P 9-5

An image quality comparison study between homemade and commercial dental CBCT systems

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INTRODUCTION

Cone-beam computed tomography (CBCT) has been widely applied in dental and maxillofacial imaging. Several dental CBCT systems have been recently developed in order to improve the performance. The image quality should be assessed quantitatively regarding spatial resolution, contrast sensitivity, and noise.

Aims and hypothesis

This study aimed to evaluate the image quality of our prototype (YMU-DENT-P001) and compare with a commercial POYE Expert 3DS dental CBCT system (system A).

MATERIALS AND METHODS

The Micro-CT contrast scale, micro-CT water and micro-CT HA phantoms were used to evaluate the two CBCT systems in terms of contrast-to-noise ratio (CNR), signal-to-noise ratio (SNR), uniformity (U), distortion, and linearity in the relationship between image intensity and calcium hydroxyapatite concentration. We also fabricated a proprietary thin-wire phantom to evaluate full width at half maximum (FWHM) spatial resolution. Both CBCT systems used the same exposure protocol, and data analysis was performed in accordance with ISO standards using a proprietary image analysis platform.

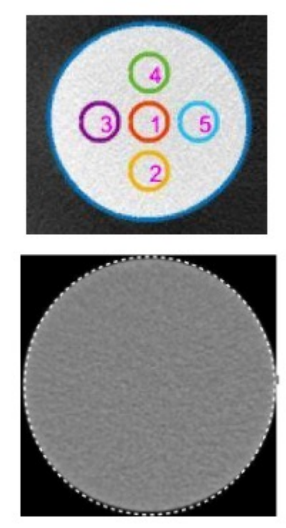
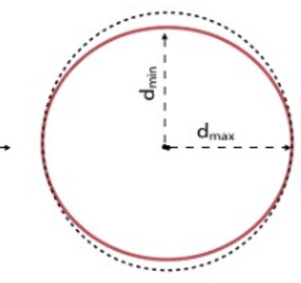
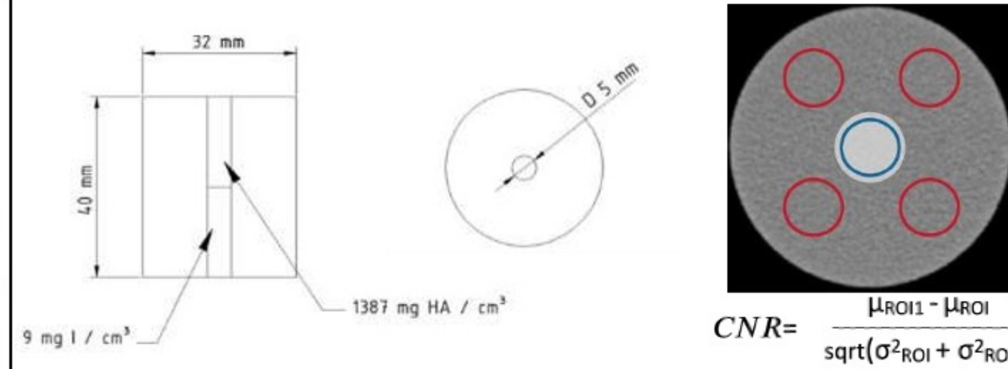
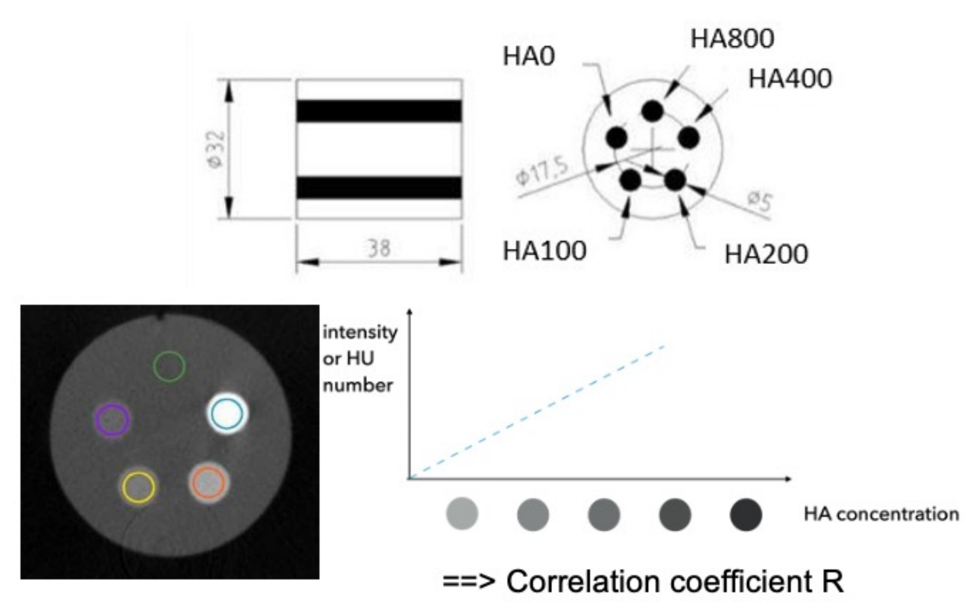
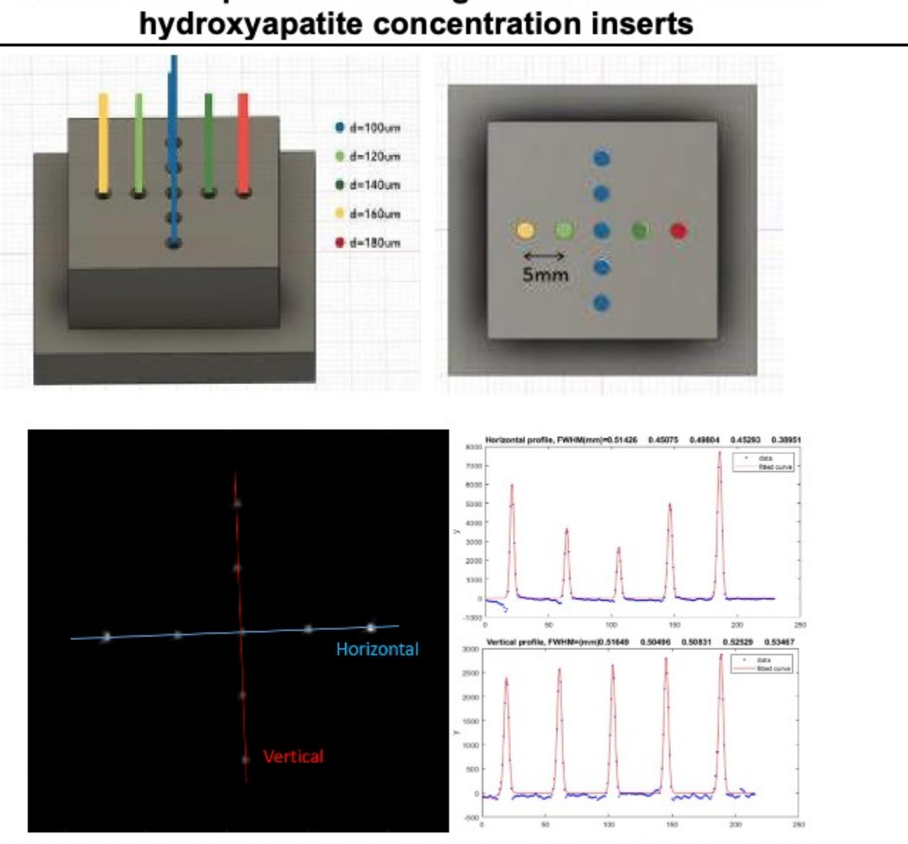
MAJOR FINDINGS

