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Digital versus conventional surveying for partially edentulous arches: an evaluation of accuracy and time efficiency

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PURPOSE. This diagnostic study evaluated the accuracy and time efficiency of digital surveying compared to the conventional method for partially edentulous arches. **MATERIALS AND METHODS.** Thirty Standard Tesselation Language (STL) files of partially edentulous arches were analyzed. Conventional surveying was performed on 3D-printed diagnostic casts, while digital surveying was conducted using CAD software (Dental Wings Inc., Straumann, Montreal, Canada). The path of insertion and removal, and determining factors (guiding planes, undercut areas, and reciprocation) were assessed. Sensitivity and specificity tests were used to measure accuracy. Sensitivity was defined as the proportion of true positives identified by both techniques, while specificity was measured as a percentage of true negatives compared with the conventional method. Accuracy was assessed as the ability to correctly differentiate true positives and negatives. The paired t-test (95% CI) compared the mean working time between the techniques. **RESULTS.** Agreement on reciprocation was 2.91 times higher in regions with a greater number of edentulous areas compared to those with fewer edentulous areas (P = .025). The agreement of guiding planes in tooth-supported abutments was 2.59 times greater than in distal extension cases (P = .031). Accuracy ranged from 0.73 to 0.85. The working time was significantly longer for the digital technique (P = .030). **CONCLUSION.** Both techniques demonstrated high levels of agreement, especially for reciprocation and guiding planes. The digital method exhibited accuracy ranging from good to very good; however, it required a longer working time compared to the conventional approach. [J Adv Prosthodont 2025;17:115-24]

KEYWORDS

Accuracy; Computer-aided design; Partially edentulous; Removable partial denture; Surveying

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INTRODUCTION

Removable partial denture (RPD) is a non-invasive and cost-effective treatment modality that remains the most common option to replace missing teeth, restore function, and improve esthetics in partially edentulous patients.[1] Designing this prosthodontic component is a challenge because it depends on several clinical and laboratory steps, requiring a great deal of professional experience and skills.[2] Moreover, the treatment's success hinges on meticulous planning and precise framework design, which are crucial for ensuring the stability, retention, and support of the RPD during its function.[3] Achieving this goal requires surveying as a critical step. It helps define the optimal path for inserting and removing dental prostheses, evaluate soft tissue contours, and ensure proper seating of rigid RPD components. This is done by analyzing diagnostic casts, which guarantees adherence to biomechanical and esthetic principles without interferences.[4-6]

Regarding the conventional workflow, surveying is often overlooked in clinical practice. The evaluation of the determining factors, such as guiding planes, undercut areas, interferences, and esthetic appearance, is an essential requirement, and dental practitioners should understand this approach as an integral part of patients' examination.[4] If the surveying process is neglected, the abutment teeth can be improperly prepared, potentially causing structural damage like carious lesion formation or harm to periodontal tissues.[5-7] Because surveying provides diagnostic elements,[4-8] it is a crucial process for planning, designing, and fabricating the RPDs. This ensures the appropriate use and excellent performance of the dental prosthesis and also minimizes future tissue complications and biomechanical injuries.[9,10]

The steady increase in the adoption of three-dimensional modeling software and computer-aided design and manufacturing (CAD-CAM) systems has provided novel solutions based on the precision and clinical effectiveness of the RPD frameworks.[11-18] Previous studies have evaluated the digital workflow regarding the fit and retention, and mechanical properties of the RPD frameworks.[17,19-23] Furthermore, dental techniques and case reports have demonstrated the digital surveying applicability.[12,24-28] However, the authors are unaware of studies that have investigated the accuracy of surveying between conventional and digital techniques.

