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ISSN 6299 -0975

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Int J Pharm Bio Sci 2015 July; 6(3): (B) 1194 - 1206

Research Article **Dentistry**

International Journal of Pharma and Bio Sciences

ISSN
0975-6299

APPLICATION OF MICRO-CT IN VARIOUS DISCIPLINE OF CLINICAL AND RESEARCH DENTISTRY

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ABSTRACT

Micro-CT (µCT) is gold standard technique and as an adjunct tool to the dental research and clinical dentistry. The main use of µCT has been the noninvasive exploration of trabecular bone for multiple analyses like investigation of bone growth and repair. The electronic database searched, that followed a combination of keywords and an overview until date. Due to advancement in the µCT system, the mineral concentration of the bone and teeth can be measured with accuracy greater than one percent; with the resolution of 5 and 30µm. 3D µCT is an investigative and diagnostic apparatus, for better understanding of the tooth structure, various dental materials and instrumentation techniques. µCT can help in assessing dentoalveolar structures qualitatively for efficient and precise treatment outcomes and developing a better understanding. µCT is being used for immensely detailed studies in every field of dentistry. It can be a great asset for 3D geomorphometric analysis of dentoalveolar structures and there anomalies.

KEYWORDS: Micro CT, dentistry, 3D tooth morphology, dental material, endodontic.

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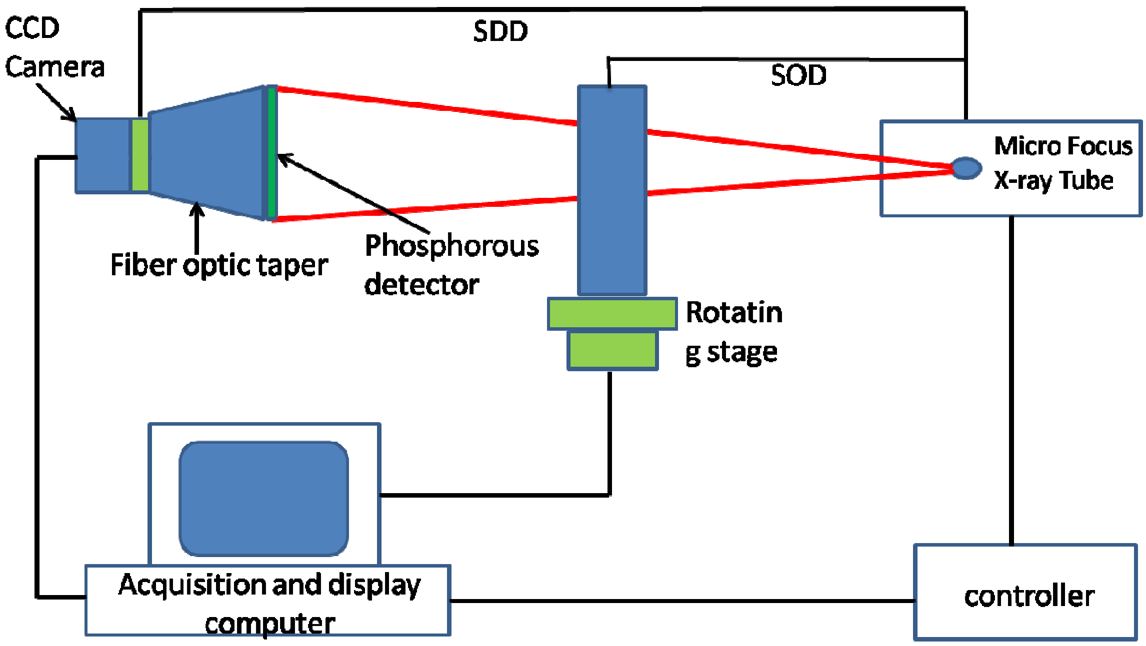
INTRODUCTION

