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Influence of Data Acquisition Techniques on the Retention of Removable Partial Denture Frameworks: An In Vitro Study

Ahmed Hussien Ahmed Hussien, Yasmine Said El-Sherbeeny Elsayed, Sawsan Maged Fadl Aly

Oral and Maxillofacial Prosthodontics Department, Faculty of Dentistry, Ain Shams University, Cairo, Egypt.

Abstract

To evaluate and compare retention of removable partial denture frameworks (RPD) manufactured via different data acquisition techniques; conventional impression, intraoral and extraoral scanning techniques. A partially edentulous maxillary resin model representing a Kennedy class III modification 1 with the first premolars and second molars bilaterally as abutments was three dimensionally (3D) printed. Upon which RPD frameworks were manufactured via three data acquisition approaches, hence three groups were identified: Group A (conventional impression with the traditional lost-wax technique); Group B (intraoral digital impression combined with 3D-printed wax patterns and the lost-wax technique); and Group C (extraoral digital scanning of physical casts combined with 3D-printed wax patterns and the lost-wax technique). Retention was subsequently evaluated using a universal testing machine. Intergroup comparison was done using one-way ANOVA followed by Tukey's test. Normality and homogeneity of variance were examined using the Shapiro-Wilk and Levene's tests, respectively. Intergroup comparison revealed a significant difference between different groups ($P < .001$), and the effect size was large (0.96). The highest retention was observed in the group C (27.67±0.94 N), followed by the Conventional group A (23.08±0.53 N), and the lowest in the Intraoral group B (17.90±1.11 N). All post hoc pairwise comparisons were statistically significant. Extraoral digital impression technique provided the highest initial retention followed by the conventional impression. However, the intraoral scanners provided the lowest initial retention. All groups provided clinically acceptable results.

Keywords: RPD framework, data acquisition, Intraoral scanner, Extraoral scanner, Retention.

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1. Introduction

Removable partial dentures (RPDs) remain an important treatment option for partially edentulous patients [1]. Traditionally, RPD frameworks have been fabricated using conventional impression techniques to produce physical models with the manual skills of dental technicians. Nowadays, Digital optical impressions are frequently used since they offer a lot of advantages such as elimination of common errors associated with material shrinkage, voids, and deformation during impression-taking or cast pouring, which results in a more predictable fit and retention [2]. Success of the RPD workflow and resulting prosthesis also relies heavily on selecting a material capable of replicating fine details while enduring intraoral forces. Cobalt-chromium (Co-Cr) alloys are widely utilized for RPD frameworks since they possess superior mechanical properties and biocompatibility [3]. The digital workflow for RPDs fabrication has modernized traditional techniques by offering a fully virtual pathway from diagnosis to final prosthesis delivery [4]. Digital scanning results in improved repeatability, standardization and objective quality control because standard tessellation language (STL) files enable replication [5]. It also results in enhanced design flexibility and digital communication besides, better patient experience and shorter chair time for impression stage with direct intraoral scanning [3]. Moreover, digital workflow results in clinically acceptable and often superior fit of digitally produced frameworks as multiple systematic reviews and meta-analyses reports a part from allowing the integration of modern manufacturing and material options [6-7].

Intraoral scanners (IOSs) capture the dentition, soft tissues, and edentulous spaces, producing a detailed three-dimensional (3D) digital model typically saved in STL format [8]. When intraoral scanning is not feasible due to extensive edentulous areas or patient limitations, a traditional impression can be made and scanned using a laboratory desktop scanner [9]. Extraoral scanners eliminate several clinical challenges associated with IOSs, including restricted intraoral access, limited mouth opening, and presence of saliva and blood [10]. Moreover, it was reported that the difference in mucosal compressibility in distinct areas intraorally results in better adaptation of the major connectors in the harder areas (mid palatine area) scanned with IOS, while the fitting of the major connectors in the areas with higher compressibility (palatal vaults and rugae areas) captured with extraoral scanners was better due to the pressure applied on these areas during the conventional impression step. Nonetheless, extraoral scanning does not fulfill the aim of complete digitalization because of the need to start with a conventional impression [11]. Despite the evolution of digital data acquisition techniques, they still possess limitations such as the dependence of extraoral scanners on the quality and positioning of the physical model, inaccuracies when interacting with reflective, translucent, or highly textured surfaces [4].

