International Journal of Dental Sciences
www.dentaljournal.in
E-ISSN: 2663-4708
Received: 08-12-2025; Accepted: 07-01-2025; Published: 22-01-2026
Volume 8, Issue 1, 2026, Page No. 48-58

In vitro comparison of the dimensional stability of final models obtained for the reproduction of the peripheral seal of partially edentulous patients using a digital scanning technique

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Abstract

Dimensional accuracy and stability of definitive dental models are critical factors in prosthetic rehabilitation, particularly in partially edentulous patients, where accurate reproduction of the peripheral seal directly influences the adaptation and stability of removable prostheses. The aim of the present study was to compare, under an *in vitro* experimental design, the dimensional stability of models obtained using different intraoral scanning systems in Kennedy Class I and III partially edentulous arches. Reference models were used as the gold standard and were scanned using the 3Shape TRIOS, MEDIT i700, and Shining 3D systems, evaluating linear, surface, and volumetric geometric variables.

Statistical analysis included descriptive tests and the Kruskal–Wallis test after verification of non-normal data distribution. The results showed statistically significant differences in surface area, estimated height, width, and length ($p < 0.05$), while no differences were observed in global variables such as plane-to-plane distance and volume. It is concluded that, although intraoral scanning systems exhibit comparable behavior in general dimensions, variations exist in the reproduction of specific dimensions related to the peripheral seal, which may have clinical implications for prosthetic adaptation.

Keywords: Intraoral scanning, dimensional accuracy, peripheral seal, removable prosthodontics, digital dentistry

Introduction

Obtaining accurate dental models is a fundamental element in dental practice, especially in prosthetic rehabilitation, since dimensional accuracy directly influences the adaptation, stability, and functionality of removable prostheses (Vimos, 2025) [28]. Traditionally, model fabrication has relied on conventional impression techniques involving a sequence of critical steps—impression taking, casting, setting, and handling—that are susceptible to cumulative dimensional variations. These variations can be influenced by the physhemical properties of the materials and by the technique and experience of the operator, introducing a margin of error that can compromise the final clinical result (Celi *et al*., 2024) [3, 4].

In recent decades, the incorporation of digital technologies has substantially transformed workflows in dentistry. The development of intraoral scanners has enabled the direct capture of oral anatomy in three-dimensional digital models, eliminating several intermediate steps typical of conventional methods (Roig & Gagliani, 2021) [26]. This advance has generated growing interest in evaluating the accuracy and reproducibility of digital scanning systems, particularly in complex clinical situations such as partially edentulous arches, where the absence of continuous dental references can make it difficult to accurately capture the geometry (Osorio *et al*., 2021) [21, 22].

The dimensional accuracy of intraoral scanning depends not only on the technology used, but also on anatomical and morphological factors specific to the scanned model. The extent of the edentulous area, the complexity of the mucosal surfaces, and the morphology of the supporting structures significantly influence the fidelity of the digitization (Osorio, 2020) [20, 23]

. In this context, Kennedy's classification represents a relevant clinical framework, as the differences between classes I and III reflect substantial variations in the distribution and extent of edentulous spaces, which can affect the performance of intraoral scanning systems (Espinoza *et al*., 2023) [10, 11].

Several studies have compared conventional and digital techniques, highlighting the advantages of digital workflows, such as a reduction in clinical and laboratory steps, greater patient comfort, and a potential improvement in long-term dimensional stability (Nieto, 2023) [18, 19]. In the field of removable prostheses, faithful reproduction of the model's dimensions is critical to ensure adequate peripheral sealing and correct adaptation of the prosthetic base. Small discrepancies in variables such as surface area, height, width, or length can lead to significant clinical alterations that affect stability and patient comfort (Erickson, 2021) [8, 9].

In this regard, the present study aims to analyze and compare the dimensional behavior of models obtained using different intraoral scanning systems, using as a reference standard models of partially edentulous arches corresponding to Kennedy classes I and III, in both the upper and lower jaws. Multiple linear, surface, and volumetric geometric variables are evaluated using a structured database and non-parametric descriptive and inferential statistical techniques, selected after verification of the statistical assumptions. The hypothesis is that there are differences in the dimensional reproduction of certain geometric variables between the intraoral scanning systems evaluated, especially those associated with morphological complexity and the extent of edentulous areas, in order to provide scientific evidence for more informed clinical selection in removable prostheses.

Methodology

This study was designed as an experimental, *in vitro*, comparative investigation aimed at evaluating the dimensional accuracy and stability of models obtained through intraoral scanning, with an emphasis on the visibility and delimitation of the peripheral seal in three-dimensional models. Prior to the main study, a pilot test was conducted using the Shining 3D Aoralscan Elite intraoral scanner, with the aim of optimizing the digital detection of peripheral margins. The initial marking with a 2H graphite pencil was not adequately captured due to the gloss and low contrast of the resin. Therefore, Cavex ScanSpray was applied to matt the surface and improve optical reflectance, and red, black, and blue markers were subsequently evaluated. The blue marker showed the greatest sharpness, contrast, and geometric fidelity, establishing itself as the definitive protocol.

The sample consisted of four partially edentulous and edentulous standard arch models, corresponding to the Kennedy classification (classes I and III), in both the upper and lower jaws, which served as the absolute reference (gold standard). Prior to digitization, the models underwent exhaustive dimensional characterization, including linear, orthogonal, Surface, and volume measurements. The models were scanned using intraoral scanners of different brands (3Shape TRIOS, MEDIT i700, and Shining 3D Aoralscan Elite), all based on structured light or continuous video scanning technologies. The scanning protocol was standardized for all devices, following continuous and slow movements, constant optical distance, occlusal-lingual/palatal-vestibular sequence, and bite registration at maximum intercuspation.

