

Comparing analog and 3D measurements of vertical dimension in edentulous subjects

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ABSTRACT

Objective: This study aimed to explore the feasibility and reliability of measuring the vertical dimension of occlusion/rest (OVD/RVD) on 3D facial scans of edentulous patients.

Methods: Nineteen edentulous participants rehabilitated with complete removable dental prostheses (CDs) participated in this study. Analog measurements (control) were obtained directly on the face for each participant with the jaws positioned at the rest position (without CDs, RVD) and at centric occlusion (with dentures, OVD), between the facial landmarks: Glabella (G) and Soft Pogonion (SP), Pronasale (PN) and SP, and Subnasale (SN) and SP. Participants' faces were scanned twice, using a face-scanner (Class 1 LASER, Obiscanner). Scans were imported into a mesh-processing software, and the OVD/RVD were measured digitally. Two investigators performed all the measurements and were blinded. Data analysis included intra-class correlation coefficient (ICC) and pairwise comparison tests ($p < 0.05$).

Results: Digital measurements were higher than analog measurements, and the mean paired difference ranged from -4.86 ± 3.2 to 0.42 ± 2.7 mm. All the differences were statistically significant, except for SN-SP ($p = 0.110$). Magnitude of the differences for the RVD were large for G-SP and SN-SP ($ES > 0.80$) and moderate for PN-SP ($ES > 0.50$). There was a large effect for G-SP when measuring OVD ($ES > 0.50$), and small effect for PN-SP and SN-SP ($ES \leq 0.20$).

Conclusion: Considering the limitations associated with the specific type of facial scanner used in this study, it can be concluded that registering the resting vertical dimension in edentulous patients through digital methods may not be currently recommended. This is due to the potential errors that may arise during the data acquisition process, which could compromise the accuracy and reliability of the measurements.

Clinical Significance: Digital methods for registering the vertical dimension of rest (RVD) in edentulous patients can introduce errors, resulting in occlusal errors and discomfort. Clinicians must, for the moment, still use conventional analog methods to ensure accurate RVD measurement for a successful denture therapy.

1. Introduction

The use of computer-aided design and computer-aided manufacturing (CAD-CAM) technology for the fabrication of complete dentures (CDs) was first reported in the early 1990s [1]. Initially, the technology was in its infancy, with limited adoption due to a big learning curve, high costs and the difficulty in access to the technology required. Over time, advancements in CAD-CAM technology have made

the process more accessible and efficient, leading to its widespread acceptance in the dental field. Integrating digital technology into this treatment protocol has transformed traditional clinical workflows, enhanced fabrication accuracy, utilized materials with superior mechanical properties, reduced both treatment and lab processing times, lowered costs, and ultimately improved patient outcomes and satisfaction [2]. However, even with all the advancements and technology available today, CDs still cannot be manufactured in a completely digital

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workflow [3]. Master impressions and the registration of jaw relations still require conventional analog clinic steps [3–6].

The accurate measurement of the vertical dimension of occlusion/rest (OVD/RVD) is a critical aspect of prosthodontic treatment, particularly in the fabrication of complete dentures for edentulous patients [7]. Establishing an optimal OVD/RVD is essential for ensuring proper function, aesthetics, and patient comfort [8–10]. Traditional methods for determining OVD/RVD rely heavily on clinical judgment and analog techniques [11]. While these methods can be effective, they are often time-consuming, require significant clinical expertise, and are subject to variability, leading to inconsistent results [7,8,10,12].

With the advent of advanced digital technologies, there is a growing interest in leveraging these innovations to enhance the precision and efficiency of prosthodontic procedures. One such technological advancement is the use of 3D facial scanners. These devices offer the potential to capture detailed and accurate three-dimensional images of a patient's facial structure, providing valuable data that can be used to assess and measure the vertical dimension of occlusion. By integrating facial scanning technology into the prosthodontic workflow, it may be possible to streamline the process, reduce chair time, and improve the consistency and reproducibility of OVD/RVD measurements [13–16].