For intraoral scanners, mobile tissues displacement during acquisition can lead to registration errors of the surface and moist tissues can lead to the pooling of saliva and can affect the reflection on surfaces, resulting in distorted or incomplete data during scanning [12]. Retention of removable partial denture (RPD) frameworks is critical to ensure the comfort of the patient, prevention of tissue atrophy and irritation and proper natural and denture teeth functioning through ensuring that the denture remains securely in place during functional movements. Moreover, retention contributes to the even distribution of occlusal forces, thereby enhancing the longevity of both the prosthesis and the natural dentition. Retention of RPDs is evaluated by various methods including the utilization of a digital force gauge device attached to the geometrical center of the RPD and the use of the Universal testing machine. This method allows accurate control of test variables, such as direction, velocity, and magnitude of the applied force, providing reproducible and standardized data [13]. Hence, this study was conducted to evaluate and compare the retention of RPD frameworks fabricated using different data acquisition modalities. This could enable clinicians and technicians the opportunity to determine which option for RPD fabrication digital or conventional may conduct the best outcome. The null hypothesis was that there will be no significant difference in retention of constructed maxillary Kennedy Class III modification 1 RPD frameworks fabricated using different data acquisition techniques.

2. Materials and Methods

This in-vitro study was conducted on a 3D printed partially edentulous maxillary resin model representing a Kennedy class III modification 1 with the first premolars and second molars as terminal abutments bilaterally. A power analysis was conducted to ensure sufficient power to detect a significant difference in retention among the tested groups. Using an alpha (α) level of (0.05), a beta (β) level of (0.2) corresponding to (80%) statistical power and effect size (Cohen's f) of (4.06) derived from the results of a previous study [14]; the minimum total required sample size (n) was found to be (6) samples (2 per group). The sample size was increased to 30 samples (10 per group) to account for potential variability and improve the robustness of statistical testing. The sample size was calculated using R statistical analysis software version 4.6.0 for Windows [15].

2.1. Study Procedures

An educational gypsum cast representing Kennedy classIII modification 1 was scanned by a desktop scanner (INEOS X5, Sirona, Bensheim, Germany) and a digital standard tessellation language (STL) file of the model was generated and saved. The STL file was imported into PartialCAD software (Exocad GmbH, Darmstadt, Germany) for cast preparation. Occlusal rest seats preparations were made virtually in the near zones of the terminal abutments bilaterally. Virtual surveying was done and undercuts were located and their depth was determined and the software blocked all unfavorable undercuts. Cast was then 3D printed and considered as reference cast on which assessment of retention of produced frameworks was done on it (Figure 1).

2.2. Study Groups

Three groups were established according to the data acquisition modality into (Group A) ten frameworks were manufactured via conventional Impression techniques, while in (group B) ten frameworks were manufactured via using intraoral scanning technique, as for (group C) ten frameworks were produced by using a desktop scanning technique. For group A, two-step putty-wash impression technique was used with addition silicon impression material (Zhermack elite HD+, Zhermack S.p.A., Badia Polesine, Italy). The putty material was hand mixed according to the manufacturer's instructions, loaded into a stock tray, and seated on the reference model until its complete setting. Light-body addition silicone was subsequently applied on the abutment teeth and adjacent structures, then the putty impression was reseated until complete setting. The impression was poured with type IV dental stone. These steps were repeated for each of the ten impressions of this group to obtain ten master casts. For group B, data were acquired directly from the reference model using an intraoral scanner (Medit i900, Medit Corp, Seoul, South Korea). Prior to scanning, the cast was inspected, cleaned from any debris and placed on a stable non-reflective surface. Scanning was initiated following the manufacturer's recommended protocol, starting from occlusal surfaces and progressing to buccal and lingual aspects. The digital models were visualized to confirm data completeness and additional scans were applied when needed to capture the fine details. The scanned data was processed to obtain a 3D model, which was exported as STL file, which was utilized for 3D printing via masked stereolithography (MSLA) technology to obtain master cast.

