Letter to editor

Nano-computed tomography: current and future perspectives

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The development of novel imaging technologies amplifies the excellence of scientific dental research. Significant technological advances in imaging have been introduced over the years in the field of restorative dentistry and endodontics. X-ray micro-computed tomography (micro-CT) systems were developed in the early 1980s, producing voxels in the range of 5 - 50 μm.[1] These micro-CT systems offer a reproducible technique for three-dimensional assessment. Because the imaging process is non-destructive, the same samples can be examined many times and continue to be available after scanning for additional biological and mechanical testing.[1,2] In recent years, micro-CT systems have rapidly gained importance as essential components of many academic and industrial research laboratories, and have been used in examining a wide range of specimens including teeth, bone, and materials.[1] Newer generations of micro-CT systems also enable *in vivo* imaging of small live animals.[1]

In general, classical experimental methods used for studying root canal morphology are destructive and produce irreversible changes to the specimens.[1] Hence, the micro-CT has gained increasing significance in the study of the root and root canal morphology because of its non-invasive nature.[3-5] Results continue to demonstrate high levels of complexity of the root canal system, and many canals are described as non-classifiable.[6] This technology has been also advocated for use in evaluating changes in root canal geometry before and after endodontic preparation.[7] The high resolution data obtained by this modern imaging modality accompanied by the ability to accurately match and compare the same pre- and post-instrumentation slices yields a valid approach for accurate assessment.[7] Other applications included the evaluation of root canal filling quality[8] and the efficacy of the file systems to remove filling materials in instances of retreatment.[9]

Ultra-high spatial resolution 'nano-CT' devices have become available as a result of the continuous technological advancements in the development of CT systems. Nano-CT systems, which generally use a nano-focal spot source (< 400 nm),[10] have been employed to analyze cartilage and bone tissues, material quality, and imaging of vascular networks.[11-15] The nano-CT system allows clear visualization of structures on the level of cells as well as internal ultrastructure of bone trabeculae and submicron hard tissue cracks.[10,15] This is attributed to the advanced technical characteristics of the nano-CT system owing to the excellent contrast resolution of the flat-panel detector. In addition, the device is equipped with a granite base and precise rotation unit, which makes it very stable during the data acquisition process.[16] The ability to obtain faster scans is another advantage compared to micro-CT.[12,16]

In dental research, high-resolution nano-CT systems have also been found to be

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useful in oral implantology and restorative dentistry.[14,17,18] Cuijpers *et al.*[14] evaluated the spatial resolution and sensitivity of the nano-CT in a dog dental implant model, and the results confirmed the high resolution of the nano-CT system in accordance with histological assessments. Nano-CT was capable of revealing sub-micron structures embedded in radiodense matrices. A group of researchers from Belgium have confirmed the ability of nano-CT to determine the nano-leakage at the resin composite restoration margins upon polymerization.[17,18] This method could also determine the 3D displacement of filler particles within the resin composite. Thus, a proper correlation analysis of these features may aid in the development of a resin composite with minimal shrinkage after polymerization.[17]

In the field of endodontics, a recent study[16] utilized this modern 3D technique (micro- and nano-CT) together with histological assessment to investigate the internal architecture of external cervical resorption. Results confirmed the ability of nano-CT to clearly identify the border between reparative tissue and dentine. The image resolution also matched the histological assessment at the tissue level, which was superior to that of the micro-CT where both structures had similar grey levels causing difficulty in differentiating between them.

Nano-CT currently represents the extremes of spatial image resolution attainable in a laboratory tomographic device, opening up new applications for tomographic imaging in the field of endodontics. The future may hold promise for the ability of nano-CT to provide reliable and innovative information on fine details of the minor canal anatomy and dentinal tubules of the root dentine (together with evaluations after the application of endodontic materials such as root canal filling materials), programmed physiological changes in the roots of primary teeth, pathological changes in the root (such as internal and external root resorption) and their reparative processes, bioactivity of endodontic materials, and pulp tissue engineering.

Notably, nano-CT technology also has its limitations. In addition to high expenses, the method, up to date, cannot replace histological assessment especially when specific staining is required for cellular evaluations.[16] Optimal parameters may also require pilot experiments.[16] Despite that nano-CT provides better resolutions than micro-CT, in terms of quantification, the nano-CT has limitations in sample size in which the achievable volume of interest is smaller, which may affect the reliability of the obtained data.[14]

Based on the discussion above, it is clear that there is a growing body of evidence for the potential applications of nano-CT in dental research which may help to expand the existing knowledge in restorative dentistry and endodontics, thus paving the way for better visualization, proper validation and thorough understanding of complex phenomena in anatomical variations, tissue responses and interactions with restorative and endodontic materials.