A suitable RPD requires a flawless design and previous mouth preparation.[7,29] The dentist's expertise regarding the precision of the surveying step is an essential requirement. Bai *et al*.[30] evaluated the trueness between CAD-CAM and freehand procedures for preparing guiding planes for RPDs, evidencing that the CAD-CAM template-assisted method improved the preparation results and could predictably aid clinicians. Moreover, an *in vitro* study performed by the same authors stated the accuracy of the guiding plane preparation using a 3D printing material of CAD-CAM guides.[31] Special attention should be given to surveying because it directly influences the biomechanical performance of the RPDs, ensuring the maintenance of periodontal health and integrity of abutment teeth. Consequently, the aim of this study was to investigate the diagnostic accuracy between conventional and digital surveying for RPD design and planning in partially edentulous arches. The study hypotheses were: (1) digital surveying would yield results comparable to the conventional method; (2) digital surveying would require less working time than the conventional technique.

MATERIALS AND METHODS

The research was approved by the Federal University of Rio Grande do Norte Institutional Review Board (registration number: 4.745.226). The study was conducted according to the Standards for Reporting for Diagnostic Accuracy Studies – STARD guidelines.[32] The digital database of diagnostic casts (Standard Tessellation Language – STL files) obtained from partially edentulous patients was assessed (Dental Prosthesis Laboratory, Brazil). For this purpose, the identity and personal information of the participants were concealed. Eligibility criteria were STL files of diagnostic casts with integrity of the abutment teeth, high-resolution mesh (optimal visual representation of the surface), and without failures or voids in the STL files generated by the 3D scanning process. Four categories of partial edentulism (Class I to Class IV) were considered,[33] including Applegate's rules for the Kennedy classification[1] because no evaluation was done regarding the components of the RPD framework. The 30 diagnostic casts [maxillary (n = 15); mandibular (n = 15)] analyzed represent a convenience sample of STL files of the partially edentulous patients [Class I (n = 7); Class II (n = 2); Class III (n = 18), and Class IV (n = 3)] who met the eligibility criteria.

A total of 111 axial walls [maxillary (n = 61); mandibular (n = 50)] were evaluated considering the guiding planes, and 143 axial walls [maxillary (n = 78); mandibular (n = 65)] were analyzed regarding the undercut areas and reciprocation for both conventional and digital surveying. The surveying was carried out based on the Roach technique, whose path of insertion and removal for RPDs is perpendicular to the occlusal plane. Three reference points (two points in a symmetrical position in the occlusal surface of posterior teeth and one point in the incisor edge of the anterior tooth) were determined, and an equilateral triangle was obtained.[29] The simulation of the height of posterior or anterior teeth was considered when these teeth were missing.

For the conventional surveying, 3D-printed resin casts (Dental model gray, Printax, Odontomega, Ribeirão Preto, SP, Brazil) using a 3D printer (Anycubic Photon Mono SE, Shenzhen Anycubic Technology Co. Ltd., Shenzhen, China) acquired from the STL files were attached to the surveying table Surveyor B2 (Bio-Art Equipamentos Odontológicos Ltda., São Carlos, SP, Brazil), and the perpendicular path was defined. The guiding planes were determined in the proximal surface surrounding the edentulous area using an analyzing rod attached to the vertical spindle of the surveyor. The presence of the guiding plane is observed when the analyzing rod stays in touch with the flat axial surface in an occlusal-gingival direction on abutment teeth, with a height ranging from 2 to 4 mm, providing support and stability to the RPDs (Fig. 1A). For the undercut areas, proportional equality (depth and convergence angle) and the contour of the teeth were considered, allowing the RPD clasp tips to engage for retention.

The presence or absence of 0.25 mm retentive undercut areas on abutment teeth was determined using the undercut gauge. These areas were defined as the triangular space formed between the axial surface of the tooth and the vertical and horizontal spindles of the 0.25 mm gauge (Fig. 1B). Identifying retentive areas allowed for assessing whether the active tip of the retentive arm could engage properly, and whether the principle of reciprocation was upheld. Although the survey line was not drawn, the height of the contour was identified using the analyzing rod and undercut gauge, as is commonly done in clinical practice to guide tooth preparation.

