Interpreting CBCT Images for implant assessment:

Part 1 - Pitfalls in image interpretation

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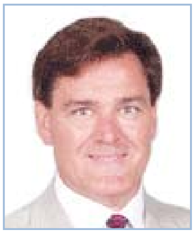

Computer reformatted cross-sectional and multi-planar displays from Cone Beam Computed Tomography (CBCT) data provide accurate two- and three-dimensional interactive images to visualize anatomy at potential implant fixture sites important for the assessment and planning of prosthetic treatment and to facilitate surgical guidance. The increasing reliance of prosthetic design and implant fixture placement on imaging allows for increasing complexity of treatment options and demands a high level of confidence and accuracy. The clinician must now assume a more dynamic and participatory role in this process. This is the first article of a two part series that will outline the imaging limitations of CBCT. The second part will provide strategies for success for interpretation when using this modality in implant site assessment.

Introduction

Maxillofacial Cone Beam Computed Tomography (CBCT) acquisition has lead to a paradigm shift in the role imaging assumes in dental implant therapy.[1,2] No other technical innovation within the last decade has supported the concept of prosthetically driven implant placement by assisting in the assessment, supporting the planning and, in some cases, ultimately guiding surgical implant placement. CBCT has, in effect, brought together surgical and prosthetic considerations necessary to satisfy aesthetic, restorative and prosthetic criteria, while respecting the surrounding anatomical structures. The increasing reliance of prosthetic design and implant fixture placement on imaging demands a high level of confidence and accuracy. The clinician therefore assumes a more dynamic and participatory role in this process. The purpose of this article is to underline the limitations of CBCT imaging with respect to the assessment and planning for dental implant placement.

Evolutions in cross-sectional imaging

Successful dental implant rehabilitation requires accurate preoperative surgical planning. Imaging diagnostics are most often directed at the pre-operative assessment of proposed implant fixture sites and include an analysis of conventional two-dimensional radiographs, most commonly periapical, bitewing and panoramic radiography. A major limitation of these modalities is the inherent magnification, distortion and the lack of cross-sectional information providing an appreciation of the

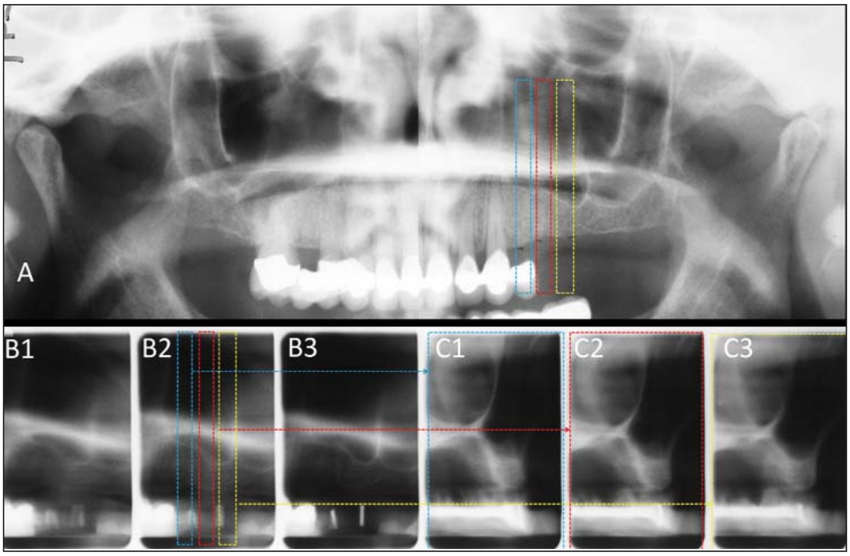

Figure 1. Tomography imaging provides imaging of implant sites in the third dimension. The panoramic image (A) provides an overview of the proposed implant fixture site in the maxillary left posterior edentulous region. 2mm contiguous regional para-sagittal tomographic sections (B1-B3) provide constant magnification of the height of the bone whereas cross-sectional images (C1-C3) provide contiguous constant magnified images depicting alveolar bone width. Cross-sectional images are cross-correlated to specific sites on the para-sagittal images (Blue, red and yellow sections).