The Micro-CT (µCT) system developed in the early 1980s had far superior spatial resolution, constructing voxel in the array of 5 -50 µm or approximately one million times lesser in volume than conventional computed tomography voxel[1,2]. Initially the µCT scanners were custom-built and not commonly available. Compact commercial systems are currently present and are promptly, attractively becoming the essential components of numerous academic and industrial research laboratories[3]. The initial described systems make use of X-ray picture intensifiers as the detector[2,4]. Even though this comes within reach of limits spatial-resolution except a micro-focus X-ray tube is employed. Use of high resolution solid-state detectors facilitates a momentous boost in spatial resolution, joined with a decrease in the general size of the system[5]. µCT is gold standard technique for enumerating the bone architecture. The main use of µCT to epoch has been the noninvasive exploration of trabecular bone for multiple analyses like investigation of bone growth and repair in the research of craniofacial skeletal development[3]. The µCT can scan various objects like bone, teeth, dental implants, textiles, concrete (dental casts) and precious metals. It discloses the details of external and internal surface of an object, which allows measurement analysis on the 3D object. More than a few µCT systems are present commercially and the majority of these contributes to some illustration features (Figure.1) with the following parts[6]: Controller, Rotating stage, Micro focus X-ray tube, Phosphor detector with fiber optic taper, CCD camera, Acquisition and display computer.

Figure 1
Illustrations of micro CT



The prime aim of the study is to investigate the relation of µCT and benefits to dental research and clinical dentistry.

MATERIALS AND METHODS

The electronic data base was searched, followed the combination of key word (Table 1)

Table 1
Sought electronic databanks sources and Key word words used in data base search

PubMed	
Medpilot	Cochrane Database of Systematic Reviews (CDSR)
Medline	Cochrane Database of Abstracts of Reviews of Effectiveness (DARE)
Scopus database	Excerpta Medical Database (EMBASE)
University Sains Malaysia database	EMBASE Alert
Springer publisher's database	BIOSIS previewsDAHTA database
Web of science	

Micro CT	Micro CT+ Orthodontics
Micro CT+ Dentistry	Micro CT+ Tooth Morphology
Micro CT+Tooth	Micro CT+ Dental material
Micro CT+ Endodontic	Micro CT+ Enamel
Micro CT+ Periodontology	Micro CT+ Cementum
Micro CT+ Dentine	

for the review till date February 2014. The inclusion criteria were defined that the article relates to dentistry was included (Table 2).

Table 2
Article searched via various data base of in relation to Micro CT and further filtering to dentistry

Total number of article found in relation to Micro CT.	7,297
After further screening close to our key words Micro CT teeth	695
Systematic search article found in relation to our key words table 3.	630
Further finishing,eligible to dentistry (table 4)	351

However, an article was included that cover various branch of dentistry using the teeth and dental material as for investigation and understanding through Micro CT. Total number of article found for Micro CT were 7,297. As the search was limited to the Micro CT in relation to teeth, article found were 695, further limited to our key word, 630 articles were deliberated. Articles found in relation to our each key word showed in with the systematic search procedures (Table 3).

Table 3
Systematic research article found in relation to our key words

Systematic search in relation key words	Number of article	Systematic search in relation key words	Number of article
KEY(micro ct)) AND ((microctteeth)) AND (microctperiodontology) AND (LIMIT-TO(SUBJAREA, "DENT")) AND (LIMIT-TO(DOCTYPE, "ar")) AND (LIMIT-TO(SUBJAREA,"DENT"))	114	Titleabskey(**microct+ enamel**) and (limitto(doctype, "ar")) and (limit-to(subjarea, "dent"))	49
(Titleabskey(micro ct)) and (**microctimplant**) and (limitto(doctype, "ar")) and (limitto(subjarea, "dent")) and (limitto(doctype, "ar")) and (limit-to(subjarea,"dent"))	189	Titleabskey(**microct+ dentine**) and (limitto(doctype, "ar")) and (limit-to(subjarea, "dent"))	28
Titleabskey(**microcttooth morphology**) and (limitto(doctype, "ar")) and (limit-to(subj-area, "dent"))	30	Titleabskey(**microct+ cementum**) and (limitto(subjarea, "dent")) and (limit-to(doctype, "ar"))	13
Titleabskey(**microct+ orthodontics**) and (limitto(doctype, "ar")) and (limit-to(subjarea, "dent"))	12	Titleabskey(**microct+ dental material**) and (limitto(doctype, "ar")) and (limit-to(subjarea, "dent"))	130
Titleabskey(**microct+ endodontic**) and (limitto(doctype, "ar")) and (limit-to(subjarea, "dent"))	46	Titleabskey(**microct+ dentistry**) and (limitto(doctype, "ar")) and (limit to(subjarea, "dent"))	19

The numbers of article published per year from 2000 to 2014 were showed in (Table 4).

