Accuracy of Vertical Dimension Augmentation Using Different Digital Methods Compared to a Clinical Situation—A Pilot Study

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Purpose: To test the accuracies of different methods of digital vertical dimension augmentation (VDA) by comparison with a clinical situation. Materials and Methods: Bite registrations with approximately 5 mm of VDA were made in the incisor regions of 10 subjects (mean VDA 4.5 mm). The conventional maxillary and mandibular stone casts in maximum intercuspation (MICP) and VDA bite registrations were digitized for all subjects using a laboratory scanner (control group). Lateral portraits were taken of all subjects to locate the position of the condylar axis. Four different digital VDA methods were compared to the control group: 100% rotation of the mandible referring to the lateral picture (100RL); 85% rotation and 15% translation referring to the lateral picture (85R15TL); 100% rotation in normal mounting mode of the Trios virtual articulator (100R); and jaw-motion analysis (JMA) equipment. The amount of VDA for each experimental group was compared to the control group. The augmented distances between the central incisors and the second molars were measured using 3D analyzing software. The ratio of the augmented distances between the posterior and anterior regions (P/A ratio) was calculated. One-way analysis of variance and multiple comparisons via least significant difference test were carried out to determine statistical significance. Results: The P/A ratio of each group was as follows: Control = 0.61; 100RL = 0.55; 85R15TL = 0.61; 100R = 0.53; JMA = 0.52. Significant differences were observed for control vs JMA and for 85R15TL vs JMA (P < .05). The addition of translational movement was the primary factor for increasing the accuracy of digital VDA, with the lateral picture being a secondary factor. Conclusion: VDA using a virtual articulator with 100% rotation induces an error when compared to the clinical situation. When a clinician performs digital VDA, the setting of 85% rotation and 15% translation produces results closer to the real clinical condition. Int J Prosthodont 2020;33:380–385. doi: 10.11607/ijp.6402

There is a range of clinical situations with a need for vertical dimension augmentation (VDA), such as functional and esthetic full-mouth rehabilitations of extensively worn dentitions or for the treatment of temporomandibular disorders (TMD) using splints. VDA is most frequently required in patients who need minimally invasive treatment for severe attrition and/or erosion.1–3 Conventionally, VDA is predicted in a dental technical laboratory by increasing the level of the incisal pin on the articulator. The hinge axis of the articulator allows rotational movement and induces VDA in models mounted in the maximum intercuspation (MICP) position. As an alternative, bite registration with increased vertical dimension can be used clinically to predict the VDA; however, this procedure usually requires additional diagnostic casts and the mounting of casts for diagnostics.1–8

Two fundamental problems are faced when clinicians attempt to increase vertical dimension in the articulator. The first problem is the error resulting from the difference in movement between the articulator and the real clinical situation (ie, the
mandible). Many authors assume that this is caused by the terminal hinge axis being in pure rotation during the early phases of mandibular opening,9–11 as mandibular movement is not a purely rotational movement, but is followed by translational movement.12–16 However, on the articulator, only rotational movement is performed when the incisal pin is increased. The second error can occur if a facebow transfer is not conducted. As a result, the 3D relationship between the hinge axis and the maxilla on normally mounted casts can differ from that of the clinical situation of the patient.17 These errors lead to different opening ratios between the anterior and posterior regions. The need for occlusal adjustment may increase with increasing error, thereby increasing the total treatment time.

In the era of digital dentistry, various methods to perform virtual VDA have been introduced.18–21 Currently, many types of computer-aided design/computer-assisted manufacturing (CAD/CAM) software, such as Exocad or Dental System (3Shape), offer virtual articulator modules. The movements of the mandible are reproduced in virtual articulators as if they were mounted on a real articulator, and the 3D mounting position can easily be modified in these virtual articulators. Alternatively, virtual VDA can be performed using industrial software (GOM Inspect 2017), which has 3D rotational and translational function in an absolute coordinate system. The function of 3D movement in absolute coordinates is in the industrial software but not in dental CAD software. Moreover, specific digital equipment to record real jaw movements can be used to perform VDA.22–25

The best digital method for VDA that is closest to the real clinical situation is unclear, and studies are needed to compare the virtual environment to the real clinical situation. Hence, this pilot study aimed to examine the accuracies of different digital methods for VDA when compared to a real clinical situation.

MATERIALS AND METHODS

Preparation for Analyses

Ten healthy volunteers (9 men, 1 woman, age range: 33.9 ± 2.1 years) without TMD diagnoses were selected for this study. In all subjects, conventional silicone impressions (Imprint 3, 3M ESPE) were taken for the maxillary and mandibular dentitions. Bite registrations in MICP were performed using a silicone bite registration material (Jet Blue Bite, Coltène). A second silicone bite registration was taken with 5 mm of VDA in the anterior region using a wax plate (Base Plate Wax, Kerr) as an anterior jig. Diagnostic casts of all subjects were fabricated using Type III stone (New Plastone, GC). The maxillary and mandibular casts were scanned with a lab scanner (IScan D104, Imetric) with bite registrations in the MICP and VDA positions.

