BJOS
Brazilian Journal of Oral Sciences

Original Research

Volume 25
2026
e260359

Effect of ultra-low dose CBCT versus conventional CBCT imaging on the accuracy and reliability of semi-automatically segmented mandibular condyle: a diagnostic accuracy study

Marina B. Salib[1,2*], Ahmed M. Abd Alsamad[2], Yara R. Helaly[2]

[1] Oral Radiology Department, School of Dentistry, Newgiza University.

[2] Oral and Maxillofacial Radiology Department, Faculty of Dentistry, Cairo University, Egypt.

Corresponding author:
Marina B. Salib
Lecturer of Oral Radiology, Oral Radiology Department, Newgiza University, Kilo 22 Cairo - Alexandria desert road.
Telephone: (20)-122-619-9248,
Email: marina.bassily@dentistry.cu.edu.eg

Editor: Dr. Altair A. Del Bel Cury

Received: July 06, 2025
Accepted: November 11, 2025

CC BY

Aim: This study evaluated the accuracy and reliability of semi-automated mandibular condyle segmentation using conventional and ultra-low-dose (ULD) cone-beam computed tomography (CBCT) protocols, with dry skull measurements as the reference standard. **Methods:** Twenty-nine dry human mandibles with intact condyles and glenoid fossae were scanned with two CBCT protocols: conventional (0.2 mm voxel size, 90 kV, 8 mA) and ULD (0.4 mm voxel size, 90 kV, 4 mA, ~50% dose reduction). Semi-automated segmentation was performed in 3D Slicer software. Linear condylar measurements (width, length, height) were obtained by two blinded evaluators, and their averages were analyzed against the reference standard. Descriptive statistics (mean, SD, CI), agreement analysis (ICC), and intergroup comparisons (ANOVA with Bonferroni correction) were performed. **Results:** Real measurements showed a mean condylar size of 12.08±0.99 mm. Conventional CBCT produced 11.88±0.91 mm, and ULD CBCT yielded 11.67±0.89 mm, with differences <0.5 mm. Both protocols demonstrated excellent agreement with the reference standard (ICC >0.8, p<0.001). Measurement errors remained <1 mm for both groups, though ULD errors were slightly higher and reached significance only when pooled collectively (p=0.029). Inter- and intra-observer reliability was excellent (ICC >0.9). **Conclusion:** ULD CBCT protocols, despite using a larger voxel size, maintained clinically acceptable accuracy (<1 mm error) while reducing radiation dose by ~50%. Semi-automated segmentation provided reproducible results, supporting ULD CBCT for safer condylar assessment, particularly in pediatric or longitudinal cases where dose reduction is critical.

Keywords: Mandibular condyle. Cone-beam computed tomography. Imaging, three-dimensional.

Clinical trial number: NCT05441423, June 28th, 2022.

Introduction

The mandibular condyle is a key component of the temporomandibular joint (TMJ) and serves as the main growth center of the mandible. Accurate assessment of its morphology is essential in diagnosing temporomandibular disorders, facial asymmetries, and malocclusions[1,2].

Segmenting the condyle is challenging due to its complex anatomy, low bone density, and proximity to the glenoid fossa. Cone-beam computed tomography (CBCT) has become the standard for craniofacial imaging, offering three-dimensional visualization, though it is affected by intrinsic limitations such as low contrast resolution and partial volume effects[3,4].

In line with the ALARA (As Low As Reasonably Achievable) and ALADA (As Low As Diagnostically Acceptable) principles, dose optimization is critical in dental radiology. Recently, the ALADA(IP) principle has emphasized tailoring radiation dose to both diagnostic need and patient profile[5]. Ultra-low-dose (ULD) protocols have been introduced to reduce exposure, though concerns remain regarding their impact on segmentation accuracy, particularly when larger voxel sizes are used.

Several segmentation techniques exist, ranging from manual tracing to fully automated algorithms. Manual segmentation is accurate but time-consuming and operator-dependent. Automatic approaches are faster but prone to thresholding errors. Semi-automated methods, which combine limited user input with automated filling, offer a practical balance and have shown good reproducibility[6,7].

