# Comparison of Open-Source Software Performance as a Measurement Tool in CBCT: A Literature Review

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**Abstract**

Cone-beam computed tomography (CBCT) is an imaging method that is becoming increasingly popular in dentistry. This imaging modality has advantages over other conventional modalities because it can display more reliable and accurate three-dimensional reconstructed images to help better planning and evaluation of treatment. More precisely, images from CBCT can display three-dimensional multiplanar visualizations using certain specific software. There are various kinds of open-source software available on the market with different characteristics of measurement methods. However, information about the capabilities of some existing open-source software is still limited. The aim of this study was to examine the use of open-source software in analyzing CBCT imaging by comparing which post-processing imaging protocol is better for planning procedures and for identifying the presence of anatomic variations.

Several related research articles were collected through a database available on PubMed and Scopus, using the search keywords CBCT three-dimensional open-source software. The selected articles are full text and free access articles published between 2006 and 2021 with Scopus Q1 and Q2 indexes.

The results show that there are no significant differences in measurement between several open-source software programs used in several studies.

The accuracy and capability of open-source software are almost comparable to commercial software, so it can be used as an alternative method for post-processing CBCT images with lower costs and easier accessibility.

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## Introduction

Cone-beam computed tomography (CBCT) is a three-dimensional (3D) imaging of the dentomaxillofacial area that can be obtained with an easier method, shorter acquisition scan time, lower cost, and dose compared to a CT scan[1-3]. Since it was first introduced in the late 1990s, CBCT has become popular for imaging in dentistry because this modality has advantages over other conventional modalities, such as better visualization of facial bones and teeth without distortion or overlapping structures, and high precision in representing anatomical structures. Another advantage of CBCT is that the 3D reconstruction images are more reliable and accurate since it uses several imaging protocols and results in better and more precise treatment planning and evaluation[4,5]. Images from CBCT can display 3D multiplanar visualizations using certain specific software that is available on a computer directly connected to the CBCT or may require a special key for activation. The analysis of CBCT images is carried out by exporting data in a standard digital imaging and communication in medicine (DICOM) file format, thereby enabling the software to process images in a 3D plane[6].

Software capability plays an important role in accurately measuring diagnostic CBCT images. With the development of technology nowadays, there is plenty of software that can be used to process DICOM files and provide various tools to facilitate measurements, such as visual

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adjustment (brightness, contrast, and greyscale), zoom, annotation, and 3D reconstruction[1]. There are various kinds of commercial software and open-source software with different characteristics of measurement methods. Commercial software is paid software that the manufacturer officially supports and the users cannot modify. Open-source software is a program that is available from certain websites and specialized in specific fields. Open-source software is free, reliable, scalable, and has quality standards. The whole community around the world could gain access to this software in order to fix any bugs. The source code is "open", which means that the code can be copied, used, studied, modified, and even redistributed without any restrictions[7].

Currently, there is plenty of open-source software that can be used to assess and analyze CBCT imaging. However, information regarding the capabilities of some existing open-source software is still limited. This study aimed to assess the reliability of several open-source software programs in analyzing CBCT imaging, determining which software performs better in post-processing imaging assessment for planning procedures and identifying the presence of anatomic variations.

## Materials and methods

The search for research data was conducted by collecting related research articles through the databases available on PubMed and Scopus. The search keyword used was CBCT three-dimensional open-source software. Inclusion criteria were CBCT data in the dentomaxillofacial area using open-source software to analyze CBCT images. The criteria for selected articles included those published from 2012 to 2021, written in English, discussing open-source software, free access, full text, and indexed by Scopus Q1 to Q3. Exclusion criteria in the article search were the use of imaging modalities other than CBCT, data analysis using only commercial software, and animal studies. The search for the articles was conducted in September 2021.

## Results

The article search found that there are only a few articles that discuss the use of open-source software in analyzing CBCT images. Due to this limited number of articles, the inclusion criteria were not specified for particular anatomical measurements and the search resulted in 10 articles that matched the inclusion criteria. Each article evaluates the reliability of open-source software using a different object or sample. The search results for articles that match the criteria and procedures used can be seen in Tables 1 and 2.

