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Micro CT settings for caries detection: how to optimize.

Pereira-Oliveira S*; Chaiben CL**; Ando M***; Freitas CF****; Zero D***; Azevedo-Alanis LR**; Ferreira-Zandona AG***.
* MD, PhD, Professor at ABO - Brazilian Dental Association.
**School of Health and Biosciences, Pontifícia Universidade Católicado Paraná (PUCPR), Curitiba, Brazil.
*** Oral Health Institute, Indiana University 415 Lansing Street Indianapolis, IN 46202-2876
**** University of São Paulo Av. Professor Lineu Prestes, 2227 Cidade Universitária– São Paulo – SP

ABSTRACT
Some important items that can influence micro CT image were reviewed in this study. Different settings were optimized for the assessment of early caries lesions. There are several researches on bone using micro CT but not too much on dental hard tissues when assessing mineral loss. Different kinds of micro CT devices and technologies are taking place today, each requiring unique settings, and this consists one of the greatest obstacles for the use of micro CT on dental hard tissues. Achieving the settings for an ideal dental image is therefore a challenge. The purpose of this study was to evaluate different micro CT settings to optimize the assessment of early caries lesions aiming the integrity of the dental specimen thus, making possible to reuse it for further studies. Three teeth with early caries lesions were submitted to different micro CT settings and different reconstruction settings, aiming a better image. The final image was compared visually through different densities and attenuation coefficients. The best setting for teeth tissues was achieved regarding contrast, definition, noise reduction and the larger difference between sound enamel and early lesions attenuation coefficient.
Keywords - Dental Caries, Diagnostic Imaging, Radiographic Image Enhancement, X-Ray Microtomography

I. INTRODUCTION

The ability of micro CT to show bone morphology and microstructure and provide quantitative mineralization assessment of calcified tissue[1] makes it an important tool to assess hard tissues. It provides fast, non-destructive assessment of bone architecture[2], allowing the evaluation of spatial differences of specimens, due to several digital sections that it can provide[3]. It has been important to increase our understanding of some disease progression and the efficacy of therapies to arrest or slow hard tissue loss. The development of 3D images and of analysis software makes it possible to have qualitative measures that can be extracted from computer data[3].

Due to the many characteristics of the micro CT there has been interest in this technique for evaluation of dental hard tissues. Some of the challenges presented are the number of micro CT apparatus available, each operating with different settings. Some micro CT have the same technology as the cone beam scanner[4] and this apparatus is being improved through the years. As it is being used in many different researches, achieving the settings for a feasible image is still a challenge. There have been several studies on bone using microCT[5,6,7,8,9,10] but not very much on dental hard tissues[11,12,13,14,15].

Phantoms are objects with known composition and density, used to calibrate CT settings for bone assessment[12,16]. Phantoms might be used to correct sensors non-uniformities, ensuring sensor optimal working condition[12], reduction of beam hardening and to provide a good approximation of equivalent monochromatic X-ray attenuation for biological specimens[13]. A suitable micro CT reference material to calibrate the scanner for hard tissue measurements might mimic the absorption properties of the material. Increasing mass attenuation coefficients corresponding to an exactly determined concentration of bone mineral have to be attained. Also, the reference material has to be homogenous on a micrometer scale such that the standard deviation of the attenuation coefficient in a given area is reduced to a minimum[16]. But even with phantoms, the methods for calibration and accuracy have not been thoroughly evaluated[20].

Several marketed phantoms are made of hydroxyapatite (HA), most of them, with HA ashes compressed through a cylinder. Other studies use a step wedge of aluminum or other aluminum object (as a small cylinder)[19]. All phantoms have limitations as short-term reproducibility of phantoms measurements, and accuracy of bone tissue mineral densities measurements by correlation to ash density[20]. This affirmative increases the difficulty in determining optimal settings, considering the differences in size, macro and micro architecture, between different hard tissues, even from the same patient.

Most of marketed phantoms are made considering the bone attenuation coefficient, and their use for dental hard tissues is limited as the enamel attenuation coefficient is extremely higher when comparing with bone.As there are no marketed phantoms to be used when assessing enamel, several considerations must be made prior to decide theideal settings for evaluation of dental tissues.

Of the first consideration when imaging a tissue is the production of artifacts. Artifacts are any systematic discrepancy between the CT numbers in the reconstructed image and the true attenuation coefficient of the object[3]. In computed tomography, artifacts can alter the image more often than conventional radiographs due to a great number of detector measurements. When acquiring microCT images two possible artifacts can occur: physics-based artifact and scanner-based artifacts[3].

Physics-based artifacts results from the acquisition data. The most common physics-based artifact is beam hardening that can produce cupping artifacts and streaks and dark bands. To minimize beam hardening filtration, calibration correction and beam hardening correction software can be used.