This study aimed to evaluate whether ULD CBCT protocols can maintain clinically acceptable accuracy for semi-automated condylar segmentation compared to conventional CBCT, using dry skull measurements as the reference standard. We hypothesized that there would be no significant differences in linear measurements (condylar width, length, height) between the two protocols.

Materials and Methods

Study Design

This study was conducted after the approval of the Research Ethics Committee of the Faculty of Dentistry, Cairo University. The study protocol was registered on www.clinicaltrials.gov (ORAD 7-1-1), ID: NCT05441423, June 28th, 2022. The study is a prospective study, as data collection was planned before the index test and reference standard were performed.

Sample Size Calculation

Sample size calculation was performed and approved by the Medical Biostatistics Unit, Faculty of Dentistry, Cairo University. Based on a previous study by Kim et al.[3], a power analysis was designed to have adequate power to apply a two-sided statistical test of the null hypothesis that semi-automatic segmentation of CBCT images will provide the same accuracy as the physical real condyles. By adopting an alpha level of

0.05, a beta of 0.2, power = 80%, and an effect size (d) of 0.543, the predicted sample size (n) was found to be 29 condyles. Sample size calculation was performed using PS Power and Sample Size Calculations software for Windows.

Study Population

Fifteen Dry human skulls and dry human mandibles (30 condyles) were recruited from the Anatomy Department, Faculty of Medicine, Cairo University. They were recruited according to the following eligibility criteria: inclusion criteria were mandibles with sound condyles and skulls with sound glenoid fossae, while exclusion criteria were skulls with fractured glenoid fossa or glenoid fossa with developmental deformities, mandibles with fractured condylar necks or heads, and the presence of pathological lesions, fractures, shipping, or developmental deformities in the condyle. Figure 1 shows a mandible with sound condyles and a skull with sound glenoid fossa following the inclusion criteria, so was included in the study [Figure 1].

Figure 1. Example of a dry human mandible included in the study, showing intact condyles and glenoid fossae. This illustrates the inclusion criteria applied for sample selection.

Linear Physical Real Measurements of the Condyles

Physical real linear measurements of the condyles were considered a reference standard, and distances were measured by a digital caliper on the dry human condyle in millimeters, as supported by García-Sanz et al.[2].

The following landmarks were demarcated on the dry mandibular condyle using a permanent marker for linear analysis, according to García-Sanz et al.[2] as follows:

- Anterior point: The most anterior extent of the mandibular condyle.
- Posterior point: The most posterior extent of the mandibular condyle.
- Lateral point: The most lateral extent of the mandibular condyle.
- Medial point: The most medial extent of the mandibular condyle.
- Superior point: The most superior aspect of the mandibular condyle.

A digital caliper was used for the linear assessment by applying the mentioned points, and distances were measured on the condyles in millimeters.

The linear distances, according to García-Sanz et al.[2], were as follows: [Figure 2]

- Condylar width: measured as the distance between lateral and medial points.
- Condylar length: measured as the distance between anterior and posterior points.
- Condylar height: measured as the distance of the perpendicular line traced from the superior point on the condyle to the width line. For each condyle, linear measurements were recorded.

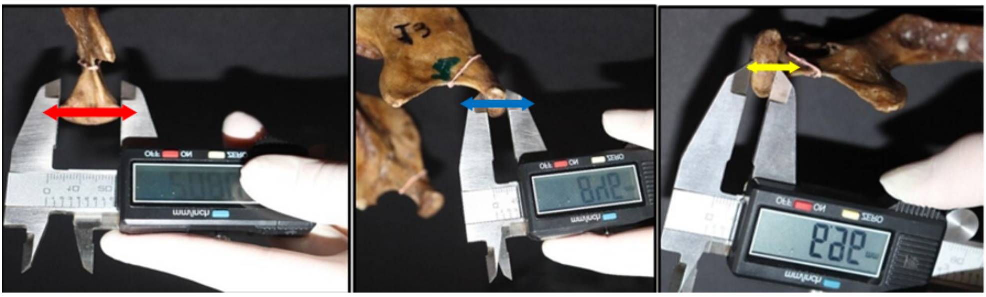

Figure 2. Measurements of the real condyle using a digital caliper. Arrows indicate the three measured dimensions: width (mediolateral, red arrow), length (anteroposterior, blue arrow), and height in a frontal view (superoinferior, yellow arrow).

