Fit accuracy of removable partial denture frameworks using conventional impressions and intraoral scanning: a clinical study

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감사의 글

본 학위 논문을 준비하며, 치의학전문대학원 재학 시절부터 연세대학교 치과대학병원의 인턴, 보철과 전공의, 박사과정 지도학생에 이르기까지 항상 따뜻한 지도와 격려를 아끼지 않으신 김지환 교수님께 가장 먼저 깊은 감사의 말씀을 드립니다. 스스로 탐구할 수 있도록 열린 마음으로 이끌어 주시고, 연구 중 어려움에 부딪힐 때마다 방향을 제시해 주신 교수님의 가르침을 평생 잊지 않겠습니다.

아울러 논문 완성을 위해 소중한 조언과 격려를 보내주신 오경철 교수님, 늘 세심한 조언을 아끼지 않으신 신유석 교수님, 연구 방법의 디지털화 과정에 큰 도움을 주신 이현종 교수님, 그리고 어려운 순간마다 섬세한 도움을 주신 강유정 교수님께도 진심으로 감사드립니다.

보철과 수련 과정 동안 끊임없는 관심과 격려를 보내주신 모든 보철과 교수님들께도 깊은 감사의 마음을 전합니다. 아울러 의국 생활을 함께한 보철과의 동기 및 선후배 선생님들께도 고마운 마음을 전합니다.

마지막으로, 어렵고 지치는 순간에 힘내라고 응원해준 부모님과 동생 명인이에게 고맙고 사랑한다고 말하고 싶습니다.

2025 년 6 월 더운 여름날

윤명아

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

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Removable partial dentures (RPDs) rely on metal frameworks for support, stability, and retention. Traditionally, these frameworks have been fabricated using conventional impression techniques, which are well-established but can be time-consuming and susceptible to certain inaccuracies. Intraoral scanning (IOS) has emerged as a digital alternative that may offer improved efficiency and fit accuracy. However, few clinical studies have directly compared the fit accuracy of RPD frameworks produced using IOS versus conventional methods. This study aimed to evaluate and compare the fit accuracy of frameworks fabricated through both approaches. A total of 15 arches from 13 patients requiring RPDs were included, with each arch receiving two metal frameworks—one fabricated using conventional impressions (CON group) and the other using IOS (IOS group). Qualitative assessments were conducted through visual inspection and pressing tests, while quantitative evaluations involved three-dimensional superimposition and gap distance measurements at rest-seat areas. Statistical analyses, including paired t-tests and two-way analysis of variance, were performed to assess differences in gap distance. All frameworks satisfied the qualitative evaluation criteria. Quantitatively, the IOS group exhibited a significantly smaller mean gap distance (201 ± 78 μm) compared to the CON group (239 ± 83 μm) ($p = 0.015$). This difference was particularly pronounced at the terminal abutments of distal-extension RPDs. Although both fabrication methods yielded clinically acceptable gap distances, IOS demonstrated significantly improved fit accuracy, especially in critical abutment areas.

Keywords: digital removable partial denture, framework, gap distance, intraoral scanning, removable partial denture, fit accuracy

I. INTRODUCTION

Removable partial dentures (RPDs) play an important role in restoring oral function and aesthetics in patients with missing teeth. The metal framework of an RPD serves as the foundation for the prosthesis, ensuring favorable support, stability, and retention. Therefore, its significance cannot be understated, as an accurate and well-fitting framework determines the success and longevity of the RPD.[1-3]

The implementation of computer-aided design and computer-aided manufacturing (CAD/CAM) technologies has facilitated numerous digital advancements in dentistry. However, in the fabrication of RPDs, the integration of metal frameworks with resin bases presents inherent complexities, necessitating the continued use of conventional manufacturing techniques. Traditional methods, such as conventional impression-taking and framework fabrication via the lost-wax technique, remain widely utilized. Nevertheless, these approaches are time-intensive and may be susceptible to inaccuracies due to the intricate design and structural complexity of the framework.[4]

The conventional workflow for RPD framework fabrication involves creating a wax or resin pattern followed by investment and casting; however, with technological development, the application of digital technologies for manufacturing of RPDs has increased, and several strategies have emerged to streamline the process. Particularly, three-dimensional (3D) printing techniques, such as selective laser melting, are becoming increasingly popular for fabrication of RPD frameworks. This method can compensate for the limitations of the conventional technique by enhancing fracture resistance through prevention of void formation and distortion, and simplifying the overall laboratory process for fabrication of metal frameworks.[5-9] Recent studies have demonstrated that 3D-printed frameworks exhibit clinically acceptable fit accuracy.[10-12] Moreover, intraoral scanning (IOS) allows for the acquisition of highly detailed 3D images of partially edentulous dental arches. Additionally, digital impressions can capture the same level of detail as traditional impression materials. By integrating additive manufacturing with digital impressions, a model-free digital workflow for fabricating RPDs can be achieved. This approach offers several benefits, including enhanced patient comfort, improved workflow efficiency, and lower material costs. Moreover, some studies have demonstrated outstanding clinical results with 3D-printed frameworks.[2,4] However, quantitative analyses and clinical studies evaluating the fit accuracy of frameworks fabricated via IOS and 3D printing remain limited.

Fit accuracy was evaluated by quantitatively measuring the gap distance at the interface between the RPD framework and the abutment, using various methods such as visual inspection, microscopy, or traditional silicone impression techniques.[2,4,10,11] While these methods are commonly used, they often present limitations in reproducibility and may risk damaging the prosthesis during assessment. Additionally, evaluations are typically confined to specific sections or measurement points, making a comprehensive and multidimensional analysis difficult. In contrast, 3D-superimposition of scan data enables multidimensional analysis, offering significant advantages in assessing RPD frameworks.[13,14] Furthermore, this approach allows for non-invasive and precise evaluations while maintaining the structural integrity of the definitive prosthesis for clinical use. By enabling a comprehensive multidimensional analysis of each framework component, digital methods significantly enhance the precision of gap distance measurements and the reliability of fit accuracy assessments, effectively overcoming the limitations of traditional techniques.