3D facial scanners work by projecting light patterns onto the face and capturing the reflected light with sensors to create a precise 3D model of the facial anatomy. This non-invasive and rapid imaging technique can provide comprehensive data on facial landmarks, which are crucial for determining the occlusal vertical dimension. The ability to accurately digitize these landmarks and measure the OVD from a 3D model opens new possibilities for fully digital workflows in denture fabrication.

This study aimed to explore the feasibility and reliability of using 3D facial scanners to measure the vertical dimension of occlusion in edentulous patients and compare it with traditional analog measurements made directly on the face. Therefore, based on the study aim, the null hypothesis set for this pilot study was that there would be no significant differences between the vertical dimension measurements made digitally on 3D facial images and the measurements made directly on the face using traditional analog methods.

2. Materials and methods

This study was conducted in the Clinic of General-, Special Care- and Geriatric Dentistry, in the Center for Dental Medicine at the University of Zurich, in Switzerland.

2.1. Ethics statement

A clarification of responsibility was received from the relevant ethics committee (BASEC Nr. Req-2023-00163).

2.2. Sample size

For the current study, an effect size, $|\rho| = 0.09864$, was obtained from the results of a previously published study [17]. With the determined effect size of $|\rho| = 0.09864$, alpha error prob = 0.05, and for a power of $(1-\beta) = 0.80$, the required total sample size was calculated to be 18 participants. Assuming a 5 % dropout rate, the final sample size was adjusted to 19 participants. A post hoc sample size calculation was planned in case of non-significant correlations. The sample size calculation was performed using validated free software (G*Power, version 3.1.9.6 for Mac OS X 10.7 to 14, Düsseldorf, Germany) [18].

2.3. Participants

The participants were included if they were completely edentulous in both jaws, rehabilitated with complete removable dental prostheses (CDs). The participants were excluded if they suffered from any Temporomandibular Joint Dysfunction (TMD) or had any visible facial

abnormality. Participation was completely voluntary.

2.4. Facial landmarks and scanning procedure

The soft-tissue landmarks on the face chosen for the vertical dimension measurements were, Glabella, Pronasale, Subnasale, Soft Pogonion [19–22]. The landmarks were located on the subject's face and were identified with a conventional marker (Staedtler permanent, Germany). After the identification and marking of the landmarks, the participants' faces were scanned utilizing a class 1 laser scanner equipped with two LEDs of varying intensities, ports for external light connections, an infrared structured red-light laser projector, and a set of sensors comprising a color sensor and an infrared sensor (Obiscanner, Fifthingenium, Milan, Italy) [23,24]. Each participant was scanned twice. Once with the prostheses *in situ* maintained in centric occlusion, and a second scan acquired without the prostheses *in situ* while maintaining the jaws in rest position. Fig. 1

Face scanning was performed under controlled conditions for all the subjects as recommended by the manufacturer and as described in previous publications [17,23–25]. The scanner features a standard (quick scan) and an advanced mode. The scans were all performed using the advanced mode for a more precise capture. The lighting conditions for this pilot study were consistent with those typically found in a standard clinical setting. No specialized or enhanced light sources were utilized, as the goal was to preserve the authenticity of the experimental setup. This approach aimed to replicate the conditions commonly encountered in routine clinical practice, ensuring that the findings would be applicable to real-world scenarios and without the necessity of elaborate armamentarium and/or complex environments for the acquisitions. The scan data was stored in .stl, .obj, and .ply formats. These data files were then exported into an open source mesh processing and editing 3D triangular meshes for performing the digital measurements (Meshlab_64bit_fp, Version 2022.02, <https://www.meshlab.net/#>) [26].