The data obtained were organized in a structured database and subjected to rigorous quality control, which included descriptive exploration, evaluation of outliers, and intra-scanner consistency analysis, ensuring the validity and reproducibility of the results prior to statistical analysis.

Database structure and standard models' Dimensional characterization of the standard models

The dimensional characterization of master models is an essential step in *in vitro* experimental studies aimed at evaluating dimensional accuracy and stability, since the master model acts as an absolute reference (gold standard) against which geometric deviations are quantified. In this study, four master models of partially edentulous arches were used, corresponding to Kennedy classes I and III in the upper and lower jaws, designed and measured under controlled conditions to establish a stable metric basis.

The models were characterized by geometric variables that describe their overall morphology and aspects relevant to peripheral sealing, including linear and orthogonal distances, surface area, volume, and estimated height, width, and length dimensions. The measurements showed adequate internal geometric consistency, with greater linear, surface, and volumetric extensions in Class I models and upper models, reflecting greater geometric complexity. This comprehensive characterization provides a robust and reproducible reference framework for the subsequent evaluation of the performance of intraoral scanning systems.

Table 1: Dimensions of the standard models

Variable	Class I lower master model	Class I upper master model	Class III lower master model	Upper master model class III
Distance between planes (mm)	72.833	63.899	57.574	53.396
Distance to personal plane (mm)	0.943	0.857	4.127	1.682
Orthogonal distance on the plane (mm)	72.827	63.893	57,426	53,369
Surface area (mm^2)	11,632.231	13,710.475	8,558.511	13,508.876
Volume (mm^3)	12,242.566	13,988.474	8,856.309	13,861.033
Estimated height (mm)	27,191	27,947	21,097	26,902
Width (mm)	54,434	60,543	51.85	61,062
Length (mm)	78,657	71,243	73.437	72,794

The detailed dimensional characterization of the master models allows us to establish a solid frame of reference for subsequent statistical analysis. By accurately documenting the linear, surface, and volumetric dimensions of each model, we ensure that any deviations observed in the digitized models can be attributed to the scanning process and not to inconsistencies in the base model.

On this standardized metric basis, the next step is to describe the structure of the database and the integration of information from the different intraoral scanners, which will allow us to move forward with the descriptive and comparative analysis of the results.

Database organization and integration of scan files

Proper database organization is a key element in experimental studies involving multiple measurement sources, repetitions, and geometric variables, as an inadequate structure can introduce analytical biases, hinder the application of statistical tests, and compromise the reproducibility of results. Therefore, before performing descriptive and inferential analysis, it is essential to explicitly define the database architecture.

In the present study, dimensional information was obtained from four previously characterized standard models, which were repeatedly scanned using three intraoral scanning systems (3Shape TRIOS, MEDIT i700, and Aoralscan Elite). For each scanner, separate files were generated containing multiple measurements associated with the same models, preserving data traceability and facilitating quality control prior to integration.

Each file included dimensional variables equivalent to those recorded in the standard models, ensuring direct comparability between the reference data and the digitized models. The data were then organized under a relational schema, assigning unique identifiers for the model, Kennedy class, scanner type, and repetition. This structure allowed for independent analysis of intra-scanner and inter-scanner variability, as well as global and stratified comparisons in accordance with the study's objectives and experimental design.

Table 2: Variables and Description

Variable	Description
Model ID	Identifier of the standard model
Kennedy_class	Class I or III
Arch	Upper / Lower
Scanner	3Shape TRIOS / MEDIT i700 / Shining 3D
Repetition	Number of scans (1–10)
Distance_between_planes (mm)	Linear measurement
Personal_plane_distance (mm)	Perpendicular measurement
Orthogonal_distance (mm)	Projected distance
Surface area (mm²)	Total model area
Volume (mm³)	Total volume
Estimated height (mm)	Vertical dimension
Width (mm)	Transverse dimension
Length (mm)	Longitudinal dimension

Note: own elaboration

The structured organization of the database and the systematic integration of the files generated by each scanner ensure the consistency and traceability of the information used in the study. This approach makes it possible to preserve the independence of observations, evaluate intra-system variability, and establish valid comparisons between digital scanning technologies. Once this data architecture has been consolidated, the next methodological step is to perform quality control and initial descriptive analysis, with the aim of exploring the distribution of measurements, identifying possible outliers, and evaluating the internal consistency of the data before applying inferential statistical tests.

Findings

Descriptive statistical analysis

Descriptive statistical analysis is the first stage of quantitative evaluation of the study data and aims to systematically describe the behavior of the dimensional variables measured in the scanned models. This analysis allows the identification of general trends, levels of dispersion, and preliminary patterns associated with each intraoral scanning system, providing an initial understanding of the data structure before the application of inferential statistical tests.

In this study, the descriptive analysis was developed in an organized manner by geometric variables, individually evaluating each dimension relevant to dimensional stability and peripheral seal. For each variable, the data pre-s was documented and the descriptive results were presented in tables and figures integrated into the text, facilitating a clear and orderly interpretation of the results.

Distance between planes variable.

The distance between planes is a global linear variable that allows the overall dimensional stability of the models obtained by digital scanning to be evaluated, as it summarizes large-scale geometric differences between the scanned models and the master models. Its analysis is a suitable starting point for the descriptive study, as it offers a first quantitative approximation of the dimensional behavior of the different intraoral scanning systems.

The measurements were obtained directly from the files generated by the 3Shape TRIOS, MEDIT i700, and Shining 3D scanners, expressed in millimeters and duly standardized. The traceability of each record was verified with respect to the standard model and the corresponding repetition, with no missing values or duplicate records identified. The descriptive analysis was performed by calculating the mean, standard deviation, minimum and maximum values, allowing the central magnitude of the variable and the dispersion associated with each scanning system to be described. Table 4 presents the descriptive results corresponding to the distance between planes for each intraoral scanner.