This study aimed to compare the fit accuracy, specifically the gap distance, of 3D-printed frameworks produced using conventional impression techniques with those fabricated based on IOS data. The null hypothesis proposed that there would be no significant difference in the gap distance at the interface between the rest and rest seat in 3D-printed metal frameworks created from conventional impressions and those generated from IOS.

II. MATERIALS AND METHODS

1. Ethical Approval and Participant Recruitment

This clinical study was approved by the Institutional Review Board of Yonsei University Dental Hospital (IRB no. 2-2021-0045). A total of 15 arches from 13 patients requiring RPDs were selected from the Department of Prosthodontics at Yonsei University Dental Hospital. Prior to enrollment, all participants provided written informed consent. The sample size was determined using G*Power software (version 3.1.9.4), with an effect size of 0.70, $\alpha = 0.05$, and a power ($1-\beta$) of 0.80, resulting in a minimum required sample size of 12 participants. Following tooth preparation, including rest seat preparation and surveyed crown placement, each participant received two metal frameworks—one fabricated using a digital workflow and the other using a conventional impression method. The gap distance of the two frameworks was then compared (**Fig. 1**).

2. Conventional Impression Workflow

In the conventional impression group (CON group), a silicone impression material (Aquasil, Dentsply Sirona, Charlotte, NC, USA) was used to create a traditional impression, which was then used to produce a stone cast (Die Stone Extreme, DK Munkyo, Gyeongsangnam-do, Republic of

Korea). The cast was scanned with a tabletop scanner (E3, 3Shape, Copenhagen, Denmark), and the framework was designed using CAD software (Dental System, 3Shape, Copenhagen, Denmark). The framework was manufactured through selective laser melting (SLM) using a Cr-Co alloy (Mediloy S-Cp, BEGO GmbH & Co. KG, Bremen, Germany) and a metal printer (Dual 150, Riton, Guangzhou, China). The print orientation was adjusted to align with the survey direction, and the layer thickness was set to 30 µm. The framework underwent post-processing in a sintering furnace at 950 °C for 240 minutes. A dental technician (M. S. W) then fitted the framework to the stone cast. The step-by-step fabrication process of frameworks was demonstrated (**Table1**).

3. Intraoral Scanning Workflow

In the experimental group (IOS group), intraoral scanning was conducted using a 3D scanner (Trios 3, 3Shape, Copenhagen, Denmark), and the resulting standard triangulated language (STL) file was imported into CAD software (Dental System, 3Shape, Copenhagen, Denmark) for framework design. The framework designed from the intraoral scanning method was printed using the same machine as the conventional method and subjected to the same post-processing. Additionally, the STL file of the arch was 3D printed using resin (Photopolymer resin, Sindoh, Seoul, Republic of Korea), and the same technician pre-fitted the framework onto the resin cast.

4. Clinical Framework Fitting and Qualitative Assessment

At the framework-fitting appointment, both frameworks were tried in. The clinician adjusted each framework and evaluated it through visual inspection and a pressing test. Minimal clinical adjustments were performed on the fitting surfaces of the RPD frameworks when necessary. Following intraoral evaluation, a standardized adjustment protocol was applied to both groups, involving the relief of minor interferences to ensure complete seating. These adjustments were confined to superficial modifications and excluded major procedures such as clasp bending, connector adjustment, or significant reshaping. As substantial modifications were not required and the frameworks generally exhibited an adequate initial fit, the impact of these adjustments on the final fit evaluation was considered negligible. Visual inspection included verifying that all rests were seated, all rigid elements touched the teeth, the major connector did not impinge on the underlying soft tissue, and visible relief space was <1 mm.[10] The pressing test involved holding a plugger on the occlusal rest perpendicular to the occlusal plane and noting any detectable movements while applying appropriate pressure on the rest.[15]

5. Quantitative Assessment Using 3D Scanning

Quantitative evaluation was performed for frameworks that met the qualitative evaluation criteria. Scan powder (Scan spray, VITA, Bad Säckingen, Germany) was applied as thinly and evenly as possible from a distance of 3 cm.[16] Each framework was three-dimensionally scanned using a table-top scanner (Freedom UHD, DOF, Seongnam, Gyeonggi-do, Republic of Korea) to obtain STL files of the frameworks fabricated using the conventional method (CF) and IOS method (IF). Subsequently, vinyl polysiloxane adhesive (VPS tray adhesive, 3M ESPE, St. Paul, MN, USA) was applied to the rest areas of the framework and left to dry thoroughly. The patient's oral cavity was dried, and a vinyl polysiloxane (VPS) impression material (Aquasil XLV, Dentsply Sirona, Charlotte, NC, USA) was applied to the rest areas of the framework before seating it in the patient's mouth (**Fig. 2A**). Hand pressure was applied to the rest areas for 5 minutes until the impression material set. After setting, excess fin-like impression material around the framework was trimmed using scissors. Scan powder was sprayed again, and the framework was scanned again using the tabletop scanner. The entire surface of each RPD framework—including both internal and external aspects—was scanned. This comprehensive dataset enabled precise superimposition with the corresponding cast and allowed for accurate measurement of the gap distance. By analyzing the full framework structure rather than isolated areas, the assessment provided a more comprehensive evaluation of overall fit accuracy. Thus, STL files representing both the framework structure and the gap distance—recorded as the VPS thickness—between the rest area of the framework and the abutment's rest seat were obtained for both the conventional (CF+D) and IOS (IF+D) groups.

6. Measurement and Analysis of Framework Gap distance

Data were analyzed using a metrology software (GOM Inspect 2018, Carl Zeiss GOM Metrology GmbH, Braunschweig, Germany). CF+D and CF were superimposed using the best-fit alignment to measure the gap distance between the rest and rest seat (**Fig. 2B**). The entire rest area (Zone C+P) was divided into eight segments to measure the central (Zone C) and peripheral (Zone P) regions separately (**Fig. 2C**). The minimum, mean, and maximum gap distances between the rest and rest seat were measured for each selected area. The same method was used to compare IF+D with IF. Based on the obtained measurements, the most clinically appropriate framework was selected for tooth arrangement and RPD fabrication.