Reciprocation was assessed based on its presence or absence. It was considered present when the field of action of the opposition clasp was equal to or greater than that of the retentive clasp (Fig. 1C).[4,34]

For the digital method, STL files were imported into Dental Wings software (DWOS, Straumann, Montreal, Canada), and the surveying was performed using the available digital tools. The path of insertion and

Fig. 1. Evaluation of the determining factors of conventional surveying. (A) Guiding plane in the axial wall surrounding the edentulous region, (B) Identification of the undercut area using the 0.25 mm undercut gauge, (C) Presence of reciprocation.

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removal was defined to enable the analysis of the determining factors, following the same steps as in the conventional method. The evaluation focused on guiding planes, undercut areas, and reciprocation (Fig. 2). All these parameters were assessed based on their presence or absence. Guiding planes were identified by the absence of color on the axial walls adjacent to the edentulous areas, particularly in the middle and occlusal thirds of the abutment teeth (Fig. 2A). A color gradient scale was used to identify undercut areas. The boundary between the blue and green colors indicated the desirable undercut area (presence of a 0.25 mm undercut) for cobalt-chromium alloys, while other colors represented greater undercut, with red indicating maximum retention (absence of a 0.25 mm undercut area) (Fig. 2B). Reciprocation was considered satisfactory when no color was present on the lingual or palatal surfaces of the abutment teeth (Fig. 2C).

The random allocation sequence of the diagnostic models (STL files) was generated by a single independent examiner M.R.S.C. to determine the early order of the surveying for conventional and digital techniques. A crossover design was used to reduce possible study biases and avoid intra-examiner variability. Thus, both groups, CM (conventional method) and DM (digital method), were split into subgroups, and the surveying was carried out after 15 days (washout period) to eliminate the residual effect of the surveying procedure. The flowchart of the study protocol is described in Fig. 3.

The determination of the path of insertion and removal, analysis of the guiding planes, undercut areas, and reciprocation for both methods was documented by a single independent examiner A.L.C.P. The digital and conventional surveyings were recorded repeatedly to determine the reliability of the procedure, and the kappa index was obtained to check the intra-investigator agreement.[35] Thus, the surveying was performed in 20% of the total sample size. Before the beginning of the study, six diagnostic casts were randomly selected to analyze the reliability of the technique. A second examiner A.F.P.C. with 25 years of experience in the removable prosthodontic field verified the path of insertion and removal and the determining factors, and an inter-rater agreement was measured.[35] The surveying time was measured with a digital stopwatch and recorded in minutes. For CM, the time included safely fixing the diagnostic cast on the cast holder, locking the tilting mechanism, and analysis of the determining factors. For DM, the record of time involved the importation of the STL files, evaluation of the path of insertion and removal, and the determining factors.

The agreement level was based on the questionnaire considering the guiding planes, undercut areas, and reciprocation. The assessment was standardized using dichotomous answers, “agreement” or “no agreement” for the conventional and digital methods, minimizing potential bias in the outcome. The measurement of the level of agreement was performed by a single independent examiner A.K.C.R. considering sensitivity, specificity, and accuracy.[36,37] Sensitivity was determined by the ratio of true positives (TP) compared between both methods, while specificity was calculated as the percentage of true negatives for both methods. Accuracy was assessed by considering the number of true positives and negatives in the total sample.[38] The formula can be expressed as follows:

