Digital and Analog Vertical Dimension Measurements: A Clinical Observational Study

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Purpose: To compare the resting vertical dimension (RVD) and occlusal vertical dimension (OVD) measurements obtained using a facial scanner to those obtained using conventional methods and to evaluate the influence of the file format on the accuracy of the digital calculations. Materials and Methods: Participants (N = 30) received marks on the glabella (Gb), tip of the nose (TN), and pogonion (Pg). Interlandmark distances Gb–TN and TN–Pg in the OVD and RVD positions were recorded by two operators conventionally (manual group) and digitally (digital group). For the manual group, measurements were obtained using a caliper. For the digital group, 10 scans in each position were obtained using a facial scanner (Face Camera Pro, Bellus3D) and exported in tessellation with polygonal faces (OBJ) and standard tessellation language (STL) file formats. Digital measurements were performed using both facial scan file formats and a specialized software (Matera 2.4, exocad). The interocclusal rest distance (IRD) and the intraclass correlation coefficient were calculated. Shapiro-Wilk test was used to determine normal distribution. Independent samples t test, one-way analysis of variance, and post hoc Tukey test were used for analyses (α = .05). Results: No significant differences were found between the manual and the digital measurements using the OBJ files or the digital measurements using the STL files (P > .05). The IRD ranged from 0.72 ± 0.48 mm to 5.00 ± 1.34 mm. The inter- and intraoperator reliability were significant (P < .001), with a Cronbach’s alpha value ranging from .994 to .997. Conclusion: No difference was found between manual and digital measurements. A high measurement consistency was encountered for each operator and between the operators. The facial scan file format did not influence the digital measurements. Int J Prosthodont 2021;34:419–427. doi: 10.11607/ijp.7270

The determination of vertical dimension is the foundation of all restorative procedures.1–7 Many techniques have been described to measure the resting vertical dimension (RVD) and the occlusal vertical dimension (OVD) in dentate and edentulous patients, including maxillary and mandibular anatomical interlandmark measurements obtained morphologically,8–15 physiologically,16–18 or craniofacially.19–21 A combination of verification techniques has been recommended to improve the reliability of estimated OVD and RVD.22,23 However, the dental literature does not provide a consensus on a universally accepted method for their precise determination.1–6 Furthermore, mandibular resting position varies between individuals, occasionally in the same setting and between settings in the same subject.6 It can be influenced by several factors, including posture, sleep, exercise, emotional tension, speech, pain, and denture status.6,24–27
The discrepancy between RVD and OVD is defined as the interocclusal rest distance (IRD) or “freeway space.” The dental literature has reported freeway space to be frequently between 1 and 3 mm, although this range has also been reported to be up to 5, 6, 7, 8, and 9 mm.

Digital technologies such as intraoral and facial scanners and computer-aided design (CAD) software have been incorporated into restorative procedures. Previous authors suggested that facial scanning to assess vertical dimension would one day be part of the ongoing transition to digital dentistry. Adjunctive records of clinical techniques made by photographic or video-graphic means are already common in some branches of dentistry.

Facial scanning accuracy can be influenced by the scanning technology, calibration, and apparatus maintenance. Previous studies have stated deviation values close to 1 mm, but a discrepancy of up to 2 mm has been considered clinically acceptable. Facial scanners produce static 3D facial representations at different positions that are similar to 2D photographic images of a patient. Therefore, different 3D facial representations of a patient could be obtained to determine OVD and RVD measurements and could be introduced in the digital workflow of restorative treatment planning procedures. However, the accuracy of those digital OVD, RVD, and IRD measurements remains unclear. Furthermore, facial scans can be obtained in different file formats, namely tessellation with polygonal faces (OBJ), standard tessellation language (STL), and polygon file format or Stanford triangle format (PLY). The STL file contains the surface geometry of the scanned object, while the OBJ and PLY files comprehend color and texture information as well. The influence of the file format used when performing digital measurements in a dental CAD software is likewise uncertain.

The objectives of this observational study were to compare the conventional and digital procedures using 3D facial reconstructions to measure the RVD and OVD and to evaluate the influence of the 3D facial reconstruction file format on the accuracy of the digital calculations. The null hypotheses were that no significant differences in the RVD and OVD measurements would be found between the conventional and digital measuring methods and that no significant differences in the RVD digital measurements would be found between the OBJ and STL formats of the 3D facial reconstructions.

