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Development and Pilot Validation of a Three-Dimensional Skeletal Coordinate-Based System for Occlusal Vertical Dimension Assessment in Elderly Korean Cadavers

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Abstract

Background: Establishing an accurate occlusal vertical dimension (OVD) remains fundamental for prosthetic rehabilitation. Historically, a 40 mm vertical reference has been widely cited; however, this value was derived from dentate adult populations using cast-based measurements. This pilot study aimed to re-evaluate anatomical OVD reference values in an elderly Korean population and to develop and preliminarily validate a three-dimensional skeletal coordinate-based measurement system for occlusal vertical dimension (OVD) using CT data. As a pilot investigation, the feasibility, reproducibility, and anatomical consistency of the proposed method were assessed in elderly Korean cadaveric specimens. These findings provide a methodological foundation for future in vivo clinical application.

Methods: Twenty-five cadaveric specimens were initially screened, and 19 specimens with clearly identifiable vestibular landmarks were included in the final analysis. Virtual mandibular closure was performed by digitally rotating the mandible around a geometrically defined condylar axis until the first posterior occlusal contact was achieved. Vertical measurements were obtained perpendicular to the Frankfort Horizontal plane. Inter-observer reliability for maxillary and mandibular vertical components was assessed using a two-way random-effects model.

Results: The mean maxillary vertical dimension was 20.3 ± 2.7 mm, and the mean mandibular vertical dimension was 15.8 ± 1.9 mm, yielding a mean OVD of 35.2 ± 3.7 mm. Inter-observer reliability was excellent (ICC = 0.986 for maxillary and 0.981 for mandibular components).

Conclusions: Within the limitations of this pilot cadaveric study, CT-based three-dimensional skeletal analysis demonstrated an OVD lower than the historically cited 40 mm reference. These findings should be interpreted as a methodological refinement rather than a contradiction of previous reports and provide standardized skeletal baseline data for future clinical investigations in elderly populations.

Keywords: occlusal vertical dimension; three-dimensional reconstruction; computed tomography; Frankfort Horizontal plane;

elderly population; skeletal reference

Background

Occlusal vertical dimension (OVD) is defined as the distance between two selected anatomical landmarks when the occluding members are in contact (1). Accurate determination of OVD is fundamental in complete denture therapy, as inappropriate vertical dimension may adversely affect facial esthetics, phonetics, masticatory efficiency, and temporomandibular joint stability (2). Both excessive and insufficient vertical dimension have been associated with compromised functional adaptation and patient dissatisfaction, emphasizing the clinical importance of reliable and reproducible determination methods (3). Traditionally, empirical approaches—including facial proportion analysis, phonetic evaluation, and the speaking method—have been used to establish OVD (4-6). However, these techniques rely substantially on neuromuscular coordination and clinician judgment, which may introduce subjective variability and limit measurement reproducibility (3, 6).

Historically, an average vertical distance of approximately 40 mm between the maxillary and mandibular labial vestibular reflections has been cited in clinical literature (7). This value was derived from cast-based measurements of dentate adult patients and was primarily intended to achieve parallel stress-bearing areas in complete denture construction. Subsequent investigations incorporating anterior tooth measurements and overbite correction were likewise conducted in dentate individuals (8). Radiographic analyses evaluating related anatomical landmarks have reported mean values closer to 34 mm (9). Importantly, these reference values were predominantly established from dentate adult populations. Their direct application to elderly individuals—particularly those undergoing prosthetic rehabilitation—may therefore require cautious interpretation. Age-related craniofacial changes and population-specific morphological characteristics may influence vertical dimension measurements (10, 11).

Two-dimensional radiographic techniques derived from classical cephalometric methodologies have been widely applied in craniofacial measurement (10). Nevertheless, projection distortion, landmark identification variability, and structural superimposition may compromise measurement precision (12-15). With advances in computed tomography and digital reconstruction, standardized three-dimensional evaluation based on reproducible skeletal reference planes—such as the Frankfort Horizontal (FH) plane—has become feasible (13, 16-18). These developments facilitate the establishment of standardized and reproducible measurement protocols, enabling consistent evaluation of craniofacial structures across different operators and settings (19).

Furthermore, digital technologies have been increasingly integrated into prosthodontic workflows, improving the precision, standardization, and reproducibility of diagnostic and treatment procedures (20).

Accordingly, the primary objective of this study was to develop and preliminarily validate a three-dimensional skeletal coordinate-based measurement system for occlusal vertical dimension (OVD) using CT data. As a pilot investigation, this study aimed to assess the feasibility, reproducibility, and anatomical consistency of the proposed method in elderly Korean cadaveric specimens prior to future in vivo clinical application.