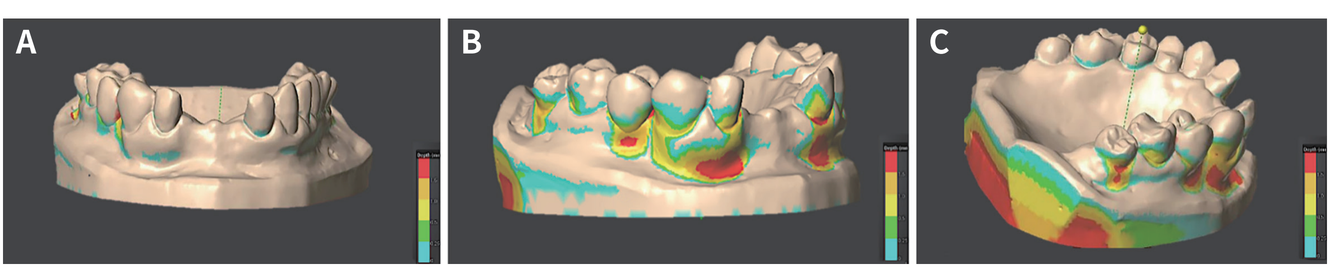

Fig. 2. Evaluation of the determining factors of the digital surveying using the Dental Wings software. (A) Definition of the path of insertion and removal, and analysis of the guiding plane, (B) Undercut areas were checked for the active tips of the retentive clasps, (C) Presence of reciprocation.

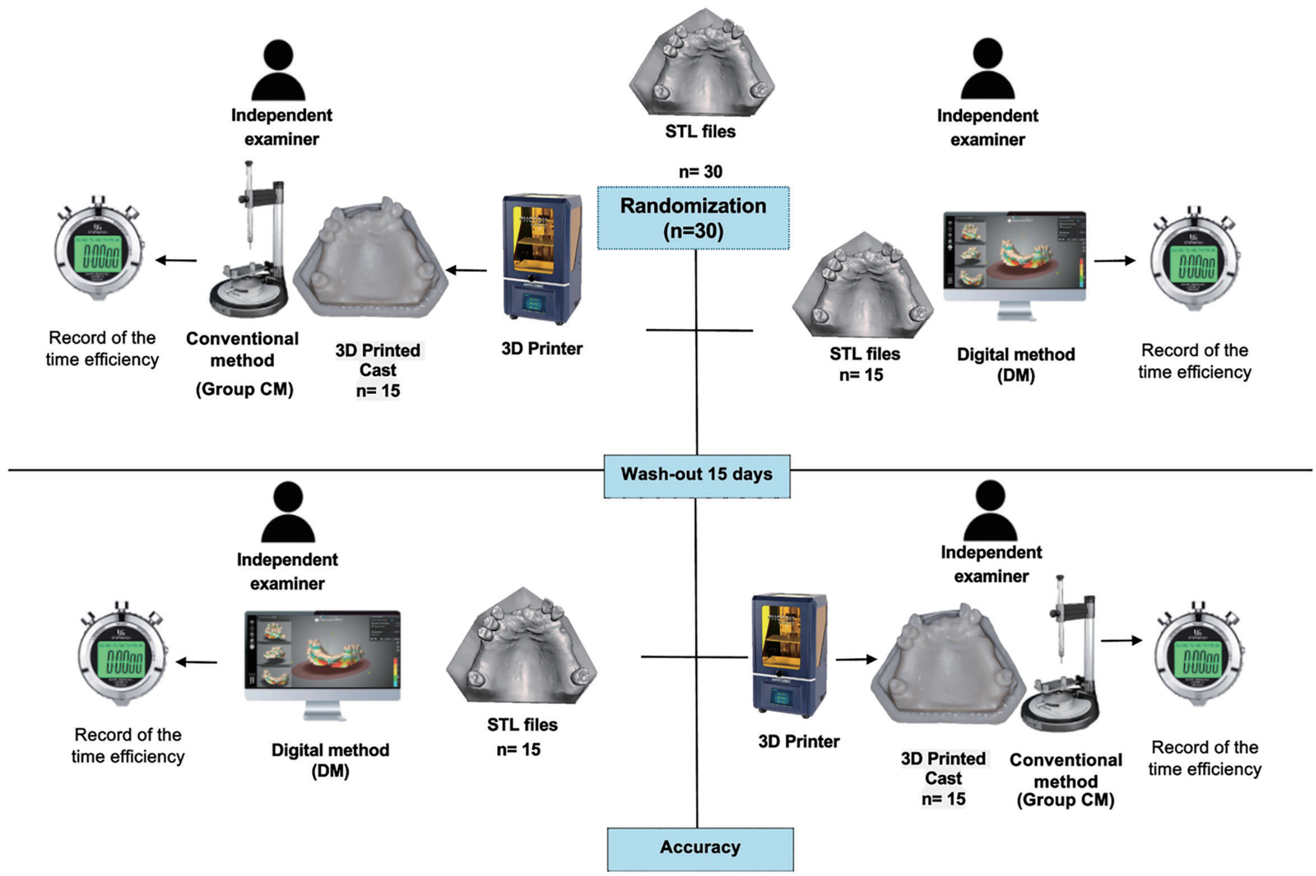

Fig. 3. Flowchart summarizing the study steps. CM: Conventional method, DM: Digital method.

