Implementation of Micro CT in CAD/CAM dentistry for image processing and soft computing: a review

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Abstract: All This review discusses the merits and area of improvement of various radiology aids employed in current dentistry and also refers to scope in CAD/CAM dentistry. However, present radiology devices are playing an important role in clinical dentistry but their area of application is limited due to harmful effects of x-ray exposure to human and high operating cost. Radiology device like Micro CT (µ-CT) is powerful tool to assess the dental prosthesis fabricated using CAD/CAM but radiology devices can also be used in whole process of dental prosthesis manufacturing using CAD/CAM. This study retrieves the interaction of advanced radiology devices in current CAD/CAM dentistry and also highlights the correlation of Micro CT’s input variables and acquired image resolutions using available data in reviewed studies.

1. Introduction

Success of dental prosthetics have been closely related with various disciplines of engineering especially production engineering. In past decades, rapid advancements of CAD/CAM technology has not only brought the remarkable transformation in production engineering but also revolutionized the dental industry. However, various manufacturing techniques and methods have been introduced in prosthetic dentistry but CAD/CAM provides rooms to manufacture the custom made optimal dental restorations with minimum discrepancy.

Application of CAD/CAM in dentistry is not only an advanced form of modeling, state of the art of materials and machining but also eliminated the conventional manufacturing methods suspected with various subjective errors. CAD/CAM systems have been using in prosthetic dentistry work on reverse engineering principle; the process starts from 3D digitization of prepared tooth to CAD modeling and finally manufacturing on CAM unit using either Rapid machining or Rapid prototyping. Implementations such type of manufacturing methods have been resulted in significant advancement in prosthetic dentistry [1-5].

On the other hand, in today’s dentistry, various radiological aides are prominent for accurate diagnosis, better treatment process, and successful assessment of outcomes. However, traditional radiography is a vital part of diagnosis process but drawbacks like constriction and distortion of 3D geometry, and structural noise of radiological tools restricted its use not only in diagnosis but in research also. In past decades, due to advancements in radiography techniques, modalities like X-ray, CT, and MRI have revolutionized the clinical dentistry as well as dental education and research [6].

Innovation of Micro Computed Tomography (µ-CT) came due to bulk size of ordinary Computed Tomography machine that was not easy to use in dental clinical practice and even in research area. µ-CT generate high resolution cross sectional images by using x-rays through the object and by reconstructing of these images three dimensional structure can be produced. In case of dentistry, µ-CT
illustrate distinguish images of mineralized tissues like bone, teeth as well as materials like biomaterial scaffolds. [7]. However, in 1954, first report of investigation using μ-CT was published but particularly in dentistry, first research was published in end of 1980. In present dentistry, radiography has been increasing its potential hence importance and popularity of μ-CT rising day by day. The objective of this review is to highlights the applications of μ-CT in recent CAD/CAM dentistry in as well as to study the input parameters of μ-CT in these studies.

2. Materials and Methods

In electronic data base search, the PubMed and Scopus were explored with combinations of key words: (Micro CT and dental restoration) and (Micro CT and ceramic restoration) and (Micro CT and CAD/CAM dentistry). The latest article considered in this study was published on 12 January 2016, whereas oldest article considered in study was published in 1997. The peer reviewed English-language publications that focused on implementation of Micro CT in CAD/CAM dentistry were considered for review. Both In-vivo as well as In-vitro studies included for review.

The publications that focused on CAD/CAM dentistry without any role of Micro CT were considered ineligible for review. This excluded various studies of dental crown, partial and fixed prostheses, Metal ceramic restorations, complete and partial denture, onlays, inlays, and implant supported restoration studies. Studies focused on Micro CT but prostheses manufactured with other than CAD/CAM technology were also excluded from review.

The appropriateness of title and abstract explored through electronic search were scrutinized by two investigators (YK and VG) independently. After testimony of possible inclusion of abstract, the full text of study was inspected and subjected to predesigned criterion of inclusion and exclusion. In addition to electronic search, the references of selected studies were also explored manually, and some of those were reviewed and included in present study. Any discordance was cleared up after discussion between two investigators.