Methods

2.1 Study subjects and ethical considerations

This study initially screened 25 fresh Korean cadavers obtained through the institutional body donation program of the Catholic Institute for Applied Anatomy (CIAA). However, only 19 specimens (12 males, 7 females; mean age 73.8 years) were ultimately included in the final analysis.

Exclusion was based on insufficient visualization or ambiguous delineation of the upper and lower labial vestibular landmarks on CT imaging. This strict selection criterion was applied to enhance anatomical precision and reduce landmark identification variability.

To ensure an accurate and reproducible simulation of occlusal vertical dimension, specimens were required to exhibit stable posterior occlusal support, with intact or adequately restored molar and premolar dentition. Cases with collapsed occlusion, gross craniofacial deformities, or histories of extensive maxillofacial surgery were excluded.

This study was approved by the Institutional Review Board of The Catholic University of Korea (Approval No. MC22EISI0102).

2.2 Computed Tomography (CT) Image Acquisition

To obtain high-resolution skeletal data for precise three-dimensional analysis, all fresh cadavers underwent multidetector computed tomography (MDCT) using a SOMATOM Definition AS+ system (Siemens Healthineers, Erlangen, Germany) at Seoul St. Mary's Hospital. Image acquisition was performed with a slice thickness of 0.6 mm and a reconstruction interval of 0.6 mm to ensure high spatial resolution and reduce reconstruction-related inaccuracies.

During scanning, gauze was gently placed within the labial vestibules to enhance visualization of the soft-tissue boundaries and to maintain the contour of the perioral soft tissues. The acquired raw data were exported in Digital Imaging and Communications in Medicine (DICOM) format for subsequent volumetric reconstruction. The use of fresh cadaveric specimens, combined with high-resolution imaging parameters, facilitated the acquisition of anatomically preserved data while minimizing distortions typically associated with chemical fixation or tissue dehydration.

2.3 Three-Dimensional (3D) Digital Reconstruction and Virtual Mandibular Closure

In clinical conditions, occlusal vertical dimension (OVD) is typically determined at maximum intercuspation (MICP), reflecting functional occlusal contact under neuromuscular control. However, in cadaveric specimens, functional occlusion cannot be reliably reproduced due to the absence of muscle activity and neuromuscular coordination.

In this study, virtual mandibular closure was performed by rotating the mandible around a geometrically defined condylar axis until the first posterior occlusal contact was achieved. This position does not represent true MICP or centric relation (CR), but rather a mechanically defined, first-contact-based mandibular closure position.

This approach was adopted to establish a standardized and reproducible reference position for three-dimensional skeletal measurement under non-functional conditions. This methodological limitation should be considered when interpreting the results in a clinical context.

The acquired DICOM datasets were imported into three-dimensional medical imaging software for volumetric segmentation of the maxilla and mandible (Figure 1A).

Because CT acquisition was performed in the supine position, the mandible frequently exhibited a post-mortem open-mouth posture that did not represent functional occlusion (Figure 1B). To reconstruct a standardized skeletal occlusal relationship, a virtual mandibular closure procedure was performed.

The mandible was digitally rotated around a geometrically defined condylar rotational axis (Figure 1B), as indicated by the illustrated rotation vector, until the first posterior occlusal contact was established. This first-contact position served as a controlled vertical stop for subsequent morphometric analysis.

The rotational alignment was performed under anatomically constrained conditions to maintain structural consistency and minimize positional artifacts associated with scanning posture. The finalized closed-position models were then exported as STL files for subsequent three-dimensional measurement.

