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Effects of exposure parameters on detecting clear and unclear mandibular canals using two digital intra-oral sensors – An experimental study

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Abstract

Aim: To evaluate the effects of exposure parameters (tube current and voltage) to detect clear and unclear mandibular canals (MCs) using a complementary metal-oxide semiconductor (CMOS) or photo-stimulable phosphor plate (PSP) sensors. **Methods:** A total of 24 dry half-mandibles were divided into two groups with clear (n = 16) and unclear (n = 8) MCs. The retro-alveolar parallel technique was performed in the six-molar region of the mandibles using direct and indirect digital intra-oral sensors. Six combinations of tube voltage (kV) (60 kV, 66 kV, and 70 kV) and tube current (mA) (2 mA, 5 mA, and 8 mA) were applied, and 144 images of each group were obtained with each CMOS and PSP sensor. Images were processed using Image J software. To evaluate diagnostic accuracy, two square images of the first-molar region were obtained from each image, one with the MC inside and the other without the MC (a total of 576 images were observed). Three radiologists diagnosed the presence or absence of MCs. The diagnostic accuracy of each exposure parameter was compared with the area under the curve (Az) in receiver-operating characteristic analysis. **Results:** The Az values for clear MCs were higher than those for unclear MCs ($P < 0.001$). There were no significant differences when the tube current was modified. For unclear MCs, the Az increased when higher tube voltages were used, showing a significant difference using the PSP sensor ($p = 0.004$). There was no significant difference for clear MCs. **Conclusions:** Lower exposure parameters should be used for clear MCs, while higher tube voltage values should be used for unclear MCs.

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Full Text

Introduction

Procedures in the mandibular bone such as implant placement or third molar surgery require precise knowledge of the localisation of the mandibular canal (MC) to reduce the risk of injury to the inferior alveolar neurovascular bundle.[1]

Computed tomography (CT) provides accurate information about the localisation of the MC.[2] However, some disadvantages of CT are related to its high dose radiation compared with radiographic dental techniques, the high cost of the equipment, and limited accessibility.[3] Considering low cost and low patient radiation exposure, retro-alveolar radiography is a good option to evaluate MC before implant and the third molar region.[4]

Digital radiology has been available in dentistry since 1989, having two different modalities – direct and indirect systems. A charge-coupled device was the first digital intra-oral sensor manufactured in 1989 by the Trophy company,[5] and it includes a pixel matrix on a silicon chip. Thereafter, a similar new system known as the complementary metal-oxide semiconductor (CMOS) was developed. Both are direct digital systems. In 1994, a photo-stimulable phosphor plate (PSP) was released by Orio Co/Sordex. It has a flexible polyester base coated with a crystalline emulsion and is considered an indirect digital system.[5]

In developed countries, digital radiology has increased in the field of dentistry in the last years, with its use rising from 34% in 2005 to 80% in 2014 and 90% at present.[6] Dental X-ray units are used for PSP and CMOS, but the exposure dose for digital radiology is lower than that for a film, and therefore, adjustments of exposure parameters including tube current (mA), tube voltage (kV), and exposure time must be made. However, previous studies have shown that exposure parameters affect image quality.[7]

Jasa et al.[7] showed that tube current and tube voltage had an impact on the localisation of the MC when using cone beam computed tomography (CBCT) and multi-detector computed tomography (MDCT). Nonetheless, each modality responds differently to the exposure factors. An increase in kV was suggested for the localisation of the MC in CBCT. On the other hand, the use of higher or lower exposure values has been suggested based on the radiological characteristics of the MC in order to reduce the exposure dose. The MC is an anatomical structure which is found within the mandibular bone extending from the mandibular foramen to the mental foramen, and its radiographic appearance is a radiolucent zone bordered by sclerotic superior and inferior lines.[8],[9] However, the density of the sclerotic lines varies among patients and sometimes in different regions of the same patients, which may explain why the MC is not well-visualised in some cases, being clear or unclear.[7],[9] Other studies found that the MC is clearer at the third molar region than at the pre-molar region and is also clearer in dentate bones.