**MATERIALS AND METHODS**

**Patient Sample**
A total of 30 volunteers participated in the present study (N = 30). All participants were recruited at the Texas A&M Health Science Center. The protocol was approved by the Institutional Review Board (IRB) committee of the College of Dentistry at Texas A&M University (IRB2019-1051D). The participants were all over 18 years of age. Non-English speakers, pregnant women, individuals with physical disabilities, and prisoners were excluded. The inclusion criteria were complete maxillary and mandibular natural dentition with bilateral molar support and absence of craniofacial syndromes or deformities, facial pain or other chronic pain conditions, facial scar tissue, lip incompetence, and previous facial trauma or maxillofacial surgery.
Data Collection and Study Design

Three anthropometric soft tissue landmarks were marked using thin, hypoallergenic eyeliner crosses on the glabella (Gb), tip of the nose (TN), and pogonion (Pg; Fig 1). The eyeliner crosses on soft tissue landmarks were kept in position until all measurement and digitizing procedures were performed, then completely removed with sanitary alcohol wipes. Measurements between landmark positions Gb–TN, TN–Pg in OVD position (OVD–TN–Pg), and TN–Pg in RVD position (RVD–TN–Pg) were obtained on each participant by two operators (M.M. and M.R.), who were blinded to each other’s measurements, using two techniques: directly on the participant’s face (manual group) and digitally on the 3D facial reconstruction (digital group; Fig 2). The order of the manual and digital measurements was decided randomly by flipping a coin.

For the manual group, interlandmark distances were measured using a digital caliper (Digital Caliper, FINO; Fig 3). The manufacturer of this digital caliper reports an accuracy of 0.01 mm. Participants were instructed to sit upright adopting a natural head position and to keep their eyes open, looking to the horizon without facial expression. They were coached to swallow saliva with their lips closed and to maintain the relaxed position while the operator measured the Gb–TN and RVD–TN–Pg. Afterwards, the participant was instructed to position in maximum intercuspation (MIP), sustaining closed lips. Then, the OVD–TN–Pg was recorded. The IRD was computed as the difference between the RVD and OVD.15 Three measurements for each interlandmark distance were obtained.

For the digital group, a facial scanner (Face Camera Pro, Bellus3D) connected to a tablet (MediaPad M3, Huawei) and controlled by a specific software (Face Camera App, Bellus3D) was selected. The scanner calibration was performed before each acquisition procedure following the manufacturer’s instructions. Scanning conditions were standardized by seating the participants in an adjustable rotating chair at a 30- to 45-cm distance from the scanner in a room with no windows, 1,000 lux (Light Meter LX1330B, Dr. Meter), and 4,100 K of illuminance. The scanning procedures were obtained in high-definition (HD) mode.

The digital group was further divided into RVD and OVD subgroups. In the RVD subgroup, 10 facial scans were sequentially performed on each participant, adopting the same facial expression and RVD position as described for the manual group. In the OVD subgroup, a further 10 facial scans were consecutively performed on each participant, adopting the same facial expression and OVD position as described for the manual group. After every digitizing procedure, the 3D facial reconstruction was reviewed in the software device to confirm the quality of the facial scan by assessing if the landmarks were visualized clearly, without distortion or duplication. The 3D facial reconstructions were based on the stereophotogrammetric algorithm and were exported as both OBJ files and STL files. The same interlandmark distance measurements that were performed on the manual group were measured on the OBJ and STL files of the 3D facial reconstructions using the measuring tool of a dental software program (Matera version 2.4, exocad) by the two operators (Figs 4 and 5). Each interlandmark distance was measured three times.

The discrepancy between the RVD and OVD of each participant was calculated by subtracting the mean of the RVD–TN–Pg distance from the mean of the OVD–TN–Pg distance. This discrepancy was also calculated on the manual measurements and digital calculations obtained using the OBJ and STL facial scan files.