The following details juiced from each study: type of specimen used, parameters investigated, type and manufacturer of Micro CT used, sample size, stage of completion of restoration, input parameters of Micro CT and resolution of images occurred, exposure time, total time duration of each specimen, step angle, total angle covered and total images captured for each specimen. For statistical analyses, Pearson correlation test implemented to find the correlation between input parameters (Voltage, Current and Exposure Time) and output response (Image Resolution).

3. Results

The present study reviewed the articles published in last 20 years hence among 159 studies explored in electronic search only 61 studies selected for review were published between 1997 and 2018 whereas six studies included in review were identified from manual search through references. The number of articles reported in vitro were 59 whereas 8 articles reported in vivo. However, total 54 articles included (among those 12 articles were related to the tooth enamel thickness and mineral density, 7 articles were related to the tissue engineering, 17 articles were related to the dental implantology, 11 articles were related to the dental biomechanics whereas 7 articles were related to the research and development areas of dentistry) in present study after screening of titles and abstracts but only 20 studies were reviewed finally after went through full articles (Figure 1).

The included articles exhibited a notable experimental diverseness and measured different discrepancies. In all articles Micro CT used as measurement tool to calculate the discrepancies. Approximately all studies were investigated on conventional Micro CT except three. Out of which two studies were investigated on synchrotron X-ray CT whereas one study was performed on specially designed setup named as Hilger & Watt Y-33 Micro focus generator.
In order to study input parameters of μ-CT, the available input data in reviewed studies tabled (table 1) and input parameters Voltage, Current and Exposure Time were tested for their correlation (Pearson Correlation Test) with image resolution (output response). In case of nature of correlation, results show (Table 2 and Table 3) that voltage, current, Tube Power and Scanning Time positively correlated to the image resolution but out of all these input factors only Tube Power correlated significantly. Meanwhile, Current moderately correlated to the image resolution while Voltage and Scanning Time had low degree of correlation to the image resolution.

| Study | Specimen | Parameter investigated | Micro CT | Volt. (kVp) | Current (μA) | Time (S) | Resolution (μm) | Findings |
|-------|----------|------------------------|----------|-------------|--------------|----------|-----------------|----------|
| Long F et al51 (2016) | Molar Teeth | Volume Concentration | Scanco Medical Viva CT40 | 50–70 | 160 | 4-3.6 | 38 | μ-CT 3D imaging technique is capable to identify pulp vitality, oxygen saturation and early diagnosis of dental lesion using phase contrast analysis. |
| Becker K et al62 (2015) | Implants | Bone Density | Scanco Medical AG µCT100 | 90 | 88 | 1.2 | 8.6 | In post implant investigation, dental tissues can be successfully segmented using μ-CT 2D image but in close proximity to implant surface, segmentation impeded by artifacts. |
| Lashgari M et al14 (2015) | Premolar | Bone Micro Structure | XRadia, Concord MicroXCT-400 | 60 | 120 | 0.5 | 14.8 | Ring artifacts in dental μ-CT images can be eliminated by Total Variation (TV) method. |
| Dessel J V et al63 (2013) | Trabecular Bone | Bone Micro Structure | SkyScan 1174μCT | 50 | 800 | 9 | 26 | In pre-operative phase, Low dose CBCT technique offers ideal accurate clinical alternative μ-CT technique but μ-CT images delineate the microarchitecture of trabecular bone in comparison to CBCT images. |
| Mangno C et al64 (2013) | Implant | Bone Micro Structure | Synchrotron X-ray Beam (SR μ-CT) | 40 | - | 0.5 | - | Higher photon flux used in SRμ-CT has main advantage over conventional μ-CT. Due to high sensitivity Of SRμ-CT bone formation and desorption can be quantified while same technique fails to resolve the fibrous tissues and vascularization. |
| Chen G et al65 (2012) | Maxillary Molar | Finite Element Modeling | Scanco Medical CT40 | 70 | - | - | 36 | The virtual simulation of 3D finite element modeling |
| Study | Specimen | Parameter investigated | Micro CT | Volt. (kVp) | Current (μA) | Time (S) | Resolution (μm) | Findings |
|-------|----------|------------------------|----------|------------|-------------|----------|-----------------|----------|
| Gonzalez R et al66 (2012) | Implant | Bone Density | SkyScan 1172μCT | 100 | 100 | 0.45 | - | The process of analysis of microstructure and morphology of trabecular bone using 3D, μ-CT images is highly accurate and faster which eliminates need of interference of stereological 2D models and any decalcification. |
| Yamaki K et al67 (2012) | Implant | Surface Characteristics | SMX-90CT | 90 | 110 | - | - | In post implant study, μ-CT images are capable to identify the influence due to proximity of artifacts and quantification of mineral volume. |
| Taylor A M et al12 (2010) | Teeth | Mineral Concentration | SkyScan 1072μCT | 100 | 98 | 6.5 | 98 | The dentine carries can be detected easily using μ-CT images. μ-CT image shows sharp changes in radiopacity that segments enamel and dentine regions automatically with sufficient accuracy for measurement to be made. |
| Neves A A et al68 (2010) | Dental Material | Mineral Concentration | SkyScan 1172μCT | 100 | 100 | - | 18.85 2D | Carious dentin can be excavated using μ-CT image processing, artifacts correction, calibration for mineral density and adequate data processing. |
| Haung T Y et al69 (2007) | PreMolar | Mineral Concentration | SkyScan 1172μCT | 100 | 100 | - | 7.6 | White spot lesions (WSLs) are quantified by mineral density (MD) and WSLs quantification data can be obtained by improving signal detection and reducing noise at data collection using μ-CT image processing rather |
Table 1: Micro CT parameters investigated