These steps were repeated for each of the ten scans of this group to obtain ten master casts. For group C, the produced casts from group A were scanned by a desktop scanner (INEOS X5, Sirona, Bensheim, Germany). The STL file was then imported into the 3D printing machine for subsequent fabrication of the master cast via MSLA as in group B. These steps were repeated for each of the ten stone casts of group A producing ten master casts. Framework design for group A was carried out conventionally. Each cast was surveyed to determine the path of insertion and verify the presence of a 0.1-mm buccal undercut on the abutment teeth. After block-out, refractory casts were produced, and a quadrilateral design of the wax pattern was applied on the refractory cast. Plain denture base wax was applied first then mid palatal strap major connector to join both sides and finally the rests and Aker clasps were applied and carved. This was done to all ten casts of this group. For groups B and

C, virtual casts of both groups were surveyed using digital surveying tool of PartialCAD software (Exocad GmbH, Darmstadt, Germany) for the same purpose. A quadrilateral clasp design was selected for all frameworks, incorporating Aker clasps on abutment teeth, occlusal rests, denture base extensions, and a single mid-palatal strap major connector (Figure 2). The completed framework designs were exported as STL files on the model and were used to 3D print the design into the wax pattern of the frameworks after 3D printing of the master casts of each group and fabrication of their corresponding refractory casts, on which the printed wax patterns were adapted on. Framework fabrication was unified for all groups using the lost-wax casting technique. All wax patterns were sprued, invested with phosphate-bonded investment material, and burned out. then Co-Cr alloy was melted and casted into the mold by an induction casting machine. Following deinvestment, all frameworks were sandblasted, finished, and polished (Figure 3).

2.3. Evaluation of Retention

A Universal testing machine (Lloyd Instruments Ltd, Fareham, Hampshire, United Kingdom) was used to provide standardized measurements of dislodging forces. Each framework of each group was fully seated on the reference model and a custom-made rigid horizontal metal plate with a ring extension was attached occlusally to the framework by auto-polymerizing acrylic resin at the predetermined geometric center to allow vertical dislodgement at a centralized and perpendicular direction. Vertical tensile forces were also applied to the frameworks by the Universal testing machine to mimic the clinical dislodging forces in order to evaluate the retentive performance of the tested frameworks [16-17] (Figure 4). The model, framework and metal plate assembly were secured to the lower custom jig of the Universal testing machine via the resin vertical extension attached to the base of the model. The framework was connected to the upper grip of the machine by a hook that engaged the metal ring on the plate (Figure 5). The crosshead speed of the machine was set at 5 mm/min. Adequate seating of the framework was ensured by applying a compressive pre-weight of 50 N was applied for 20 seconds. The initial pull-off test was applied and the maximum tensile load that dislodged the framework from the model was recorded in newtons. Three measurements were recorded for each sample and their mean was calculated to provide the retentive value.

2.4. Statistical Analysis

Retention data were presented as means with 95% confidence intervals (CIs), standard deviations (SDs), and minimum (min.) and maximum (max.) values. They were examined for normality and homogeneity of variance using the Shapiro-Wilk and Levene's tests, respectively. Data were normally distributed with homogeneous variances. Across groups comparison of retention of RPD frameworks acquired via conventional impression, intraoral digital scanning and extraoral digital scanning was done using one-way ANOVA followed by Tukey's test. The significance level was set at $P < 0.05$. Statistical analysis was performed with R statistical analysis software version 4.6.0 for Windows (R Core Team (2026). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

3. Results and discussions

3.1. Results

As shown in Table 1, the retention in each group measured in Newton (N). For group A, the mean was 23.08 (95% CI: 22.75 to 23.41 N), the standard deviation was 0.53 N, for group B, the mean was 17.90 (95% CI: 17.22 to 18.59 N), the standard deviation was 1.11 N and for group C, the mean was 27.67 (95% CI: 27.09 to 28.26 N), the standard deviation was 0.94 N. The minimum was 22.10 N, and the maximum was 23.77 N, the minimum was 15.27 N, and the maximum was 19.44 N. the minimum was 25.99 N, and the maximum was 29.46 N. Respectively. As shown in Table 2, there is an intergroup comparison between the three groups of retention measured in N. For group A the retention values were (23.08±0.53B), For group B the retention values were (17.90±1.11C), For group C the retention values were (27.67±0.94A). There was statistically significant difference between the three groups and the P value was <0.001.