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References

1. Swain MV, Xue J. State of the art of Micro-CT applications in dental research. *Int J Oral Sci* 2009;1:177-188.
2. Marciano MA, Duarte MAH, Ordinola-Zapata R, Del Carpio-Perochena A, Cavenago BC, Villas-Bôas MH, Minotti PG, Bramante CM, Moraes IG. Applications of micro-computed tomography in endodontic research. In: Méndez-Vilas A, editor. Current microscopy contributions to advances in science and technology. Badajoz, Spain: Formatex research center; 2012. p782-788.
3. Versiani MA, Ordinola-Zapata R, Keleş A, Alcin H, Bramante CM, Pécora JD, Sousa-Neto MD. Middle mesial canals in mandibular first molars: a micro-CT study in different populations. *Arch Oral Biol* 2016;61:130-137.
4. Verma P, Love RM. A micro CT study of the mesiobuccal root canal morphology of the maxillary first molar tooth. *Int Endod J* 2011;44:210-217.
5. Versiani MA, Pécora JD, Sousa-Neto MD. Microcomputed tomography analysis of the root canal morphology of single-rooted mandibular canines. *Int Endod J* 2013;46:800-807.
6. Ahmed HMA. A paradigm evolution shift in the endodontic map. *Eur J Gen Dent* 2015;4:98.
7. Junaid A, Freire LG, da Silveira Bueno CE, Mello I, Cunha RS. Influence of single-file endodontics on apical transportation in curved root canals: an *ex vivo* micro-computed tomographic study. *J Endod* 2014;40:717-720.
8. Keleş A, Alcin H, Kamalak A, Versiani MA. Micro-CT evaluation of root filling quality in oval-shaped canals. *Int Endod J* 2014;47:1177-1184.
9. Rödig T, Reicherts P, Konietschke F, Dullin C, Hahn W, Hülsmann M. Efficacy of reciprocating and rotary NiTi instruments for retreatment of curved root canals assessed by micro-CT. *Int Endod J* 2014;47:942-948.

10. Peyrin F, Dong P, Pacureanu A, Langer M. Micro- and nano-CT for the study of bone ultrastructure. *Curr Osteoporos Rep* 2014;12:465-474.

11. Kerckhofs G, Sainz J, Maréchal M, Wevers M, Van de Putte T, Geris L, Schrooten J. Contrast-enhanced nanofocus X-ray computed tomography allows virtual three-dimensional histopathology and morphometric analysis of osteoarthritis in small animal models. *Cartilage* 2014;5:55-65.

12. Kerckhofs G, Sainz J, Wevers M, Van de Putte T, Schrooten J. Contrast-enhanced nanofocus computed tomography images the cartilage subtissue architecture in three dimensions. *Eur Cells Mater* 2013;25:179-189.

13. van Hove RP, Nolte PA, Vatsa A, Semeins CM, Salmon PL, Smit TH, Klein-Nulend J. Osteocyte morphology in human tibiae of different bone pathologies with different bone mineral density-is there a role for mechanosensing? *Bone* 2009;45:321-329.

14. Cuijpers VM, Jaroszewicz J, Anil S, Al Farraj Aldosari A, Walboomers XF, Jansen JA. Resolution, sensitivity, and *in vivo* application of high-resolution computed tomography for titanium-coated polymethyl methacrylate (PMMA) dental implants. *Clin Oral Implants Res* 2014;25:359-365.

15. Salmon PL, Sasov AY. Application of nano-CT and high-resolution micro-CT to study bone quality and ultrastructure, scaffold biomaterials and vascular networks. In: Qin L, Genant HK, Griffith JF, Leung K, editors. Advanced bioimaging technologies in assessment of the quality of bone and scaffold materials. 1st ed. Berlin: Springer Verlag Heidelberg; 2007. p323-331.

16. Mavridou AM, Pyka G, Kerckhofs G, Wevers M, Bergmans L, Gunst V, Huybrechts B, Schepers E, Hauben E, Lambrechts P. A novel multimodular methodology to investigate external cervical tooth resorption. *Int Endod J* 2016;49:287-300.

17. Wevers M: X-ray computed tomography for nondestructive testing. International Conference on Industrial Computed Tomography; 2012. Available from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.303.807&rep=rep1&type=pdf. (updated 2016 Jul 20).

18. Van Ende A, Kerckhofs G, Wevers M, Meerbeek BV: High-resolution X-ray computed tomography in dental research. Available from: https://www.mtm.kuleuven.be/Onderzoek/ndt/downloads_links/9-Van%20End.pdf (updated 2016 Jul 20).