REVIEW ARTICLE

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Micro Computed Tomography – Potential Research and Diagnostic Tool in Dentistry

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ABSTRACT:

Micro Computed Tomography (Micro CT) is an advanced imaging modality based on multi slice x ray images which allows three dimensional reconstructions of the viewed structures. This review highlights the significance of micro CT, its working principle and also throws light on its advantages and limitations over conventional 2D radiography as well as Cone beam Computed Tomography. This review also discusses its wide range of applications in dental research and its scope for routine clinical practice in future.

Keywords: Dental Research, Micro computed Tomography, Three dimensional imaging, X rays.

INTRODUCTION

The combination of a thorough dental history, clinical examination and radiological assessment aids in accurate diagnosis, treatment planning and evaluation of success outcomes in the field of endodontics. Although conventional radiography is an extremely useful diagnostic tool, drawbacks like compression of 3D structures, geometric distortion and anatomical noise limited its use in dental diagnosis as well as research. During the last few decades, numerous technical advancements have led to the development of innovative diagnostic modalities like Spiral CT, MRI and Ultra Sound which revolutionized dental research, clinical practice as well as dental education.[1]

Micro Computed Tomography (Micro CT), a miniaturized form of CT is a non invasive imaging technique which uses x rays to create higher resolution cross section images through a specimen which later can be reconstructed three dimensionally. It can be used to examine a wide range of mineralized tissues like teeth, bone and materials such as polymers, biomaterial scaffolds etc.[2] The first report on micro tomography was published in 1954 and at the end of 1980's first research on micro CT was published in dental field. However only in the recent years it is gaining importance and popularity in dental research.

WORKING PRINCIPLE OF MICRO CT:

Micro CT is derived from Computerized Axial Tomography (CAT) and the two main differences of micro CT from original CAT scanners is the possibility to rotate the object instead of X ray source and the smaller size of x ray source (5-10 µm) which helps in achieving much better spatial resolution, increased sharpness and reduced noise. [1] The linear resolution of micro CT varies from 2-100µm depending upon the X ray source and scanner design and the data can be registered in three dimensions for qualitative as well as quantitative analysis.

The principle of micro CT is based upon reconstructing the linear attenuation coefficient, with in an object on the basis of attenuation data of an X-ray beam passing

through the sample from different directions. Differences tissues have their unique linear attenuation coefficient determined by the Atomic composition of the material samples, which is responsible for contrast in an X ray image. Micro CT uses micro focal spot X ray sources and detectors with high resolution which allows for projections from different orientations to produce 3D reconstructions. The volumetric pixel (Voxel) provided by micro CT range in 5-50µm which is approximately 1, 00,000 times smaller in volume than CT voxels. Thus it provides enhanced image analysis capability and the reconstructed three dimensional images are observed in 0.125-1 mm slice intervals[1] in the Coronal(X), Sagittal(Y) and Facial (Z) directions.

Currently, there are In vitro and In vivo micro CT scanners. In invitro scanners, the object rotates between a static x ray source and detector and time as well as amount of radiation may not be a concern enabling much higher spatial resolution (30 to 1 µm) than in vivo micro CT. In case of In vivo micro CT, x ray source and detector rotate around a static object. The spatial resolution of in vivo micro CT ranges from 100 to 30 µm and produces faster images than exvivo micro CT. Examples of invitro scanners are Sky Scan 1172 and 1174 and in vivo scanners are Sky scan 1076 and 1178.

ADVANTAGES OF MICRO CT:

- Imaging process is nondestructive and the samples remain available for additional biological or mechanical testing.
- Eliminates noise thereby allowing high spatial resolution (5 µm) and also allows multiplanar reconstructions.
- Provides very high contrast resolution which is higher than CBCT thus allowing excellent discrimination of very small differences in attenuation coefficient (< 1%).
- Do not require time consuming specimen preparation as for histological examination which also affects its internal structural organization.
- Aids in analyzing the 3D relationship between anatomical structures and the data can be saved for future comparative or qualitative assessment.

LIMITATIONS OF MICRO CT

- Greater complexity in equipment construction and the necessity of long exposure times may be problem with pediatric, geriatric and mentally compromised patients.
- High radiation dose and high cost of the scans.
- Scatter due to metallic objects
- Beam hardening and Cupping artifacts.
- Not recommended at present for in vivo studies or routine clinical practice due to high level of radiation exposure and there is also specimen size limitation which may be a problem with certain analysis.

