operating room of Marmara University Faculty of Dentistry, Department of Oral and Maxillofacial Surgery. All the surgeries were performed by the same surgical team.

The surgical technique and osteotomy lines were standardized across all patients. Osteotomies were performed with piezo surgery (Piezosurgery®, Mectron, Italy). In Le Fort osteotomy, the osteotomy lines are determined between a standard apertura piriformis and zygomatic buttresses. The osteotomy lines were made at the same nasal level in the patients. Posteriorly, the osteotomy line is extended bilaterally to the lower part of the pterygomaxillary junction and the pterygoid processes are separated from the tuber region. The nasal mucosa was preserved intact and a down fracture was performed.

The sagittal split osteotomy line starting from the anterior edge of the ramus and extending anterolaterally to the middle of the second molar is determined. After the vertical bone incision extending to the lower edge of the mandible is prepared, the bone segments are separated with the help of hammers and osteotomes. The segments are freed with osteotomes. In genioplasty the osteotomy lines begin in the median region and extended laterally about 5 mm below the mental foramen, ensuring the roots of the teeth are preserved.

Polysomnography Evaluation

The patients were hospitalized in the Sleep Laboratory of Süreyyapaşa Chest Diseases Training and Research Hospital. All participants underwent a standard overnight polysomnography (PSG) test (Comet Grass; Astro-Med, Inc., West Warwick, RI, USA). The PSG procedure included monitoring sleep using three-channel electroencephalography, two-channel electrooculography, one-channel submental electromyography, oxygen saturation measured with an oximeter, respiratory movements tracked via chest and abdominal belts, nasal airflow monitored through a pressure sensor, thermistor, electrocardiography, and leg movements recorded with tibial surface electrodes. Sleep stages and respiratory parameters were scored based on the 2012 criteria set by the American Academy of Sleep Medicine (AASM). Apnea was defined as a reduction in airflow of 90% or more for at least 10 seconds, while hypopnea was defined as a reduction in airflow by at least 30% with a desaturation of 3% or more over the preceding 30 seconds, along with

reduced chest wall movement and/or arousal. The apnea-hypopnea index (AHI) represents the average number of apneas and hypopneas per hour of sleep. Obstructive sleep apnea syndrome (OSAS) was diagnosed with an AHI of at least 5 events per hour, and the severity of OSAS was classified as mild (AHI 5.0–14.9 events/hour), moderate (AHI 15-29.9 events/hour), or severe (AHI >30.0 events/hour). (Berry et al., 2012).

The standard recording parameters during PSG included the following: AHI (/h), sleep onset (min), sleep efficiency (%), sleep stages (SS) 1 (%), 2 (%), and 3 (%) and rapid eye movement sleep (REM) (%). Arterial oxygen saturation (SaO_2) was measured continuously using pulse oximetry. The PSG results were evaluated by two experienced pulmonologists (SS, FO).

Evaluation of the Pharyngeal Airway

Digital Imaging and Communications in Medicine (DICOM) data from 3D CBCT were transferred to NemoStudio software (Nemotec, Madrid, Spain). Two reference lines (x-axis, i.e. the line tangent to the inferior part of the sella turcica and parallel to the Frankfort horizontal (FH) plane; y-axis, i.e. the line perpendicular to the x-axis and passing through N) were defined. The threshold for the assessing airway volume was set to a range of 1024 to 600 Hounsfield units, where the pharyngeal airway could be effectively distinguished from the adjacent soft tissue. The total pharyngeal airway volume is divided into two regions: nasopharyngeal volume (NPV) and oropharyngeal volume (OPV) (Fig. 1) These regions were defined using the PNS and cervical vertebra (CV) references according to a previous report (Yang et al., 2020).

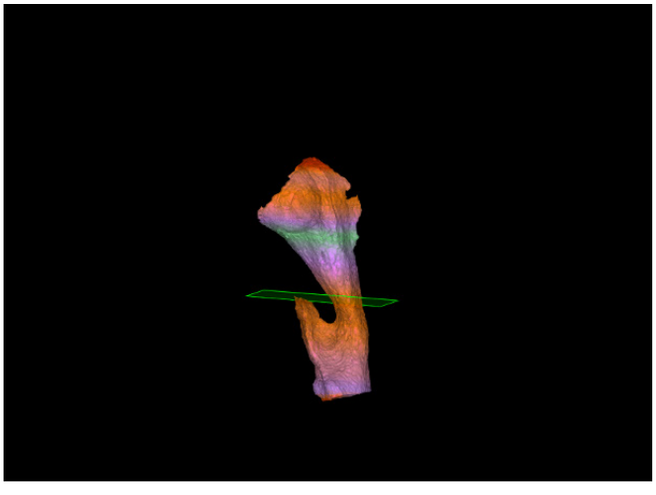

Figure 1: STL version of the total airway volume measured by CBCT.

The CV1 and CV2 planes are parallel to the FH plane through the most inferior point of each CV. For nasopharynx, the superior border was determined as the line between posterior nasal spine (PNS) – posterior part of the ala of vomer (Vp) and the inferior border was determined as the CV1 plane (Fig. 2A) For the oropharynx, the superior border was determined as the CV1 plane and the inferior border as the CV2 plane. (Fig. 2B) The minimum axial space (MAS) was recorded as the narrowest axial airway area detected by the program in the sagittal section and calculated by the own algorithm.

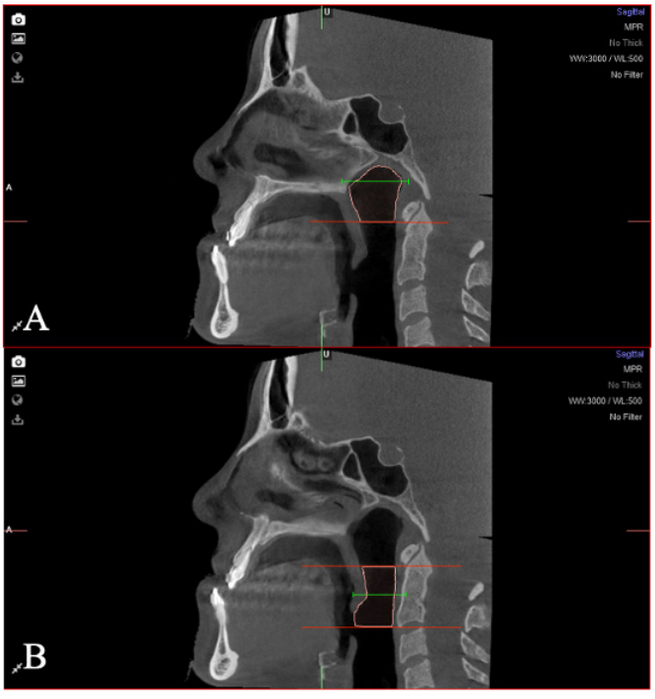

Figure 2: (A): For nasopharynx: Vp – PNS – CV, (B): For oropharynx: CV1 – CV2

Statistical Evaluation

The SPSS (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.) program was used for data analysis. The conformity of the variables to normal distribution was examined by histogram plots and the Kolmogorov – Smirnov and Shapiro-Wilk tests. Mean, standard deviation, median and minimum – maximum values were used to present descriptive analyses. Pearson's chi-squared test was used to compare the results in eyes with more than 2x2. An independent t-test was used to evaluate normally distributed (parametric) variables between the groups. The change between preoperative and postoperative data was analyzed by a paired-samples t-test and the change between groups was analyzed by repeated measures analysis. P-values below 0.05 were considered as statistically significant results.

RESULTS

Fourteen patients, 5 males and 9 females, were included in the study. The mean age of the patients was 29.57 ± 8.05 years. The total volume, NPV, OPV, and AHI changes of the patients are shown in Table 1. The preoperative and postoperative values of NPV, OPV, AHI, total volume and PSG data were calculated. The significance of the change between the preoperative and postoperative values was analyzed, and no significant p-value was found.

Table 1. Demographic and Clinical Characteristics of Patients

		N /Mean ± SD	%/Median (Min-Max)
Sex	Male	5	(35,71)
	Female	9	(64,29)
Age		29,57 ± 8,05	28 (21-44)
Orthognathic	Bimaxillary	10	(71,43)
	Mandible	1	(7,14)
	Bimaxillary +Genioplasty	3	(21,43)
Total volume change	Increased	9	(64,29)
	Decreased	5	(35,71)
NPV change	Increased	9	(64,29)
	Decreased	5	(35,71)
OPV change	Increased	9	(64,29)
	Decreased	5	(35,71)
AHI change	Increased	6	(42,86)
	Decreased	7	(50)
	Unchanged	1	(7,14)

N: number, SD: Standart Deviation, NPV: Nasopharyngeal Volume, OPV: Oropharyngeal Volume, AHI: Apnea-Hypopnea Index

PSG data were compared between the groups with increased and decreased total volume, and no significant p-value was obtained. PSG data were compared between the AHI groups, and it was found that the mean postoperative SS 3 % of those with increased AHI was higher that of than the other groups. Preoperative – postoperative changes in PSG data between the groups were analyzed. The change in the REM percentage in those with decreasing AHI was higher than the other groups. Standard deviations could not be calculated because there was only one patient whose AHI preoperative – postoperative score did not change. (Table 2) (Fig. 3)

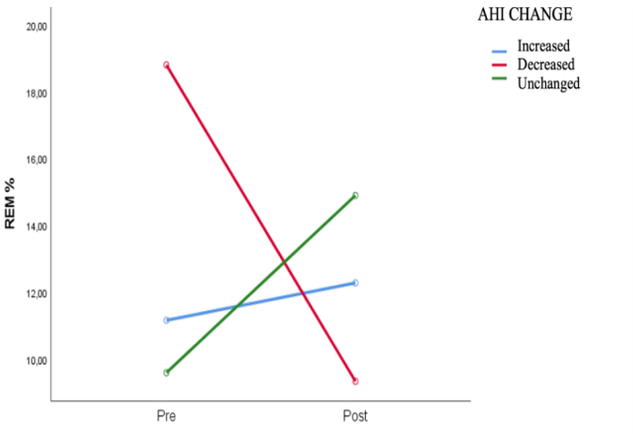

Figure 3: The Change in REM Percentage in Relation to AHI

Table 2. Preoperative and Postoperative Changes in PSG Data by AHI Groups

		AHI CHANGE						p[1]
		Increased		Decreased		Unchanged		
		Mean ± SD	Median (Min-Max)	Mean ± SD	Median (Min-Max)	Mean ± SD	Median (Min-Max)	
Sleep Onset (min)	Preop	424,85 ± 66,18	450,8 (298-474)	422,07 ± 66,75	433,5 (281,5-479)	465 ±.	465 (465-465)	0,834
	Postop	401,13 ± 64,52	400,25 (306-506,3)	446,11 ± 71,63	463,5 (304,3-527)	474,3 ±.	474,3 (474,3-474,3)	0,422
	p[2]	0,473						
Sleep Efficiency (%)	Preop	81,17 ± 9,54	77,65 (71,7-98,4)	82,99 ± 7,63	84,4 (66,6-89,5)	66,6 ±.	66,6 (66,6-66,6)	0,244
	Postop	84,25 ± 11,31	82,55 (69,5-98,6)	83,63 ± 13,87	90 (54,7-94,4)	99,2 ±.	99,2 (99,2-99,2)	0,532
	p[2]	0,082						
SS 1 (%)	Preop	6,23 ± 4,5	4,45 (1,9-12,6)	5,61 ± 4,78	3,7 (1,3-12,5)	7,4 ±.	7,4 (7,4-7,4)	0,927
	Postop	4,3 ± 6,13	1,45 (0,5-16,2)	6,43 ± 7,01	3,7 (0,9-20,5)	6,8 ±.	6,8 (6,8-6,8)	0,833
	p[2]	0,851						
SS 2 (%)	Preop	53,18 ± 19,68	57,25 (16,6-70,3)	49,9 ± 12,39	52,4 (28,8-62,8)	44,8 ±.	44,8 (44,8-44,8)	0,866
	Postop	52,97 ± 7,16	54,5 (42,8-60)	68,64 ± 14,79	67,3 (43,8-93,1)	72,2 ±.	72,2 (72,2-72,2)	0,082
	p[2]	0,193						
SS 3 (%)	Preop	29,42 ± 16,36	26,65 (11,3-58,8)	27,23 ± 8,67	24,1 (20,8-46,3)	38,2 ±.	38,2 (38,2-38,2)	0,725
	Postop	32,25 ± 9,15	36,75 (19-39,8)	15,57 ± 6,03	15,6 (5,9-23,9)	6,1 ±.	6,1 (6,1-6,1)	**0,003**
	p[2]	0,15						
REM (%)	Preop	11,17 ± 6,12	11,5 (3,7-19,6)	18,8 ± 8,93	15,7 (10,6-33,2)	9,6 ±.	9,6 (9,6-9,6)	0,211
	Postop	12,28 ± 7,62	13,85 (0-22)	9,34 ± 6,84	8,7 (0-20)	14,9 ±.	14,9 (14,9-14,9)	0,663
	p[2]	**0,019**						
Saturation (%)	Preop	96,17 ± 0,75	96 (95-97)	93,14 ± 3,63	93 (87-97)	98±.	98 (98-98)	0,108
	Postop	95,67 ± 1,51	96 (93-97)	96,29 ± 0,95	96 (95-98)	97±.	97 (97-97)	0,512
	p[2]	0,071						
SD: Standart Deviation, AHI: Apnea-Hypopnea Index, SS: Sleep Stage								

* p: Independent T Test / p2: Repeated Measures Analysis

The total volume, NPV, OPV, and AHI were compared between orthognathic conditions, and no significance was found. A significant p-value was obtained as a result of the comparison between the AHI change conditions, indicating that the rate of decrease in NPV score was higher in those with an increased AHI score than in the other groups (Table 3).

Table 3. Relationship Between AHI Changes and Pharyngeal Airway Volume Alterations

	AHI Change							p
	Increased		Decreased		Unchanged			
	n	%	n	%	n	%		
Total Volume Change	Increased	2	-33,33	6	-85,71	1	-100	0,108
	Decreased	4	-66,67	1	-14,29	0	0	
NPV Change	Increased	1	-16,67	7	-100	1	-100	**0,006**
	Decreased	5	-83,33	0	0	0	0	
OPV Change	Increased	3	-50	5	-71,43	1	-100	0,537
	Decreased	3	-50	2	-28,57	0	0	

N: number, NPV: Nasopharyngeal Volume, OPV: Oropharyngeal Volume, AHI: Apnea-Hypopnea Index

DISCUSSION

The aim of the study was to examine the changes in posterior airway volume caused by orthognathic surgery and to investigate the effect of these changes on PSG data. According to the findings, there were significant changes in the airway volume of the patients after surgery.

In several studies, orthognathic surgery has been performed on patients with dentofacial deformities, and its effect on the patients' airways has been investigated with 2D and 3D measurements (Gokce et al., 2012; Al-Moraissi et al., 2015; Canellas et al., 2016a). However, very few studies performed in the sleep laboratory have used PSG and 3D measurements. In this study, the effect of changes in the posterior airway after orthognathic surgery on the risk of OSAS development was reported by jointly evaluating 3D volume and PSG measurements in the sleep laboratory.

Few studies have used 3D imaging methods in airway evaluations after orthognathic surgery. Although previous studies have considered 2D cephalometric films to be the gold standard for measuring the airway, recent studies indicate that the pharynx is a 3D structure and that accurate volume measurements cannot be made only with linear and angular measurements (Larson, 2012; Kim et al., 2016). Although previous studies used CT for airway measurements, recent studies have recommended CBCT to eliminate the disadvantages of CT, such as high radiation, the use of a metal artifact, and its high cost (Degerliyurt et al., 2008; Larson, 2012; Tepecik et al., 2018). In this study, airway volume measurement with CBCT was preferred because of these advantages.

There is no definite consensus in the literature on the segmentation of the airway. Various studies have examined the posterior airway in one, two (oropharynx, nasopharynx), and three (oropharynx, nasopharynx, hypopharynx) sections (Park et al., 2010; Hernandez-Alfaro et al., 2011; Abramson et al., 2011; Li et al., 2014; Gokce et al., 2014). Usegi et al. reported that the obstruction causing apnea was mostly located in the oropharynx and nasopharynx (Uesugi et al., 2014). White et al. reported that the level of collapse in OSAS patients was usually not in the hypopharynx (White & Younes, 2012). Similarly, this study examined the airway in two sections, namely, the oropharynx and nasopharynx.

Many different time intervals have been used as follow-up periods in studies evaluating the airway. Hochban et al. reported that there was no significant difference in airway measurements at one-week, three-month, and one-year postoperative follow-up (Hochban et al., 1996). Kawakami et al. reported that one month postoperatively was sufficient for the physiologic adaptation of soft tissues that narrow the airway (Kawakami et al., 2005). Since it was thought that patients would have difficulty cooperating when the follow-up period was prolonged, three months was considered a sufficient postoperative follow-up period for the CBCT and PSG measurements in this study.

In their study, Gokce et al. reported a significant postoperative decrease in AHI values despite a decrease in oropharynx and hypopharynx volumes and reported that this result may be associated with an increase in NPV (Gokce et al., 2014). Similarly, this study found a greater reduction in NPV among patients with elevated AHI values.

The typical sleep cycle is made up of four stages: SS 1, SS 2, SS 3, and REM (rapid eye movement), which are categorized based on electroencephalography and the tone of the suprahyoid muscles. These stages account for approximately 5%, 50%, 25%, and 20% of total sleep time, respectively. The SS 1 stage is considered light sleep, during which a person can be easily awakened. SS 2 represents the transition to deeper sleep. SS 3, or slow-wave sleep, is when the body and mind undergo restorative processes, while the REM stage is associated with dreaming, memory consolidation, and high brain activity. Both the quality and quantity of sleep are indicators of overall health and well-being. A lack of sufficient sleep can result in reduced SS 3 and REM stages. In conditions like OSAS, the SS 3 phase is often diminished in the sleep pattern. During the REM stage, muscles around the oropharynx relax, leading to a narrowing of the upper airway and a higher risk of obstruction. As a result, episodes of apnea and hypopnea are more likely to occur in this stage, contributing to hypoxemia. Engboonmeskul et al. stated that since OSAS is usually more prominent during REM sleep, decreased REM sleep duration may contribute to lower AHI (Engboonmeskul et al., 2020). In this study, the rate of decrease in REM sleep was found to be higher in patients with decreased AHI than in the other groups.

Polysomnography is the gold standard in the diagnosis of OSAS. AHI has been reported as the most important indicator in PSG measurements (Tepecik et al., 2018). Although no statistically significant difference was observed in AHI in the PSG evaluations in our study;

when the patients were evaluated individually, the AHI was measured as 0 in three patients after orthognathic surgery. Total airway volume increased in three of the patients whose AHI value decreased to 0. One of these patients was a patient with preoperative OSAS (AHI:7.03).

The limitations of the study include the relatively small number of patients, the follow-up period of 3 months, and the fact that the preoperative and postoperative CBCT were taken while the patients were standing and the sleep tests were performed in the supine position.

Conclusions

This study showed that orthognathic surgery causes changes in posterior airway volume and these changes cause changes in PSG data. The effect of these dimensional changes on PSG data should be evaluated in future studies by increasing the number of patients.

Ethics Committee Approval

The ethics committee approval of the study was obtained from Marmara University Faculty of Medicine Clinical Research Ethics Committee (reference no: 09.2022.1034).

Conflicts of Interest

The authors declare that they have no conflict of interest.

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ERD European Journal of Research in Dentistry

ORIGINAL ARTICLE / ARAŞTIRMA MAKALESİ

Konvansiyonel Tam Protez ve İmplant Destekli Overdenture Protezlerde Hasta Memnuniyetinin Değerlendirilmesi

Comparison of Implant-supported Overdentures and Conventional Complete Dentures Regarding Patient Satisfaction

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ÖZ

Amaç: İmplant destekli overdenture protez veya konvansiyonel tam protez kullanım tecrübesi olan hastalar arasında, bu iki tedavi yönteminin hasta memnuniyeti açısından karşılaştırılması ve hasta memnuniyetine etki eden faktörlerin değerlendirilmesidir.
Gereç ve Yöntemler: Bu çalışma; Marmara Üniversitesi Diş Hekimliği Fakültesinde tam protez veya implant destekli overdenture protez tedavisi görmüş olan 100 hastaya telefon görüşmesiyle yöneltilen anket soruları ile yürütülmüştür. Anket, hastaların yaş, cinsiyet, eğitim düzeyi gibi dermografik verileri ve protezlerinin fonksiyon, fonasyon, estetik, temizlenebilirlik, uygulama kolaylığı, tedaviye ulaşabilme kolaylığı gibi farklı parametreleriyle ilgili memnuniyetlerini değerlendirmeye yönelik sorulardan oluşmaktadır. Anket sorularının skorlanmasında, görsel analog skala (VAS) kullanılmıştır. Çalışmada elde edilen bulgular %95 güven aralığında, $p<0,05$ anlamlılık düzeyinde değerlendirilmiştir.
Bulgular: Çiğneme rahatlığı, kendini güvende hissetme, yemek yemeye olan ilginin artması konularında implant destekli overdenture protezlerin memnuniyet skorları anlamlı olarak daha yüksektir. Tedaviye ulaşabilme kolaylığı, tedavi kolaylığı ve gıda retansiyonunun azlığı konularında konvansiyonel tam protezler anlamlı olarak daha yüksek memnuniyet skorları sergilemiştir. Estetik, fonasyon, retansiyon, temizlenebilirlik, tat ve koku alma, protezlerin takıp-çıkarılabilme kolaylığı ve genel memnuniyet açısından iki protez tipi arasından birinin diğerine karşı istatistiksel bir üstünlüğü bulunmamaktadır.
Sonuç: Her iki protez tipinin de birbirlerine karşı farklı değerlendirmelerde üstünlükleri olsa da hastaların genel memnuniyeti açısından iki protez tipi arasında anlamlı bir fark yoktur.
Anahtar Kelimeler: Tam protez, implant destekli overdenture protez, hasta memnuniyeti

ABSTRACT

Objectives: This study aims to compare patient satisfaction between implant-supported overdenture prostheses and traditional complete dentures, and to examine the factors that influence satisfaction among individuals who have experienced either treatment modality.
Materials and Methods: The study was conducted through telephone interviews with 100 patients who were treated with either complete dentures or implant-supported overdentures at the Faculty of Dentistry, Marmara University. The survey includes questions designed to assess patients' demographic information, including age, gender, educational attainment, and their satisfaction with various aspects of their prosthesis, such as functionality, phonation, aesthetics, cleanability, ease of application, and accessibility to treatment. The visual analog scale (VAS) was employed to score the survey questions. The results of the study were assessed at a 95% confidence interval with a level of significance of $p<0.05$.
Results: The satisfaction ratings for implant-supported overdenture prosthesis were significantly higher regarding chewing comfort, psychological safety, and enhanced pleasure for eating. Traditional complete dentures have significantly higher satisfaction ratings for treatment accessibility, treatment simplicity, and reduced food retention. Neither type of prosthesis has statistical superiority over the other on aesthetics, phonation, retention, cleanability, taste and smell, ease of insertion and removal, and overall satisfaction.
Conclusions: Although both types of prosthesis have advantages over each other in different evaluations, there is no significant difference between the two types of prosthesis in terms of overall patient satisfaction.
Keywords: Complete denture, implant-supported overdenture, patient satisfaction

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GİRİŞ

Günümüz diş hekimliğindeki restoratif ve koruyucu uygulamalardaki gelişmelere rağmen; tam dişsizlik toplumlarda sıkça görülen bir durum olmaya devam etmektedir (Al-Rafee, 2020). Türkiye' deki 65 yaş üstü popülasyonda tam dişsizlik görülme oranı %48 olarak rapor edilmiştir (Doğan BG & Gökalp, 2012). Konvansiyonel tam protezler yüzyılı aşkın süredir tam dişsizliğin tedavisinde sıklıkla kullanılsa da özellikle mandibulada retansiyon ve stabilite eksikliği, çiğneme fonksiyonunda azalma, devam eden kemik rezorpsiyonuna bağlı retansiyon ve stabilite kaybında artış, sosyal kaygı gibi dezavantajlarından dolayı yeterli hasta memnuniyeti sunamayabilirler (Müller & Schimmel, 2010). Konvansiyonel tam protezlerin, özellikle mandibulada, sahip oldukları dezavantajlardan dolayı, günümüzde implant destekli overdenture protezler tam dişsizlik olgularında tercih edilen bir tedavi alternatifi olmuştur (Doundoulakis ve ark., 2003).

İmplant destekli overdenture protezlerde ihtiyaç olan implant sayısının iki ila dörde kadar azaltılması tedavi maliyetini düşürmekte, cerrahi uygulamaları kolaylaştırmaktadır. Stabilitenin ve retansiyonun artması ile protezin işlevselliği de artmakta, tam protezlere göre çiğneme performansları artmaktadır (Geçkili ve ark., 2010). Kalan dokuların korunması, tüm tedavilerde ortak amaçtır. Literatürde implant destekli overdenture protez kullanan hastalardaki rezidüel kemik rezorpsiyonunun, konvansiyonel tam protez kullanan hastalara göre daha az olduğu bildirilmiştir (Aldhohrah ve ark., 2020; Gray & Patel, 2021).

Protetik tedavi başarısındaki en önemli faktörlerden biri hasta memnuniyetinin sağlanabilmesidir. İmplant destekli overdenture protezlerin konvansiyonel tam protezlere göre daha yüksek sağ kalım oranları ve gelişmiş oral fonksiyonlar sunduğu, hasta memnuniyeti ve Ağız Sağlığı ile İlgili Yaşam Kalitesini (OHRQoL) artırmada daha etkili olduğu rapor edilmiştir (Nogueira ve ark., 2018; Passia ve ark., 2019; Zhang ve ark., 2017).

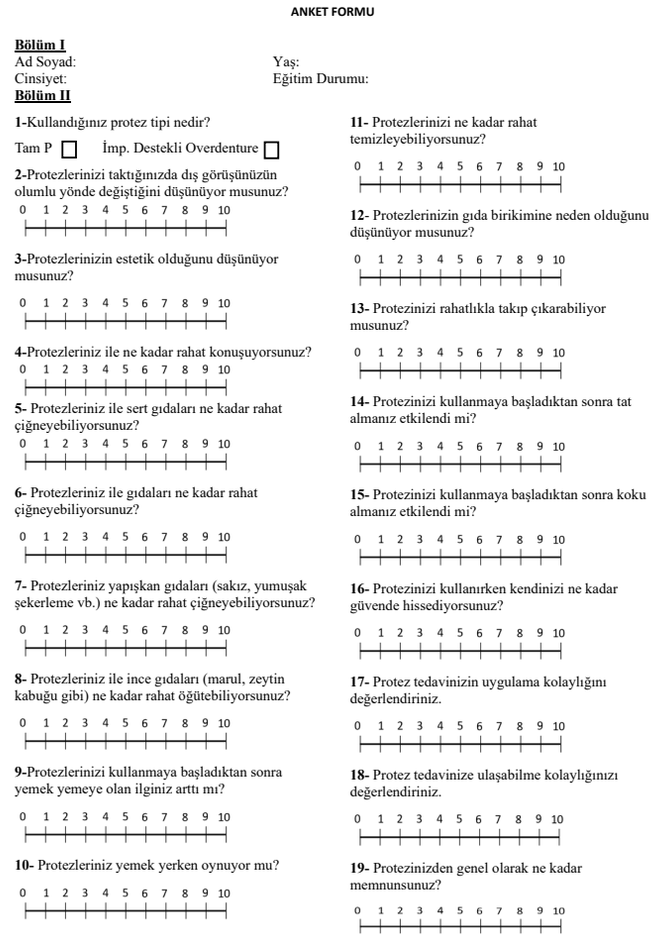
Bu çalışmanın amacı, konvansiyonel tam protezler ve implant destekli overdenture protez kullanan bireylerde hasta memnuniyetinin karşılaştırılması ve hasta memnuniyetine etki eden faktörlerin değerlendirilmesidir. Çalışmanın hipotezi implant destekli overdenture protez kullanan katılımcıların konvansiyonel tam protez kullananlara göre hasta memnuniyetlerinin daha fazla olacağı yönündedir.

GEREÇ VE YÖNTEMLER

Bu çalışmaya Marmara Üniversitesi Diş Hekimliği Fakültesi Klinik Araştırmalar Etik Kurulu'nun 2022-33 Protokol numaralı Etik Kurul Onayı alınarak başlandı.

Marmara Üniversitesi Diş Hekimliği Fakültesi Ağız, Diş ve Çene Cerrahisi Anabilim Dalı'nda implant tedavileri ve Protetik Diş Tedavisi Anabilim Dalı'nda implant destekli overdenture protez ve konvansiyonel tam protez yaptırmış ve en az 6 aylık kullanım süresini tamamlayan hastalar arasından rastgele seçilen ve telefonla aranarak bu anket çalışmasına katılmayı kabul eden 100 gönüllü çalışmaya dahil edildi.

Gönüllülerin memnuniyetlerini değerlendirilmesinde 2 bölümden oluşan bir anket formu kullanıldı. Birinci bölümde gönüllülere yaş, cinsiyet ve eğitim durumu gibi bilgilerine yönelik; ikinci bölümde ise estetik, fonasyon, fonksiyon, temizlenebilirlik, takıp çıkarma kolaylığı ve genel memnuniyetlerinin değerlendirilmesine yönelik sorular soruldu (Şekil 1). Gönüllülerden soruları 1 ve 10 (1 en düşük, 10 en yüksek memnuniyet skoru olacak şekilde) arasında skorlamaları istendi.



ANKET FORMU

Bölüm I
Ad Soyad: Yaş:
Cinsiyet: Eğitim Durumu:
Bölüm II

1-Kullandığınız protez tipi nedir?
Tam P ☐ İmp. Destekli Overdenture ☐

2-Protezlerinizi taktığınızda dış görüşünüzün olumlu yönde değiştiğini düşünüyor musunuz?
0 1 2 3 4 5 6 7 8 9 10

3-Protezlerinizin estetik olduğunu düşünüyor musunuz?
0 1 2 3 4 5 6 7 8 9 10

4-Protezleriniz ile ne kadar rahat konuşuyorsunuz?
0 1 2 3 4 5 6 7 8 9 10

5- Protezleriniz ile sert gıdaları ne kadar rahat çiğneyebiliyorsunuz?
0 1 2 3 4 5 6 7 8 9 10

6- Protezleriniz ile gıdaları ne kadar rahat çiğneyebiliyorsunuz?
0 1 2 3 4 5 6 7 8 9 10

7- Protezleriniz yapışkan gıdaları (sakız, yumuşak şekerleme vb.) ne kadar rahat çiğneyebiliyorsunuz?
0 1 2 3 4 5 6 7 8 9 10

8- Protezleriniz ile ince gıdaları (marul, zeytin kabuğu gibi) ne kadar rahat öğütebiliyorsunuz?
0 1 2 3 4 5 6 7 8 9 10

9-Protezlerinizi kullanmaya başladıktan sonra yemek yemeye olan ilginiz arttı mı?
0 1 2 3 4 5 6 7 8 9 10

10- Protezleriniz yemek yerken oynuyor mu?
0 1 2 3 4 5 6 7 8 9 10

11- Protezlerinizi ne kadar rahat temizleyebiliyorsunuz?
0 1 2 3 4 5 6 7 8 9 10

12- Protezlerinizin gıda birikimine neden olduğunu düşünüyor musunuz?
0 1 2 3 4 5 6 7 8 9 10

13- Protezinizi rahatlıkla takıp çıkarabiliyor musunuz?
0 1 2 3 4 5 6 7 8 9 10

14- Protezinizi kullanmaya başladıktan sonra tat almanız etkilendi mi?
0 1 2 3 4 5 6 7 8 9 10

15- Protezinizi kullanmaya başladıktan sonra koku almanız etkilendi mi?
0 1 2 3 4 5 6 7 8 9 10

16- Protezinizi kullanırken kendinizi ne kadar güvende hissediyorsunuz?
0 1 2 3 4 5 6 7 8 9 10

17- Protez tedavinizin uygulama kolaylığını değerlendiriniz.
0 1 2 3 4 5 6 7 8 9 10

18- Protez tedavinize ulaşabilme kolaylığınızı değerlendiriniz.
0 1 2 3 4 5 6 7 8 9 10

19- Protezinizden genel olarak ne kadar memnunsunuz?
0 1 2 3 4 5 6 7 8 9 10

Şekil 1. Gönüllülerin memnuniyetinin değerlendirilmesinde kullanılan anket formu

Çalışmada elde edilen verilerin istatistiksel analizi için IBM SPSS (Statistical Package for Social Sciences) 20.0 programı kullanıldı. Çalışma verileri değerlendirilirken tanımlayıcı istatistiksel metotlardan (Frekans, yüzde, ortalama, standart sapma) yararlanıldı. Verilerin değerlendirilmesinde Independent Samples t testi, Ki-kare, One-Way Anova analizi kullanıldı. Sonuçlar; %95 güven aralığında, anlamlılık $p<0,05$ düzeyinde değerlendirildi.