3.2. Discussion

The study showed a statistically significant difference in the retention of RPD frameworks acquired from the three groups, so the null hypothesis was rejected. RPDs continue to be the most suitable treatment options in many situations specially when economic or biologic conditions prohibits the use of fixed or implant based prosthesis.18 Assessment of RPDs frameworks retention is important because adequate retention influences functional performance of the prosthesis and patient's comfort, while inadequate retention leads to dislodgment during function and leads to RPD failure [19]. A maxillary Kennedy class III modification 1 model was used because it is prevalent clinically and allows stabilized support from proximal abutments leading to a more accurate assessment to fit and retention. Additionally, maxilla provides a stable broad surface that aid in scanning in contrary to the movable small mandibular surface. Furthermore, digital scanning of free end saddles presents challenges such as absence of landmarks, soft tissue mobility and errors of stitching which can compromise the scan data and results.9 The selection of a modified model allows inclusion of extra clasps for further assessment of retention. Moreover, the modified cases provide improved cross arch stabilization for comparing design variables [20]. The rests were placed in the near zone of model so that occlusal loads are transmitted directly to abutment teeth, which maximizes vertical support by them and improves stress distribution along their long axis [21].

3D printing reference model was done as this results in a cost-effective, reproducible production of models with clinically acceptable dimensional accuracy and enhanced capability for complex geometries [22]. Conventional impression technique is included as the first group because they remain the clinically established gold standard for capturing RPD master casts with high detail reproduction and dimensional accuracy, providing a baseline against which newer digital methods can be compared. Conventional impressions produce clinically acceptable frameworks and are widely accepted as a reference for retention outcomes, ensuring that any observed differences reflect true methodological effects rather than inconsistencies in data acquisition [23]. The two-step putty and light-body conventional impression technique was chosen because it provides a stable primary putty framework and controlled wash space, allowing the low-viscosity light body material to flow into fine details and thereby enhances dimensional accuracy of the cast [24]. The Medit i900 intraoral scanner, which is a recent generation of IOSs was chosen for data acquisition of second group because it has demonstrated clinically acceptable trueness and precision, enabling accurate 3D capturing of dental anatomy [25]. Additionally, recent in-vitro evidence supports that current IOS including the Medit i900 achieve deviations within acceptable ranges for full-arch models, supporting its suitability for detailed prosthodontic assessment [26].

As for the third group the rationale behind selection of desktop scanner INEOS is the same as was mentioned for scanning the reference model. In the Class III modification 1 cases with bilateral bounded edentulous spaces, a quadrilateral clasping system places direct retainers on all four available abutments, increasing support and resistance of dislodging forces more effectively than linear or triangular support configurations. This four point support enhances denture stability and retention by distributing functional loads across multiple anchor points. Selection of quadrilateral support is relevant for assessing framework retention from different data acquisition techniques, since it minimizes design related variability, since all abutments are clasped [27]. Lost wax technique was chosen for converting wax patterns into Co-Cr frameworks in all groups because it remains standard, clinically accepted method for producing high quality RPD metal frameworks with well-defined detail and predictable fit & retention. Additionally, this ensures that any differences in retention arise from data acquisition techniques rather than variations in casting technique. In other words, using a unified casting protocol eliminates an additional variable in comparing framework retention across groups, isolating influence of data acquisition techniques themselves [7].

Phosphate-bonded investment was selected because its refractory phosphate binder and high silica content provide thermal stability and sufficient strength at the elevated burnout, which is needed for high-melting base-metal alloys like Co–Cr. Moreover, its controlled setting and thermal expansion help to compensate for alloy solidification shrinkage preserving the mold accuracy in the lost-wax process [28]. A universal testing machine was chosen to measure retention because it provides precise, reproducible tensile force application at controlled crosshead speeds, which allows an accurate comparison of peak dislodgement forces of RPD frameworks created by different data acquisition techniques under standardized in-vitro conditions. This method is widely accepted in prosthodontic research for quantifying retentive forces of removable partial denture frameworks [29]. The study showed a statistically significant difference in the retention of RPD frameworks acquired from the three groups. Group C exhibited the highest retention values, followed by group A, while group B demonstrated the lowest retention values. Since the retention of a RPD framework is highly dependent on the accurate reproduction of abutment teeth, guide planes, rest seats, and retentive undercuts, the differences can be attributed to variations in the accuracy of the data acquisition workflow. Previous systematic reviews have highlighted the critical influence of digital and conventional fabrication workflows on the fit accuracy of RPD frameworks [6-30-31].