2.5. Measurements

Measurements of the vertical dimension at rest, and at occlusion were made by as in a previously published report [17]. The distances measured and used for analysis in this study were the measurements obtained without the prostheses *in situ* with the jaws at the rest position, and with the prostheses *in situ* while maintained in centric occlusion (Figs. 2& 3). The distances were measured between:

1. Glabella (G) and Soft-tissue pogonion (SP)
2. Pronasale (PN) and SP
3. Subnasale (SN) and SP

Initially, all measurements were conducted directly on the face utilizing a digital Vernier caliper (Walter Digital Caliper, manufactured by Walter Werkzeuge GmbH, Salzburg, Austria). The digital measurements were performed digitally in a 3D mesh processing software (MeshLab, 64bit, ver. 2022.02, www.meshlab.net). All measurements were performed independently by two investigators (S. H. and I. B.) who were reciprocally blinded to each other's measurements. The software's built-in measuring tool was used for the digital measurements. The measurements were made in triplicate for each measurement by each investigator.

2.6. Data analysis

Data was checked for a normal distribution with the Kolmogorov-Smirnov test, and descriptive statistics were performed. The paired *t*-test was used for within-group comparisons. Reliability analysis using intra-class correlation coefficient (ICC) was performed to assess the consistency of the measurements across raters, where values below 0.5

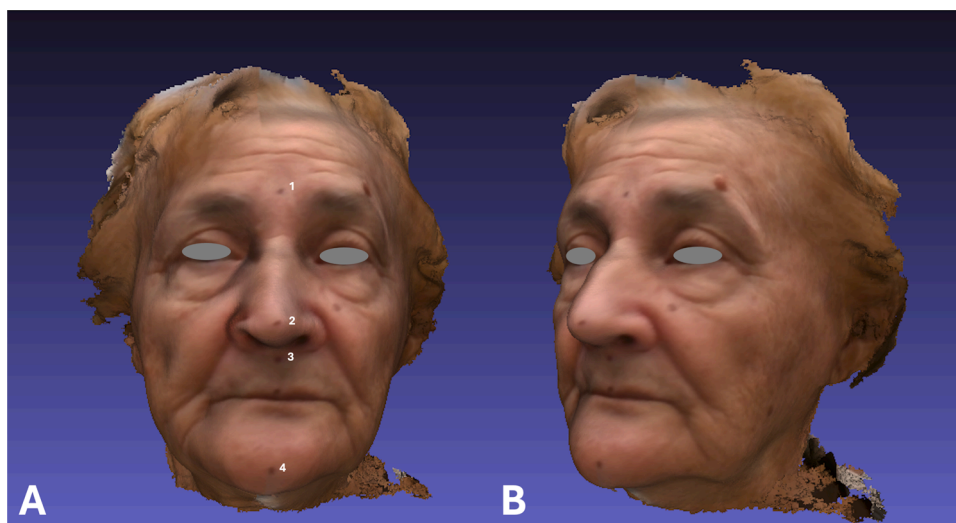


Fig. 1. An example of the face scan (A- frontal view, B – lateral view) with the marked anatomical landmarks (1- Glabella, 2- Pronasale, 3- Subnasale, 4-Soft-tissue pogonion) of one of the participants without the dentures *in situ* for capturing the resting vertical dimension (RVD).