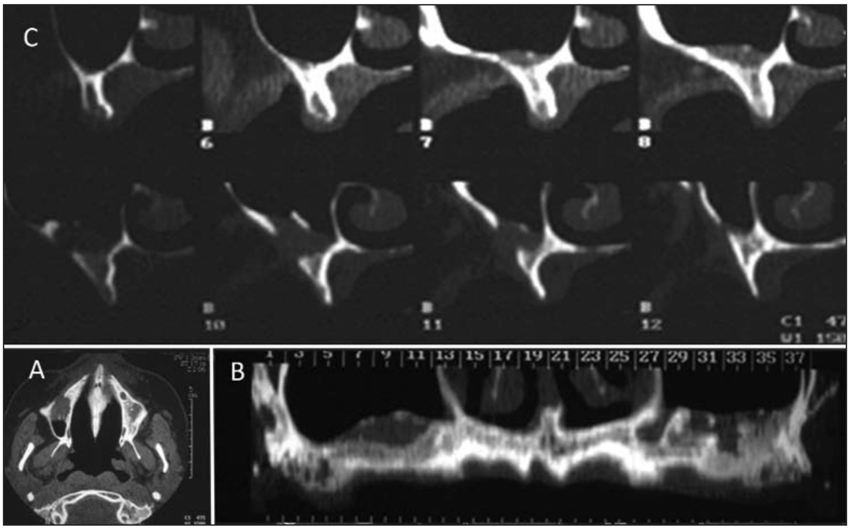

Figure 2. Standard computerized tomography display comprising an axial (A), oblique curved multi-planar reformed image similar to the panoramic (B) and contiguous cross-sectional images 1-2mm thick at 1-2mm intervals perpendicular to the panoramic image (C).

third dimension. Such imaging is desirable to determine the bucco-lingual width and topology and inclination of available alveolar bone and is recommended by both the AAOMR[3] and the European Association for Osseointegration.[4] Tomography, derived either by linear or spiral motion, was the first technology that provided additional two dimensional information in the Z-plane. This modality produces multiple contiguous images of 2-4mm in thickness in both the para-sagittal and cross-sectional planes (Figure 1). Interpretation of these images was challenging as it is necessary to relate multiple co-relational images (Figure 1). The introduction of conventional computerized tomography (CT) in the late 1980's provided multi-slice 1-2mm contiguous sectional images in the axial plane which, for the first time, could be collated electronically to provide a composite volumetric image set. Initially workstation-based applications and later personal computer based software became available that could re-section the volumetric dataset in relation to the dental arches. The functionality of this software introduced the standard visualization protocol for the pre-operative assessment of the maxilla and the mandible which forms the basis of current image display formats (Figure 2). While facilitating an integrated approach to visualization, CT images were most often static, provided on analog film and thus not interactive.

Since the beginning of this millennium, cone beam computerized technology has been available for specific applications in maxillofacial imaging.[5] CBCT is based on the acquisition of a series of single projection basis images produced during the synchronous rotation of a cone, or more recently a pyramidal shaped x-ray beam and a reciprocating area detector around a patient's head (Figure 3).[6] Software inte-

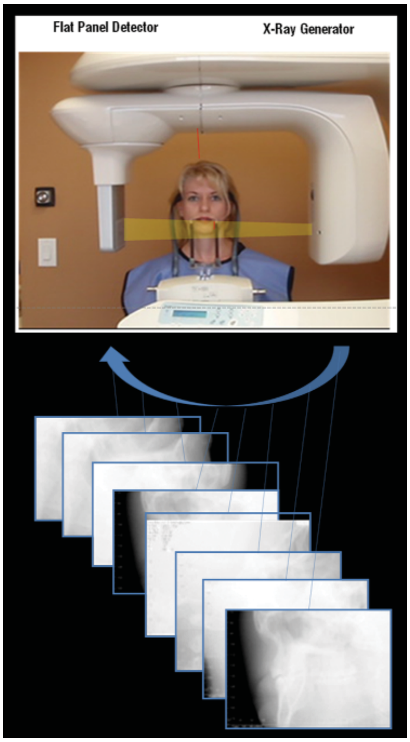

Figure 3. Acquisition of CBCT images consists of a pyramidal or cone shaped x-ray beam directed through a volume of interest in the patient is recorded by a digital receptor. As the apparatus rotates multiple basis images are acquired, forming the dataset.