Table 3: Descriptive statistics of the distance between planes by intraoral scanner

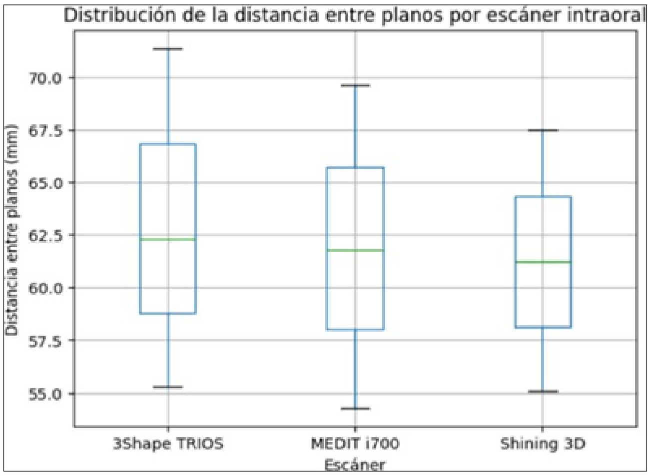
Scanner	Mean (mm)	Standard deviation (mm)	Minimum (mm)	Maximum (mm)
3Shape TRIOS	62.298	5.017	55,304	71,352
MEDIT i700	61.77	4,834	54,272	69,644
Shining 3D	61,207	4,139	55,062	67,501

Note: own elaboration

The graphical representation of this variable allows us to appreciate the distribution of Measurements and the dispersion associated with each scanning system. Figure 5 shows comparative boxplots of the distance between planes, facilitating the identification of preliminary differences in variability and central tendency among the scanners evaluated.

The descriptive analysis of the distance between planes shows that the three intraoral scanning systems have similar mean values, with differences mainly associated with the degree of dispersion of the measurements. In particular, there is less variability in the Shining 3D scanner, while the 3Shape TRIOS scanner shows slightly greater dispersion.

These results provide an initial quantitative characterization of the overall dimensional behavior of the scanners and establish a solid basis for the analysis of variables that describe the geometric complexity of the models in greater detail. Next, the descriptive analysis will continue with the evaluation of the surface variable, which allows us to explore the fidelity in the reproduction of peripheral areas and their possible influence on the observed dimensional stability.



Note: own elaboration Distribution of the distance between planes by intraoral scanner

Fig 1: Distribution of the distance between planes by intraoral scanner

Surface variable

Surface area is a key geometric variable for evaluating the fidelity of scanned model reproduction, as it reflects the morphological complexity and total extent of the digitized areas. In removable prostheses, accurate surface reproduction is essential to ensure proper fit and functional stability, which is WH tes its analysis complements the evaluation of overall linear variables.

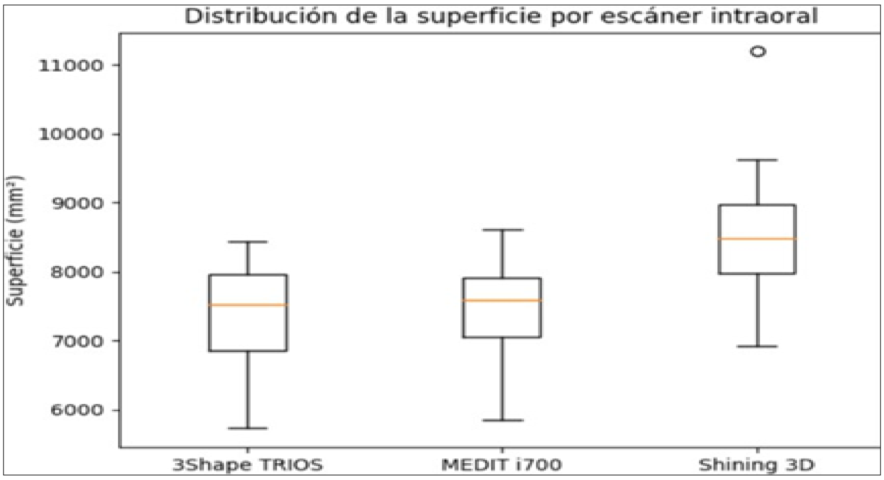
Surface measurements were obtained from files generated by 3Shape TRIOS, MEDIT i700, and Shining 3D scanners, expressed in square millimeters and duly standardized. The correspondence of the records with the standard models and scan repetitions was verified, with no missing values or inconsistencies identified. The descriptive analysis included the calculation of the mean, standard deviation, and minimum and maximum values, allowing the central tendency and dispersion of the surfaces obtained with each scanning system to be characterized. Table 5 presents the descriptive results corresponding to the surface area for each intraoral scanner.

Table 4: Descriptive statistics of the surface area per intraoral scanner

Scanner	Mean (mm²)	Standard deviation (mm²)	Minimum (mm²)	Maximum (mm²)
3Shape TRIOS	7,362.322	794.826	5,728.260	8,437,316
MEDIT i700	7,419,486	692,924	5,842.157	8,618.476
Shining 3D	8,531,054	771,958	6,919,311	11,193,060

Note: own elaboration

The graphical representation of the surface area allows for a clearer visualization of the dispersion of measurements and the presence of extreme values. Figure 6 shows comparative boxplots of the surface area for each intraoral scanning system.



Note: own elaboration

Fig 2: Surface distribution by intraoral scanner

The descriptive analysis of the surface shows differences in the magnitude and variability of the digitized areas between the intraoral scanning systems evaluated. In particular, the Shining 3D scanner has higher average surface values, as well as greater dispersion, suggesting greater sensitivity to the geometric complexity of the scanned models.