Image quality has been widely studied in digital intra-oral radiology, and comparisons between conventional and digital systems have been made, as well as between CMOS and PSP, to

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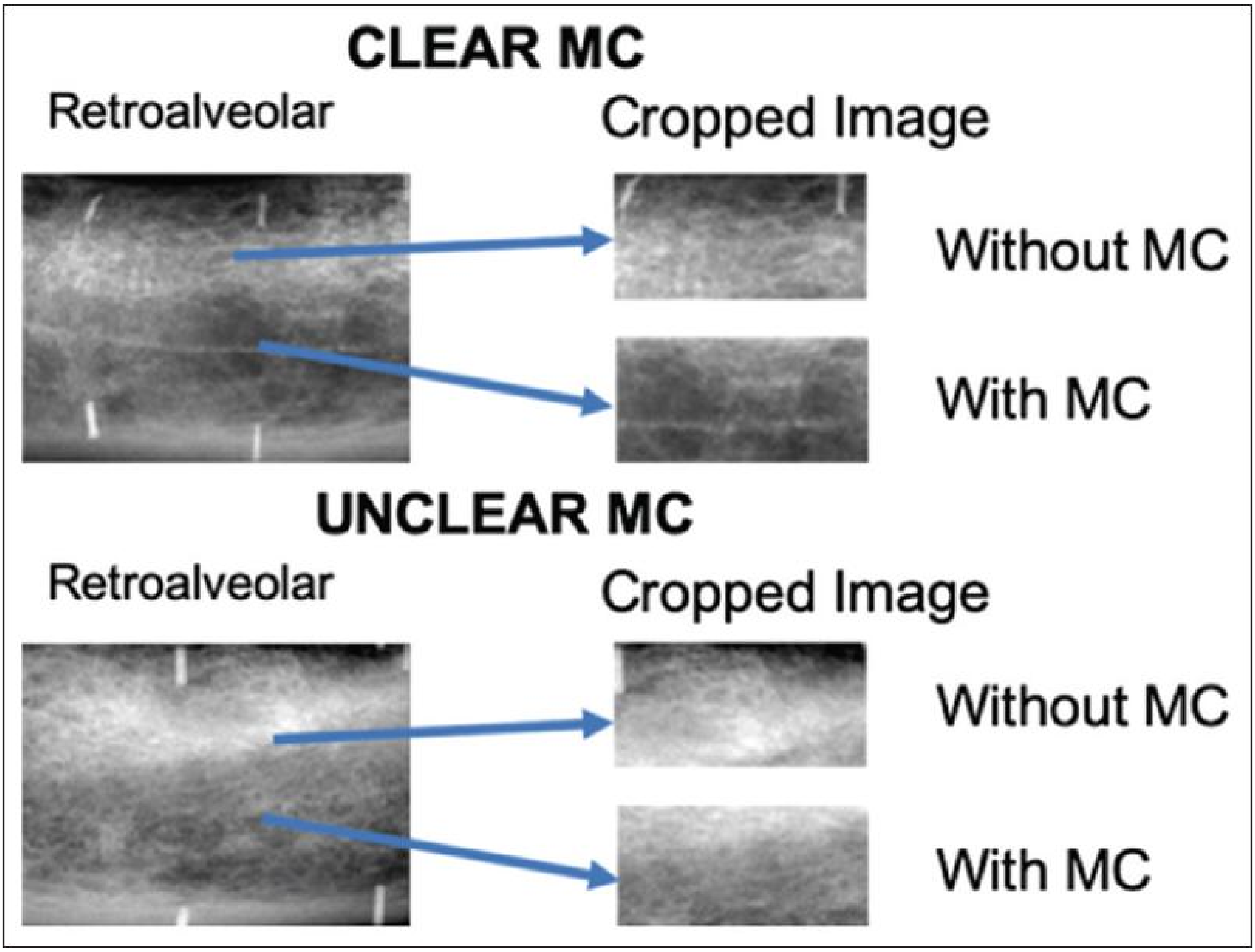
Figure 1: Example of a retro-alveolar cropped image with a clear mandibular canal and an unclear mandibular canal. MC, mandibular canal



obtain the best quality images. However, little is known about digital sensors in terms of tube voltage and tube current response functions.