7. Statistical Methods and Data Analysis

The primary evaluation criterion was the mean thickness of the VPS impression material in different areas. A VPS thickness ≤ 50 μm was defined as contact.[17] Statistical analysis was performed using SPSS (version 27; IBM). Paired t-tests were used if dependent variables followed a normal distribution in the Kolmogorov–Smirnov test at a significance level of $\alpha = 0.05$, and the Wilcoxon signed-rank test was used for non-normally distributed variables. The significance level was set at $\alpha = 0.05$ for all analyses. Independent t-tests were used to compare the gap distance in different areas, and repeated-measures two-way analysis of variance (ANOVA) was used to evaluate the interaction between the framework fabrication method and the location of the abutment teeth.

Figure 1. Flowchart of the experimental procedures (CON and IOS groups)

CON, conventional impression method; IOS, intraoral scanning method.

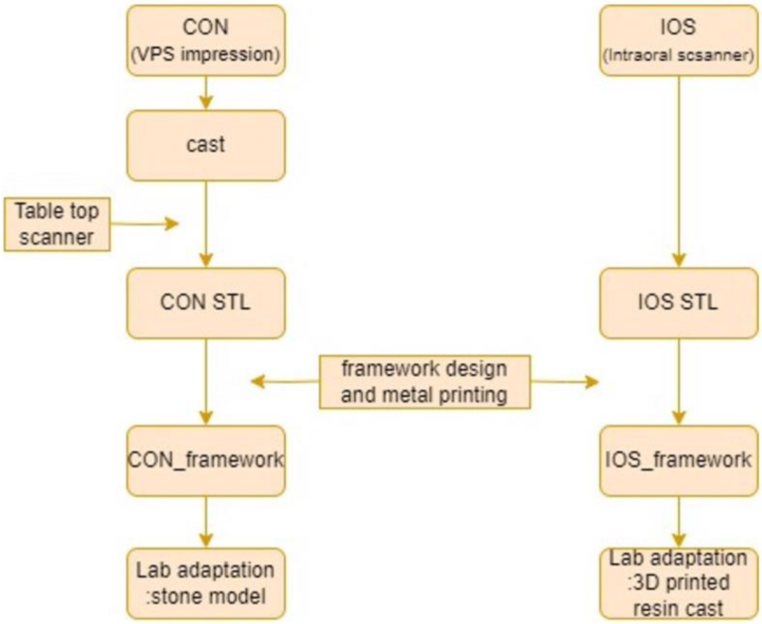
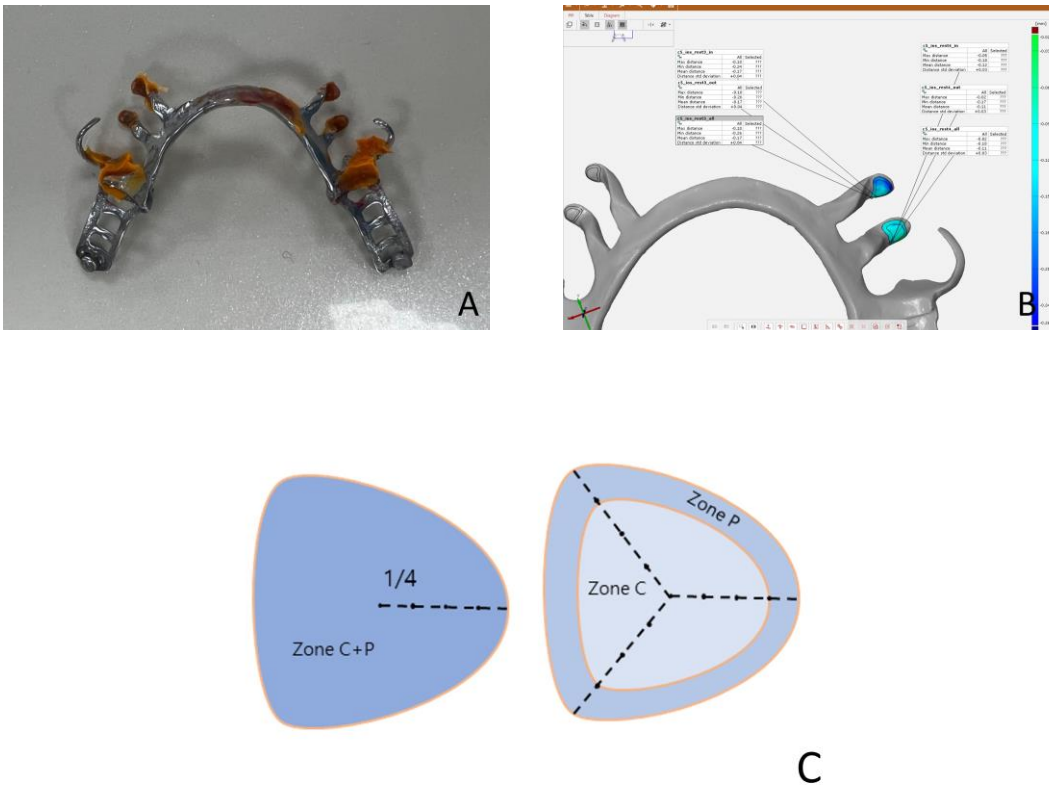


Figure 2. **Quantitative evaluation of frameworks by measuring gap distance**



(A) Rests with vinyl polysiloxane. (B) Measurement of gap distance using metrology software. (C) Diagram showing division of central and peripheral areas of rest.