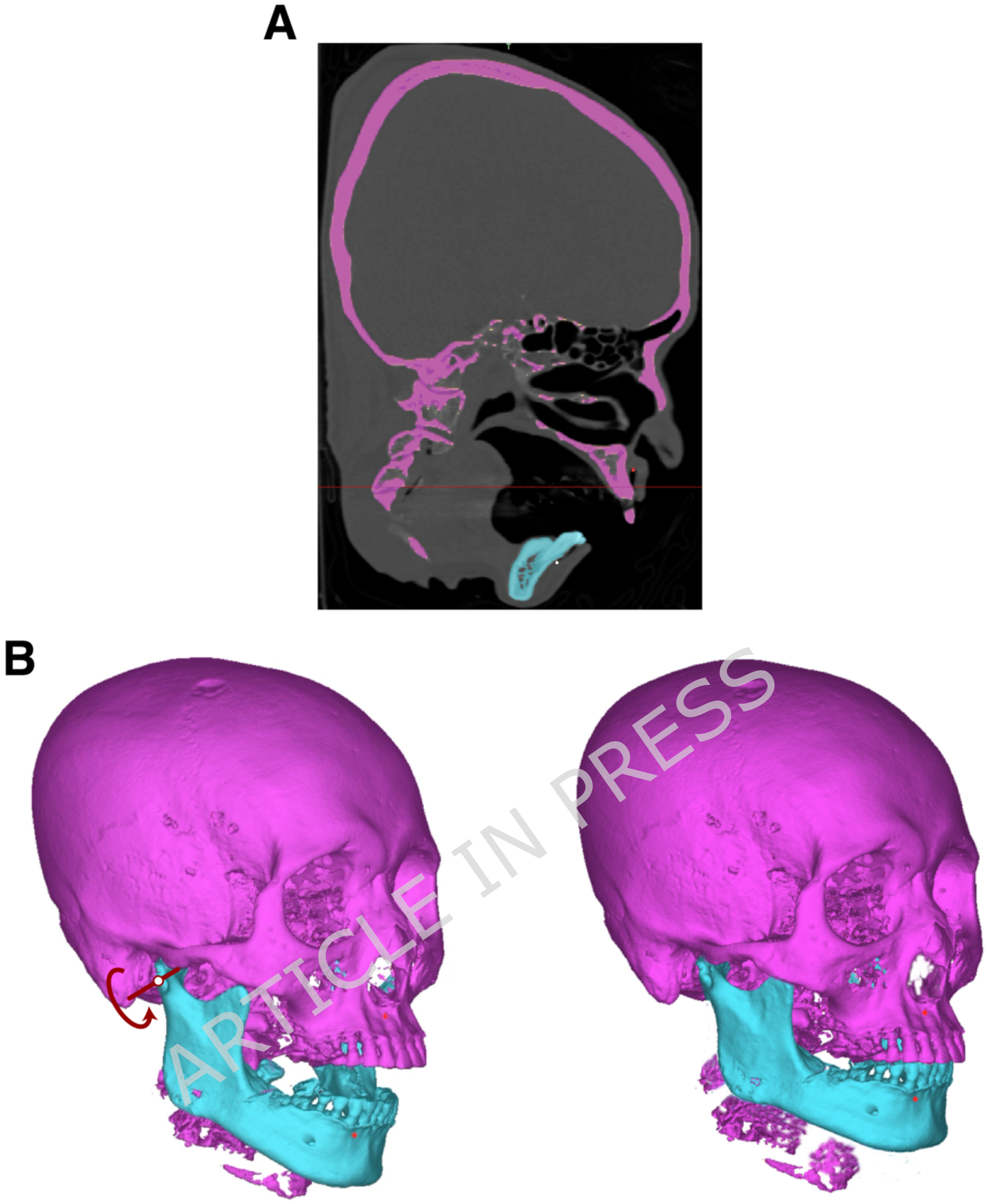

Figure 1. Three-dimensional reconstruction and virtual mandibular closure workflow.

(A) Volumetric segmentation of the maxilla and mandible from CT-derived DICOM datasets.

(B) Initial open-mouth posture and digitally simulated mandibular closure performed by rotation around a geometrically defined condylar axis (indicated by the rotation vector) until the first posterior occlusal contact was established.

2.4 3D Measurement and Morphometric Analysis

Following virtual mandibular closure, the finalized three-dimensional models were exported as STL files and imported into industrial-grade inspection software for morphometric analysis.

To establish a standardized three-dimensional coordinate system, the Frankfort Horizontal (FH) plane was constructed by connecting the bilateral superior points of the porion and the orbitale (Figure 2). A midsagittal reference plane was additionally defined to ensure spatial consistency prior to vertical measurement.