Digital systems and digital photon detectors are continuously being improved. Their association with X-ray energy should be evaluated to clarify the effects of kV and mA on image quality and possible reductions in exposure doses. Thereof, the aim of this study was to evaluate the effects of exposure parameters (tube current and voltage) to detect clear and unclear MCs using complementary CMOS or PSP sensors.

Methods

Sample characteristics, eligibility criteria, and ethical issues

This experimental study evaluated 24 dry hemi-mandibles with the edentulous posterior region, obtained from the Anatomy Museum of the School of Dentistry, Científica del Sur University. The Ethics Committee of Científica del Sur University approved this research, with number code 092-2019-POS8. The sample was divided into two groups based on the visibility of the MC walls in a previous CBCT study of the same samples,[7] 16 "clear" when the MC wall was easy detected and 8 "unclear" when the MC wall was difficult to detect. The half-mandibles were rotated on the horizontal axis in the sagittal plane so that the MCs became horizontal in the sagittal view. The MC walls were then observed from mesial to distal in the cross-sectional view. First, the cortication of the MC was evaluated by each observer as clearly visible, partially disrupted, or completely disrupted, and the MC was then rated as "clear", "partially clear", or "unclear", respectively. After consensus with a third specialist from the Department of Radiology, two groups of "clear" and "unclear" MCs were confirmed. Mark 2 corresponded to the location of the first molar region, which is the most common site of insertion for endo-osseous implants.[10] Each half-mandible was fixed and immersed in a container of warm soapy water to simulate the presence of soft tissues and decrease the surface tension of the water to achieve its penetration into the bone.[11] The height and width of the containers were larger than the mandibular bone.

Image acquisition

Images were acquired using the PlanmecaProx (Asentajankatu 6F1-00880 Helsinki, Finland) dental X-ray equipment and two digital intra-oral sensor systems, CMOS number 2 (rvg 6100) and SP number 2 (cs7600) (Carestream Health Inc., Marne-la-Vallée, France).

First, each half-mandible was scanned with a wire (0.25 mm diameter) inside the MC to obtain a gold standard. After removal of the wire, the retro-alveolar radiography technique was performed using different exposure parameters for each sensor maintaining the bone, X-ray equipment, and sensor in the same position. The retro-alveolar parallel technique was used maintaining a distance of 20 cm between the sensor and the X-ray tube.

To evaluate tube voltage effects, three different values (60, 66, and 70) were used combining different currents (2, 5, and 8) and exposure times (0.16, 02, and 04 seconds) (60 kV–8 mA/0.16 s, 66 kV–5 mA/0.2 s, and 70 kV–8 mA/0.4 s). The same exposure dose was used in all combinations based on dose product area (DPA) according to the manufacturer's instruction of the X-ray dental equipment (Planmeca Oy, Asentajankatu 6, Helsinki, Finland) for obtaining 144 images.

To evaluate tube current effects, the tube voltage and exposure time were fixed at 70 kV and 0.2 s, respectively, and three different values of tube current (2, 5, and 8) were used, acquiring 144 images using different combinations (70 kV/2 s/2 mA, 70 kV/2 s/5 mA, and 70 kV/2 s/8 mA).