The SNR of our prototype system was nearly five times higher than that of system A (prototype: 159.85 ± 3.88; A: 35.42 ± 0.61; $p < 0.05$) and the CNR was three times higher (prototype: 329.39 ± 5.55; A: 100.29 ± 2.31; $p < 0.05$). The spatial resolution of the prototype (0.2446 mm) greatly exceeded that of system A (0.5179 mm) and image distortion was lower (prototype: 0.03 mm; system A: 0.285 mm). Little difference was observed between the two systems in terms of the linear relationship between bone mineral density (BMD) and image intensity.

CONCLUSION

Within the scope of the current study, the proposed system and system A both presented acceptable image quality; however, the prototype outperformed system A in terms of SNR, CNR, spatial resolution, and distortion. The proprietary phantom fabricated in this study suggests a simplified approach to phantom design for the periodic assessment and quality control of CBCT systems.

Different phantoms used for image quality assessment:

Phantom	Description and Quantitative assessment	Contained materials	Purpose of use
QRM Micro-CT water phantom 	 Regions of interest for signal-to-noise ratio (SNR) & uniformity (U) analysis: from 1 to 5; region for distortion determination: outline blue circle: mean($\mu_{ROI} \pm \sigma_{ROI}$) → SNR = μ_{ROI} / σ_{ROI}; U = $(\mu_{max} - \mu_{min}) / (\mu_{max} + \mu_{min})$ → mean(U)  Roundness calculation: Roundness = $d_{max} - d_{min}$	Distilled water	SNR U Distortion
QRM Micro-CT Contrast Scale phantom 	 $CNR = \frac{\mu_{ROI1} - \mu_{ROI}}{sqrt(\sigma^2_{ROI} + \sigma^2_{ROI1})}$ Details of contrast phantom and regions of interest determination for contrast-to-noi ratio (CNR)	1387 mg HA/cm³ 9ml Iodine/cm³	CNR
QRM Micro-CT HA phantom 	 ==> Correlation coefficient R. Details of HA phanton and regions of interest of each hydroxyapatite concentration inserts	HA concentration of 5 cylindrical inserts: 0, 100, 200, 400, 800 (mg HA/cm³)	Linear relationship between BMD and intensity
The proprietary thin-wire phantom 	 The spatial resolution evaluation of the proprietary wire phantom: The horizontal direction is to evaluate FWHM from different wire thicknesses (from left to right: 160, 120, 100, 140, 180 µm) and the vertical direction is to calculate the mean value of spatial resolution (same 100 µm wires).	5 different sizes of wire: 100, 120, 140, 160, and 180 (µm)	Spatial resolution

Comparison results:

	System A	Prototype YMU-DENT-P001	Can be affected by:
CNR*	100.29±2.31	329.39±5.55	Dynamic range of the detector, exposure factors, bit depth, display setting, graphic card's quality, noise, artifacts.
Linearity (R)	0.99992	0.99928	
SNR*	35.42±0.61	159.85±3.88	Three sources of noise: • Quantum noise; • Electronic noise; • Noise introduced by the reconstruction process. Be affected by intensity of X-ray source, circuit, detector design, number of projections, exposure time, reconstruction algorithm, etc.
Uniformity (U)*	30.59±2.32	36.34±0.35	
Spatial resolution*	0.5179 mm	0.2446 mm	Focal spot size, detector element size, number of projections, smoothing filter, reconstructed voxel size, reconstruction algorithm.
Diameter difference*	1.59±0.04 mm	1.14±0.005 mm	Distortion correction, center of rotation correction, flat field correction, position of the reconstructed slice, radiation beam geometry, reconstruction algorithm, the overlap of treatment and imaging center.
Distortion*	0.285±0.003 mm	0.03±0.002 mm	

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