Observer Agreement in Temporomandibular Joint Space Measurement using Open-Source Software and Commercial Software

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Abstract

The performance of CBCT software plays an important role in analyzing a CBCT image. Several types of software are available, which can be accessed as open-source and commercial software. There are several studies about the performance of open-source CBCT software, however, there have not been any publications about the comparison of the performance of open-source software to commercial software in measuring TMJ joint space yet. The aim of this study is to examine the reliability of TMJ joint space measurement on CBCT images using open-source and commercial software through intra-interobserver measurement.

TMJ joint space measurement from secondary CBCT data from the dental hospital Faculty of Dentistry Universitas Indonesia was performed using three different software i.e. open-source software Horos, ITK-Snap, and commercial software CS 3D dental imaging.

Technical Error of Measurement (TEM) obtained a value of d < 1, showing good reliability of intra and interobserver measurements of those three different software in measuring TMJ joint space.

This study shows that the result obtained from intra- and interobserver in measuring the TMJ joint space from all software was reliable.

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Introduction

CBCT is a modality that can be used to evaluate the condition of the Temporomandibular Joint (TMJ), a complex joint of the human body that has an important role in the processes of mastication, swallowing, and pronunciation. CBCT can overcome the limitations of pre-existing 2D radiographic examination modalities including TMJ examination. The advantage of CBCT is that it can display a more reliable and accurate three-dimensional reconstruction image so that it can help better and more precise assessment of diagnosis, treatment planning, and evaluation.[1]

Data from CBCT examination results in the multiplanar 3D reconstruction process for various abnormalities including TMJ can be performed using a standard data format, namely Digital imaging and Communication in Medicine (DICOM). Software development for 3D analysis is an important factor in the field of radiodiagnostic maxillofacial imaging.[2] The ability of the software to process images with a high degree of accuracy for linear measurements, especially for measuring joint space and concentricity of the condyle heads in determining abnormalities of the TMJ is one of the performance diagnostics of the software. There are various kinds of software programs available, namely commercial software including dedicated software and Open-source software which have different data processing capabilities. Commercial software is paid software and is relatively high cost. While Open-source software is a program that meets the quality standards for operating digital data and can be downloaded, copied, studied, modified, and distributed to other parties.[3]

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Currently, there are a few open-source software options that can match the capabilities of commercial software. Despite several studies on the use of open-source software for TMJ cases, the number of studies is still limited. In addition, none of the studies have examined the reliability of intra-interobserver measurements for TMJ assessments using open-source compared with commercial software. Therefore, this study aims to analyze the results of intra-interobserver measurements using both open-source and commercial software in measuring the joint space of the TMJ.

Materials and methods

The research was conducted after obtaining ethical approval from the Research Ethics Commission of the Faculty of Dentistry, University of Indonesia (Number: 52/Ethical Approval/FKG UI/VIII/2022). The study was conducted at the Radiology Unit RSKGM FKG University of Indonesia, with secondary data as the sample from CBCT images with good quality. Exclusion criteria in this study were the presence of pathological lesions on the TMJ, patients with a history of systemic disease, autoimmune disease, previous head, and neck radiotherapy, and previous trauma or surgery to the TMJ.

Measurement of CBCT images using CBCT software was carried out by two observers. Measurements were made based on the method used by Tsuruta (2004) with line and point references as follows:

Sagittal:

Line A, is a straight line that runs parallel to the Frankfort plane and passes through the lowest point of the articular eminence. Line B is perpendicular to line A, through the highest point of the glenoid fossa. The intersection between lines A and B is the midpoint of the glenoid fossa (point M). After determining the reference points and lines, then linear measurements are carried out using several measurements, namely:[4]

- Anterosuperior joint space (S1) : refers to the distance between the cortical surface of the condyle and the posterior portion of the articular eminence. It is measured using a line through point M at a 45º inclination from line A.
- Superior joint space (S2): refers to the distance between the cortical surface of the condyle and the glenoid fossa on the B line.
- The Posterosuperior joint space (S3) : the distance between the cortical surface of the condyle and the temporal bone. It is measured by the line that passes through point M at 135º inclination from line A.

