Letter to editor

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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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