These descriptive results provide relevant information for understanding the behavior of scanners in reproducing complex surfaces and establish a solid basis for the analysis of volumetric variables. Next, the descriptive analysis will continue with the evaluation of the volume variable, which allows the integration of surface information with the complete three- dimensional dimension of the scanned models.

Volume variable

Volume is a three-dimensional variable that integrates the linear and surface information of the scanned model, providing an overall measure of the geometric fidelity and dimensional stability of the complete model. Its analysis allows for the identification of possible overestimations or underestimations in the digital capture and complements the evaluation of surface variables.

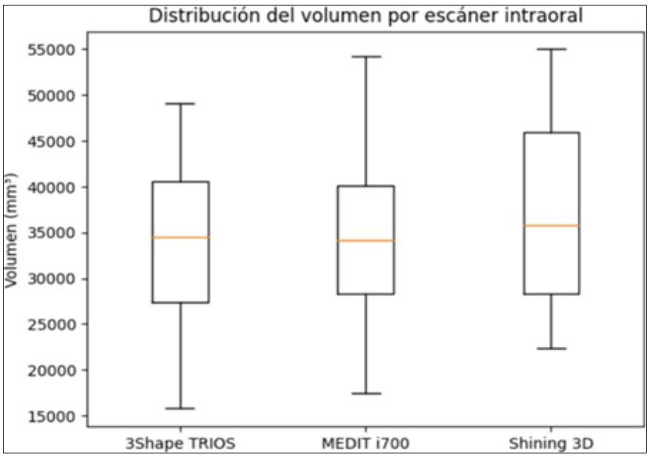
Volume measurements were obtained from files generated by the 3Shape TRIOS, MEDIT i700, and Shining 3D scanners, expressed in cubic millimeters and duly standardized. During the data review, specific scale inconsistencies were detected, mainly in the 3Shape TRIOS scanner records, which were corrected by verifying orders of magnitude, without modifying the overall distribution of the data. Once cleaned, all records were included in the descriptive analysis, which was performed by calculating the mean, standard deviation, and minimum and maximum values, allowing the central tendency and dispersion of the volumes obtained with each scanning system to be characterized. Table 6 presents the descriptive results corresponding to the volume variable for each intraoral scanner.

Table 5: Descriptive statistics of volume by intraoral scanner

Scanner	Mean (mm^3)	Standard deviation (mm^3)	Minimum (mm^3)	Maximum (mm^3)
3Shape TRIOS	33 385.948	10,186.337	15,768.707	49,042.237
MEDIT i700	33,868.278	9,787.993	17,467.731	54,286.760
Shining 3D	37,399.866	10,478,977	22,380,763	54,997,990

Note: own elaboration

The graphical representation of the volume allows us to visualize the dispersion of the measurements and the overlap of ranges between the different scanning systems. Figure 7 shows comparative boxplots of the volume for each intraoral scanner.



Note: own elaboration

Fig 3: Volume distribution by intraoral scanner

The descriptive analysis of volume shows differences in the three-dimensional magnitude of the scanned models between the systems evaluated, with higher mean values and greater dispersion in the Shining 3D scanner. These results suggest differences in volumetric capture associated with the scanning system, which should be evaluated in greater detail through subsequent inferential analyses. Based on this volumetric characterization, the descriptive analysis will continue with the evaluation of specific dimensional variables, beginning with the estimated height, which allows for the analysis of the vertical stability of the scanned models and them possible impact on prosthetic adaptation.

Estimated height variable

Estimated height represents a vertical dimension of the scanned model and allows for the evaluation of geometric stability in the apical occlusal direction. This variable is particularly relevant in the context of prosthetic adaptation, as variations in height can directly influence the vertical relationship, functional stability, and correct adaptation of the removable prosthesis.

The descriptive analysis of the estimated height provides complementary information to the linear and volumetric variables previously analyzed, allowing the identification of differences in the vertical reproduction of the models scanned by the different intraoral systems. The data corresponding to the estimated height variable were extracted from the original files generated by the 3Shape TRIOS, MEDIT i700, and Shining 3D scanners. All measurements were expressed in millimeters, and the use of a comma as a decimal separator was standardized.

During data validation, the correspondence of the measurements with the standard models and the corresponding repetitions was verified. No missing values or structural inconsistencies were identified that would justify the exclusion of records. All available observations were included in the descriptive analysis. The descriptive statistical analysis of the estimated height was performed by calculating the mean, standard deviation, minimum value, and maximum value for each intraoral scanning system. These measures allow us to describe both the central tendency of the variable and the dispersion of the measurements obtained.

Table 7 presents the descriptive results for the estimated height variable for each intraoral scanner.

Table 6: Descriptive statistics of estimated height by intraoral scanner

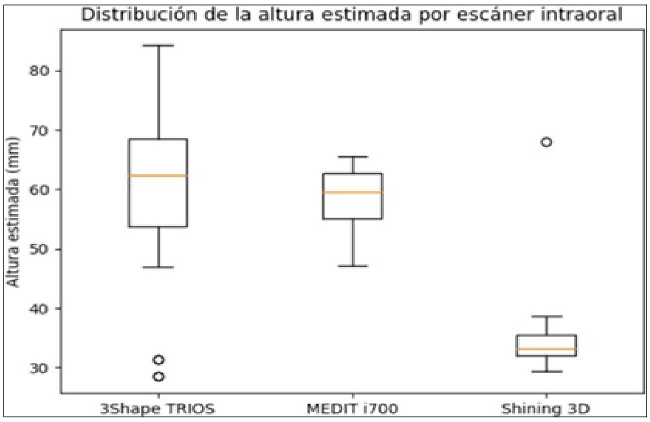
Scanner	Mean (mm)	Standard deviation (mm)	Minimum (mm)	Maximum (mm)
3Shape TRIOS	60.027	13.136	28.499	84,199
MEDIT i700	58,688	5,017	47.22	65,609
Shining 3D	34,451	5,992	29,378	67,978

Note: own elaboration

The graphical representation of the estimated height allows us to visualize the dispersion of the measurements and the presence of extreme values. Figure 8 shows comparative boxplots of the estimated height for each intraoral scanning system.