Axial :

- Horizontal Joint space (A1): The distance between the cortical surface of the medial condyle and the wall of the temporal bone.

Measurement of the TMJ joint space in the position of opening the mouth was carried out based on the method of Menezes (2008) in the following way:[5]

- Determine the most inferior point of the articular eminence (E), the most superior point of the glenoid fossa (F), and the most superior point of the head of the condyle (C).
- Draw a horizontal line through point E and a vertical line through point F.
- The distance between the eminent (E) and the glenoid fossa (F) is referred to as "X" while the distance between the head of the condyle (C) and the glenoid fossa (F) is referred to as "T"

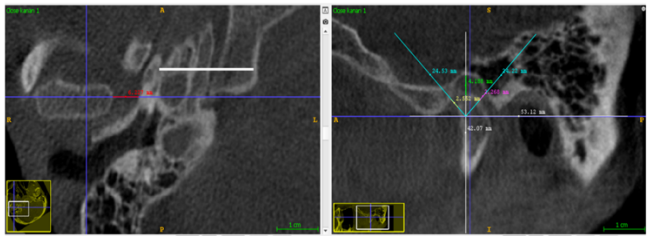

Figure 1. Joint space measurements using the ITK-Snap in the closed mouth position.

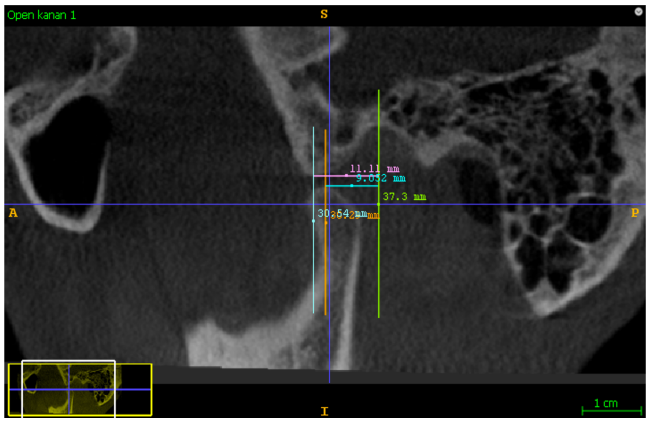

Figure 2. Joint space measurement using the ITK-Snap in the mouth-open position.

Data analysis was carried out after all measurement data were obtained from both the first and second observers. The Technical Error

of Measurement test with Dahlberg's formula was used to see the reliability of the results of measurements of the TMJ joint space between observers.

$$d = \sqrt{\frac{\sum_{i=1}^{n}(X_{1i} - X_{2i})^2}{2n}}$$

d = Relative Dahlberg Error (Error) / mean of two corresponding measurements.
X_1 = measurement1
X_2 = measurement 2
n = sample

Results

The research data obtained was in the form of numerical data which was then tested for reliability to assess the consistency and reliability of the TMJ joint space measurements using Open-source software and commercial software between observers in the first and second measurements, with the second measurements two weeks apart after the first measurement. The observer measured the TMJ joint space according to the measurement method and reference points, namely S1, S2, S3, and A in the closed mouth position, and X and T in the mouth open position. Technical Error of Measurement (TEM) by Dahlberg was used in this study to see the consistency of repeated measurement results with a measurement reference value of d < 1. The TEM value indicates that there is compatibility between observers and shows the reliability of using Horos, ITK-Snap, and CS 3D Dental Imaging software in measuring the TMJ joint space (table 1, 2, 3).

TMJ	*Horos* x *CS 3D*	*ITK-Snap* x *CS 3D*
	d	d
S1 Right	0.34	0.18
S2 Right	0.32	0.19
S3 Right	0.31	0.10
A Right	0.77	0.59
X Right	0.36	0.40
T Right	0.68	0.57
S1 Left	0.33	0.17
S2 Left	0.50	0.20
S3 Left	0.31	0.19
A Left	0.48	0.23
X Left	0.62	0.77
T Left	0.88	0.69

Table 1. TEM values in the intraobserver reliability test for measuring the TMJ joint space using Horos, ITK-Snap, and CS 3D Dental Imaging software.

