



ORIGINAL ARTICLE

Comparative study of the accuracy of CBCT implant site measurements using different software programs



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KEYWORDS

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CBCT

Abstract *Purpose:* To measure and compare the accuracy of the linear dimensions of implant sites recorded from cone beam computed tomography (CBCT) images using Blue Sky Plan, coDiagnostiX, and RadiAnt.

Materials and Methods: Five human dry skulls were imaged with a CBCT device then sectioned to obtain sample transverse cross-sections of the edentulous ridges, and the height and width of the ridge were measured with a digital caliper to provide the gold standard measurements. The CBCT datasets were exported in DICOM format and imported into the three test software programs which were used to obtain reformatted sectional images corresponding to the sample transverse cross-sections, and the height and width of the edentulous ridge was recorded using the linear measurement tool. Reliability of the measurements were measured using the intraclass correlation coefficient. One-sample *t*-test (test value: zero) was used to test the statistical significance of the mean of the absolute errors for each software program. Analysis of Variance with Repeated Measures was used to test the statistical significance of the difference between the means of the absolute errors obtained by the different software programs. Statistical significance was set at a *p*-value of 0.05.

Results: The reliability of the gold standard and image measurements were excellent. All three software programs demonstrated a statistically significant mean absolute measurement error of between 0.43 and 0.56 mm (*p*-value < 0.01), but no significant difference in error values was found between any of the tested programs (*p*-value = 0.18).

Conclusions: There was no statistically significant difference in accuracy of linear CBCT measurements of implant sites recorded using Blue Sky Plan, coDiagnostiX, and RadiAnt.

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1. Introduction

Dental implant therapy is rapidly increasing in use as a treatment option for missing teeth. With the widespread use of den-

tal implants, there is now also an associated increase in the number of software programs for viewing and analysis of CT images. Such software programs have different capabilities with regards to reformatting, analysis, and implant treatment planning. However, the most basic features which must be present in any software program is the ability to accurately depict the bone-soft tissue interface, and to accurately record linear measurements. These features are the basis upon which operators determine the amount of bone available in a particular implant site, and measure the distance between a proposed implant site and vital structures such as teeth, neurovascular canals and the maxillary sinus. The ability of a software program to accurately measure linear distances is also a basic prerequisite for more complex tasks such as placement of simulated implants of specific dimensions, and subsequent computer designed surgical guides. The most basic tool which is commonly used to measure linear dimensions in sectional images is the linear measurement tool of the software program.

The accuracy of the linear measurement tool in recording bone dimensions in CT images has been reported for numerous software programs (Al-Ekrish, 2012, Fokas et al., 2018, Kamiyama et al., 2012, Loubele et al., 2008, Luangchana et al., 2015, Sabban et al., 2015, Sforza et al., 2007, Suomalainen et al., 2008, Torres et al., 2012, Veyre-Goulet et al., 2008, Ganguly et al., 2016, Vasconcelos et al., 2015, Freire-Maia et al., 2017, Silva et al., 2017), but none of the reports tested the linear measurement accuracy of a widely used and well-established implant planning software program, coDiagnostiX. Furthermore, newer programs are continuously being developed and made available to users, some at reduced or no cost, and their linear measurement accuracy also needs to be investigated. Two such programs are Blue Sky Plan and RadiAnt. Blue Sky Plan is a free software program for implant treatment planning and design of surgical guides for implant osteotomies. RadiAnt is a software program for versatile reformatting and analysis of CT images.

There is a published study which reported on the accuracy of periodontal CBCT measurements recorded using Blue Sky Plan (Sreih et al., 2019), and another study which tested the accuracy of measurements between radiopaque markers seen in CBCT images using RadiAnt (Tolentino et al., 2018). How-

ever, at the time of writing, the author is unaware of any published studies testing the accuracy of linear measurements of the bone at potential implant sites using RadiAnt or Blue Sky Plan. Therefore, the aims of the present study are to measure the accuracy of the linear dimensions of implant sites recorded from CBCT images using Blue Sky Plan, coDiagnostiX, and RadiAnt, as compared to the gold standard measurements recorded directly from the bone, and to compare the absolute measurement errors of the above three software programs. Knowledge of the measurement accuracy of CBCT images using the above software programs is important for validation of their use for implant site analysis, and for understanding and relating the possible sources of error in the multistep and complex process of implant surgery.