BULGULAR

Demografik Bulgular

Çalışmaya 50' si erkek, 50' si kadın, 50 – 89 yaş aralığında, farklı eğitim düzeylerine sahip 100 gönüllü katılmıştır.

Gönüllülerin 50 (%50) si implant destekli overdenture protez, 50(%50) si konvansiyonel tam protez kullanmaktadır. Kullanılan protez tipi ile demografik veriler arasındaki ilişki değerlendirildiğinde yaş, cinsiyet ve eğitim düzeyleri ile kullanılan protez tipleri arasında istatistiksel olarak anlamlı bir farklılık tespit edilememiştir (Tablo 1).

Tablo 1. Gönüllülerin cinsiyet, yaş ve eğitim düzeylerine göre dağılımı

Demografik Özellikler		n:100 (n)(%)
Cinsiyet	Kadın	50 (50)
	Erkek	50 (50)
Yaş	50-59	25 (25)
	60-69	45 (45)
	70-79	25 (25)
	80-89	5 (5)
Eğitim Düzeyi	İlköğretim	68 (68)
	Lise	23 (23)
	Lisans	9 (9)
	Yüksek Lisans-Doktora	0 (0)

Estetik ve Fonasyonun Değerlendirilmesi

Gönüllülerin estetik beklentilerine yönelik sorulan 2. ve 3. sorular ve konuşma rahatlığının değerlendirilmesine yönelik sorulan 4. sorunun memnuniyet skorları değerlendirildiğinde protez tipleri açısından anlamlı bir farklılık bulunamamıştır. Bu soruların genel memnuniyetler ile arasındaki ilişki değerlendirildiğinde, protezi estetik bulma ile genel memnuniyet arasında %30'luk (düşük seviye); konuşma rahatlığı ile genel memnuniyet arasında %58' lik (orta seviye) pozitif bir ilişki mevcuttur (Tablo 2).

Fonksiyonun Değerlendirilmesi

Gönüllülerin çiğneme fonksiyonuna yönelik memnuniyetleri 5., 6., 7., 8., 9. ve 10. sorularla ölçülmüştür. Yapışkan gıdaların çiğneme rahatlığına yönelik 7. Soru ve yemek yerken protezlerin hareketine yönelik 10. Soruda protez tipi açısından overdenture ve konvansiyonel tam protez arasında anlamlı farklılık bulunmazken, 5.,6., 8., 9. Sorularda çiğneme fonksiyonuna yönelik memnuniyet derecesi overdenture protezlerde anlamlı olarak daha yüksektir (Tablo 2). Genel memnuniyet ile çiğneme etkinliği arasındaki ilişki değerlendirildiğinde 7. (%48) ve 10. (%49) sorularda orta seviyede bir ilişki mevcuttur. Bu ilişkinin overdenture protezlerde çiğneme etkinliğinin anlamlı olarak fazla olduğu 5.(%75), 6.(%67) ve 8.(%61) sorularda yüksek seviyede iken; 9. soruda (%38) ise düşük seviyede olduğu görülmüştür (Tablo2).

Temizlenebilirliğin Değerlendirilmesi

Gönüllülerin protezlerini temizleyebilme rahatlığına yönelik memnuniyetleri 11. Soru ile değerlendirilmiştir. Protez tipi ile protezi rahat temizleyebilme arasında istatistiksel olarak anlamlı bir ilişki bulunamamıştır. Genel memnuniyet ile temizleme rahatlığı arasında ise düşük seviyede (%19) bir ilişki mevcuttur. Gönüllülerin, protezlerindeki gıda birikmesine yönelik memnuniyetleri değerlendirildiğinde ise (12. Soru) overdenture kullanan hastalar protezlerinde daha çok gıda biriktiğini ifade etmişlerdir ve protez tipi ile protezlerin gıda retansiyonuna neden olması arasında istatistiksel olarak %20' lik pozitif, anlamlı bir ilişki olduğu bulunmuştur. Bu soru ile genel memnuniyet arasında %33'lük (düşük seviye) pozitif bir ilişki tespit edilmiştir (Tablo2).

Tablo 2. Gönüllülerin protez tiplerine göre memnuniyet skorları

Sorular (1=en az, 10= en çok)	Protez Tipine göre memnuniyet skoru		Protez tipleri arasındaki ilişki	Genel memnuniyet derecesi ile ilişkisi
	O.P (ort ±ss)	T.P (ort ±ss)		
Protezlerinizi taktığınızda dış görüşünüzün olumlu yönde değiştiğini düşünüyor musunuz?	6,2±3,18	6,3±2,94	-	%30 (düşük)
Protezlerinizin estetik olduğunu düşünüyor musunuz?	8±2,36	8,04±2,23	-	%30 (düşük)
Protezleriniz ile ne kadar rahat konuşabiliyorsunuz?	9,06±2,34	8,46±3,11	-	%58 (orta)
Protezleriniz ile ne kadar rahat çiğneme yapabiliyorsunuz?	8,1±2,28	6,76±3,19	%24 pozitif	%75 (yüksek)
Protezleriniz ile sert gıdaları ne kadar rahat çiğneyebiliyorsunuz?	7,38±2,57	6,24±3,23	%20 pozitif	%67(yüksek)
Protezleriniz yapışkan gıdaları ne kadar rahat çiğneyebiliyorsunuz?	3,3±2,48	3,78±3,06	-	%48 (orta)
Protezleriniz ile ince ne kadar rahat öğütebiliyorsunuz?	8,8±2,36	6,62±3,35	%35 pozitif	%61 (yüksek)
Protezlerinizi kullanmaya başladıktan sonra yemek yemeye olan ilginiz arttı mı?	5,92±3,77	4,47±3,04	%21 pozitif	%38 (düşük)
Protezleriniz yemek yerken oynuyor mu?	3,02±2,79	3,3±2,95	-	%49 (orta)
Protezlerinizi ne kadar rahat temizleyebiliyorsunuz?	9,12±2,03	9,14±2,45	-	%19 (düşük)
Protezlerinizin gıda birikimine neden olduğunu düşünüyor musunuz?	5,24±3,24	4±2,82	%20 pozitif	%33 (düşük)
Protezinizi takıp çıkarmada ne derecede rahatsınız?	8,74±2,83	9,48±1,92	-	-
Protezinizi kullanmaya başladıktan sonra tat almanız ne derecede etkilendi?	5,48±1,59	4,88±0,69	-	-
Protezinizi kullanırken koku almanız ne derecede etkilendi?	5±0	4,98±0,14	-	-
Protezinizi kullanırken kendinizi ne kadar güvende hissediyorsunuz?	8,72±2,11	7,02±3,09	%31 pozitif	%75 (yüksek)
Protez tedavinizin uygulama kolaylığını değerlendiriniz.	4,46±3,16	7,24±2,03	%47 pozitif	-
Protez tedavinize ulaşabilme kolaylığınızı değerlendiriniz.	4,54±3,44	6,18±2,09	%30 pozitif	-
Protezinizden genel olarak ne kadar memnunsunuz?	7,66±2,37	6,8±3,01		

Gönüllülerin protezlerine yönelik estetik, fonksiyon, fonasyon ve temizlenebilirlik açısından memnuniyetlerinin değerlendirilmesinin yanı sıra protezlerini takıp çıkarma rahatlıkları (13. Soru), protez kullanımı sonrası tat almadaki (14. Soru) ve koku almadaki (15. Soru) değişiklik miktarları da değerlendirilmiştir. Overdenture protez ve konvansiyonel tam protezler arasında tat ve koku alma miktarı ve protezlerin takıp çıkarma rahatlığı açısından anlamlı bir farklılık bulunamamıştır (Tablo2).

Gönüllülerin protezlerini kullanırken kendilerini ne kadar güvende hissettikleri (16. Soru) değerlendirildiğinde overdenture protez kullanan hastaların kendilerini daha güvende hissettiği; Protez tipi ile protezleri kullanırken kendini güvende hissetme arasında istatistiksel olarak %31'lik anlamlı bir ilişki olduğu bulunmuştur. Gönüllülerin protezleriyle kendilerini güvende hissetmeleri ile protezlerinden genel memnuniyetleri arasında %75'lik pozitif (yüksek düzey) bir ilişki vardır (Tablo2).

Protez tedavisinin uygulama kolaylığı (17. Soru) ve hastaların tedaviye erişim kolaylıkları (18. Soru) değerlendirildiğinde protez tipleri arasında anlamlı farklılık bulunmuştur. Her iki soruda da konvansiyonel tam protez kullanan hastaların memnuniyet skorları daha yüksektir. Protez tipi ile tedavi kolaylığı arasında istatistiksel olarak %47'lik; protez tipi ile tedaviye ulaşabilme kolaylığı arasında istatistiksel olarak %30'luk pozitif anlamlı bir ilişki bulunmaktadır. Fakat bu iki sorunun gönüllülerin genel memnuniyet dereceleri ile ilişkisi bulunamamıştır (Tablo2).

Gönüllülerin protezlerinden genel memnuniyetleri değerlendirildiğinde ise protez tipleri arasında anlamlı bir farklılık bulunamamıştır (Tablo2).

TARTIŞMA

Overdenture protez ve konvansiyonel tam protez kullanan bireylerde hasta memnuniyetinin karşılaştırılması ve hasta memnuniyetine etki eden faktörlerin değerlendirilmesi amacıyla yaptığımız çalışmamızda protez tipi ile genel memnuniyet arasında anlamlı bir ilişki bulunamamıştır. Bu sebeple overdenture protezlerde genel memnuniyetin daha yüksek olacağı yönündeki hipotezimiz reddedilmiştir.

Tam dişsizliğin en eski ve yaygın tedavi şekli tam protezlerdir. Ancak tam protezlerin sahip olduğu dezavantajlara karşılık geliştirilen implant destekli overdenture protezler, tam protezlere karşı önemli bir alternatif oluşturmuşlardır (Doundoulakis ve ark., 2003; Zitzmann ve ark., 2007).

Literatürde, implant destekli overdenture tedavisi ile konvansiyonel tam protez tedavisinin hasta memnuniyeti açısından incelendiği pek çok çalışma mevcuttur. (Allen ve ark., 2001; Assunção ve ark., 2010; Brennan ve ark., 2013; Geçkili ve ark., 2012; Pjetursson ve ark., 2005; Tomruk ve ark., 2013) Hasta memnuniyeti üzerine yapılan çalışmaların en önemli zorluk ve dezavantajları; memnuniyet gibi sübjektif bir kavramın hastadan hastaya değişiklik göstermesi, memnuniyet kavramının hastaların psikolojik ve sosyal geçmişine göre şekillenmesi ve standardize edilmemiş anket soruları ile farklı çalışmaların karşılaştırılamamasıdır (Assunção ve ark., 2010). Bunların yanı sıra retrospektif anket çalışmalarının en önemli dezavantajlarından birisi de özne belleğine güven mecburiyetidir (Allen ve ark., 2001). Bununla birlikte anketler; düşük maliyetli, uygulaması kolay ve toplumun bakış açısını ifade edebilen araştırma yöntemleri olduğundan hasta memnuniyetinin değerlendirildiği çalışmalarda önerilmektedir (Erdil ve ark., 2019). Çalışmamızda, hastalara protezlerini estetik, fonksiyon, fonasyon, temizlenebilirlik, uygulama kolaylığı ve tedaviye ulaşılabilirlik gibi farklı faktörlere göre değerlendirdiği özelleştirilmiş soruların ve protezlerinden genel memnuniyetlerini değerlendirdikleri bir sorunun olduğu anket formları kullanılmıştır.

Literatürde hasta memnuniyeti ile yaş ve cinsiyet değerlendirildiğinde farklı sonuçlar rapor edilmiştir. Torres ve arkadaşları (Torrez ve ark, 2011) tam protezler ve implantüstü overdenture protez kullanan hastalarda hasta memnuniyeti ve yaşam kalitesini değerlendirdikleri çalışmalarında erkek hastaların memnuniyet skorlarının daha yüksek olduğunu bildirmişlerdir. Bununla birlikte Geçkili ve arkadaşları, (Geçkili ve ark., 2012) geleneksel tam protez ve implant destekli overdenture uygulanan hastalarda cinsiyet faktörünün hasta memnuniyeti ve yaşam kalite skorlarını etkilemediğini bildirmiştir. Çalışmamızda, hastaların kullandığı protez tipi ile yaş, cinsiyet, eğitim durumu arasında istatistiksel olarak anlamlı bir ilişki bulunmamıştır. Bunun nedeni, eğitim araştırma hastanesinde yürütülen bu tedavilerde, tedavi planlamasında hastaların tedaviye fizyolojik uygunluklarına öncelik verilmesi ile açıklanabilir.

İmplant destekli overdenture protezlerde ve konvansiyonel tam protezlerde estetiği ve konuşmayı etkileyen faktörler ve protezlerin temizleme yöntemleri benzerdir. Assunçao ve arkadaşları (Assunçao ve ark., 2010) geleneksel tam protezler ve implant destekli overdenture protezlerdeki hasta memnuniyeti ve yaşam kalitesini değerlendirmişler ve protez tipleri arasında kullanım rahatlığı, fonasyon, estetik, ağrı, genel memnuniyet ve fonksiyon açısından anlamlı bir farklılık bulamamışlardır. Çalışmamızda; estetik, fonasyon, temizleme rahatlığı, tat ve koku alma miktarındaki değişiklikler açısından protez tipleri arasında memnuniyet skorlarında anlamlı bir farklılık bulunamamıştır.

Melas ve arkadaşları (Melas ve ark., 2001), geleneksel alt tam protez kullanan hastaların, implant destekli mandibular overdenture kullanan hastalar ile kıyaslandığında, gıdaların ısırılması (%66.9), çiğnenmesi (%75.7) ve gıdaların yutulmasında daha fazla zorluk yaşadıklarını bildirmiştir. Geçkili ve arkadaşları (Geçkili ve ark.,2012) ise 2-implant destekli mandibular overdenture uygulanan hastaların, ısırma kuvveti değerlerinin 60,5 N ile 305,5 N (ortalama 127.3 N) arasında, geleneksel tam protez uygulanan hastaların, ısırma kuvvet değerlerinin 21 N ile 144 N (ortalama 53.09 N) arasında değiştiğini bildirmiştir. Benzer grupların karşılaştırıldığı bir diğer retrospektif çalışmada, 2-implant destekli mandibular overdenture kullanan hastaların, ısırma kuvveti değerlerinin ve hasta

memnuniyet skorlarının daha yüksek olduğu, fakat yaşam kalitesi skorlarının geleneksel tam protez kullananlar ile kıyasladığında fark olmadığı rapor edilmiştir. (Feine ve ark., 2002). Konvansiyonel tam protezlerde çiğneme kuvveti daha düşüktür ve doku reziliensine bağlı olarak fonksiyon sırasında protez dokuya doğru gömülme hareketi yapar. Bu durum öğütme fonksiyonunun azalmasına neden olur. Çalışmamızda çiğneme rahatlığı, sert ve ince gıdaların öğütülmesi açısından implant destekli overdenture protez kullanan hastaların memnuniyet skorları anlamlı olarak daha yüksek bulunmuştur.

Awad ve arkadaşları (Awad ve ark., 2003) iki implantla desteklenmiş mandibular overdenture protezler ve tam protez kullanan 60 hastanın tedavi öncesi ve tedaviden 2 ay sonraki genel yaşam kalitesi, çiğneme yeteneği, konuşma rahatlığı, protezini kullanırken kendini güvende hissetme derecesi gibi pek çok faktörü değerlendirdikleri çalışmalarında; overdenture kullanan hastaların kendini daha güvende hissettiğini ve yaşam kalitesi skorlarının anlamlı olarak daha yüksek olduğunu bildirmiştir. Bu çalışmayla paralel olarak çalışmamızda overdenture kullanan hastalar, konvansiyonel tam protez kullanan hastalara göre kendilerini daha güvende hissetmektedir.

Hastalar genel memnuniyet sorusuna, özelleşmiş memnuniyet sorularına göre daha yüksek puan vermiştir. Bu durum, hastaların protezlerinden memnun olmadıkları hususlar olsa da protezlerine alışarak kabullenmeleri sebebiyle ortaya çıkmış olabilir. Memnuniyet skorları yüksek olmakla birlikte genel memnuniyet açısından protez tipleri arasında anlamlı farklılık bulunamamıştır. Bu sonuca ulaşılmasında; hastaların mevcut protezlerine alışmaları ve protezlerin olumsuz yanlarını görmezden gelmeleri, farklı bir protez tipi kullanmamış hastaların karşılaştırma yapamadıkları için mevcut protezlerini en doğru protez şekli olarak görmeleri, protez tipi fark etmeksizin, tedavilerin eğitim araştırma hastanesinde yapılmış olması dolayısıyla tedavinin bütün temel kurallarının uygulanmasının etken olduğunu düşünmekteyiz.

SONUÇ

İmplant destekli overdenture protez ve konvansiyonel protezleri hasta memnuniyeti açısından karşılaştırdığımız anket çalışmamızın sonuçları ile örtüşen ve çelişen pek çok araştırma mevcuttur. Bu farklı sonuçların temel nedeni standart bir metodolojinin kullanılmamış olmasıdır. Memnuniyet kavramının sübjektif oluşu ve hastaların sosyopsikolojik durumlarından, geçmiş tecrübelerinden, tedaviden ve sonraki yaşamlarından beklentilerinden etkilenmesi araştırma sonuçları arası farklılıklara neden olmaktadır. Araştırmalardaki bu dezavantajların minimalize edilmesi için anket sorularında, örneklem seçiminde, takip-değerlendirme sürelerinde belirli kriter ve standartların belirlenmesi, memnuniyet değerlendirmesine psikolojik ve sosyal değerlendirmelerin dahil edilmesi faydalı olacaktır.

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ORIGINAL ARTICLE / ARAŞTIRMA MAKALESİ

The Effectiveness of ChatGPT in Temporomandibular Joint Pathologies and Sequence Determination in Magnetic Resonance Imaging

Manyetik Rezonans Görüntülemede Temporomandibular Eklem Patolojileri ve Sekansın Belirlenmesinde ChatGPT'nin Etkinliği

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ABSTRACT

Objectives: Temporomandibular joint (TMJ) pathologies is a general term for pain and dysfunction of the TMJ complex and masticatory muscles. Magnetic resonance imaging (MRI) is the gold standard for evaluating the TMJ complex, disc-condylar relationship and disc displacement. The aim of this study was to evaluate the effectiveness of ChatGPT version 4.0 (ChatGPT-V4) in identifying TMJ pathologies, slice plane and sequence in MR images.

Materials and Methods: One hundred MR images of patients with bilateral TMJ pathology (200 TMJs) were recorded. TMJ pathologies, slice plane, sequence of the MR images and ChatGPT responses were evaluated. The subheadings in the ChatGPT-V4 answers were recorded as true if present in the image and false if not. The slice plane was categorized as true-false and the sequence as true-false-missing.

Results: In all images, ChatGPT-V4 correctly recognized the slice plane. The correct MR sequence determination rate was 81.5%. Missing sequence recognition rate was 12% on both sides. It failed to identify the fat-suppressed sequences. ChatGPT-V4 misidentified the sequence in 6.5% of the images. The accuracy of ChatGPT-V4 in identifying TMJ pathologies remained at 50.7%. ChatGPT-V4 achieved the highest accuracy in the diagnosis of anterior disc dislocation and osteoarthritis.

Conclusions: ChatGPT-V4 can be relied upon to control the slice plane and sequence of MR images. The results show that ChatGPT-V4 is currently limited in its ability to produce responses related to TMJ pathologies on MR images. Therefore, ChatGPT cannot replace a dentist and physicians should be aware of this limitation during their use of chatGPT to check for TMJ pathologies.

Keywords: Artificial intelligence, Magnetic resonance imaging, Temporomandibular joint

ÖZ

Amaç: Temporomandibular eklem (TME) patolojileri, TME kompleksi ve çiğneme kaslarının ağrı ve işlev bozukluğu için kullanılan genel bir terimdir. Manyetik rezonans görüntüleme (MRG), TME kompleksini, disk-kondiler ilişkiyi ve disk deplasmanını değerlendirmek için altın standarttır. Bu çalışmanın amacı ChatGPT versiyon 4.0'ın (ChatGPT-V4) TME patolojilerini, kesit düzlemini ve MR görüntülerindeki sekansı belirlemedeki etkinliğini değerlendirmektir.

Gereç ve Yöntemler: Bilateral TME patolojisi olan hastaların yüz MR görüntüsü (200 TME) kaydedildi. TME patolojileri, kesit düzlemi, MR görüntülerinin sırası ve ChatGPT yanıtları değerlendirildi. ChatGPT-V4 yanıtlarındaki alt başlıklar görüntüde varsa doğru, yoksa yanlış olarak kaydedildi. Kesit düzlemi doğru-yanlış ve sekans doğru-yanlış-eksik olarak kategorize edildi.

Bulgular: Tüm görüntülerde ChatGPT-V4 kesit düzlemini doğru şekilde tanıdı. Doğru MR sekansını belirleme oranı %81,5'ti. Eksik sekans tanıma oranı her iki tarafta da %12 idi. Yağ baskılı sekansları tanımlamada başarısız oldu. ChatGPT-V4 görüntülerin %6,5'inde sekansı yanlış tanımladı. ChatGPT-V4'ün TME patolojilerini tanımlama doğruluğu %50,7'de kalmıştır. ChatGPT-V4, anterior disk dislokasyonu ve osteoartrit tanısında en yüksek doğruluğu elde etti.

Sonuç: ChatGPT-V4'e MR görüntülerinin kesit düzlemini ve sekansını kontrol etmek için güvenilebilir. Sonuçlar ChatGPT-V4'ün şu anda MR görüntülerinde TME patolojileriyle ilgili yanıtlar üretme kabiliyetinin sınırlı olduğunu göstermektedir. Bu nedenle ChatGPT bir diş hekiminin yerini alamaz ve hekimler TME patolojilerini kontrol etmek için chatGPT'yi kullanırken bu sınırlamanın farkında olmalıdır.

Anahtar Kelimeler: Yapay zeka, Manyetik rezonans görüntüleme, Temporomandibular eklem

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INTRODUCTION

ChatGPT (Chatbot Generative Pre-Trained Transformer) is one of the latest and most powerful Large Language Models (LLM). Its disruptive capabilities have taken the world by storm, opening a new era of possibilities and challenges in every field, including healthcare. Although ChatGPT is not trained on medical data, medical professionals and researchers have experimented with analyzing and interpreting medical data, demonstrating multiple benefits of this chatbot in research and practice settings (Sinha et al., 2023).

While traditional language models are programmed to use statistical techniques to predict the next word in a sentence, ChatGPT uses transducer-based models that allow processing large amounts of data in parallel. The result is a revolution in the ability of these models to understand and produce text. Within seconds, ChatGPT is capable of producing persuasive and grammatically fluent prose indistinguishable from content produced by human researchers (Alberts et al., 2023). ChatGPT version 3.5 was introduced in November 2022 and is available to users free of charge (Freire et al., 2024). The newest version to date, ChatGPT version 4.0 (ChatGPT-V4), requires a paid subscription (Deiana et al., 2023).

As AI platforms become an important source of information, they can play a role in influencing health-related behaviors (Pan et al., 2023). However, controversy continues regarding optimal diagnostic methods, treatment strategies and the importance of occlusal factors in temporomandibular joint (TMJ) pathologies (Olliver et al., 2020; Stegenga, 2010). Understanding TMJ function is challenging due to its complex nature and wide range of TMJ symptoms that often overlap with other dental and non-dental disorders (Stegenga, 2010). The lack of consensus among healthcare professionals on the etiology and management of TMJ makes this condition even more difficult to understand (Farook & Dudley, 2023).

Accurate information about this complex TMJ disease group is crucial for patients and clinicians. ChatGPT, a natural language processing technology developed by OpenAI, shows promise in various sectors, including healthcare. ChatGPT can facilitate information sharing, support clinical decision-making and improve patient communication and education in the management of TMJ pathologies. It can also serve as a useful information tool to improve patient and clinician outcomes (Kula et al., 2024). To the best of our knowledge, there is no study in the literature evaluating ChatGPT efficacy related to TMJ using magnetic resonance imaging (MRI). The aim of this retrospective study was to evaluate the effectiveness of ChatGPT in identifying TMJ pathologies, slice plane and sequence in MR images. The research hypothesis was that image analysis of TMJ pathologies by ChatGPT would not be accurate or reproducible.

MATERIALS AND METHODS

This study was approved by the Local Ethics Committee of the Hatay Mustafa Kemal University University (Date: 19.03.2025, Decision No: 07) and the study protocol was conducted in accordance with the principles set out in the World Medical Association Declaration of Helsinki of 1964 and later version.

Sample size was determined by using Sample Size Calculator (95% confidence interval). Sample size calculated was 167. 200 TMJs of 100 MR images of patients with TMJ complaints and underwent MR examination were included in the study.

Inclusion criteria:

1. Closed – and open-mouth MR sagittal images in patients with bilateral TMJ pathologies shown in Table 1

Exclusion criteria:

1. MR images of patients with unilateral TMJ pathologies or normal TMJ
2. MR images with severe artifacts in terms of diagnostic accuracy

TMJ pathologies, slice plane, sequence of the MR images and ChatGPT responses were evaluated by two associate professors (G.S-C.A.B) with nearly 10 years of experience in Oral and Maxillofacial Radiology. All inter-observer assessments were compared against the Gold standard created and noted by the professor researcher (K.G) with more than 20 years of experience in Oral and Maxillofacial Radiology. Figure 1 presents a representative example of the radiological assessment performed in this study. MR images with pathologies created by compiling the basic sources (Okeson, 1995; Bell, 1986; Griffıths, 1983; Hasso et al., 1989) on TMJ (Table 1) were saved in jpg format. Some criterias used for evaluation (Bertram et al., 2001; Roh et al., 2012; Larheim et al., 2001) were shown in Table 2.

Table 1. Pathologies in TMJ included in the study and referred to chatGPT-V4 (Okeson, 1995; Bell, 1986; Griffıths, 1983; Hasso et al., 1989)

1. Discrepancies of the condyle-disc complex
a. Displacement of the disk
b. Reduced disk displacements
c. Displacements of the disc without reduction
2. Structural mismatches of articular surfaces
a. Form disorders
i. Disk
ii. Condyle
iii. Fossa
b. Adhesions
i. Between the disc and condyle
ii. Between the disk and the fossa
c. Subluxations (Hypermobility)
d. Spontaneous Dislocations

Table 2. Criteria for evaluation of common TMJ pathologies

Disc-condyle relationship (Bertram et al., 2001)	Osteoarthritis (Roh et al., 2012)	Effusion (Roh et al., 2012; Larheim et al., 2001)
Normal disc position (posterior band of the disc in superior or 12 o'clock position relative to the condyle), Displacement of the disc (posterior band of the disc in anterior, anteromedial, anterolateral, medial or lateral position relative to the superior part of the condyle)	Erosion (interruption or absence of the cortical lining), Sclerosis (dense and thickened variations of subchondral bone shown as thickening of cortical bone), Flattening (loss of rounded contour), Osteophytes (marginal hypertrophic bone formation)	Dots or streaks, bands and aggregation of bright T2 signal intensity in the joint space

3. Inflammatory pathologies
- a. Synovitis
- b. Retrodiscitis
- c. Arthritis
  - i. Osteoarthritis
  - ii. Osteoarthrosis
  - iii. Polyarthritis
- d. Inflammatory pathologies of the structures surrounding the joint
  - i. Temporal tendonitis
  - ii. Inflammation of the stylomandibular ligament

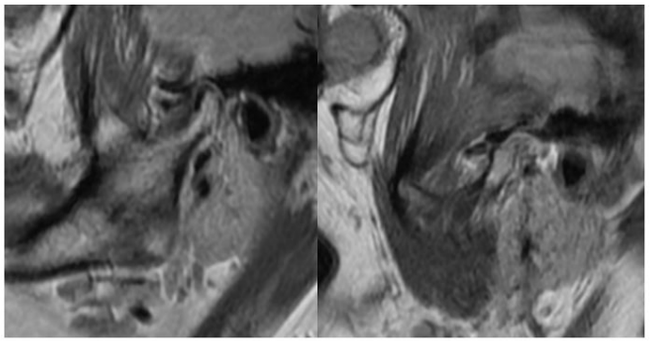
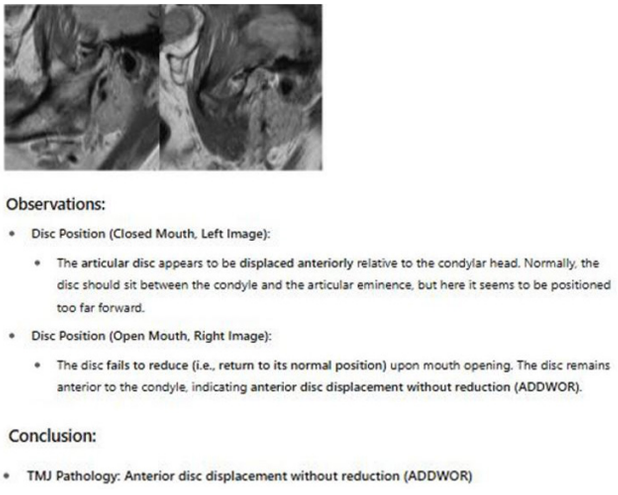


Figure 1. Closed – and open-mouth sagittal proton density fat-suppressed MR images showing anterior disc displacement without reduction. The articular disc is positioned anterior to the condylar head in both mouth positions, with no evidence of recapture upon opening. These images illustrate our radiological evaluation method for diagnosing temporomandibular joint internal derangement.

Subsequently, MR images with pathologies, plane and sequence were uploaded to chatGPT-V4 and all were asked the same question to ensure standardization: '*What is the slice plane, sequence and current TMJ pathology in this closed - and open-mouth MR image?*' (Figure 2). In order not to affect the performance of ChatGPT-V4 and to reduce the impact of randomness, we did not provide any prior guidance and MR images were entered into ChatGPT-V4 over a period of time. Each researcher made these entries in different randomized sequences, with different user accounts and different personal computers. The subheadings in the ChatGPT-V4 answers were recorded as true if present in the image and false if not. For example, assuming that ChatGPT-V4 identified pathologies under four headings, if two of these headings were present in the image, the accuracy was calculated as 50%. The slice plane was categorized as true-false and the sequence as true-false-missing.



Observations:

- **Disc Position (Closed Mouth, Left Image):**
  - The articular disc appears to be displaced anteriorly relative to the condylar head. Normally, the disc should sit between the condyle and the articular eminence, but here it seems to be positioned too far forward.
- **Disc Position (Open Mouth, Right Image):**
  - The disc fails to reduce (i.e., return to its normal position) upon mouth opening. The disc remains anterior to the condyle, indicating anterior disc displacement without reduction (ADDWOR).

Conclusion:

- **TMJ Pathology: Anterior disc displacement without reduction (ADDWOR)**

Figure 2. Example of response of ChatGPT version 4.0's MR image on TMJ pathology. Since ChatGPT version 4.0 gives the present pathology as an anterior disc dislocation without reduction, the accuracy rate was calculated as 100%.

This study accepted the findings of observer K.G as the gold standard and evaluated the degree of agreement between observer G.S and observer C.A.B in TMJ pathologies. Kappa statistics was used for assessing the agreement between observers. The kappa values were interpreted according to Landis and Koch (1977) (k ≤0.20 Poor, 0.21-0.40 Fair, 0.41-0.60 Moderate, 0.61-0.80 Good, 0.81-1.00 Very good). Since there was no need to make statistical comparisons, descriptive statistics (mean, standard deviation, median, frequency, rate, minimum,

and maximum) were performed using Microsoft® Excel® 2016 64-Bit Edition.

RESULTS

The kappa coefficients for inter-observer assessments were high. The kappa value for the agreement of slice plane and MR sequence was perfect (kappa = 1). A very good inter-observer agreement was achieved in the TMJ patologies with kappa values of 0.85 on the right side and 0.81 on the left side.