| Study          | Specimen | Parameter investigated         | Micro CT          | Volt. (kVp) | Current (μA) | Time (s) | Resolution (μm) | Findings                                                                 |
|---------------|----------|--------------------------------|-------------------|-------------|--------------|-----------|-----------------|---------------------------------------------------------------------------|
| Schicho K et al (2007) | Implant   | Implant Surface Area           | Ray Scan 250E 3D  | -           | 160-225      | -         | 19-25           | Surface area is one of factors that has impact on biomechanical situation in post implant where μ-CT images provide such geometrical details. |

Figure 1: Flow chart for inclusion and exclusion of studies.

Table 2: Descriptive statistics of I/P and O/P data for Micro CT.

|                      | Mean (sum of Squares) | SD       | N  |
|----------------------|-----------------------|----------|----|
| Current              | 175.2                 | 207.3    | 12 |
| Voltage              | 81.0                  | 28.7     | 12 |
| Power                | 13465.9               | 12464.6  | 12 |
| Time                 | 16.1                  | 46.5     | 12 |
| Resolution           | 20.5                  | 15.4     | 12 |

Table 3: Results of Pearson correlation test.

|                      | Current | Voltage | Power | Time | Resolution |
|----------------------|---------|---------|-------|------|------------|
| Resolution           | Pearson | .351    | .176  | .648*| .098       |
| Correlation Sig.     | (2-tailed) N | .263    | .585  | .023 | .762       |

*Correlation is significant at the 0.05 level (2-tailed).
4. Discussion

However, μ-CT is mostly used for laboratory purpose only, but it can also be used for other clinical, educational and research purpose. In this order, it has been proved that μ-CT provides non invasive way of scanning and has capability to produce high resolution 3D reconstructions; hence it may be possible to use it as a powerful research tool. Although μ-CT can be implemented in various dental areas but some of these are discussed in this study (Figure 2).

![Figure 2: Implementation of Micro CT in CAD/CAM Dentistry.](image)

**Role of Micro CT (μ-CT) in CAD/CAM Dentistry**

*Tooth enamel thickness and bone density measurement.*

Tooth enamel thickness has been playing an important role in interpretations of the phylogenetic values in anthropological studies and also significantly interprets the occlusal loading stresses in studies of dental CAD/CAM restorations. In past, several measurement techniques have been utilized for tooth enamel thickness measurement but physical cross-sectional method has remained most prevalent among them. Physical cross-sectional method is a destructive technique hence destruction of specimen tooth is one of major drawback whereas data furnished using this method may also be less than actual data due to orientation of specimen. Although researchers had also made efforts to illustrate the tooth enamel thickness using Computed Tomography (CT) but due low resolution, obtained standard CT images were evidently characterized inaccurate.