APPLICATIONS OF MICRO CT

Micro CT is a powerful research tool and is mostly used for laboratory purposes at present which make it possible to use in higher order of energy and finer resolution. Micro CT has proven to be a noninvasive method for 3D reconstruction of teeth ex vivo. It has been used in various fields like endodontic research, caries research, Bone & Mineral research, Biomechanics, anthropology as well as in tissue regeneration.[2]

I) *Endodontic research*

A comprehensive understanding of the complexity of internal tooth anatomy is necessary to ensure successful root canal treatment. The distinct advantage of micro CT is that it provides three dimensional view of root canal morphology.[3] It is an exciting tool for experimental endodontology and can

analyze root canals before and after endodontic instrumentation. The advent of micro CT coupled with mathematical modelling has allowed a 3D assessment of internal and external root canal anatomy with a very high resolution of 15-25 µm.[4]

Micro CT can be used for the qualitative as well as quantitative three dimensional analysis of the root canal system without destroying the sample. It can also be used to evaluate 3D changes in shape and volume of canals after instrumentation with the help of 3D volume rendering technique and computer technology.[5] It can analyze changes in a root canal before and after preparation such as surface area, volume, amount of dentin removed, canal thickness, curvature, canal transportation, SMT (Structure Model Index), transportation of centre of mass, and canal centering ratio. [2] It can also evaluate the volume changes in tooth structure following endodontic procedures and post space preparation by 3D volumetric analysis.[6- 8]

It has also been used to analyze porosities within obturation and its interfacial quality with root dentin.[9,10] Micro CT also provides information about the existence of voids within endodontic materials and aids in material science research.[11] It helps in 3D quantitative evaluation of residual filling material and amount of dentin removed during retreatment.[12]

High resolution micro CT results in better imaging of small isthmuses, inter canal connections, accessory canals, multiple apical foramen as well as complex anatomic variations such as C shaped canals.[13,14] Micro CT also has the potential to analyze surface changes on Niti rotary instruments and development of micro cracks on radicular dentin after rotary instrumentation.[15] There is also need for improvement in mechanical tests in endodontic research which is possible with micro CT based finite element analysis.[16]

II) Caries research:

In caries research, there is absolute need for non-destructive techniques of mineral change analysis such as mineral loss, gain and its kinetics.[2] Micro CT has the potential to evaluate mineral content changes in dental hard tissues based on attenuation coefficient which is equivalent to mineral content.[17]

The morphogenesis of carious lesions, development of subjacent tertiary dentinogenesis, demineralization and remineralization effects of different procedures on enamel and dentin can be quantitatively and qualitatively analyzed using micro CT, contributing a lot in caries research. It is a very sensitive technique and can be used to assess mineral density of white spot lesions and dentinal caries. Thus it has a promising potential for future caries and remineralization studies.

III) Bone & mineral research:

The main application of Micro CT has been the non-invasive analysis of trabecular bone. Micro CT imaging has facilitated measurement of bone parameters like trabecular thickness, number, separation, bone volume, Total tissue volume, Trabecular bone volume fraction and Structural model Index (SMI) making it a standard method for quantitatively evaluating bone internal morphology.[18] It can also be used to investigate periradicular bone destruction quantitatively based on void volume and bone destruction thickness exhibiting a very high correlation with histological staining.[2]

Micro CT can assess the mineral concentration of teeth with a very high accuracy and resolution (5-30 µm), thus used to assess mineral density (MD) changes in cases of enamel or dentin hypoplasia and hypo mineralization as well as analyze the effect of iatrogenic procedures like bleaching, demineralizing and remineralising agents on tooth dentin and enamel.[17]

IV) *Tissue engineering:*

Tissue engineering is an emerging field that focuses on the development of viable substitutes to regenerate functional tissues and organs by replacing diseased or dead tissues.[2]

In the research field of tissue engineering, scaffold material and design of porous architecture plays a vital role in regeneration. Micro CT is a non invasive 3D imaging technique to evaluate internal structure as well as porosity of biomaterials, scaffolds and the micro architecture of mineralized tissues which paves the way for research.

The variation of scaffold architecture as well as mineralization inside a scaffold /bone construct can be evaluated using a combination of CAD/CAM, Computer imaging technology and micro CT.[19] The bone scaffolds apart from 3D porous structure should be strong enough to tolerate high forces in the bone following implantation and should also be flexible enough to enable growth of cells to meet the necessities of the future bone complex. Therefore, it is necessary to carry out mechanical measurement and 3D imaging of bone scaffold before seeding of mesenchymal stem cells which can be done by finite element analysis using micro CT data.[2]

V) *Implants:*

In the field of implantology, the measurement of stability and osseointegration of an implant is crucial to assess the treatment outcome. Stability of an implant is determined by mechanical properties of implant-bone interface and quality of fixation between implant surface and bone. The Osseo integration of the interface is commonly assessed by histomorphometric analysis which is a destructive method and may also result in artefacts.