Image analysis

Images were exported to ImageJ software (National Institutes of Health, Bethesda, MD) with the Joint Photographic Group (JPG) format. Regions of interest (ROIs) were cropped on the retro-alveolar images, obtaining two square images. One had the MC inside the ROI, and the other did not. This was performed considering the gold standard image (image with the wire inside the MC). Finally, we evaluated two images from each original retro-alveolar image [Figure 1]. The cropped images with and without MC, exported in JPG from the software without previous adjustments, were randomly and digitally evaluated by three radiologists. The first observation was made to evaluate the effect of tube voltage (in 288 images). The second observation was made to evaluate the effect of tube current (in 288 images).{Figure 1}

Observers were instructed to use a five-point scale to classify the presence or absence of the MC as follows: Definitely not present = 1, probably not present = 2, do not know = 3, probably present = 4, and definitely present = 5.

Error study

Evaluations were performed twice after a 2-week interval. Intra-observer agreement was evaluated with the Kappa coefficient, obtaining good agreement (more than 0.84).

Statistical analysis

Diagnostic accuracy was compared considering the area under the curves (Az) of receiver-operating characteristic (ROC) analysis using ROCKIT 1.1B software (Charles E Metz, University of Chicago, Chicago, IL, USA). The Az values of the different imaging protocols were compared using the Tukey–Kramer test. Inter-group comparisons were performed with the Mann–Whitney U test. All tests were performed using the R-statistics (http://www.r-project.org/) with $P < 0.05$.

Results

Az values of 0.901 (clear), 0.806 (unclear) and 0.848 (clear), 0.757 (unclear) were obtained for the MC using CMOS and PSP, respectively [Figure 2]. In PSP and CMOS, the Az were higher for clear MC when compared to unclear MC ($P < 0.001$). The Az of CMOS was higher than that of PSP in the localisation of the MC, with Az values of 0.869 and 0.819, respectively, with no significant differences.{Figure 2}

With the same exposure dose, the Az value increased with lower kV for CMOS and PSP; however, there were no significant differences among the different kV.

By maintaining a constant exposure time and kV with a higher mA, the Az was almost constant for CMOS (2 mA = 0.826, 5 mA = 0.880, 8 mA = 0.861) and for PSP (2 mA = 0.821, 5 mA = 0.822, 8 mA = 0.809).

The Az values for unclear MCs were higher with increasing kV, being very low using 60 kV (0.785) for CMOS [Figure 3]; however, for clear MCs, the Az value was similar with different kV (60 kV = 0.929, 66 kV = 0.911, 70 kV = 0.902) [Table 1].{Table 1}{Figure 3}

When PSP was used for unclear MCs, the Az value was greater with a higher kV [Figure 3], and there was a significant difference between 60 kV and 70 kV ($p = 0.004$).

The Az value was greater when a higher mA was used for CMOS in clear and unclear MC, but there were no significant differences [Figure 4].{Figure 4}

The Az value for PSP was greater when a higher mA was used for clear and unclear MCs, but there were no significant differences [Figure 4].

Discussion

The effects of tube voltage and tube current on the localisation of the MC using direct and indirect digital sensors were evaluated in this study. These factors directly affect the energy and the number of X-ray photons and indirectly affect the quality of the image obtained. Their combination is important to obtain good image quality using an exposure dose as low as possible. Increasing the tube voltage requires a decrease in tube current or exposure time to thereby achieve a constant exposure dose.[7]

The results of this study demonstrate that tube voltage influences the visibility of clear and unclear MCs differently when using PSP and CMOS. However, the tube current affects the visibility of clear and unclear MCs equally using both the PSP and CMOS digital sensors. Although the present study was made with cadaveric material, it provides some information that could be considered as preliminary research for application under in vivo conditions. Some studies have reported comparisons between digital sensors and film radiography;[6] nevertheless, an analogic intra-oral film was not included in this study.