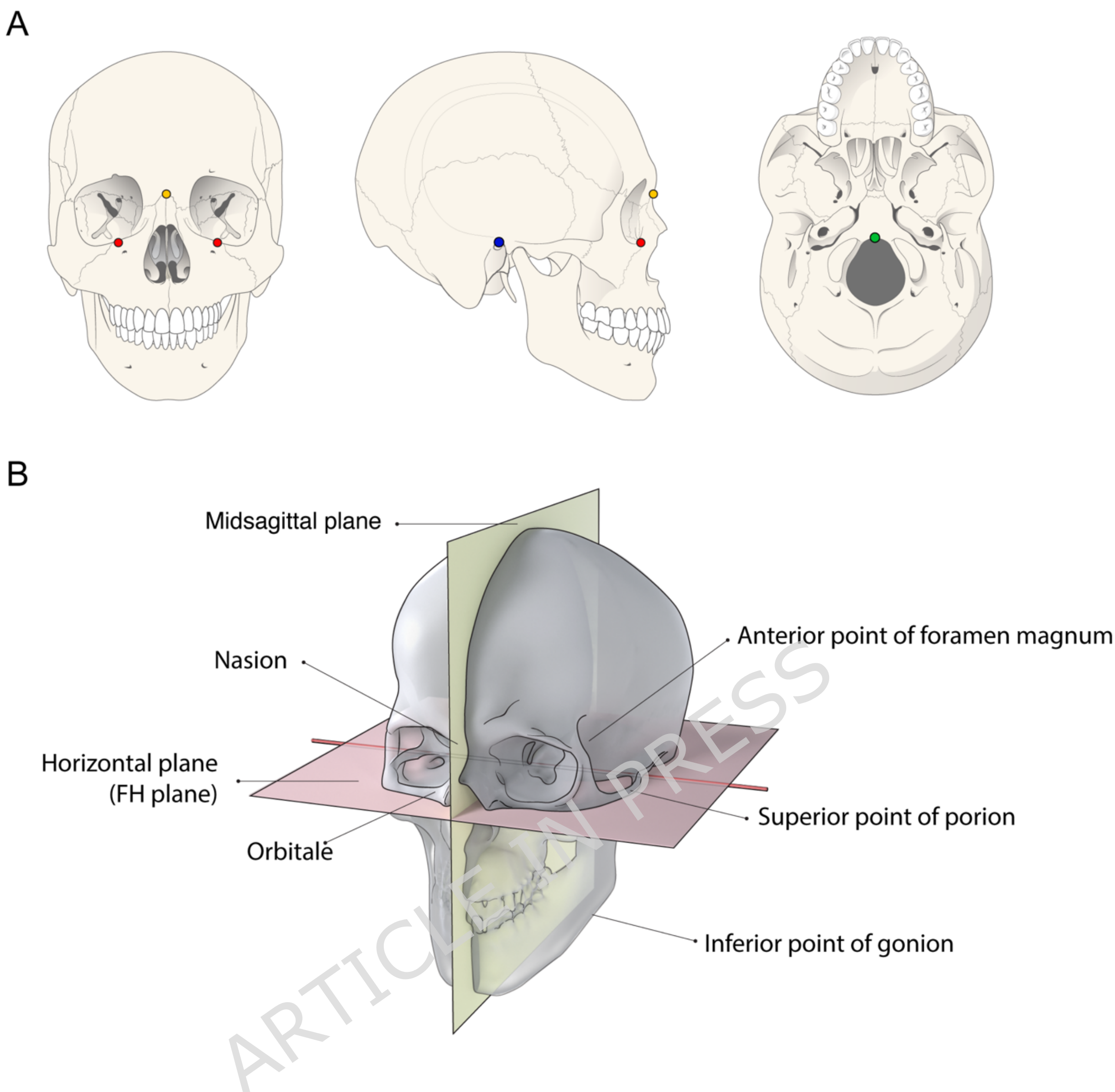

Figure 2. Anatomical landmarks and reference planes for three-dimensional craniofacial orientation.

(A) Color-coded anatomical landmarks used for plane construction: nasion (yellow), orbitale (red), superior point of the porion (blue), and anterior point of the foramen magnum (green).

(B) Construction of the reference planes, where the midsagittal plane passes through the nasion and anterior point of the foramen magnum, and the Frankfort Horizontal (FH) plane is defined by the orbitale and superior point of the porion. These planes were used to standardize spatial orientation prior to vertical measurement. This figure was created by the authors for the present study.

Four anatomical landmarks were identified for vertical analysis: the upper labial vestibule (UV), maxillary central incisor tip (U1), mandibular central incisor tip (L1), and lower labial vestibule (LV). All linear distances were measured perpendicular to the FH plane (Figure 3).

To ensure methodological clarity and reproducibility, all measurements were performed in a standardized three-dimensional coordinate system, with distances calculated perpendicular to the Frankfort Horizontal (FH) plane.

The vertical parameters were mathematically defined as follows: the maxillary vertical dimension (Maxillary VD) = (FH–U1) − (FH–UV), the mandibular vertical dimension (Mandibular VD) = (FH–LV) − (FH–L1), and the occlusal vertical dimension (OVD) = (FH–LV) − (FH–UV).