Recently, μ-CT has become popular and effective device to measure the tooth enamel thickness. μ-CT provides high resolution images without destruction of specimen. The data illustrated using μ-CT scans for tooth enamel thickness has proved highly accurate. Only 3%-5% difference had evaluated in measurements made on physical and μ-CT sections [8]. Results from past studies apparently manifest that data imparted using μ-CT scans are more accurate and reliable as compared to data obtained using direct measurement, 3D scanners or by photography techniques [9]. In addition, volumetric data of tooth structure can be obtained from 3D reconstructions produced with the help of imaging software [10]. Although, μ-CT provides accurate measurements of enamel thickness but fails to distinguish the dental tissues in case of extremely mineralized teeth. Moreover, it is hard to sort out extremely fine regions from pixel based raw μ-CT images [9].

In a review study of application of polychromatic Micro CT for assessment of factors that help to minimize inaccuracies ensuing due to beam hardening, beam filtration and mineral density calibration, results showed that high contrast and minimal beam hardening artifacts can be achieved by filtration in addition to minimum feasible source voltage [11]. A study designed the algorithm of human tooth using Micro CT scans and tested to quantify natural occlusal caries lesions
automatically, results concluded that approach successfully segmented the Micro CT scans into occlusal enamel and dentine regions and using these scans, dentine caries lesion’s depth can be measured objectively and accurately [12]. In another study, Micro CT technique was optimized to qualitative assessment of the effectiveness of contemporary caries-excision techniques. Results showed that Micro CT scans significantly allow the detailed volumetric calculation of caries-excision techniques [13]. In a study, mineral density of caries dental lesion was assessed quantitatively by Micro CT scans. In this comparative study of TV method and BM3D method, it had been found that TV method well executed the Micro CT images and had much better CNR index than BM3D method. In last, TV method was able to remove ring artifacts whereas BM3D method couldn’t [14]. Morphology of silicon rubber impression was measured and demonstrated successfully three dimensionally using Micro CT [15]. In another study Micro CT was used to calculate hydroxyapatite density in regions of interest of 20 enamel slabs [16]. In comparative study of four different removal methods, Micro CT was used to determine the dentinal caries removal effectiveness (CRE) and minimal invasiveness potential (MIP) of carious molars [17]. Micro CT was used to assess the mineral density, surface morphology, element content and crystal characteristics of two carious primary upper-central incisors [18]. In another clinical study, the effect of fluoride induced density of remineralized teeth of 12 orthodontic patients was assessed by Micro CT [19]. In a vivo study on 28 patients of age group of 34 to 74, Micro CT scans were used to assess the bone volumes and tissue mineral concentrations [20].

**Tissue Engineering.**

CAD/CAM technology has become integral part of tissue engineering research and development. In this approach, CAD/CAM has been implemented in three significant areas of TE: Computer-aided Tissue-modeling, Computer-aided Tissue scaffold informatics and Biomimetic design, and Bio-manufacturing of scaffolds of tissues and organs. In Computer-aided tissue modeling process, a Bio-CAD model construction usually begins from image acquisition using suitable medical imaging modality. After three dimensional reconstructions of acquired images they convert into voxel volume and finally, CAD model generates from the voxel-based volumetric morphometry. While Computer-aided tissue scaffold informatics and modeling process starts with tissue morphology classification and then scaffold is characterized with morphological properties and biological intents to create database informatics and modeling. Although, Biomimetic design holds multiple biological and biophysical information and these features may accumulate from real anatomical data images acquired using medical imaging modality or can be design within CAD environment. Moreover advanced manufacturing methods, e.g. Solid Freeform Fabrication (SFF) have been used to fabricate these complex porous scaffold constructions [21-23].

Recently, Tissue Engineering (TE) has become prominent multidisciplinary field in which concepts of biology and engineering are used to replace diseased, damaged or dead tissues by recreating functional, aerobicized tissues and organs. However, TE assess the methods to re-create bio-artificial organs in laboratory that can implant into patient but particularly in dentistry, TE researches have been used to cure the oral-maxillofacial framework, hard and soft tissue defects [24]. Although, tissue generation using preserving tissue volume technique, porous architecture design and scaffold material have significant importance as well as temporarily contribute for mechanical function and direct biofactors [25]. In TE, Micro CT has been used to study architecture of scaffold, in vitro scaffold degradation and bone growth into scaffold structure [26]. In general, Micro CT based 3D data obtained for different studies show greater accuracy and authenticity than data obtained using other 2D methods. Tissue engineering is the regeneration of the diseased or dead tissues with the help of scaffold material. Although, porous design architecture of scaffold is the important factor in tissue engineering and μ-CT evaluate all parameters like porosity of biomaterials, scaffold and architecture of mineralized tissues with the help of non invasive three dimensional imaging techniques. Combination of μ-CT with CAD/CAM system easily evaluates scaffold architecture and mineral inside a scaffold/bone construct [27].