2. Materials and methods

2.1. Preparation of skulls

Five human dry skulls, obtained from the Anatomy Department of the King Saud University College of Medicine, were used in the study. The study was approved by the King Saud University College of Dentistry Research Center (Registration number: NF2119).

Gutta percha (GP) fiducial markers were placed around the bone to delineate sample sites and measurement paths. The Electronic [Supplementary File](#) details how the skulls were prepared prior to imaging. The position of the fiducial markers relative to the sample sites, and the position and path of the linear measurements are demonstrated in Fig. 1.

The sample size needed to detect an error of 0.3 mm (for a study power of 0.9 and $\alpha = 0.05$) was calculated as 25 samples, based upon the standard deviation obtained in a previous study (Al-Ekrish and Ekram, 2011) and using the sample size equation for paired studies (Dell et al., 2002). Forty-eight sample measurements were obtained by recording the height and width of the edentulous ridge at 24 sample sites from the five skulls used. Twelve sites were in the maxillae and 12 in the mandibles, with the sample sites equally distributed among the molar, canine-premolar, and incisor regions. [Table 1](#)

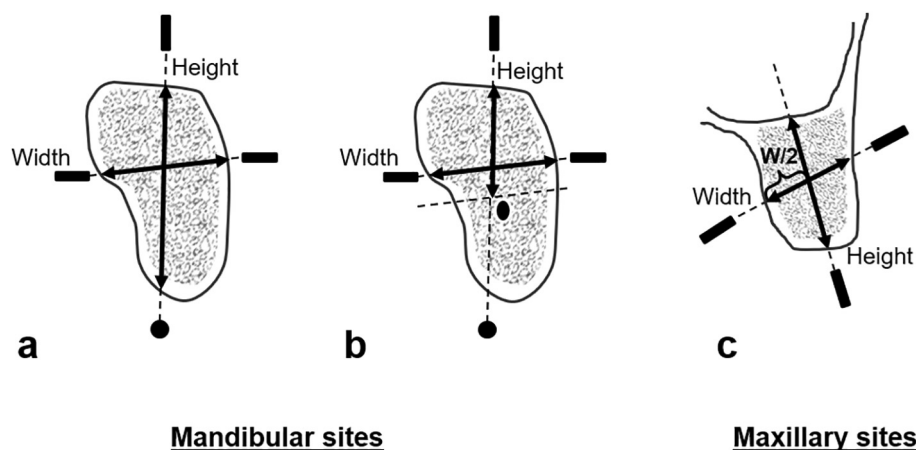


Fig. 1 Diagrammatic representation of transverse cross-sectional images of sample sites demonstrating the position of the fiducial markers relative to the sample sites, and the position and path of the linear measurements. (a) Mandibular sections anterior to the mental foramen, (b) Mandibular sections at, and posterior to, the mental foramen, (c) Maxillary sections.

Table 1 Distribution of sample sites according to skull, jaw, and region.

		Skull 1	Skull 2	Skull 3	Skull 4	Skull 5	Total
Maxillary Sites	Incisor	0	1	0	2	1	4
	Canine-Premolar	3	0	0	1	0	4
	Molar	2	1	0	0	1	4
Mandibular Sites	Incisor	1	1	0	1	1	4
	Canine-Premolar	0	1	1	1	1	4
	Molar	0	1	1	1	1	4
Total		6	5	2	6	5	24

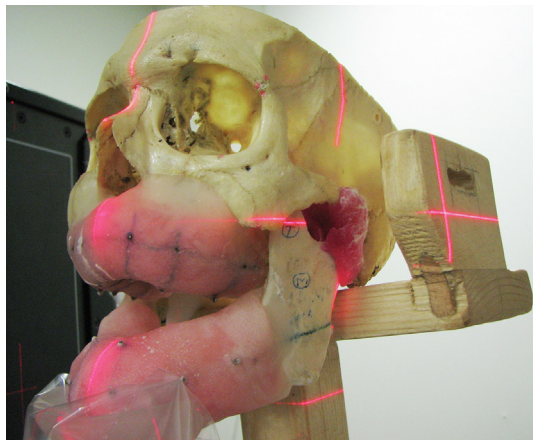


Fig. 2 Picture of skull positioned for imaging within the CBCT machine with the flat panel detector visible to the right of the skull. The skull is seen stabilized on a wooden stand; not seen is a vertical wooden bar protruding into the foramen magnum to stabilize the cranial base. The mandibular symphysis is resting on the chin rest of the machine. Also seen is the wax covering the temporomandibular joint which immobilized the mandible to the maxilla. The laser guidelights seen were used to ensure centering of the skull within the image field of view.

details the site distribution of the sample sites amongst the five skulls.