Table 1. Step-by-step process for creating frameworks (CON and IOS groups)

	Conventional method	Intra-oral scanning method
Impression	PVS impression material (Aquasil XLV, Dentsply Sirona Charlotte, NC, USA)	Intraoral scanning (Trios3, 3Shape, Copenhagen, Denmark)
Cast	Stone pouring Die (Stone Extreme, DK Munkyo, Gyeongsangnam-do, Republic of Korea)	3D resin printing (Photopolymer resin, Sindoh, Seoul, Republic of Korea)
STL files for fabrication of framework	Table-top scanning of the stone cast (E3, 3Shape, Copenhagen, Denmark)	Intraoral scanning 3D STL file
Framework design & metal printing	Designing on software (Dental system, 3Shape Copenhagen, Denmark) and SLM metal printing (Mediloy S-Cp, BEGO GmbH, Bremen, Germany & Co. KG, Dual 150, Riton, Guangzhou, China)	
Laboratory adaptation	On the stone cast	On the 3D printed resin cast
Quantitative assessment using 3D scanning	Tabletop scanner (Freedom UHD, DOF, Seongnam, Gyeonggi-do, Republic of Korea) Scan powder (Scan spray, VITA, Bad Säckingen, Germany)	
Measurement & Analysis	Metrology software (GOM Inspect 2018, Carl Zeiss GOM Metrology GmbH, Braunschweig, Germany)	

III. RESULTS

This study comprised 15 dental arches from 13 patients (8 males and 5 females) aged between 66 and 89 years. The sample included six maxillary and nine mandibular removable partial dentures (RPDs), categorized as 13 Kennedy Class I, one Kennedy Class II, and three Kennedy Class IV edentulous arches. A total of 54 rests were analyzed, consisting of 40 occlusal rests and 14 cingulum rests. (**Table 2 and 3**).

The qualitative evaluation of all frameworks was satisfactory. All rests were adequately seated in the rest seats with no visible gap, and retention and stability were satisfactory. Thus, quantitative evaluation was performed for all frameworks. In this study, contact rate was defined as the proportion of rests that exhibited a gap distance of 50 μm or less between the rest and the rest seat, relative to the total number of rests. In the CON group, among the 54 rests, 20 (37%) were in contact. The number of contacts was greater in Zone P (37%) than in Zone C (19%). By contrast, the IOS group showed 31 (57%) rests in contact. The number of contacts was greater in Zone P (54%) than in Zone C (37%) (**Table 4).**

The average of mean gap distances (MEAN) in the total area (Zone C+P) of the 54 rests was 239±83 μm in the CON group and 201±78 μm in the IOS group (p = .015), indicating that IOS-based fabrication offers enhanced fit accuracy compared to conventional impressions. Nevertheless, both groups remained within clinically acceptable ranges.[18,19] An independent t-test showed no significant difference in MEAN between Zone C and Zone P. However, when comparing average of minimum values (MIN) and average of maximum values (MAX), the IOS group demonstrated a more uniform and consistently smaller gap distance. Although the difference in MIN for Zone P did not reach statistical significance (p = 0.056), the IOS method still showed a favorable trend. A significant difference was found in the MIN between Zone C and Zone P (p = 0.002), with Zone C exhibiting a larger discrepancy. In contrast, there were no significant differences in the MAX (p = 0.578), suggesting similar peak discrepancies in both regions. These findings suggest that while average and maximum values are comparable between central and peripheral areas, the peripheral zone (Zone P) is more prone to minimal adaptation errors (**Table 5**).

An interaction analysis was conducted to evaluate the effect of the impression method in relation to arch type (maxilla vs. mandible), tooth position (anterior, premolar, and molar), terminal tooth position (terminal abutments of distal extension RPD vs. other abutments) and abutment design (surveyed crown vs. tooth preparation). The analysis covered three zones—Zone C+P, Zone C, and Zone P—in terms of MIN, MEAN, and MAX gap distance values. The results indicate that the interaction between the impression method and arch type did not show statistical significance across all zones (p > 0.05). Similarly, no significant differences in gap distance were observed in relation to tooth position and in relation to abutment design. However, a significant interaction was found between the impression method and terminal tooth position in specific zones. In Zone C+P, the MEAN reached statistical significance (p = 0.05), suggesting that the impression method influences gap distance in this area. In Zone C, both MEAN (p = 0.030) and MIN (p = 0.039) values were significant, indicating a notable impact of the impression method. Additionally, in Zone P, the MEAN value also reached significance (p = 0.044). These findings suggest that the impression method significantly affects gap distance, particularly at the terminal abutments of distal extension RPDs, where statistically significant differences were observed (**Table 6**).

A one-way ANOVA was conducted to evaluate gap distances according to the impression method for each dental arch. The analysis revealed no significant differences in the maxilla. However, for the mandible, the intraoral scanning (IOS) group exhibited a significantly lower mean gap distance compared to the conventional (CON) group (p = 0.007). This finding suggests that the IOS method may result in improved fit accuracy of the final restoration in the mandibular arch compared to conventional impression techniques (**Fig. 3A, Table 7**).

The one-way ANOVA analysis further evaluated the effect of the impression method on gap distance across different tooth positions. The results showed that there was no statistically significant difference between the impression methods in the anterior and molar regions, indicating that both methods provide comparable gap distance in these areas. This suggests that IOS may serve as a reliable alternative to the conventional method for these tooth positions without compromising fit accuracy. However, a significant difference was observed in the premolar region, where the intra-oral scanning method demonstrated smaller gap distance. This finding suggests that digital scanning may be particularly beneficial in this area, potentially leading to better fit accuracy of restorations and improved clinical outcomes. The premolar region may be more prone to distortions in conventional impressions due to its anatomical characteristics, which could explain the observed difference in gap distance. Figure 3B illustrates these findings, emphasizing the premolar region as the only area with a significant difference between methods. The presence of statistical significance in this region further supports the idea that the choice of impression method can impact gap distance, particularly in specific zones of the dental arch. In summary, while the impression method does not appear to influence gap distance in anterior and molar teeth, intra-oral scanning offers a clear advantage in the premolar region (**Fig. 3B, Table 8**).

The interaction between the impression method and terminal tooth position (terminal abutments of distal-extension RPDs and others) was significant. The IOS method yielded significantly lower MEAN for the terminal abutments in distal-extension RPDs (**Fig. 3C)**. Regarding the gap distance between the rests and rest seats in Zones C and P, significant differences were observed between the terminal abutments in distal-extension RPDs and other abutments. The IOS group showed lower MEANs in all zones (Zones C+P, C, and P) for the terminal abutments of distal-extension RPDs, indicating better fit accuracy. For non-terminal abutments, the IOS group exhibited lower MEANs in all zones compared to the CON group. Regarding the interaction between the impression method and terminal tooth position showed significant differences between the groups ($p < 0.05$), particularly for the mean values in Zone C and P. This suggests that the IOS method tends to achieve smaller gap distance than the conventional method at the terminal abutments of distal-extension RPDs (**Table 9**).