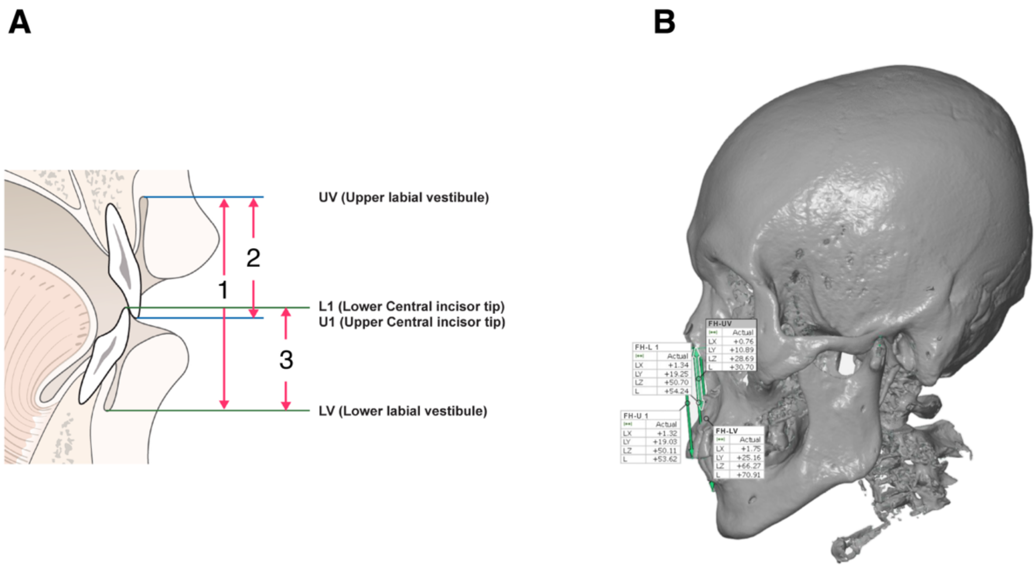

Figure 3. Vertical measurement scheme based on the Frankfort Horizontal (FH) plane.

(A) Schematic illustration of the vertical parameters, where 1 indicates occlusal vertical dimension (OVD), 2 indicates maxillary vertical dimension (VD), and 3 indicates mandibular vertical dimension (VD).

(B) Representative three-dimensional measurement performed using GOM Inspect software, demonstrating perpendicular distance acquisition relative to the FH plane.

To enhance landmark reliability, the UV and LV soft tissue landmarks were jointly verified and fixed by the two board-certified prosthodontists prior to measurement. Because OVD was derived from these jointly confirmed reference points, inter-observer reliability analysis was performed only for the maxillary and mandibular vertical components (U1 and L1).

Independent measurements of U1 and L1 were performed by the two prosthodontists, and the mean values were used for statistical analysis.

2.5 Statistical analysis

Statistical analyses were performed using SPSS Statistics (IBM Corp., Armonk, NY, USA). Descriptive statistics, including means, standard deviations (SD), and ranges, were calculated for all vertical parameters. The normality of data distribution was assessed using the Shapiro–Wilk test prior to parametric statistical analysis, and no significant deviation from normality was observed for all variables ($p > 0.05$). In addition to p-values, effect sizes and 95% confidence intervals were calculated to provide a quantitative estimate of the magnitude of the differences. Sex-based differences were evaluated using independent-samples t-tests. Paired t-tests were applied to compare maxillary and mandibular vertical components within the same specimens. Statistical significance was set at $p < 0.05$.

Inter-observer reliability for the maxillary and mandibular vertical dimensions was assessed using a two-way random-effects model with absolute agreement (single measures). ICC values were interpreted according to established guidelines (poor < 0.5, moderate 0.5–0.75, good 0.75–0.9, and excellent > 0.9) (21).

Results

3.1 Measurement reliability

Of the 25 initially screened cadaveric specimens, 19 met the inclusion criteria and were included in the final analysis. Excluded specimens demonstrated insufficient soft tissue delineation of vestibular landmarks on CT imaging, which could compromise measurement precision.

Inter-observer reliability between the two prosthodontists was assessed for the maxillary and mandibular vertical dimensions using a two-way random-effects model with absolute agreement (single measures).

The ICC for the maxillary vertical dimension was 0.986 (95% CI: 0.964–0.995), and the ICC for the mandibular vertical dimension was 0.981 (95% CI: 0.946–0.993), both indicating excellent reliability.

3.2 Descriptive statistics of vertical dimensions

Vertical dimensions were measured in 19 elderly Korean cadavers. The mean maxillary vertical dimension was 20.3 ± 2.7 mm (range: 16.0–26.0 mm), and the mean mandibular vertical dimension was 15.8 ± 1.9 mm (range: 12.5–19.1 mm). The mean OVD was 35.2 ± 3.7 mm (range: 29.5–40.5 mm). Detailed descriptive statistics and reliability results are summarized (Table 1).

Table 1. Descriptive statistics and inter-observer reliability of vertical measurements (n = 19).

Measurement	Mean ± SD (mm)	Range (mm)	ICC (95% CI)
Maxillary VD	20.3 ± 2.7	16.0–26.0	0.986 (0.964–0.995)
Mandibular VD	15.8 ± 1.9	12.5–19.1	0.981 (0.946–0.993)
OVD	35.2 ± 3.7	29.5–40.5	–

a Inter-observer reliability was not assessed for OVD, as it was derived from jointly confirmed UV and LV landmarks.