Table 4
Categorization of our search to the number of articles published in relation to dentistry

Article published in relation to Micro CT per year	Number of article	Article published in relation to Micro CT per year	Number of article
2014	9	2006	13
2013	78	2005	4
2012	55	2004	7
2011	59	2003	6
2010	31	2002	1
2009	40	2001	4
2008	20	2000	3
2007	21		

RESULTS AND DISCUSSION

The resulting sub headings and Table 5 emphasized the µCT uses in various discipline of dentistry in details.

µCT in Endodontic and assessment of the tooth morphology

Information of the internal anatomy of the teeth is of paramount importance. Though, conventional clinical x-rays show the 2D view rather than 3D information of a tooth. Root canal has great variations and complexity in there shapes, usually exist fins, webbing, accessory canals and multiple foramina.

For the successful endodontic treatment it is very important to develop the comprehensive understanding of the three dimensional features of the root canal structure and the allied changes during endodontic canals treatment procedures. Customarily in-vitro method of studying morphological characteristics of the root canal systems are generally damaging and yield the permanent changes to the specimen such as tooth slicing, translucent tooth and dye penetration etc. The conventional CT provides the noninvasive method but was not of high resolution. However with the availability of Micro-CT, root canal structure and shape could be noninvasively and precisely studied[7]. 3D µCT acquisition can explore numerous features of internal and external tooth structure. Many investigators have used µCT to produce both qualitative and quantitative outcome measure for research of dental pulp and root canal morphology. A study was established on 3D investigation of the pulp cavities of the maxillary first premolar indicated that after scans, reconstructed images, the morphological appearances of the pulp cavity, the size ratio at the horn, floor and overall regions of the maxillary first premolars brought a new thought in understanding of tooth structure in detail[8]. Researcher used the µCT as an investigation apparatus to study root canal morphology. By the triangulation methods surface area and volume of each root canal can be calculated. In addition the root canal curvature could be measured by creating an imaginary central axis for each canal[9], by computing the rate of rotating of the tangent vector at a given point of the central axis, and overturning this rate to curvature of the canal by special mathematical modeling software[10]. In endodontic treatment the C-shaped canal, one of the complex anatomic variations of the canal system, the process of root canal debridement and obturation for the mandibular molar produced many challenging problems. Therefore it was essential to explain the thorough morphologic arrangement and anatomic distinction of such canals[11]. However, with the application of the µCT to analyze the C-shaped canals has produced valuable results. Fan et al, (2004) studied the C-shaped canal including the anatomical and radiographic features on the Chinese mandibular second molar, morphology of the pulp chamber floor, 3D root canal analysis, transverse measurement and apical structural changes after the use of rotary instruments in root canal treatment (RCT) and the C-shaped canal system of the mandibular first premolar respectively through µCT images[12-15].Their results were helpful in understanding the root canal system.

Assessment of root canal planning

Prosperous endodontic treatment depends on numerous factors, the most vital step being canal preparation. The successful initial preparation determines the efficacy of all consequent techniques counting the irrigation of canals, the creation of space for the medicament delivery and obturation. Though, root canal treatment may be badly influenced by the variations of the canals and the inability of the operator to visualize the tooth framework from the radiograph[16].Due to the recent advancement in the root canal instruments, the success of the root canal preparation been significantly enhanced. But it is not easy to fully evaluate and compare the different root canal preparation tools performance. However, with the µCT system, 3D assessment of canal preparation comparison can be made easy and convenient[17].

Many researchers have evaluated and compared different root canal instruments with µCT, as the K-files[18], K-flexofiles[19], Profile[13,20,21], ProTapers[19-22], Hero Shaper System GT[18,19,21], Lightspeed[18], K3[20], Endo-Eze AET[23], RaCe[22],Flexmaster[24], SAF (self-adjusting nickel- titanium files)[25]. From the µCT 3D data, it is conceivable to the measure many variations before and after preparation of the root canals, such as surface area and volume, amount of tooth structure removed, canal widths, shaved surfaces, curvature and changes in the form of filling the canals[26]. The majority of instruments enables easy access and depends on the experience of the user. However, some researchers reported the transportation of the instrument (RaCe files, Endo-Eze AET) in root canals[19,22]. Micro CT was used to investigate the removal of root canal filling material with the help of k-files and ProTaper result indicate that no one tested material could be completely removed by either system (hand and rotary files). Gutta-percha was more efficiently removed by hand K-files[27]. Peters and Paque (2011) studied the SAF via µCT for the endodontic preparation of tooth canals in vitro. Results shown that SAF nickel-titanium tools for cutting of canals, remained equivalently and circumferentially shaved the canals with little canal transportation[28]. Peters et al. (2010) studied the dentin removal from the root canal of maxillary anterior teeth by SAF files. µCT scanned was compared to before and after the teeth were shaped. The canals dentin was removed for the six minutes through