A one-way ANOVA was conducted to evaluate the effect of impression method on gap distance according to abutment design. In the surveyed crown group, the intraoral scanning (IOS) method resulted in a significantly lower mean gap distance compared to the conventional (CON) method ($p = 0.012$), indicating improved fit accuracy when IOS is used for surveyed crowns. In contrast, no significant difference was observed between the two methods in the natural tooth group (all $p > 0.05$) (**Fig. 3D, Table 10**).

The findings of this study suggest that IOS frameworks generally provide superior fit accuracy compared to conventional impression-based frameworks. In particular, the IOS method resulted in significantly reduced gap distances in the mandible, premolar region, terminal abutment teeth and surveyed crown. These results indicate that the IOS method may be advantageous for the fabrication of removable partial dentures (RPDs) and support the expanded clinical application of digital technologies in prosthodontics.

Table 2. Clinical profile summary of cases included in study

Case number	Age	Sex	Kennedy class (Mod)	Arch	Rest position	Occlusal rest	Cingulum rest	Residual teeth
1	80	F	IV (0)	U	18m, 16m, 26m, 27d	2	2	18, 17, 16, 26, 27
2	67	M	I (0)	U	14m, 13c, 23c, 24m	2	2	14, 13, 12, 11, 21, 22, 23, 24
3	66	M	I (1)	L	45m, 44m, 34m, 35m	4	0	45, 44, 34, 35
4	85	M	I (0)	L	45m, 43c, 33c, 34m	2	2	45, 44, 43, 42, 41, 31, 32, 33, 34
5	89	F	I (0)	L	45m, 44m, 34m, 35m	4	0	45, 44, 43, 42, 41, 31, 32, 33, 34, 35
6	81	F	I (1)	U	16d, 14m, 11c, 24m, 26d	4	1	16, 15, 14, 11, 21, 22, 23, 24, 25, 26
7	66	M	I (1)	L	46m, 44m, 34m, 36m	4	0	46, 45, 44, 34, 35, 36
8	89	F	I (0)	U	13c, 23c, 24m,	2	2	13, 12, 11, 21, 22, 23, 24
9	89	F	I (0)	L	44m, 43c, 33c, 34m	1	2	45, 44, 43, 42, 41, 31, 32, 33, 34
10	66	M	I (1)	L	44m, 33c, 34m	2	1	44, 43, 34
11	72	F	II (0)	U	14m, 24m, 26d	3	0	14, 13, 12, 11, 21, 22, 23, 24, 25, 26
12	72	F	I (0)	L	45m, 44m, 34m, 35m	4	0	45, 44, 43, 42, 41, 31, 32, 33, 34, 35
13	73	M	I (1)	L	46m, 44m, 33c, 34m	2	1	46, 45, 44, 33, 34
14	73	M	I (1)	U	14m, 13c, 11c, 25d	2	2	14, 13, 12, 11, 23, 24, 25
15	67	M	I (1)	L	44m, 42c, 33c, 34m	2	2	44, 43, 32, 33, 34

F, female; M, male; U, upper jaw; L, lower jaw; m, mesial; d, distal;

Table 3. Extended summary of clinical characteristics and prosthodontic parameters in study population

Sex		
Male, n (%)	8 (62)	
Female, n (%)	5 (38)	
Average age, years	75.7	
Kennedy classification		
	Arch, n (%)	Rest, n (%)
I	13 (88)	47 (87)
II	1 (6)	3 (6)
III	0 (0)	0 (0)
IV	1 (6)	4 (7)
Arch		
	Arch, n (%)	Rest, n (%)
Maxilla	6 (33)	23 (43)
Mandible	9 (67)	31 (57)
Rest type		
Cingulum rest, n (%)	14 (26)	
Occlusal rest, n (%)	40 (74)	
Abutment design		
Surveyed crown, n (%)	45 (83)	
Natural teeth preparation, n (%)	9 (17)	
Tooth position		
Anterior, n (%)	14 (26)	
Premolar, n (%)	30 (56)	
Molar, n (%)	10 (18)	
Terminal tooth position		
Terminal abutment of distal-extension RPD, n (%)	26 (48)	
Others, n (%)	28 (52)	

Table 4. Comparison of rest contact rates across zones in CON and IOS Groups

n (%)	zone C+P	zone P	zone C
CON group	20 (37)	20 (37)	10 (19)
IOS group	31 (57)	30 (54)	2 0(37)

CON, conventional method; IOS, intraoral scanning method; Zone C, zone near the occlusal center; Zone P, zone near rest periphery; Zone C+P, zone of the entire rest, sum of zones C and P

Table 5. Comparison of gap distance between impression methods (CON vs. IOS) in different zones

	Group		CON	IOS	*p* value*
Gap distance measurements (Mean±SD : μm)	Zone C+P	MIN	81±59	60±48	0.043
		MEAN	239±83	201±78	0.015
		MAX	409±136	346±124	0.009
	Zone C	MIN	129±80	99±73	0.04
		MEAN	251±88	209±87	0.018
		MAX	402±139	341±117	0.015
	Zone P	MIN	84±60	64±50	0.056
		MEAN	234±182	197±73	0.015
		MAX	387±138	325±120	0.02
	p between**	MIN	0.002	0.002	
		MEAN	0.327	0.426	
		MAX	0.578	0.491	

* Paired t test; ** Independent t test between zones C &P; CON, conventional method; IOS, intra-oral scanning method; MIN, average of minimum values; MEAN, average of mean values; MAX, average of maximum values; Zone C, zone near the occlusal center; Zone P, zone near the peripheral of the rest; Zone C+P, zone of the entire rest, sum of the zone C and P

Table 6. Interaction effects of impression method with arch type, tooth position, and terminal tooth position on gap distance in different zones

p value*		Impression method *Arch type	Impression method *Tooth position	Impression method * Terminal tooth position	Impression method * Abutment design
Zone C+P	MIN	0.64	0.231	0.072	0.855
	MEAN	0.187	0.441	0.05	0.431
	MAX	0.15	0.706	0.133	0.175
Zone C	MIN	0.193	0.161	0.039	0.317
	MEAN	0.136	0.366	0.03	0.383
	MAX	0.33	0.799	0.195	0.741
Zone P	MIN	0.599	0.281	0.095	0.827
	MEAN	0.203	0.481	0.044	0.436
	MAX	0.106	0.715	0.096	0.107