The effects of exposure parameters on the location of the MC were evaluated using CBCT and MDCT.[3],[7] When exposure parameters are evaluated in dental X-ray equipment, the variations of kV values and mA values did not show great differences. There were no significant differences between PSP and CMOS in relation to the location of the MC, and the Az values were 0.869 and 0.819, respectively, which agree with previous studies.[12]

[Figure 4] and [Figure 5] show that kV affected the visibility of the unclear MCs differently compared to clear MCs in PSP and CMOS. The Az values decreased with low kV, and there was a significant difference between 60 and 70 kV when using PSP ($P = 0.004$). Thus, in adults and patients with edentulous bones, the use of a higher kV may be necessary in the inferior premolar region, similar to what has been reported previously for unclear MCs.[9] On the other hand, in regions in which the MC is clear, such as the third molar region, in young people and dentate regions, the use of low kV and mA values should be chosen, thereby providing a lower exposure dose.

With the use of CBCT, Jasa et al.[7] and Pauwels et al.[13] found that the image quality increased by maintaining almost the same exposure dose with a higher kV. This was similar to what was found for unclear MCs in the present study. Some authors have reported no differences in linear measurements with different kV.[14] In other studies, using PSP, the effect of tube voltage was practically negligible.[15] There were no significant differences for dental anatomical areas in one phantom dry skull with exposures using tube values of 60 and 70 kV, but direct sensor application showed higher image quality with lower exposure doses. However, indirect sensors showed the same diagnostic performance with all the combinations of exposure factors.[16]

The tube combination used in the present study did not show significant differences using both digital sensors in clear and unclear MCs. Based on our results, if the DPAs with 2, 5, and 8 mA are 15, 38, and 61, respectively, the lowest mA possible could be used. On the contrary, one study reported significant differences between exposure time and image quality, with a higher exposure time increasing the diagnosis of caries using PSP.[16]

Another study used the six-molar region, an aluminium phantom, and simulated periapical lesions, maintaining the kV constant and changing the exposure time from 0.1 to 1.0 seconds, and found statistical differences among the means attributed to the exposure times using PSP.[17] Although the mAs in the current study were modified, we observed similar effects on the X-ray beam as the exposure time, with no significant differences. Attaelmanan et al.[18] used direct and indirect digital sensors, with different combinations of exposure time. They obtained higher image quality by increasing the exposure dose but without significant differences. In the present study, there were no significant differences among the different mAs. Therefore, the goal would be to obtain higher image quality using less exposure dose. Futures studies should focus on how image quality is affected by the exposure parameters of the modern digital sensors. On the other hand, previous studies in CBCT showed higher image quality with increases of the mA and kV.[7],[19] According to Jung et al.,[20] when the MC is easily visualised in one imaging modality, it should not be difficult to identify using another modality. Thus, when patients have clear MCs in previous panoramic radiographs, CBCT or MSCT, lower exposure parameters such as mA and kV can be used to reduce the radiation dose when using PSP and CMOS.

Conclusions

In summary, based on the results for clear MCs, lower exposure parameters should be used, whereas higher tube voltage values should be used for unclear MCs. These implications should be considered by radiologists.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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Figure 2: ROC curves comparing the observation of clear and unclear mandibular canals: (a) shows the area under the curve using CMOS, and (b) shows this using PSP