3.3 Comparison by sex and anatomical region

3.3.1 Sex-based Comparison (Independent t-tests)

Sex-based comparisons of the vertical components are presented in Figure 4A and 4B.

No statistically significant differences were observed between males and females in either component. The maxillary VD measured 21.0 ± 2.9 mm in males and 19.1 ± 2.1 mm in females ($p = 0.1399$) (Figure 4A). Similarly, the mandibular VD measured 16.1 ± 2.1 mm in males and 15.3 ± 1.6 mm in females ($p = 0.3722$) (Figure 4B).

3.3.2 Regional Comparison (Paired t-test)

In contrast, a highly significant difference was observed between the maxillary and mandibular vertical components within the same specimens ($p < 0.0001$). As shown in Figure 4C, the maxillary VD (20.3 ± 2.7 mm) was significantly greater than the mandibular VD (15.8 ± 1.9 mm), indicating a non-uniform skeletal contribution to OVD.

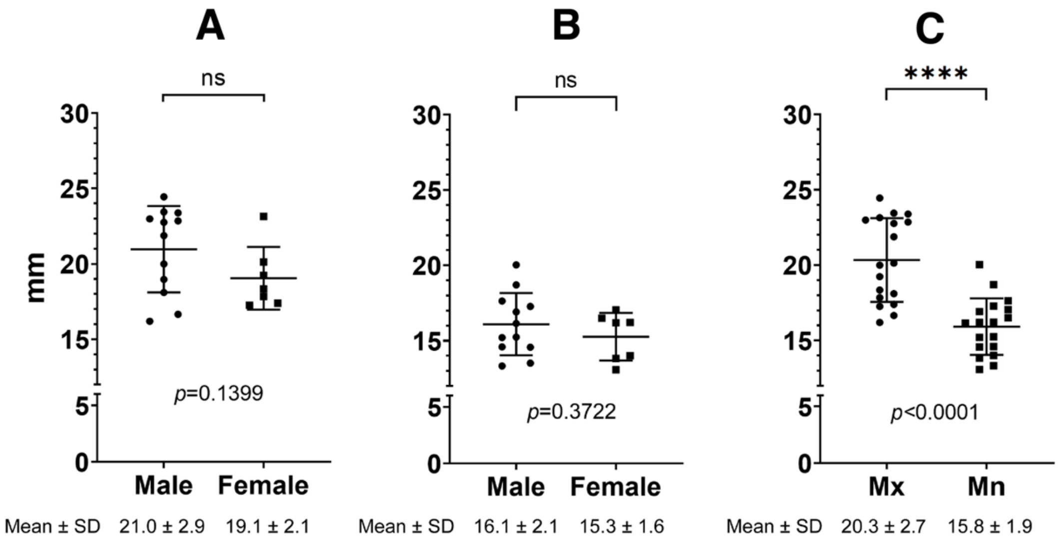

Figure 4. Comparison of vertical dimensions according to sex and anatomical region.

(A) Maxillary vertical dimension (VD) by sex.

(B) Mandibular vertical dimension (VD) by sex.

(C) Comparison between maxillary and mandibular vertical dimensions.

Data are presented as mean ± SD. Independent t-tests were used for sex comparisons (A, B), and a paired t-test was used for anatomical comparison (C). ns: not significant; **** $p < 0.0001$.

Discussion

The present pilot study re-evaluated the historically cited 40 mm vertical reference (7) using a three-dimensional CT-based skeletal framework in elderly Korean cadaveric specimens. The mean OVD was 35.2 ± 3.7 mm, which differs from the traditionally cited 40 mm value. However, this difference should be interpreted in light of methodological and population related factors rather than as a direct contradiction of previous findings.

McGrane's original reference (7) was derived from cast-based measurements of dentate adult patients and was primarily intended to establish parallel stress-bearing areas in complete denture construction. Similarly, Fayz et al. (8) conducted anterior tooth-based measurements in dentate individuals with overbite correction. These investigations did not incorporate standardized three-dimensional skeletal alignment and were not performed in elderly populations typically indicated for complete denture therapy. In contrast, the present study employed CT-based digital reconstruction with a reproducible skeletal reference plane (FH plane) and virtual mandibular closure under controlled conditions.

The mean OVD observed in the present study approximates radiographic values reported by Ellinger (9), suggesting that skeletal-based assessments may yield measurements closer to anatomical craniofacial relationships than impression-based techniques. Importantly, age-related craniofacial changes and population-specific morphological characteristics may influence vertical dimension measurements (10, 11), further supporting the need for cautious application of historical dentate-based references to elderly cohorts.