A dot was positioned on the face to indicate the condyle, and a lateral facial photograph was taken with retraction to the maxillary second premolar using a digital camera (EOS 70D, Canon). The length in pixels between the tip of the incisor and the premolar in the lateral picture can be converted into a real distance in millimeters by measuring the same position in the stereolithography (STL) file. Two lines (b and c) were drawn on the lateral picture, and the lengths were calculated using image software (Photoshop CC, Adobe) to locate the position of the condylar axis (Fig 1).

The maxillary and mandibular STL data were aligned with the MICP position, superimposed using the MICP data as a control, and then aligned three-dimensionally in the absolute coordinate system (GOM Inspect 2017).

Group Information and Analysis Method

Four different virtual VDA methods were performed and compared to the clinical conditions of the study subjects.

The 100R group represents 100% rotation with the lateral picture. The maxillary dentition was aligned with the condylar axis as identified in the lateral portrait (Fig 1), and the VDA was performed with a 100% rotational movement of the mandible using 3D analyzing software (GOM Inspect 2017). The 85R15TL group represents 85% rotation and 15% translation referring to the lateral picture. The VDA was performed with 85% rotational movement and 15% downward translational movement of the mandible using the 3D analyzing software (GOM Inspect 2017). The condylar axis was set using the lateral portrait of each subject (Fig 1).

The 100R group represents 100% rotation. The VDA was performed with a 100% rotational movement of the “normally mounted” jaw scans and a virtual articulator using CAD software (Dental System, 3Shape). The virtual articulator used in this group was the Stratos 300 (Ivoclar Vivadent).

In the JMA group, 3D jaw-motion analysis (JMA) equipment (zebris) was applied to record the jaw movement of each subject. The recorded data were transferred to dental CAD software (Exocad) and combined with the STL files of the maxillary and mandibular dentitions in the software. VDA was conducted using the mandibular opening data of the JMA.

Each subject received a clinical VDA bite registration (Jet Blue Bite) as a control with a 5-mm increase in bite in the incisor region using a wax plate as an anterior jig (Base Plate Wax). The buccal and labial surfaces of the diagnostic cast with bite registration were scanned using an intraoral impression scanner (Trios 3, 3Shape). The amount of VDA of the clinical situation was measured, and the amount of virtual VDA of each test procedure was compared to that of the control. The
Fig 1  (a) The distance between the maxillary central incisor and premolar on the lateral picture was measured in pixels in the software and then as (b) real distance in millimeters based on the 3D scan data. (c) The condyle was located using palpation, and the distances “b” and “c” were then measured to identify the condylar axis. (d) The real distances for “b” and “c” were calculated in millimeters, and the maxillary and mandibular dentitions were aligned in maximum intercuspation using the condylar axis information.

Fig 2  Distance measurements for the maximum intercuspation (MICP) and vertical dimension augmentation (VDA) positions. A = Distance between central incisors and second molars in MICP position; B = Distance between central incisors and second molars in VDA position; C = net VDA calculated from B – A.
measuring procedures were as follows. Three points were defined on the surface of each dentition to measure the distances: one was on the mandibular central incisor tip, and two were on the distobuccal cusp tips of the second molars in the mandible. The same was applied for the maxillary second molars, but the third maxillary point was defined as the palatal surface of the central incisor. The y-axis distances of the test and control groups were measured in the MICP and VDA positions, and the augmented distance was calculated using 3D software (GOM Inspect 2017) (Figs 2 and 3).

As shown in Figs 2 and 3, the distance between points 1 and 4 was equal to the y-axis distance between the incisors in MICP and VDA. The distance between points 2 and 5 represents the distance between the right second molars, and between points 3 and 6 the distance between the left second molars. The augmented distance as the posterior/anterior (P/A) ratio was calculated using the following equation:

\[ \text{P/A ratio} = \frac{\Delta R \text{Post} + \Delta L \text{Post}}{2 \Delta \text{Ant}} \]

\( \Delta \text{Ant} \) is the difference in distance of the y axis between the interincisal points of the MICP and VDA positions; ie, the net amount of VDA. \( \Delta R \text{Post} \) and \( \Delta L \text{Post} \) represent the same for distances of the right and left second molars, respectively.

Statistical Analyses
Kolmogorov-Smirnov and Levene tests were performed to evaluate the normality and homogeneity of variance, respectively. Thereafter, one-way analysis of variance and multiple comparisons via least significant difference test were carried out to determine the statistical significance among the groups using SPSS software (version 22, IBM). The significance threshold was set at .05.

RESULTS
The mean and standard deviation P/A ratios were as follows for each procedure: control = 0.62 ± 0.072; 85R15TL = 0.61 ± 0.040; 100RL = 0.55 ± 0.042; 100RVA = 0.53 ± 0.051; JMA = 0.53 ± 0.097. The value of the control, 0.62, means that when the VDA in a patient is 1 mm in the anterior area, the VDA of the posterior area would be 62.1% that of the anterior.