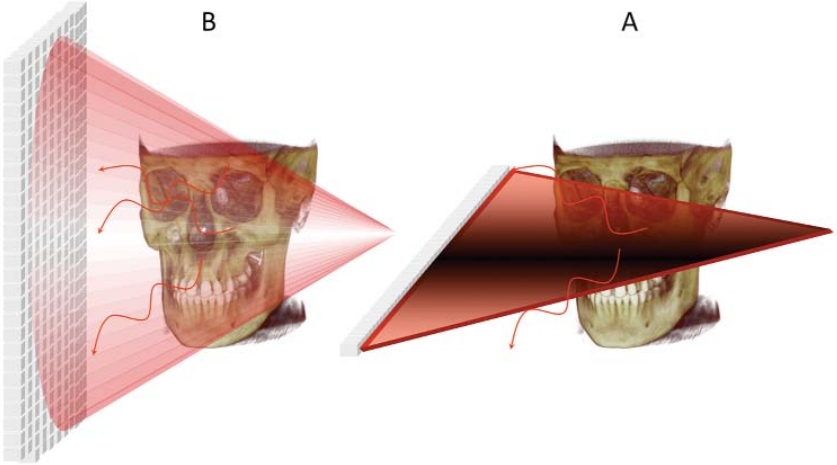

Figure 4. Fan beam acquisition used in conventional CT imaging (A) produces scatter radiation within the irradiated tissues at divergent angles from the primary beam. This errant radiation is not recorded in the fan beam arrangement, however in cone beam imaging, all scatter radiation is recorded throughout the scan (B).

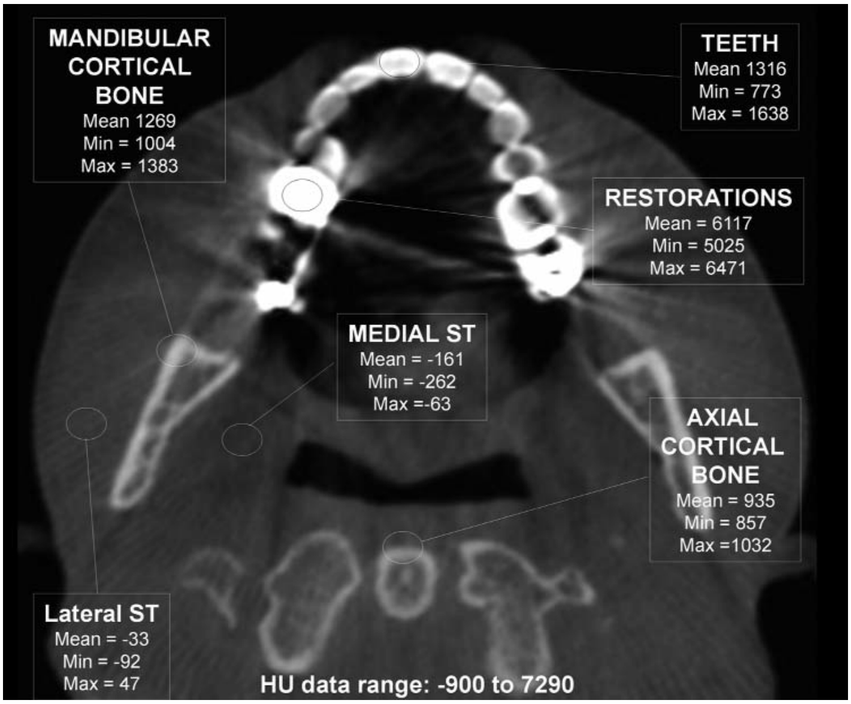

Figure 5. Mean, minimum (min) and maximum (max) grayscale values measured for specific tissues in an axial CBCT scan. Note the large range in grayscale measurements in relatively homogeneous tissues. These values are not calibrated to water as in conventional CT measurements and should not be referred to as Hounsfield Units.