TMJ	A1 x B1	A1 x B2	A2 x B1	A2 x B2
	d	d	d	d
S1 Right	0.28	0.33	0.29	0.16
S2 Right	0.21	0.33	0.05	0.206
S3 Right	0.34	0.22	0.15	0.090
A Right	0.51	0.59	0.59	0.636
X Right	0.38	0.67	0.65	0.773
T Right	0.41	0.60	0.57	0.860
S1 Left	0.48	0.48	0.29	0.310
S2 Left	0.52	0.57	0.61	0.522
S3 Left	0.23	0.25	0.27	0.306
A Left	0.42	0.35	0.29	0.248
X Left	0.63	0.59	0.66	0.632
T Left	0.67	0.76	0.60	0.639

Table 2. TEM values in the interobserver reliability test for measuring the TMJ joint space using Horos and CS 3D Dental Imaging software.

TMJ	A1 x B1	A1 x B2	A2 x B1	A2 x B2
	d	d	d	d
S1 Right	0.448	0.277	0.401	0.229
S2 Right	0.263	0.191	0.257	0.310
S3 Right	0.072	0.233	0.203	0.291
A Right	0.703	0.421	0.668	0.177
X Right	0.498	0.471	0.709	0.640
T Right	0.773	0.449	0.544	0.157
S1 Left	0.257	0.247	0.432	0.352
S2 Left	0.173	0.134	0.351	0.433
S3 Left	0.100	0.115	0.109	0.172
A Left	0.377	0.229	0.332	0.162
X Left	0.352	0.468	0.369	0.600
T Left	0.547	0.770	0.618	0.882

Table 3. TEM values in the interobserver reliability test for measuring the TMJ joint space using ITK-Snap and CS 3D Dental Imaging software.

S1 = anterior joint space closed-mouth position
S2 = superior joint space closed-mouth position
S3 = posterior joint space closed-mouth position
A = joint space of the axial section in the closed mouth position
X = distance of the glenoid fossa – articular eminence the position of opening the mouth.
T = distance of glenoid fossa - head of condyle in the opening mouth position.
A= Observer 1
B= Observer 2
d = Relative Dahlberg Error

The Temporomandibular Joint (TMJ) is a complex joint of the human body consisting of the condyle, articular disc, articular eminence, and mandibular fossa, and is supported by several masticatory muscles.[6] Several types of radiographic examination can be used to evaluate the condition of the TMJ, one of which is one of them is Cone Beam Computed Tomography (CBCT) because this modality can obtain three-dimensional (3D) images, and

shorter scan acquisition times, resulting in lower radiation doses to patients and lower examination costs. CBCT also has good diagnostic accuracy, one of which is for evaluating TMJ. Zhang, et al. in 2012 conducted research on the accuracy of CBCT for TMJ evaluation and concluded that measurements of the TMJ joint space on CBCT were identical to the actual joint space.[7]

CBCT imaging has two basic principles, namely image production and image display. Image production is the process of forming CBCT images obtained through three stages, namely (1) the acquisition stage, namely the geometric configuration of the image acquisition process from X-rays and detectors directed at the area to be evaluated according to the desired FOV, (2) image detection using a flat panel detector (FPD) that captured X-ray photons and send signals to the computer within a certain time and (3) image reconstruction, when raw CBCT data is processed into a volumetric dataset according to the acquisition parameters (voxel size, FOV and number of projections).[8]

CBCT image displays are displayed in a digital format that is different from other 2D images because CBCT acquisition displays volumetric data and 3D information. Therefore, in order to display digital information, data in the standard Digital imaging and communication in medicine (DICOM) file format must be transferred from hard copy to volumetric view with the help of software available on the computer and connected directly to the CBCT device. The ability of the CBCT software to have more advanced performance in the form of specific tasks is an important factor in improving the appearance of images to be more dynamic so that they can be interpreted according to the needs of case analysis.[9]