A principal strength of this study lies in the implementation of a standardized three-dimensional skeletal coordinate system. Traditional two-dimensional cephalometric approaches are subject to projection distortion and landmark superimposition (12-14, 22). Advances in digital imaging and three-dimensional landmark identification have demonstrated improved accuracy and reproducibility (13, 16, 23).

Previous studies have demonstrated that CBCT-based three-dimensional analysis provides reliable and reproducible measurements of craniofacial structures (18). The high ICC values for both maxillary (0.986) and mandibular (0.981) vertical components confirm the reliability of the measurement protocol.

The virtual mandibular closure process warrants careful interpretation. Because cadaveric CT acquisition does not necessarily represent functional maximal intercuspation, digital rotation around a geometrically defined condylar axis was performed and terminated at the first posterior occlusal contact. This approach provided a reproducible skeletal reference position while minimizing positional artifacts associated with scanning posture. Nevertheless, future in vivo investigations under functional occlusal conditions may yield additional insight into dynamic vertical relationships.

An additional methodological consideration relates to soft tissue visualization in CT imaging. Although gauze placement was employed to enhance delineation of the vestibular boundaries, thin single-layer gauze may not always provide sufficient radiographic contrast at a slice thickness of 0.6 mm. In several initially screened specimens, vestibular landmarks could not be clearly distinguished, leading to their exclusion from analysis. This strict selection criterion (25 screened, 19 included) was applied to enhance anatomical precision and reduce landmark ambiguity. This exclusion rate (24%) should be considered when interpreting the immediate clinical applicability of the present protocol.

In particular, variability in vestibular soft tissue visualization may limit case selection and measurement consistency in routine clinical settings. Future refinement of imaging protocols and landmark enhancement methods may improve broader applicability.

For future clinical applications, reliable vestibular demarcation under CT-based evaluation may require improved soft tissue separation protocols or modified imaging parameters to ensure consistent landmark identification. Future studies may also consider radiopaque contrast media or barium sulfate markers to improve vestibular soft tissue visualization on CT images. Enhanced contrast techniques or alternative imaging strategies may further refine digital OVD assessment in elderly patients. In clinical settings, three-dimensional imaging techniques have been increasingly utilized to enhance diagnostic accuracy and treatment planning in prosthodontics and orthodontics (20).

Within the limitations of this pilot cadaveric study, the present findings provide standardized three-dimensional skeletal baseline data for OVD assessment in an elderly population. Rather than contradicting historical references, the results should be interpreted as a methodological refinement achieved through controlled digital alignment and skeletal-based measurement.

A key limitation of this study is the use of cadaveric specimens, which do not fully replicate functional clinical conditions. In particular, the absence of muscle activity, neuromuscular control, and dynamic soft tissue behavior limits direct extrapolation of the measured OVD values to living patients. In clinical settings, OVD is influenced by functional occlusion, patient-specific neuromuscular adaptation, and soft tissue dynamics, which cannot be reproduced in cadaver-based analyses.

The sample size of this pilot study was limited and was not determined based on formal power analysis. However, the primary objective of this study was methodological development and validation rather than hypothesis-driven statistical inference. Therefore, the sample size was considered sufficient to assess feasibility, reproducibility, and measurement consistency. Future studies with larger sample sizes will be necessary to confirm statistical generalizability and clinical applicability. However, the present study was not intended to directly reproduce clinical occlusal conditions, but rather to establish a standardized and reproducible skeletal measurement framework under controlled conditions. By eliminating functional variability, this approach allows consistent anatomical comparison across specimens and provides a methodological baseline for further investigation.

Importantly, this pilot study was designed as a preliminary step toward ongoing in vivo clinical research. In clinical applications, CT or CBCT imaging can be performed under natural occlusal conditions, enabling direct measurement of OVD without the need for virtual mandibular closure. Therefore, the virtual closure process applied in this study should be interpreted as a methodological adaptation specific to cadaveric conditions. Future clinical studies are expected to validate and extend the present findings under functional occlusal environments.

Conclusions

Within the limitations of this pilot cadaveric investigation, three-dimensional CT-based skeletal analysis demonstrated a mean OVD of 35.2 mm in elderly Korean specimens. This value differs from the historically cited 40 mm reference derived from dentate adult populations. The discrepancy is most appropriately interpreted as a reflection of methodological and population-related differences rather than inconsistency in clinical principles. These findings may not be directly generalizable to younger populations or individuals of different ethnic backgrounds.

The present study establishes standardized three-dimensional skeletal baseline data under controlled digital conditions and may serve as a methodological foundation for future in vivo investigations and digitally guided prosthodontic rehabilitation in elderly patients.