Thirty patients were recruited. On each patient, three distances, including Gb–TN, RVD–TN–Pg, and OVD–TN–Pg, were measured. Each of these measurements was repeated using manual, digital OBJ, and digital STL methods. Ten samples were taken from each patient for the digital OBJ and digital STL measurements. The two operators performed each measurement separately, and each operator repeated each measurement three times within each sample. The eventual number of manual measurements for each of the above distances was 6 per patient. The eventual digital OBJ, respecting the number of patients = 30, operators = 2, samples = 10, and repetitions within each sample = 3, gave a total of 1,800 measurements for each of the above distances. The same number of measurements was performed for digital STL. From the basis of 30 patients in the study, the following numbers of measurements were the basis of this study: Gb–TN manual = 180; RVD–TN–Pg manual = 180; OVD–TN–Pg manual = 180; Gb–TN digital OBJ = 1,800; RVD–TN–Pg digital OBJ = 1,800; OVD–TN–Pg digital
OBJ = 1,800; GB–TN digital STL = 1,800; RVD–TN–Pg digital STL = 1,800; and OVD–TN–Pg digital STL = 1,800.

Outcome Variables
The present observational accuracy study aimed to analyze differences between the means and SDs of GB–TN manual, digital OBJ, and digital STL measurements; RVD–TN–Pg manual, digital OBJ, and digital STL measurements; and OVD–TN–Pg manual, digital OBJ, and digital STL measurements (Fig 6).

Statistical Analysis
Shapiro-Wilk test was used to determine normally distributed data. An independent samples t test and one-way analysis of variance (ANOVA) followed by post hoc Tukey test or a similar nonparametric test were used to analyze the data as appropriate (α = .05) using a statistical software program (SPSS Statistics for Windows, version 26, IBM). The inter- and intraoperator reliability were calculated using the intraclass correlation coefficient (ICC) between and by each operator for each interlandmark distance.

RESULTS
For the Gb–TN interlandmark distance evaluation, no significant differences were found between the mean ± SD of the manual measurements, digital measurements performed on the OBJ files, and digital measurements performed on the STL files according to one-way ANOVA (P = .410). The mean ± SD for the RVD–TN–Pg interlandmark measurements was 69.20 ± 5.06 mm in the manual group, 68.63 ± 4.93 mm in the digital OBJ group, and 68.50 ± 4.94 mm in the digital STL

Fig 4 Interlandmark distance measured on a 3D facial reconstruction in OBJ file format using a dental CAD software. (a) Gb–TN. (b) TN–Pg at occlusal vertical dimension.
group. However, comparing the above three groups using one-way ANOVA, no significant differences were computed among the groups ($P = .175$). The mean ± SD for the OVD–TN–Pg was 67.26 ± 4.93 mm in the manual group, 66.84 ± 4.88 mm in the digital OBJ group, and 66.71 ± 4.87 mm in the digital STL group. However, using one-way ANOVA, no significant differences were computed among the groups ($P = .322$; Table 1).

The IRD values were calculated based on the discrepancy between OVD and RVD using independent samples $t$ tests for a result that ranged from 0.72 ± 0.48 mm to 5.00 ± 1.34 mm. In the manual group, the IRD ranged from 0.87 ± 0.97 mm to 5.00 ± 1.34 mm; in the digital OBJ group, the IRD ranged from 0.80 ± 0.90 mm to 4.44 ± 0.99 mm; and in the digital STL group, the IRD ranged from 0.72 ± 0.48 mm to 4.84 ± 0.98 mm (Table 2).

Table 1  Interlandmark Distances (mm) Evaluated in the Manual and Digital Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Gb–TN</th>
<th>RVD–TN–Pg</th>
<th>OVD–TN–Pg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual</td>
<td>56.55 ± 6.01$^a$</td>
<td>69.20 ± 5.06$^b$</td>
<td>67.26 ± 4.93$^c$</td>
</tr>
<tr>
<td>Digital OBJ</td>
<td>56.08 ± 5.98$^a$</td>
<td>68.63 ± 4.93$^b$</td>
<td>66.84 ± 4.88$^c$</td>
</tr>
<tr>
<td>Digital STL</td>
<td>55.99 ± 6.01$^a$</td>
<td>68.50 ± 4.94$^b$</td>
<td>66.71 ± 4.87$^c$</td>
</tr>
</tbody>
</table>