A total of MR images of 200 TMJs were included in the study. In all images, ChatGPT-V4 correctly recognized the slice plane. The correct MR sequence recognition rate was 81.5% (163 of 200 images). Missing sequence recognition rate was 12% (24 of 200 images). ChatGPT-V4 failed to identify the fat-suppressed sequences. It underdetermined every fat-suppressed MR sequence (Table 3). ChatGPT-V4 misidentified the sequence in 13 of the 200 (6.5%) images (Table 4). There was no explanation where the pathology was missed and the case was classified as normal. The overall pathology diagnostic accuracy was 50.7% ([right side: 49.9%±13.6 [min 20-max 80, median: 50], left side: 51.4%±16.3 [min 20-max 80, median:50]), with a high rate of 49.3% hallucinations. Furthermore, the highest hallucination rate belonged to subchondral sclerosis (95%) and synovial thickening (88.9%), respectively. The diagnostic hallucinations were shown in Table 5.

Table 3. Shortcomings of ChatGPT for sequence determination. The same table applies for the left and right side. Note the lack of fat suppressed sequence determination.

Correct MR sequences	ChatGPT response
Fat Suppressed Contrast-Enhanced T1W	Contrast-Enhanced T1W
T1W fat suppressed	T1W
Fat Suppressed Contrast-Enhanced T1W	Contrast-Enhanced T1W
T1W fat suppressed	T1W
T1W fat suppressed	T1W
T1W fat suppressed	T1W
T1W fat suppressed	T1W
T1W fat suppressed	T1W
T1W fat suppressed	T1W
T1W fat suppressed	T1W
Fat Suppressed Contrast-Enhanced T1W	Contrast-Enhanced T1W
T1W fat suppressed	T1W

Table 4. ChatGPT's sequence determination errors for the right and left side.

RIGHT	
Correct MR sequences	**ChatGPT response**
T2W	Contrast-Enhanced T1W
T1W fat suppressed	Contrast-Enhanced T1W
T1W fat suppressed	Contrast-Enhanced T1W
T1W	T2W
T1W	T2W
T1W	T2W
T1W	T2W
LEFT	
Correct MR sequences	**ChatGPT response**
T2W	Contrast-Enhanced T1W
T1W fat suppressed	Contrast-Enhanced T1W
T1W fat suppressed	Contrast-Enhanced T1W
T1W	T2W
T1W	T2W
T1W	T2W

Table 5. Diagnostic hallucination rates according to findings

Findings	Hallucinations (n)	ChatGPT response (n)	%
Effusion	73	93	78.5%
Joint space narrowing	72	106	67.9%
Subchondral sclerosis	57	60	95%
Disc deformity	-	16	0%
Condyle deformity	25	30	83.3%
Adhesion	11	12	91.7%
Condyle dislocation	-	2	0%
Synovial thickening	8	9	88.9%

DISCUSSION

The research hypothesis that the answers generated by ChatGPT-V4 regarding TMJ pathologies would not be accurate or reproducible was not rejected due to its limited ability to address TMJ pathologies. Since the popularity of artificial intelligence systems has increased significantly, ChatGPT's image analysis performance should be evaluated and compared with other artificial intelligence platforms.

In this study, we evaluated the effectiveness of ChatGPT-V4 in identifying TMJ pathologies, slice plane and sequence in MR images. We found that ChatGPT-V4 correctly recognized the slice plane in all images. The correct MR sequence recognition rate was 81.5%. Missing sequence recognition rate was 12%. ChatGPT-V4 misidentified the sequence in 6.5% of the images. The accuracy of ChatGPT-V4 in identifying TMJ pathologies remained at 50.7%. ChatGPT-V4 achieved the highest accuracy in the diagnosis of anterior disc dislocation and osteoarthritis. It failed to identify the fat-suppressed sequences. It underdetermined every fat-suppressed MR sequence.

These results are consistent with other studies demonstrating the ability of ChatGPT to provide limited answers about radiologic image analysis. Ren et al. (2024) reported that the limitations of ChatGPT-V4 in diagnosing bone disorders with or without space-occupying lesions should be considered. In the study by Ren et al. (2024) the accuracy rate of ChatGPT-V4 in radiologic image analysis of osteosarcoma was found to be 60%. In the study of Brin et al. (2024), GPT-4V identified the pathology in 35.2%. They found a diagnostic hallucination rate of 46.8% for ChatGPT-V4. Therefore, Brin et al. (2024) concluded

that despite its broad potential, ChatGPT-V4 is not yet a reliable tool for clinical radiologic image interpretation. These results are close to the result found in our study (50.7%). However, in the systematic review by Chelli et al. (2024), hit rates for GPT-4 were found to be 13.4% (16/119). Hallucination rates were 28.6% (34/119) for GPT-4. These rates are lower than our study. This result may be due to the fact that image analysis was not performed in all of the compiled studies. We think that text and image analysis may yield different results.

The high rate of diagnostic errors observed in the performance of the ChatGPT-V4 is a major concern. These errors, where the model produces false or fabricated information, highlight a critical limitation in its current capability. Such inaccuracies emphasize that ChatGPT-V4 is not yet suitable for use as a standalone diagnostic tool. These errors can lead to misdiagnosis and patient harm if used without appropriate control mechanisms. It is therefore crucial that radiologiwsts are involved in any task where these models are used. Radiologists can ensure patient safety and accuracy of diagnoses by providing the necessary clinical judgment and contextual understanding that AI models currently lack (Brin et al., 2024).

Ren et al. (2024) conducted a random selection of 40 X-ray images. In another study, the performance of ChatGPT-V4 in multiple medical imaging modalities, including computed tomography, X-ray and MRI, was evaluated using a dataset of 56 images (Yan et al., 2023). In contrast, our study not only increases the sample size with a total of 200 MR slice images, but also provides the first findings in the literature by including TMJ disorders, which are highly prevalent in populations. Our approach supports the conclusion that ChatGPT-V4 is insufficient in terms of reliability for image analysis, as reported by previous studies on different image analysis for different subjects, and emphasizes that AI should not be blindly trusted in image analysis and should be used under the supervision of a radiologist.

Our analysis had several limitations, including a relatively small sample size and the absence of patient-specific data such as age, gender, and clinical findings. Although the simultaneous evaluation of right and left TMJ images was not included in the same question, we do not consider this a major limitation, as both open – and closed-mouth images were available. Including right and left sides would simply result in four distinct images per case, which is a manageable input for evaluation. Additionally, AI analysis was restricted to one-dimensional images; factors such as disc morphology, masticatory muscle conditions, underlying causes of mandibular hypomobility, and developmental anomalies were not incorporated. Nevertheless, to our knowledge, this is the first study in the literature to explore ChatGPT-V4's capabilities in detecting TMJ pathologies using radiologic images. Our findings offer preliminary insights into the potential of ChatGPT-V4 in radiologic image interpretation and may guide future research and software innovation. In this context, we believe that enhancing ChatGPT-V4 to support three-dimensional radiologic modalities could significantly improve the accuracy and reliability of cross-sectional evaluations, offering substantial benefits for the radiologic workflow.

Conclusions

ChatGPT-V4 has considerable potential to facilitate radiological image analysis and accelerate radiological workflow. However, uncontrolled integration of the technological advancement of ChatGPT-V4 into dental radiology may lead to inaccurate, biased and misleading diagnoses. This undesirable situation may have legal consequences for radiologists and may increase malpractice lawsuits. Under all circumstances, we recommend that ChatGPT image analysis should be under the supervision of a radiologist and that clinicians should start treatments after radiologist approval.

Conflict of Interest

The authors declare that they have no conflict of interest.

Ethics Committee Approval

This study was approved by the Local Ethics Committee of the Hatay Mustafa Kemal University University (Date: 19.03.2025, Decision No: 07) and the study protocol was conducted in accordance with the principles set out in the World Medical Association Declaration of Helsinki of 1964 and later version.

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ORIGINAL ARTICLE / ARAŞTIRMA MAKALESİ

Effect of Applying Mouthwashes with an Oral Irrigator on Surface Roughness of Nanohybrid Resin Composites

Ağız Gargaralarının Ağız Duşu ile Uygulanmasının Nanohibrit Kompozitlerin Yüzey Pürüzlülüğü Üzerine Etkisi

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ABSTRACT

Objectives: This study aimed to evaluate the effects of different mouthwashes, applied either directly or via an oral irrigator, on the surface roughness of stained nanohybrid single-shade resin composites.
Materials and Methods: Two hundred disk-shaped specimens (8×2 mm) were prepared from two nanohybrid single-shade resin composites (Charisma Diamond One and Vittra APS Unique). All specimens were immersed in a coffee solution (3 g/50 mL) for 12 days to simulate one year of staining. Half of the specimens were treated with direct mouthwash immersion for 12 hours, while the other half were exposed to mouthwash solutions delivered using an oral irrigator for 40 seconds. Each method included subgroups (n=10) treated with distilled water, Sensodyne Pronamel, Listerine Fresh Burst, Colgate Plax White+Charcoal, and Crest 3D White. Surface roughness (Ra, µm) was measured using a profilometer at baseline, after staining, and following mouthwash application. Data were analyzed at p<0,05 level by using Robust ANOVA and Bonferroni post-hoc tests (α=0.05).
Results: Coffee staining significantly increased surface roughness compared to baseline (p<0.001). Mouthwash applications reduced roughness compared to the stained condition, but values remained above baseline (p<0.05). No significant difference was found between the application methods (p>0.05). All mouthwashes produced similar surface roughness changes (p>0.05).
Conclusions: Colored beverages increase the surface roughness of nanohybrid single-shade resin composites used in this study. Mouthwashes reduced roughness in stained specimens but did not restore surfaces to original smoothness. Oral irrigator use did not significantly affect the outcome compared to direct application. Mouthwash and dietary habits should be considered in restorative material selection.
Keywords: Oral irrigator, mouthwash, surface roughness, nanohybrid resin composite, profilometer.

ÖZ

Amaç: Bu çalışmada farklı ağız gargaralarının, ağız duşu kullanılarak veya doğrudan uygulanmasının, renklendirilmiş nanohibrit tek renkli rezin kompozitlerin yüzey pürüzlülüğü üzerindeki etkilerinin incelenmesi amaçlanmıştır.
Gereç ve Yöntemler: İki ayrı nanohibrit tek rezin renkli kompozitten (Charisma Diamond One ve Vittra APS Unique) 8×2 mm boyutlarında toplam 200 adet disk şeklinde örnek hazırlandı. Örneklerin kahve solüsyonunda (3 g/50 mL, 12 gün) bekletilerek bir yıllık kullanıma denk renklendirme yapıldı. Örneklerin yarısına ağız gargaraları doğrudan; diğerlerine ağız duşu aracılığıyla uygulandı. Her grupta distile su, Sensodyne Pronamel, Listerine Fresh Burst, Colgate Plax White+Charcoal ve Crest 3D White gargaralarından oluşan 5 alt grup oluşturuldu (n=40). Doğrudan ağız gargarası uygulanacak örnekler ilgili solüsyonda 12 saat bekletildi. Kalan örneklere ağız duşu haznesine konan solüsyonlar 40 sn süreyle uygulandı. Başlangıç, renklendirme sonrası ve gargara uygulanması sonrası yüzey pürüzlülüğü bir profilometre (Ra, µm) ile ölçüldü. Veriler p<0,05 anlamlılık düzeyinde Robust ANOVA ve Bonferroni çoklu karşılaştırmaları ile değerlendirildi (α=0,05).
Bulgular: Kahve ile renklendirmeden sonra tüm örneklerin yüzey pürüzlülüğünde başlangıca kıyasla anlamlı ölçüde arttırdı (p<0,001). Gargara uygulamaları sonrası pürüzlülük değerleri renklendirme sonrasına göre azaldı ancak başlangıç değerlerinin üzerinde kaldı (p<0,05). Ağız duşu ile uygulama ile doğrudan uygulama arasında nihai yüzey pürüzlülüğü açısından istatistiksel fark bulunmadı (p>0,05). Farklı gargara solüsyonlarında benzer yüzey pürüzlülüğü değişimleri gözlendi (p>0,05).
Sonuç: Renkli içecekler bu in vitro çalışmada kullanılan her iki nanohibrit rezin kompozitin yüzey pürüzlülüğü değerlerinde başlangıca kıyasla anlamlı ölçüde artış gözlendi (p<0,001). Ağız gargaraları renkli yüzeylerin pürüzlülük değerlerini iyileştirse de nihai pürüzlülük değerlerinde artışı engelleyememiştir. Ağız duşu kullanımı, gargara solüsyonlarının yüzey pürüzlülüğü üzerindeki etkisini doğrudan uygulamaya kıyasla anlamlı derecede değiştirmemiştir. Restoratif materyal seçiminde renkli içecek ve günlük kullanılan ağız gargaralarına maruziyet göz önünde bulundurulmalıdır.
Anahtar Kelimeler: Ağız duşu, ağız gargarası, yüzey pürüzlülüğü, nanohibrit rezin kompozit, profilometre.

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INTRODUCTION

Resin composites are widely used in restorative dentistry due to their aesthetic and mechanical advantages. Recently, single-shade universal nanohybrid composites have been developed to simplify shade selection by matching a wide range of tooth colors with one material (Cruz da Silva et al., 2023). These composites utilize optical blending capabilities, known as the "chameleon effect," to mimic surrounding tooth structure (Islam et al., 2023). Manufacturers incorporate specialized fillers and monomers to enhance color adjustment and translucency (Korkut et al., 2023; Zhu et al., 2023). Although some studies report higher discoloration over time compared to multi-shade composites, these changes often remain clinically acceptable (Tepe et al., 2025). Current research continues to evaluate their properties such as hardness, gloss, and roughness (Atalay et al., 2023).

Apart from color, the surface quality of composite restorations is essential for clinical success. A smooth surface enhances aesthetics and reduces plaque accumulation and staining (Gehlot et al., 2022). Surface roughness, often quantified as Ra, is measured by profilometry per ISO standards, with contact profilometers preferred for their precision (Lucena et al., 2021). Surfaces rougher than 0.2 µm are more prone to biofilm adhesion and discoloration. Surface texture is influenced by both intrinsic factors (e.g., filler size, matrix bonding, resin hardness) and extrinsic ones (e.g., polishing technique, oral exposure) (Chowdhury et al., 2023; Yilmaz & Mujdeci, 2021). Proper finishing can achieve Ra values of ~0.1 µm, particularly in nanohybrid composites (Zhang et al., 2021). Polymerization parameters such as light intensity, duration, and wavelength also affect surface characteristics. Inadequate curing may leave an oxygen-inhibited layer and unreacted monomers, leading to a softer and rougher surface more vulnerable to degradation (Sarialioglu Gungor et al., 2023; Yilmaz Atalı et al., 2022). Higher degrees of conversion are associated with smoother, more durable surfaces, emphasizing the need for optimized light-curing protocols (Duratbegović et al., 2024).

Oral irrigators (water flossers) are increasingly used in oral hygiene as they deliver pressurized fluid to remove plaque and debris from interdental and subgingival areas. They support periodontal health by reducing gingival inflammation and bleeding (Altalhi et al., 2023). However, their impact on restorative materials remains underexplored. Compared to studies on toothbrushing or mouth rinses, limited research has assessed how oral irrigators affect composite surfaces. Existing studies have examined variables like solution type and pressure settings, with inconsistent results—some reporting increased surface roughness, while others found no significant effect (Alharbi et al., 2020; Alavi et al., 2022; Alavi et al., 2023). These conflicting outcomes highlight the need for further investigation, particularly under conditions simulating both mechanical and chemical stress.

The present study investigates the effects of different mouthwashes, applied either directly or using an oral irrigator, on the surface roughness of single-shade nanohybrid resin composites. By analyzing changes in surface texture under simulated oral conditions, this research aims to provide evidence-based guidance for optimizing restorative material performance and maintaining surface integrity.

The null hypotheses of the study were as follows:

1. There is no statistically significant difference in surface roughness values among different nanohybrid resin composites exposed to the same mouthwash.
2. There is no statistically significant difference in surface roughness values of nanohybrid resin composites treated with different mouthwashes.
3. There is no statistically significant difference in surface roughness values between direct immersion and oral irrigator application methods.

MATERIALS AND METHODS

Two single-shade nanohybride resin composite materials from different manufacturers were used in this study: Charisma Diamond One (Kulzer, Germany), Vittra APS Unique (FGM, Brazil). The details of these composites, including brand names, manufacturers, monomer compositions, filler types, filler loadings, and lot numbers, are provided in Table 1.

Table 1. The brand names, manufacturers, monomer compositions, filler types, filler loadings, and lot numbers of the single-shade universal resin composites.

Composite Material	Abbreviation	Manufacturer	Type	Monomer Composition	Filler Composition / Size	Filler % (W/V)	Lot Number
Charisma Diamond One	DO	Kulzer, Germany	Nanohybrid	UDMA, TCD-DI-HEA, TEGDMA	B_2O_3-F-Al_2O_3-SiO_2, silica, TiO_2, fluorescent and metallic oxides, organic pigments (5–20 µm)	81 / 64	N010209
Vittra APS Unique	VU	FGM, Brazil	Nanohybrid	UDMA, TEGDMA	Zirconia and silica fillers (200 nm)	82 / 72	230921

Abbreviations: TEGDMA = triethylene glycol Di methacrylate; UDMA = urethane dimethacrylate; TCD-DI-HEA = 2-propenoicacid; (octahydro-4,7-methano-1H-indene-5 – diyl) bis (methyleneiminocarbonyloxy-2,1-ethanediyl) ester; TiO2 = Titanium dioxide, YbF3 = Ytterbium trifluoride; B2O3-F-Al2O3-SiO2 = Boro-fluoro-aluminosilicate. * The data were provided by the manufacturers.

In the experimental group, a total of 160 samples were prepared, including four mouthwashes in which we would keep the samples colored with coffee, a group in which these mouthwashes would be applied with an oral irrigator; Oral-B Oxyjet (Procter& Gamble, USA), and a control group consisting of 40 samples in which distilled water (DW) would be applied directly and with an oral irrigator, and a total of 200 samples were prepared (n=10). Mouthwashes used in the experiment: Sensodyne Promine (SP), Colgate Plax activated charcoal and whiteness (CP), Crest 3D White (CW), Listerine Fresh Burst (LF) and their brand names, manufacturers and ingredients are presented in Table 2.

Table 2. The brand names, manufacturers, ingredients of mouthwashes used in this study.

Mouthwash	Manufacturer	Ingredients
Listerine Fresh Burst (LF)	Johnson & Johnson, UK	Alcohol, menthol, eucalyptol, thymol, methyl salicylate, benzoic acid, poloxamer 407, sodium benzoate, sorbitol solution, water, flavor
Colgate Plax Whitening + Charcoal (CP)	Colgate-Palmolive, USA	Water, sorbitol, propylene glycol, PEG-40 hydrogenated castor oil, flavor, sodium saccharin, menthol, eugenol, sodium fluoride, charcoal powder
Crest 3D White (CW)	Procter & Gamble, USA	Water, glycerin, hydrogen peroxide, propylene glycol, sodium hexametaphosphate, poloxamer 407, sodium citrate, flavor, sodium saccharin, citric acid
Sensodyne Pronamel (SP)	GSK, UK	Water, sorbitol, propylene glycol, potassium nitrate, PEG-60 hydrogenated castor oil, poloxamer 407, flavor, sodium fluoride, citric acid, sodium saccharin

Specimen Preparation

Composite disc-shaped specimens were prepared using 2 mm thick, 8 mm diameter silicon mold. The material placed in the molds was covered with transparent strip (Universal strips, Extra Dental, Istanbul, Turkey) and finger pressure was applied with a glass slide. After ensuring that there were no air bubbles on the surface, polymerization was performed using a VALO Cordless LED curing light (Ultradent, USA) at 1000 mW/cm^2 following the manufacturer's instructions, and light exposure was provided on both the upper and lower surfaces. After polymerization, each specimen was polished with discs (SofLexTM XT, 3M ESPE, USA) in order from coarse to fine grain. Then, they were polished with the Diamond Polish system kit (SofLex, 3M ESPE, USA).

Staining Procedure

All prepared specimens were stored in distilled water for 24 hours. Samples were kept in coffee solution (Nescafe Classic, Nestle, Switzerland) prepared by dissolving 3 grams of coffee in 50 mL of boiling water for 12 days, equivalent to one year's use. The solution was renewed daily (Korkut et al., 2020).

Surface Roughness Measurement (Ra)

Before and after the discoloration procedure, roughness measurements of samples were made. Measurements were made from 3 different areas using a contact profilometer (Mitutoyo, Japan) roughness measuring device and Ra values were recorded. Calibration of the device was performed after each new group according to the manufacturer's instructions and using the calibration plate, which is a part of the device. After calibration, each sample was placed on the standard measurement table of the device in order so that the contact angle between the profilometer's reader tip and the sample disk was 90°. Measurements were made by taking care to ensure that the samples were in the center. Three measurements were taken from each sample and the average of the values was taken.

After the experiment was completed, the surface roughness of the samples was measured

again under the same conditions and the values were recorded.

Mouthwashes Application

The samples in the group where mouthwashes would be applied directly were placed in the solutions and kept for 12 hours. It was reported that this period was equal to using mouthwash twice a day for one minute (Haghi et al., 2023), and corresponds to approximately one year of clinical use. In the other group, each solution was placed separately in the mouthwash device and applied once a week for 4 weeks for 10 minutes each use in order to extend the process and better simulate the clinical situation. It was reported that this period was equivalent to using the device twice a day for 3 seconds on each surface (Alavi et al., 2022), and corresponds to approximately one year of clinical use. The tip of the device was fixed vertically to the surface of the samples at a distance of 2 mm in accordance with the manufacturer's instructions. The samples were fixed to the inner surface of a plastic container from their backs with double-sided tape, and the device was placed at a distance of 2 mm so that it would remain stable on its stand. The device was adjusted to a medium level to apply a constant pressure again in accordance with the manufacturer's instructions. The liquid chamber of the device was continuously filled with the relevant solution and applied so that it could be used continuously until the end of the experiment. Each sample was then rinsed with water spray for 10 seconds and stored in distilled water at room temperature until the next stage of the treatment.

Statistical Analysis

The Ra data were analyzed using R software with a robust two-way repeated measures ANOVA approach to accommodate any non-normal distributions and outliers in roughness data (5% trimmed means were used for robustness). The factors in the ANOVA were: Composite type (DO vs VU, between-subjects), Application method/

solution (5×2 combinations, treated as a single between-subjects factor with 10 levels, since each specimen was in one combination of method and solution), and Time (after staining vs after treatment, within-subjects). The three-way interaction (Composite × Group-Solution × Time) was tested. Post hoc comparisons were performed with Bonferroni adjustment for multiple comparisons. In addition, paired t-tests (with Bonferroni correction) were used to compare roughness before and after treatment within each subgroup. Significance was set at $p<0.05$. Statistical results are presented as mean ± standard deviation (SD) unless otherwise noted.

RESULTS

Comparison of surface roughness values according to composite type, group and solution, and time is presented in Table 3. Regardless of solution and time, the main effect of composite type was found to be statistically significant on surface roughness values ($p<0.001$).

Table 3. Comparison of surface roughness values according to composite type, group and solution, and time.

Source of Variation	Q	p-value
Composite	15.170	<0.001
Group and Solution	21.900	0.016
Time	366.700	0.001
Composite × Group and Solution	30.120	0.002
Composite × Time	3.280	0.197
Group and Solution × Time	13.320	0.814
Composite × Group and Solution × Time	9.200	0.965

*Q: Robust regression-based ANOVA test statistic.

According to the multiple comparison results of surface roughness values, the mean surface roughness value of the DO composite was higher (0.198) compared to the VU composite (0.186) (Table 4).

Table 4. Multiple comparison results of surface roughness (Ra, µm) based on composite type, group, mouthwash solution, and time intervals.

Group and Solution	Time	Composite		Total
		DO	VU	
CP'	T_0	0.175 ± 0.016	0.144 ± 0.014	0.158 ± 0.008
	T_1	0.268 ± 0.027	0.195 ± 0.01	0.227 ± 0.015
	T_2	0.201 ± 0.017	0.158 ± 0.017	0.177 ± 0.01
	Total	0.211 ± 0.013	0.167 ± 0.009	0.186 ± 0.007
CW'	T_0	0.171 ± 0.012	0.168 ± 0.014	0.17 ± 0.008
	T_1	0.239 ± 0.018	0.227 ± 0.017	0.232 ± 0.012
	T_2	0.192 ± 0.012	0.186 ± 0.015	0.19 ± 0.009
	Total	0.199 ± 0.01	0.193 ± 0.009	0.195 ± 0.006
SP'	T_0	0.168 ± 0.009	0.142 ± 0.015	0.157 ± 0.008
	T_1	0.239 ± 0.016	0.212 ± 0.015	0.224 ± 0.01
	T_2	0.2 ± 0.014	0.171 ± 0.017	0.186 ± 0.011
	Total	0.2 ± 0.009	0.175 ± 0.01	0.188 ± 0.007
LF'	T_0	0.159 ± 0.01	0.172 ± 0.009	0.166 ± 0.006
	T_1	0.249 ± 0.017	0.262 ± 0.021	0.257 ± 0.013
	T_2	0.205 ± 0.013	0.208 ± 0.013	0.208 ± 0.008
	Total	0.203 ± 0.01	0.214 ± 0.011	0.208 ± 0.008
DW'	T_0	0.173 ± 0.01	0.148 ± 0.011	0.163 ± 0.007
	T_1	0.255 ± 0.02	0.232 ± 0.018	0.246 ± 0.012
	T_2	0.212 ± 0.017	0.181 ± 0.012	0.195 ± 0.01
	Total	0.213 ± 0.011	0.187 ± 0.01	0.199 ± 0.007
CP	T_0	0.162 ± 0.008	0.151 ± 0.007	0.156 ± 0.005
	T_1	0.257 ± 0.02	0.215 ± 0.01	0.233 ± 0.011
	T_2	0.199 ± 0.016	0.162 ± 0.013	0.176 ± 0.009
	Total	0.204 ± 0.011	0.175 ± 0.008	0.187 ± 0.007
CW	T_0	0.147 ± 0.007	0.163 ± 0.011	0.155 ± 0.006
	T_1	0.205 ± 0.009	0.245 ± 0.02	0.223 ± 0.011
	T_2	0.192 ± 0.011	0.188 ± 0.015	0.191 ± 0.008
	Total	0.181 ± 0.007	0.198 ± 0.011	0.188 ± 0.006
SP	T_0	0.145 ± 0.009	0.143 ± 0.009	0.144 ± 0.006
	T_1	0.21 ± 0.009	0.212 ± 0.009	0.21 ± 0.006
	T_2	0.204 ± 0.016	0.175 ± 0.018	0.189 ± 0.012
	Total	0.186 ± 0.008	0.176 ± 0.009	0.181 ± 0.006
LF	T_0	0.158 ± 0.012	0.152 ± 0.009	0.157 ± 0.007
	T_1	0.239 ± 0.016	0.238 ± 0.018	0.237 ± 0.011
	T_2	0.207 ± 0.015	0.21 ± 0.014	0.209 ± 0.01
	Total	0.202 ± 0.01	0.199 ± 0.011	0.2 ± 0.007
DW	T_0	0.146 ± 0.011	0.151 ± 0.01	0.149 ± 0.007
	T_1	0.221 ± 0.014	0.229 ± 0.016	0.223 ± 0.01
	T_2	0.214 ± 0.017	0.182 ± 0.011	0.196 ± 0.01
	Total	0.193 ± 0.01	0.186 ± 0.009	0.189 ± 0.007
Toplam	T_0	0.16 ± 0.003	0.154 ± 0.003	0.157 ± 0.002^{c}
	T_1	0.235 ± 0.005	0.226 ± 0.005	0.231 ± 0.004^{b}
	T_2	0.201 ± 0.004	0.183 ± 0.005	0.192 ± 0.003^{a}
	Total	0.198 ± 0.003	0.186 ± 0.003	0.192 ± 0.002

*Trimmed Mean ± Standard Error; a–c: No significant difference among main effects sharing the same lowercase letter; A–J: No significant difference among interaction groups sharing the same uppercase letter; Trimmed mean method was used as the analysis approach with a trimming proportion of 5%.

Abbreviations: **CP:** Colgate Plax Whitening + Charcoal (direct application); **SP:** Sensodyne Pronamel (direct application); **CW:** Crest 3D White (direct application); **DW:** Distilled Water (direct application); **LF:** Listerine Fresh Burst (direct application); **CP':** Colgate Plax Whitening + Charcoal (applied with oral irrigator); **SP':** Sensodyne Pronamel (applied with oral irrigator); **CW':** Crest 3D White (applied with oral irrigator); DW': Distilled Water (applied with oral irrigator); **LF':** Listerine Fresh Burst (applied with oral irrigator); VU: Vittra APS Unique composite resin; **DO:** Charisma Diamond One composite resin; T_0: Initial; T_1: After coffee immersion; T_2: After mouthwashes application.

The main effect of solution type was also statistically significant ($p = 0.016$) (Table 3), although pairwise comparisons did not reveal a significant difference between specific solution groups. Among all solutions, the highest surface roughness value was observed in the LF' group (0.208), while the lowest was found in the SP group (0.181) (Table 4 and Figure 1). The main effect of time was significant ($p = 0.001$); mean roughness values increased from baseline (t0; 0.157) to post-coffee exposure (t1; 0.231), then slightly decreased after mouthwash application (t2; 0.192).

The main effect of the interaction between composite type and solution was found to be statistically significant ($p = 0.002$). Among the composite-solution combinations, the VU composite exhibited the highest surface roughness value when exposed to Listerine Fresh Burst (mean = 0.214), while the lowest roughness value was recorded in

the same composite with CP solution (mean = 0.167). In contrast, the interactions between composite and time, solution and time, as well as the three-way interaction among composite, solution, and time were not statistically significant ($p>0.05$), indicating that these factors did not result in meaningful differences in surface roughness values.

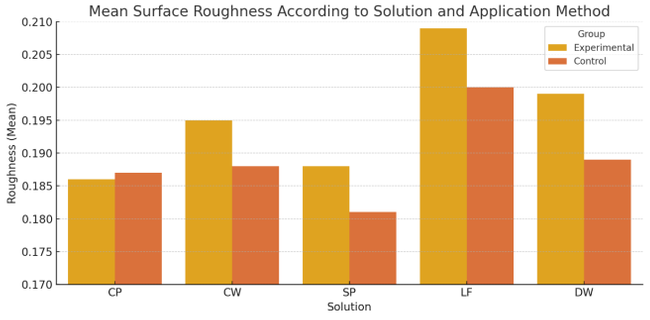

Figure 1. Mean Surface Roughness According to Solution and Application Method

These results indicate that both the type of composite and the type of solution significantly influenced the surface roughness, while the effect of time and specific composite-solution combinations also contributed to the variation in surface texture. However, no consistent pattern of surface roughness reduction or increase was observed between the experimental (mouthwash applied via irrigator) and control (direct immersion) groups across all solutions.

DISCUSSION

In this study, the surface roughness of two single-shade nanohybrid resin composites; Charisma Diamond One and Vittra APS Unique was evaluated after exposure to coffee staining and different mouthwashes, applied either directly or via an oral irrigator. Both composites exhibited similar surface behavior overall, aligning with recent studies reporting comparable roughness outcomes in universal shade nanohybrid materials (Lucena et al., 2021). Slight differences observed between the two may be attributed to compositional factors: Charisma Diamond One contains larger filler clusters, which may become more easily dislodged or exposed under mechanical or chemical stress, while Vittra APS Unique incorporates finer zirconia-silica fillers, potentially enhancing polishability and surface resistance (Yilmaz Atalı et al., 2022; Duratbegović et al., 2024).

Coffee exposure has been shown to increase surface roughness in single-shade resin composites, aligning with studies indicating that acidic and chromogenic beverages can degrade the resin matrix, leading to erosion and pigment retention (Rohym et al., 2023).

The findings of this study regarding the application of mouthwash with an oral irrigator align with several previous reports. Alharbi and Farah (2020) demonstrated that oral irrigator had no significant effect on the surface roughness or color stability of resin-based composites, emphasizing the safety of such devices when used within clinical pressure limits. Naser-Alavi et al. (2022) investigated the effect of oral irrigation using water and chlorhexidine at different pressures on bulk-fill composites and found the oral irragator using increased the surface roughness values. In a more recent study, Alavi et al. (2023) evaluated the impact of varying pressures and irrigating solutions on Giomer, another resin-based material, and reported that oral irrigator use at high pressure, increased the surface roughness values of the material. In the present study, surface roughness values increased after coffee immersion, and while oral irrigator application slightly reduced this roughness, the values did not fully return to baseline. However, the final roughness remained within clinically acceptable limits (≤0.2 μm). These findings may support that oral irrigator use at clinically appropriate pressure levels may lead to minimal surface alterations in composite resins, remaining within acceptable roughness thresholds. However, considering the variability in device settings, application techniques, and material compositions, further studies are needed to better define the optimal parameters for safe and effective clinical use.