Many studies have been carried out using special software according to the aircraft brand (dedicated software) for CBCT to see various conditions and abnormalities in dentistry. One such study was conducted by Lukat, et al (2015) using the Carestream 9000 CBCT unit, with the dedicated CS 3D Dental Imaging software (Carestream Dental, Rochester, NY) to detect bone changes associated with TMJ disorders. In this study, which was a diagnostic test, the dedicated software proved to be valid and reliable.[10] Gamache, et al also conducted a study of measuring external root resorption using a CBCT CS 9300 and Carestream 3D CBCT software (Carestream Health, Inc., Rochester, NY) with the aim of observing the image quality produced by a CBCT in several imaging modes. The results of this study indicate that the CBCT CS 9300 can produce high image quality even at low kV and mA settings. In this study it was also stated that measurements using the Carestream 3D CBCT software showed near-perfect results with an ICC value 0.98.[11] Junior, et al observed the anatomical landmarks of the mental foramen using Osirix suggested that the open-source Osirix software has effective and reliable digital analysis capabilities for viewing the mental foramen and can provide good guidance for dental implant treatment plans.[12] Villoria et al also conducted research using the open-source ITK-SNAP software to measure periapical lesions post-endodontic treatment, with the conclusion that ITK-SNAP can be used as an alternative diagnostic tool software in endodontic treatment cases.[13]

This study compares the performance of open-source software with commercial software in measuring the TMJ joint space. The open-source software used are Horos and ITK-Snap, both of which are often used in various studies.[14] Horos is software that is only compatible with MacOS X-based operating systems, and ITK-Snap is used on Windows. Meanwhile, the Commercial software used in this study is CS 3D Dental Imaging software which can be used on Windows-based operating systems. Measurement of the TMJ joint space was carried out by two observers who had obtained an agreement or calibration method of measurement and were trained in reconstructing and interpreting CBCT images. Observations were made twice at different measurement times, with the interval between the first measurement and the second measurement was two weeks.

The results of the TMJ joint space measurements carried out by the two observers were then carried out a reliability test to see the reliability of the measurement results between the first observer and the second observer. The reliability test used is the Technical error of measurement using the Dahlberg's formula, with an acceptable measurement tolerance (MT) value of < 1 mm. From the results of TMJ joint space measurements carried out both by intra- and interobserver using Horos, ITK-Snap and CS 3D Dental Imaging software, the overall value

was <1 mm, which means that the results of TMJ joint space measurements using Horos, ITK-Snap were reliable with TMJ joint space measurement results using CS 3D Dental Imaging software.

Open-source and commercial software each have features that suit the needs of their users. The reason some users choose open-source software is because this software can be copied, modified, and distributed freely. Commercial software has the advantage that vendors or licensees always strive to develop product and software functionality on an ongoing basis and adapt it to the needs of its users. Commercial software users can also ask for direct accountability from the vendor concerned if there are problems related to the use of the software. While users of Open-source software do not have an official vendor, so users cannot get guarantees or accountability if there are problems with the software used.[15]

Research on the ability of open-source software compared to commercial software for TMJ joint space measurement is still very limited. Therefore, the purpose of this study is to provide initial information about the performance of open-source software compared to commercial software. The weakness of this study is the limited number of samples with only 2 observers. This research does not use the gold standard in the form of a dry skull, so a diagnostic test has not been carried out on the Open-source Software being tested. In addition, this study did not evaluate the perceived ease of use of Open-source software by observers.

Conclusion

Studies to investigate the performance of Open-source software compared to commercial software to analyze the TMJ joint space are still very limited. Moreover, there have not been any publications about the comparison of the performance of open-source software to commercial software in measuring TMJ joint space yet.

This study provides initial information about the reliability of Horos and ITK-Snap compared to CS 3D Dental Imaging software in analyzing TMJ joint space. This study shows that the result obtained from intra- and interobserver in measuring the TMJ joint space from all software was reliable. Further research is needed on the error rate and accuracy of Open-source and commercial CBCT software.

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Declaration of Interest

The authors report no conflict of interest.

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