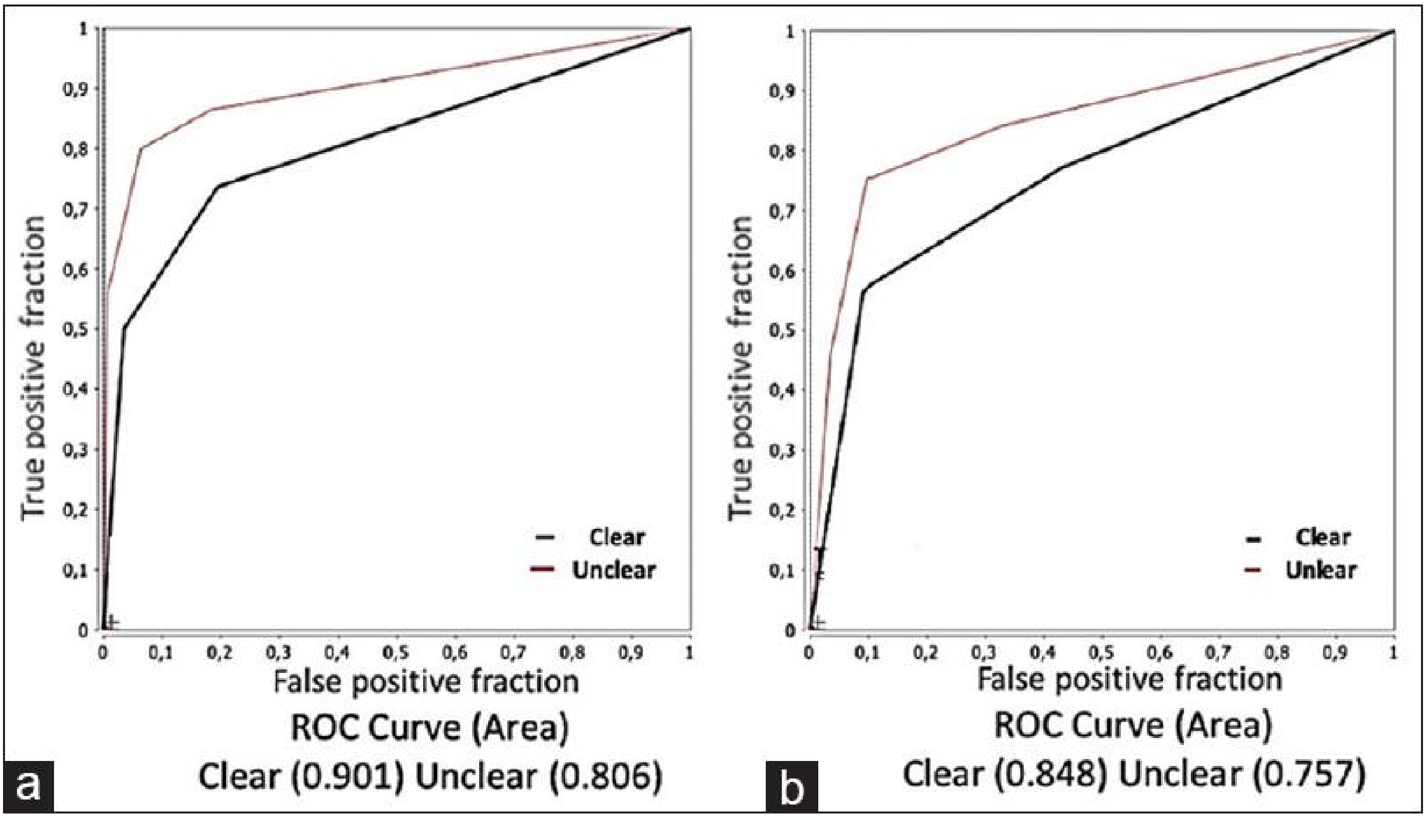

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Figure 3: ROC curves for different tube voltages (60 kV, 66 kV, 70 kV), showing the area under the curve for CMOS (above) and PSP (below): (A) clear mandibular canals and (B) unclear mandibular canals