In this study, the activated charcoal-based mouthwash (Colgate Plax Whitening + Charcoal) demonstrated a greater reduction in surface roughness of nanohybrid composites after coffee-induced staining compared to the hydrogen peroxide-based mouthwash (Crest 3D White). This finding aligns with previous research indicating that hydrogen peroxide-containing whitening agents can increase surface roughness due to their oxidative effects on the resin matrix (Hamdy et al., 2022). Conversely, while activated charcoal has been associated with abrasive properties, its impact on surface roughness appears to be less pronounced. For instance, Sarıalioğlu Güngör et al. (2023) reported that an activated charcoal-containing toothpaste (Colgate Optic White Charcoal) resulted in a lower percentage change in enamel surface roughness ($\Delta Ra = -39.73 \pm 8.84$) compared to a hydrogen peroxide-containing toothpaste (Colgate Optic White Expert) ($\Delta Ra = -55.16 \pm 3.77$). These findings suggest that activated charcoal-based whitening agents may be less detrimental to the surface integrity of dental tissues and restorations than their hydrogen peroxide counterparts.

Among all the mouthwashes tested, only Listerine Fresh Burst contained alcohol, and it led to slightly higher surface roughness values compared to the alcohol-free alternatives. This observation is consistent with prior findings that ethanol-based formulations can soften the resin matrix by partially dissolving the polymer network, contributing to microstructural alterations and surface degradation (Yilmaz & Mujdeci, 2021). However, the observed roughness increase was modest, likely due to the short duration of exposure and the high resistance of nanohybrid composites to chemical challenges.

The findings of this study provide partial support for the null hypotheses. No statistically significant difference was

found between the two nanohybrid composites tested (Charisma Diamond One and Vittra APS Unique) indicating that composite type did not significantly influence surface roughness. Similarly, the method of application (direct immersion vs. oral irrigator) showed no significant effect, supporting the third null hypothesis. However, the main effect of mouthwash type on surface roughness was statistically significant ($p=0.016$), suggesting that certain formulations may alter surface texture more than others. Although pairwise comparisons between specific rinses were not provided, trends observed in the data (e.g., higher roughness with peroxide – and alcohol-containing rinses) support rejecting the second null hypothesis. These results highlight that while composite formulation and application method may be less critical under short-term conditions, the chemical composition of oral hygiene products can play a significant role in surface degradation.

In this study, surface roughness was assessed using a contact profilometer, which is widely accepted as a gold standard for quantitative surface analysis in dental material research. Stylus-based profilometry provides high-resolution and reproducible measurements of Ra values, making it particularly suitable for detecting fine surface irregularities on resin-based composites following chemical or mechanical exposure. Compared to non-contact optical techniques, contact profilometers offer enhanced sensitivity in tracing topographical changes. The use of a calibrated, standardized device in this study ensured precise evaluation of surface alterations, thereby supporting the validity and reliability of the reported data (Yılmaz Atalı et al., 2022).

In this study, the use of the VALO Cordless LED curing light ensured optimal polymerization of the composite specimens. High-intensity LED units like VALO Cordless provide effective light penetration and uniform polymerization, which contribute to enhanced surface hardness and resistance to degradation (Duratbegović et al., 2024). In addition, the application of the multi-step 3M Sof-Lex polishing system helped achieve smoother composite surfaces. Previous studies have demonstrated that multi-step polishing protocols produce significantly lower surface roughness compared to simplified one-step systems, supporting improved aesthetics and long-term clinical success (Chowdhury et al., 2023). These standardized procedures likely contributed to maintaining surface roughness within clinically acceptable limits throughout the experimental phases.

Despite observable trends in surface roughness changes, not all intergroup differences reached statistical significance. This may be attributed to the short duration of exposure or the inherent chemical and mechanical stability of nanohybrid composites. These materials typically exhibit high filler loading, advanced silane coupling, and optimized resin matrices that improve resistance to softening, hydrolytic degradation, and wear (Duratbegović et al., 2024; Yılmaz Atalı et al., 2022). Overall, the findings suggest that while coffee immersion can increase surface roughness, commonly used mouthrinses—particularly alcohol-free or milder formulations—are unlikely to cause significant surface degradation in the short term.

CONCLUSION

Within the limitations of this in vitro study, it can be concluded that surface roughness of single-shade nanohybrid resin composites is influenced by chemical exposure, particularly the type of mouthwash and prior staining. Key findings are summarized as follows:

1. Coffee immersion significantly increased surface roughness, confirming its potential to chemically degrade composite surfaces under prolonged exposure.
2. Hydrogen peroxide-containing whitening mouthwash caused greater surface roughness compared to the charcoal-based rinse, likely due to its oxidative mechanism.
3. The alcohol-containing rinse (Listerine Fresh Burst) produced slightly higher roughness values than alcohol-free alternatives, although differences remained within clinically acceptable limits.
4. No statistically significant difference was observed between the two composite types or between the application methods (direct vs. oral irrigator), indicating the materials' high resistance to surface degradation.
5. All tested resin composites maintained surface roughness values below critical thresholds for biofilm accumulation, supporting their clinical suitability in restorative dentistry.

These results indicate that while nanohybrid composites demonstrate excellent surface resilience, the chemical composition of mouthwashes plays a key role in surface integrity. Clinicians should consider the impact of peroxide and alcohol-containing oral care products on composite restorations. Future research should include long-term aging, mechanical fatigue, and combined chemical-mechanical cycling to better simulate intraoral conditions.

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Conflicts of Interest:

The authors have no financial interest in any companies or products mentioned in this article.

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ORIGINAL ARTICLE / ARAŞTIRMA MAKALESİ

A Comprehensive Analysis of the Factors Influencing Academic Productivity in Endodontics in Turkey

Türkiye'de Endodonti Alanında Akademik Üretkenliği Etkileyen Faktörlerin Kapsamlı Analizi

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ABSTRACT

Objectives: The present study aims to analyse the factors influencing academic productivity in endodontics in Turkey, with a particular focus on academic status of faculty members (professors, associate professors, and assistant professors), cities hosting university, and university type (state vs. foundation universities) in Turkey.

Materials and Methods: The study data of a total of 269 academics in department of endodontics of the universities in Turkey were obtained through an advanced search of YOK akademik, Web of Sciences, and Google Scholar Akademik. The H-index, number of articles, and citation rates for each academic were determined by utilizing these global platforms.

Results: State universities have produced a greater number of publications ($P = 0.017$), and faculty members at these institutions have demonstrated higher H-indices. ($P = 0.019$). Professors have significantly higher H-indices, total publication, and citation counts ($P < 0.05$). The H-index and citation rates of male academics were found to be significantly higher than those of female academics ($P = 0.009$ and $P = 0.007$, respectively). There were no significant differences in research metrics among universities in metropolitan and other cities ($P > 0.05$).

Conclusions: Despite limitations, these findings offer valuable insights into academic performance dynamics across various contexts. The findings highlight the necessity of increasing support and equitable opportunities for female academics and those working at foundation universities to enhance research capacity and academic performance in the field of endodontics in Turkey.

Keywords: Academic performance, academic success, endodontics, manuscript, publications.

ÖZ

Amaç: Bu çalışma, Türkiye'deki endodonti alanında akademik üretkenliği etkileyen faktörleri analiz etmeyi amaçlamaktadır. Özellikle öğretim üyelerinin akademik statüsü (profesör, doçent ve doktor öğretim üyesi), şehir dağılımı ve üniversite türü (devlet üniversitesi vs. vakıf üniversitesi) üzerine odaklanılmıştır.

Gereç ve Yöntemler: Türkiye'deki üniversitelerin endodonti anabilim dalında görev yapan toplam 269 akademisyene ait veriler, YÖK Akademik, Web of Science ve Google Scholar Akademik platformlarından ileri düzey arama yapılarak elde edilmiştir. Bu küresel platformlar kullanılarak her bir akademisyenin H-indeksi, makale sayısı ve atıf oranları belirlenmiştir.

Bulgular: Devlet üniversitelerinde daha fazla makale yayımlanmış ($P = 0,017$) ve bu üniversitelerde görev yapan akademisyenlerin H-indeks değerleri daha yüksek bulunmuştur ($P = 0,019$). Profesörlerin H-indeksi, toplam yayın sayısı ve toplam atıf sayısı anlamlı derecede daha yüksektir ($P < 0,05$). Erkek akademisyenlerin H-indeksi ve atıf oranları, kadın akademisyenlere göre anlamlı derecede daha yüksek bulunmuştur (sırasıyla $P = 0,009$ ve $P = 0,007$). Metropol ve diğer şehirlerdeki üniversiteler arasında araştırma metrikleri açısından anlamlı bir fark bulunmamıştır ($P > 0,05$).

Sonuçlar: Çalışma sınırlamalarına rağmen bu bulgular, çeşitli bağlamlarda akademik performans dinamiklerine dair değerli veriler sunmaktadır. Bulgular, özellikle kadın akademisyenlere ve vakıf üniversitelerinde görev yapan akademisyenlere, akademik araştırma yapmak için destek ve eşit fırsatların artırılmasının, Türkiye'de endodonti alanında araştırma kapasitesinin ve akademik performansın geliştirilmesi açısından önemli olduğunu ortaya koymaktadır.

Anahtar Kelimeler: Akademik başarı, akademik performans, endodonti, makale, yayınlar.

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INTRODUCTION

The academic roles of higher education institutions comprise three major components: educator, researcher, and clinician (Edgar & Geare, 2013; Jauch & Glueck, 1975). The importance of research productivity, recognized as one of the three core functions of higher education, has been rapidly increasing in light of novel developments. In recent years, there has been a notable advancement in scientific research within the fields of medicine and dentistry, largely due to the technological innovations that have led to improvements in techniques and materials, which in turn have enhanced the quality of life (Pellino et al., 1984).

In the field of endodontics, research plays a pivotal role in advancing clinical practices and enhancing patient care through innovations in techniques, materials, and treatment outcomes (Siqueira & Rôças, 2008). The field of endodontics, which focuses on root canal treatments and associated biological responses, has been substantial growth in research output, driven by technological advancements and evolving clinical protocols (Connert et al., 2022; Siqueira & Rôças, 2014). Globally, researchers are increasingly recognizing the importance of academic productivity as it directly correlates with the dissemination of evidence-based practices, improvements in patient care, and the advancement of dental technologies (Joyce & Cartwright, 2019). In addition to the provision of routine patient care, it is imperative that active involvement in a range of scientific research activities is regarded as an indispensable aspect of professional education and development, particularly for those engaged in academic institutions. In Turkey, policies and practices aimed at enhancing research productivity in higher education have become more prominent in recent years (Özsoy & Balyer, 2023).

As the demand for high-quality research increases, there has been a growing emphasis on the factors that influence academic productivity, particularly among dental professionals (Demarco et al., 2020). It was mostly reported that research productivity is highly variable and influenced by numerous factors (Jung, 2012). The following factors were identified as influencing the research environment: individual characteristics (gender and years of experience), workload (time spent teaching, conducting research and instruction time for doctoral programmes), research style (research preference, collaboration, applied and multi-disciplinary research) and institutional characteristics (performance-based management, commercial orientation and shared governance) (Jones & Preusz, 1993; Hoskin, 2020). Factors such as academic rank, type of university, geographical location, and institutional resources have been demonstrated to significantly impact research output in specialized fields like endodontics (Doğramacı & Rossi-Fedele, 2022).

In light of the aforementioned points, the aim of this study was to investigate academic productivity of the academic faculty members (professor, associated professor, and PhD assistant professor) who are affiliated with the Department of Endodontics in state or foundation universities in Turkey.

MATERIALS AND METHODS

In the present study, ethical approval was not required, as the study relied entirely on publicly available data. All stages of the research were conducted in accordance with the principles of the Helsinki Declaration.

This comparative study was conducted in January 2025. Data were obtained from publicly accessible university websites and international academic databases, including YÖK Akademik (https://akademik.yok.gov.tr/), WoS InCites electronic database (https://www.webofscience.com/wos/author/author-search), and Google Scholar Akademik (https://scholar.google.com/), because of their global recognition as a credible and comprehensive database (Alryalat et al., 2019; Falagas et al., 2008). The current study was designed in accordance with a similar methodology that had previously been employed by Eliacik and Karahan (Eliacik & Karahan, 2021).

All information about a total of 439 academics in endodontics was collected from the Yüksek Öğretim Akademik Arama (https://akademik.yok.gov.tr/AkademikArama/) online website. Faculty members' names, genders, academic titles, affiliated universities, and cities were recorded. The type of university was classified as state or foundation. A total of 137 duplicate records (due to different spellings of surnames) and 24 academics whose data could not be found were excluded from the study. Nine academics affiliated with universities located in the Turkish Republic of Northern Cyprus were excluded from the study. A total of 269 academics, affiliated with the Department of Endodontics within the Faculty of Dentistry of universities in Turkey, were included in the present study.

For each academic, bibliometric indicators including H-index, total citation count, and total number of publications were retrieved from Web of Science website (the researchers section on the website) as of Januray, 2025. WoS InCites electronic database and Google Scholar Akademik were utilized in cases sufficient information could not be obtained. This process enabled us to access the total number of articles and citation rates available in reliable records for each academic. Universities were grouped according to their geographical locations (city), and comparisons were made based on gender, academic title, university type, and city. The data were collected by two independent observers (V.H.A and N.G) and subsequently compared and in case of discrepancy, data was rechecked and corrected. All data were recorded in Microsoft Excel program (Microsoft, 2023).

The normality of the distribution was evaluated using the Shapiro Wilk test, revealing that the data deviated from a normal distribution across all groups ($P<0.05$). The Mann Whitney U test and Kruskal Wallis test were used to compare groups with non-parametric data. A significance level of $P < 0.05$ was considered statistically significant All

statistical analyses were performed using Jamovi (Version 2.3.28.0; The Jamovi Project, Sydney, Australia).

RESULTS

Overall, 269 academics were identified in Department of Endodontics of the universities in Turkey. The dependent and independent variables are shown in Table 1.

Table 1. Conceptual framework.

Independent Variables	Dependent Variable
☐ Gender	☐ H-index
☐ Academic status	☐ Number of articles
☐ Cities hosting universities	☐ Number of citations
☐ University type (State /Foundation)	

Two-hundered-and-one state universities and 68 foundation universities included in the study. Among the 269 academics, 94 were professor (Prof.), 73 were associate professors (Assoc. Prof), and 102 were PhD assistant professor (Asst. Prof.). Out of these, 126 were male and 143 were female. The distribution of the proportions of academics working in two different types of universities by city is illustrated in Figure 1. It was determined that, the number of academics working at foundation universities (n=54) is higher than that at state universities (n=28) in Istanbul. In Izmir, 11 academics were working at state universities, while 2 were affiliated with foundation universities. In Ankara, 31 academics working at state universities while 5 at foundation university. The highest number of faculty members was found in Istanbul (n=82).

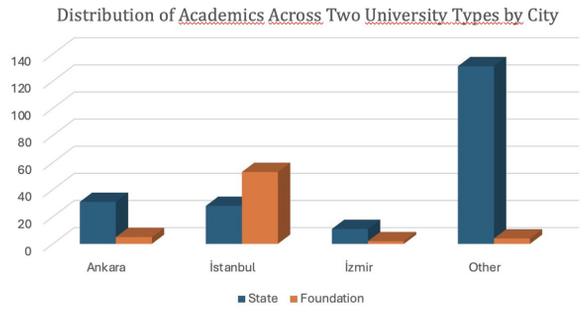

Figure 1. The number of faculty members in different types of universities across cities.

The descriptive statistics of dependent variables are presented in Table 2. A significant differences in H-indices, the number of articles published, and the number of citations received was observed among academics at varying academic ranks ($P < 0.001$) (Table 3). A pairwise comparisons were performed to determine the source of this difference (Table 4). The H-index, total count of articles, and total citations of professors were found to be significantly higher ($P < 0.05$) compared to those of associate professors and PhD assistant professor (Table 4). Similarly, the H-index, total publication counts, and total citation rates of associate professors were statistically significantly higher ($P < 0.001$) than those of PhD assistant professor (Table 4).

The H-index and citation rates of male academics were found to be significantly higher than those of female academics ($P = 0.009$ and $P = 0.007$, respectively). However, no significant difference was observed between genders regarding the number of articles published ($P = 0.086$) (Table 5).

Table 2. Descriptive statistics of academic performance data.

Descriptives	N	Mean	Median	SD	Min.	Max.
H-index	269	8.11	5.00	7.96	0	54
Number of articles	269	32.73	25.00	28.97	0	165
Number of citations	269	498.57	134.00	1000.01	0	8593

Table 3. Descriptive statistics and comparisons of academic performance regarding to academic status

	Academic status	N	Mean	Median	SD	Min.	Max.	*P* value
H-index	Prof.	94	13.26	12.00	9.84	1	54	<0.001*
	Assoc. Prof.	73	8.89	8.00	5.05	1	24	
	Asst. Prof.	102	2.81	2.00	2.71	0	16	
Number of articles	Prof.	94	53.51	44.00	34.99	4	165	<0.001*
	Assoc. Prof.	73	32.51	28	15.42	7	92	
	Asst. Prof.	102	13.75	10.50	12.79	0	89	
Number of citations	Prof.	94	1036.05	520.00	1488.62	3	8593	<0.001*
	Assoc. Prof.	73	383.92	213.00	429.97	4	1820	
	Asst. Prof.	102	85.29	24.00	174.36	0	1330	

Kruskal Wallis test, *P value significant at the 0.05 level.

Table 4. Post hoc comparisons of academic status groups for H-index, number of articles, and number of citations

Comparison			Post-hoc comparisons	
Dependent variable	Academic status (Independent variables)		W	P
H-index	Prof.	Assoc. Prof.	-3.97	0.014*
	Prof.	Asst. Prof.	-13.60	< .001*
	Assoc. Prof.	Asst. Prof.	-12.73	< .001*
Number of articles	Prof.	Assoc. Prof.	-6.68	< .001*
	Prof.	Asst. Prof.	-14.13	< .001*
	Assoc. Prof.	Asst. Prof.	-12.33	< .001*
Number of citations	Prof.	Assoc. Prof.	-4.06	0.011*
	Prof.	Asst. Prof.	-12.92	< .001*
	Assoc. Prof.	Asst. Prof.	-11.32	< .001*

Dwass-Steel Pairwise analysis. *P value significant at the 0.05 level.

Table 5. Descriptive statistics and group comparisons of academic metrics according to gender

	Gender	N	Mean	Median	SD	Min.	Max.	*P* value
H-index	Male	126	9.56	6.50	8.91	0	54	0.009*
	Female	143	6.83	5.00	6.80	0	50	
Number of articles	Male	126	37.71	27.00	34.28	0	165	0.086
	Female	143	28.35	24.00	22.53	0	142	
Number of citations	Male	126	644.54	200.00	1123	0	8593	0.007*
	Female	143	369.95	116.00	860	0	8284	

Mann Whitney U test, **P* value significant at the 0.05 level.

Statistical analysis revealed that academics affiliated with state universities had significantly higher H-index ($P = 0.048$) and number of articles ($P = 0.017$) compared to those from foundation universities. However, no significant difference was found in the number of citations between the two groups ($P = 0.134$) (Table 6).

Table 6. Descriptive statistics and comparison of academic performance according to university type

	Type	N	Mean	Med.	SD	Min.	Max.	*P* value
H-index	State	201	8.53	6.00	8.15	0	54	0.048*
	Foundation	68	6.88	5.00	7.29	0	32	
Number of articles	State	201	34.04	27.00	27.93	0	148	0.017*
	Foundation	68	28.87	21.50	31.73	0	165	
Number of citations	State	201	524.78	141.00	1067.34	0	8593	0.134
	Foundation	68	421.49	117.50	768.74	0	3356	

Mann Whitney U test, **P* value significant at the 0.05 level.

In the comparison of cities, they were categorized as the three major cities (Istanbul, Ankara, Izmir) and cumulatively other cities. There is no significantly difference among Istanbul, Ankara, Izmir, and other cities with regard to the H-index ($P = 0.055$), the number of articles ($P=0.070$), and the number of citations ($P=0.081$).

DISCUSSION

In Turkey, academic productivity in the field of dentistry has demonstrated notable progress over the last decade. Between 2010 and 2020, the number of dental publications originating from Turkey increased by 67%, reflecting a growing commitment to scientific research (Demirci, 2021; Uslu, 2019). However, despite this increase, the quantity of research produced in Turkey was found to be comparatively low in comparison to the output of leading global research centres, with countries such as the United States, the United Kingdom, and China having produced a greater number of publications in dentistry (Demir, 2018).

In today's context, where research productivity is emphasized both as a criterion for international success and as a key aspect of dental professionals' career goals, factors that can enhance publication output and improve Turkey's global ranking in academic achievements have become a focal point of interest in studies. Many factors may affect the academic productivity, such as whether the funding of the university, type of the university, the academic status, etc. To the best of our knowledge, no study has previously evaluated the factors influencing academic productivity in the field of endodontics. This study addresses a significant gap in the existing literature on the subject by conducting a comprehensive investigation and presenting a detailed analysis of the factors influencing academic productivity in the field of endodontics.

Despite the absence of a universally accepted metric for the quantification of academic productivity, markers including total number of publications as well as total number of publication citations are frequently used for this purpose (Garner, 2018; García-Villar, 2021). The number of publications and citations, among other metrics, serve as key indicators of scholarly success across various disciplines, including endodontics (Abramo & D'Angelo, 2018). The studies aimed at evaluating the increasingly significant concept of 'scientific productivity' in our country have frequently taken publication and citation rates into consideration (Bazeley, 2010; Chow & Harrison, 1998; Wills et al., 2013). Consequently, in the present study, H-index, the number of publications, and the number of citations were used as the basis for measuring research productivity.

Factors such as funding of institution, geographical location, and academic rank have been identified as key determinants of research productivity (Heng et al., 2020; Tamtekin, 2017). The findings of another study indicated that, for 63.7% of the participants, the primary factor impeding research productivity was not individual but environmental such as location, economic class etc. (Ak & Gülmez, 2014). A study evaluating academic productivity in state and foundation universities in South East Nigeria found that academic productivity was higher in state universities compared to foundation ones (Mbachu, 2022). However, the authors noted that this region belongs to a lower economic class, which contributes to the overall lower levels of academic productivity (Mbachu, 2022). A recent study conducted at Saudi universities has revealed

that state universities produce a greater number of published papers than their foundation counterparts (Gadhoum, 2016). In accordance with these results, we found that the state universities have a greater number of articles and also higher H-index, when compared to foundation universities. It can be hypothesised that the underlying cause of this observed disparity between state and foundation type universities is the greater level of foundation support, incentives, and contributions to academic research and activities observed in state universities.

Although the number of academics in each state university in Istanbul is greater than that in each foundation university, the total number of academics in foundation universities has surpassed the total count of academics in state universities due to the fact that the total number of foundation universities exceeds that of state universities in Istanbul.

In the present study, the number of female academics in the field of endodontics was found to be higher than that of their male counterparts. However, the H-index and citation rates of male academics were found to be statistically significantly higher than those of female academics (P = 0.009 and P = 0.007, respectively). This result is consistent with the findings of a similar study conducted by Eliacik and Karahan in the field of pedodontics (Eliacik & Karahan, 2021). On the other hand, no significant difference was found between genders regarding the number of articles published (P = 0.086). Regardless of an author's publication count, a low citation rate will result in a low H-index. For instance, the H-index is particularly limited for studies published in journals that are unlikely to attract citations (Hönekopp & Kleber, 2008). In this study, the H-index recorded was based on data from Web of Science. Due to these factors, although there was no significant difference in total publication count between genders, differences were found in citation rates and H-index values.

It is reported that academic rank plays a crucial role, as professors and associate professors generally produce more research outputs compared to their junior colleagues (Abramo et al., 2016). According to these findings of the present study, it was observed that H-index, total publication counts, and total citation rates of professors were found to be significantly higher (P < 0.05) compared to those of associate professors and PhD assistant professor (Table 4). Similarly, the H-index, total publication counts, and total citation rates of associate professors were statistically significantly higher (P < 0.001) than those of PhD assistant professor. Consequently, it is clear that there is a direct correlation between academic status and academic performance.

The results of this study showed that no discernible discrepancy was identified between Istanbul, Ankara, Izmir, and other cities with respect to the H-index, the number of articles, and the number of citations. Conversely, it was reported that faculty members in metropolitan universities, with greater access to research funding and infrastructure, tend to publish more frequently compared to those in smaller or rural institutions (Uslu, 2019). This difference can be attributed to a number of factors. While larger cities may offer greater resources, the high patient density and the pressures of metropolitan living may limit the time available for academic research despite infrastructural advantages, compared to other cities. It is therefore hypothesised that the three major cities, such as Istanbul, Ankara and Izmir, may exhibit similar academic performance averages to those of other cities.

As with any study, the present study is also subject to certain limitations. It should be noted that data related to academics who are active in their field but whose information is not accessible through YÖK Akademik or Web of Science, and Google Scholar could not be included in the present study. Also, the findings of the study are limited by the specific time period during which the search was carried out. The results of this study may vary depending on the specific period and institutional affiliation of the academics during the data collection phase, as academic performance was assessed only within the timeframe of the study. On the other hand, academics may have recently transitioned between state and foundation universities or between cities. As a consequence of the inherent difficulty in identifying such transitions, this study is constrained by this limitation. To address these limitations, future studies should consider alternative approaches, such as conducting searches across multiple time periods and databases. This would facilitate a more comprehensive analysis of academic productivity of the academics in the field of endodontics.

CONCLUSION

Despite its limitations, this comprehensive analysis provides valuable insights into the dynamics of academic productivity within the field of endodontics in Turkey, revealing significant disparities influenced by academic rank, gender, and university type.

The present study reveals that academic productivity in the field of endodontics in Turkey is higher among male academics, professors, and those affiliated with state universities. These findings offer a valuable benchmark for the evaluation of academic performance and highlight the critical need to enhance incentives, support mechanisms, and equitable opportunities, particularly for female academics and those working at foundation universities.

The implementation of such improvements to strengthen research capacity in these underperforming areas will contribute to elevating overall academic achievement across Turkey and reducing disparities within the field. It is imperative to acknowledge that the promotion of equitable opportunities for scholarly advancement across all academic ranks, genders, and institution types is pivotal to the promotion of sustainable growth and excellence in endodontic research on a national scale.

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Conflicts of Interest

The authors declare that they have no conflict of interest.

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ORIGINAL ARTICLE / ARAŞTIRMA MAKALESİ

Maxillary Canine Impaction Occurrence and Severity in Relation with Dimensions and Morphology of Sella Turcica: A Retrospective Observational CBCT Study

Maksiller Kanin Dişlerinin Gömülü Kalmasının Görülme Sıklığı ve Şiddeti ile Sella Turcica'nın Boyutları ve Morfolojisi Arasındaki İlişki: Retrospektif Gözlemsel Bir Dental Volumetrik Tomografi Çalışması

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ABSTRACT

Objective: To investigate dimensions and morphological characteristics of Sella Turcica (ST) in patients with impacted maxillary canines (IMC), compared to a control group of patients with normally erupted canines, using CBCT images. A secondary aim was to investigate the relationship between the impaction severity and ST parameters.

Materials and Methods: This retrospective study analyzed CBCT images from 100 patients. The study group included 55 subjects with IMC (n=38 unilateral, U-IMC; n=17 bilateral, B-IMC) and the control group included 45 subjects exhibiting normally erupted canines. ST parameters included linear dimensions (length, depth, diameter), morphological categorization and bridging types. IMC parameters were canine's three-dimensional positional angles according to Frankfort Horizontal Plane (FHP) and midsagittal plane (MP). Statistical analyses were conducted using two-sample t-test, Man-Whitney U, and One-Way ANOVA tests. Statistical significance was set at 5%.

Results: U-IMC-R and B-IMC exhibited significantly higher FHP-RC-Frontal ($p<0.001$) and MP-RC ($p=0.002$) angles, but a lower FHP-RC-Lateral angle ($p<0.001$) compared to U-IMC-L and control groups. Moreover, U-IMC-L and B-IMC groups exhibited significantly higher FHP-LC-Frontal ($p<0.001$) and MP-LC ($p<0.001$) angles, but a lower FHP-LC-Lateral angle ($p=0.003$) compared to U-IMC-R and control groups. There was a significant inverse relationship of 25.5% between ST length and FHP-LC-Lateral angle ($p=0.011$).

Conclusion: IMC was linked with increased FHP-C-Frontal and MP-C angles, but with a decreased FHP-C-Lateral angles. A significant 25.5% inverse relationship between ST length and FHP-LC-Lateral angle was observed. Besides, IMC occurrence and its three-dimensional position did not exhibit correlation with ST's dimensions or morphology.

Keywords: Tooth, impacted, Cone-Beam Computed Tomography, Sella Turcica

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ÖZ

Amaç: DVT görüntüleri kullanılarak, gömülü maksiler kanin dişi (IMC) sahip hastalarda Sella Turcica'nın (ST) boyutları ve morfolojisi, normal şekilde sürmüş kanin dişlerine sahip kontrol grubu hastalarla karşılaştırarak araştırmak amaçlandı. İkincil amaç, gömüklük şiddeti ile Sella Turcica parametreleri arasındaki ilişkiyi incelemektir.

Gereç ve Yöntem: Bu retrospektif çalışmada 100 hastadan alınmış DVT görüntüleri analiz edildi. Çalışma grubuna 55 IMC'ye sahip hasta (n=38 tek taraflı, U-IMC; n=17 çift taraflı, B-IMC) ve normal şekilde sürmüş kanin dişlerine sahip 45 kontrol hastası dahil edildi. ST'nın parametreleri; doğrusal boyutları (uzunluğu, derinliği, çapı), morfolojik sınıflandırma ve köprüleşmesi tiplerinden oluşuyordu. IMC parametreleri, kaninin Frankfort Horizontal düzlemi (FHP) ve midsagittal düzleme (MP) göre üç boyutlu pozisyonel açılarından oluşmaktaydı. İstatistiksel analizler, iki-örneklem t-testi, Mann-Whitney U ve Tek-Yönlü Varyans Analizi (ANOVA) testleri kullanılarak gerçekleştirildi. İstatistiksel anlamlılık düzeyi %5 olarak belirlendi.

Bulgular: U-IMC-R ve B-IMC grupların, U-IMC-L ve kontrol gruplarına kıyasla, FHP-RC-Frontal ($p<0.001$) ve MP-RC ($p=0.002$) açılarında istatistiksel olarak anlamlı derecede daha yüksek, ancak FHP-RC-Lateral açısında ($p<0.001$) daha düşük olduğu bulundu. U-IMC-L ve B-IMC grupların, U-IMC-R ve kontrol gruplarına kıyasla, FHP-LC-Frontal ($p<0.001$) ve MP-LC ($p<0.001$) açılarında istatistiksel olarak anlamlı derecede daha yüksek, ancak FHP-LC-Lateral açısında ($p=0.003$) daha düşük olduğu bulundu. ST uzunluğu ile FHP-LC-Lateral açı arasında %25,5 oranında istatistiksel olarak anlamlı ters ilişki gözlendi ($p=0.011$).

Sonuç: IMC, etkilenen gömme tarafında artmış FHP-C-Frontal ve MP-C açıları ile ilişkilendirilirken, azalmış FHP-C-Lateral açıları ile ilişkilidir. ST'nın uzunluğu ile FHP-LC-Lateral açısı arasında %25.5 ters ilişki vardır. Bunun dışında, IMC'nin varlığı ve üç boyutlu pozisyonu, ST'nin boyutları veya morfolojisindeki değişikliklerle korelasyon göstermemektedir.

Anahtar Kelimeler: Diş, Gömülü, Konik ışınlı bilgisayarlı tomografi, Sella tursika.

INTRODUCTION

Maxillary canine impaction is a common anomaly requiring a multidisciplinary approach, particularly involving orthodontic treatment (Bedoya & Park, 2009; Haji Ghadimi et al., 2017; Canigur Bavbek et al., 2022). Despite its unclear cause, two predominant theories attempt for explanation. First, guidance theory suggests that maxillary lateral incisor roots influence canine eruption paths, and their absence leads to the impaction of maxillary canine (IMC). Secondly, genetic theory attributes IMC to genetic factors disrupting eruption (Bedoya & Park, 2009; Haji Ghadimi et al., 2017; Canigur Bavbek et al., 2022).