$$\text{Sensitivity} = \frac{TP}{TP + FN}$$

$$\text{Specificity} = \frac{TN}{TN + FP}$$

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

in which,

True Positives (TP): The sum of the agreements between conventional and digital techniques.

False Negatives (FN): The sum of the agreements of conventional technique and no agreements with the digital method.

True Negatives (TN): The sum of the no agreements between conventional and digital techniques.

False Positives (FP): The sum of the no agreements of conventional technique and agreements with the digital technique.

The interpretation of the accuracy was defined as excellent (0.9 – 1.0), very good (0.8 – 0.9), good (0.7 – 0.8), sufficient (0.6 – 0.7), bad (0.5 – 0.6), and < 0.5 as poor (useless test).[36]

The post-hoc power was measured on the OpenEpi website (https://www.openepi.com/). For statistical analysis, a p-value was calculated using a statistical software program (IBM SPSS Statistics v20, IBM Corp., Armonk, NY, USA). Prevalence values for reciprocation in relation to lower edentulous areas were compared between the conventional and digital methods, with a 95% confidence interval (CI) and 80% power, based on 111 (guiding planes) and 143 (reciprocation) axial walls. Data normality was assessed using the Shapiro-Wilk test. Mean and standard deviation (SD) were compared using a paired-t test for both conventional and digital methods, with respect to time, and considering a 95% confidence interval. The Chi-square

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test was employed to evaluate the differences between the levels of agreement between the methods, considering the guiding planes, undercut areas, and reciprocation (α = 0.05). Accuracy, sensitivity, and specificity were quantitatively measured, and the corresponding estimates were provided.

RESULTS

For 143 axial walls evaluated, comparing conventional and digital methods regarding the reciprocation, the sample power was 95.15%. The agreement test for intra-examiner and inter-rater reliability of the surveying demonstrated a kappa index of 0.80 and 0.87, respectively, indicating almost perfect agreement.[35] The evaluation encompassed a total of 30 diagnostic casts and 143 axial walls, focusing on undercut areas and reciprocation. For the assessment of the guiding planes, 111 axial walls were analyzed. A higher mean of guiding planes (4.27 ± 1.80) and undercut areas (5.05 ± 1.34) were evaluated in Kennedy's Class III, followed by Class I with 3.14 ± 0.89 and 3.85 ± 0.69, respectively. Regarding the edentulous spaces, the majority of diagnostic casts presented two spaces (n = 16; 53.3%), followed by one space (n = 7; 23.3%), four spaces (n = 4; 13.3%), and three spaces (n = 3; 10.0%).

Considering the location of the arches, the highest agreement was observed for the evaluation of the guiding planes in the maxillary arch (n = 39; 63.9%). Undercut areas and reciprocation demonstrated a high agreement level regardless of the arch's position. However, the differences were not statistically significant (*P* > .05) (Table 1).

The large agreement level for reciprocation was significantly associated with a greater number of edentulous spaces (*P* = .025) (Table 2). For Kennedy's classification, the agreement was high for the analysis of the undercut area and reciprocation. However, only guiding planes showed a significantly increased agreement associated with tooth-support abutment (Class III or Class IV) (*P* = .031) (Table 3).

For the surveying factors under evaluation, the accuracy values between digital and conventional techniques ranged from good to very good (0.73 – 0.85) (Table 4). The results indicated that the mean duration of conventional surveying (4.61 ± 1.60 min) was shorter than that of digital surveying (5.26 ± 0.95 min), suggesting that digital surveying required significantly more time (*P* = .030) (Table 5).