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of the College of Medicine, The Catholic University of Korea (Approval No. MC22EISI0102). The study was conducted in accordance with the Declaration of Helsinki. The requirement for informed consent was waived due to the use of donated cadaveric specimens in accordance with institutional guidelines.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

JP conceptualized the study and designed the methodology. JP and SSL performed the investigation. JP conducted formal analysis and drafted the original manuscript. SSL and AC contributed to manuscript revision and supervision. All authors read and approved the final manuscript.

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References

1. The Glossary of Prosthodontic Terms 2023: Tenth Edition. J Prosthet Dent. 2023;130(4 Suppl 1):e1-e3.
2. Zarb GA, Hobkirk J, Eckert S, Jacob R. Prosthodontic treatment for edentulous patients: complete dentures and implant-supported prostheses: Elsevier Health Sciences; 2012.
3. Abduo J, Lyons K. Clinical considerations for increasing occlusal vertical dimension: a review. Australian dental journal. 2012;57(1):2-10.
4. Silverman MM. The speaking method in measuring vertical dimension. The Journal of prosthetic dentistry. 2001;85(5):427-31.
5. Pound E. Esthetic dentures and their phonetic values. The Journal of prosthetic dentistry. 1951;1(1-2):98-111.
6. Turrell A. Clinical assessment of vertical dimension. The Journal of prosthetic dentistry. 2006;96(2):79-83.
7. McGrane H. Five basic principles of the McGrane full denture procedure. The Journal of the Florida State Dental Society. 1949;20(11):5-8.
8. Fayz F, Eslami A, Graser GN. Use of anterior teeth measurements in determining occlusal vertical dimension. The Journal of prosthetic dentistry. 1987;58(3):317-22.
9. Ellinger CW. Radiographic study of oral structures and their relation to anterior tooth position. The Journal of Prosthetic Dentistry. 1968;19(1):36-45.
10. Enlow DH, Hans MG, McGrew L. Essentials of facial growth. 1996.
11. Hwang H-S, Kim W-S, McNamara Jr JA. Ethnic differences in the soft tissue profile of Korean and European-American adults with normal occlusions and well-balanced faces. The Angle Orthodontist. 2002;72(1):72-80.
12. Ludlow JB, Gubler M, Cevidanes L, Mol A. Precision of cephalometric landmark identification: cone-beam computed tomography vs conventional cephalometric views. American Journal of Orthodontics and Dentofacial Orthopedics. 2009;136(3):312. e1-. e10.
13. Pittayapat P, Jacobs R, Bornstein MM, Odri GA, Lambrichts I, Willems G, et al. Three-dimensional Frankfort horizontal plane for 3D cephalometry: a comparative assessment of conventional versus novel landmarks and horizontal planes. European journal of orthodontics. 2018;40(3):239-48.
14. Green MN, Bloom JM, Kulbersh R. A simple and accurate craniofacial midsagittal plane definition. American Journal of Orthodontics and Dentofacial Orthopedics. 2017;152(3):355-63.
15. Khabadze Z, Mordanov O, Shilyaeva E. Comparative analysis of 3D cephalometry provided with artificial intelligence and manual tracing. Diagnostics. 2024;14(22):2524.
16. Downs WB. Analysis of the dentofacial profile. The Angle Orthodontist. 1956;26(4):191-212.
17. Hassan B, van der Stelt P, Sanderink G. Accuracy of three-dimensional measurements obtained from cone beam computed tomography surface-rendered images for cephalometric analysis: influence of patient scanning position. The European Journal of Orthodontics. 2009;31(2):129-34.
18. Serafin M, Baldini B, Cabitza F, Carrafiello G, Baselli G, Del Fabbro M, et al. Accuracy of automated 3D cephalometric landmarks by deep learning algorithms: systematic review and meta-analysis. La radiologia medica. 2023;128(5):544-55.
19. Cai C, Li H, Zhang H, Huo N, Wang J, Li T, et al. Evaluating the precision and reproducibility of cephalometric landmarks in locally reconstructed lateral cephalometric radiographs from cone beam computed tomography (CBCT).

BMC Oral Health. 2025;25(1):866.
20. Joda T, Gallucci G, Wismeijer D, Zitzmann NU. Augmented and virtual reality in dental medicine: A systematic review. Computers in biology and medicine. 2019;108:93-100.
21. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. Journal of chiropractic medicine. 2016;15(2):155-63.
22. Broadbent BH. A new x-ray technique and its application to orthodontia. The angle orthodontist. 1931;1(2):45-66.
23. Dot G, Rafflenbeul F, Arbotto M, Gajny L, Rouch P, Schouman T. Accuracy and reliability of automatic three-dimensional cephalometric landmarking. Int J Oral Maxillofac Surg. 2020;49(10):1367-78.