**Implantology.**
Advancements in CAD/CAM has been raising its popularity in implant dentistry and also successfully eliminating the conventional fabrication techniques of implant based prosthetics since last two decades. Past studies result outcomes assessed that implant-supported prostheses (ISP) fabricated using CAD/CAM are better in every clinical aspect compared to prosthesis fabricated with conventional techniques. Although, specific information of patient’s jaw bone and dental morphology are preliminary requirements hence volumetric representations of bone formation at implant surface become more important for quality dental implant supported prosthesis restoration.

In field of implantology, success of treatment outcomes depend on the stability of the implant whereas stability of implant is influenced by various factors like implant-bone interface and fixation quality of implant into bone. Although, a destructive method, histomorphometric analysis was prevalent to assess the Osseo integration of interface and results may effected by its artifacts. High resolution images facilitate to measure the bone parameters like trabecular thickness, number of bones, bone volume, tissue volume, and separation. Micro CT is a non-destructive technique and volume changes technique of μ-CT helps to determine the destruction void volume and bone destruction thickness to examine the bone structure [28]. μ-CT provides high resolution images of bone structure these help in accurate implantation and also help to determine mechanical testing for stability of implant using 3D structure reconstructions [29,30].

A study for much prevalent material Titanium to evaluate load bearing of implants resulted that Micro CT imaging as well as bone density calculation parameters was affected by partial volume effect due to inherent halation artifacts of titanium [31]. In last two decades Micro CT has been popular in research of field of implantology where many authors have studied for especially implant [32], periimplant [32,33], bone-implant integration and osseointegration interface [28,31,35-36].

A study analyzed two porous titanium implants using Histological and Synchrotron radiation based Micro CT. Histological results showed that the cursory fragments exist on implant surface and particle compositions were presented in enclosing tissues near to the bone area, findings were confirmed by Micro CT investigations [37]. In a novel approach, 3D-2D slices of dental implant biopsies were constructed using Micro CT (μ-CT) and Histology (HI) to evaluate the position and normal vector of the oblique slice from μ-CT that corresponds to HI. Results suggested that Micro CT technique may become rational and an option for construction of 3D images to diagnose osseointegration [38]. In a study, Micro CT images of 80 maxillas (left & right) from 40 Japanese adult skulls were used to measure thickness of cortical bone, width of alveolar procedure and to evaluate root adjacency hence data could be used for mini implantation in the maxillary alveolar process [39].

Biomechanics.

For success of dental restoration, it is essential to know the biomechanics of dental structure. During mastication, various spatial forces generate due to non uniform teeth structures and uneven occlusal surfaces. Hence, longevity of dental restoration also depends on the nature of these spatial forces. So, it becomes necessary to evaluate the materialistic and structural strength of dental prosthetics before fabrication. However, various testing techniques are available but these methods are destructive hence Finite Element Analysis (FEA) method has become integral part of CAD/CAM dentistry. Basic principal of FEA is division of large structure into number of small and simple elements. However, calculation of stress and strain of whole undivided structure is complicated but it is easy to determine the stress and strain of individual elements [7]. Deformation of the whole structure can be assessed by solving the deformation of all elements. Past geometry acquisition techniques provided less information in formation of mess while model produced by Micro CT are very fine in texture so that 3D FEM of teeth can be generate in details [40,41].

Although, teeth and bones have layered structures and anatomical shapes hence these cannot be assimilate by simplified geometric representation. CT scan provide better options to elaborate the solid replica of teeth and bones based on meshing algorithms using patient’s dental configuration. In similar approach, reconstructed 3D images obtained through Micro CT scanner enable to create
precise FEM of compact structures such as teeth. On the basis of different pixel gray level values or mineral density, the enamel, dentin and pulp can be segmented easily from the images constructed with Micro CT and also different material properties can be assigned to simulate the strain and stress variation of restoration using FEA technique. In a study human premolar’s 3D FEM was created using Micro CT and simulated. Results of this study stated that stress patterns were three dimensional and area of loading was centre of stress concentration [42].