*Two-way repeated measured ANOVA; CON, conventional method; IOS, intra-oral scanning method; MIN, average of minimum values; MEAN, average of mean values; MAX, average of maximum values; Zone C, zone near the occlusal center; Zone P, zone near the peripheral of the rest; Zone C+P, zone of the entire rest, sum of the zone C and P; arch type(maxilla and mandible), tooth position (anterior, premolar and molar), and terminal tooth position(terminal abutments of distal extension RPD and, other abutments); abutment design(surveyed crown and tooth preparation)

Table 7. Comparison of mean gap distance between impression methods (CON vs. IOS) according to dental arch type (maxilla vs. mandible)

		N	Mean±SD (μm)	F	*p* value *
Maxilla	CON	23	227±70	0.405	0.527
	IOS	23	212±96		
Mandible	CON	31	248±92	7.777	0.007
	IOS	31	191±60		

Mean gap distance values of zone C+P are presented as mean ± SD; *One-way ANOVA; CON, conventional method; IOS, intra-oral scanning method

Table 8. Comparison of mean gap distance between impression methods (CON vs. IOS) according to tooth position (anterior, premolar, molar)

		N	Mean ±SD (μm)	F	*p* value *
A	CON	14	245±73	0.324	0.571
	IOS	14	227±72		
PM	CON	30	233±78	7.420	0.009
	IOS	30	177±69		
M	CON	10	246±115	0.177	0.675
	IOS	10	231±95		

Mean gap distance values of zone C+P are presented as mean ± SD; *One-way ANOVA; CON, conventional method; IOS, intra-oral scanning method; A, anterior teeth; PM, premolar teeth; M, molar teeth

Table 9. Comparison of mean gap distances (Zone C, P, and C+P) between impression methods (CON vs. IOS) by terminal tooth position

	Group	N	Mean ±SD (μm)		
			Zone C+P	Zone C	Zone P
Terminal abutment of distal-extension RPD	CON	26	240 ± 96	256 ± 106	237 ± 95
	IOS	26	171 ± 68	177 ± 75	169 ± 63
Others	CON	28	238 ± 71	246 ± 70	232 ± 70
	IOS	28	228 ± 78	240 ± 89	224 ± 73

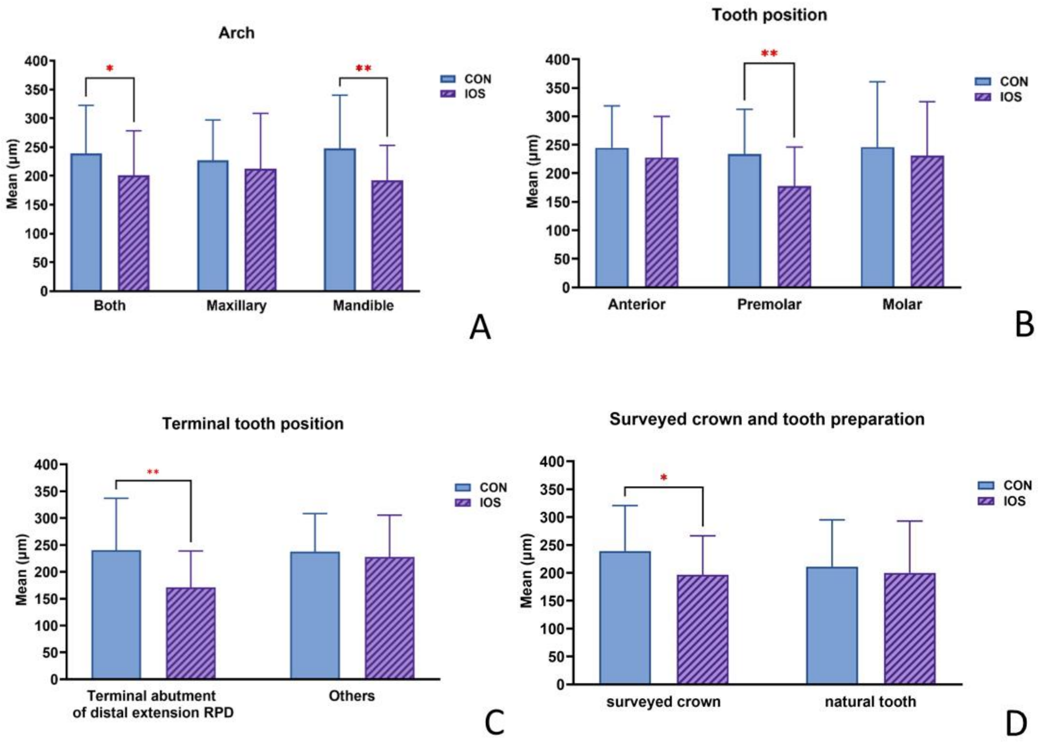
Mean gap distance values are presented as mean ± SD; CON, conventional method; IOS, intraoral scanning method; Zone C, zone near the occlusal center; Zone P, zone near rest periphery; Zone C + P, zone of entire rest; sum of zones C and P

Table 10. Comparison of mean gap distances (Zone C, P, and C+P) between impression methods (CON vs. IOS) by surveyed crown and tooth preparation

	Group	N	Mean ±SD (μm)		
			Zone C+P	Zone C	Zone P
Surveyed crown	CON	45	244 ± 83	256 ± 106	239 ± 95
	IOS	45	200 ± 74	208 ± 84	196 ± 70
Tooth preparation	CON	9	214 ± 84	224 ± 106	211 ± 83
	IOS	9	203 ± 99	217 ± 106	224 ± 93

Mean gap distance values are presented as mean ± SD; CON, conventional method; IOS, intraoral scanning method; Zone C, zone near the occlusal center; Zone P, zone near rest periphery; Zone C + P, zone of entire rest; sum of zones C and P

Figure 3. **Gap distance under specific conditions (arch type, tooth position, and terminal tooth position).**



(A) Arch (maxilla and mandible); (B) Tooth position (anterior, premolar, and molar); (C) Terminal tooth position (terminal abutments of distal-extension RPD and other abutments); (D) Surveyed crown and tooth preparation. Comparisons among groups are expressed as *p <0.05, **p <0.001, asterisks and horizontal bars indicate statistically significant differences between groups.