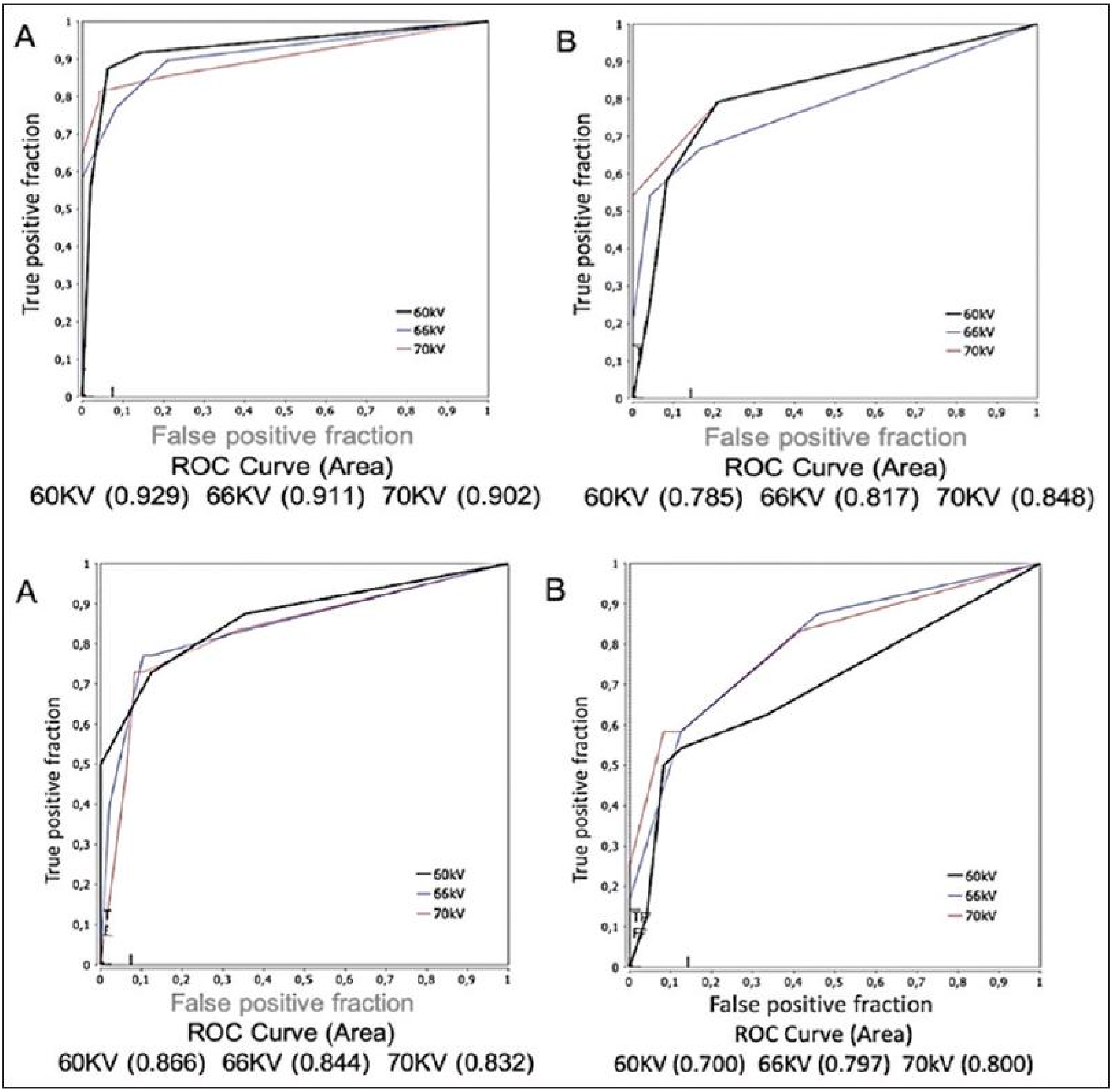

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Figure 4: ROC curves for different tube currents (2 mA, 5 mA, 8 mA), showing the area under the curve for CMOS (above) and PSP (below): (A) clear mandibular canals and (B) unclear mandibular canals