Embryologically, sella turcica (ST) and dental epithelial progenitor cells share a neural crest cell origin with maxillary and palatal structures. Genetic mutations can affect midface and ST development, hence affecting its dimensions and morphologies (Leonardi et al., 2006; Ali et al., 2014; Scribante et al., 2017; Canigur Bavbek et al., 2022). One of the common anomalies that can affect ST is its bridging, a morphological abnormality caused by abnormal bone formation between tuberculum sella and dorsum sella, causing either decrease in ST length, or its closure superiorly, giving the appearance of full closed margin circle in lateral cephalometric radiography (Leonardi et al., 2006; Meyer-Marcotty et al., 2010; Leonardi et al., 2011; Ali et al., 2014; Haji Ghadimi et al., 2017; Scribante et al., 2017; Baidas et al., 2018; El Wak et al., 2018; Ortiz et al., 2018; Kaya et al., 2021; Canigur Bavbek et al., 2022; Agani Sabah & Dinçer, 2023).

Traditionally, ST-related anomalies can be diagnosed via 2-dimensional radiographs, like lateral cephalometric scans (Haji Ghadimi et al., 2017; Canigur Bavbek et al., 2022). Most studies focused on ST bridging in relation to palatally impacted canines, though the 2-dimensional nature of this technique limits anatomical scrutiny. Conversely, three-dimensional imaging, such as cone-beam computed tomography (CBCT), offers more accurate assessments, and plays a crucial role for early detection of ST abnormalities before maxillary canines' eruption (Leonardi et al., 2006; Ali et al., 2014; Scribante et al., 2017).

This study aimed to fulfill two main objectives. First, to evaluate ST's linear dimensions and morphology (including ST's bridging) in patients with IMC using CBCT images and to compare these findings with a control group with normally erupted maxillary canine teeth. Secondly, to examine the relationship between ST's linear dimensions and morphology changes, and IMC's impaction severity degree. Study hypotheses were that the IMC occurrence (unilaterally or bilaterally) is associated with the ST's linear dimensions and morphology's changes, and that the IMC's impaction severity degree is affected by ST's dimensional and morphological changes.

MATERIALS AND METHODS

Ethical approval for this retrospective study was obtained from the Clinical Research Ethical Committee of Medicine Faculty, Marmara University, Istanbul, Turkiye, on 8 December 2023 (Protocol number: 09.2023.1644). Since this retrospective study used already existed CBCT images of subjects without obtaining their identifying information, collecting informed consent was not needed.

Sample Size Determination

To identify the strength of correlation between the ST's linear dimensions (Sella's length, depth, and diameter) and canine's impaction degree, a sample size calculation was conducted first. Based on power analysis conducted using Independent Two-Sample t-test anticipated for the study data, the required sample size was determined to be at least 47 subjects in IMC study group and at least 43 subjects in control group, totaling a minimum of 90 patients (Canigur Bavbek et al., 2022). This calculation assumed a

test power of 80%, a significance level of 0.05, and was performed with a G*Power software (version 3.1.9.7).

Sampling

CBCT images taken for individuals examined at the Faculty of Dentistry, ## University, between January 2016 and May 2024 were collected from the hospital archive. The images were examined and categorized by one investigator based on IMC occurrence, and clear appearance of maxillary canines and ST regions. IMC was defined as the maxillary canine's eruption failure into its normal position in the arch within its required eruption period despite the absence of local factors.

Study group's inclusion criteria were: presence of artifacts-free high-quality CBCT images including ST and maxillary regions; age ranges between 15 and 40 years; presence of IMC; absence of other teeth number or eruption anomalies; no previous orthodontic treatment history; no trauma or surgery history; and absence of any systemic illness and any syndromes associated with ST changes.

Control group's inclusion criteria were: presence of artifacts-free high-quality CBCT images of patients consulted for temporomandibular disorder, implant and third molar surgery reasons, showing ST and maxillary regions clearly; age ranges between 15 and 40 years; absence of other teeth number or eruption anomalies (excluding third molars); no past or fore-going orthodontic treatment history; no trauma or other surgery history; and absence of any systemic illness and any syndromes associated with ST changes.

1500 CBCT images were examined. Upon application of the study criteria, the study sample included a total of 100 subjects: 55 subjects with IMC for the study group and 45 subjects with normally erupted maxillary canines as control group. The total sample included 28 males and 72 females, with a mean age of 24 years (range: 15 – 40 years). The IMC study group included 38 subjects exhibiting unilateral IMC (n=18 right side impaction, U-IMC-R; n=20 left side impaction, U-IMC-L) and 17 subjects exhibiting bilateral IMC. Demographic characteristics are summarized in Table 1.

Table 1. Descriptive statistics of the demographic characteristics of the sample groups

Groups	Gender		Age			
	Female	Male	Mean ± SD	Median	Minimum	Maximum
U-IMC-R (n = 18)	13	5	21 ± 5	20	16	40
U-IMC-L (n = 20)	14	6	23 ± 5	23	16	37
B-IMC (n = 17)	11	6	22 ± 6	21	15	40
Control (n = 45)	34	11	26 ± 8	26	15	40
Total (n = 100)	72	28	24 ± 7	22	15	40

Note. n: Number of subjects, Numerical variables are given as mean ± standard deviation, median, and minimum and maximum values. SD: standard deviation, U-IMC-R: unilateral impacted right side maxillary canine group, U-IMC-L: unilateral impacted left side maxillary canine group, B-IMC: bilateral impacted maxillary canine group, Control: control group.

Data Collection

CBCT scans were obtained employing the same machine (Promax 3D Mid; Planmeca Oy, Helsinki, Finland), and same exposure parameters (90 kVp; 12 mA; 0.4-mm voxel size; scan time 13.2 seconds; field of view of 20x3x17 cm and 20x3x10 cm), while adhering to radiation protection guidelines. DICOM (Digital Imaging and Communications in Medicine) data obtained with 0.3 mm slice intervals were analyzed with ITK-SNAP (Version 3.8.0) software program (www.jtksnap.org open source).

One researcher processed all CBCT images using the same program settings. First, calibration and reorientation protocols were applied for images standardization. For head positioning standardization, the following reference planes were used: [1] Sagitally, Frankfort Horizontal Plane (FHP; line extending from the lowest radiographical point of orbital rim's inferior margin to the highest radiographical point of external auditory canal's superior margin); [2] Coronally, Midsagittal Plane (MP; line passing through Nasion and Basion); and [3] Axially, Midsagittal Plane (MP, line passing through Nasion and Menton anteriorly and Basion posteriorly) were used. After reorientation in every 3 sections, images were resliced.

ST Linear Measurements

Linear measurements, including *length, diameter, and depth*, were measured in millimeters on midsagittal plane sections. Sella length was described as the linear measurement from tuberculum Sella's crest to dorsum sella in the anteroposterior direction, Sella diameter as the anteroposterior distance between the deepest point in the posterior wall of ST and tuberculum Sella's crest, and Sella depth as the perpendicular distance from the deepest point of ST floor to a line drawn between dorsum sella and tuberculum sella (Fig. 1 (a)).

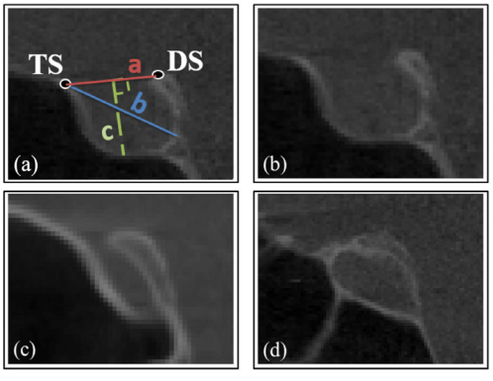

Figure 1: (a) Sella Turcica linear dimensions; a. Sell Turcica length, b. Sella turcica diameter, c. Sella Turcica depth. TS: Tuberculum Sella, DS: Dorsum Sella. Leonardi et al.'s classification of Sella Turcica's bridging was shown as: (b) No calcification (Type I), (c) Partial calcification (Type II), and (d) Complete calcification (Type III). This classification was introduced by Leonardi et al. (2006).

ST Morphology

The categorization of the ST morphology was done based on the Axelsson et al's classification, which has 6 categories: Normal, Oblique anterior wall, Double contour of the floor, ST bridging, Irregularity (notching) in the posterior part of the dorsum sellae, and Pyramidal shape of dorsum sellae (Fig. 2) (Axelsson et al., 2004; Haji Ghadimi et al., 2017).

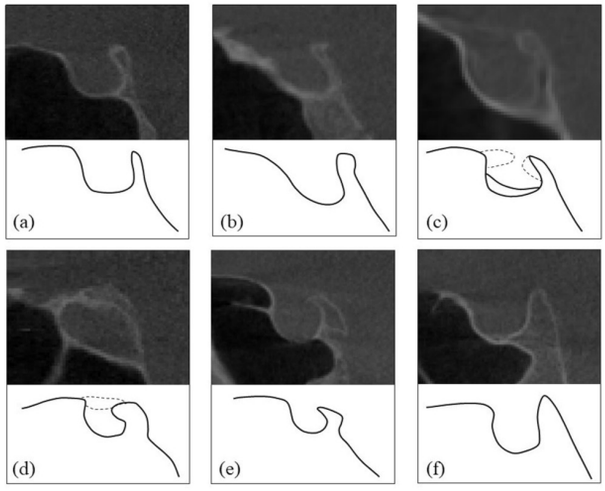

Figure 2: Sella turcica's morphology classification according to Axelsson et.al. (a) Normal, (b) Oblique anterior wall, (c) Double contour of the floor, (d) ST bridging, (e) Irregularity (notching) in the posterior part of the dorsum sellae, and (f) Pyramidal shape of dorsum sella. This classification was produced by Axelsson et.al. (2004).

ST Bridging Types

ST Bridging was defined as the presence of synostosis between anterior and posterior clinoid processes in any right or left sagittal views of sphenoid bone. Moreover, subjects showing ST bridging were categorized based on conventional scoring system of Leonardi et al (Fig. 1 (b-d)) into : No calcification (Type I), in which the sella length was at least equal to 3 quarters of the ST's greatest anteroposterior diameter, Partial calcification (Type II), in which the sella length was less than 3 quarters of the ST's greatest anteroposterior diameter, and Complete calcification (Type III), when anterior and posterior clinoid processes showed full fusion (Leonardi et al., 2009; Haji Ghadimi et al., 2017).

Angular Measurements

For the evaluation of the maxillary canine's impaction severity degree, three angular measurements were used (Fig. 3). *FHP-C-Frontal* was the angle between the long axis of the canine and Frankfort Horizontal Plane (FHP) on coronal section. *MP-C* was the long axis of the canine and midsagittal plane (MP) on coronal section. *FHP-C-Lateral* was the angle between the long axis of the canine and FHP on sagittal section.

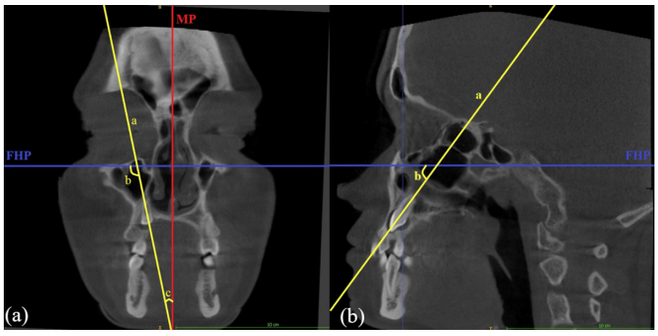

Figure 3. Canine angles in frontal and lateral sections. (a) a. Canine's axis, b. The angle between canine's long axis and FHP on coronal section (FHP-C-Frontal angle), c. The angle between canine's long axis and midsagittal plane on coronal section (MP-C angle). (b) a. Canine's axis, b. The angle between canine's long axis and FHP on sagittal section (FHP-C-Lateral angle). MP: Midsagittal Plane, FHP: Frankfort Horizontal Plane.

The ITK-SNAP software (Version 3.8.0) was used to locate and calculate all the linear measurements. Same investigator re-analyzed all CBCT images two additional times, at 4 weeks and 8 weeks following initial measurements, for intra-observer agreement evaluation.

Statistical Analysis

Data was analyzed using IBM SPSS Statistics version 24.0. Intraclass correlation coefficients (ICC) were used to assess measurement reliability. Normality was checked; Independent Two-Sample T-tests or Mann-Whitney U tests were applied contingently. Comparing multiple groups was done either by using One-Way ANOVA or Kruskal-Wallis tests, with Duncan and Dunn-Bonferroni tests for post-hoc comparisons. Categorical variables' analyzation was done by using Pearson Chi-Square and Exact tests, while Pearson and Spearman correlations assessed numerical relationships. Significance was set at $p < 0.05$. Variables with $p < 0.25$ were considered in logistic regression, which then found no statistically significant predictors ($p > 0.05$). Thus, a valid logistic regression model wasn't established from the data.

RESULTS

The study's sample size ensured a test power exceeding 80% for comparing ST bridging. ICC tests showed excellent intra-observer consistency for all variables (range: 0.985-0.999).

Regarding ST dimensions, control and total IMC groups (IMC-Total) did not show any statistically significant differences between them for ST length ($p = 0.187$), depth ($p = 0.372$), and diameter ($p = 0.630$) (Table 2).

Table 2. Intergroup evaluation of Sella Turcica's linear dimension parameters between impacted maxillary canine-total group and control group

Sella Turcica Linear Measurements	Groups		p value
	IMC-Total (n = 55)	Control (n = 45)	
	Mean ± SD	Mean ± SD	
Sella Length	10,33 ± 1,36	9,95 ± 1,53	0,187€
Sella Depth	8,17 ± 1,33	8,40 ± 1,08	0,372€
Sella Diameter	12,09 ± 1,11	12,21 ± 1,37	0,630€

Note. n: Number of subjects, Numerical variables are given as Mean ± SD values, SD: standard deviation, IMC-Total: total impacted canine group (unilateral and bilateral impacted canine groups combined), Control: control group, €: Independent Sample t test analysis value.

All groups in ST morphology's distribution did not show any significant differences between them ($p > 0.05$) (Table 3). Although statistically insignificant, the most seen ST morphology was the normal shape in all groups, succeeded by ST bridging. Double contour of ST's floor was not found in any group.

Table 3. Comparison of Sella Turcica's morphology in unilaterally and bilaterally impacted canine and control groups.

Sella Turcica's shape, n (%)	Group			p value
	U-IMC (n=38)	B-IMC (n=17)	Control (n=45)	
Normal	17 (44,74%)	8 (47,06%)	17 (37,78%)	0,338Φ
Oblique anterior wall	4 (10,52%)	3 (17,65%)	2 (4,44%)	
Double contour of the floor	-	-	-	
Bridging of sella turcica	14 (36,84) %	4 (23,53%)	13 (28,89%)	
Irregularity (notching) in the posterior part of the dorsum sella	2 (5,26%)	1 (5,82%)	8 (17,78%)	
Pyramidal shape of dorsum sella	1 (2,63%)	1 (5,88%)	5 (11,11%)	

Note. n: Number of patients, %: Column percentage, U-IMC: unilaterally impacted maxillary canine group, B-IMC: Bilaterally Impacted maxillary canine group, Control: Control Group, Φ: Exact test.

There was no statistically significant relationship between the ST bridging and IMC-Total group ($x^2(2) = 3.348$, $p = 0.187$) when they were compared with control group, exhibiting a very weak strength of association as measured by Camer's value ($V = 0.183$) (Table 4).

Table 4. Examining the relationship between the Sella Turcica's bridging types and the impaction of the maxillary canine

Sella Turcica Bridging Types	Groups			x^2 Value	df	p-value	Camer's V
	IMC-Total	Control	Total				
Type 1 (No Calcification)	37	32	69	3.348*	2	.187	.183
Type 2 (Partial Calcification)	16	8	24				
Type 3 (Complete Calcification)	2	5	7				
Total	55		100				

Note. N = 100 participants, IMC 45-Total: total impacted canine group (unilateral and bilateral impacted canine groups combined), Control: control group, x^2: Pearson Chi-Square Test value, df: degrees of freedom, $p > .05$ indicates no significant association between the variables. Camér's V was used to assess the effect size of the association. *: 2 cells (33.3%) have expected count less than 5. The minimum expected count is 3.15.

The FHP-RC-Frontal (Frankfort Horizontal plane-right canine-in frontal coronal section view) and MP-RC (midsagittal plane-right canine) angles were statistically higher in the U-IMC-R (unilaterally impacted right side maxillary canine) ($P < 0.001$) and B-IMC (bilaterally impacted canine) ($P = 0.002$) groups compared to the U-IMC-L (unilaterally impacted left side maxillary canine) and control groups. However, the FHP-RC-Lateral (Frankfort Horizontal plane-right canine-in lateral section view) angle was statistically lower in the U-IMC-R and B-IMC ($P < 0.001$) groups compared to the U-IMC-L and control groups (Table 5).

Table 5. Descriptive statistics of the canine angular positions and comparison between groups

Canine Angular Measurements	Group				P value
	U-IMC-R (n=18)	U-IMC-L (n=20)	B-IMC (n=17)	Control (n=45)	
FHP-RC-Frontal(°) M (min-max)	102,12 (55,95-148,16)[a]	77,45 (69,11-88,64)[b]	97,22 (42,80-136,35)[a]	80,76 (63,38-103,60)[b]	**<0,001**ϒ
MP-RC(°) M (min-max)	21,08 (0,62-62,50)[a]	12,16 (1,05-20,71)[b]	23,90 (2,01-46,20)[a]	9,93 (1,06-26,42)[b]	**0,002**ϒ
FHP-RC-Lateral(°) M (min-max)	58,81 (30,91-104,50)[a]	69,59 (56,42-82,37)[b]	54,11 (28,55-85,95)[a]	71,14 (50,14-89,35)[b]	**<0,001**ϒ
FHP-LC-Frontal(°) M (min-max)	78,62 (61,29-97,30)[a]	115,02 (71,72-150,82)[b]	119,86 (52,50-228,96)[b]	82,11 (62,48-97,52)[a]	**<0,001**ϒ
MP-LC(°) M (min-max)	11,53 (1,46-29,42)[a]	25,16 (1,33-60,74)[b]	33,37 (2,93-45,47)[b]	9,47 (1,05-27,71)[a]	**<0,001**ϒ
FHP-LC-Lateral(°) M (min-max)	73,03 (41,46-86,11)[a]	62,32 (26,33-102,95)[b]	60,14 (27,61-83,91)[b]	72,01 (45,86-84,92)[a]	**0,003**ϒ

Note. n: Number of subjects, Numerical variables are given as median (minimum-maximum) values. U-IMC-R: unilaterally impacted right side maxillary canine group, U-IMC-L: unilateral impacted left side maxillary canine group, B-IMC: bilateral impacted canine group, Control: control group, FHP-RC-Frontal) (°): Frankfort horizontal plane - right side canine angle in the frontal view, MP-RC(°): midsagittal plane - right side canine angle, FHP-RC-Lateral(°):

Frankfort horizontal plane – right side canine angle in the lateral view, FHP-LC-Frontal(°): Frankfort horizontal plane – left side canine angle in the frontal view, MP-LC(°): midsagittal plane – left side canine angle, FHP-LC-Lateral(°): Frankfort horizontal plane – left side canine angle in the lateral view, *y:* Kruskal-Wallis test, superscripts a and b indicate differences between groups in variables in the same row. There is no statistically significant difference between groups with the same superscripts.

The FHP-LC-Frontal (Frankfort Horizontal plane-left canine-in frontal coronal section view) and MP-LC (midsagittal plane-left canine) angles were statistically higher in the U-IMC-L and B-IMC ($P < 0.001$) groups compared to the U-IMC-R and control groups. However, the FHP-LC-Lateral angle (Frankfort Horizontal plane-left canine-in lateral section view) was statistically lower in the U-IMC-L and B-IMC ($P = 0.003$) groups compared to the U-IMC-R and control groups (Table 5).

When the relationship between the canine's angular position angles and the Sella Turcica's linear dimensions were studied, it was noted that there was a statistically significant weak inverse relationship of 25.5% between the ST length and the FHP-LC-Lateral angle (rho = – 0.255, ρ = 0.011) (Table 6).

Table 6. Descriptive statistics of the relationship between the canine's angular position values and the Sella Turcica's linear dimension

Canine's Angular Measurements	Test Value	Sella Turcica's Length(mm)	Sella Turcica's Depth(mm)	Sella Turcica's Diameter(mm)
FHP-RC-Frontal(°)	*rho*	-0,009	0,088	-0,173
	p	0,928	0,383	0,084
MP-RC(°)	*rho*	0,004	-0,019	-0,033
	p	0,969	0,850	0,743
FHP-RC-Lateral(°)	*rho*	-0,065	-0,185	-0,020
	p	0,520	0,065	0,844
FHP-LC-Frontal(°)	*rho*	-0,015	-0,160	-0,138
	p	0,880	0,112	0,170
MP-LC(°)	*rho*	0,024	0,001	0,015
	p	0,813	0,996	0,884
FHP-LC-Lateral(°)	*rho*	-0,255	-0,068	-0,148
	p	**0,011***	0,504	0,141

Note. FHP-RC-Frontal(°): Frankfort horizontal plane – right side canine angle in the frontal view, MP-RC(°): midsagittal plane – right side canine angle, FHP-RC-Lateral(°): Frankfort horizontal plane – right side canine angle in the lateral view, FHP-LC-Frontal(°): Frankfort horizontal plane – left side canine angle in the frontal view, MP-LC(°): midsagittal plane – left side canine angle, FHP-LC-Lateral(°): Frankfort horizontal plane – left side canine angle in the lateral view, *rho*: Spearman correlation coefficient.

DISCUSSION

Sella Turcica is a cranial structure that has a significant role in diagnosis and treatment planning of orthodontics. Size and shape changes of ST can result from multiple skeletal anomalies that affect cranial or facial structures (Leonardi et al., 2006; Leonardi et al., 2011; Scribante et al., 2017; Baidas et al., 2018; Ugurlu et al., 2020; Canigur Bavbek et al., 2022). Neural crest cells differentiate into progenitor cells, constructing the stem cells of both ST and dentition. Hence, sharing the same genetic origin, ST changes can be an indicator of dental aberrations and irregularities, such as dental transpositions and impactions (Leonardi et al., 2006; Leonardi et al., 2011; Scribante et al., 2017; Baidas et al., 2018; Canigur Bavbek et al., 2022). Since maxillary canine is one of the most frequently impacted maxillary teeth, many studies focused on finding a relationship between the ST changes and IMC. This current study aimed to examine the ST's dimensions and morphological characteristics in patients with IMC, compared to patients with normally erupted canines as control group, using CBCT images. A secondary aim was to examine the relationship between the severity of impaction and ST parameters.

Age

Silverman (1957) studied the effects of age on ST dimensions and found that they become nearly stable at the age of 15 years. Moreover, Björk (1955) showed that ST morphology remains stable after the age of 12 years. Accordingly, all subjects were chosen in the age range of 15-40 years.

Linear Dimensions

Assessing the ST dimensions and IMC relationship using 2D radiographic techniques yielded conflicting results. Baidas et al. (2018) reported significant reduction in all dimensions of IMC group compared to controls. Other researchers found that only the length was reduced in IMC groups, while diameter and depth differences were not significant (Najim & Nakib, 2011; Ali et al., 2014; Tepedino et al., 2020). Contrarily, Omastova et al. (2023) reported an increase in all linear dimensions in the IMC groups, whereas Scribante et al. (2017) could not find any significant differences. Three-dimensional CBCT studies also reported conflicting results. Acikgoz et al. (2024) had stated that a significant reduction in ST linear dimensions in IMC groups was present, after investigating their CBCT images. Ugurlu et al. (2020) reported that the only significant difference was in the reduction of right ST length in the unilateral IMC. Bavbek et al. (2022) reported reduction in ST diameter in bilateral IMC only. The current study could not find any significant difference in the ST linear dimensions between study and control groups. This can be due to sample's categorization differences between studies.

Morphology

ST morphology differs, and the studies tried to classify it for reproducibility (Gordon & Bell, 1922; Davidoff & Epstein, 1950; Axelsson et al., 2004). This study used Axelsson et al.'s (2004) classification (Fig. 2). Tepedino et al. (2020) concluded that a significant association between ST morphology and IMC was present, noting that the ST's bridging was more exhibited in the group exhibiting palatally displaced canine. However, the literature is contradictory, as some studies have found no

association between ST morphology and IMC (Silverman, 1957; Baidas et al., 2018; Canigur Bavbek et al., 2022).

Majority of the studies evaluated the relationship between ST bridging and IMC using lateral cephalometric radiographs (Ali et al., 2014; Baidas et al., 2018; Vitali et al., 2022; Omastova et al., 2023). A significant increased incidence (i.e. 3-4 times or 70% more) of ST bridging in IMC was reported by Najim et al.'s study (Najim & Nakib, 2011). Conversely, El Wak et al. (2018) aimed to assess the consistency between the 2D lateral cephalometric radiographs and 3D CBCT images in diagnosing ST's bridging, and stated that there was a statistically significant inconsistency. Contrary to 2D studies, CBCT studies denied a significant relationship between unilateral and bilateral IMC and ST bridging, which were consistent with our study results (Ortiz et al., 2018; Canigur Bavbek et al., 2022).

Angular Parameters

According to the current present literature and evidence, there was only one study focused on analyzing the relationship between the ST changes and maxillary canine's impaction severity, presented by angulation of maxillary canines and unilateral or bilateral occurrence. Bavbek et al. (2022) did not find a significant association between angular position of palatal IMC and ST dimensions, or morphology compared to control group. In the present study, 25.5% inverse relationship was found between ST length and FHP-LC-Lateral angle (Table 6). Moreover, IMC was found to be linked with increased FHP-C-Frontal and MP-C angles, but with a decreased FHP-C-Lateral angle on affected impaction side (Table 5). This difference can be due to the difference in IMC angular position's evaluation techniques (Fig. 3).

Limitations

It was observed that there are no studies investigating the possibility of the relationship between IMC's occurrence and impaction severity degree (according to midsagittal and Frankfort horizontal planes), and its relationship with ST's linear dimension and morphology (including bridging), using three-dimensional CBCT images of a large study sample. Therefore, the present study was the first to investigate these relationships. However, the retrospective design of this study yielded some limitations. Due to the strict inclusion criteria, out of 1500 CBCT images present in our database, only 55 cases of IMC were found eligible. Accordingly, a relatively small sample size with palatally impacted canines was obtained. There were no subjects with buccally impacted canines. So, future research with a larger sample size including both buccally and palatally IMC can provide different results. Also, a classification for three-dimensional morphology of ST should be implemented by new research to generate comparable and consistent research results.

CONCLUSION

1. There is a 25.5% inverse relationship between ST length and the angle between the maxillary left canine and the Frankfort horizontal plane in lateral view sections (FHP-LC-Lateral).
2. IMC is linked with increased Frankfort horizontal plane – canine angle in the frontal coronal section view (FHP-C-Frontal) and Midsagittal plane-canine (MP-C) angles, but with a decreased Frankfort horizontal plane – canine angle in the lateral section view (FHP-C-Lateral) angle on the affected impaction side.
3. The IMC's occurrence and its three-dimensional position, hence severity, presented no correlation with ST's dimensions or morphology changes.

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Conflicts of Interests

The authors have no financial or proprietary interests in any material discussed in this article.

Ethics Committee Approval

Ethical approval for this retrospective study was obtained from the Clinical Research Ethical Committee of Medicine Faculty, Marmara University, Istanbul, Turkiye, on 8 December 2023 (Protocol number: 09.2023.1644).

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REVIEW / DERLEME

Diş Hekimliğinde Kullanılan CAD/CAM Materyalleri

CAD/CAM Materials Used in Dentistry

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ÖZ

CAD/CAM, computer aided design ve computer aimed manufacturing kelimelerin baş harfleri ile elde edilmiş kısaltmadır. Türkçesi, bilgisayar destekli dizayn ve bilgisayar destekli üretim anlamına gelmektedir. CAD/CAM sağlık sektöründe, fizyoterapi ve ortez-protez alanında protez soketi ve ortezleme ölçü alımı ve üretiminde, ayak basınç analizine bağlı bireysel tabanlık uygulamalarında ve diş hekimliğinde çeşitli alanlarda kullanılmaktadır. Diş hekimliğinde CAD/CAM ilk defa 1970'li yıllarda kullanılmıştır. Diş hekimliğinde CAD/CAM dijital ortodonti, cerrahi kılavuz ve modellerde, dental implantlarda ve protetik diş tedavilerinde kullanılmaktadır. CAD/CAM ile protetik restorasyonların üretilmesi alternatif bir yaklaşım sunmaktadır. CAD/CAM geleneksel yöntemler ile kıyaslandığında mum modelaj, döküm gibi hataya yol açabilen basamakları atlayabilme avantajına sahiptir. CAD/CAM sistemlerinin gelişmesi ile estetik ve fonksiyonel beklentiler de artmıştır. Bu beklentileri karşılamak için yeni materyaller geliştirilmiştir. Üretimde kullanılan materyaller özetle şu şekilde sınıflandırılmaktadır; kompozitler, metaller, polimerler, polimetilmetakrilatlar ve seramiklerdir.
Anahtar Kelimeler: CAD/CAM, diş hekimliği, materyal, protez, seramik

ABSTRACT

CAD/CAM is the abbreviation obtained with the initials of the words computer aided design and computer aimed manufacturing. In Turkish, it means computer-aided design and computer-aided production. CAD/CAM is used in the health sector, in the field of physiotherapy and orthosis-prosthesis, in the measurement and production of prosthetic sockets and orthoses, in individual insoles based on foot pressure analysis, and in various fields in dentistry. CAD/CAM was first used in dentistry in the 1970s. In dentistry, CAD/CAM is used in digital orthodontics, surgical guides and models, dental implants, and prosthetic dental treatments. The production of prosthetic restorations with CAD/CAM offers an alternative approach. Compared to traditional CAD/CAM methods, it has the advantage of skipping steps that can cause errors such as wax modeling and casting. With the development of CAD/CAM systems, aesthetic and functional expectations have also increased. New materials have been developed to meet these expectations. The materials used in CAD/CAM production are briefly classified as follows; composites, metals, polymers, polymethylmethacrylates, and ceramics.
Keywords: CAD/CAM, ceramic, dentistry, material, prosthodontic

GİRİŞ

Günümüzde hastaların beklentileri dahilinde estetik kaygıların ön plana çıkmasıyla diş hekimliğinde metal desteksiz restorasyonların üretimi gittikçe önem kazanmaktadır. Gelişen teknolojiden yararlanılarak estetik ve dayanıklı restorasyonların yapımını destekleyen materyal ve sistemler geliştirilmiştir (Bornfather & Brunton,2007; Brunton, 1999).

Günümüzde CAD/CAM (computer aided design ve computer aimed manufacturing) sistemleri inley, onley, laminate veneer, bölümlü kron, tüm seramik kron, köprü sistemleri, hareketli bölümlü protezlerin iskelet yapıları ve implant cerrahisinde kullanılan stentlerin üretilmesi gibi restorasyon öncesi üretimde ve implantların yerleştirilmesinden hemen sonra restorasyonların anında (immediat) hazırlanabilmesine olanak tanıyan çalışma modellerinin üretilmesi gibi geniş bir endikasyon alanını kapsamaktadır (Leinfelder ve ark., 1989).

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Diş hekimliğinde CAD/CAM kullanımı ile birlikte seramik materyalinin restorasyona özgü tasarlanmasının özel bir yere sahip olduğu söylenebilir. Çünkü diğer restoratif materyallere kıyasla birçok avantajı olmasının yanında hala estetik olarak en tatmin edici sonuç seramik ile alınmaktadır. Rengi, ışık geçirgenliği, dokular ile uyumluluğu açısından günümüzde de seramiğin yerine başka bir materyal koymak mümkün olmamıştır (Rosenblum & Schulman, 1997).

CAD/CAM

CAD/CAM, İngilizce bir terim olup; Computer Aided Design and Computer Aimed Manufacturing kelimelerin baş harflerinden elde edilen bir kısaltmadır. CAD/CAM, iki kısımdan oluşmaktadır: Bilgisayar destekli tasarım (CAD) ve Bilgisayar destekli üretim (CAM). CAD, bilgisayar uygulamalarını kullanarak modelin sanal ortamda üç boyutlu olarak tasarlanmasını sağlayan kısımdır. CAM ise, CAD ile tasarlanan modelin yine bilgisayar desteği ile üretiminin yapılmasıdır (Jedynakiewicz & Martin, 2004).