Statistically significant differences were observed for the comparison of control vs JMA and for 85R15TL vs JMA (P < .05) (Table 1, Fig 4).

DISCUSSION
The present study showed how closely the various methods of VDA reproduced a real oral situation. The VDA is usually performed with a semi-adjustable articulator...
achieved by rotational movement of the condylar axis, and 0.75 mm (15%) of the opening was performed by downward translational movement of the mandible. The closest P/A ratio compared to the real situation was accomplished in this group considering the translational movement and the position of the condylar axis.

In the 100R group, the STL files of both dentitions were mounted with average values on the virtual articulator. No individual information on the condylar axis was available, and there was no translational movement. In the 100R and 100RL groups, the P/A ratios were 0.53 and 0.55, respectively, which deviated 14% and 12% from the respective control values. This means that the position of the condylar axis in standard mounting was close to the condylar position in the real position. Translation had a greater effect on the result than the position of the condyle from the lateral picture.

In the control and 85R15TL groups, the P/A ratios were 0.62 and 0.61, respectively, showing only a 1.4% difference. In the JMA group, a wide distribution of results was found. One reason might be that many steps are involved in recording jaw movement in this group. The maxillary headgear needed to be fixed firmly to the head, and the mandibular jig needed to be fixed on the mandibular dentition. The jaw registration system recorded opening and closing movements of the mandible by measuring the travel time of ultrasound impulses.\(^{23}\) The complete recorded data should be transferred to the software (Exocad). The data were expected to be close to the control group because with average mounting that shows rotational movement for the VDA. However, the group that mixed rotation and translation for VDA was closer to the real condition than the others. The approximate ratio of rotation to translation proportions was measured during the early phase of mouth opening.

In the early phase of mouth opening, the movement of the mandible shows rotation on the terminal hinge movement based on Posselt’s envelope of movement.\(^{9,10,26}\) However, translation in addition to rotation would also occur at the same time in a real clinical situation. When VDA is performed using an incisal pin on a virtual or real articulator, the mandible is opened with 100% rotation. The VDA was performed using the location of the condylar axis identified from a lateral picture during smiling—like using a facebow transfer—in the 100RL group. Some translational movement was also combined with rotational movement in this study (85R15TL) to make the result close to the real clinical situation.

The P/A ratio of the 100RL group was 0.55, whereas that of the control was 0.62. This means that in the virtual situation, a mandibular opening of 1 mm in the anterior region through a 100% rotational movement should induce 0.55 mm of VDA in the posterior region, but the VDA of the real situation was 0.62 mm in the posterior region. This suggests that in the early phases of opening, there is some translational movement simultaneous with the rotational movement.

In the 85R15TL group, the movement was composed of 85% rotation and 15% downward translational movement adjusted to the location of the condylar axis from the lateral picture. When the mandible was opened 5 mm in the incisor area in this setting, a 4.25-mm (85%) opening was achieved by rotational movement of the condylar axis, and 0.75 mm (15%) of the opening was performed by downward translational movement of the mandible. The closest P/A ratio compared to the real situation was accomplished in this group considering the translational movement and the position of the condylar axis.

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![Fig 4](image-url)
of the 3D recording of mandibular movement. During these multi-step procedures, however, errors appeared to accumulate, and the outcomes exhibited high SDs. This is likely because the JMA group was the only group in which the opening was not measured with an idealized computer model and because the sample size was not sufficient. Additional studies with larger sample sizes seem to be needed for assessment of JMA.

According to the 100R group (representing arbitrary mounting through a virtual articulator), the P/A ratio would be approximately 0.53, meaning that an increase of approximately 2 mm in the second molar would be obtained, while in the incisal area this increase would be 4 mm. Therefore, approximately 0.1 mm of error occurred in the posterior area for every 1-mm increase in the anterior area compared to the clinical situation because the P/A ratio was 0.62 under real conditions (diagnostic casts with average mounting).

If a splint or provisional restoration is fabricated with a 5-mm increase in the anterior area using an articulator, approximately 0.5 mm of underbite in the molar area will be expected in a real situation. If VDA can be increased with 85% rotational and 15% translational movement in the virtual articulator, then a much closer result to the real situation may be obtained, and the clinical chair time to perform occlusal adjustments could consequently be reduced.

The primary limitation of the present pilot study was that the P/A ratio was used to assess a simple and applicable method by modeling a real situation in daily practice when virtual VDA is performed. For this context, 85% rotational movement and 15% downward translational movement were found to be closest to the clinical situation. On the other hand, the P/A ratio may differ among patients, corresponding to variations in clinical situation. On the other hand, the P/A ratio may consequently be reduced.

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CONCLUSIONS

When virtual VDA is performed, the P/A ratio can be close to a real situation through the setting of 85% rotation and 15% translation.

REFERENCES


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Interview with Dr Hyeonjong Lee by MDT Vincent Fehmer.

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