Data are reported as mean ± SD. The same superscript letter in a column indicates no statistically significant differences according to one-way ANOVA ($\alpha = .05$) between groups. Gb = glabella; TN = tip of the nose; Pg = pogonion; RVD = resting vertical dimension; OVD = occlusal vertical dimension.
Interoperator reliability for all facial measurements using the ICC was significant ($P < .001$), with a Cronbach’s alpha value of .997 for Gb–TN, .995 for RVD–TN–Pg, and .994 for OVD–TN–Pg. This indicates a significantly high level of consistency of the measurements performed between both operators. Intraoperator reliability of operator 1 for the Gb–TN measurement using the ICC was significant ($P < .001$) with a Cronbach’s alpha of .999, and for both the RVD–TN–Pg and OVD–TN–Pg measurements was significant ($P < .001$) with a Cronbach’s alpha of .997. This indicates a significantly high level of consistency on the measurements performed by operator 1. Intraoperator reliability of operator 2 was significant ($P < .001$) with a Cronbach’s alpha of .999 for both the Gb–TN and RVD–TN–Pg measurements, and was significant ($P < .001$) with a Cronbach’s alpha of .998 for the OVD–TN–Pg measurement. This indicates a significantly high level of consistency for the measurements performed by operator 2.

**DISCUSSION**

No significant differences were discovered among the manual and digital measurements or between the digital measurements computed on the OBJ and STL facial scan formats using a dental CAD software program. Therefore, neither null hypothesis could be rejected.
Facial digitalization procedures could help facilitate treatment planning and the design of dental prostheses. For example, the digital workflow could be incorporated as a factor aiding the measurement of a patient’s RVD, from which the new OVD can be estimated and applied to design for additive manufacturing of a base plate with a tooth arrangement on a partially or completely edentulous patient. Subsequently, the incorporation of a facial scanner and a dental CAD software to estimate the RVD and OVD has the potential to minimize the number of clinical appointments needed when elaborating a dental prosthesis and to provide more efficient interventions. However, additional clinical studies are needed to fully analyze the facial digitalization procedures to compute the RVD and OVD when developing dental prostheses in different clinical situations, such as partially and completely edentulous patients.

The chosen anatomical landmarks were extraorally located in order to be visible on the 3D facial representation of the participants; therefore, intraoral landmarks were discarded. The use of extraoral landmarks is considered a reliable procedure due to their prominent positions on minimally displacable skin. Direct manual measurement with calipers or rulers is a simple method, but it may be susceptible to errors from inadvertent compression of the soft tissues. CAD software programs standardize environmental variables and measure distances on 3D models without risk of soft tissue distortion. The crossline mark aimed to minimize the measurement point discrepancies between operators. The results of the present study demonstrated a high level of consistency on the inter- and intraoperator reliability; this supports the use of the crossline mark design compared to other designs, such as stickers or dot marks. Furthermore, the facial digitizer selected in this study requires 15 seconds to obtain the data, which challenges the patient to remain still during the digitizing time. Minor movements of the patient cause imprecision in the 3D reconstruction and might have impacted the results of the present study. Detailed commands were transmitted to the participants to minimize this error.

A previous study analyzed the accuracy of the selected facial digitizer. In that study, two independent operators measured interlandmark distances with calipers directly on the patient’s face and digitally on the 3D facial representations of 10 participants. The authors reported a mean trueness value of 0.91 mm, a mean precision value of 0.32 mm, and a mean intraclass correlation coefficient (ICC) between the two operators of 0.99, which is rated as excellent. The facial scanner demonstrated a clinically reliable technique for treatment planning purposes. Scanning accuracy discrepancies might be expected if a different facial scanner is used.

Data of the present study showed that the 3D facial reconstruction file format did not influence the measurements performed. The OBJ file contains not only the 3D surface geometry, but also the color and texture information of the scanned object; therefore, no significant difference was expected between the digital measurements performed on both 3D facial representation file formats. However, to the authors’ knowledge, there is no previous study that compares the file format’s impact on 3D facial measurements. Furthermore, the two operators of this study found it easier to view the demarcation of the landmarks in the color-incorporated format of OBJ files compared to the noncolored STL file format. The collected data presented a generalized tendency for the digital measurements to be smaller than the manual measurements, and the digital measurements obtained using the OBJ files to be smaller than those from the STL files. This discrepancy might be explained by the digitalization procedure’s distortion, as well as by possible manual measurement inaccuracies.

Different techniques have been described to position the mandible in a relaxed position in order to compute the RVD, including phonetics, deglutition/swallowing, and mandibular muscular relaxation using transcutaneous electroneural stimulation. In the present study, the participants were sitting upright adopting a natural head position. Also, participants were coached to swallow saliva with their lips closed and then to keep the relaxed position while obtaining each facial scan. Results might differ with a substitute technique to record the RVD. The IRD calculations varied from 0.72 ± 0.48 mm to 5.00 ± 1.34 mm, which is in agreement with the clinical ranges reported by previous authors. Of the participants, 70% presented an IRD from 1 to 2 mm, 20% from 2 to 3 mm, and 10% from 4 to 5 mm.