## Discussion

Open-source software used in selected journals includes ITK-Snap (www.itksnap.org), OsiriX (Pixmeo, Geneva, Switzerland), 3D SLICER 4.6® (http://www.slicer.org), NETFABB basic 5.0®(https://netfabb-basic.software.informer.com/5.0/), Blue Sky Plan (BlueSkyBio, New York City, United States), and RadiAnt (Medixant, Poznan, Poland). The ITK-SNAP is an open-source application featuring image visualization with manual and semi-automatic segmentation. This software can create 3D models quickly and reliably, which is an advantage to its users. This software offers two different manual segmentations, namely polygon mode and brush mode. Brush mode allows for boundary setting using isotropic, 3D, and customizable brush sizes, making it faster than polygon mode[8].

OsiriX® is a free DICOM software that Rosset et al.[9] developed from the University of Geneva and is widely used in the medical field and can reconstruct several types of 3D images[10]. The simple interface allows radiologists to use this software but also for doctors and researchers to use it[11]. The 3D SLICER 4.6® is an open-source software that allows 3D visualization and processing of medical images, while NETFABB basic 5.0® is an open-source software that allows for repairing and printing 3D models[12]. Blue Sky Plan is a free software program that can be used for planning implant and surgical guide design for implant osteotomy[13]. The type of software used and the results from each article are presented in Table 3.

Weissheimer et al. conducted a study to measure the oropharyngeal volume from CBCT images using 33 secondary sources of CBCT data from growing patients (mean chronological age of 10.7 years; age range of 7.2-14.5 years) with rapid maxillary expansion. Measurement of

CBCT images used 6 software programs (4 commercial software and 2 open-source software) to measure the volume of the patient's oropharynx and phantom acrylic oropharynx (as the golden standard). The results of the oropharyngeal volume measurement obtained are underestimated by all types of software used. Mimics 14.12 (Materialise, Leuven, Belgium), Dolphin3D 11.7 (Dolphin Imaging & Management Solutions, Chatsworth, Calif), OsiriX 4.0 (Pixmeo, Geneva, Switzerland), and ITK-Snap 2.2.0 (www.itksnap.org) software showed better accuracy with error rates of 0.2%, 1%, 1.3%, and 1.8%, respectively, compared to Ondemand3D 1.0.9.1451 (CyberMed, Seoul, Korea) and InVivo Dental 5.0 (Anatomage, San Jose, Calif) which had an error rate of 6.4% and 11.1%, respectively. According to Weissheimer et al., the poor accuracy of Ondemand3D software is due to inadequate segmentation and sensitivity control, while in the InVivo Dental software, users can only adjust the threshold interval in 3D viewing mode, not in axial, coronal, or sagittal as is commonly found in all other software programs. As a result, the user cannot accurately check the upper airway's segmentation. Based on this study, it was found that the OsiriX and ITK-SNAP software had good and reliable results for use in upper airway measurements[14].

Junior et al. conducted a study to observe the anatomical landmarks of the mental foramen and additional mental foramen in 71 patients who were to undergo dental implant treatment in the mandible's edentulous area. The software used in this research is OsiriX 4.0 (Pixmeo, Geneva, Switzerland), and the analysis used is qualitative and quantitative. In the qualitative analysis, it was found that OsiriX can change the position or orientation of one plane in order to obtain a reconstructed image showing two foramina, making it reliable for measurements. In the quantitative analysis, the results of the Intraclass correlation coefficient (ICC) calculation show that the results range from 0.9032 to 0.9565 (maximum value = 1) for interobserver analysis, and the results range from 0.9184 to 0.9666 for intraobserver analysis. This indicates that there is a very good agreement between observers when using the OsiriX software. This study concludes that the OsiriX software is an effective and reliable digital analysis tool used to assist in diagnosis and treatment planning, especially in viewing the mental foramen and additional mental foramen, thereby ensuring the best guide for dental implant surgical intervention[15].

Gaia et al. conducted a study to compare the precision and accuracy of Le Fort I linear measurements using two different software programs, Vitrea 3.8.1 (Vital Images Inc., Plymouth, MN) and the open-source DICOM viewer OsiriX 1.2 64-bit (Pixmeo, Geneva, Switzerland). The results shows that there was a significant difference between OsiriX and the gold standard, while for Vitrea, there was no significant difference compared to the gold standard. The significant difference using the OsiriX software was obtained through only one view of the 3D reconstructed image, and the measurement that needs different translations and rotations to be identified, such as the pterygoid process, may not be readily identifiable and therefore not considered sufficient for preoperative planning of the Le Fort I osteotomy. The OsiriX software tested in this study (v. 1.2 64-bit) is not the latest version available. If a newer version is used, it could provide better results[16].