SAF files, observed the cutting efficacy. Results from the micro-computed tomography showed that minute canals surface remained un-prepared and un-instrumented[29].

Craniofacial skeletal development and structure

3D images of the craniofacial region has facilitated various measurement of the bone morphology such as thickens, trabecular number, bone volume, total tissue volume and bone density with respect to standard hydroxyapatite in bone[30]. Renders et al. (2007) studied the human mandibular condyle through µCT. They concluded that the cortical bone porosity not different significantly at various cortical regions, but the trabecular bone has significant negative correlation between the degree of mineralization and surface area. Results showed that the amount of the remodeling was larger in trabecular bone than the cortical bone[31]. Von et al. (2003) used the µCT for the assessment of periradicular bone destruction. In their research, the volume, surface area and thickness of the pathological void were investigated by 3D record in comparison with the 2D lesion area by histology slides. The 3D µCT images were highly correlated with the two dimensional sectional measurements of the periapical lesion[32].

Mineral concentrations of teeth

The tooth structure materials densities and mineral concentration distribution can be measured either by direct or indirect methods as chemical analysis of the micro-sample and contact micro-radiography respectively[33]. Though, these procedures were invasive and time wasting in model slice preparation. Due to availability and advancement in the µCT system the mineral concentration of the bone and teeth can be measure with the accuracy better than one percent with the resolution of 5 and 30 micro meters. Micro CT is noninvasive procedure by which we can obtain the constant slice thickness; the disproportion due to the physical cutting of the sample can be escaped. In addition, the µCT slice thickness (due to x-ray source) can be much thinner than the physical cutting machine for the sample processing[34].

The following studies were conducted on the mineral concentration of the dental hard tissues via utilization of µCT. Anderson et al. (1996) studied the mineral content of enamel pearls, enamel and dentin of extracted premolars by comparing the µCT acquisitions. The result showed that the concentration of mineral in enamel pearls decline from the outer enamel surface towards the enamel-dentinal junction but the mineral were same as enamel. In difference, the crystal content for the dentin of the pearl was greatest at the enamel dentinal junction. In conclusion, mineral content of the pearl dentine differs from the permanent coronal dentin of tooth[35]. Fearne et al. (2004) deliberate the idiopathic hypomineralized enamel compared with normal enamel of the first permanent molar revealed that, there was twenty percent drop of the mineral content in hypomineralized enamel[36]. Wong et al. (2004) studied the mineral concentration in the enamel of deciduous teeth. They found that the total density of the observed teeth was 2.81 $g{\cdot}cm^{-3}$ (S.D. = 0.065 $g{\cdot}cm^{-3}$). Slice with the width of 1.5, 2.0 and 2.5mm were taken and analysis showed no differences in the mineral concentration for each tooth. Though, there was 8% distinction between different teeth (2.69– 2.92 $g{\cdot}cm^{-3}$). The mineral concentration of the occlusal surface was more than the cervical area slices. The variation of 1.5% to 8.7% among the inner and outer surface of enamel for the mineral concentration were observed[33]. Dowker et al. (2004) investigated the quantitative analysis of the carious lesion mineral concentration at the micron scale for the sound and carious enamel[37]. Gao (1993), with the help of µCT, observed the demineralization and mineralization of enamel rods that how much mineral was regained after remineralization following the same area of enamel rods[38]. Efeoglu et al. (2005 and 2007) conducted a research on the bleaching agent (Carbamide Peroxide) demineralization effect on the tooth surface. They smeared ten percent (10%) and thirty five percent (35%) tooth whitening agent (Carbamide Peroxide) on tooth. The 10% bleaching agent washed out the 50 µm tooth mineral from the surface enamel. While 35% bleaching agent loss the tooth structure of 250µm the loss of the mineral, observed more the area near to the application zone of enamel. However, there were no significant differences observed in the mineral content of dentin after bleaching[39,40]. Hung et al. (2007) investigated the tooth densities for enamel, white spot lesion of enamel and carious dentin. The densities measured were 2.65 to 2.89 for healthy enamel, 2.23 to 2.58 for the unhealthy white spot and 1.48 to 2.03 for the carious dentin. Each µCT scan with the calibration standard used for five different hydroxyapatite phantoms[41]. Zou et al. (2009) have done the study on the carious and noncarrious dentin[42]. Micro-CT is a precise thoughtful in vitro procedure and is proficient of describing and measuring mineral densities of healthy enamel, dentin and carious enamel, dentin. However the technique has potential for impending caries and quantitative remineralization studies.