CBCT imaging for the Dry Skulls and Mandibles

A piece of cloth was secured between the condyle and the glenoid fossa to avoid bone-to-bone contact. The cloth material was chosen instead of wax, which was used in previous studies by Yadav et al.[8] and García-Sanz et al.[2] to avoid any radiopaque masking of the condyle, which happened with the wax, and to simulate the radiolucency of the disk space radiographically [Figure 3].

Figure 3. The piece of cloth used to avoid bone-to-bone contact between the condyle and the glenoid fossa.

Each skull was assembled with its corresponding mandible using a clear wrap to ensure complete stabilization during the imaging procedures. Additionally, a thick layer of pink wax was applied as a soft tissue simulation on the skull to mimic the attenuation properties of soft tissues during imaging.

Dry human skulls and assembled mandibles were scanned in the Oral and Maxillofacial Radiology Department, Faculty of Dentistry, Cairo University, using the CBCT machine Planmeca ProMax® 3D Mid.

Scanning was performed using the CBCT machine as follows

I1 (Index test): CBCT imaging with conventional dose using the following exposure parameters:

- Kilovoltage: 90 kV.
- Milliampere: 8 mA.
- Field of view: 20 x 6 cm.
- Voxel size: 0.4 mm.
- Exposure time: 13.5s

I2: CBCT imaging with ultra-low dose using the following exposure parameters:

- Kilovoltage: 90 kV.
- Milliampere: 5 mA.
- Field of view: 20 x 6 cm.
- Voxel size: 0.4 mm.
- Exposure time: 4.5s

Primary reconstruction and processing of the scans, as well as image analysis, were done using Romexis® software (Planmeca, Helsinki, Finland).

For each skull, two CBCT scans were acquired: one with a conventional dose and the second with an ultra-low dose (ULD), as mentioned previously.

Image Analysis

After applying the index test, DICOM files of both CBCT conventional imaging and ultra-low dose CBCT imaging were imported from Romexis software (Romexis® software Planmeca- Helsinki, Finland) to 3D Slicer open-source segmentation software (https://www.slicer.org/), to generate the whole volume of the condyle by using the semi-automated segmentation tool.

3D Slicer software is an open-source segmentation software that was used in the segmentation of many maxillofacial structures, such as teeth, mandibular segmentation, and airway segmentation, with reported accuracy and reliability[9,10]. To the best of our knowledge, it hasn't been used in the segmentation of mandibular condyles before, which is considered a gap of knowledge to be covered by the current study.

In the 3D Slicer software, the DICOM files were first imported in “DICOM files” format. After importing the CBCT scan, volume orientation was done to allow the condyle under investigation to be clearly seen and investigated in the software window.

The following steps were performed for each condyle to generate a 3D segmented volume:

- ***First***, the condyle under investigation was centered and oriented in the three orthogonal planes: axial, coronal & sagittal.
- ***Second***, the segmentation editor module was selected, and then two new segments were added, each renamed with the name and the side of the condyle under investigation, for example, C1 RT (condyle number one, the right side).

For the two created segments, one was designated for the interior structure of the condyle, and the second was for the surrounding structures, which were considered the limits of the segmented volume, each with a different color annotation from the other for ease of demarcation.

- ***Third***, the “Paint” tool was activated, and the brush diameter was selected to be 3 mm for ease and convenient painting of the condyle, also “Sphere brush” & “Edit in 3D” options were selected to allow application of the painting action in the two second cuts (coronal & sagittal) other than the working one (axial).
- ***Fourth***, by selecting the two previously mentioned segments, the painting brush was applied in random sequential cuts in the axial plane. Painting of the condyle included the whole condylar area, till the radiopaque gutta-percha markers already secured before imaging at the deepest point of the sigmoid notch to demarcate the condylar whole volume.

The same steps were continued until the complete coverage and painting of the whole condyle in the axial plane.

- ***Fifth***, the “Grow from Seeds” tool was activated for the semi-automated segmentation process to occur and to generate the 3D condylar volume.
- ***Sixth***, smoothening of the condyle was performed slice by slice until complete smoothening of the segmented condylar volume. The smoothening aims to remove any extra condylar painted areas.