Burkhard et al. conducted a study to measure the reliability of several different software programs in measuring Posterior Airway Space (PAS) and the morphology changes of oropharyngeal structures before and after orthognathic surgery. The devices used in this study include commercial software Mimics (Materialise, Leuven, Belgium) and BrainLab (AG, Feldkirchen, Germany) and open-source software OsiriX (Pixmeo, Geneva, Switzerland). This study suggested that the three software programs are reliable for measuring PAS[17].

Villoria et al. described the use of ITK-SNAP v.3.0 (www.itksnap.org) to measure periapical lesions after endodontic treatment. This was the first clinical study on the analysis of a periapical healing 3D image using open-source software. Two existing cases found that ITK-Snap can provide a fairly good appearance of periapical lesions before endodontic treatment, and show a good image of periapical lesion healing after endodontic treatment. The researcher described that the ITK-SNAP used in this study is reliable for comparing and analyzing images of periapical lesions. This software can assist endodontists in the post-treatment control of lesions of endodontic origin, increasing diagnostic resources for confirming lesion regression and preventing unnecessary surgical

procedures[18].

Sonmez et al. compared linear and volumetric measurements of artificial external root resorption (ERR) using four different software programs: Romexis (Planmeca Oy, Helsinki, Finland), 3D Doctor (Able SoftwareCorp., Lexington, MA), ITK-SNAP (www.itksnap.org), and OsiriX (Pixmeo, Geneva, Switzerland). In this study, the linear and volumetric measurements were obtained by using different voxels and software. The two observers used CBCT images obtained with four different voxel sizes, then performed the ERR quantification measurements using different software to measure diameter, height, and volume. The result of this study was a statistically significant difference between the voxel sizes only in the height measurement. Researchers obtained a higher mean variation for depth measurements compared to other measurements. This may be due to difficulties in reformatting the image, and describing and measuring the cavity's depth. This study suggested that the observer's performance was better when using 3D-Doctor and OsiriX for diameter measurement and with the ITK-SNAP software. However, the authors note that all of the software used in this study can be reliably used as ERR quantification, if needed[8].

Pinheiro et al. conducted a study to assess the accuracy of pharyngeal volumetric reconstruction by comparing the volume and minimum cross-sectional area (mCSA) determined with ITK-Snap (www.itksnap.org) and Dolphin3D 11.8 (Dolphin Imaging & Management Solutions, Chatsworth, Calif). The sample consisted of CBCT images of 35 patients with unilateral cleft lip and palate with a mean age of 29 ± 15. Dolphin3D has an automatic function and can determine which axial slice shows the smallest segmented area. The determination of this mCSA depends on the head's orientation at the time of segmentation. On the other hand, to determine mCSA using open-source software some additional steps are required, such as remove "bubbles" and spicules from the original segmentation, and export segmentation files to the SPHARM-PDM module on SlicerCMF, to get a smoother surface model, mean axis, and the cross-sectional plane perpendicular to the mean axis. Although there are technical differences between the two devices, the authors conclude that open-source software ITK-Snap can be an option for measuring upper airway dimensions in CBCT examination[19].

De Stefano et al. conducted a study using open-source software to evaluate differences in condylar volume, surface area, and Morphological Index (MI) between affected and unaffected condyles in patients with unilateral condylar hyperplasia (UCH), which was evaluated through 3D CBCT reconstruction using 3D SLICER 4.6 ® (http://www.slicer.org) for the reconstruction of 3D images and NETFABB basic 5.0 ® (https://netfabb-basic.software.informer.com/5.0/) for measuring volume and condyle area of reconstructed images. The results obtained in this study indicate that the use of open-source software for 3D reconstruction with manual segmentation to evaluate condylar volume and surface is a valid tool and is reliable for diagnosing and evaluating patients with hyperplastic condyles[12].