The superior retention observed in group C (desktop scanner group) may be explained by high accuracy associated with laboratory scanning procedures. In this study, the desktop scanner digitized the models of the conventional impressions, hence combining the proven ability of elastomeric impression materials to capture oral structures with the precision and reproducibility of laboratory digitalization. Laboratory scanning is performed under controlled conditions and is not affected by saliva, limited accessibility, patient movement, or soft tissue interference10, which improves the dimensional accuracy and framework adaptation, contributing to the higher retention values observed in this group [6-30]. Group A (conventional impression group) demonstrated significantly lower retention than C (desktop scanner group). However, it resulted in a significantly higher retention than group B (intraoral scanner group). Conventional impressions have been considered as a reliable method for reproducing dental structures and retentive undercuts. However, the conventional workflow involves several laboratory procedures, including cast pouring, duplication, waxing, investing, and casting, each of which may result in dimensional inaccuracies. This may explain lower retention values observed compared to desktop scanner workflow.

Nevertheless, ability of conventional impressions to accurately record hard tissue structures may account for their superior performance relative to direct intraoral scanning. Similar observations regarding the strengths and limitations of conventional workflows have been reported in studies evaluating RPD fabrication accuracy [6-30-31]. Group B (intraoral scanner group) demonstrated lowest retention values among all tested groups. One possible explanation is reduced accuracy of intraoral scanners when recording partially edentulous arches and extended edentulous areas. Intraoral scanners generate virtual models through stitching of multiple images, and dimensional deviations may accumulate as the scanning area increases. Moreover, edentulous regions often lack distinct anatomical landmarks necessary for accurate image alignment, which may negatively affect accuracy of final digital model [32-34]. Although statistically significant difference in retention was present among three groups ($P < 0.001$), measured retention values obtained from group A (conventional impression), group B (intraoral scanner), and group C (desktop scanner) remained within a clinically acceptable range. Desktop scanner group demonstrated highest mean retention, followed by conventional impression group, whereas intraoral scanner group showed lowest mean value.

Figure 1: Virtually prepared 3D printed resin model.