The same steps were performed for all the condyles for both the conventional & ULD imaging protocols [Figure 4].

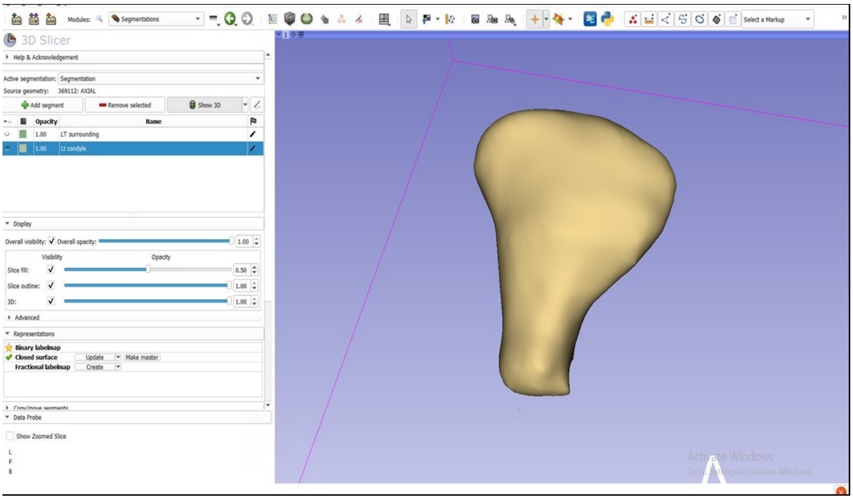

Figure 4. The final semi-automated segmented condylar volume in the 3D window.

Linear Measurements for the Segmented Condyle

Linear measurements for each condyle on the software were calculated according to the reference lines taken and measured on the real condyles, and the following steps on the software took place.

- The “Segmentation editor” module on the 3D Slicer software was switched to the “Markups” module.
- The “ROI” tool in the “Markups” module was used to generate a three-dimensional rectangle that surrounded the already segmented condylar volume.
- The lower horizontal longest sides of this box represent condylar width. The lower horizontal shortest sides of the rectangle represent condylar length. The vertical shortest sides represent condylar height.
- The measurements were recorded by the software in a table automatically generated by the software.
- Condylar width, Condylar length & Condylar height were recorded.
- The same steps were done for all the condyles for both the conventional & ULD imaging protocols [Figure 5].

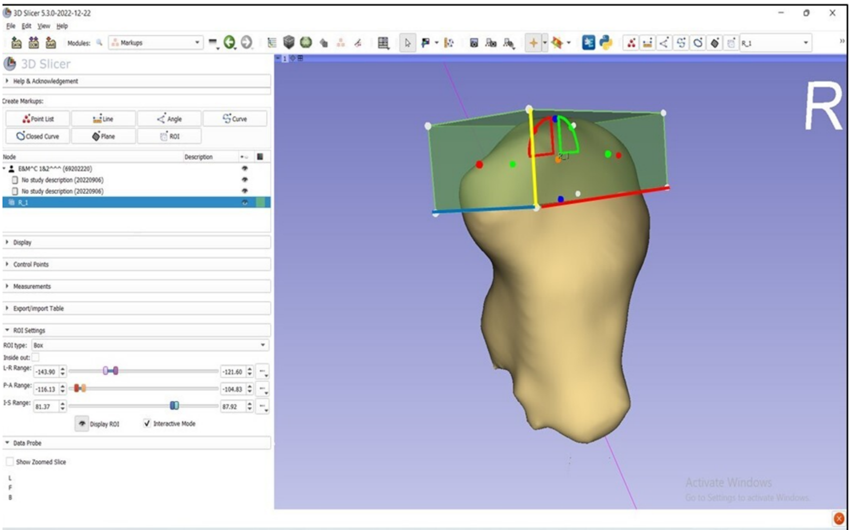

Figure 5. The linear measurements condylar width: red line, condylar length: blue line & condylar height: yellow line, on the final semi-automated segmented condyle by 3D slicer software.