2.2. Imaging of the skulls

Prior to imaging, each mandible was attached to its corresponding skull base by use of wax surrounding each temporomandibular joint (TMJ). During the CBCT examination, the skulls were positioned on a flat horizontal platform of a wooden stand which had a vertical wooden bar projecting upward into the foramen magnum of the skull. The skulls were further stabilized by resting the mandibles on the chin rest of the CBCT device (Fig. 2). A CBCT examination of each skull was then performed at the King Saud University College of Dentistry, Department of Oral and Maxillofacial Radiology, using an Iluma device (Iluma, Imtek Imaging, 3 M Company, USA) using a large field of view. The detector of the CBCT device was a flat panel detector, 19 × 24 cm in size, and composed of 127 μm amorphous silicon. The x-ray source focal spot size was 0.3 mm. The CBCT exposure parameters used

were 3.8 mA, 120 kV, and 40 s exposure time. The number of basis images acquired was 602, and the reconstruction isotropic voxel size was 0.29 mm.

2.3. Obtaining gold standard measurements

After imaging, the jaws were sectioned with a bandsaw to obtain the sample transverse cross-sections. Fig. 3a demonstrates one sample site, after sectioning. The Electronic Supplementary File details how the bone was sectioned and the measurements recorded from the bone. For each linear measurement, the bone measurement was recorded twice by a single examiner, one week apart. The average of the two measurements was considered the gold standard linear measurement.

2.4. Computer and software programs used

The CBCT dataset for each skull was exported in digital imaging and communication in medicine (DICOM) format to a DVD. The datasets were then downloaded to the hard drive of a laptop computer, Nitro AN515-52 (Acer Inc., New Taipei City, Taiwan), to which the study software programs were all installed. The specifications of the computer display were as follows: display size 15.6 in. (16:9); display resolution used 1920 × 1080 (highest, recommended); pixel size (calculated) 0.177 mm; bit depth 8-bit RGB; luminance 260 cd/m² (on power). All the study measurements were recorded with the power cord plugged in to standardize, and benefit from, the maximum screen luminance.

The three software programs installed on the computer were: Blue Sky Plan, version 4.5.9 (BlueSkyBio, New York City, United States), coDiagnostiX, version 9.10 (Dental Wings GmbH, Chemnitz, Germany), and RadiAnt DICOM Viewer, version 5.5.0 (Medixant, Poznan, Poland). Each CBCT dataset was viewed with the three test software programs on the same computer and using the same display settings.

2.5. Image processing and recording of measurements

The DICOM datasets were imported into the software programs and the datasets were reformatted to obtain transverse cross-sectional images at the sites marked by the GP markers. The image sections were the thinnest image sections possible, 0.29 mm. The reformatting of all the sample sites was performed by the author, an oral and maxillofacial radiologist with 14 years' experience in reformatting and analysis of CT

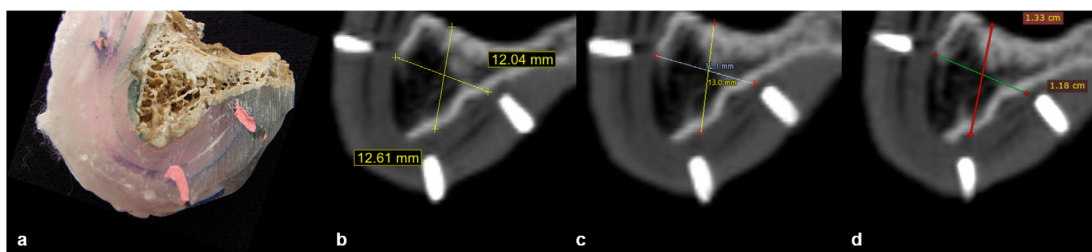


Fig. 3 (a) Bone section of a sample site showing the wax, gutta percha, and acrylic around the bone, and CBCT images and linear measurements obtained using the software programs b) Blue Sky Plan, c) coDiagnostiX and d) RadiAnt.