gration of projection data generates a 3D volumetric data set, which can be used to provide familiar secondary reconstruction images in 3 orthogonal planes (axial, sagittal and coronal). In contrast to tomography and multi-slice CT imaging, the increasing availability of CBCT units presents clinicians with a dynamic, responsive and interactive process with three unique characteristics. First, clinicians have a pivotal role in imaging - either in acquiring the image (by prescribing or directly performing CBCT scans) or in the manipulation of software to provide task specific display of images for the assessment of bone characteristics and anatomic structures. Secondly, CBCT imaging has facilitated the use of either proprietary or third party software via DICOM export that enables greater sophistication in analysis and facilitates planning by providing interactive methods enabling implant selection and virtual prosthetic positioning. Finally CBCT imaging provides data that can be used to direct the placement of implant fixtures either directly by the use of image guided navigation or indirectly via the construction of restrictive surgical guides.

Limitations of CBCT in implant site assessment

Current CBCT technology has limitations related to reduced exposure settings used, the "cone beam" projection geometry and detector sensitivity that produce images which lack the fidelity of conventional CT images. CBCT images are affected by artifacts, noise and poor soft tissue contrast and partial volume averaging - all of which may reduce the diagnostic yield of reformatted images for implant site assessment. As implant planning increasingly relies on 3D visualization of the bony support, awareness of artifacts, particularly in the 3D reconstruction process, is becoming increasingly important.

Noise and contrast

The results of current studies indicate that while Hounsfield Units from conventional CT and bone density measurements derived from CBCT software show some degree of correlation, measurements are unreliable and are generally higher than those obtained from CT. The reason for this stems from the method of image acquisition (Figure 4). In addition, reduced detector sensitivity, X-ray beam inhomogeneity and reconstruction technique all interact to produce a lower overall signal-to-noise ratio reducing contrast throughout the entire image. This means that the range of grayscale values in CBCT images can vary greatly for specific tissues within the image, even those structures which have high attenuation such as cortical bone (Figure 5) and invalidates grey scale values. This limitation is of particular importance in relying on the use of grey scale values in the assessment of bony quality. Some software applications capable of virtual implant placement offer analysis modules capable of diagrammatically depicting grey scale values

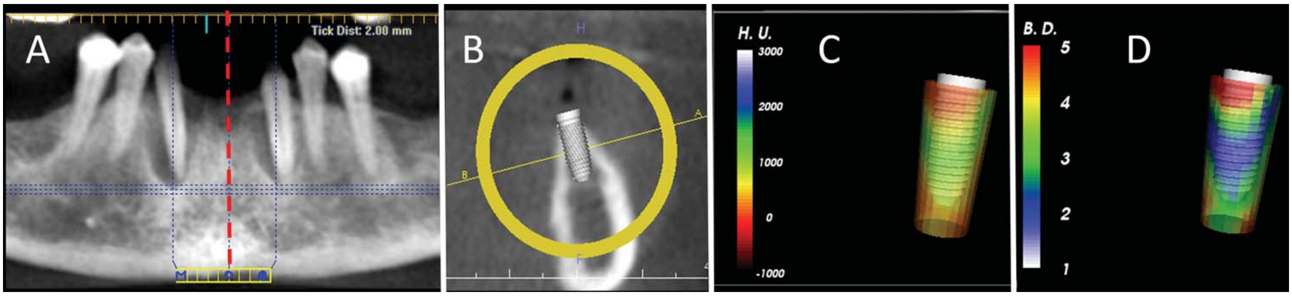

Figure 6. Reformatted panoramic image (A) showing proposed implant fixture placement site (red line) and cross-sectional image with virtual implant placement (B). Virtual 3D rendering of implant density profile analyses. The sampled volume (in this case, 2mm) is colour coded according to absolute grayscale measurement values (C) or according to Misch's bone density classifications (D) (Images developed using InVivo5, Anatomage, San Jose, CA).