Filtration is used to make the beam harder before reaching the object. It has the objective to eliminate the lower-energy photons before it passes through the specimen. With a more uniform beam, the X-ray photons will not reach the detectors more intensively, this way, avoiding the described artifacts. If a good filtration is not performed, a multi-energy beam can reach the specimen and by the time it is passing through the object, the lower photons are absorbed, making the beam harder[17].

Calibration Correction is frequently made with phantoms in a range of sizes to allow the detectors to be calibrated with compensation for the beam hardening effects of different tissue of the specimen. However, there are no marketed phantoms designed for dental tissues and natural tissues never exactly match with the phantom’sshape. Enamelis the hardest issue on human body and its thickness must also be considered for further analysis. It is also important to perform flat field optimization to correct the images recorded by the detectors, not only with the phantoms but with each specimen scanned. Flat field optimization helps to calibrate the detectors avoiding beam hardening effects[17].

Beam hardening correction software is based on algorithms applied to the images during reconstruction.

The number of projections used to reconstruct a microCT image is one of the determining factors in image quality. The undersamplingmode decreases the reconstruction time but may create a too large interval between projections.Undersamplingcan produce an effect known as view aliasing due to misregistration by the computer of information relating to sharp edges. This effect can create fine stripes distant from a dense structure[17].

Scanner based artifacts results from imperfections in scanner function. This malfunction may cause ring artifacts, which are one of the most common problems with tomographic images. Ring artifacts result from detectors out of calibration. In high-resolution microCT using flat detectors (FD), imperfect or defect detector elements may cause concentric-ring artifacts due to their continuous over- or underestimation of attenuation values, which often disturb image quality[18]. The noncalibrated detector will read erroneously each angular position, resulting in a circular artifact. Even when these artifacts are visible they will rarely be confused with a lesion. However, to improve image quality, flat field correction can be performed during the acquisition and the reconstruction software has the option of ring artifact reduction that can be used at its maximum performance.

Dental caries remains one of the most prevalent diseases. The use of fluoride has changed its behaviorslowing its progression and bringing challenges to its detection. Early detection of caries lesions is increasingly more significant as management of dental caries at an early stage becomes the norm. New tools for early caries detection are even more investigated, such as microCT, and validation of this methodology also becomes crucial.(3-4)[19,20]

Histology has been used as a validation method on many in vitro dental caries studies.Although capable of detecting minute changes, it requires destruction of the specimen, limiting its use when longitudinal assessment of specimens would be desirable.MicroCT produces images with excellent resolution and is being used in dentistry to evaluate the mineral content of hard tissues due to its accuracy in measuring the linear attenuation coefficient.[21,22]

The purpose of this study is to systematically evaluate different microCT settings on the assessment of early caries lesions.

II. Material and Methods

Three teeth were collected in the premises of Indiana University School of Dentistry (IUSD, Indianapolis IN, USA) (IRB #0306-64 exempt). Teeth were kept in a solution of Thymol 0,1% between the scans. They were cleaned with a Robinson brush and water and, the coronal surface was evaluated using the ICDAS criteria[22,23,24,25] by one trained examiner. As the goal is to optimize the settings for assessment of early lesions the3teeth selected (1 molar and 2 premolars) had ICDAS codes 0-2 on proximal surfaces:

Specimen 1: ICDAS code 0 on both surfaces;

Specimen 2: ICDAS code 0 on one proximal surfaces and 1 on the other;Specimen 3: ICDAS code 2 on both surfaces.

The initial settings were selected from the study of Huang et al. (2007). In order to optimize the settings, changes in power (kV and µA), filtration, degree of rotation and rotation steps, were made, aiming to optimize the images for the specimen with ICDAS code 1.

MicroCT imaging of the whole teeth were done using the microCTSkyscan 1172 from the Indiana University (IUPUI) (Skyscan 1172, Brussels-Belgium). To avoid the dehydration of the specimens, the teeth were wrapped in a thin layer of parafilm 'M' (Laboratory Film, American CAN Company, Greenwich, CT 06830).

Fifteen different scan settings and sixteen different reconstructions were performed on the three selected teeth. As the ICDAS 1 code (specimen 2) was impossible to identify on the first scans, two different scan settings were performed with ICDAS 2 (specimen 3) aiming the best lesion visualization. After achieving the best setting for specimen 3, the same settings were performed with specimen 2, which allowed identification of the lesion on specimen 2.

As we were working with high energy parameters, to achieve the best image quality for enamel the Al + Cu filter of the Sky scan 1172 equipment was chosen. This specific filter delivered better diagnostic images and no beam hardening artifacts were detected with this filtration. Reconstruction was performed with 100% of beam hardening correction.

To calibrate the scans, the Scan co Phantom was used and also a phantom constructed in house. The Scan co phantom is a marketed unit, made of hydroxyapatite (HA) of known densities: 0.000 (resin only), 0.099, 0.199, 0.399, and 0.800 g x cm^{-3} of HA. With the higher density areas of the phantoms used, the corrections were made and the calibration was performed.