Blinding & Inter- and Intra-Observer Agreement

All scanning results for all the different index tests were reviewed by two oral radiologists with different experiences, ranging from 5 to 18 years. The two oral radiologists did the assessment in two separate sessions and were blinded to all the scanning information, including the change in CBCT doses. They were also blinded to each other's results as well as the physical real measurements. One of the two oral radiologists assessed the radiographs twice, with a two-week interval between the two sessions to assess intra-observer agreement.

Statistical Methods

Numerical data were presented as mean with 95% confidence intervals (CI), standard deviation (SD), minimum (min) and maximum (max) values. For each measurement, the average of the two evaluators' values was used for statistical analysis to ensure consistency and minimize observer bias. They were tested for normality by viewing data distribution and by using Shapiro-Wilk's test. Data were normally distributed and were analyzed using repeated measures ANOVA followed by Bonferroni post hoc test. Correlations were analyzed using Pearson's correlation coefficient. Reliability was analyzed using intraclass correlation coefficient (ICC). The significance level was set at $p<0.05$ within all tests. Statistical analysis was performed with R statistical analysis software version 4.3.2 for Windows[1].

[1] R Core Team (2024). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Results

Linear Measurements

Descriptive Statistics for Linear measurements

Descriptive statistics (mean, SD, CI, and range) provide an overview of measurement distribution and consistency. As shown in Table 1, real measurements had a mean of 12.08 mm (SD 0.99). Conventional CBCT produced a similar mean of 11.88 mm (SD 0.91), while ULD yielded 11.67 mm (SD 0.89). All groups showed narrow CIs and low variability (<1 mm), indicating consistent data.

These findings suggest that both CBCT protocols closely approximate real anatomy, supporting their use for condylar evaluation.

Table 1. Descriptive statistics of linear measurements collectively in mm.

Measurement	Group	Mean	95% CI		SD	Min.	Max.
			Lower	Upper			
Linear measurements collectively (mm)	Real measurements	12.08	11.73	12.44	0.99	10.17	13.77
	Software measurements (Conventional semi-automated)	11.88	11.56	12.21	0.91	9.83	13.40
	Software measurements (ULD semi-automated)	11.67	11.35	11.99	0.89	10.33	13.50

Intergroup Comparisons for linear measurements

Real measurements were slightly higher than those obtained from CBCT. Post hoc analysis indicated that the measurements from real specimens were significantly greater than those from the ULD group (p < 0.001). However, no significant differences were observed between real and conventional CBCT measurements or between conventional and ULD measurements (Table 2).

These results indicate that ULD-CBCT slightly underestimates condylar size, whereas conventional CBCT measurements closely approximate the actual values.

Table 2. Intergroup comparison of linear measurements collectively in mm.

Measurement	Linear measurements (Mean±SD)			p-value
	Real measurements	Software measurements (Conventional semi-automated)	Software measurements (ULD semi-automated)	
Linear measurements collectively (mm)	12.08 ± 0.99^{A}	11.88 ± 0.91^{AB}	11.67 ± 0.89^{B}	0.002*

Values with different superscript letters within the same horizontal row are significantly different *; Significant (p<0.05).

Agreement of Software Measurements for linear measurements collectively

Agreement analysis showed both conventional and ULD protocols had strong consistency with real measurements (ICC >0.8, p<0.001).

This confirms that semi-automated segmentation provides reliable results across dose protocols, as shown in Table 3.

Table 3. Agreement analyses for software measurements for linear measurements collectively in mm.

Measurement	ICC (95% CI)	
	Real-Software (Conventional semi-automated)	Real-Software (ULD semi-automated)
Linear measurements collectively (mm)	0.881 (0.747:0.943)*	0.828 (0.525:0.928)*

*; Significant (p<0.05)

Measurement Error

Descriptive Statistics for Measurement Error

The mean error for conventional CBCT was 0.46 mm (SD 0.44), while ULD showed 0.63 mm (SD 0.43). Both errors remained <1 mm, within clinically acceptable limits.

This reflects minimal deviation from real measurements, though ULD showed slightly higher average error, as shown in Table 4.

Table 4. Descriptive statistics of linear measurement error collectively in mm.