DISCUSSION

The present study compared the diagnostic accuracy and working time associated with conventional and digital surveying in partially edentulous arches. Given the high accuracy, the first hypothesis of the study was accepted. However, the second hypothesis was rejected as the digital technique required a longer

Table 1. Agreement level regarding guiding planes, undercut areas, and reciprocation for both methods based on the maxillary and mandibular arches

	N	Agreement n (%)	No agreement n (%)	OR	95% CI	*P*
Guiding planes						
Maxillary arch	61	39 (63.9)	22 (36.1)	0.52	0.24 – 1.11	.092
Mandibular arch	50	24 (48.0)	26 (52.0)			
Undercut areas						
Maxillary arch	78	48 (61.5)	30 (38.5)	1.76	0.86 – 3.61	.119
Mandibular arch	65	48 (73.8)	17 (26.2)			
Reciprocation						
Maxillary arch	78	55 (70.5)	23 (29.5)	1.28	0.60 – 2.69	.515
Mandibular arch	65	49 (75.4)	16 (24.6)			

Chi-square test.

Table 2. Agreement level regarding guiding planes, undercut areas, and reciprocation for both methods based on the edentulous space

	N	Agreement n (%)	No agreement n (%)	OR	95% CI	*P*
Guiding planes						
1 or 2 edentulous spaces	69	41 (59.4)	28 (40.6)	0.75	0.34 – 1.62	.468
3 or 4 edentulous spaces	42	22 (52.4)	20 (47.6)			
Undercut areas						
1 or 2 edentulous spaces	101	67 (66.3)	34 (33.7)	1.13	0.52 – 2.45	.753
3 or 4 edentulous spaces	42	29 (69.0)	13 (31.0)			
Reciprocation						
1 or 2 edentulous spaces	101	68 (67.3)	33 (32.7)	2.91	1.16 – 7.59	.025*
3 or 4 edentulous spaces	42	36 (85.7)	6 (14.3)			

Chi-square test. *Statistically significant difference was found.

Table 3. Agreement level regarding guiding planes, undercut areas, and reciprocation for both methods based on the Kennedy classification

	N	Agreement n (%)	No agreement n (%)	OR	95% CI	*P*
Guiding planes						
Distal extension (Class I or Class II)	28	11 (39.3)	17 (60.7)	2.59	1.07 – 6.24	.031*
Tooth-supported abutment (Class III or Class IV)	83	52 (62.7)	31 (37.3)			
Undercut areas						
Distal extension (Class I or Class II)	33	23 (69.7)	10 (30.3)	0.85	0.37 – 1.98	.721
Tooth-supported abutment (Class III or Class IV)	110	73 (66.4)	37 (33.6)			
Reciprocation						
Distal extension (Class I or Class II)	33	21 (63.6)	12 (36.4)	1.75	0.76 – 4.03	.181
Tooth-supported abutment (Class III or Class IV)	110	83 (75.5)	27 (24.5)			

Chi-square test. *Statistically significant difference was found.

Table 4. Sensitivity and specificity tests, and accuracy between digital and conventional methods regarding the surveying parameters (guiding planes, undercut areas, reciprocation)

Surveying parameters	Sensitivity	Specificity	Accuracy
Guiding planes	0.78	0.84	0.79
Undercut areas	0.82	0.88	0.85
Reciprocation	0.75	0.61	0.73

Table 5. Mean (SD) (minutes) of the surveying time between the methods

	Conventional method		Digital method			
N	Mean (SD)	95% CI	Mean (SD)	95% CI	Difference mean (SD)	*P*
30	4.61 (1.60)	4.01 – 5.21	5.26 (0.95)	4.90 – 5.61	0.64 (1.54)	.030*

Paired-t test. *Statistically significant difference was found.

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working time for surveying.