CAD/CAM Kullanım Alanları/ Amaçları

Bilgisayar destekli tasarım, bilgisayar destekli üretim ve bilgisayar destekli mühendislik (CAD/CAM/CAE) teknolojileri, otomotiv, havacılık ve denizcilik sektörleri gibi günümüz endüstrisinde giderek daha fazla uygulama alanı bulmaktadır. Bu teknolojiler, mühendislerin ve araştırmacıların üretkenliğini büyük ölçüde artırırken, aynı zamanda araştırma faaliyetlerinin daha yüksek performans seviyelerine ulaşmasına olanak tanır. Gerçekleştirilmesi zor bir dizi tasarım ve üretim süreci, mevcut daha fazla metodoloji kullanılarak simüle edilebilir, yani regresyon analizi, varyans analizi, Taguchi metodolojisi, derin öğrenme gibi istatistiksel araçlarla birleştirilmiş deneysel çalışmalar yeterince erken uygulanarak, tasarım döngüsü ve optimizasyonları için CAD tabanlı araçlar ve işleme optimizasyonları için CAM tabanlı araçlar kullanılabilmektedir. Mevcut araçlar daha karmaşık hale geldikçe, mühendisler/araştırmacılar bu zorluğu daha doğru tasarım, üretim ve simülasyonlar için bir fırsat olarak görmektedir (Kyratsis ve ark., 2020).

Sağlık sektöründe ise, fizyoterapi ve rehabilitasyon ve ortez-protez sektörlerinde; protez soketi ve ortez ölçü alımında, uygun cihazların üretiminde, ayak basınç analizine bağlı bireysel tabanlık uygulamalarında kullanılmaktadır. Diş hekimliğinde ise protetik ve restoratif diş tedavisi, ortodonti gibi çeşitli alanlarda kullanılmaktadır (Wong ve ark., 2005; Healy ve ark., 2012).

Diş Hekimliğinde CAD/CAM

Diş hekimliğinde CAD/CAM ilk defa 1970'li yıllarda kullanılmıştır. Fransa'da Francois Duret, İsviçre'de Werner Mörmann ve Marco Brandestini, Amerika'da Bruce Altschuler diş hekimliği ile ilgili çalışmalara başlamıştır. Bruce Altschuler ilk defa ağız içi yüzeyin taranması için bir optik tarayıcı üzerinde çalışmıştır. (Young & Altschuler, 1977) 1984 yılında ise Duret, kendi sistemini tanıtmıştır. Bu sistemdeki amacı basit ve ucuz şekilde restorasyonu tamamlamak, iş gücünü azaltarak insan üzerindeki yükü azaltmaktı fakat yaptığı sistemin pahalı ve kompleks olmasından dolayı istediği başarıya ulaşamamıştır (Duret ve ark., 1988; Tinschert ve ark., 2004).

Başarılı olan ilk CAD/CAM sistemi 1980 yılında Mörmann ve Brandestini tarafından geliştirilen CEREC'dir (Mörmann & Bindl., 2002; Liu, 2005).

Diş hekimliğinde kullanılan CAD/CAM temel olarak üç unsurdan oluşmaktadır. Bunlar:

- Hazırlanan modelin geometrisini üç boyutlu olarak bilgisayara aktaran optik veya mekanik tarayıcı,
- Bilgisayara aktarılan modeli istenildiği gibi tasarlayan yazılım programı,
- Tasarlanan dizaynı restorasyona dönüştüren frezeleme ünitesinden oluşmaktadır (Burke & Qualtroug,1998; Hickel ve ark., 1997).

Diş Hekimliğinde CAD/CAM Kullanım Alanları

Diş hekimliğinde CAD/CAM dijital ortodonti, cerrahi kılavuz ve modellerde, dental implantlarda ve protetik diş tedavilerinde kullanılmaktadır.

Dijital ortodonti

Ortodontist hekimler dişleri taradıktan sonra braketler tasarlayıp üretebilmektedir. Ayrıca bu işlem sırasında hastaya özel ayarlamalar da bilgisayar üzerinden yapılabilmektedir (Evans & Desai, 2016; Krey ve ark., 2016). CAD/CAM üzerinde, Invisalign (Align Technology, California, USA) ve hastanın dişlerini üç boyutlu olarak modellemek için planlayan sistemler de mevcuttur (Papadimitriou ve ark., 2018).

Ayrıca temporomandibular eklem rahatsızlığına sahip olan hastalar için okluzal splint ve diş hizalayıcıların yapımında da CAD/CAM kullanılmaktadır (Pugalendhi ve ark.,2020).

Cerrahi kılavuzlama ve modelleme

Anatomik cerrahi kılavuzlar üretilerek, elde edilen modeller ile karmaşık olabilecek bir cerrahi operasyon öncesi planlama yapılabilir. Ayrıca bu modeller cerrahi işlem sırasında da referans olarak kullanılır (Ramasamy ve ark., 2013).

Dental implantlar

Günümüzde CAD/CAM ile gözenekli ve pürüzlü yapıya sahip implantların üretilmesi mümkündür. Gözenekli ve pürüzlü yapının yanında daha az klinik adımla minimal invaziv ve maksimum doku korumasıyla ideal bir implantın yapılması mümkün olmuştur (Chen ve ark., 2014; Xiong ve ark., 2012). CAD/ CAM sistemi ile implant üretimi ve tasarımının avantajları: Kişiye özgü uygulama imkanı sunması, implantı kimyasal ve mekanik olarak ayarlayabilme olanaklarına sahip olmasıdır (Oliveira & Reis , 2019).

Dezavantajı: Boyutsal hassasiyet sağlanamaması, ürünün tamamen yeterli olmayan mekanik özelliklere sahip

olması ve yüzey kalitesinin optimalliği sağlamaması dezavantajlarındandır (Dawood ve ark., 2015).

Protetik restorasyonlar

CAD/CAM ile protetik restorasyonların üretilmesi alternatif bir yaklaşım sunmaktadır. CAD/CAM geleneksel yöntemler ile kıyaslandığında mum modelaj, döküm gibi hataya yol açabilen basamakları atlayabilme avantajına sahiptir (Miyazaki & Hotta, 2011). Üç boyutlu modelleme; sabit ve iskelet protezler, mum modeller, geçici protezler, metal alt yapılar, tam protezler ve çene yüz protezlerinde kullanılmaktadır (Torabi ve ark, 2015).

Üç boyutlu modelleme

Üç boyutlu yazıcılarla üretilen modeller; düşük maliyet, iş gücü ve zamandan tasarruf sağlaması ile geleneksel yollara alternatif olmuştur. Geleneksel yöntemler ile kıyaslamasını yapan Jeong ve ark. CAD/CAM ile yapılan modellerin daha başarılı olduğunu ortaya çıkarmıştır (Kasparova ve ark., 2013; Jeong ve ark., 2018).

Geçici protezler

Geçici protetik restorasyonların üç boyutlu olarak yapılması mümkündür. Hem hareketli ve hem de sabit restorasyonlar elde edilebilir (Revilla-León ve ark., 2019). CAD/CAM ile yapılan geçici restorasyonların bükülme direncini ve mikro sertliğini geleneksel yöntem ile kıyaslayan Digholkar ve arkadaşları, eklemeli yöntemin daha başarılı sonuçlara ulaştığını görmüşlerdir (Digholkar ve ark., 2016).

Lin ve arkadaşlarının yaptığı çalışmada ise, üç boyutlu olarak üretilen geçici restorasyonların daha ucuz ve kısa sürede elde edildiğini fakat uzun klinik çalışmaların yapılamadığı için renk stabiliteleri ve biyouyumluluğu hakkında net bilgiler elde edememiştir (Lin ve ark., 2018).

Hareketli protezler

Dijital diş hekimliğinin gelişmesi ile hareketli protezler de CAD/CAM'ler ile kolayca yapılabilmektedir (Bilgin ve ark., 2015). Inokoshi ve arkadaşları geleneksel yöntemler ile yapılan tam protezleri, eklemeli yöntem ile yapılan tam protezlerle hasta ve uzman görüşü bakımından kıyaslamışlardır. Hastalar iki ayrı yöntem ile yapılmış tam protezleri kullandıklarında herhangi bir fark görmediklerini beyan etmişlerdir. Uzmanlar ise, gerek zaman tasarrufundan gerekse hastaların memnuniyeti açısından eklemeli tercihi daha avantajlı bulmuşlardır (Inokoshi ve ark., 2012). Hareketli bölümlü iskelet protezler üç boyutlu olarak metalden veya rezinden üretilebilir. Özellikle komplike şekle sahip iskeletlerin doğru yapıda üretilmesi üç boyutlu yazıcılar ile mümkün hale gelmiştir. Üretilen modellerin maliyetinin yüksek olması ise geliştirilmesi gereken bir başlıktır (Eggbeer ve ark., 2005).

Çene yüz protezleri

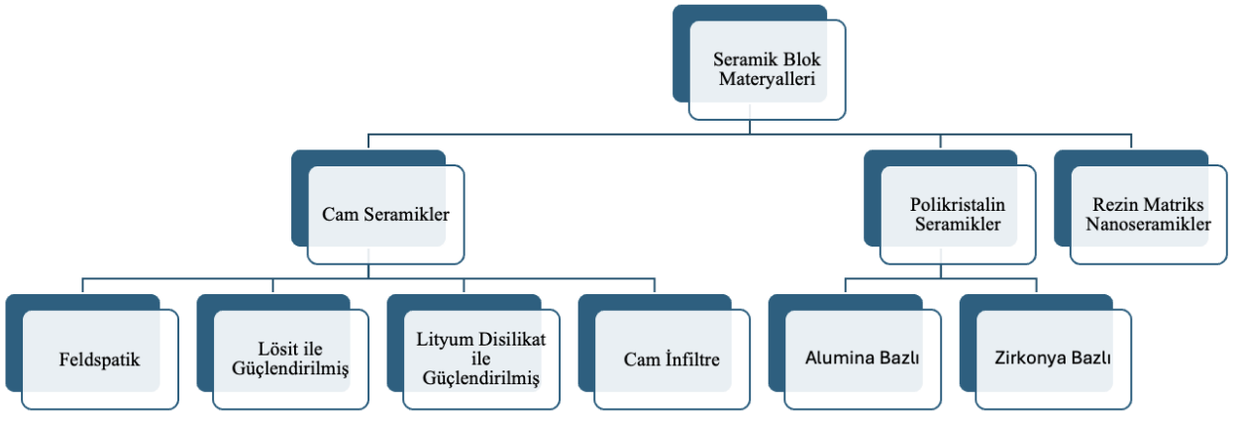
Fasiyal defektlerin protetik açıdan restorasyonu son zamanlarda üç boyutlu tasarım ve üretim ile de yapılabilmektedir (Van Noort, 2012). Çene yüz protezleri sadece üç boyutlu makineler ile yapılamaz. Protetik restorasyonun yapılabilmesi için bilgisayarlı tomografi ve manyetik rezonans ile birlikte CAD/CAM sistemleri birlikte kullanılmalıdır. Böylece fasiyal form kolayca elde edildikten sonra eklemeli yöntem ile protezin üretimi sağlanabilmektedir (Feng ve ark., 2010).

Metal alt yapılar

CAD/CAM sistemlerinin kullanım alanlarından bir diğeri de sabit restorasyonların alt yapısının oluşturulmasıdır. Eklemeli yöntemler ile yapılan sabit restorasyonların geleneksel yöntemlere oranla daha iyi marjinal ve internal uyuma sahip olduğu bildirilmiştir (Yıldırım & Bayındır, 2013).

Seramikler

Bir süredir eklemeli üretim teknolojileri polimerik veya metalik malzemelerden prototipler veya modeller üretmek için kullanılmıştır. Son zamanlarda, eklemeli yöntemlerin kullanımında seramiklerin üretimi popülerlik kazanmıştır (Zocca ve ark., 2015). (Şekil 1)



Şekil 1. CAD/CAM sisteminde diş hekimliğine yönelik kullanılan seramik blok çeşitleri

Diş Hekimliğinde CAD/CAM Kullanımının Avantaj ve Dezavantajları

CAD/CAM avantajları

- Zorlayıcı geleneksel ölçü yöntemleri yerini basit dijital ölçü alım prosedürlerine bırakmıştır (Palin & Burke, 2005).
- CAD/CAM sistemleri ile birlikte daha uyumlu restorasyonlar daha kısa sürede elde edilmektedir.
- Çapraz kontaminasyonların önüne geçilmiştir (Karaalioğlu & Duymuş, 2008).
- Tek seansta bitirilebildiği için geçici kron yapımının önüne geçilmiştir (Feuerstein, 2004).

CAD/CAM dezavantajları

-Birden fazla CAD/CAM sistemi geliştirilip denenmesine rağmen hala ekonomik olarak uygun fiyatta değildir.

-Tek renkli üretim yapılması estetik kaygılar oluşturmaktadır, ancak son zamanlarda yeni üretilen malzemeler ile bu kaygı yavaşça ortadan kalkmaktadır.

-Derin subgingival diş preperasyonların dijital ortama yansıtılmasında sorun çıkabilmektedir, retraksiyon ipi kullanımı bu dezavantajı minimalize edebilir (Christensen, 2001).

Diş Hekimliğinde Kullanılan CAD/CAM Materyalleri

CAD/CAM sistemlerinin gelişmesi ile estetik ve fonksiyonel beklentiler de artmıştır. Bu beklentileri karşılamak için yeni materyaller geliştirilmiştir. Üretimde kullanılan materyaller şu şekilde sınıflandırılmaktadır; kompozitler, metaller, polimerler, polimetilmetakrilatlar ve seramiklerdir (Fasbinder, 2010; Fasbinder, 2012).

Kompozitler

Tek diş kron ya da onlay restorasyonlarında kompozitler günümüzde sıklıkla tercih edilebilmektedir. Bunun sebebi ise yapısal, fiziksel, biyolojik ve estetik açıdan akrilik reçine esaslı bloklara oranla daha başarılı özellikler göstermesidir. Ayrıca kompozit esaslı kronlar bruksizme sahip hastalarda karşıt dişte daha az aşınmaya sebep olacağından da tercih edilmektedir. Estetik açıdan da sorun oluşturmayan kompozitler çiğneme kuvvetlerini de absorbe edebilmektedir (Höland ve ark., 2000).

Metaller

CAD/CAM sistemlerinin geliştirilmesi ile implant üstü protezlerin yapımında kullanılan metal destekli seramiklerde alt yapı olarak metal ürünler kullanılmaya başlanmıştır. Dökümden kaynaklanan büzülmeleri ve uyumsuzlukları gidermek amacıyla günümüzde CAD/CAM sistemlerinde metaller sıkça kullanılmaktadır. Diş hekimliğinde saf titanyum, titanyum alaşımları ve krom-kobalt alaşımları kullanılmaktadır (Mehl ve ark., 2013).

Geçmişte saf metal blokların kullanımından sonra günümüzde sinterlenen metal bloklar kullanılmaktadır. Bu materyallerden restorasyonun üretilmesi ile zirkonya esaslı bloklardan üretilmesi benzerlik göstermektedir. Sinterlenen metal blokların büzülme miktarlı göze alınarak daha büyük biçimde freze edilirler. Freze edilen metal bloklar argon gazlı ortamda son kez sinterlenerek mekanik özellik ve boyut bakımından son haline ulaşır (Zimmermann ve ark., 2013).

Polimerler

CAD/CAM sisteminde polimerler geçici restorasyonlar üretmek amacıyla kullanılır. Belirli durumlarda rezin içerikli materyallerden ürettiğimiz restorasyonların marjinal adaptasyonu ve estetik görünümünden emin olunduktan sonra maliyeti daha fazla olan seramik bloklardan üretim yapılabilmektedir. Prova amaçlı kullanılan polimerler tek renk veya çok renkli optik özelliklere sahip olabildiği gibi içeriğinde polimetilmetakrilat içermeyen materyallerde üretilmeye başlanmıştır. Bunun yanı sıra akrilik reçine içeren blokların CAD/CAM ile kullanımıyla artık monomer içeriğine sahip olmayan, döküme girebilen altyapı modelajları ve cerrahi plaklar da hazırlanabilmektedir (Lauvahutanon ve ark., 2014).

Polimetilmetakrilatlar

Hareketli protezlerin yapımında polimetilmetakrilat en çok tercih edilen kaide materyalidir. Akrilik rezinlerin uygulunma kolaylığı, estetik beklentileri karşılaması, kolay şekilde polisaj yapılabilmesi ve ağız içinde stabil bir materyal olmasından dolayı çok tercih edilmektedir. Bunun yanı sıra düşük kırılma direncine sahip olması, artık monomer salınımı ve bakteriler için tutunma yüzeyi oluşturması gibi olumsuz özelliklere de sahiptirler (Ayman, 2017; Alp ve ark., 2019).

CAD/CAM akrilik rezin kaide materyallerinin, hareketli protezlerin yapımında uygun rezin olduğu görülmüştür. Yapılan çalışmalar sonucunda CAD/CAM ile üretilen kaide materyalinin, polimetilmetakrilatın ısı ile polimerize olan örnekler ile kıyaslandığında daha iyi fiziksel özellikler gösterdiği sonucuna ulaşılmıştır (Şahin ve ark., 2021).

Seramikler

CAD/CAM sistemlerinin gelişmesi ile birlikte çok kısa sürede çok az maliyetli restorasyonların üretilmesi mümkün olmuştur. Camsı matriks içeriği ise seramiğin estetiği açısından önemini belirler. Cam içeriğinin artması translüsensi için çok önemli olup, mine ve dentin özelliklerini taklit eder. Kırılgan cam içerik mekanik özellikleri azaltırken, estetik özellikleri arttırmaktadır. Seramiğin sahip olduğu doldurucu içerik ise mekanik özellikleri arttırmakta olup, mikroçatlakların oluşmasını da engellemektedir. Geleneksel yöntemde mekanik özellikleri düşük olan cam içerikli seramiklerin alt yapısında metal kullanılırken, günümüzde CAD/CAM teknolojileri ile birlikte monolitik restorasyonların üretimi de diş hekimliğinde mümkün hale gelmiştir (Kelly, 2008; Fischer & Marx, 2002). İndirekt restorasyonlarda kullanılan seramik materyalleri de blok veya disk şeklinde

hazırlanmaktadır. Bu disk veya bloklar zirkonyum oksit (ZrO_2), alüminyum oksit (Al_2O_3), rezin kompozit ve lityum disilikat gibi maddelerin eklenmesiyle CAD/CAM sistemlerinde kullanılmaya hazır duruma getirilmiştir (Belli ve ark., 2017; Wendler ve ark., 2017).

Bu yüzden CAD/CAM'de kullanılan seramikler kısaca; cam seramikler, polikristalin seramikler ve rezin matriks içerikli seramikler olmak üzere üç ana başlıkta incelenmektedir.

Diş Hekimliğinde Kullanılan Seramik Blok Çeşitleri

Seramik blok materyalleri; cam, polikristalin ve rezin matriks nanoseramikler olmak üzere üç alt başlıkta incelenir.

Cam seramikler

Cam seramikler CAD/CAM seramik blok materyalleri kullanımında temel olarak dört başlığa ayrılır. Bunlar; feldspatik, lösit ile güçlendirilmiş, lityum disilikat ile güçlendirilmiş, ve cam infiltre seramiklerdir.

Feldspatik seramikler

Dental seramiklerdeki camlar esasen alüminyum oksit ve silikon oksit temelli feldspat denilen mineral grubundan elde edilir. Bu camlar son derece biyouyumlu maddelerdir. CAD/CAM sistemlerinde kullanılmak üzere üretilen feldspatik içerikli seramik bloklarda 3-4 mikron büyüklüğünde feldspar partikülleri homojen biçimde bulunmaktadır. Vakum altında sinterlenen bu yapı laboratuvarda üretilip sinterlenen seramiğe göre daha homojen ve stabil yapıdadır. Diğer seramiklerden ayıran en büyük avantajı ise frezeleme işleminden hemen sonra cila yapılıp tek seansta hastaya uygulanabilmesidir (Pjetursson ve ark., 2007).

Feldspatik cam seramik bloklar ile inlay, onlay, veneer ve anterior kron restorasyonları yapılabir. Kırılma dirençlerinin düşük olmasından dolayı posterior kron restorasyonları, köprü protezleri ve endokron restorasyonlarında yapımı kontraendikedir (Conrad ve ark., 2007).

Lösit ile güçlendirilmiş seramikler

Lösit esaslı cam seramiklerin temelinde silisyum oksit, alüminyum oksit ve potasyum oksit yer almaktadır. Total hacminin %30-40 kadarını lösit kristal fazı oluşturmaktadır. Doğal dişe benzeyen yarı geçirgenlik ve aşındırma özelliğine sahiptir (Pröbster ve ark., 1997; Kelly ve ark., 1996).

Bükülme direnci ise 160 MPa'dır. Elastik modülü 62 GPa ve materyal sertliği ise 6200 MPa'dır. Bulunduğu konumda çevre dokuların rengini alabilme özelliğine sahiptir. Lösit kristallerinin materyalin dayanıklılığına etkisi iki farklı mekanizma ile açıklanmaktadır. Bunlardan birincisi seramiğin ısı kaybı sonunda cam matriks içerisinde baskı geriliminin oluşmasıdır. Materyalin içerisinde yaklaşık % 40 oranında bulunan lösit kristallerinin sahip olduğu genleşme katsayısı içinde bulunduğu cam matriksten daha fazladır. Böylece seramik ısıtılıp soğutulurken lösit kristalleri büzülerek, cam matriksi içerisine doğru çeker ve oluşturduğu iç basınç ile mikro çatlakların ilerlemesini doldurur. Bir diğer mekanizma ise lösit kristallerinin çatlağın yönünün aksine ilerleyerek çatlak ilerlemesini durdurmasıdır (Albakry ve ark., 2004; Tinschert ve ark., 2000). Kullanımları anterior kron restorasyonları, inlay, onlay ve laminate veneer ile sınırlıdır.

Lityum disilikat ile güçlendirilmiş seramikler

Yapı ve biyofizik açısından lösit ile güçlendirilmiş cam seramiklere benzer yapıdadır. Fakat iç yapısı lösit içerikli seramiklere oranla daha dayanıklıdır bunun sebebi ise daha fazla oranda kristalin fazı içermesidir. Üst yapıya uygulanan seramikte ise daha fazla miktarda florapatit kristali bulundurur, bu yapının fazla olması estetik açıdan lityum disilikat içerikli cam seramiklere avantaj sağlar (Silva ve ark., 2012).

CAD sistemleri için üç farklı ışık geçirgenliğine sahip lityum disilikat blokları mevcuttur. Bunlardan ilki; inlay ve onlay yapımında kullanılabilen yüksek translusensiye sahip, çevre dokuların rengini alabilen ve estetik özellikleriyle ön planda olan bloktur. Düşük translusensiye sahip bloklar ise çeşitli renk seçeneklerine sahip full anatomik restorasyonların yapımında kullanılmaktadır. Özellikle renklenmiş dişlerin tedavisinde ise tabakalama tekniği uygulanarak multi blokların kullanılması tercih edilmektedir (Guess ve ark., 2010). Lityum disilikat ile güçlendirilmiş cam seramiklerin bükülme dayanımı 350-450 MPa, sertliği 5800 MPa ve elastik modülü ise 95 GPa'dır. Bu seramikler gelişmiş dayanıklılığa, iyi optik özelliklere ve birçok translusensi seviyesi ve renk tonlarına sahiptir. Dayanıklılığı ve yapısı, çatlak başlangıcını engellemekten çok çatlağın ilerlemesini durduran iyi bir direnç sağlar. Bu seramiklerde çatlak oluşturmak için uygulanması gereken kuvvet, geleneksel seramiklere göre iki kat daha fazladır (Bindl ve ark., 2006). Kısa dişsiz boşlukların restore edilmesi ancak lityum disilikat ile mümkündür. Bunun dışında inlay, onlay, anterior ve posterior restorasyonlarda kullanılabilir. Endokron yapımına da endike bir materyaldir. Ancak posterior köprü restorasyonlarında, bruksizm ve çok sayıda diş eksikliğine sahip hastalarda kullanılması kontraendikedir.

Tek kron restorasyonları dışında 3 üyeli sabit protetik restorasyonlarda da endikasyon alanı ikinci premolar dişlerin anterioru ile sınırlıdır (Taskonak ve ark., 2005).

Cam infiltre seramikler

Cam infiltre oksit seramikler son sertlik derecelerine ulaşana dek Ianthan Oksit cam infiltrasyonu işlemine maruz kalırlar. In-Ceram Spinell, In-Ceram Alumina ve In-Ceram Zirkonya olmak üzere üç alt tipi mevcuttur. In-Ceram Spinell, In Ceram Alumina sistemine alternatif olarak 1994 yılında üretilmiştir. Magnezyum ve alümina karışımı içerirler. ($MgAl_2O_4$) In-Ceram sistemleri arasında en iyi translusensliğe sahip materyaldir. Ayrıca translusensliği In-Ceram Alumina'dan iki kat daha iyidir ancak bükülme direnci daha kötüdür. Estekik beklentinin fazla olduğu

anterior kron restorasyonlarında kullanılabilir. Kırılma direnci 350 MPa olup orta derecede dirençlidir (Magne & Belser, 1997; Fredeani & Redemagni M, 2002).

In-Ceram Alumina, sinterlenmiş alümina altyapısına, düşük viskoziteli sodyum ıanthan oksit cam infiltrasyonu ile elde edilmiştir. In-Ceram Spinell materyalinden önce kullanılmıştır (Sorensen & Torres, 1992). Kırılma direnci 400-600 MPa elastik modülü ise 380 GPa'dır. Translusensliği fazla olmadığından dolayı estetik açıdan çok kullanışlı değildir. Estetiği arttırmak amacıyla metal alt yapısı üzerine feldspatik porselenler işlenebilir. In-Ceram Alumina sistemleri tek kron restorasyonlarında ve anterior, posterior bölge üç üyeli köprü restorasyonlarında endikedir (Conrad ve ark., 2007; Gür & Kesim, 2004).

In-Ceram Zirkonya, alüminyum oksit içeriğine %33 oranında seryum stabilize zirkonyum katılması ile oluşturulmuş bir materyaldir. İçeriğinin %70'ini aluminyum oksit, %30'unu ise zirkonyum oksit oluşturur. 1100 °C'de iki saat boyunca sinterlendikten sonra cam infiltrasyonu gerçekleşmektedir. Bu işlem sonucunda tüm yapının %23'ünü cam faz kaplamaktadır. Materyalin bükülme direnci 421-800 MPa arasındadır (Vagkopoulou ve ark., 2009; Guazzato ve ark., 2004). In-Ceram Zirkonya materyali aşırı opak bir maddedir. Bu yüzden anterior restorasyonlarda kullanılması endike değildir. İçerdiği zirkonya miktarının fazla olmasından dolayı fırınlama sonrasında büzülme oranı düşüktür, bu sebeple marjinal uyumu iyidir. Estetik kaygı yaratmayan posterior bölgede köprü ve tek kron restorasyonlarında kullanılabilir (Conrad ve ark., 2007; Gür & Kesim, 2004).

Polikristalin seramikler

CAD/CAM sistemlerinin gelişmesi ile zirkonya diş hekimliğinde sıkça kullanılan materyal haline gelmiştir. Polikristalin seramikler içerisinde, ıtriyum-tetragonal zirkonya içerikli restorasyonların elde edilmesi için iki farklı CAD/CAM üretim tekniği kullanılmaktadır (Vagkopoulou ve ark., 2009). Bunlardan ilki; tam sinterlenmemiş blokların frezeleme ile şekillendirilerek yüksek sıcaklıklarda tam sinterize edilmesi, diğer bir üretim tekniği ise tam sinterize edilmiş blokların sisteme ait freze ünitesi tarafından şekillendirilmesi ile restorasyonların üretilmesidir. Son teknik ile beraber hasta başında restorasyon frezelenebilir, laboratuvar işlemlerine gerek kalmadığı için süre kazanılabilir (Kouatayas & Kern, 1999).

Günümüzde monolitik zirkonya seramik restorasyonlar posterior bölgede kullanılması amacıyla tasarlanmıştır. Zirkonya alt yapılı restorasyonlarda görülen porselen atması gibi başarısızlıkların önüne geçilmesi planlanmıştır. Itriyum tetragonal zirkonyalar 3-4 üyeli köprü restorasyonlarında uygulanabilir. Derin kapanışa ve bruksizme sahip hastalarda ise dayanıklılığının az olması sebebi ile kullanılması kontraendikedir (Griffin, 2013).

Monolitik zirkonyanın içerisindeki alümine %0,1'e kadar azaltılmıştır. Böylece dayanımı arttırılmıştır. Monolitik zirkonya restorasyonlarının derin kapanışa sahip ve bruksizm gibi parafonksiyonel alışkanlıklara sahip olan bireylerde de kullanılabileceği söylenmiştir. Ancak, yetersiz estetik görüntü ve opak bir materyal oluşu sebebiyle posterior bölge kron protezleriyle endikasyonu sınırlandırılmıştır (Preis ve ark., 2013).

Alumina bazlı seramik bloklar

Alumina bazlı seramikler ve zirkonya bazlı seramikler, presinterize durumdadır. %99,9 oranında sinterize edilmiş alüminyum oksit kristali içerirler. Sinterleme sırasında oluşacak büzülmeyi kompanse edebilmek amacıyla modeller normalden %20 daha büyük boyutta hazırlanır. Restorasyon elde edildikten sonra 1520°C'de fırına atılırlar. Elde edilen altyapı düşük ısıda seramik ile veneerlenmektedir. Sinterlenen alümina bazlı oksit seramiklerin kırılma direnci 500 MPa'nın üzerinde, bükülme dayanımı ise yaklaşık 610 MPa'dır. Elastik modülü ise 380 GPa'dır. Procera All Ceram restorasyonların translusensliğinin iyi olması ve yüksek bükülme mukavementi nedeniyle anterior, posterior tek üye kronlarda, inlay, onlay restorasyonlarda ve veneerlerde kullanılabilmektedir (Griffin, 2013; Otto & De Nisko, 2002).

Zirkonya bazlı seramik bloklar

Zirkonyum 1900'lü yıllardan beri diş hekimliğinde kullanılmaktadır. Seramikler ile karşılaştırıldığında daha iyi mekanik dirence ve kırılma dayanımına sahiptir (Özkurt ve ark., 2010). Günümüzde tam porselen restorasyonların alt yapılarının yapımında en çok kullanılan materyaldir. Zirkonyum dioksitler üretim şekillerine göre üç grupta incelenir. Bunlar; sinterlenmemiş, yarı sinterlenmiş ve sinterlenmiş zirkonyum dioksit bloklardır. Sinterlenmemiş zirkonyum dioksit bloklar, restorasyonun üretim safhasında herhangi bir basınç olmaksızın preslenmesi ile elde edilir. Basınçsız ortamda elde edildiğinden dolayı kolay aşındırılır, sonrasında ise sinterlenerek kullanılabilir (Beuer ve ark., 2008).

Yarı sinterlenmiş zirkonyum dioksit bloklar ise zirkonyum dioksit tozunun içerisine bağlayıcı madde eklenip, preslenerek blok haline getirilmesi ile elde edilir. Zirkonyum dioksit tozu sonrasında basınçla sıkıştırılır ve 1350-1550°C 'de ön sinterleme işlemine maruz bırakılır (Denry & Kelly, 2008).

Tam sinterlenmiş zirkonyum dioksit bloklar ise 1300°C'de sinterlenir ve yoğunluğu artarak % 95'e çıkar, böylece aşındarması çok zorlaşır (Beuer ve ark., 2008).

Zirkonyum diğer oksit seramiklere göre daha avantajlı özelliklere sahiptir. İç yapısı daha homojen olup, korozyona karşı direnci yüksektir. Ayrıca sahip olduğu düşük ısı iletkenliği ve yüzeyinin bakteri adezyonuna uygun olmaması gibi özellikleri zirkonyumun avantajları arasında sayılabilir. Estetik açıdan da iyi görünüme sahiptir. Mekanik olarak da avantajlara sahiptir; bükülme direnci 900-1200 MPa ve kırılma dayanımı ise 9-10 MPa arasındadır. Zirkonya, monoklinik, kübik ve tetragonal olmak üzere 3 ana fazda bulunmaktadır. Oda ısısında monoklinik fazda olan saf zirkonyum, 1170°C 'de üzerinde tetragonal faza geçmektedir. Tetragonal faz, eklendiği

seramiğin konsantrasyonu ve tanecik büyüklüğüne bağlı olarak oda ısısında stabilize edilebilmekte, çok daha yüksek sıcaklarda kübik faza geçmektedir (Malkoç & Sevimay, 2009). Sinterizasyon işlemi sonrasında büyük ısı düşüşü ile hacminde belirli değişiklikler olmaktadır ve zirkonyum artık stabil olmayan bir hale gelmektedir. Stabilizasyonu sağlamak amacıyla yapının içerisine stabilize edici oksitler eklenebilir. Bu oksitlere kalsiyum oksit (CaO), magnezyum oksit (MgO), sezyum oksit (CeO_2) ve yitriyum oksit (Y_2O_3) örnek olarak verilebilir. Stabilize edici oksitlerin eklenmesiyle zirkonyum, parsiyel stabilize zirkonya haline gelmektedir. En çok kullanılan oksit ise yitriyum oksittir ve zirkonya ağırlığının %3-5 miktarı kadar ilave edilerek yitriyum tetragonal zirkonya polikristalin (Y-TZP) oluşmaktadır (Piconi & Maccauro, 1999; Guazzato ve ark., 2004). Zirkonya bazlı seramik bloklar; ön arka bölge 3-4 üyeli köprü altyapıları, teleskop kron primeri ve abutmentları olarak kullanılabilir.