The present clinical study presents some limitations, including the small number of facial digitizers analyzed, the CAD software program selected, and the inclusion criteria restricting participants’ clinical characteristics, such as partial or complete edentulism. Additional studies are recommended to analyze the clinical efficiency and reliability of the digital workflow for vertical dimension calculations in different clinical settings and with different patient characteristics.

**CONCLUSIONS**

Within the limitations of the present clinical study, the following conclusions were drawn:

- The digital workflow tested to compute the RVD and OVD measurements, which included facial digitizing procedures and a dental CAD software program, demonstrated no significant difference compared to conventional direct manual measurements.
The clinical workflow showed a high consistency from the measurements obtained between and by each operator.

The file format of the 3D facial representation did not influence the digital measurements' calculations.

The interocclusal rest distance calculations from the manual and digital groups varied from 0.72 ± 0.48 mm to 5.00 ± 1.34 mm, and 70% of the participants presented an IRD from 1 to 2 mm, 20% from 2 to 3 mm, and 10% from 4 to 5 mm.

ACKNOWLEDGMENTS

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REFERENCES

The use of oral implants as a form of replacing missing teeth in partially or totally edentulous patients is considered the gold standard in oral rehabilitation. Although this modality has a history of success in contemporary dentistry, surgical complications may occur, such as excessive bleeding, damage to the adjacent teeth, and/or mandibular fractures. Persistent pain and abnormal somatosensory responses after the ordinary surgery healing time are also potential problems and may lead to the development of a condition named posttraumatic trigeminal neuropathic pain (PTNP). Though relatively rare, PTNP has a profound impact on quality of life. Appropriated previous image 46. Weinberg SM, Naidoo S, Govier DP, Martin RA, Kane AA, Marazita ML. Anthropometric precision and accuracy of digital three-dimensional photogrammetry: Comparing the Genex and 3dMD imaging systems with one another and with direct anthropometry. J Craniofac Surg 2006;17:477–483.

Literature Abstract

The Human Salivary Proteome Wiki: A Community-Driven Research Platform

Saliva has become an attractive body fluid for onsite, remote, and real-time monitoring of oral and systemic health. At the same time, the scientific community needs a saliva-centered information platform that keeps pace with the rapid accumulation of new data and knowledge by annotating, refining, and updating the salivary proteome catalog. The authors developed the Human Salivary Proteome (HSP) Wiki as a public data platform for researching and retrieving custom-curated data and knowledge on the salivary proteome. The HSP Wiki is dynamically compiled and updated based on published saliva proteome studies and up-to-date protein reference records. It integrates a wide range of available information by funneling in data from established external protein, genome, transcriptome, and glycome databases. In addition, the HSP Wiki incorporates data from human disease-related studies. Users can explore the proteome of saliva simply by browsing the database, querying the available data, performing comparisons of data sets, and annotating existing protein entries using a simple, intuitive interface. The annotation process includes both user feedback and a curator committee review to ensure the quality and validity of each entry. This article presents the first overview of features and functions offered by the HSP Wiki. As a saliva proteome-centric and publicly accessible database, the HSP Wiki will advance the knowledge of saliva composition and function in health and disease for users across a wide range of disciplines. As a community-based knowledge and database, the HSP Wiki will serve as a worldwide platform to exchange salivary proteome information, inspire novel research ideas, and foster cross-discipline collaborations. The HSP Wiki will pave the way for harnessing the full potential of the salivary proteome for diagnosis, risk prediction, therapy of oral and systemic diseases, and preparedness for emerging infectious diseases. Database URL: https://salivaryproteome.nidcr.nih.gov/

—David Ojcius, USA

Literature Abstract

Pain Complications of Oral implants: Is That an Issue?

The use of oral implants as a form of replacing missing teeth in partially or totally edentulous patients is considered the gold standard in oral rehabilitation. Although this modality has a history of success in contemporary dentistry, surgical complications may occur, such as excessive bleeding, damage to the adjacent teeth, and/or mandibular fractures. Persistent pain and abnormal somatosensory responses after the ordinary surgery healing time are also potential problems and may lead to the development of a condition named posttraumatic trigeminal neuropathic pain (PTNP). Though relatively rare, PTNP has a profound impact on quality of life. Appropriated previous image


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