Implant and peri-implant bone

Dental implantology is the field of dentistry which deals with the implant fixation in the bone and osseointegration around the implant. The strength of an implant is defined by the mechanical properties of the implant–bone and the surface area in contact around. For the qualitative and quantitative morphometric bone integration around dental implants can be assessed by µCT. The 3D nondestructive images of the trabecular and cortical bone can be obtained and analyzed very fast and accurate through µCT[43]. The use of µCT in implantology and bone deposition around the implant, exploration has been general for the previous decade, many researcher have deliberate the implant[44], bone deposition around the implant[45-48]. The µCT technique analysis of bone formation and bone-implant integration showed some significant results[49-52]. From the acquisitions of the µCT images, one may observe the bone arrangement around the implant. Such as bone volume, bone densities, trabecular width, trabecular gap and the fusions of the implant and bone to each other. Accuracy of µCT was qualitatively evaluated by comparing to standard histo-morphometric data with the corresponding CT slices for the same specimen. The results showed that, in general there was a good correlation between histo-morphometric data and micro tomographic data. One author obtained a 0.855 correlation coefficient[43]. Micro-CT was used for the bone profiling around the implant, the result supported that µCT is non-invasive and can rapidly analyze the bone ratio measurement around the implant. However, Micro CT shows the new perspective for the Osseointegration research[49]. Thus, information acquire from Micro-CT could work as a foundation for advance investigation of root canal composition in investigational endodontology, preclinical training in various endodontic techniques, and a valuable measuring procedure of tooth morphology. 3D root canal analysis and transverse measurement, apical anatomy, changes after the use of rotary instruments in root canal treatment (RCT) and the C-shaped canal system of the mandibular first premolar respectively through µCT images[12-15]. Their results were helpful in understanding the root canal system. Many researchers have evaluated and compared different root canal instruments with µCT like: K-files, K-flexofiles, Protapers, Hero Shaper System GT, Lightspeed, K3, Endo-Eze AET, RaCe, Flexmaster, SAF (self-adjusting nickel- titanium files). µCT was also used in the experimental antimicrobial effect assessment in periodontitis for assessment of the drug's effects on the bone loss[53].Anderson et al. (1996) studied the mineral content of enamel pearls[35]. Fearne et al. (2004) deliberate the idiopathic hypomineralized enamel compared with normal enamel[14]. Wong et al. (2004) studied the mineral concentration in the enamel of deciduous teeth[33].Dowker et al. (2004) investigated the quantitative analysis of the carious lesion mineral concentration at the micron scale for the sound and carious enamel[37]. Gao (1993), with the help of Micro CT, observed the demineralization and mineralization of enamel rods[38].Peariasamy et al. (2001) observed via Micro CT the structure of tooth loss by the effect of pumicing and etching on enamel opacities[54,55]. Zou et al. (2009) have done the study on the carious and non-carious dentin[42].The use of µCT in implantology and bone deposition around the implant, were studied by various investigators[44-52].

Summary of Micro CT used is adjunct diagnostic tool in recent studies conducted were showed in **(**Table 5)

.