images. For coDiagnostiX and Blue Sky Plan the curvilinear reformatting tool was used to trace the jaw on an axial section and the transverse cross-sections were then automatically generated by the program. Since the sections would not necessarily pass through the GP markers, fine adjustments had to be done to the orientation of the axial section and the shape of the curve to ensure that the transverse cross-sections corresponded to the sample sites, as determined by presence of the GP markers buccally, crestally, and lingually. For RadiAnt, the orthogonal sectional planes could be individually shifted and tilted by adjusting the reformatting lines corresponding to the sectional images. So, the lines were precisely adjusted to display images of the sample sites. Fig. 3 demonstrates the bone section of a sample site and the corresponding CBCT sectional images as viewed using the three software programs.

Viewing of the images and recording of the measurements were performed in a dimly lit room. The examiner was the same operator who reformatted the sample sections. Window width and window level of all the sample images were fixed at 3000/600. The linear measurement tool of each software program was used to record the height and width measurement at each sample site. Due to the partial volume averaging of the grey density within the CBCT voxels, the margin of the bone in the magnified image appears blurred. Therefore, in order to standardize the measurements and increase the chances of reproducibility of the measurements, the measurement points were set in the middle of this blurred area between the most superficial edge and the deepest edge of the blurred boundary (Fig. 3b-d). The measurements were rounded to the nearest 0.1 mm because coDiagnostiX only measures to nearest 0.1 mm. Fig. 3 demonstrates the linear measurements recorded at a sample site using the three software programs.

Then, 30 measurements were selected for reliability testing. Five sample sites were randomly selected for each software program using an online random number generator (<http://stattrek.com/statistics/random-number-generator.aspx>), and the height and width measurements at each site were used for reliability testing. The measurements were recorded by two examiners (the first examiner, and another oral and maxillofacial radiologist with 14 years' experience in reformatting and analysis of CT images).

2.6. Statistical analysis

The recorded measurements were analyzed with the program Statistical Package for the Social Sciences (SPSS) version 20 (International Business Machines Corp. (IBM), Armonk, NY). Intra-examiner reliability of the gold standard measure-

ments, and intra- and inter-examiner reliability of the CBCT measurements were measured using the intraclass correlation coefficient. For calculation of the inter-examiner reliability, the second examiner's CBCT measurements were compared to the first examiner's second measurements.

The first CBCT measurements recorded by the first examiner were used to calculate the measurement error. The measurement error was calculated as the direct bone measurement minus the measurement recorded from the CBCT image. For each software program, the mean and 95% confidence interval of the absolute error values were calculated. The One-sample *t*-test (test value: zero) was used to test the statistical significance of the mean of the absolute errors for each software program. Analysis of Variance with Repeated Measures was used to test the statistical significance of the difference between the means of the absolute errors obtained by the different software programs.

Statistical significance was set at a *p*-value of 0.05.

3. Results

The intra-examiner reliability of the gold standard measurements was found to be 1.0 which is excellent. The intra- and inter-examiner reliability of the CBCT measurements were 0.999 and 0.998, respectively, which are also excellent (Koo and Li, 2016).

The mean and 95% confidence intervals of the absolute error values from the different software programs are presented in Table 2. Fig. 4 is a box and whisker plot demonstrating the interquartile range and outliers of the absolute error values obtained using the three test programs. All three software programs demonstrated a statistically significant mean absolute measurement error of between 0.43 and 0.56 mm (p -value < 0.01), but no significant difference in error values was found between any of the tested programs (p -value = 0.18).

4. Discussion

The present study compared the linear measurement accuracy of implant sites recorded using three software programs which have not been previously investigated for this purpose. No statistically significant difference in measurement error were found between the three programs, but all three programs were associated with a statistically significant absolute measurement error. As such, the results of the present study indicate that the basic function of depiction of the bone boundaries and accuracy of the linear measurement tool is not different between

Table 2 Comparison of absolute measurement errors from the test programs.