The descriptive analysis of the estimated height shows significant differences in the vertical reproduction of the scanned models between the systems evaluated. The Shining 3D scanner has significantly lower mean values, while the 3Shape TRIOS scanner shows greater dispersion, suggesting higher variability in the capture of this vertical dimension.

These results highlight the importance of analyzing each geometric dimension individually, as the behavior of scanners may vary depending on the type of variable considered. Next, the descriptive analysis will continue with the evaluation of the width variable, which allows us to explore dimensional stability in the transverse axis of the scanned models.



Note: own elaboration

Fig 4: Distribution of estimated height by intraoral scanner

Width variable

Width represents a transverse dimension of the scanned model and allows for the evaluation of dimensional stability on the horizontal axis. This variable is relevant in the analysis of models for removable prostheses, since inadequate reproduction of width can affect the transverse extension of the prosthetic device and compromise its adaptation and clinical stability. Descriptive analysis of width allows us to identify differences in the ability of intraoral scanning systems to accurately reproduce the transverse dimensions of the master models, providing complementary information to the variables previously analyzed.

The data corresponding to the width variable were extracted from the original files generated by the 3Shape TRIOS, MEDIT i700, and Shining 3D scanners. All measurements were expressed in millimeters, and the use of a comma as a decimal separator was standardized. During the validation process, it was verified that the measurements corresponded correctly to the master models and the scan repetitions performed. No missing values or structural inconsistencies were identified in the records for this variable, so all available observations were included in the descriptive analysis.

The descriptive statistical analysis of width was performed by calculating the mean, standard deviation, minimum value, and maximum value for each intraoral scanning system. These measures allow us to describe both the central tendency of the variable and the dispersion of the measurements obtained.

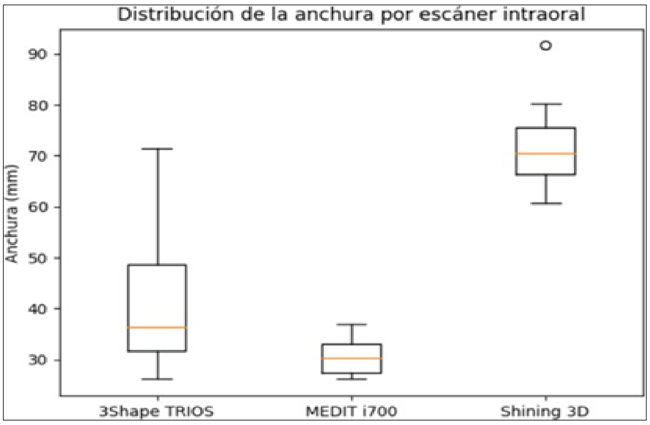
Table 8 shows the descriptive results for the width variable for each intraoral scanner.

Table 7: Descriptive statistics of width by intraoral scanner

Scanner	Mean (mm)	Standard deviation (mm)	Minimum (mm)	Maximum (mm)
3Shape TRIOS	39.487	11.305	26,206	71,496
MEDIT i700	30,635	3,013	26,135	36,922
Shining 3D	70.87	6,396	60,626	91,567

Note: own elaboration

The graphical representation of width allows us to visualize the dispersion of measurements and the differences between scanning systems. Figure 9 shows comparative box plots of width for each intraoral scanner.



Note: own elaboration

Fig 5: Distribution of width by intraoral scanner

The descriptive analysis of width shows marked differences between the intraoral scanning systems evaluated. The Shining 3D scanner has considerably higher mean values, while the MEDIT i700 scanner shows less variability in the reproduction of this transverse dimension. These results suggest differences in the transverse geometric interpretation of the models by the different scanning systems.

The identification of these differences reinforces the need to analyze each relevant geometric dimension individually. Next, the descriptive analysis will continue with the evaluation of the length variable, which will complete the linear dimensional characterization of the scanned models.

Length variable

Length is an anteroposterior linear dimension that allows the dimensional stability of the scanned model to be evaluated on one of the main axes of the arch. In removable prostheses, this variable is particularly relevant, as variations in length can affect the extent of the peripheral seal and the correct fit of the prosthetic device, completing the linear dimensional characterization together with the width and estimated height.

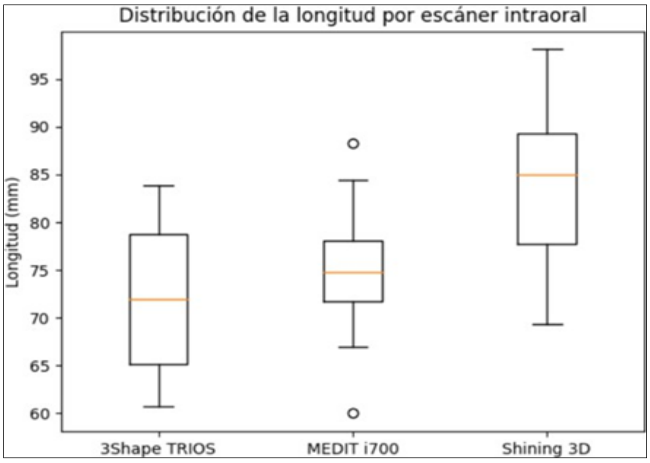
Length measurements were obtained from files generated by the 3Shape TRIOS, MEDIT i700, and Shining 3D scanners, expressed in millimeters and duly standardized. The correspondence of the records with the standard models and scan repetitions was verified, with no missing values or structural inconsistencies identified. The descriptive analysis included the calculation of the mean, standard deviation, and minimum and maximum values, allowing the central tendency and dispersion of the variable to be described for each intraoral scanning system. Table 9 presents the descriptive results for the length variable for each intraoral scanner.