Table 5

Micro CT in current dental investigation

Micro CT in Endodontic and assessment of the tooth morphology		
Author	**Subjects used**	**Micro CT study**
(Rodig *et al.*, 2014)[56]	90 mandibular molar with root end fillings	Pre and post-operative Micro CT scans were used to determine volumes of the filling material and residual filling material as well as the amount of dentine removal. Through Hedström files and FlexMaster no significant difference found for both.
(Angerame *et al.*, 2013)[57]	60 single-rooted teeth	Micro CT investigated the quality of fillings in canals, shaped with Reciproc, considering the effects of filling technique and post insertion.
(Balakrishnan *et al.*, 2013)[58]	21 males and 20 females (deciduous incisor teeth)	Using MicroCT tooth crown volumes and dentin volumes were calculated.
(Naseri *et al.*, 2013)[59]	20 extracted maxillary first molars	Micro CT was used In Vitro to measure the internal volume of root canals and to compare the quality of four different root canal obturation techniques.
(Siqueira *et al.*, 2013)[60]	Extracted Mandibular. Molars.	Micro CT was used in comparison according to the preparation technique on disinfecting and shaping performance in 3 instrumentation systems.
(Silva-Filho *et al.*, 2013)[61]	Root canals of 20 maxillary central incisors.	Micro CT was used to observe the filled tooth with gutta-percha and sealer.
(Moeller *et al.*, 2013)[62]	67 roots with oval and ribbon-shaped canals.	.Cross-sectional Micro CT scans to determine voids in relation to the root canal fillings were assessed.
Mineral concentrations of teeth dental material and carries		
(Elian *et al.*, 2014)[63]	12 Orthodontic patient	Micro CT scan assesed the effect of fluoride induced density of remineralization.
(Mei *et al.*, 2014)[64]	2 carious primary upper-central incisors AGE 6-year-old children	The mineral density, elemental contents, surface morphology, and crystal characteristics were assessed by Micro CT, For the primary carious teeth biannually treated with silver diamine fluoride (SDF) and carious teeth without such treatment.
(Zhang *et al.*, 2013)[65]	Carious Molar	The study was to determine the dentinal caries removal effectiveness (CRE) and minimal invasiveness potential (MIP) by Micro CT, in four different removal methods.
(He *et al.*, 2010)[66]	20 enamel slabs	(The hydroxyapatite density for each region of interest was calculated via micro CT.
(Kamegawa *et al.*, 2010)[67]**.**		Direct 3D morphological measurements of silicone rubber impression using micro-focus X-ray CT. Direct three-dimensional impression modeling was successfully demonstrated using microfocus X-ray CT.
Micro CT in Bone study and Implantology:		
(Farina *et al.*, 2013)[68]	28 patients (age range: 34-74	MicroCT scans as well as histomorphometric markersto assess bone volume and tissue mineral content.
(Sawada *et al.*, 2013)[69]	80 milxillas rights and left side from40 Japanese adult skulls.	The purpose of this study was to evaluate the interradicular cortical bone thickness, alveolar process width and root proximity for planning mini-implant placement in the maxillary alveolar process. The samples were imaged and measured using a Micro CT system.

(Matsunaga *et al.*, 2013)[70]	82-year-old man mandibular (cadaver) containing implants	Micro CT was used in assessing mechanics of peri-implant trabecular bone structure.
Micro CT in Orthodontics		
(Kang *et al.*, 2013)[71]	3 types maxillary right central incisor brackets	Micro CT calculated stainless steel brackets, whole and unit, bracket base surface areas.
(Cheng *et al.*, 2010)[72]	Extracted pre molars	Micro CT was used to assist in the identification of the region of Correlative microscopy with micro CT a new dimension to current root resorption investigation techniques.

CONCLUSION

- Due to advancement in the µCT system the mineral concentration of the bone and teeth can be measure with the accuracy better than one percent with the resolution of 5 and 30 micro meters.
- Micro CT is a noninvasive procedure by which we can obtain the constant slice thickness, the disproportion due to the physical cutting of the sample can be escaped. In addition, the µCT slice thickness (due to x-ray source) can be much thinner than the physical cutting machine for the sample processing.
- Micro CT is a precise thoughtful in vitro procedure and is proficient of describing and measuring mineral densities of healthy enamel, dentin and carious enamel, dentin. However the technique has potential for impending caries and quantitative remineralization studies.
- From the Micro CT 3D data, it is conceivable to the measure many variations before and after preparation of the root canals.
- From the acquisitions of the Micro CT images, one may observe the bone arrangement around the implant. Such as bone volume, bone densities, trabecular width, trabecular gap and the fusions of the implant and bone to each other.

ACKNOWLEDGMENT

The authors would like to acknowledge the support from the Universiti Sains Malaysia 304/PPSG/61313104 short-term grant.

CONFLICT OF INTEREST

None declared.

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