Almeida et al. investigated the software's accuracy in evaluating mandibular defects on panoramic reformatted images from CBCT. The software used was DentalSlice® (BioParts—Biomedical Prototyping, Brasília DF, Brazil); Dolphin Imaging 3D® 11.5 (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA); and OsiriX® (Pixma SARL, Geneva, Switzerland). Previously, standardized procedures for creating panoramic images were carried out from each software. The height and width of the mandibular bony defect were measured in the most central section (Figure 4). The bone height and width of the mandible were measured manually with digital calipers for the gold standard. Two examiners conducted the study twice, with an interval of 7 days between assessments. The results are that there is no statistically significant difference between the measurements of each software, even though the measurement results are overestimated from the gold standard. It is concluded that linear measurement of panoramic reformat CBCT images using these three types of software is quite accurate and can be used to analyze and plan the treatment[20].

Al-Ekrish conducted another study on the use of open-source software. This study used several software programs—coDiagnostiX version 9.10 (Dental Wings GmbH, Chemnitz, Germany), Blue Sky Plan version 4.5.9 (BlueSkyBio, New York City, United States), and RadiAnt DICOM Viewer version 5.5.0 (Medixant, Poznan, Poland)—to compare each program's

ability and accuracy to measure the location of dental implants. The result was that there are no statistically significant differences in measurement errors found between the three programs. It shows that there is no difference in the basic function of bone delineation and linear measurement accuracy between commercial and relatively more expensive software programs (coDiagnostiX), and cheaper or free open-source software (RadiAnt and Blue Sky Plan)[13].

## Conclusions

OsiriX and ITK-Snap are the software programs most frequently used in studies about accuracy and capabilities compared with commercial software. There are various other programs that can be used as an alternative method for post-processing CBCT images, with various advantages and limitations. Newer programs are continuously being developed and made available to users, but information about the accuracy and reliability of available open-source software is still very limited. Therefore, it is necessary to conduct more research about the accuracy and reliability of other open-source software to provide references to clinicians and practitioners in choosing alternative software that is easier and more affordable.

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## Declaration of Interest

The authors declare that there is no conflict of interest concerning the publication of this article.

| Author | Title | Year | Type of Study | Sample | Objectives | Scopus Index |
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| Weissheimer, et al. | Imaging Software Accuracy for 3-Dimensional Analysis of the Upper Airway | 2012 | Original Article | Thirty-three patients with transverse maxillary deficiency and no congenital malformations. | To compare the precision and accuracy of 6 software programs in measuring oropharyngeal volume from CBCT images, with the main hypothesis that there is no significant difference in airway volume measurement among the 6 different software programs. | Q1 |
| Junior, et al. | Assessment of Open-Source Software for CBCT in Detecting Additional Mental Foramina | 2013 | Original Article | The CBCT data from 71 patients (29 males and 42 females) who underwent dental implant treatment planning in the edentulous area of the mandible. | To assess CBCT imaging using open-source software, by analyzing which post-processing imaging protocol is better for planning procedures and for identifying the presence of anatomic variations. Another objective was to assess the reproducibility of 3D-CBCT using open-source software to measure anatomical landmarks (MF and AMF). | Q1 |

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| Gaia, et al. | Comparison of Precision and Accuracy of Linear Measurements Performed by Two Different Imaging Software Programs and Obtained from 3D-CBCT Images for Le Fort I Osteotomy | 2013 | Research Article | Eleven dry skulls (8 males and 3 females), ages 19 - 56 years. | To compare the precision and accuracy of linear measurements for Le Fort I osteotomy from 3D-CBCT images using two different imaging software programs. | Q1 |
| Burkhard, et al. | Cephalometric and Three-Dimensional Assessment of the Posterior Airway Space and Imaging Software Reliability Analysis Before and After Orthognathic Surgery | 2014 | Research Article | Morphological changes of the posterior airway space of 11 patients (8 women and 3 men) who underwent treatment for correction of Class III anteroposterior mandibular prognathism. | To compare the reliability of three different imaging software programs to measure the PAS and simultaneously to investigate the morphological changes of oropharyngeal structures in mandibular prognathic patients before and after orthognathic surgery. | Q1 |
| Villoria, et al. | Post-Processing Open-Source Software for CBCT Monitoring of Periapical Lesions' Healing Following Endodontic Treatment: Technical Report of Two Cases | 2016 | Technical Report | The CBCT was taken from two endodontic patients. | To describe the use of open-source software in post-processing CBCT imaging when measuring periapical lesion progression after endodontic treatment. | Q1 |
| Sönmez, et al. | Accuracy of Linear and Volumetric Measurements of Artificial Eternal Root Resorption (ERR) Cavities by Using CBCT Images Obtained at 4 Different Voxel Sizes and Measured by Using 4 Different Software Programs: An Ex Vivo Research | 2018 | Research Article | Forty single-rooted, extracted, anterior teeth were then made into an ERR cavity. | To compare the accuracy of linear and volumetric measurements of ERR with CBCT images using four different software programs. | Q1 |