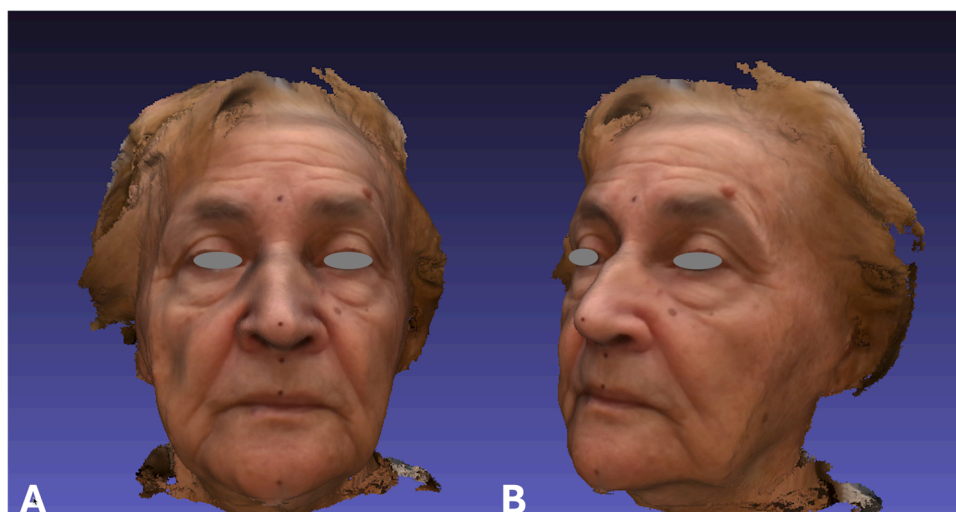


Fig. 2. An example of the face scan (a- frontal view, b – lateral view) of one of the participants with the dentures *in situ* for capturing the occlusal vertical dimension (OVD).

indicate poor reliability, between 0.5 and 0.75 moderate reliability, between 0.75–0.9 good reliability, and values above 0.9 indicates excellent reliability.

The Bland-Altman plot was used to compare the two measurement techniques (analog and digital), by depicting the differences between the two techniques plotted against the averages of the two techniques. Since there were multiple measurements per subject for each method, the Bland-Altman plots with multiple measurements per subject were used. The analog technique was considered the reference method, and results were expressed as the mean differences, and their corresponding limits of agreement (± 1.96 SD of differences).

Then, multiple regression analysis was performed using Generalized Estimating Equations (GEE), considering the correlation of within-subject data in the repeated-measured design, due to the multiple measurements within-examiner, and the duplicated assessment for the same patient using the different methods (analog and digital) and different mandibular positions (RVD and OVD). Regression parameter estimates were expressed as regression coefficients (B) and their standard errors (SE), and p-values lower than 0.05 were considered statistically significant.

The IBM-SPSS 24.0 and the MedCalc 20.111 software were used for the statistical analyses.

3. Results

Complete data were obtained from 18 patients, and for one patient the digital measures of the SN – SP distance was not measured due to a faulty reproduction of the SN point in the scan. Therefore, three repeated measurements each were obtained from the 19 edentulous for each assessment, by the two independent examiners, under two conditions (RVD and OVD), using analog and digital methods, for the three measured vertical distances (G – SP, PN – SP, and SN – SP).

Table 1 summarizes the data for the analog and digital measurements for RVD and OVD. Overall, the digital measures were greater than the analog ones and all the differences were statistically significant (Table 1). Moreover, the magnitude of the differences for the RVD were large for G-SP and SN-SP and moderate for PN-SP. There was a large effect for G-SP when measuring OVD, and small effect for PN-SP and SN-SP (Table 1).

Table 2 depicts the measure of reliability, specifically the reliability

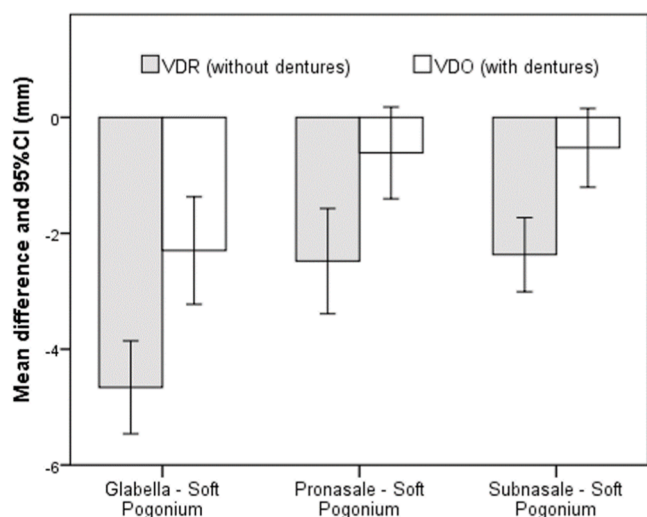


Fig. 3. Differences between Analog and digital (analog – digital) measurements according to the registration position and face distance parameter.

of the two different raters to measure the similarly (inter-rater) for both the analog and digital measurements. There was excellent reliability for the analog and digital measurements and the findings demonstrated that the measurement procedures were robust to changes among the raters, independent of the method.