Measurement	Group	Mean	95% CI		SD	Min.	Max.
			Lower	Upper			
Linear measurements collectively (mm)	Software measurements (Conventional semi-automated)	0.46	0.30	0.61	0.44	0.03	1.58
	Software measurements (ULD semi-automated)	0.63	0.47	0.78	0.43	0.03	1.53

Intergroup Comparisons for linear measurements

Intergroup comparisons for measurement error are summarized as follows. For condylar width, the error was slightly higher in the ULD group (0.95 ± 0.69 mm) compared to the conventional group (0.80 ± 0.92 mm), but this difference was not statistically significant (p = 0.427, Table 5).

Condylar length showed a slightly greater error in the conventional group (0.90 ± 0.63 mm) than in the ULD group (0.64 ± 0.44 mm), although the difference did not reach statistical significance (p = 0.062, Table 6). For condylar height, the ULD group again exhibited slightly higher error (1.16 ± 0.86 mm) compared to the conventional group (1.02 ± 0.81 mm), without statistical significance (p = 0.174, Table 7).

When condylar width and length were considered together, no difference was observed between the groups (p = 0.991, Table 8). However, when all linear measurements were pooled, the ULD group showed a significantly greater error (0.63 ± 0.43 mm) than the conventional group (0.46 ± 0.44 mm, p = 0.029, Table 9).

Overall, ULD demonstrated slightly higher measurement error than conventional CBCT, achieving statistical significance only when measurements were analyzed collectively; nevertheless, errors remained below 1 mm, indicating clinical acceptability.

Table 5. Intergroup comparison of measurement error for Condylar width in mm.

Measurement	Mean±SD		p-value
	Software measurements (Conventional semi-automated)	Software measurements (ULD semi-automated)	
Condylar Width (mm)	0.80±0.92	0.95±0.69	0.427ns

*; Significant (p<0.05).

Table 6. Intergroup comparison of measurement error for Condylar length in mm.

Measurement	Mean±SD		p-value
	Software measurements (Conventional semi-automated)	Software measurements (ULD semi-automated)	
Condylar Length (mm)	0.90±0.63	0.64±0.44	**0.062ns**

*; Significant (p<0.05).

Table 7. Intergroup comparison of measurement error for Condylar height in mm.

Measurement	Mean±SD		p-value
	Software measurements (Conventional semi-automated)	Software measurements (ULD semi-automated)	
Condylar height (mm)	1.02±0.81	1.16±0.86	**0.174ns**

*; Significant (p<0.05).

Table 8. Intergroup comparison of measurement error for Condylar Width & Condylar Length combined in mm.

Measurement	Mean±SD		p-value
	Software measurements (Conventional semi-automated)	Software measurements (ULD semi-automated)	
Condylar Width & Condylar Length combined	0.58±0.53	0.58±0.41	**0.991ns**

*; Significant (p<0.05).

Table 9. Intergroup comparison of measurement error collectively.

Measurement	Mean±SD		p-value
	Software measurements (Conventional semi-automated)	Software measurements (ULD semi-automated)	
Linear measurements collectively (mm)	0.46±0.44	0.63±0.43	**0.029***

*; Significant (p<0.05).

Inter- and Intra-observer Reliability

All measurements demonstrated excellent reproducibility (ICC >0.9, p<0.001).

This shows that semi-automated segmentation minimizes observer variability, strengthening its reliability in clinical and research use.

Overall, both conventional and ULD CBCT protocols demonstrated clinically acceptable accuracy and reliability, with ULD achieving substantial dose reduction at the expense of slightly higher but still minimal measurement error. These findings provide the basis for the following discussion, where methodological considerations and clinical implications are examined in detail.

Discussion

The current study provides a comprehensive evaluation of semi-automated condylar segmentation accuracy using conventional and ultra-low dose (ULD) CBCT protocols. Our findings demonstrate that ULD techniques achieve clinically acceptable results for most linear measurements while significantly reducing radiation exposure, supporting their use in diagnostic applications where dose reduction is prioritized[2,5].

The excellent agreement between ULD and conventional protocols for condylar width and length measurements (differences <1 mm) aligns with previous work by García-Sanz et al.[2], who reported similar submillimeter accuracy. This consistency holds particular clinical relevance for orthodontic assessment and TMJ evaluation, where these dimensions are diagnostically crucial[1,2]. The slightly greater variability observed in height measurements (ULD: 1.16±0.86 mm vs conventional: 1.02±0.81 mm) likely reflects the anatomical complexity of the condylar superior border and technical challenges in low-dose image segmentation[4]. While statistically significant, this difference remains below our predefined 1 mm threshold for clinical significance in most diagnostic scenarios.