In a study of dental restorative procedure, Micro VCT was used to create 3D FEM for analysis. Results showed the efficient caliber and validation of Micro CT in detailed 3D Finite Element Modeling and simulation of stress distribution [41]. In another study of microstructure of human mandibular candyl, Micro CT was used to evaluate mechanical significance. It had been found that significant tensile stress develops in trabecular structure and orientation of strain was in direction parallel to the plane of applied load [43]. In a group study, Micro CT was used for Finite Element Analysis of partial influenced third molar of human mandible with angle fractured. FEA resulted that stress concentration was across the root crest of third molar [44]. In another study of FEA to evaluate the impact of bite force on the mandible having dental implant, Micro CT was used as scanning modality. The FEA results found that stress was concentrated across the implanted area and transferred to internal structure of mandibular through implant whereas dispersion of pressure took along internal trabecular alignment [45]. Mechanics of peri-implant trabecular mandibular bone structure of 82 year old man was assessed by Micro CT [46]. In a Micro CT based finite element analysis study, stress distributions of three nickel-titanium (Ni-Ti) rotator files subjected to torsion and bending conditions were measured. Analysis showed that the maximum stress was marked on the flute base and cutting edge surfaces in the course of bending. When instrument was subjected to torsion, stress concentration was marked at the bottom of the flute [47].

In a study, evaluation of fatigue lifetime before crack failure by simulating 3D finite element modeling created using Micro CT imaging technique. Results showed that areas having shortest fatigue life were dictated near the fillets of the class 2 MOD cavity having highest static stress [48]. In a comprehensive finite element analysis study, a finite element model of tooth was generated with the help of 3D images scanned and reconstructed by Micro CT to evaluate the strength and predict the fracture risk for endodontically treated teeth. It had been found that proposed method can be used to generate precise 3D FE model that can be use for fracture risk simulationQ [49]. In an another study of FEM simulation of five human posterior molars, Micro CT imaging data was used to derive specific Computer Aided Design (CAD) modeling using Reverse Engineering (RE). Analysis results confirmed the validation of proposed approach and found that this method have caliber to create productive 3D reconstructions of teeth with an excellent estimate of the shape [50].

Research and Development of CAD/CAM Dentistry
Success of a dental restoration depends on various factors but tooth preparation and prosthetic material play vital role. Improper tooth preparation leads to poor fit that causes periodontal diseases hence patient feel uncomforted and it may also impact the life of restoration. Additionally, marginal fit protect the tooth preparation from oral environment whereas internal fit helps in transverse of spatial forces from restoration to preparation during mastication. However, restorations fabricated by CAD/CAM attain acceptable range of fits but there is scope for work to achieve maximum adaptation. Although, dentistry has been serving the human being since ancient and various materials have remained in this practice but from last few decades CAD/CAM technology makes possible use of ceramic materials in prosthetic dentistry. Ceramic materials exhibit all necessary qualities for ideal dental restoration e.g. physical property, biocompatibility, aesthetic property and machinability hence even in CAD/CAM dentistry all ceramics restorations are more prevalent than metal-ceramic restorations. Moreover, ceramics have great aspect to be ideal material for dental restoration but material go through different environmental conditions during fabrication process that may cause change in physical properties of material; and all day patient intakes various foods at different temperatures so there is need of research on various properties of material post fabrication as well as post restoration.
It is essential to understand morphology and internal anatomy of tooth for better dental restoration. μ-CT provides highly accurate anatomical and morphological details of tooth structure with high resolution. μ-CT helps to analyze three dimensionally quantitative as well as qualitative assessment of internal structure without destroying the sample. 3D volumetric analysis technique of μ-CT evaluates the shape and volume changes as well as structural details of specimen that helps to improvise the dental prosthesis quality. μ-CT high resolution images better distinguish the different small size internal parts of tooth as well as μ-CT provides a non-destructive imaging process hence specimen remains available for further biological and mechanical testing. Post treatment mechanical testing can be done with finite element analysis of three dimensional reconstructions generated using μ-CT scanner. Additionally, μ-CT can be used as efficient tool to analyze the relationship between three dimensional anatomical structures and future assessments data can be saved. In a research, Micro CT was used for validation of image of the pulp and root canals in teeth developed using Laminar Optical Tomography (LOP) to investigate dental lesion located in the pulp [51]. In assessment of relationship of voids to the root canal fillings, Micro CT scans were used by Moeller et al in 2013 [52]. In a clinical study of root canals of 20 maxillary central incisors filled with gutta-percha and sealer, Micro CT was used for observation [53]. In a study of extracted mandibular molars Micro CT was used to compute the disinfecting and shaping performance in three instrument systems differentiated by their preparation techniques [54]. Tooth crown volumes and dentine volumes of 41 deciduous incisor teeth were measured using Micro CT [55]. The qualities of fillings in canals of 60 single rooted teeth were investigated using Micro CT where effects of filling techniques and post insertion conditions were considered [56]. In a study of 90 mandibular molars with root end fillings, Micro CT scans were used for pre and post operative calculations. These scans successfully measured the filling material volumes as well as the amount of dentine removal [57].