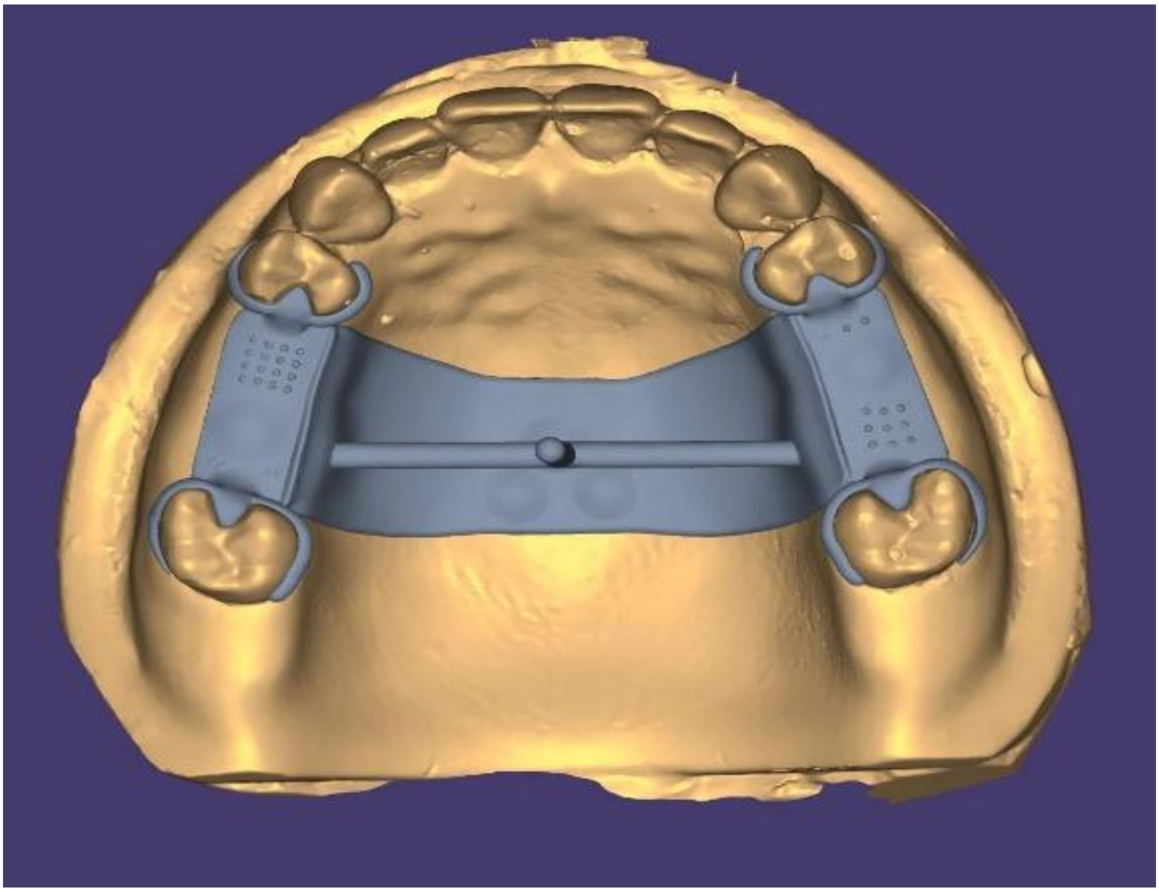

Figure 2: Virtually designed and seated RPD framework on the virtual master cast.

Figure 3: Finished and polished Co-Cr framework.

Figure 4: Metal plate attached to the geometric center of the framework.

Figure 5: The framework attached to the Universal testing machine.

Table 1: Descriptive statistics for retention (N) in different groups.

Group	Mean	95% Confidence interval		SD	Min.	Max.
		Lower	Upper			
Group A Conventional technique	23.08	22.75	23.41	0.53	22.10	23.77
Group B Intraoral scanner	17.90	17.22	18.59	1.11	15.27	19.44
Group C Desktop scanner	27.67	27.09	28.26	0.94	25.99	29.46

Table 2: Intergroup comparison and summary statistics of retention (N).

Retention (N) (Mean±SD)			p-value	PES (95% CI)
Group A Conventional technique	Group B Intraoral scanner	Group C Desktop scanner		
23.08 ± 0.53^{B}	17.90 ± 1.11^{C}	27.67 ± 0.94^{A}	**<0.001***	**0.96 (0.92 to 0.97)**

PES: Partial Eta Squared; CI: Confidence interval; Values with different superscripts are significantly different; * significant ($p < 0.05$).

However, the lowest recorded mean retention (17.90 N) exceeded the retention forces that are generally considered adequate to provide clinical function and resistance to dislodgement during normal mastication. Therefore, the statistical differences observed among the groups do not necessarily indicate clinically significant differences in the RPD frameworks' functioning. These findings are supported by Alageel et al., who demonstrated that the retentive force required for RPDs is controlled by the functional dislodging forces during mastication and reported clasp retention values ranging from approximately 2.9 to 14.5 N depending on clasp design and abutment characteristics. Since all mean retention values obtained in the present study were higher than these functional requirements, all data acquisition techniques in this study can be considered capable of producing clinically acceptable retention, despite their statistically significant differences [13]. Within the limitations of the present study, the findings suggest that the method of data acquisition plays an important role in the initial retentive performance of digitally fabricated RPD frameworks. The desktop scanner workflow produced the highest retention values, indicating that the combination of conventional impression making and laboratory digitalization may provide a highly accurate foundation for framework fabrication. Although intraoral scanning has advantages such as enhanced patient comfort, simplified clinical procedures, and immediate digital data acquisition, further improvements in scanning technology and acquisition protocols may be necessary to optimize its application in partially edentulous cases [6-30-32]. Limitations of this study are its in vitro design that does not completely mimic the complexity of the oral environment. Therefore, the findings should be interpreted with caution when generalizing them to clinical conditions. Furthermore, the evaluation of the long-term performance is necessary to confirm these results. Future studies are also recommended to evaluate RPD frameworks fabricated with different scanning technologies.

4. Conclusion

Extraoral digital impression technique provided the highest initial retention followed by the conventional impression. However, the intraoral scanners provided the lowest initial retention. All groups provided clinically acceptable results.

Ethical approval: Non-applicable since the study is an in vitro study with no human or animal participants.

Competing interest: The authors declare that they have no competing interests.

Informed consent: Not applicable since there were no human subjects involved.

Data availability: Data is available upon request from the corresponding.

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