Our semi-automated approach using 3D Slicer software demonstrated superior inter-observer reliability (ICC>0.9) compared to manual segmentation methods reviewed by Kim et al.[3]. This supports the methodology described by Xi et al.[4,11] and da Silva et al.[12], where limited operator involvement improved consistency. The results complement Alrashed et al.[13], though we employed different segmentation techniques. Notably, our findings contrast with Nicolielo et al.[14] regarding CBCT reliability, potentially due to our standardized protocols and modern software capabilities[9,10].

Several limitations warrant consideration: First, the dry skull model lacks soft tissue attenuation effects present in clinical imaging, which may influence segmentation accuracy[2]. Second, evaluation was limited to a single segmentation platform, and results may not fully generalize across different software[9,10]. Third, variability in height measurements suggests that conventional protocols may still be preferable when maximal precision of superior condylar border delineation is required[4,14]. Fourth, voxel size is another important technical factor. Although smaller voxels generally provide greater segmentation accuracy, their use is associated with longer scan times and higher radiation exposure. Alrashed et al.[13] (2024) reported that while 0.15 mm voxels yield the highest trueness, larger voxels (0.3–0.45 mm) can still achieve clinically acceptable results when paired with optimized exposure protocols and artifact management. For this reason, our study deliberately employed a larger voxel size as a balance between measurement accuracy and dose reduction, consistent with the ALADA principle.

Future studies should validate these findings in living patients and explore AI-enhanced segmentation to address current limitations[5,13].

The successful 50% dose reduction achieved with ULD protocols directly addresses the ALADA principle emphasized by Yeung et al.[5]. This advancement is particularly significant for pediatric applications and serial imaging where cumulative dose reduction is critical[5]. Our results fill an important gap identified in recent reviews regarding low-dose protocol effects on segmentation accuracy[5].

This study demonstrates that ULD CBCT protocols can achieve clinically acceptable accuracy for semi-automated condylar segmentation while significantly reducing radiation exposure. The technique shows particular reliability for width and length measurements, with height measurements requiring cautious interpretation. These findings support the judicious use of ULD protocols in appropriate clinical scenarios, advancing efforts to optimize diagnostic imaging while minimizing patient radiation risk[2,5,13].

This study confirms that ultra-low-dose CBCT provides clinically reliable condylar measurements for width and length, supporting its use in routine diagnostics. While height measurements show slightly greater variability, the protocol's 50% dose reduction makes it ideal for pediatric and serial imaging. The semi-automated segmentation method offers efficient, reproducible results comparable to conventional CBCT. These findings enable safer TMJ assessment without compromising essential diagnostic accuracy.

Acknowledgements

Not applicable.

Availability of data and materials

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

Ethics approval and consent to participate

Revised and approved by the Research Ethics Committee, Faculty of Dentistry, Cairo University, 26th of July 2022.

Consent for publication

Not Applicable.

Competing interests

The authors declare that they have no competing interests.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' contributions

Marina B. Salib: conceptualized and designed the study, collected the data, performed data analysis and interpretation, and wrote the original draft of the manuscript. **Ahmed M. Abd Alsamad:** participated in study design, supervised the research process, and contributed to manuscript review and editing. **Yara R. Helaly:** contributed to the study conceptualization and design, assisted in methodology development, participated in data analysis and interpretation, and contributed to manuscript review and editing. All authors read and approved the final manuscript.