Undersampling was not used to reconstruct the images because it might cause view aliasing artifacts, as described before.

It was chosen maximum ring artifact reduction on the reconstruction software of the Skyscan apparatus.

As identification of early enamel lesions (code 1) is likely to be the most challenging, after the initial scans, it was decided to determine the optimal settings, both for acquisition and for reconstruction on one of the selected teeth with ICDAS code 1 (Specimen 2). Three different acquisition settings varying the rotation of the scan and beam power, and four different reconstructions for each acquisition, varying the post alignment, beam hardening correction and threshold of contrast were performed, aiming to achieve optimal image for lesions ICDAS code 1.The selected settings were the ones with greater differences between the attenuation coefficient on sound enamel and on the lesion as detected by the Data Viewer software (v. 1.3.2 http://skyscan.be/products/downloads.htm). Visually the selected settings were considered to be the easiest to recognize the initial lesion as well. The settings considered optimal were, resolution of 2K, kV 80, µA 124, pixel size of 6 µm, rotation step of 0.2, frame average of 4 and 360 degrees of rotation. The best reconstruction was ring artifact reduction of 20, beam hardening of 100%, with a threshold of 0,010 to 0,070. All images were stored in a tiff (16 bit) file. Tables 1 and 2 present all last tested settings, performed on specimen 2 (ICDAS code 1):

TABLE 1 – ACQUISITION SETTINGS:

Acquisition	Resolution	Filter	kv	µA	Rotation Step	Frame average	Rotation
1.1a	2K	Al+Cu	80	124	0.2	4	360
1.1b	2K	Al+Cu	80	124	0.2	4	180
1.1 c	2K	Al+Cu	100	100	0.2	4	360

TABLE 2 – RECONSTRUCTIONS SETTINGS:

Reconstructions	Ring Artifact Reduction	Beam Hardening	Thresholds	Storage
Rec	20	88%	0 x 0.095	16 Tiff
Rec2	20	100%	0 x 0.095	16 Tiff
Rec3	20	100%	0 x 0.110	16 Tiff
Rec4	20	100%	0.010 x 0.070	16 Tiff

III. Discussion:

Some hard tissue studies use micro CT as gold standard for some measurements[27,28]. This is still not well defined and accepted for dental hard tissues. Although micro CT is increasing its role on the analysis of enamel and dentin, it must have an optimal performance, especially if the goals of observation are slight differences in mineralization, as initial caries lesions.

To achieve the best settings for dental hard tissues, microCT should be performed withbeam hardening correction. To minimize the effects of beam hardening, several steps can be taken during the acquisition and also in reconstruction as: selection of the appropriate scan field of view; the use of an appropriate filter; use of beam hardening correction during reconstruction[17].In our study this was initially minimized with the Al + Cu filtration. This filter brought better images regarding the quantity of energy used. The selection of the appropriate field of view was acquired with the 2K image, that produced at the end an image of 6 µm of resolution. Also in the reconstruction it was applied beam hardening correction from the reconstruction software indicated for Skyscan 1172.

Calibration Correction is frequently made with phantoms in a range of sizes to allow the detectors to be calibrated with compensation for the beam hardening effects of different tissue of the specimen[17]. In our study we used the Scanco phantom, but the enamel is considerably harder than bone and this phantom is more indicated to bone specimens calibration. So we also tested natural teeth before performing microCT best settings.

It is also important to perform flat field optimization to correct the images recorded by the detectors, not only with the phantoms but with each specimen scanned. Flat field optimization helps to calibrate the detectors avoiding beam hardening effects[17].

We tried to use higher energies (100kV and 100mA) aiming that small differences in mineralization could be better visualized, but this did not happen. Images with 84kV and 124mA were better to analyze, showing good radiopaque differences on densities for enamel and dentin.

The characteristic that brought a lot of difference on the image interpretation was the 360^0 of rotation during acquisition. Definition was much better than with 180^0 of rotation. The acquisition in 180^0 should give an image projected as a mirror, but the best quality of the 360^0 images proved that information is being missed when the acquisition is limited to 180^0.

Although maximum ring artifact reduction was chosen during the reconstruction, in some scans this artifact was still observed.

The threshold chosen was the one that delivered the highest differences between the lesion visualized and the sound enamel. It can be noticed that small lesions analyzed were the ICDAS code 1, that it can be observed clinically when dried for 5 seconds. Although it is a lesion that the examiner should be trained to recognize it, we might remember that it is also clinically visible. It is still not known if microCT has the ability to recognize such small lesions, not clinically visible.

It is also important to note that these settings may not be fully generalized across all microCT scanners and specimens[29]. Each scanner has its own physical characteristics and a proper software to perform its reconstruction.

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