Band-Altman analysis (Table 2) shows that the discrepancy between the methods is biased for the digital measurements (digital measures were larger than analog values), and larger for RVD (without dentures). The measurement errors were lower for the PN and SN points, and negligible for measurements with the dentures (OVD). The wide limits of agreement suggest low precision and indicate that the two methods are not reasonably comparable.

The differences between analog and digital measurements are depicted in Fig. 3, showing lower discrepancies for OVD when the PN and SN points were considered as reference landmarks. The differences between analog and digital measures with the dentures in position (OVD) were negligible when the PN and SN points were used.

Finally, GEE regression models corroborate the effect of the measurement method on the variability of all the parameters (Table 3). However, the effect of the mandibular position was not affected for the SN measures, and less affected for the PN measures (Table 3). Therefore, the findings suggest that the measurements with the face scanner may be more reliable when the PN or SN landmarks are considered, and when the measurements were performed with the dentures in occlusion (OVD).

4. Discussion

The results of this study provide an insightful evaluation of using a 3D facial scanner to measure the vertical dimension of occlusion (OVD) and at rest (RVD) in edentulous patients. The primary aim was to determine whether digital measurements obtained from 3D facial

images could reliably match traditional analog methods, which involved direct measurements on the patient’s face. The study revealed several key findings. Findings show that the digital measurements were generally larger than analog measurements. These differences were statistically significant, thus indicating that the two methods were not interchangeable. The study revealed a bias in digital measurements, which tended to be larger than analog measurements and this discrepancy was more pronounced for RVD measurements. The study null hypothesis, therefore, must be rejected.

The main limitation in this study that could have affected the results could have been the type of the scanner employed. The scanner used was a portable class I laser scanner [23,24]. The scanner lacked a one-shot capture procedure and required that the participant perform controlled, rapid movements to complete the acquisition process, and various errors may have occurred during this procedure. In edentulous patients, maintaining the jaws separated in a relaxed position and make the above-mentioned movements might have been a difficult task, and this could have resulted in inconsistencies. This could have been the logical explanation as to why the RVD measurements were more exaggerated. Perhaps the RVD measurements may have been accurate by using a scanner that could acquire the face scan without having the participant to perform movements. However, it has been documented in former studies that the scanner used in the current study has been accurate for OVD measurements [17,25], and this was also confirmed by the present study findings.

However, it is pertinent to acknowledge the fact that RVD measurements and registrations are done by analog methods that may not be considered entirely accurate, and are dependent highly on clinical judgements [27–38]. Hence, the errors may not only be related to the scanner or the scanning procedure, nevertheless the differences revealed

Table 2 Reliability measures for the analog and digital measurements, with and without dentures.

		Inter-rater reliability – ICC (95 %CI)		Analog vs Digital – Measurement error (95 %CI)*
		Analog	Digital	
Without dentures	Glabella – Soft Pogonium	0.956 (0.927 – 0.974)	0.999 (0.999 – 1.00)	–4.9 (–11.3; 1.6)
	Pronasale – Soft Pogonium	0.958 (0.929 – 0.975)	0.998 (0.997 – 0.999)	–2.5 (–9.1; 4.1)
	Subnasale – Soft Pogonium	0.938 (0.897 – 0.963)	0.997 (0.995 – 0.998)	–2.2 (–7.0; 2.7)
With dentures	Glabella – Soft Pogonium	0.986 (0.977 – 0.992)	0.999 (0.999 – 1.00)	–2.3 (–9.0; 4.5)
	Pronasale – Soft Pogonium	0.973 (0.954 – 0.984)	0.999 (0.998 – 0.999)	–0.6 (–6.6; 5.3)
	Subnasale – Soft Pogonium	0.963 (0.937 – 0.978)	0.997 (0.996 – 0.999)	–0.4 (–5.9; 5.0)

* Bland-Altman plot with multiple measurements per subject.

Table 1 Summary of the original measurements (in millimeters), paired differences, and magnitude of the differences between measurements with and without dentures.