References

1. Altan Şallı G, Öztürkmen Z. Semi-automated three-dimensional volumetric evaluation of mandibular condyles. Oral Radiol. 2021 Jan;37(1):66-73. doi: 10.1007/s11282-020-00426-1. Epub 2020 Feb 4.
2. García-Sanz V, Bellot-Arcís C, Hernández V, Serrano-Sánchez P, Guarinos J, Paredes-Gallardo V. Accuracy and reliability of cone-beam computed tomography for linear and volumetric mandibular condyle measurements. A human cadaver study. Sci Rep. 2017 Sep;7(1):11993. doi: 10.1038/s41598-017-12100-4.
3. Kim JJ, Nam H, Kaipatur NR, Major PW, Flores-Mir C, Lagravere MO, et al. Reliability and accuracy of segmentation of mandibular condyles from different three-dimensional imaging modalities: a systematic review. Dentomaxillofac Radiol. 2020 Jul;49(5):20190150. doi: 10.1259/dmfr.20190150. Epub 2019 Dec 3.
4. Xi T, Schreurs R, Heerink WJ, Bergé SJ, Maal TJ. A novel region-growing based semi-automatic segmentation protocol for three-dimensional condylar reconstruction using cone beam computed tomography (CBCT). PLoS One. 2014 Nov;9(11):e111126. doi: 10.1371/journal.pone.0111126.
5. Yeung AWK, Jacobs R, Bornstein MM. Novel low-dose protocols using cone beam computed tomography in dental medicine: a review focusing on indications, limitations, and future possibilities. Clin Oral Investig. 2019 Jun;23(6):2573-81. doi: 10.1007/s00784-019-02907-y.
6. Fan Y, Beare R, Matthews H, Schneider P, Kilpatrick N, Clement J, et al. Marker-based watershed transform method for fully automatic mandibular segmentation from CBCT images. Dentomaxillofac Radiol. 2019 Feb;48(2):20180261. doi: 10.1259/dmfr.20180261. Epub 2018 Nov 9.
7. Lo Giudice A, Quinzi V, Ronsivalle V, Farronato M, Nicotra C, Indelicato F, et al. Evaluation of imaging software accuracy for 3-dimensional analysis of the mandibular condyle. A comparative study using a surface-to-surface matching technique. Int J Environ Res Public Health. 2020 Jul;17(13):4789. doi: 10.3390/ijerph17134789.

8. Yadav S, Palo L, Mahdian M, Upadhyay M, Tadinada A. Diagnostic accuracy of 2 cone-beam computed tomography protocols for detecting arthritic changes in temporomandibular joints. Am J Orthod Dentofacial Orthop. 2015 Mar;147(3):339-44. doi: 10.1016/j.ajodo.2014.11.017.

9. Herren FL, Gerber V, Meier R, Schweizer-Gorgas D, Klopfenstein Bregger MD. Semi-automatic segmentation of cone beam computed tomography datasets for volume measurements of equine cheek teeth. J Vet Dent. 2022 Mar;39(1):41-8. doi: 10.1177/08987564211061630. Epub 2021 Dec 6.

10. Lo Giudice A, Ronsivalle V, Gastaldi G, Leonardi R. Assessment of the accuracy of imaging software for 3D rendering of the upper airway, usable in orthodontic and craniofacial clinical settings. Prog Orthod. 2022 Jun;23(1):22. doi: 10.1186/s40510-022-00413-8.

11. Xi T, van Loon B, Fudalej P, Bergé S, Swennen G, Maal T. Validation of a novel semi-automated method for three-dimensional surface rendering of condyles using cone beam computed tomography data. Int J Oral Maxillofac Surg. 2013 Aug;42(8):1023-9. doi: 10.1016/j.ijom.2013.01.016.

12. da Silva RJ, Valadares Souza CV, Souza GA, Ambrosano GMB, Freitas DQ, Sant'Ana E, et al. Changes in condylar volume and joint spaces after orthognathic surgery. Int J Oral Maxillofac Surg. 2018 Apr;47(4):511-7. doi: 10.1016/j.ijom.2017.10.012. Epub 2017 Nov 2.

13. Alrashed S, Dutra V, Chu TG, Yang CC, Lin WS. Influence of exposure protocol, voxel size, and artifact removal algorithm on the trueness of segmentation utilizing an artificial-intelligence-based system. J Prosthodont. 2024 Jul;33(6):574-83. doi: 10.1111/jopr.13827.

14. Nicolielo LFP, Van Dessel J, Shaheen E, Letelier C, Codari M, Politis C, et al. Validation of a novel imaging approach using multi-slice CT and cone-beam CT to follow-up on condylar remodeling after bimaxillary surgery. Int J Oral Sci. 2017 Sep;9(3):139-44. doi: 10.1038/ijos.2017.22.