	Mean Absolute Error (S.D.) (mm)	95% CI of Absolute Error (mm)		p-value*	F**	Sig.(2-tailed)**
		Lower Bound	Upper Bound			
Blue Sky Plan	0.43 (0.48)	0.29	0.57	0.00***	1.795	0.18
coDiagnostiX	0.56 (0.45)	0.43	0.69	0.00***		
RadiAnt	0.50 (0.42)	0.38	0.63	0.00***		

S.D.: Standard deviation.

CI: Confidence interval.

* One-sample T-test (test value: zero).

** ANOVA with Repeated Measures.

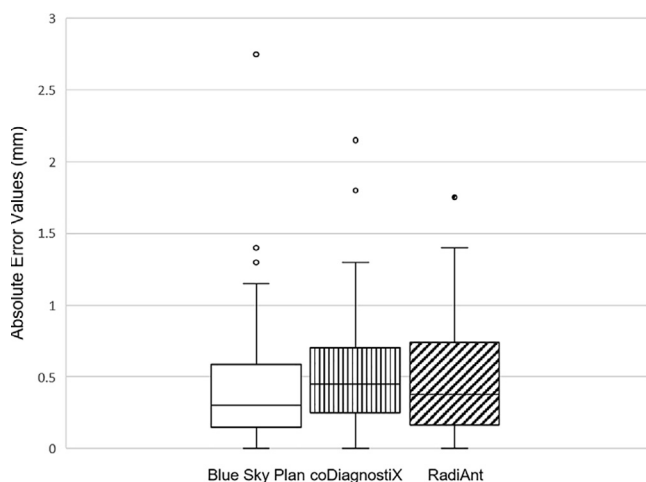


Fig. 4 Box and whisker plot demonstrating the interquartile range and outliers of the absolute error values of the measurements obtained using the three test software programs.

a well-established and relatively more expensive software program, coDiagnostiX, and the less expensive or free programs of RadiAnt and Blue Sky Plan.

The excellent intra- and inter-examiner reliability of the measurements obtained in the present study can be explained by standardization of the position and path of the measurements, as well as calibration of the examiners with regards to where the measurement points were placed within the blurred margin of the bone. The error values obtained in the present study are comparable to the results obtained by a previous study which used the same CBCT machine and exposure parameters but viewed the images in their native format and using the proprietary software program of the machine (Al-Ekrish and Ekram, 2011). This similarity in the results between third party software programs and the proprietary program indicates that the diagnostic quality and dimensional accuracy of the CBCT datasets was unaffected by format conversion and transport to another software program. The measurement accuracy of the software programs tested in the present study, however, could not be compared with the results of previous studies which investigated accuracy of CBCT measurements at implant sites using different proprietary and third party software programs (Loubele et al., 2008, Suomalainen et al., 2008, Veyre-Goulet et al., 2008, Torres et al., 2012,

Luangchana et al., 2015, Sabban et al., 2015, Ganguly et al., 2016, Freire-Maia et al., 2017, Silva et al., 2017) because the CBCT images were acquired with different machines and exposure parameters than the ones used in the present study.

The present study's finding of no difference in measurement error between CBCT reformatting programs is comparable to the findings of Vasconcelos et al. (2015) and Silva et al. (2017) which found no statistically significant difference between linear measurement accuracy at implant sites using different software programs (Vasconcelos et al., 2015, Silva et al., 2017). The programs compared by Vasconcelos et al. (2015) were KDIS 3D, OnDemand, and XoranCat, and the programs compared by Silva et al. (2017) were Imaging Studio and Implant Viewer. The findings of the present study are also comparable to those of a previous study which compared linear measurements between radiopaque markers in CBCT images of dry mandibles using InVesalius, Radiant, and XoranCat and found no statistically significant difference between the results from the different software programs (Tolentino et al., 2018).

Although the measurement accuracy of the programs tested in the present study were similar, the versatility of their reformatting capabilities were found to be different. The most versatile reformatting for single sites was achievable with RadiAnt, which is the only program tested in the present study which allows adjustment of all three orthogonal image planes by shifting and tilting the reformatting planes individually. With Blue Sky Plan and coDiagnostiX, reformatted images can only be obtained by drawing a panoramic curve along the axial image of the jaw which automatically produces panoramic and transverse cross-sections parallel and perpendicular to the curve. As such, achieving precise positioning and orientation of transverse cross-sections of the jaws using Blue Sky Plan and coDiagnostiX was more labor intensive.