The findings of this study showed that good accuracy was obtained for all determining factors. However, higher disagreement levels for guiding planes considering the Kennedy classification (Class I or Class II) were observed (P = .031). Kennedy's Class I and II demonstrated a lower sample size when compared with Kennedy's Class III and IV. So, fewer axial walls and intercalated spaces were observed. This limitation in sample size may have reduced the diversity in the clinical context evaluated, influencing the agreement consistency of guiding plane evaluation. Consequently, the percentage of disagreement may appear higher than in a larger sample, where minor differences would have a lower proportional impact. However, this does not necessarily mean that the evaluation or identification of guiding planes in distal extension cases is inherently more challenging than in tooth-supported abutments. Instead, the limited representativeness of these cases may have contributed to the observed variations in agreement among the methods.

Typically, the number of edentulous spaces induces an increase in the complexity of defining guiding planes, maintaining reciprocation, and ensuring the undercut areas. In this diagnostic study, the reciprocation for multiple edentulous spaces had an odds ratio of 2.91, indicating a significantly higher agreement compared to a lower number of edentulous spaces (P = .025). This greater concordance between methods can be attributed to the reduced need for preparation of the abutment teeth in the opposition clasp zones. Managing several missing teeth requires a higher degree of reciprocation to ensure the stability and functionality of the prosthodontic devices. Consequently, the balance forces on the dental prosthesis are more challenging in cases involving multiple areas of edentulism, requiring meticulous design to compensate for the missing teeth.

Conventionally, the surveying involves technical complexity regarding the handling of the parallelogram components being more susceptible to errors. The manual inclination of the cast holder to obtain the proper path of insertion and removal depends on the recurrent opening and closing of screws and requires operator abilities and skills to identify and record the adjustments that should be conducted in the support system for providing the correct performance of the dental prosthesis. The digital technique seems easier and more objective because the design CAD software exhibits a color gradient scale that helps the visualization of the undercut areas, assuring clinicians with higher confidence to carry out the preparation of the abutment teeth.[19] This method facilitates a clear visual representation of the survey line, which supports the high degree of accuracy observed.

CAD-CAM systems in removable prosthodontics offer several advantages, including potentially reducing clinical appointments and chairside time, simplifying laboratory procedures, improving ease of handling, and enabling digital file storage.[7,13] Sivaramakrishnan *et al*.[39] reported that the operating time to perform 3D intraoral scanning was longer compared with the conventional method. In this study, digital surveying required a higher working time, implying that performance with the digital technology and proper handling of the software tools depends on the learning curve.

Understanding the dental surveying of the diagnostic casts is important for obtaining the optimal fit of the RPD frameworks regarding the patient's anatomical structures and providing accurate prosthodontic planning.[25] The diagnostic casts assessed in this study reflect actual clinical scenarios, including the presence of tipped and rotated teeth, which affect the complexity of dental surveying. However, the use of a single planning software and only one operator A.L.C.P. for data consistency may be a limitation of the study. The surveying steps were performed by a postgraduate student A.L.C.P., who participated in a graduate teaching internship and has supervised undergraduate students regarding the applicability of both surveying techniques. Aiming to minimize biases, a second examiner A.F.P.C. who has expertise in the prosthodontic field checked the path of insertion and removal and determining factors. To comprehensively evaluate digital surveying, further clinical studies are essential. These studies should focus on accuracy and time efficiency, incorporating feedback from dental laboratory technicians, clinicians, prosthodontists, and undergraduate students. Additionally, a comparison of abilities and performance between the expert and non-expert professionals is needed to provide a thorough understanding. Although the results have been promising, adapting long-standing habits and methods is challenging. Given the transition period from conventional and digital techniques, a learning curve with software tools is required to optimize the process and improve the efficiency of this process.

CONCLUSION

Based on the findings of this diagnostic study, the following conclusions were drawn: (a) The digital surveying method demonstrated accuracy ranging from good to very good. (b) The level of agreement between both techniques attained high percentages, especially for the reciprocation in multiple edentulous spaces and guiding planes, considering tooth-support abutments (Class III or Class IV). (c) The digital surveying technique proved to be the least time-efficient when compared to the conventional method.

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