Correlation of input parameters of Micro CT (μ-CT) to the acquired image resolution
The tube capacity impacts two discrete image quality standards. On one side, the spatial resolution is limited by the focal size and it also intended to be more enlarged for greater tube capacity whereas on other side, to attain suitable signal-to-noise ratios adequate radiation potencies are essentials. Hence, an illustrative definite balance between these two image qualities standards which are conversely associated with the tube capacity is required [58]. Resolution is directly related to the scanning time (Exposure Time) and In fact, noise will be inherently present in any micro-CT slices, especially if reasonably short scanning times are used (less than 1h) [59,60]. The correlation test results showing that Tube Capacity or Tube Power (Voltage*Current) significantly (p<0.05) positively impacts the resolution of acquired image but Current, Voltage and Scanning Time had no significant correlation but to the image resolution. In other hand, results also saw that in spite of insignificant correlation Pearson correlation factor (r) for Current, Voltage and Scanning Time was greater than Zero and values of ‘r’ were also indicating that all these input factors had positive correlation in nature and Current had moderate whereas Voltage and Scanning Time had low degree of correlation to the image resolution. However, as earlier studies described the significant correlation between these input factors to the Image resolution and in present study on one side, resulted significant correlation between Tube Power and Image resolution but on other side, denied any significance of correlations of Current and Voltage to the Image resolution independently. Hence, it seems that data population to test these correlations is inadequate as well as present study evaluated the results on the basis of data collected from earlier studies which were not specific to input parameters of Micro CT.

5. Future Micro CTs
Although, μ-CT digital imaging technique exhibits but it has been used to research applications. High dose of radiation limited its use only for in vitro studies. In future, to reduce the radiation dose that will make possible use of μ-CT for in vivo examinations are still under experimentation and Synchrotron μ-CT device is one of example of this kind. In synchrotron radiation device electrons circulating in storage rings emit several Giga electron volts (GeV) energy when generated magnetic field activates them further. Synchrotron μ-CT device generate huge photon flux and excellent
collimation hence great discharge of x-ray flux allows high spatial resolution (apprx. 1 μm). In comparison to standard x-ray source, SR device has double capacity to deliver energy and less time in scanning process with an excellent resolution. A very small size spot distance of 0.3 μm is used in construction of Nano-CT device which has capability to provide images with 150 nm pixel size. Nano-CT devices are excellent tool for dental examinations and research. Phonix Nanotom S from GE and Sky Scan 2011 Nano CT from Bruker are common example of Nano CT device.

6. Conclusions

However, μ-CT is a substantial tool employed in dental research but still it has not been used for clinical purpose. Various segments of dental structure like bone, tooth and implants can be analyze for qualitative as well as quantitative purpose using high resolution images provided by μ-CT. Based on results of the present analyses, significant positive correlation was found between tube power and image resolution and it also found that scanning time and image resolution had a low degree (not significant) and positive correlation.

Although, μ-CT has wide range of applications in various areas but there is scope to make it more applicable especially for clinical practice if it might be possible to overcome challenges like radiation safety, ease of use, cost etc. There is scope of μ-CT and Nano-CT devices and their implementation can revolutionize the dentistry in near future.

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