		Analog	Digital	Mean difference (SD)	p-value (paired t-test)	Effect size*
Without dentures	Glabella – Soft Pogonium	118.1 (7.5)	123.0 (8.2)	–4.86 (3.24)	<0.001	1.50
	Pronasale – Soft Pogonium	70.2 (7.0)	72.7 (6.8)	–2.48 (3.30)	<0.001	0.75
	Subnasale – Soft Pogonium	54.1 (5.6)	56.3 (5.4)	–2.15 (2.41)	<0.001	0.89
With dentures	Glabella – Soft Pogonium	117.3 (7.8)	119.6 (9.3)	–2.27 (3.37)	<0.001	0.67
	Pronasale – Soft Pogonium	69.0 (7.1)	69.6 (7.9)	–0.63 (2.99)	0.026	0.21
	Subnasale – Soft Pogonium	54.1 (5.1)	54.6 (5.9)	–0.42 (2.72)	0.110	0.15

* 0.2 (small effect), 0.5 (moderate effect) and 0.8 (large effect).

Table 3

GEE regression model estimates for the face measurements, according to the methods (analog vs digital) and mandibular position (RVD vs OVD).

Parameter		Glabella – Soft Pogonion		Pronasale – Soft Pogonion		Subnasale – Soft Pogonion	
		B (SE)	p-value	B (SE)	p-value	B (SE)	p-value
Intercept		12.02 (0.21)	<0.001	7.00 (0.18)	<0.001	5.50 (0.05)	<0.001
Method	Analog	–0.357 (0.50)	<0.001	–0.155 (0.04)	<0.001	–0.171 (0.06)	0.002
	Digital	0		0		0	
Position	RVD (without dentures)	0.208 (0.08)	0.009	0.213 (0.10)	0.038	0.089 (0.08)	0.285
	OVD (with dentures)	0		0		0	

in the current study should not be ignored.

An interesting finding that was confirmed by the present study was that the landmarks selected for the measurements played a significant role in the differences between the analog and digital measures. PN and SN points showed lower measurement errors and discrepancies between digital and analog methods, when compared to measurements made from the Glabella and this finding confirms the previously documented evidence in literature [39]. Although this may have not been the scope of the current study, a clinical recommendation to measure the OVD/RVD from the PN can be made based on the findings of this study [39].

Although the present study adhered to a robust methodology, it is important to acknowledge certain limitations that may have influenced the findings. The study's sample size was relatively small, and this may limit the generalizability of the results. Future studies with larger sample sizes are deemed necessary to validate these findings. This was conducted in a single center and might have introduced location-specific biases. However, the methodology adopted followed all the established procedures and as previously documented in former studies. Hence, this location bias may be assumed negligible. However, a multi-center study on a diverse cohort could perhaps provide more comprehensive data and is recommended. Additionally, a significant limitation of this study was the reliance on a single type of facial scanner. The inherent constraints and capabilities of this specific scanner may have influenced the scope and accuracy of the findings. These limitations are particularly relevant when considering the proposed applications outlined in the study, as they may restrict the generalizability and applicability of the results to broader contexts or alternative technologies.

5. Conclusion

Considering the limitations associated with the specific type of facial scanner used in this study, it can be concluded that registering the resting vertical dimension in edentulous patients through digital methods may not be currently recommended. This is due to the potential errors that may arise during the data acquisition process, which could compromise the accuracy and reliability of the measurements.

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CRedit authorship contribution statement

Murali Srinivasan: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Stefan Handel:** Writing – original draft, Writing – review & editing, Validation, Visualization, Investigation, Methodology, Data curation. **Innocenzo Bronzino:**

Writing – review & editing, Methodology, Investigation, Data curation. **Porawit Kamnoedboon:** Writing – review & editing, Methodology, Formal analysis. **Gerry McKenna:** Writing – original draft, Writing – review & editing, Validation. **Claudio Rodrigues Leles:** Writing – original draft, Writing – review & editing, Validation, Formal analysis.

Declaration of competing interest

The authors declare that they have no conflict of interests.

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