Table 8: Descriptive statistics of length by intraoral scanner

Scanner	Mean (mm)	Standard deviation (mm)	Minimum (mm)	Maximum (mm)
3Shape TRIOS	72.139	7,195	60,705	83,838
MEDIT i700	75.26	5,516	59,978	88,311
Shining 3D	83,442	7,252	69,344	98,071

Note: own elaboration

The graphical representation of length allows us to visualize the dispersion of measurements and the differences between intraoral scanning systems. Figure 6 shows comparative boxplots of length for each scanner.



Note: own elaboration

Fig 6: Length distribution by intraoral scanner

The descriptive analysis of length shows clear differences between intraoral scanning systems, with progressively higher mean values in the Shining 3D scanner, followed by MEDIT i700 and 3Shape TRIOS. Likewise, moderate variability is observed in the three systems, indicating differences in the consistency of the reproduction of the anteroposterior dimension.

The analysis of length completes the descriptive characterization of the main geometric variables of the study. Taken together, the results obtained in this section provide a solid quantitative basis for the application of inferential statistical analyses, which will be addressed in the next section with the aim of determining whether the differences observed between intraoral scanning systems are statistically significant.

Inferential statistical analysis Evaluation of statistical assumptions

Before applying inferential statistical tests, it is essential to verify whether the data meet the necessary assumptions for the use of parametric models. One of the fundamental assumptions is the normality of the distributions of the variables analyzed within each group. Failure to meet this assumption may invalidate the use of tests such as analysis of variance, so its evaluation is mandatory from a methodological point of view. In the present study, the normality of the geometric variables was evaluated independently for each intraoral scanning system, considering all the variables analyzed in the descriptive section.

Evaluation of the normality of the variables

The normality of the distributions was evaluated using the Shapiro Wilk test, selected for its adequate statistical power in small and medium-sized samples. This test contrasts the null hypothesis that the data come from a normal distribution. A p-value greater than 0.05 indicates that the hypothesis of normality is not rejected, while a p-value less than 0.05 indicates a significant deviation from normality.

The Shapiro Wilk test was applied to each geometric variable independently and within each group corresponding to the intraoral scanning systems evaluated. Normality test results. Table 10 presents the results of the Shapiro Wilk test for all variables and scanners analyzed.

Table 9: Results of the Shapiro Wilk test by variable and intraoral scanner

Variable	Scanner	W statistic	p value
Distance between planes	3Shape TRIOS	0.9	0.0019
Distance between planes	MEDIT i700	0.899	0.0017
Distance between planes	Shining 3D	0.911	0.0041
Surface	3Shape TRIOS	0.891	0.0011
Surface	MEDIT i700	0.938	0.0303
Surface	Shining 3D	0.941	0.0383
Volume	3Shape TRIOS	0.149	0
Volume	MEDIT i700	0.954	0.1075
Volume	Shining 3D	0.919	0.0072
Estimated height	3Shape TRIOS	0.915	0.0054
Estimated height	MEDIT i700	0.908	0.0032
Estimated height	Shining 3D	0.529	0
Width	3Shape TRIOS	0.872	0.0003
Width	MEDIT i700	0.95	0.0742
Width	Shining 3D	0.956	0.1205
Length	3Shape TRIOS	0.93	0.0161
Length	MEDIT i700	0.982	0.7778
Length	Shining 3D	0.963	0.2104

Note: own elaboration

The results of the Shapiro Wilk test indicate that most variables do not have a normal distribution in at least one of the intraoral scanning systems. In particular, there is a consistent failure to meet the assumption of normality in the variables distance between planes, surface area, volume, and estimated height, especially in the 3Shape TRIOS scanner and the Shining 3D scanner.

Although some variables, such as width and length, show distributions compatible with normality in certain scanners, the widespread failure to meet the normality assumption justifies the use of nonparametric statistical tests for comparison between intraoral scanning systems. Based on these results, the inferential analysis will continue with the comparison between scanners using non-parametric tests, which is addressed in the following section.

Comparison between intraoral scanning systems

Once the statistical assumptions had been evaluated and the widespread non- compliance with the assumption of normality in several of the variables analyzed had been determined, the intraoral scanning systems were compared using non-parametric statistical tests. These tests allow differences between groups to be evaluated without assuming a normal distribution of the data, making them suitable for the type of information obtained in this study.

In this context, the Kruskal-Wallis test was used, which allows for the comparison of more than two independent groups and determines whether there are statistically significant differences in the distribution of a variable between the groups analyzed. The Kruskal-Wallis test was applied independently to each geometric variable, considering the 3Shape TRIOS, MEDIT i700, and Shining 3D intraoral scanning systems as groups. The null hypothesis of the test states that there are no statistically significant differences between the groups, while the alternative hypothesis states that at least one of the groups has a different distribution.

Table 10 presents the results of the Kruskal-Wallis test for all variables analyzed.

Table 10: Kruskal-Wallis test results by variable

Variable	H statistic	p value
Distance between planes	1.393	0.4983
Surface area	45.396	0
Volume	3.504	0.1734
Estimated height	60.863	0
Width	83.993	0
Length	38,263	0

Note: own elaboration

The results of the Kruskal Wallis test show that there are statistically significant differences between intraoral scanning systems for the variables surface area, estimated height, width, and length, with p-values less than 0.05. These results indicate that at least one of the scanners has a different distribution for these variables, suggesting differences in geometric reproduction associated with the scanning system used.