Rezin-matriks nanoseramikler

UDMA (üretan dimetakrilat) adı verilen reçine matriks ve nanoboyutta seramik partiküllerinden oluşmaktadırlar. Materyalin içerisinde 4-11 nm çapında zirkonya monomerler ile 20 nm silika monomerler bulunmaktadır. Üretim aşamasında yapıya katılan silan, reçine matriks ile nanomer yapı arasında kimyasal bir bağ görevi görmektedir (Fradeani ve ark., 2005). Nanoseramikler, %80 nanoseramik partikülleri (birbirine bağlı zirkonyum ve siliko – nano partiküller) ve %20 resinden oluşmaktadır. Kırılma direncinin 200 MPa'dır. Kırılma direnci ve elastik katsayısı özellikleri feldspatik, lösitle güçlendirilmiş seramiklere oranla daha iyidir. Ancak ve lityum disilikat ile güçlendirilmiş seramiklere oranla daha düşüktür. Nanoseramik blokları dayanıklılığı yüksek bloklardır. Ancak bu dayanıklılığına rağmen elastikiyet modülünün dentine yakın olması seramiğe esneklik özelliği sağlar. Bu esneklik özelliği sayesinde hem restorasyonda oluşan stres miktarları azalır hem de restorasyonun antagonist diş minesinde meydana getirdiği aşınma miktarı minimuma iner (Zhang ve ark., 2013; Raigrodski, 2004).

Nanoseramikler materyal tek diş restorasyon veya kısa köprüler için tercihen posterior bölgede uygun olduğu söylenebilir. Makyaj işlemiyle birlikte anterior bölgede kullanımı olasıdır. Veneerler, inlay/onlay, anterior ve posterior tek kronlar, anterior ve posterior köprüler için endikedir.

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REVIEW / DERLEME

Hareketli Bölümlü Protezlerde Dijital İş Akışı Uygulamaları

Manufacturing Removable Partial Dentures by Digital Methods

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ÖZ

Geleneksel hareketli bölümlü protezler üzerinde yapılan çalışmaların sonucunda, dizayn ve üretim aşamalarında kusurlar olduğu belirtilmiştir. Bu kusur ve eksiklikler göz önünde bulundurularak, hareketli bölümlü protezler günümüz teknolojisinin imkanları ile birleştirilerek üretilmesi amaçlanmıştır. Son zamanlarda teknolojinin gelişmesiyle beraber, dijital tekniklerle üretilen hareketli bölümlü protezler prostodontik alanda devrim yaratmıştır. Hareketli bölümlü protez üretimi için eklemeli veya eksiltmeli yöntem olan birçok dijital teknikten yararlanılabilmektedir. Güncellenmiş üretim teknikleriyle beraber kullanılan materyal yelpazesi genişlemektedir. Bu makalenin amacı, güncel dijital yöntemler kullanılarak üretilen hareketli bölümlü protezlerin klinik uygulamalarda umut verici sonuçlar ortaya koyduğunu göstermektir.
Anahtar Kelimeler: Hareketli bölümlü protez, dijital diş hekimliği, eklemeli üretim, eksiltmeli üretim

ABSTRACT

Some problems on design and production stage during the construction of conventional partial removable dentures could be solved with today's technology.
Nowadays, digital techniques have reformed the production of partial removable dental prostheses (PRDPs). Recently, several digital methods are available in the request for RPD product including subtractive and additive techniques. Digital techniques increase the variety of materials that can be used for RPD production. The aim of this article was give information about the clinical application of the removable partial protheses produced by digital methods.
Keywords: Removable partial dentures, digital dentistry, additive techniques, substractive techniques

GİRİŞ

1. Dijital Hareketli Bölümlü Protez

Kısmi diş eksiklikleri birden fazla protetik seçenek ile tedavi edilebilir. Planlanan her protezin, kalan diş, implant ve dokudan destek alması gereklidir (Jorge ve ark., 2012). Tedavi planlaması, bilimsel veriler rehberliğinde her hastanın ihtiyaç ve beklentilerini en iyi şekilde karşılaması için hekim tarafından dikkatlice değerlendirilmelidir.

Hareketli bölümlü protez, destek diş ve dişsiz alveol kretin üzerine gelen fonksiyonel kuvvetlerin dağılımını dengeli bir şekilde sağlayarak desteklik özelliğine sahip sert ve yumuşak dokuları korur. Eksik veya kaybedilmiş fonksiyonların ve psikolojik problemlerin rehabilitasyonu, estetik ve fonasyonun sağlanması hareketli bölümlü protezin yapım amaçlarıdır. Bu amaç ışığında, hastaya yapılacak her bir protez için en uygun dizayn ve planlamanın yapılması önem taşımaktadır (Davenport ve ark., 2000).

Geçmiş yıllar boyunca geleneksel hareketli bölümlü protezler üzerinde yapılan çalışmaların sonucunda, dizayn ve üretim aşamalarında problemler olduğu belirlenmiştir (Radhi ve ark., 2007; Haj-Ali ve ark., 2012).

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Olası problemlerin çözümü amacı ile geleneksel hareketli bölümlü protezlerin günümüz teknolojisinin imkanları ile birleştirilerek üretilmesi amaçlanmıştır.

Diğer birçok endüstride olduğu gibi, diş hekimliği teknolojisinde de üretim aşamaları giderek dijitalleşmektedir. Dental laboratuvar ücretleri, klinik ve laboratuvar safhalarına bağlı hatalar ve tedavi süresinin uzaması dijital üretim ile elimine edilir hale gelmektedir. Dijital teknikler ile üretilen protetik restorasyonların kullanımı yaygınlaşmaktadır (Neumeier TT, Neumeier H., 2016).

1.1. Dijital Hareketli Bölümlü Protez Yapımı

Her geçen gün güncellenen CAD/CAM (Bilgisayar Destekli Tasarım/ Bilgisayar Destekli Üretim) teknikleri, diş hekimliğinde yazılım ve üretim aşamalarında önemli gelişmelere yol açmıştır. Teknolojinin ilerlemesiyle beraber makinelerin boyutlarının küçülmesi ve üretim maliyetlerinin azalması ile protetik restorasyonlar dijital olarak üretilmeye başlanmıştır. Dijital diş hekimliği, günümüze kadar daha çok sabit protetik restorasyonlar, diş üstü ve implant üstü kuron restorasyonlarının üretiminde rutin olarak kullanıma girerken, artan üretim teknikleriyle beraber tam ve bölümlü protez üretiminde de kullanılmaya başlanmıştır. Ancak, dijital teknolojiler kullanılarak üretilen bölümlü protezler hakkında yeterli sayıda klinik çalışmalardan elde edilen veriler halen istenilen yeterlilikte değildir.

1.1.1. Hareketli Bölümlü Protezin Dijital Üretim Teknikleri

Bilgisayar ve otomasyon sistemlerinin gelişmesi ile diş hekimliğinde geleneksel üretim yötemlerine alternatif üretim yöntemleri ve geleneksel döküm materyallerine alternatif yüksek kalitede protez altyapı materyallerinin (örn: PEEK, PMMA) kullanımı gündeme gelmiştir (Strub ve ark., 2006; Yıldırım ve Bayındır, 2013). CAD/CAM ile üretim tekniklerinde başlıca 2 farklı yöntem kullanılmaktadır.

1.1.1.1. Eksiltme Prensibine Dayalı Üretim Yöntemi

Diş hekimliği protetik tedavi alanında eksiltme yöntemi ile üretime oldukça sık başvurulmaktadır. Eksiltme yönteminde, protezin alt yapısının üretiminde, bilgisayar sistemi üzerinde tasarlanan prefabrike bloklar üzerinden, bilgisayar destekli nümerik kontrol cihazında (CNC) frezler, driller veya elmas diskler yardımıyla kazıma işlemi gerçekleşmektedir. Eksiltme prensibine dayalı üretim yöntemleri, kopya frezeleme ve kıvılcım erozyon (spark erozyon) olmak üzere iki gruba ayrılmaktadır (Kesmezacar ve Gaucher, 2015; Van Noort, 2012; Bilgin ve ark., 2016). Eksiltme yöntemi ile üretilen restorasyonların; distorsiyon, pörözitenin az oluşu ve homojen materyal kullanımı gibi avantajlar var iken, kompleks dizaynların üretiminde yaşanan zorluk, materyal israfı, maliyet fazlalığı gibi dezavantajları bulunmaktadır (Azeez ve Çekiç Nagaş, 2017).

Kopya-Frezeleme (Kopya Milleme) Yöntemi

Eksiltme prensibine dayalı olan kopya freze yöntemi, metal alt yapı üretiminde kullanılan hızlı bir yöntemdir (Bilgin ve ark., 2016; Açıkalın ve ark., 2011). Bu yöntem ile üretimin zamandan tasarruf sağlama, karmaşık iç yapıları ve ince detayları kolaylıkla üretebilme gibi avantajları mevcuttur. Ancak, etkin bir yöntem olan frezeleme yöntemi ile restorasyonu oluşturacak blok %100 verimle kullanılamadığı için malzeme israfı nedeni ile meydana gelen yüksek maliyet dezavantaj olarak karşımıza çıkmaktadır (Kesmezacar ve Gaucher, 2015; Arnold ve ark., 2018). Üretilen yapıların homojen olması, yüksek mekanik ve fiziksel özelliklere sahip olması, gözeneksiz olması ve dolayısıyla güvenilir olması, üretilen restorasyonların uzun dönem başarısı için kritik öneme sahiptir (Srinivasan ve ark., 2018).

Kıvılcım erozyon (Spark erosion, Electic discharge machining) Yöntemi

Kıvılcım erozyon tekniği geleneksel laboratuvar safhalarında karşılaştığımız sorunları gidermek ve üretimi daha doğru ve hassas gerçekleştirmek amacı ile geliştirilmiştir. Metal şekillendirmek için elektrik akımı kullanılan CAD/CAM kazıma yöntemlerinden biridir (Jacob Jo, 2011). 1940'ların başında endüstriyel alanda yaygın olarak kullanılan bu yöntem, materyali aşırı ısıtmadan saniyede 250.000 defa elektriksel deşarj ederek hassas metali uzaklaştırmaktadır. Kablo ve prob olmak üzere 2 tipi mevcuttur ve prob ucu diş hekimliğinde, hassas bağlantılı hareketli bölümlü protezlerin, sabit protezlerin, titanyum kuronların, teleskobik protezlerin, implant destekli overdenture protezlerin yapımında ve metal-rezin bağlantısının geliştirilmesinde kullanılmaktadır. Kıvılcım erozyon tekniği ile üretilen restorasyonlar ile pasif uyumu sağlanır, distorsiyon gözlenmez ve üretim hızlı ve verimli gerçekleşir. Ancak, tekniğin yüksek maliyeti ve kullanım için becerikli personel ve özelleşmiş laboratuvar ekipmanının bulunmasının zorluğu dezavantaj olarak karşımıza çıkmaktadır (Berger ve Driscoll, 2006; Presotto ve ark., 2018; Zhao ve ark., 2021).

1.1.1.2. Ekleme Prensibine Dayalı Üretim Yöntemi (Hızlı Protipleme)

30 yılı aşkın bir geçmişi olan hızlı protipleme (rapid prototyping-RP) yöntemleri ile nesnelerin kısa sürede eklemeli fiziksel model üretimi yapılmaktadır. Malzemelerin sıvı, toz veya katı halde, lazer, foton veya ısı yöntemleri uygulayarak bilgisayar kumandası ile şekillendirilmesi olarak açıklanmaktadır (Sofu ve Delikanlı, 2006; Çetinkaya, 2013). Solid-free üretim, dijital üretim, ya da katmanlı imalat olarak da bilinen hızlı prototipleme yöntemleri üretimin her alanında hızla yer almaya başlamıştır. Ekleme prensibine dayalı üretimin gelişmesiyle, tam ve bölümlü protezlerin dijital teknik ile üretilmesinin önünü açmıştır. Hızlı protip üretim sistemleri, geleneksel döküm işleminin aksine tek bir üretim işlemi sırasında birden çok ve farklı dizayna sahip restorasyon veya alt yapı üretme imkanı sunar. Üretim sayesinde alet değişimi gerektirmemektedir, bu sayede zaman ve maliyet konusunda tasarruf yapılabilinmektedir (Joda ve ark., 2017).

Günümüzde kullanılan hızlı prototip üretim sistemlerinden başlıcaları Stereolithografi, Eriterek şekil verme, Selektif elektron ışını ergitme, 3D Yazdırma ve Lazer ışını ile toz partiküllerini şekillendirme olarak sıralanabilir (Liu ve ark., 2006; Aretxabaleta ve ark., 2021).

Stereolithografi (SLA, Stereolithography)

Stereolitografi terimi tarayarak ışık ile kür tekniğinini literatürdeki karşılığıdır, tarihte ilk kez 1986 yılında Charles W. Hull tarafından ortaya çıkarılmıştır. Sıvı fotopolimer ile dolu bir tanktaki polimerlerin üzerine odaklanan yoğun bir ultraviyole ışını ile polimerlerin katı hale gelmesi yani kür haline gelmesi esasına dayanır. Üretilecek nesne, bilgisayar kontrolü ile yansıtılan nokta şeklindeki lazer ışının tank içerisindeki sıvı malzemenin üst yüzeyinde belirlenen kısımları katılaştırmasıyla tabaka tabaka inşa edilir. SLA teknolojisi günümüzde dental implantların yerleştirilmesi öncesinde hazırlanan cerrahi rehber modellerin hazırlanmasında, geçici kuron-köprülerin hazırlanması ve kayıp mum tekniğinde dökümü yapılacak rezin modellerin elde edilmesi gibi işlemlerde de kullanılmaktadır (Türker ve ark., 2022; Apak, 2010).

Eriterek Şekil Verme (FDM, Fused Deposition Modeling)

1980'lerin sonlarında S. Scott Crump tarafından eriterek şekil verme teknolojisi geliştirilmiş ve 1990'da ticarileştirilmiştir. FDM tekolojisi kullanımında birden fazla teknik olmakla beraber, ana yöntemde tel formunda bobin üzerine sarılı olarak cihaza hammaddeler kullanılmaktadır. Ekstrüzyon kafasında **ısınan** hammadde 0,3 mm **çapındaki** uçtan sıvı veya macun kıvamında sıkılarak **çıkarılır** ve istenilen noktaya sürülür. Platformun tekrar bir kat kalınlık kadar alçaltılmasıyla başlayan sıvama işlemi, parça yapılana kadar döngü halinde devam eder (Ishida ve ark., 2020; Konieczny ve ark., 2021).

Selektif Elektron Işını Ergitme (SEBM, Selective Electron Beam Melting)

Hızlı protipleme üretim sistemi olan, selektif elektron ışını ergitme, geometrik şekle sahip olan metal parçaları üretmek için kullanılır. Bu teknoloji de elektron demeti ile metal toz katmanı yüksek vakum altında eritilerek tabakalama yöntemiyle üretilir. Metal sinterleme tekniklerinin aksine tam yoğun, boşluksuz ve son derece dayanıklı parçalar **üretilir.** Bu tekniğin en büyük avantajı ise Cp-Titanyum, Ti-6Al-4V ve Co-Cr gibi metal alaşımlarında oldukça gözenekli yapılar oluşturma kabiliyetidir. Avantajların yanı sıra, pahalı olması, işlem süresinin uzun olması ve üretimde kullanılan metalin büyük bir kısmının kullanılmayıp atılması gibi dezavantajları bulunmaktadır. Bu teknoloji, maksillofasiyal ve ortopedi cerrahisinde kişiye özel implantların yapımı için geniş uygulama alanı bulmuştur (Van Noort 2012; Konieczny ve ark., 2021).

3B Yazdırma (3D Ink Jet Printing)

3B yazdırma teknolojisinin çalışma mekanizmasında, toz yatağı yüzeyine serilmiş ince bir toz dağılımı üstüne bağlayıcı malzeme yardımı ile çok kanallı püskürtme başlığı kullanılarak uygulanır. Sistemde hazır olan tabakayı ve toz yatağını piston yardımı ile aşağı doğru indirilir, yeni bir kat toz serpilir. Bu işlem planlanan parça tamamlanana kadar devam eder. Bu üretim sisteminde, zaman tasarrufu, malzeme maliyetinin az oluşu büyük bir avantajdır. Sistemle uyumlu materyal çeşitliliğinin sınırlı oluşu, yüzey bitim işlemleri ve çözünürlük dezavantajlarıdır (Liu ve ark., 2006; Yoo ve ark., 2021).

Seçici Lazer Sinterleme (SLS) ve Seçici Lazer Ergitme (SLM) Sistemleri (Isıtarak Toz Bağlama Tekniği)

Seçici lazer sinterleme uygulaması, toz haline getirilmiş metalleri (çelik, titanyum, titanyum alaşımları, Co-Cr alaşımları), lazer enerjisi uygulayarak birleştirilmesi ve tasarlanan üç boyutlu nesnelere dönüştürülmesidir (Torii ve ark., 2018). Hammadde olan metal alaşım tozu, işleme tablası üzerine katmanlar halinde yayılır ve fiber lazer ışınının yüzeye çarptığı noktada oluşan ısı, toz malzemeyi eritir ve eriyen toz parçacıkları diğer parçacıklarla birleşir. Bu döngüyü, 3B nesne tamamlanana kadar her katmanda termal ve mekanik aşamalar takip eder (Liu ve ark., 2006; Goguta ve ark., 2021). Üretimin yapıldığı kafes kapalıdır ve işlem oksidasyonunu önlemek amacı ile inert bir atmosferde (nitrojen ya da argon) gerçekleştirilmektedir. İşlem sonrasında, post sinterizasyon sürecine ihtiyaç duyulmaktadır. Üretim sonrası fırınlama işlemine tabi tutularak yapısal bütünlüğünün tamamlanması sağlanmaktadır (Jevremovic ve ark., 2012). Kraniyal ve dental implantlarda, hareketli bölümlü protez metal iskeletlerinde, sabit protezlerde metal alt yapılarda, implant üstü sabit restorasyon üretiminde, hibrit restorasyonlarda ve dental modellerin oluşturulmasında bu sistem yaygın olarak kullanılmaktadır (Torii ve ark., 2018). SLS tekniğinde, döküm işlemleri sırasında meydana gelen büzülmenin ortadan kalkmasıyla yüksek doğruluk, boyutsal stabilizasyon, üretim sürecinin kısa ve kolay oluşu, üretim sonrası sürecin basit oluşu bu yöntemi en sık kullanılan hızlı üretim teknikleri arasına getirmiştir. Bilgisayar ortamında hazırlanmış tasarımının, hızlı protipleme üretim sistemlerine naklini sağlamak için en sık kullanılan STL (Standard Template Library) ara yüzey formatına ihtiyaç duyulması, yüksek kapasitede STL dosyalarının çözümlenmesi için fazla vakit ihtiyacı duyulması, STL formatında geometri kusurlarının bulunması bu sistemin dezavantajlarındandır (Williams ve Bibb, 2008; Xin ve ark., 2014). SLM, kullanılan ekipman ve çalışma prensibi bakımından seçici lazer sinterleme yöntemine benzemektedir. Aralarındaki en belirgin fark, SLM'de çok daha yoğun bir enerji kaynağı kullanılarak, tozun tamamen ergimesine neden olmasıdır. Böylece yüksek yoğunlukta malzemeler üretilebilmektedir. SLM teknolojisi, çok iyi yüzey ve mekanik özelliklere sahip parçalar üretir, ancak uygun işlem kontrolleri sağlanmazsa, üretilen parçalar yüksek iç gerilimlere ve zayıf yüzey kalitesine maruz kalır (Ali ve ark., 2020).

2. Dijital Hareketli Bölümlü Protezde Kaide Plağı ve Yapay Dişlerin Proteze Entegrasyonu

Dijital hareketli bölümlü protezlerin üretiminde, kaide plağı ve yapay dişlerin proteze entegrasyonu estetik,

fonksiyonel ve biyomekanik başarının sağlanması açısından kritik bir adımdır. Günümüzde dijital teknolojiler sayesinde bu entegrasyon süreci daha hassas, tekrarlanabilir ve verimli bir şekilde gerçekleştirilebilmektedir (Piao ve ark., 2022).

Süreç, öncelikle hastadan alınan ağız içi dijital verilerle başlar. Bu veriler, yüksek çözünürlüklü intraoral tarayıcılar kullanılarak elde edilir ve CAD (bilgisayar destekli tasarım) yazılımlarında işlenerek, hem kaide plağının hem de yapay dişlerin üç boyutlu olarak tasarlanmasına olanak tanır. Özellikle sanal diş dizimi ile yapay dişlerin konumları, estetik ve fonksiyonel kriterlere göre optimize edilebilir. Bu, geleneksel yöntemlerde karşılaşılan diş dizimi hatalarının önüne geçer (Al-Haj Husain ve ark., 2020).

Kaide plağının üretiminde genellikle PMMA (polimetil metakrilat) kullanılır. Bu malzeme hem biyouyumlu yapısı hem de mekanik dayanıklılığı nedeniyle sıklıkla tercih edilmektedir. CAM (bilgisayar destekli üretim) teknolojileri kullanılarak bu dijital tasarım, ya frezeleme yöntemiyle homojen bir bloktan kazınarak ya da 3B yazıcılarla katmanlı olarak üretilebilir. Katmanlı üretim yönteminde, kaide plağına yapay dişlerin oturacağı yuvalar da önceden modellenerek, dişlerin sonradan stabil bir şekilde entegre edilmesi sağlanır (Wang ve ark., 2021).

Yapay dişlerin protez sistemine entegrasyonu ise iki şekilde olabilir: ya üretim esnasında kaide ile birlikte entegre olarak basılır, ya da üretim sonrası pozisyonlarına yerleştirilir ve adeziv sistemlerle sabitlenir. Özellikle tam dijital iş akışlarında, protez üzerinde yüksek hassasiyetle oluşturulan diş yuvaları sayesinde yerleştirme hatalarının önüne geçilir (Oh ve ark., 2021).

Dijital iş akışıyla gerçekleştirilen kaide plağı ve yapay diş entegrasyonu, protezin estetikten fonksiyona kadar birçok yönünü olumlu etkileyerek hem hasta memnuniyetini hem de klinik başarıyı artırmaktadır. Literatürdeki güncel çalışmalar, bu dijital entegrasyonun geleneksel yöntemlere kıyasla daha yüksek uyum ve daha kısa üretim süresi sunduğunu göstermektedir (Nishiyama ve ark., 2020).

3. Dijital İş Akışı ile Hareketli Bölümlü Protez Yapımında Klinik Başarıyı Artırma Yöntemleri

Dijital teknolojiler ile desteklenen iş akışları, hem protezin biyomekanik başarısını artırmakta hem de hasta konforunu önemli ölçüde avantajlar sunmaktadır.

Protez tasarımı, CAD tabanlı yazılımlar aracılığıyla optimize edilerek üç boyutlu analizlerle yük dağılımı dengelenebilmekte ve böylece destek dokular üzerindeki stres konsantrasyonları azaltılmaktadır. Bu durum, protezin stabilitesini artırırken, retantif problemlerin de önüne geçilmesini sağlar (Khorasani ve ark., 2025).

Dijital tarama tekniklerinin sağladığı yüksek çözünürlük sayesinde ölçü distorsiyonları en aza indirilmekte, bu da protezin klinik uyumunu doğrudan olumlu yönde etkilemektedir. Geleneksel yöntemlerle karşılaştırıldığında dijital ölçü alma süreci, hata riskini azaltmakta ve tedavi süresini kısaltarak klinik verimliliği artırmaktadır (Valenti ve ark., 2024).

Aynı zamanda dijital üretimle işlenebilen biouyumlu malzemeler, hem dayanıklılık hem de dokularla uyumluluk açısından başarılı sonuçlar vermektedir. PMMA, PEEK, Co-Cr ve titanyum gibi malzemelerin dijital olarak işlenmesiyle elde edilen protezlerde, pörözite oranlarının daha kontrollü olduğu ve bu sayede uzun ömürlü restorasyonlar sağlandığı bildirilmiştir (Liu ve ark., 2022).

Tüm bu sürecin en önemli katkılarından biri ise hasta bazlı özelleştirilmiş tasarımların mümkün hale gelmesidir. Her hastanın anatomik ve fonksiyonel ihtiyaçlarına göre bireyselleştirilen tasarımlar sayesinde hem estetik hem de biyomekanik açıdan daha uyumlu protezler üretilebilmekte, bu da hasta konforu ve tedaviye adaptasyonu önemli ölçüde artırmaktadır (Almufleh ve ark., 2023).

Dijital iş akışının sunduğu bu stratejiler, hareketli bölümlü protezlerin klinik başarısını artırmakta ve modern protetik yaklaşımlar için güçlü bir temel oluşturmaktadır. Ancak, bu yöntemlerin uzun dönem klinik başarısını değerlendirebilmek için daha fazla randomize kontrollü klinik çalışmaya ihtiyaç vardır.

Dijital Hareketli Bölümlü Protezler ile Yapılan Çalışmalar

Tregerman ve arkadaşları, 2019 yılında yayınladıkları in-vivo çalışmada 3 teknikle üretilen; konvansiyonel, konvansiyonel-dijital kombine ve dijital HBP iskeletinin uyumunu değerlendirmişlerdir. Araştırma için kısmi diş eksikliği bulunan, 4 adet Kennedy sınıf I, 3 adet Kennedy sınıf II ve 2 adet Kennedy sınıf III olmak üzere 9 kişi seçilmiştir. Dijital üretim olan hareketli bölümlü protez iskeleti, selektif lazer ergitme tekniği ile Co-Cr alaşımından üretmişlerdir. Çalışmanın sonucunda, dijital teknik ile üretilen iskelet uyumunun analog teknikle ve analog-dijital kombine teknikle üretilene göre daha iyi; analog teknikle üretilen iskelet uyumunun analog-dijital kombine teknikle üretilen iskelete göre daha iyi olduğunu rapor etmişlerdir. 9 hastadan 7'sinin dijital teknikle üretilen iskelet protezden daha memnun olduğunu, Kennedy sınıflamasına dair önemli bir fark bulunmadığını bildirmişlerdir (Tregerman ve ark., 2019).

Ye ve arkadaşları, 2018 yılında yaptıkları in-vitro çalışmada, (CAD-CAM, PEEK) materyali kullanılarak üretilen hareketli bölümlü protez iskeletinin uyumlarını değerlendirmişlerdir. 5 – akslı freze makinesinden (Organical Multi, R+K) PEEK blokları ile 15 adet HBP iskeleti üretmişlerdir. Aynı modelden 15'er adet konvansiyonel teknik ile HBP iskeleti de üretmişler ve okluzal tırnaklar, ana bağlayıcılar ve kaide arasındaki mesafeleri karşılaştırmışlardır. Estetik olarak tatmin edici olan PEEK ile üretilen HBP'lerin model ile daha uyumlu olduğunu bildirmişlerdir (Ye ve ark., 2018).

Francois ve arkadaşları, kopya freze yöntemi kullanarak polimetilmetakrilat (PMMA) materyali ile dijital hareketli bölümlü protezler üretmiş; benzer şekilde, Islam ve

arkadaşları da aynı yöntemle polieter-eter-keton (PEEK) materyali kullanarak dijital protezler tasarlamışlardır. Her iki çalışmada da, bu protezlerin klinik uygulanabilirliği ve hasta memnuniyeti üzerindeki etkileri vaka raporları üzerinden değerlendirilmiştir. Sonuçlara göre, hastaların protezleri kullanırken rahatlıkla çiğneme yapabildikleri ve estetik beklentilerinin karşılandığı bildirilmiştir. Ayrıca, geleneksel yöntemle üretilen protez kaidelerinde polimerizasyon sürecine bağlı olarak %0,45 ila %0,9 arasında değişen distorsiyonların oluşabileceği vurgulanırken; frezeleme tekniği ile üretilen dijital protezlerde ise pörözitenin düşük olduğu, dolayısıyla Candida albicans gibi mikroorganizmaların kolonizasyon riskinin azaldığı ifade edilmiştir (Islam ve ark., 2018). Hastalar, protezlerin estetik ve fonksiyonundan memnun olduğunu ancak protezlerinin tutuculuğunda azalma olduğunu bildirmişlerdir. Araştırmacılar, PEEK kroşe için daha derin retantif (≥0.5 mm) alanlara yerleşim yapılması veya daha hacimli olarak oluşturulmasını önermişlerdir. PEEK materyalinin, HBP iskeleti için alternatif bir malzeme olarak kabul edilebileceğini bildirmişlerdir. Kopya freze tekniği ile hareketli bölümlü protez üretiminin klinik olarak kabul edildiği, geleneksel yöntem ile üretilen protezlerde oluşabilecek laboratuvar hatalarının, uzayan prova seanslarınun ve üretim basamaklarının, dijital üretim ile önüne geçildiğini rapor edilmiştir (Virard ve ark., 2018).

Yoon ve arkadaşlarının, 2024 yılında gerçekleştirdikleri in vivo çalışmada, CAD/CAM frezeleme yöntemiyle üretilen polieter-eter-keton (PEEK) hareketli bölümlü protezler ve konvansiyonel yöntemlerle hazırlanan protezlerinn ağırlık, ağız içi uyum ve hasta memnuniyeti açısından değerlendirilmesi amaçlanmıştır. Elde edilen bulgular doğrultusunda, dijital iş akışıyla üretilen PEEK protezlerin, konvansiyonel yöntemlerle hazırlanan protezlere kıyasla istatistiksel olarak anlamlı derecede daha hafif olduğu belirlenmiştir ($p < 0.01$). Protez kaidesi ve dayanak bölgelerindeki doku uyumu bakımından iki grup arasında anlamlı bir fark saptanmamışken ($p> 0.05$), ana bağlayıcı bölgelerde PEEK protezlerin daha iyi adaptasyon gösterdiği tespit edilmiştir ($p< 0.05$). Görsel analog skala (VAS) sonuçlarına göre; hasta konforu ve çiğneme etkinliği açısından iki grup arasında anlamlı fark bulunmamış ($p > 0.05$), ancak estetik görünüm, özellikle kroşe estetiği bakımından PEEK protezlerin daha yüksek hasta memnuniyeti sağladığı rapor edilmiştir ($p< 0.05$) (Yoon ve ark., 2024).

Pooya ve arkadaşları 2019 yılında yayınladıkları in-vitro çalışmada konvansiyonel ve stereolitografi tekniği ile üretilen HBP iskeletinin doğruluğunu ve uyumunu değerlendirmişlerdir. Çalışma için 3 boyutlu yazıcı ile akrilonitril bütadien strien materyalinden Kennedy sınıf III modifikasyon I maksiller ark üretmişlerdir (Stratasys Inc. Eden Prairie, MN). Stereolitagrafi tekniğinde iskelet alt yapıyı ise, 3 boyutlu yazıcı (3DRPD Company, Montreal, Kanada) yardımı ile biouyumlu rezin materyali (Dental SG; Formlabs Inc) kullanılarak üretmişlerdir. Çalışma verileri sonucunda, konvansiyonel teknik ile üretilen iskeletin uyum ve doğruluğu, stereolitografi tekniği ile üretilen iskelete göre daha iyi olduğu gözlenmekle beraber, çalışmada geçen iki tekniğin de klinik olarak kabul edilebileceği bildirilmiştir. İki üretim tekniğinde de en uyumlu bölgeler, tırnak ve resiprokal kol olarak belirlenmiş, stereolitografi tekniği ile üretilen ana bağlayıcının anterior bandının adaptasyonu en uyumsuz bölge olarak rapor edilmiştir (Pooya ve ark., 2019).