Micro CT is a non-invasive, precise and fast technique which provides a three dimensional representation of bone formation in the peri implant region up to few microns. The use of micro CT in implant and peri implant bone research has been popular for the past decade and many authors studied interface osseointegration by determining parameters like bone volume, trabecular thickness, bone connectivity etc with micro CT. [20]

Furthermore, as the complete digital set of bone implant data is available, it is possible to carry out Finite Element analysis of the bone implant system facilitating the study of stress concentration at the interface of bone and implant. [21]

VI) *Finite element analysis[FEA]:*

In the last few decades, FEA has emerged as the popular technique used for analyzing physical phenomenon in the field of structural, solid and fluid mechanics. Finite element analysis divides a large structure into numerous small, simple elements and the stress and strain of these individual elements can be more easily calculated than the whole undivided structure. By solving the deformation of all the small component elements simultaneously, deformation of the structure can be assessed.[2]

Earlier techniques used for the purpose of geometry acquisition resulted in formation of meshes with less detail reproduction whereas micro CT data produces models which are very fine in texture thus can generate detailed and valid 3D FEM of teeth. After micro CT scan of a tooth, it is possible to divide enamel, dentin and pulp into separate parts based on pixel gray values facilitating the assignment of various material properties along with appropriate boundaries, to simulate the stress and strain variations following restorative procedures. [22,23] Micro CT based FEM bone analysis has also become an area of great interest in recent years owing to micro CT's high resolution and precision in trabecular imaging.

VII) *Development of hard tissues:*

Dental hard tissue development is a dynamic process resulting in the development of complex mineralized tissues that are optimized for specific functions. In a study by Dong etal, it was concluded that micro CT was sensitive enough to provide 3D image data of dental hard tissue development without destroying the specimen.[24]

Therefore micro CT is a non invasive, high resolution, multi planar tool for the evaluation of volume, mineral density and degree of

mineralization of dental hard tissues, thus can be used for basic as well as clinical dental research for monitoring tooth germ development.

VIII) *Diagnostic applications:*

Though not routinely used in clinical practice owing to its high radiation exposure and longer scanning times, micro CT has better diagnostic accuracy over CBCT. It can be used for differentiation of radicular cysts and granulomas which may not be possible with routine radiography. It has also shown high correlation with histological examination for the detection of tumours like Garre's Osteomyelitis. It can be used to determine the mesiodistal extent of pathology like tumour margins and is also used to assess the thickness and distance between anatomical structures which aids in pre surgical assessment. It helps in diagnosis of maxillofacial, dentoalveolar and root fractures with high precision [25] and also aids in 3D virtual treatment planning for orthognathic surgeries. It can also be useful for the diagnosis of poorly localized odontogenic pain.

Micro CT is better than conventional radiography and CBCT for the detection of carious lesions, tooth resorption, periodontal diseases as well as periapical pathology. It can overcome the dilemma of cracked tooth syndrome which may not be accurately detected even by CBCT. 3D images also assist in preventing accidental pulp exposure during routine restorative and fixed prosthodontic procedures and are also useful in assessing the quality of adhesive restorations. In endodontics, high resolution micro CT images can assist in root canal treatment by diagnosing apical periodontitis, root fractures and variations in root canal morphology with better image quality and resolution than CBCT. It can also be used to assess the success outcomes of periodontal regenerative therapy.

FUTURE OF MICRO CT

Nevertheless, despite a lot of advantages over other digital imaging techniques, currently its use is limited to research applications owing to its high radiation dose which makes it inapplicable for human imaging in vivo. Experimental systems with reduced dose are still being tested like Synchrotron micro CT devices.

Synchrotron radiation

Synchrotron radiation (SR) refers to the electromagnetic radiation emitted by several Gev energy electrons circulating in storage rings, when they are further activated by a magnetic field. Its large flux of photons and better collimation provides more x rays per unit area allowing better spatial resolution near to 1 µm. SR sources deliver twice the amount of energy as a standard x ray source. The use of SR micro CT offers an excellent resolution keeping the sample scanning time to a minimum compared to micro CT. Other recent modifications of CT are Mini CT devices (Voxel size of $10^{-3}mm^3$) and Nano CT devices (Voxel size of $10^{-7}mm^3$).

Nano CT devices

These devices employ an x ray source with a spot size of 0.3 µm. With this device, pixel sizes down to 150 nm are possible. It represents a key modality to study the organic and inorganic interfaces in bio ceramic materials such as enamel, dentin and bone. Examples of Nano CT devices are **Phoenix Nanotom S** from GE and **Sky Scan 2011** Nano CT from Bruker.

CONCLUSION

Micro CT, despite its wide array of applications, is not suitable for clinical use at present but can be a powerful tool for dental research. It produces high resolution images as well as allows quantitative and qualitative analysis of tooth, bone and implants. Micro CT is likely to become more applicable in clinical practice if the challenges related to radiation safety, targeted field of vision, cost

and ease of use can be overcome. Micro CT and Nano CT possess a considerable room to grow in the near future which may be a quantum leap in the field of dentistry.

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