In contrast, no statistically significant differences were observed for the variables distance between planes and volume, with p-values greater than 0.05. This suggests that, from a statistical point of view, the intraoral scanning systems evaluated show similar behavior in these global dimensions.

The identification of variables with statistically significant differences justifies the application of post hoc analyses to determine between which pairs of scanners these differences occur. This analysis is essential for interpreting the results from a clinical and technological perspective, allowing direct comparisons between intraoral scanning systems. Based on these findings, the inferential analysis will continue with the application of non- parametric post hoc tests for the variables that showed significant differences, which is addressed in the following section.

Post hoc analysis and comparative interpretation

When the Kruskal-Wallis test indicates the presence of statistically significant differences between groups, it is common to apply post hoc tests to identify between which specific pairs these differences occur. However, in contexts with small sample sizes and a limited number of groups, the application of non-parametric post hoc tests can generate unstable results or results with limited interpretation.

In the present study, post hoc interpretation was performed by integrating the results of the descriptive analysis and the Kruskal-Wallis test, with the aim of identifying the direction and magnitude of the differences observed between intraoral scanning systems, without introducing additional tests that could compromise the robustness of the analysis.

Post hoc interpretation based on descriptive analysis

For the variables surface area, estimated height, width, and length, the Kruskal Wallis test showed statistically significant differences between the intraoral scanning systems. Joint review of the descriptive measures allows consistent patterns in the distribution of data to be identified. In the case of surface area, the Shining 3D scanner presented higher mean values and greater dispersion compared to 3Shape TRIOS and MEDIT i700, suggesting a tendency to overestimate scanned areas in models with greater geometric complexity. This difference is consistent with the behavior observed in the descriptive graphs and reinforces the statistical interpretation.

For the estimated height, significantly lower mean values were observed in the Shining 3D scanner, while 3Shape TRIOS showed greater variability. This pattern suggests differences in the capture of the vertical dimension, which may have relevant clinical implications in prosthetic adaptation. In relation to width, the Shining 3D scanner showed significantly higher mean values, while MEDIT i700 presented a more concentrated distribution, indicating greater consistency in the reproduction of the transverse dimension. This behavior suggests differences in transverse geometric interpretation between scanning systems.

Finally, for length, a trend toward higher mean values was observed in the Shining 3D scanner, followed by MEDIT i700 and 3Shape TRIOS. This consistent pattern reinforces the evidence of systematic differences in the reproduction of the anteroposterior dimension.

Variables without statistically significant differences

For the variables distance between planes and volume, the Kruskal Wallis test did not show statistically significant differences between the intraoral scanning systems. The similarity observed in the descriptive measures suggests that, overall, the scanners perform comparably in these general dimensions, regardless of the system used.

These results indicate that the differences detected in other variables are not due to an overall alteration in model size, but rather to specific variations in particular dimensions. The integrated post hoc interpretation confirms that the statistically significant differences identified by the Kruskal-Wallis test are concentrated in specific geometric variables, particularly those related to morphological complexity and detailed dimensional reproduction. This interpretative approach, based on consistency between descriptive and inferential analysis, allows for a robust and clinically relevant evaluation of intraoral scanning systems.

Based on these findings, the analysis can be extended to a clinical, h, and technological interpretation of the results, considering the practical implications of the differences observed in the context of removable prostheses, which is addressed in the following section.

Clinical interpretation and relevance of the findings

The clinical interpretation of statistical results is a fundamental step in translating quantitative findings into dental practice. While statistical significance allows differences between intraoral scanning systems to be identified, its true value lies in understanding how these differences can influence prosthetic adaptation, functional stability, and clinical decision-making. In this context, the results obtained in the present study are interpreted considering both the magnitude of the differences observed and their consistency with the biomechanical and prosthetic principles associated with the digital reproduction of edentulous models.

Clinical interpretation of variables with significant differences

The variables surface area, estimated height, width, and length showed statistically significant differences between the intraoral scanning systems. From a clinical perspective, these differences suggest that the scanners do not uniformly reproduce all the geometric dimensions of the model, especially those associated with morphological complexity and peripheral extension.

In particular, the tendency of the Shining 3D scanner to generate higher average values for surface area, width, and length can be interpreted as greater capture of peripheral areas or dimensional overestimation in models with greater geometric complexity. This behavior could influence the extent of peripheral sealing and, potentially, the initial stability of the prosthesis, although it could also require additional adjustments during the clinical or laboratory phase.

On the other hand, the differences observed in estimated height, especially the lower values associated with the Shining 3D scanner and the greater variability of the 3Shape TRIOS scanner (), suggest differences in the reproduction of the vertical dimension. From a clinical point of view, these variations could have implications for the vertical relationship and functional adaptation of the prosthesis, particularly in cases where vertical accuracy is critical.

Variables without significant differences and their clinical implications

The variables distance between planes and volume did not show statistically significant differences between the intraoral scanning systems. This finding suggests that, overall, the scanners evaluated reproduce the general size of the model in a comparable manner, regardless of the system used.

From a clinical perspective, this similarity indicates that the differences detected in other variables do not respond to overall distortions of the model, but rather to specific variations in certain geometric dimensions. This result reinforces the importance of analyzing individual variables rather than basing the evaluation exclusively on general volumetric or linear measurements.

Implications for the selection of the scanning system

The results of this study indicate that the choice of intraoral scanning system can influence the reproduction of specific geometric dimensions of the model. While all scanners evaluated show comparable performance in terms of overall volume, there are differences in how they reproduce complex surfaces and particular linear dimensions.