Chaturverdi ve arkadaşlarının, 2024 yılında yayınladıkları derlemede geleneksel ve dijital (3B baskı ve frezeleme) yöntemleri ile üretilen HBP iskeletlerinin uyum doğruluğunu ve hassasiyetini değerlendirmişlerdir. Çalışmada 413 literatür arasından, 8 güncel in vitro çalışma değerlendirmeye alınmıştır. HBP iskeletlerinin uyum doğruluğunun üretim yöntemine göre değişkenlik gösterdiği gözlenmiştir. Konvansiyonel yöntemler, reçine frezeleme, seçici lazer eritme (SLM) ve 3 boyutlu baskı arasında karşılaştırma yapılmıştır. Çalışmalar arasında, reçine frezeleme tekniği ile üretilen PEEK iskelette, en yüksek uyum doğruluğunu gözlenmiştir (Chatuverdi ve ark., 2024).

Ye ve arkadaşları, 2018 yılında, yaptıkları in-vivo çalışmada hızlı protip (RP) tekniği ile üretilen hareketli bölümlü protez iskeletinin klinik uygulanabilirliğini 15 hastada değerlendirmişlerdir. Çalışmada 8 adet Kennedy Sınıf I, 3 adet Kennedy Sınıf II, 3 adet Kennedy Sınıf III ve 1 adet Kennedy sınıf I sınıflandırmasına dahil hastalar için HBP iskeleti hazırlanmıştır. Çalışmanın sonucunda, hızlı protip tekniği ile üretilen iskeletin doku ile uyumunun, geleneksel döküm iskeletinden daha düşük olduğunu rapor etmişlerdir. Ancak hızlı protip tekniği ile üretilen hareketli bölümlü protez iskeletin klinik uygulamada etkili bir şekilde tasarlanabilir ve üretilebilir olduğunu bildirmişlerdir (Ye ve ark., 2018).

Arnold ve arkadaşları, 2018 yılında yapmış oldukları in-vitro çalışmada farklı üretim teknikleri ile üretilen hareketli bölümlü protezlerin uyumunu değerlendirmişlerdir. Kontrol grubu olarak geleneksel HBP'in kullanıldığı çalışmada, dört farklı CAD/CAM tekniğini (indirekt hızlı protipleme, selektif lazer ergitleme, indirekt frezeleme ve direkt frezeleme) ile karşılaştırmışlardır. Çalışmanın verileri göz önünde bulundurulduğunda, CAD/CAM frezeleme yöntemi ile üretilen HBP'lerdeki kroşe uyumunun, geleneksel yöntem ile üretilen kroşelere göre daha iyi olduğunu rapor etmişlerdir. En düşük uyum değerinin, CAD/CAM hızlı protipleme tekniği ile üretilen HBP'lerdeki kroşede olduğunu bildirmişlerdir (Arnold ve ark., 2018).

Chen ve arkadaşları 2019 yılında yaptıkları in vitro çalışmada Kennedy sınıflamalarında, selektif lazer ergitleme tekniği ile üretilen hareketli bölümlü protezlerin adaptasyonlarını değerlendirmişlerdir. Çalışma modelleri, 3 boyutlu dental tarayıcı (IScan D104i; Imetric 3D SA) ile taranmış ve HBP dizaynı için yazılıma (3Shape Dental System 2013; 3Shape A/S) aktarılmıştır. Co-Cr alaşım kullanılarak, 3 boyutlu yazıcıdan selektif lazer erigtleme (Mlab cusing R; Concept Laser GmbH) tekniği ile üretilmiştir. Döküm iskelet için, Kennedy III diğer sınıflamalara göre daha düşük adaptasyon değeri göstermiştir. Selektif lazer ergitleme için en iyi adaptasyon Kennedy IV'de bulunurken en düşük adaptasyon Kennedy II'de bulunmuştur. Kennedy I ve II için döküm iskeletin uyumu, selektif lazer ergitleme tekniği

ile üretilen iskelete göre daha iyi bulunmuştur. Kennedy III ve IV için belirgin bir fark gözlenmemiştir. Sonuç olarak, büyük ve karışık dizaynlar haricinde selektif lazer ergitme tekniği ile üretilen iskeletin uyumunun kabul edilebilir seviyede olduğunu bildirmişlerdir (Chen ve ark., 2019).

SLM tekniği ile üretilen hareketli bölümlü protez (HBP) iskeletlerine ilişkin çalışmalar bulunmasına rağmen, bu yöntemle üretilen metal altyapıların geometrik doğruluğunu değerlendiren araştırmalar sınırlıdır. Bu kapsamda, Peng ve arkadaşlarının, 2022 yılında yayınladıkları in vitro bir çalışmada, toz formundaki kobalt-krom (Co-Cr) ve titanyum alaşımı (Ti-6Al-4V) kullanılarak selektif lazer ergitme (SLM) yöntemiyle üretilen HBP iskeletlerinin doğruluğu değerlendirmişlerdir. İstatistiksel analizler sonucunda, geleneksel yöntemle üretilen grubunun, SLM gruplarına kıyasla anlamlı derecede daha fazla uyumsuzluk gösterdiği tespit edilmiştir (SLM-Co-Cr için p =0.03; SLM-Ti-6Al-4V için p = 0.016). Bununla birlikte, iki SLM grubunun birbirleri arasında anlamlı bir fark göstermediği bildirilmiştir (p = .787). Bu sonuçlar, SLM teknolojisinin HBP iskeletlerinde yüksek geometrik doğruluk sağlayabileceğini ve klinik olarak daha başarılı restorasyonlar üretme potansiyeli taşıdığını ortaya koymaktadır (Peng ve ark., 2022).

SONUÇ

Hareketli bölümlü protez, kısmi dişsiz arklar için önemli bir geleneksel tedavi yöntemidir. Hareketli bölümlü protezlerin dijital üretimi ile hastaların seanslarında ve laboratuvar maliyetlerinde azalma, hekim ve teknisyen kaynaklı hataların minimale inmesi gibi avantajlı yönlerinin bulunmasına karşın, henüz bu sistemlerle üretilen protezlerin klinik uyum ve doğruluğu hakkında yeterli araştırma bulunmamaktadır. Diş hekimliğinde dijital bölümlü protez yapımının yaygınlaşması ve erişebilirliğinin artması için daha fazla çalışma yapılmasına ihtiyaç vardır.

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REVIEW / DERLEME

Oral and Dental Health of Children with Mucopolysaccharidoses: A review

Mukopolisakkaridozisli Çocukların Ağız ve Diş Sağlığı: Bir Derleme

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ABSTRACT

Mucopolysaccharidosis (MPS) constitutes a group of rare inherited metabolic disorders characterized by deficiencies in specific lysosomal enzymes responsible for the degradation of glycosaminoglycans (GAGs), resulting in their pathological accumulation within various tissues and organs. This accumulation disrupts normal cellular processes, causing progressive damage to multiple systems including the eyes, central nervous system, bones, respiratory, cardiac, and gastrointestinal systems. There are seven main types of MPS, each associated with a specific enzyme deficiency and GAG accumulation. The clinical manifestations of MPS vary widely, from mild to severe forms, and often include physical, neurological and skeletal abnormalities. Oral health issues are common in MPS patients, with dental problems such as caries, gingival inflammation, jaw deformities and delayed dental eruption frequently observed. Given that general anaesthesia poses significant challenges in these patients due to airway limitations and skeletal abnormalities, maintaining optimal oral health becomes even more critical to reduce the need for invasive procedures. The complexity of MPS requires a multidisciplinary approach to treatment, including careful planning for dental procedures. This review highlights the importance of addressing oral health in the broader management of MPS, emphasizing the need for tailored care to mitigate complications and improve overall patient outcomes. Dental professionals must be vigilant in recognizing and managing oral health concerns in each type of MPS patients to ensure comprehensive and safe treatment.
Keywords: Mucopolysaccharidosis, genetic disorders, oral health

ÖZ

Mukopolisakkaridoz (MPS), glikozaminoglikanların (GAG'lar) yıkımından sorumlu enzimlerin eksikliği nedeniyle oluşan nadir bir genetik hastalıktır. Bu eksiklikler, çeşitli doku ve organlarda GAG birikimine yol açar. Birikim, normal hücresel süreçleri bozarak gözler, merkezi sinir sistemi, kemikler, solunum, kardiyovasküler ve gastrointestinal sistemler dahil olmak üzere birçok sistemde ilerleyici hasara neden olur. MPS'nin her biri belirli bir enzim eksikliği ve GAG birikimi ile ilişkili yedi ana tipi vardır. MPS'nin klinik belirtileri hafif ile şiddetli arasında değişiklik gösterebilir ve genellikle fiziksel, nörolojik ve iskeletsel bozuklukları içerir. MPS hastalarında ağız ve diş sağlığı sorunları yaygındır; çürükler, diş eti iltihabı, çene deformiteleri ve gecikmiş diş sürmesi gibi diş problemleri sıkça gözlenir. Bu hastalarda hava yolu kısıtlılıkları ve iskelet anormallikler nedeniyle genel anestezi önemli zorluklar oluşturduğundan, invaziv işlemlere duyulan ihtiyacı azaltmak için ağız sağlığının en iyi şekilde korunması çok daha büyük önem taşımaktadır. MPS'nin karmaşık yapısı, dental işlemler için dikkatli planlamayı içeren multidisipliner bir yaklaşım gerektirir. Bu derleme, MPS'nin genel yönetimi içinde ağız sağlığının ele alınmasının önemini vurgulayarak, komplikasyonları azaltmak ve prognozu iyileştirmek için kişiselleştirilmiş bakımın gerekliliğine dikkat çekmektedir. Diş hekimleri, her tip MPS hastasında dental sorunları tanıma ve yönetme konusunda dikkatli olmalı, kapsamlı ve güvenli bir tedavi sağlamalıdır.
Anahtar Kelimeler: Mukopolisakkaridozis, genetik hastalıklar, ağız sağlığı

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INTRODUCTION

Mucopolysaccharidosis (MPS) is a heterogeneous group of hereditary disorders classified into seven types (I, II, III, IV, VI, VII, and IX) and 13 subtypes, all resulting from congenital enzymatic deficiencies involved in the catabolism of glycosaminoglycans (GAGs). (Table 1). The impaired degradation of GAGs leads to their excessive accumulation within the lysosomes of multiple organs, affecting the eyes, central nervous system, skeleton, respiratory, cardiac, gastrointestinal, and nervous systems. The clinical presentation ranges from mild systemic and ocular abnormalities with a normal lifespan to severe forms that can be fatal within the first few months of life (Nagpal et al., 2022; Ballikaya et al., 2018). The overall prevalence of MPS is approximately 4 per 100,000 live births, corresponding to a rate of 0.04%. (Ponciano et al., 2017).

Glycosaminoglycans (GAGs), also called mucopolysaccharides, are long chains of sugar molecules (carbohydrates) found in cells. They play a crucial role in forming bones, cartilage, tendons, corneas (the transparent eye covering), skin, and connective tissues. GAGs are also present in the fluid that lubricates joints. Within cells, GAGs are broken down and recycled by a set of 11 specialized enzymes. MPS develops when these enzymes are either absent or malfunctioning, preventing the proper breakdown of GAGs. The pathological accumulation of GAGs within lysosomes of connective tissue, cartilage, bones, and ligaments impairs normal cellular functions. Over time, this excessive storage disrupts tissue integrity and functionality, ultimately resulting in progressive tissue degeneration and organ impairment (de Bode et al., 2022).

Table 1. Types of MPS are characterized by specific enzyme deficiencies and the consequent accumulation of GAGs (Leal et al., 2020).

Type	Syndrome	Enzyme Deficiency	Accumulated GAGs
MPS I	Hurler Scheie	α-L-iduronidase	Heparan sulphate Dermatan sulphate
MPS II	Hunter	Iduronate-2-sulfatase	Heparan sulphate Dermatan sulphate
MPS III	Sanfilippo A B C D E	 Heparan-N-sulfatase α-N-acetylglucosaminidase Acetyl-CoA-α-glycosaminidase N-acetylglucosamine 6-sulfatase N-glucosamine-3-O-sulfatase	Heparan sulphate
MPS IV	Morquio A B	 Galactose 6-sulfatase ß - galactosidase 1	Keratan sulphate Chondroitin 6-sulphate
MPS VI	Maroteaux-Lamy	N-acetylgalactosamine 4-sulfatase (Arilsulfatase B)	Dermatan sulphate
MPS VII	Sly	ß-glucuronidase	Heparan sulphate Dermatan sulphate
MPS XI	Natowicz	Hyaluronidase	Hyaluronic acid

With the exception of type II MPS, which is linked to the X chromosome, all other MPS are autosomal recessive diseases (Nunes et al., 2022).

Significant physical and neurological developmental complications can arise, including structural abnormalities in the upper airways, difficulties associated with restrictive lung disease, and various skeletal deformities. Additionally, patients may experience irregularities in the cervical spine, which can contribute to mobility issues and discomfort. Neurological challenges, such as cognitive impairments and behavioural difficulties, may also be present, further impacting daily life and overall well-being. These complications often require multidisciplinary medical management, including respiratory support, orthopaedic interventions, and specialized neurological care, to improve the patient's quality of life and mitigate the progression of symptoms over time (James et al., 2012).

Most patients with MPS, with the exception of MPS III, exhibit facial and oral abnormalities that pose significant challenges in managing their airways. These anatomical abnormalities complicate airway management, making it difficult to establish proper ventilation. Additionally, the presence of atlantoaxial joint instability in many MPS patients further restricts the ability to achieve the required head and neck positioning, which is crucial for successful mask ventilation and tracheal intubation. These combined factors make airway management in MPS patients particularly complex and challenging (Alden et al., 2017).

The accumulation of glycosaminoglycans in the upper airway leads to the enlargement of the adenoids, tonsils, tongue, and laryngopharynx, all of which can complicate airway management during anesthesia. (Clark et al., 2018) In patients with MPS, the challenges associated with intubation and extubating during dental treatment under general anaesthesia further complicate the situation. Therefore, the importance of preventive dental treatments and regular dental visits is paramount.

The management of MPS necessitates a comprehensive approach that integrates oral health care, which is often overlooked. Poor dental hygiene and untreated oral conditions, such as gum disease and tooth decay, can exacerbate the physical challenges faced by MPS patients, leading to complications like infections, pain, and difficulties with nutrition. Incorporating dental care into treatment plans, especially during bone marrow transplantation (BMT), is essential for preventing these issues and enhancing patient comfort and quality of life. Given the significant implications of MPS on dental and skeletal development, a multidisciplinary strategy is imperative. This includes orthodontic interventions, periodontal care, and airway assessments, which collectively contribute to the long-term well-being of affected individuals. MPS patients exhibit complex oral health needs due to the prevalence of dental caries, gingival inflammation, and jaw deformities. The requirement for general anesthesia for dental procedures poses additional challenges, particularly due to the

increased sedation risks associated with their physical and neurological complications (Ponciano et al, 2017; de Bode et al., 2022).

Studies indicate that dental professionals play a crucial role in the care of MPS patients. Their expertise is essential for managing the challenges of maintaining proper oral hygiene, as these patients are more susceptible to plaque accumulation and caries. Early intervention and specialized dental care, including regular check-ups and preventive strategies, are vital to mitigate the risks of oral health issues. Ultimately, dentists are positioned to identify early signs of dental decay, enabling timely interventions that can significantly enhance the quality of life for MPS patients through proactive oral health management (Deps et al, 2021; Nourbakhsh & Esfahani, 2024).

This review aims to ensure that physicians and dentists are extensively informed on this topic, while considering the significance of a multidisciplinary approach, in order to prevent serious dental problems in children with all type of MPS.

MPS TYPE I (HURLER SYNDROME)

MPS type I is a rare hereditary disorder first clinically described in 1919 by Gertrud Hurler, a German pediatrician. It is inherited in an autosomal recessive pattern and results from a deficiency of the enzyme α-L-iduronidase. This enzymatic deficit leads to the accumulation of GAGs, including dermatan sulfate and heparan sulfate, in multiple organs and tissues. Without intervention, individuals with the severe phenotype generally do not survive beyond the first decade of life. Early detection is essential to prevent life-threatening complications, especially those affecting the heart, lungs, and cognitive function. However, the initial symptoms are often vague, making early diagnosis challenging (Hampe et al., 2020). The range of intraoral abnormalities is quite extensive and can be observed either clinically or radiographically. Broadly, it encompasses dental anomalies such as delayed tooth eruption, malocclusion, taurodontism, hypodontia, microdontia, peg-shaped teeth, hypoplastic enamel, gingival hyperplasia, radiolucency in maxilla/mandible, condylar defects, thick lips and temporomandibular joint disorders (Rodrigues Barros et al., 2023; Hingston et al., 2006). A high-arched palate and anterior open bite and macroglossia can be observed in patients with MPS Type 1 (Hirst et al., 2021; Nourbakhsh, 2024). Additionally, individuals with Hurler's syndrome often exhibit flattened alveolar ridges, macroglossia, a high-arched palate, and a short, broad mandible with abnormal condyles. Localized dentigerous cyst-like radiolucency are also frequently observed (Fig. 1). These dental manifestations are part of a broader clinical presentation of MPS, which involves the accumulation of glycosaminoglycans due to an enzyme deficiency. Early diagnosis and intervention, such as bone marrow transplantation, may improve outcomes (Hingston et al., 2006).

Figure 1: Child with MPS Type I – Hurler Syndrome (Kumar et al., 2022).

MPS TYPE II (HUNTER SYNDROME)

MPS type II is an X-linked recessive genetic disorder. The *iduronate 2-sulfatase* (IDS) gene (HGNC ID: 5389; ENSG00000010404) is located at the Xq28 chromosomal region, spans 44 kb, and consists of nine exons. The complex disease results from a deficiency in the lysosomal hydrolase IDS, an essential enzyme involved in the stepwise breakdown of heparan and dermatan sulphate (D'Avanzo et al., 2020). Hunter syndrome presents in two phenotypic forms, distinguished by the degree of central nervous system (CNS) involvement and overall survival. Type A represents the more severe variant, characterized by an earlier onset and a median life expectancy of approximately 14 to 15 years. Conversely, Type B is milder, with a projected lifespan of 30 to 50 years, and exhibits phenotypic features that are similar but less pronounced than those observed in Type A (Savitha et al., 2015). (Fig. 2) Patients with MPS type II may also display orofacial manifestations, including gingival hyperplasia, delayed dental eruption, malocclusion, radiolucent areas in the maxilla or mandible, and condylar abnormalities. (Hirst et al., 2021). High-arched palate, condylar defect, flattened condyle head, hypoplastic condyle, limited mouth opening, short ramus, coronoid process defect, macroglossia, gingiva hyperplasia, thick dental follicle, dentigerous cysts, delayed eruption/prolonged retention, taurodontism, peg-shaped teeth can be also observed in MPS Type II (de Bode et al., 2022) (Fig. 2).

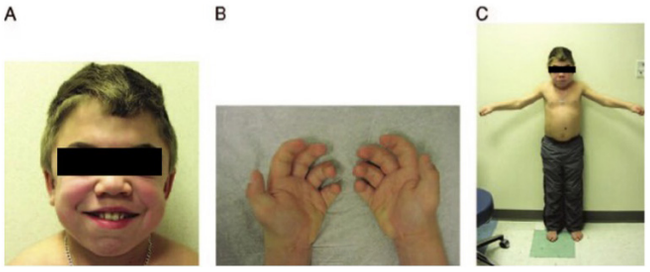

Figure 2: A 14-year-old male diagnosed with Hunter syndrome exhibiting characteristic coarse facial features (A), digital clubbing (B), and restricted shoulder joint mobility (C), limiting his ability to elevate his arms (Martin et al., 2008).

MPS TYPE III (SANFILIPPO SYNDROME)

Sanfilippo syndrome, also known as MPS Type III, comprises a group of inherited lysosomal storage disorders characterized by progressive central nervous system (CNS) degeneration and systemic manifestations that typically manifest during childhood. It is characterized by neurocognitive decline, loss of functional abilities, and premature death. Sanfilippo Syndrome has four autosomal recessive subtypes (types A, B, C, and D), each caused by a deficiency in a different enzyme responsible for degrading the GAG heparan sulphate. This results in the accumulation of substrates and subsequent cellular dysfunction (Muschol et al., 2022). MPS III is the most common lysosomal disorder among the various types of MPS, yet only a limited number of studies have explored its oral and dental manifestations. In MPS Type III, features may include prominent oral ridges and an enlarged tongue (macroglossia), gingival hyperplasia, peg-shaped teeth, and a high-arched palate (Al Malak et al., 2025) (Fig. 3).

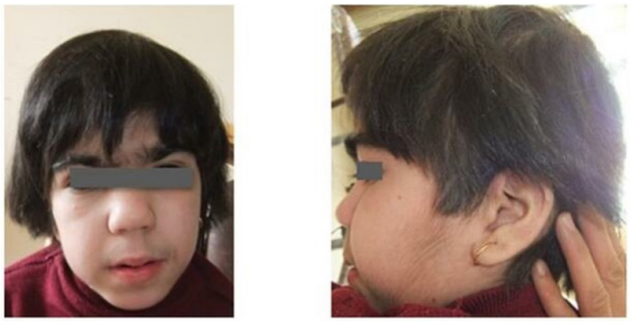

Figure 3: A child with MPS Type III (Malbin et al., 2019).

MPS TYPE IV: MORQUIO SYNDROME

MPS Type IV results from mutations in the GALNS gene, which encodes the enzyme galactosamine-6-sulfate sulfatase. This disorder is characterized by systemic manifestations affecting multiple organ systems, including musculoskeletal, respiratory, cardiovascular, rheumatologic, neurological, dental, ophthalmological, and otological domains (Fig. 4). Typically diagnosed within the first few years of life, the condition has an average life expectancy of approximately 25.3 ± 17.43 years (Peretz et al., 2020). Dental abnormalities frequently observed in patients with MPS Type IV include enamel defects such as discoloration and hypoplasia, as well as tooth surface loss, increased spacing between teeth, peg-shaped incisors, malocclusions like crossbites, and flattened condyles. (Hirst et al., 2021). A cross-sectional study by Vinod et al. (2022) was performed on 26 patients diagnosed with MPS IV. The most prevalent findings in this cohort were gingival diseases (84.6%) and dental caries (76.9%), both of which underscore the need for regular and comprehensive dental care. In addition to the common dental issues, the study also observed macroglossia (65.4%) and high arched palate (69.2%) as significant features in these patients. The increased size of the tongue can interfere with normal speech and swallowing, while the high arched palate may contribute to difficulties with occlusion and mastication. Furthermore, mouth breathing (65.4%) and tongue thrusting (65.4%) were frequently reported, both of which can exacerbate the development of malocclusions, including anterior open bite (69.2%) and spaced dentition (73%). The study also highlighted the issue of delayed dental eruption, which was observed in 100% of the patients in this cohort. This delayed eruption can impact the timing and sequence of treatment, making early diagnosis and regular monitoring essential in managing these patients effectively. Overall, the findings of this study emphasize the importance of a multidisciplinary approach to the dental treatment of patients with Morquio Syndrome. Preventive dental care, early orthodontic intervention, and management of oral habits such as mouth breathing and tongue thrusting are crucial in maintaining both functional and aesthetic outcomes for these patients (Vinod et al., 2022).

Figure 4: A male patient diagnosed with mucopolysaccharidosis type IV (Ramphul et al., 2018).

MPS TYPE VI: MAROTEAUX-LAMY

The disorder is caused by mutations in the arylsulfatase B (ARSB) gene, which is located on the long arm of chromosome 5 (5q13–5q14). The musculoskeletal, cardiorespiratory, ocular, auditory, and occasionally neurologic manifestations of MPS VI can significantly affect mobility, daily activities (ADL), and health-related quality of life (HRQoL) (Leiro et al., 2021) (Fig. 5). These features can be observed in MPS Type VI, including taurodontism, elongated tooth roots, abnormal frenum, missing teeth, supernumerary teeth, and microdontia (Kantaputra et al., 2013). According to de Almeida-Barros et al. (2018) anterior open bite was exclusively observed in patients with MPS VI. Additionally, it was reported that mouth opening, a higher prevalence of unerupted teeth, hyperplastic dental follicles, and notable condylar defects were seen in these patients. The degree of skeletal and joint involvement in MPS VI contributed to more severe oral health complications compared to MPS IVA (de Almeida-Barros et al., 2018).

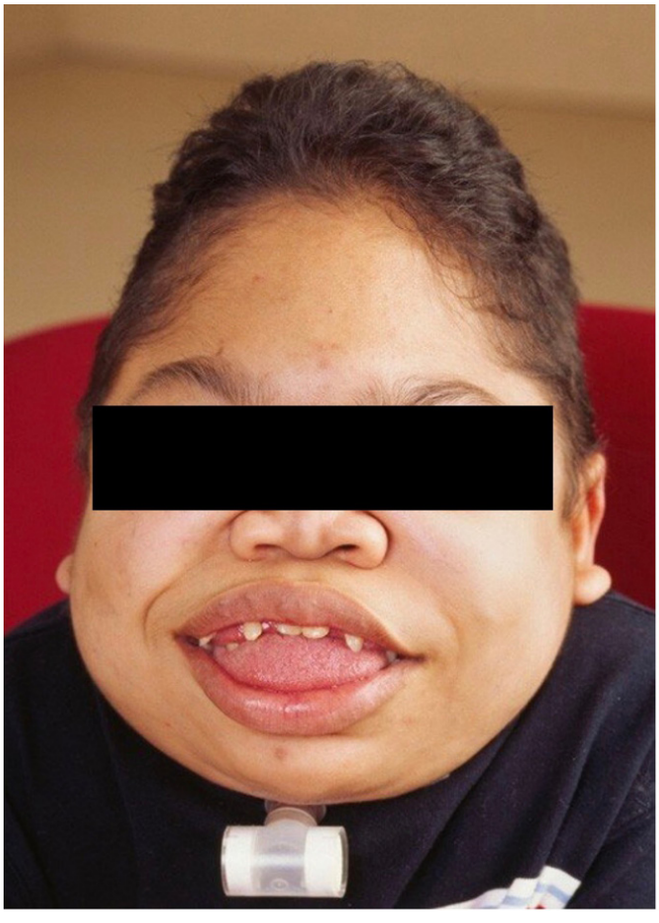

Figure 5. A 16-year-old patient with rapidly progressing MPS VI presenting with coarse facial features, including frontal bossing, macroglossia, thickened lips, abnormal dentition, and gingival hyperplasia, as shown in the facial photograph (Valayannopoulos et al., 2010).

MPS TYPE VII: SLY SYNDROME

MPS type VII is an exceedingly rare, life-threatening, progressive condition caused by genetic mutations that impact lysosomal storage and function. The estimated prevalence of MPS VII is less than 1 in 1,000,000, representing less than 3% of all MPS diagnoses (Grand et al., 2024). This disease is caused by a deficiency in the enzyme β-glucuronidase (GUS) (Poswar et al., 2022).

Patients with MPS type VII (MPS VII) present with a wide range of clinical manifestations, including cognitive impairment, hepatosplenomegaly, coarse facial features, cardiac valve abnormalities, recurrent upper respiratory infections, short stature, and skeletal dysplasia.

MPS TYPE IX: NATOWICZ SYNDROME

MPS Type IX results from a deficiency of the enzyme hyaluronidase 1 (Hyal-1), which is responsible for breaking down hyaluronan (hyaluronic acid, HA) (Kıykım et al., 2016). It is the rarest type among all types of MPS (Shrinkhal & Mamgain, 2023).

Craniofacial characteristics commonly associated with MPS include coarse facial features, a prominent forehead, and a broad nasal tip, alongside thick lips and an open mouth posture. Ballıkaya et al. (2018) reported that 90% of patients had dental caries and gingival inflammation, with radiographs revealing abnormalities such as a short mandibular ramus, enlarged dental follicles, taurodontism, trabecular changes resembling osteoporosis, and condylar defects in 30 MPS patients (17 males, 13 females, median age 8). (Ballıkaya et al., 2018). In a cross-sectional study consisted of twelve MPS patients in Portugal exhibited dental occlusion issues such as anterior open bite, right and left posterior cross-bites, limited mouth opening, and maxillary compression compared to controls. Additionally, the study showed that 75% of MPS patients had a higher incidence of bleeding gums on over 30% of the tooth surfaces (Ponciano et al, 2017). In a systematic review by de Bode et al. (2022), orofacial abnormalities were present in all subtypes of MPS, as well as in mucolipidosis (ml) II and III. These abnormalities included thickened lips, midface hypoplasia, a high-arched palate, hypoplastic condyles, coronoid hyperplasia, macroglossia, gingival hyperplasia, thick dental follicles, dentigerous cysts, misshapen teeth, enamel defects, and open bite (de Bode et al., 2022). A study by Yoon et al. (2019) reported that a 21-year-old female MPS patient underwent cyst treatment and marsupialization. This study emphasizes that MPS patients are prone to dental root cysts, which, if untreated, can lead to infections and further complications. Yoon et al.'s (2019) findings reinforce the need for dental professionals to be vigilant in the management of oral manifestations in MPS (Yoon et al., 2019)

In a cross-sectional study by Deps et al. (2021), 29 individuals with MPS had higher rates of dental caries, gingivitis, malocclusion, and dental anomalies compared

to 29 without MPS with statistically significant differences ($p < 0.05$). The study found that the MPS group had higher rates of dental caries, gingivitis, malocclusion, and dental anomalies compared to the non-MPS group, with statistically significant differences ($p < 0.05$) (Deps et al, 2021).

According to the case report by Nourbakhsh and Esfahani (2024), a 9-year-old male patient with MPS syndrome exhibited a widened mouth, macroglossia, anterior open bite, and spaced teeth. The patient also exhibited gingivitis, a high frenal attachment, and a midline shift in the mandible. However, the temporomandibular joint (TMJ) appeared normal, with no detected abnormalities in mastication, mouth opening, or lateral movements. (Nourbakhsh & Esfahani, 2024).

A higher prevalence of obstructive sleep apnea (OSA), as detected by polysomnography and nocturnal oximetry, has been observed in infants with MPS, often accompanied by prolonged hypoventilation and/or central apnea. Sleep and respiratory issues are present in all types of MPS, typically involving OSA and restrictive lung disease (Rapoport & Mitchell, 2017).

Maintaining optimal dental hygiene is critical for children's overall health, facilitating proper nutrition, speech development, and social interactions. Neglected oral health can lead to painful conditions that hinder daily activities, particularly in children with special needs who may find routine oral hygiene practices challenging. Thus, regular dental care from practitioners experienced with MPS is crucial, allowing for tailored preventive measures and treatment plans that cater to the patients' specific limitations. Moreover, MPS patients often prioritize specialist visits, which can inadvertently lead to neglect of their dental care (Rabello et al., 2024). Therefore, interdepartmental collaboration among healthcare providers is vital to address all aspects of the patient's health, including oral care. Educating families on the significance of dental health and its integration into comprehensive treatment plans is essential for promoting the overall health and quality of life for MPS patients.

Specialized dental approaches in patients with Mucopolysaccharidosis (MPS) may enhance treatment outcomes, given the disorder's complex multisystem involvement and characteristic oral manifestations. Craniofacial anomalies such as macroglossia, gingival hyperplasia, and delayed tooth eruption, combined with airway obstruction risks and possible cognitive impairments, complicate routine dental care. These patients often require tailored treatment plans, careful anesthesia management, and interdisciplinary coordination. Standard dental procedures may pose significant risks; therefore, a customized, preventive-focused, and patient-specific approach is essential to ensure both safety and effective oral health outcomes.

The AAPD describes special health care needs as any physical, developmental, mental, sensory, behavioral, cognitive, or emotional impairment or condition that necessitates medical management, health care intervention, and/or the use of specialized services or programs. These individuals might face a heightened risk of developing oral diseases throughout their lives. According to the American Academy of Pediatric Dentistry (AAPD), children with a high risk of dental caries should have dental visits scheduled approximately every three months. These regular check-ups are important for early prevention of caries, appropriate preventive treatments, and providing necessary education (American Academy of Paediatric Dentistry, 2024).

In the future, dental approach for patients with MPS are likely to focus on early diagnosis, personalized care, and the integration of advanced technologies. Oral manifestations such as delayed tooth eruption, macroglossia, and malocclusion may serve as early indicators, positioning dental professionals to play a key role in early detection. Artificial intelligence – based dentistry might work on individualized preventive strategies. As gene therapy continues to evolve, its impact on craniofacial and dental development will be an important area of research. Furthermore, advancements in sedation and anaesthesia protocols tailored to the unique airway challenges in MPS are important to consider. Overall, a multidisciplinary, technology-driven approach might shape the future of dental management in this patient population.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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