IV. DISCUSSION

Although digital dentistry is widely adopted, its application to RPDs remains limited. Although some studies have qualitatively compared the fit accuracy of digitally fabricated RPD frameworks, quantitative clinical evaluations remain scarce. To the best of current knowledge, no previous clinical study has evaluated IOS-fabricated frameworks using a similar methodology.[7,20,21] This study used IOS data to fabricate frameworks that were clinically evaluated. In patients with limited mouth opening or severe gag reflex, conventional impression methods are not feasible; however, IOS can be applied. This study clinically evaluated RPD frameworks fabricated using IOS and conventional methods, and found that both produced clinically acceptable fits, with IOS demonstrating a statistically significant advantage.

To quantitatively evaluate the fit, a VPS impression material was applied between the framework and the tooth, and its thickness was measured using a CAD program. Stern et al. and Dunham et al. proposed methods to evaluate the gap distance of RPD frameworks by applying a VPS impression material and measuring its thickness.[17,22] Recently, quantitative evaluations have been performed using metrology software. Few studies have used best-fit measurements, whereas others have measured vertically using Geomagic Control X.[12,23] While in vitro studies allow silicone to remain on the cast for thickness measurements, clinical applications require removal of the material with the framework. In this study, the thickness of the silicone was measured by overlapping the STL files of the framework alone with those of the silicone-covered framework. While previous studies primarily measured silicone thickness microscopically, the present investigation employed a CAD program for this purpose.

First, the qualitative evaluation of this study confirmed that all frameworks had an adequate fit, aligning with previous findings in the literature.[15] In the quantitative evaluation, the mean gap distance of the IOS group (201±78 µm) was significantly smaller than that of the CON group (239±83 µm, p = 0.015). Compared to previous studies, the gap distance values observed in this study showed both similarities and differences. The mean gap distance of the IOS group (201±78 µm) was greater than the 150±13 µm reported by Soltanzadeh et al. and the 174 ±117 µm reported by Ye et al.[10,12] However, it was lower than the 327 µm median gap distance reported by Muehlemann et al.[24] Additionally, the contact rate of the IOS group (57%) was greater than the 42.5% observed in Ye et al.'s study, while the conventional group (37%) showed a similar value.[10] In a clinical study evaluating RPD frameworks, Tregerman et al. found that the digital method (IOS + SLM 3D printing) provided significantly smaller gap distance than the conventional method.[2] These findings indicate that while digital impressions generally reduce gap distance, differences in study methodologies, fabrication techniques, and evaluation criteria may contribute to variations across studies. Furthermore, the results of this study support the notion that digital impressions can enhance consistency by enabling more precise data acquisition and streamlining the manufacturing process.

According to Almufleh et al., patient satisfaction with frameworks fabricated using SLM was higher than that with frameworks fabricated using conventional methods.[1] Additive manufacturing offers advantages such as reduced time and cost, as well as excellent biocompatibility. In this study, metal frameworks were fabricated using SLM in both groups. However, in the IOS group, the framework was applied to a 3D-printed resin cast, whereas in the CON group, the framework was applied to a stone cast. Because stone casts are relatively more rigid than resin-printed casts, more adjustments might have been made to the frameworks fitted to stone casts. Furthermore, in the conventional impression method, slight movement of teeth with minor mobility can occur during impression taking.

The findings suggest that while the overall gap distance is comparable between Zone C and Zone P, the minimum gap distance is significantly higher in Zone C. This indicates that the peripheral zone provides a more stable and consistent fit, whereas the central zone may be more prone to variations in adaptation. The lack of statistical significance in mean and maximum values suggests that deviations in adaptation are more pronounced in the lower range rather than the overall or extreme values. This may be due to variations in material properties or scanning accuracy, which could influence adaptation in central and peripheral zones. Previous studies also evaluated the entire rests by dividing them into zones. Stern et al. reported better fit accuracy at the marginal ridge, which they attributed to less shrinkage during the casting process in the thicker marginal ridge area.[17] Similarly, Dunham et al. reported that occlusal rests had slightly better contact in the peripheral areas than in the central areas. However, Ye et al. divided rests into areas closer to the occlusal center and the marginal ridge instead of central and peripheral zones and found no significant differences between zones using one-way ANOVA.[22] This study found differences only in the minimum values between the central and peripheral zones, with no significant differences in the mean or maximum values.

Notably, the IOS group demonstrated significantly smaller gap distance in the terminal abutments in distal extension RPDs, suggesting that digital impressions can effectively capture complex anatomical structures. Previous in vitro studies have shown that the gap distance of impressions can be compromised in the case of posterior isolated teeth.[25,26] In comparison, this study suggests that the terminal abutment in distal extension RPDs may have the advantage of creating a more accurate framework with IOS method than conventional impression method. This finding may be attributed to the anatomical and biomechanical characteristics of terminal abutments, which often lack adjacent teeth, leading to increased mobility. During conventional impression procedures, if the impression tray's stop is positioned near the terminal abutment, any tooth movement induced by pressure may hinder the accurate capture of its anatomical form. As a result, achieving precise reproduction of the terminal abutment area can be more challenging with conventional methods compared to intraoral scanning.

In this study, intraoral scanning achieved high accuracy in capturing the surface details of surveyed crowns, which are often challenging to digitize due to their complex morphology, undercuts, and metallic surfaces. The findings showed significantly smaller gap distances in the IOS group, suggesting that digital impressions were not compromised despite the high proportion of metallic surveyed crowns. This may be attributed to the use of scan powder, which mitigated surface reflection and enhanced scan precision. [27] These results support the reliable use of IOS for surveyed metallic abutments in clinical practice.