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| Pinheiro, et al. | Volumetric Reconstruction and Determination of Minimum Cross-Sectional Area of the Pharynx in Patients With Cleft Lip and Palate: Comparison Between Two Different Softwares | 2018 | Original Article | Thirty-five CBCT scans of unilateral cleft lip and palate patients, with a mean age of 29 ± 15. | To assess the volumetric accuracy of pharyngeal reconstruction by comparing the volume and minimum cross-sectional area (mCSA) between open-source software and commercial software. | Q1 |
| Stefano, et al. | Unilateral Condylar Hyperplasia: A Three-Dimensional CBCT Morphometric and Volumetric Evaluation of Mandibular Condyle by Open-Source Softwares | 2021 | Original Article | The CBCT of 16 patients with Unilateral Condylar Hyperplasia (9 women and 7 men; mean age 25.13 ± 6.8 years). | To evaluate differences in condylar volume, surface area, and morphological index (MI) between affected and normal condyles in patients with Unilateral Condylar Hyperplasia using open-source software. | Q3 |
| Almeida, et al. | Linear Measurement Accuracy of CBCT Panoramic Reconstructions: Experimental Study with Dry Human Mandibles | 2021 | Original Article | Ten CBCT of dry mandibles, then assess the linear measurement from panoramic reconstruction using three different software programs. | To evaluate the software accuracy of the reformatted panoramic views of the CBCT. | Q3 |
| Asma'a Al-Ekrish | Comparative Study of the Accuracy of CBCT Implant Site Measurements Using Different Software Programs | 2021 | Original Article | The CBCT images of 5human skulls. There are 24 sample locations from the 5 skulls used. Twelve sample sites were in the maxilla and 12 in the mandible. The sample locations were evenly distributed among the molar, premolar, and incisor areas. | To assess and compare the linear dimensional accuracy of the implant location from CBCT images using different software. | Q2 |

**Table 1.** Search results for research articles.

| Author | CBCT | Procedures |
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| Weissheimer, et al. | i-CAT (Imaging Sciences International, Hatfield, PA) | Scanning was performed with parameters of 120 kVp, 8 mA, scanning time of 40 seconds, and voxel size of 0.3 mm. Images are reconstructed at 0.3 mm slice thickness and saved in DICOM format. |
| Junior, et al. | i-CAT (Imaging Sciences International, Hatfield, PA) | The image acquisition protocol was 120 kVp, 36.12 mAs, the field of view (FOV) 60 mm x 160 mm, and voxel size 0.25 mm. Data was saved in DICOM format. |
| Gaia, et al. | i-CAT (Imaging Sciences International, Hatfield, PA) | Mandibular scans were performed with 0.25 mm voxel for 40 seconds, with FOV of 20 cm (height) and 16 cm (diameter), and greyscale 14 bits, saved in DICOM format. |
| Burkhard, et al. | KaVo 3D exam digital volume tomography (KaVo Dental GmbH, Biberach, Germany) | The CBCT scan was performed while the patient was sitting in an upright position, breathing calmly, tongue relaxed, and with Frankfort's horizontal plane parallel to the floor (CBCT parameters not listed). |
| Villoria, et al. | PreXion 3D device (TeraRecon, SanMateo, CA) | Scans were performed at 90 kVp, 4 mA, scan time 19 seconds, FOV 8 x 7.5 cm, and voxel size 0.1 mm. Data was saved in DICOM format. |
| Sonmez, et al. | ProMax®<br>3D Max CBCT (Planmeca, Helsinki, Finland). | The scanning parameters used were 96 kVp, 7mA, 15 s, and 55 × 50 mm FOV, with different voxel sizes and scanning times. |
| Pinheiro, et al. | N/A | N/A |
| Stefano, et al. | N/A | N/A |
| Almeida, et al. | i-CAT (Imaging Sciences International, Hatfield, PA). | The CBCT scans were obtained with 3 voxel sizes (0.2 mm, 0.3 mm, and 0.4 mm) and FOV of 8 × 8 cm (130 kV and 45 mAs). Data was saved in DICOM format. |
| Asma'a Al-Ekrish | Iluma device (Iluma, Imtek Imaging, 3 M Company, USA) | The mandibular scanning parameters used were 3.8 mA, 120 kV, and 40 seconds, and the voxel size was 0.29 mm. |