When using Blue Sky Plan and coDiagnostiX, adjustment of the mesio-distal orientation of transverse cross-sections at an individual implant site can only be done by modifying the panoramic curve at that site. Adjustment of the supero-inferior orientation of the transverse cross-sections is even more labor intensive with these two programs. When using coDiagnostiX, such an adjustment requires opening a separate window which allows tilting of the entire dataset; tilting the dataset allows eventual adjustment of the supero-inferior orientation of the transverse cross-sections by trial and error. When using Blue Sky Plan, adjustment of the supero-inferior orientation is only possible when initially opening a CBCT

dataset, which was not practical for making fine adjustments. For this reason, it was not always possible to obtain cross-sectional images in the exact plane of the sample sites when using Blue Sky Plan. This difference in reformatting capabilities between the software programs influenced user-friendliness but did not affect the resultant accuracy of the measurements when painstaking efforts were applied to obtain transverse cross-sections as closely oriented with the sample sites as possible.

Another major difference between the programs, in addition to the versatility of reformatting, is their additional features which influence how useful the program is in the overall digital workflow of implant treatment planning. Blue Sky Plan and coDiagnostiX allow implant simulation and design of surgical guides, whereas RadiAnt only allows reformatting and basic measurements because it is more medically oriented, and not marketed as an implant planning software. In addition, Blue Sky Plan and coDiagnostiX have different features and capabilities regarding prosthetic treatment planning and design of surgical guides. Therefore, the usefulness of the test programs in implant site analysis must be determined by the end-user based upon the intended digital workflow and accuracy of the diagnostic and therapeutic tasks the user hopes to achieve.

Previous studies have investigated the accuracy of implant placement using the coDiagnostiX program (Nickenig et al., 2010, Köhl et al., 2013). However, the sources of error in implant placement cannot be determined by one study because there are numerous possible sources of error which may occur during the various steps involved in implant site analysis and therapeutics (Tamimi et al., 2014, Al-Ekrish, 2018, Cassetta et al., 2013). As such, the results of the present study should not be used to indicate overall suitability or similarity between the software programs for implant treatment planning. Rather, the results of the present study should be analyzed in conjunction with other studies which investigate other causes of error to develop a fuller understanding of how to reduce errors during implant treatment planning and placement. Accuracy of other tasks along the digital workflow must be considered to make overall recommendations in this regard.

One of the limitations of the present study is that dry skulls were used. For, even though wax and acrylic were used in an attempt to replicate the effects of soft tissue attenuation and scatter of x-rays, the absence of the dense tongue muscles and cervical vertebrae may have led to less scatter and noise in the study images. As such, it is possible that the study images were of higher diagnostic quality compared to patient images. Another limitation of the present study is that images from a single CBCT device and only one examination protocol were used. For, there are numerous CBCT devices in use with highly variable examination and reconstruction protocols, which have been shown to influence image quality (Ludlow et al., 2015, Liang et al., 2010). It is not known what effect lower quality images may have on the comparison between different software programs, but it is conceivable that it may lead to differences in accuracy of identification of bone boundaries or segmentation of images using different software programs. Therefore, further studies are recommended to compare the accuracy of different software programs in the various tasks of implant therapeutics using CBCT images of cadaveric heads acquired using multiple CBCT devices and examination and reconstruction protocols.

5. Conclusions

There was no statistically significant difference in accuracy of linear CBCT measurements of implant sites recorded using Blue Sky Plan, coDiagnostiX, and RadiAnt. All three software programs demonstrated a statistically significant mean absolute measurement error of between 0.43 and 0.56 mm. The results of the present study should be analyzed in conjunction with studies investigating the sources of error during other diagnostic and therapeutic steps of implant placement to develop a clearer understanding how to reduce errors in implant placement.

Ethical statement

No live patients or animals were used in the study. The study was approved by the King Saud University College of Dentistry Research Center (Registration number: NF2119).

CRedit authorship contribution statement

Asma'a A. Al-Ekrish: Conceptualization, Funding acquisition, Data curation, Formal analysis, Project administration.

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.sdentj.2020.07.003>.

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