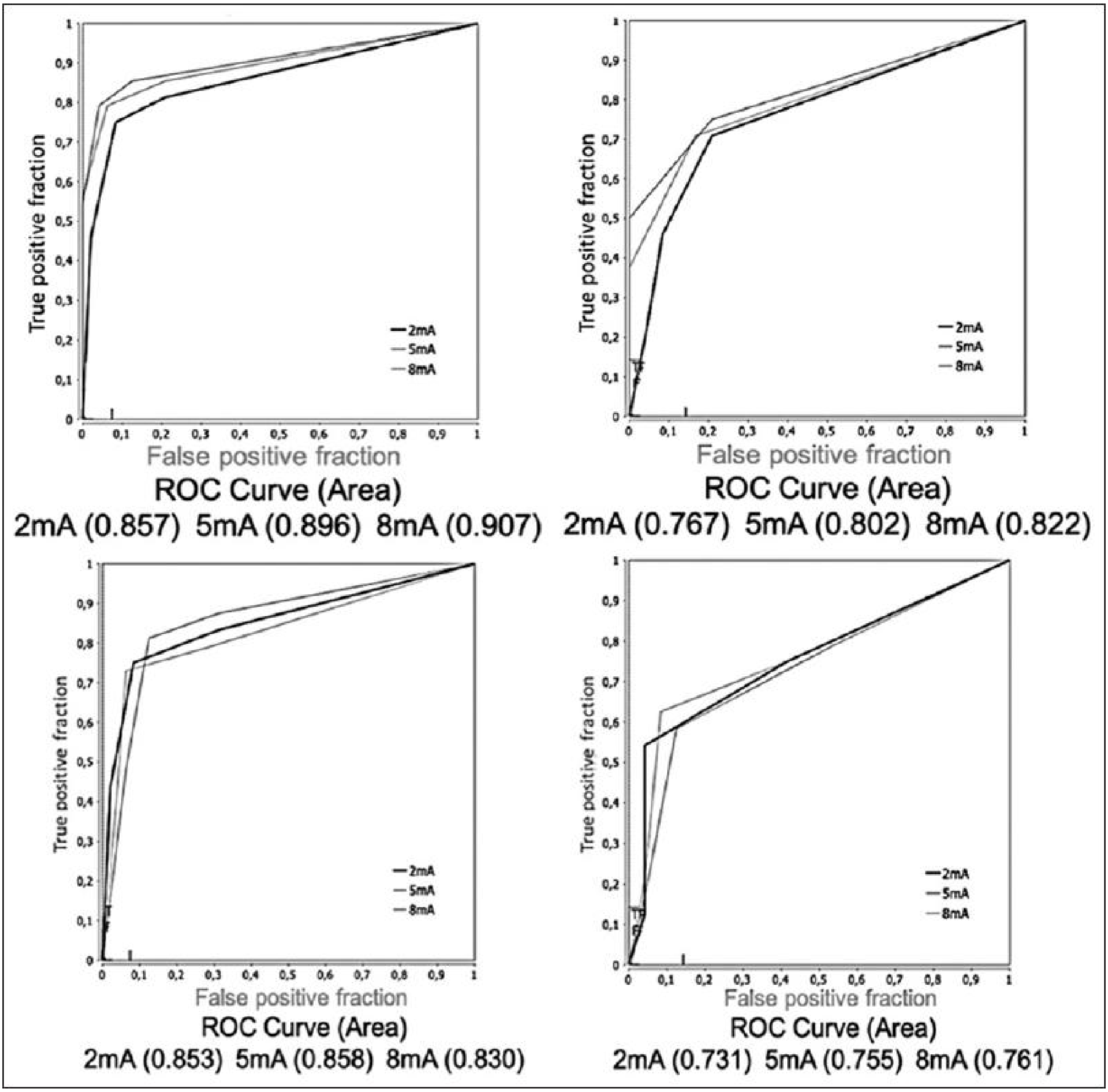

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Table 1: Area under the curve value using different voltages and currents for clear and unclear MCs

V. and Curr. values	Uncl. MCs PSP	Cl. MCs PSP	Uncl. MCs CMOS	Cl. MCs CMOS
60 kV	0.700	0.866	0.785	0.929
66 kV	0.797	0.844	0.817	0.911
70 kV	0.800	0.832	0.848	0.902
2 mA	0.731	0.853	0.767	0.857
5 mA	0.755	0.858	0.802	0.896
8 mA	0.761	0.830	0.822	0.907

V. (Voltage), Curr. (Current), Uncl. (Unclear), Cl. (Clear), MCs. (Mandibular Canals), PSP (photo-stimulable phosphor plate), CMOS (complementary metal-oxide semiconductor)