**Table 2.** CBCT scan parameters.

| Author | Objects | Software | Operating System | Result |
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| Weissheimer, et al. | Oropharynx | Dolphin3D<br>InVivo Dental<br>Ondemand3D<br>Mimics<br><br>*Open-Source Software*:<br>ITK-Snap<br>OsiriX | Windows<br>Windows<br>Windows<br>Windows<br><br><br>Windows, Mac OS X, Linux<br>Mac OS X | Mimics, Dolphin3D, ITK-Snap, and OsiriX had similar results for measurements and are considered more accurate than InVivo Dental and On-demand 3D software for upper airway measurement. |
| Junior, et al. | Mental Foramen (MF) and Additional Mental Foramen (AMF) | OsiriX | Mac OS X | High reproducibility of measurements for anatomical variations of Mental Foramen using OsiriX can be recommended for pre-operative planning. |

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| Gaia, et al. | Le Fort I osteotomy | Vitrea<br><br>*Open-source software*:<br>OsiriX | Windows<br><br>Mac OS X | Vitrea can be considered precise and accurate in performing all 3D linear measurements, while linear measurements performed using OsiriX failed to produce accurate linear measurements for Le Fort I osteotomy. |
| Burkhard, et al. | Posterior Airway Space | Mimics<br>BrainLab<br><br>*Open-source software*:<br>OsiriX | Windows<br>Windows<br><br>Mac OS X | All three software programs show similar results in cephalometric analysis and 3D measurement techniques |
| Villoria, et al. | Endodontic treatment | *Open-Source Software*<br>ITK-Snap | Windows, Mac OS X, Linux | Open-source software used in this research is reliable for comparison and analysis of periapical lesion images. |
| Sönmez, et al. | Anterior teeth with artificial external root resorption | Romexis<br>3D-DOCTOR<br><br>*Open-Source Software*<br>ITK-SNAP<br>OsiriX | Windows, Mac OS X<br>Windows<br><br>Windows, Mac OS X, Linux<br>Mac OS X | There are no significant differences between the software used. |

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| Pinheiro, et al. | Pharyngeal area in patients with cleft lip and palate | Dolphin3D<br><br>*Open-source software*:<br>ITK-Snap | Windows<br><br>Windows, Mac OS X, Linux | Volume and mCSA measurements between the software showed no significant difference statistically. Open-source software can be an option for measuring upper airway dimensions from CBCT images. |
| Stefano, et al. | Condyles | *Open-source software*:<br>3D SLICER 4.6®<br>NETFABB basic 5.0® (https://netfabb-basic.software.informer.com/5.0/) | Windows, Mac OS X, Linux<br>Windows, Linux | Open-source software is reliable for 3D reconstruction with manual segmentation for evaluating condylar volume and surface in patients with condylar hyperplasia. |

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| Almeida, et al. | Artificial defect in dry mandible | DentalSlice®<br>Dolphin Imaging 3D®<br><br>*Open-source software*:<br>OsiriX® | Windows<br>Windows<br><br><br>Mac OS X | There was no significant difference between the software in performing linear measurements of CBCT panoramic reconstruction. |
| Asma'a Al-Ekrish | Height and width of dental implant location | coDiagnostiX<br><br>*Open-source software*:<br>Blue Sky Plan<br>RadiAnt DICOM Viewer | Windows, Mac OS X<br><br><br>Windows<br>Windows | There was no significant difference statistically in the accuracy of linear CBCT measurements from implant sites analyzed using Blue Sky Plan, coDiagnostiX, and RadiAnt. |

**Table 3**. Types of software used and the results.

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