Although no tissue impingement was observed when fitting any framework, a quantitative evaluation of the tissue surfaces was not performed, which is a limitation of this study. Chen et al. reported that the accuracy of scanning soft-tissue areas is crucial for further digital processes.[28] However, a secondary impression is often necessary for RPDs, and the fit of the rest areas of the framework is relatively important; therefore, this study quantitatively evaluated rest areas.

This study evaluated data acquired immediately after the frameworks were fabricated and fitted. However, changes in the frameworks may occur during fabrication of the resin base, necessitating an evaluation of the gap distance at that stage. Furthermore, long-term evaluation of the framework gap distance after extended use in the oral cavity is necessary. Post-processing is crucial to prevent framework deformation; thus, evaluating potential changes under intraoral conditions is warranted. Overall, SLM-printed frameworks fabricated using either IOS data or conventional VPS impressions achieved clinically acceptable gap distance. However, further research is needed on the application of digital technology to the subsequent stages of RPD treatment, such as denture base impression methods, software to simulate mucosal displacement under pressure, and methods for recording interocclusal relationships in patients with insufficient posterior occlusal support.[29]

V. CONCLUSION

Clinically acceptable fit accuracy in removable partial denture (RPD) frameworks can be achieved using both intraoral scanning (IOS) and conventional impression techniques followed by selective laser melting (SLM). However, RPD frameworks fabricated based on intraoral scanning data demonstrate significantly superior fit accuracy, as evidenced by smaller gap distances, compared to those produced from conventional impressions. Notably, the IOS approach yields significantly more favorable fit accuracy for terminal abutments in distal-extension RPDs.

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Abstract in Korean

전통적 인상법과 디지털 인상법을 이용하여 제작한 가철성 국소 의치 금속구조물의 적합도 비교 임상 연구

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윤 명 아

가철성 국소 의치(Removable Partial Denture, RPD)는 부분 무치악 환자의 저작 기능과 심미성 회복에 중요한 역할을 하며, 그 핵심은 정확한 적합도를 갖춘 금속구조물에 있다. 전통적인 인상법은 오랜 기간 동안 임상적으로 널리 사용되어왔으며, 신뢰성과 안정성을 인정받아왔다. 다만, 디지털 기술의 발전에 따라 구강내 스캐너를 이용한 디지털 인상법(Intraoral Scanning, IOS)과 선택적 레이저 용융(Selective Laser Melting, SLM)을 통한 금속 3D 출력이 도입되면서, 보다 효율적이고 정밀한 대안으로 주목받고 있다. 그러나 전통적 인상법과 IOS를 통한 금속구조물 제작 방식 간 내면 적합도를 직접 임상적으로 비교한 연구는 아직 제한적이다.

본 연구는 IOS를 이용한 디지털 인상법이 전통적 인상법에 비해 가철성 국소 의치 금속구조물의 내면 적합도에서 어느 정도의 임상적 타당성과 우수성을 가질 수 있는지를 평가하고자 하였다. 연구에는 총 13명의 환자(15 악궁)가 참여하였으며, 각 악궁에 대해 동일한 설계로 두 개의 금속구조물(전통 인상법 그룹: CON, 디지털 인상법 그룹: IOS)을 제작하였다. 모든 금속구조물은 Co-Cr 합금을 사용하여 SLM 방식으로 제작되었고, 각각

석고 모형(CON 그룹) 또는 3D 프린팅 수지 모형(IOS 그룹)에 사전 적합 후 임상 평가를 진행하였다. 정성적 평가는 육안 관찰과 플러거를 이용한 압력 검사로 수행되었으며, 정량적 평가는 VPS 인상재를 금속구조물과 지대치 사이에 도포한 후 디지털 스캐닝과 CAD 기반 중첩분석을 통해 레스트와 레스트 시트 사이 간극을 중앙부(zone C), 주변부(zone P)와 전체 영역(zone C+P)에서 측정하였다. 통계 분석은 대응표본 t-검정, 독립 t-검정과 반복측정 이원분산분석을 통해 진행하였다. 연구 결과, 모든 금속구조물은 정성적 평가 기준을 충족하였으며, 두 방법 모두 임상적으로 허용 가능한 내면 적합도를 보였다. 그러나 정량적 평가에서는 IOS 그룹이 전반적으로 더 작은 간극을 보여주었다. 전체 영역(zone C+P)에서 IOS 그룹의 평균 간극은 201±78 μm 로, CON 그룹(239±83 μm)보다 유의하게 작았다(p = 0.015). 특히 후방연장형 국소 의치의 최후방 지대치 부위에서는 IOS 금속구조물이 더욱 뛰어난 적합도를 보였다(p <0.05). 또한, 하악과 소구치 부위에서도 IOS 방식의 우수성이 관찰되었다. IOS 그룹은 최소 간극(MIN)과 최대 간극(MAX)에서도 보다 일관되고 안정적인 결과를 보였으며, 주변부(zone P)에서 중심부(zone C)보다 상대적으로 더 나은 적합도를 보였다. 이는 디지털 인상이 복잡한 해부학적 구조를 정밀하게 재현할 수 있음을 시사한다. 전반적으로 전통적 인상법 또한 충분히 임상적 기준을 충족시키는 신뢰할 수 있는 방법임을 확인할 수 있었으며, IOS 는 이에 상응하거나 특정 조건에서는 더욱 우수한 대안이 될 수 있음을 입증하였다.

결론적으로, 본 연구는 디지털 인상법과 SLM 제작 방식을 이용한 가철성 국소 의치 금속구조물이 전통적 인상법을 통한 금속구조물에 비해 우수한 내면 적합도를 보일 수 있으며, 특히 후방연장 국소 의치의 최후방 지대치 등 임상적으로 중요한 부위에서 더욱 뛰어난 결과를 제공할 수 있음을 보여주었다. 이는 디지털 기술이 전통적 방법을 보완하거나 대체할 수 있는 임상적 가능성을 뒷받침하며, 향후 디지털 의치 제작의 확대 적용을 위한 근거를 마련하였다.

핵심이 되는 말: 내면 적합도, 가철성 국소 의치 금속 구조물, 3 차원 금속 출력 (SLM), 디지털 중첩, 구강 스캔