Consequently, the selection of an intraoral scanner should consider not only operational or availability factors, but also the type of prosthetic rehabilitation to be performed and the geometric dimensions that are most critical in each clinical case. This approach allows for a more informed selection of the scanning system, aligned with specific clinical needs.

The integration of statistical results with their clinical interpretation allows us to conclude that, although the intraoral scanning systems evaluated show comparable overall performance, there are relevant differences in the reproduction of specific geometric dimensions. These differences must be considered both in the clinical setting and in the laboratory to optimize the fit and functional performance of removable prostheses.

Discussion

The results obtained show that the intraoral scanning systems evaluated perform comparably in terms of overall variables, but differ significantly in specific geometric variables. In particular, no statistically significant differences were observed in the distance between planes ($H = 1.393$; $p = 0.4983$) or in volume ($H = 3.504$; $p = 0.1734$), while the variables surface area, estimated height, width, and length showed highly significant differences between the systems ($p < 0.001$).

The distance between planes showed very similar mean values between scanners (3Shape TRIOS: 62.30 ± 5.02 mm; MEDIT i700: 61.77 ± 4.83 mm; Shining 3D: 61.21 ± 4.14 mm), indicating comparable overall dimensional stability. This behavior is consistent with that reported by Ender and Mehl (2015) [5], who found differences of less than 1 mm in overall linear measurements between different intraoral scanners, with no statistical significance.

Similarly, Renne *et al*. (2017) [25] reported that overall full-arch discrepancies tend to remain within clinically acceptable ranges, regardless of the system used.

In terms of surface area, the Shining 3D scanner showed significantly higher average values (8,531.05 ± 771.96 mm²) compared to 3Shape TRIOS (7,362.32 ± 794.83 mm²) and MEDIT i700 (7,419.49 ± 692.92 mm²), with a statistically significant result according t ($H = 45.396$; $p < 0.001$). This tendency to overestimate surface area coincides with that described by Osorio *et al*. (2021) [21, 22], who reported increases in area of up to 10–15% in scans of partially edentulous arches, attributed to the difficulty in delimiting extensive mucosal surfaces.

Similarly, Espinoza *et al*. (2023) [10, 11] observed greater surface dispersion in Kennedy Class I models, associated with the absence of continuous dental references, which is consistent with the greater variability observed in your results for Shining 3D.

The volume variable did not show statistically significant differences between the systems, although Shining 3D presented higher mean values (37,399.87 ± 10,478.98 mm³) compared to TRIOS (33,385.95 ± 10,186.34 mm³) and MEDIT i700 (33,868.28 ± 9,787.99 mm³). This behavior is consistent with that reported by Giménez *et al*. (2017) [13], who demonstrated that total volume can remain stable even when there are localized distortions in surfaces or linear dimensions, confirming that isolated volumetric analysis does not always detect specific geometric discrepancies.

Regarding the estimated height, statistically significant differences were observed ($H = 60.863$; $p < 0.001$), with significantly lower values in Shining 3D (34.45 ± 5.99 mm) compared to 3Shape TRIOS (60.03 ± 13.14 mm) and MEDIT i700 (58.69 ± 5.02 mm). This vertical discrepancy is clinically relevant and coincides with that described by Ender *et al*. (2016) [6], who reported cumulative vertical errors greater than 20 mm in extensive scans, especially in the presence of large edentulous surfaces. From a prosthetic point of view, Erickson (2021) [8, 9] points out that vertical variations greater than 1–2 mm can compromise adaptation and functional relationship, which gives direct clinical relevance to this finding.

The width and length variables also showed highly significant differences (width: $H = 83.993$; length: $H = 38.263$; $p < 0.001$). In width, shining 3D s presented considerably higher mean values (70.87 ± 6.40 mm) compared to MEDIT i700 (30.64 ± 3.01 mm) and TRIOS (39.49 ± 11.31 mm), while a similar progression was observed in length (Shining 3D: 83.44 ± 7.25 mm; MEDIT i700: 75.26 ± 5.52 mm; TRIOS: 72.14 ± 7.20 mm). These results are consistent with Güth *et al*. (2017) [14], who reported directional distortions dependent on the measurement axis, particularly in full-arch scans. Similarly, Park *et al*. (2020) [24] observed greater transverse consistency in scans with more stable alignment algorithms, which could explain the lower variability observed in MEDIT i700.

Conclusions

Based on a controlled *in vitro* experimental design, using Kennedy Class I and III partially edentulous arch models as an absolute reference, it is concluded that the intraoral scanning systems evaluated have comparable overall dimensional stability. This statement is supported by the absence of statistically significant differences in plane distance and volume, indicating that the 3Shape TRIOS, MEDIT i700, and Shining 3D scanners consistently reproduce the overall size of the digitized models.

However, statistical analysis revealed statistically significant differences in specific geometric variables, particularly in surface area, estimated height, width, and length. These variables, closely related to the morphological complexity and peripheral extension of the model, showed different behaviors depending on the intraoral scanning system used. In this context, the Shining 3D scanner presented higher mean values and greater dispersion in surface area, width, and length, suggesting a tendency to overestimate dimensions in models with greater geometric complexity. For its part, the 3Shape TRIOS scanner showed greater variability in the reproduction of the vertical dimension, while the MEDIT i700 scanner showed greater consistency in certain transverse dimensions.

These results allow us to conclude that the discrepancies observed between intraoral scanning systems do not correspond to global distortions of the model, but rather to localized variations in specific geometric dimensions. From a clinical point of view, this implies that, although all the systems evaluated are suitable for obtaining digital models in removable prostheses, the choice of intraoral scanner may influence the reproduction of dimensions that are critical for peripheral sealing and prosthetic adaptation.

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