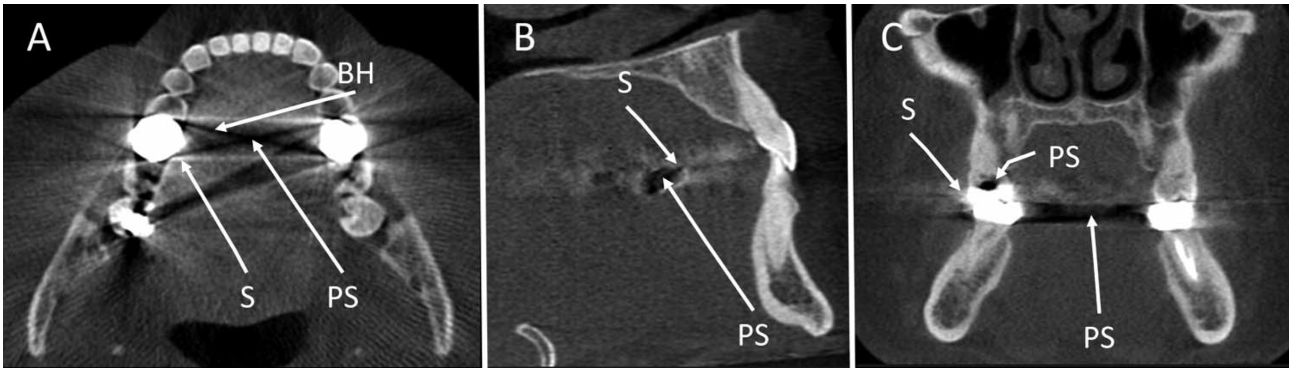

Figure 7. Axial (A), sagittal (B) and coronal (C) CBCT orthogonal images demonstrating the appearance of beam hardening (BH), scatter radiation (S) and photon starvation (PS).

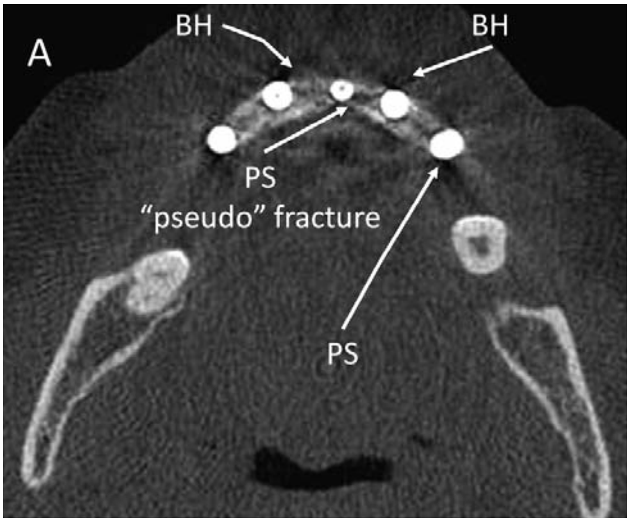

Figure 8. The axial image demonstrates marked regional beam hardening (BH) and photon starvation (PS) at the level of the mandibular alveolar crest from titanium endosseous implants. PS between adjacent implants can result in an appearance similar to a cortical alveolar defect or "pseudo" fracture.

using colour or histogram plots (Figure 6); unfortunately the validity of these tools have yet to be confirmed. Promising developments have been directed at using the Misch CT scale from D1-D5 incorporating the Hounsfield scale (Figure 6) and at the development of phantoms to calibrate grey scale readings.

Artifacts

An artifact is any distortion or error in the image that is unrelated to the subject being studied. Artifacts can be problematic for cross-sectional image interpretation. Two X-ray beam artifacts affect image quality (Figure 7). The first is beam hardening. This appears as a series of streaks or dark bands and is due to the increasing absorption of incident radiation by radiodense objects such as crowns and amalgam restorations and the loss of information for reconstruction. In severe cases when insufficient photons reach the detector, a complete void exists due to "photon starvation". The second effect is the scatter radiation which appears as white bands at edges and "star" artifacts and results from the absorption and re-emission of radiation. While these effects are predominantly seen in axial images at the level of the occlusal plane, they may be prominent within the alveolar bone adjacent to teeth restored with root canal filling materials and in particular, are associated with titanium implants. In particular, photon starvation effects can present as apparent alveolar "pseudo" fractures on axial images (Figure 8). These artifacts are of particular concern when assessing the status of the alveolar bone adjacent to or between titanium implants (Figure 9).

Patient motion is another artifact that is due to misregistration of data during the scan. It may appear as unsharpness or double contours in the reconstructed image (Figure 10). The effects of minor patient motion can be minimized by use of a head restraint, using as short as scan time as possible or the application of specific image enhancements (Figure 11).

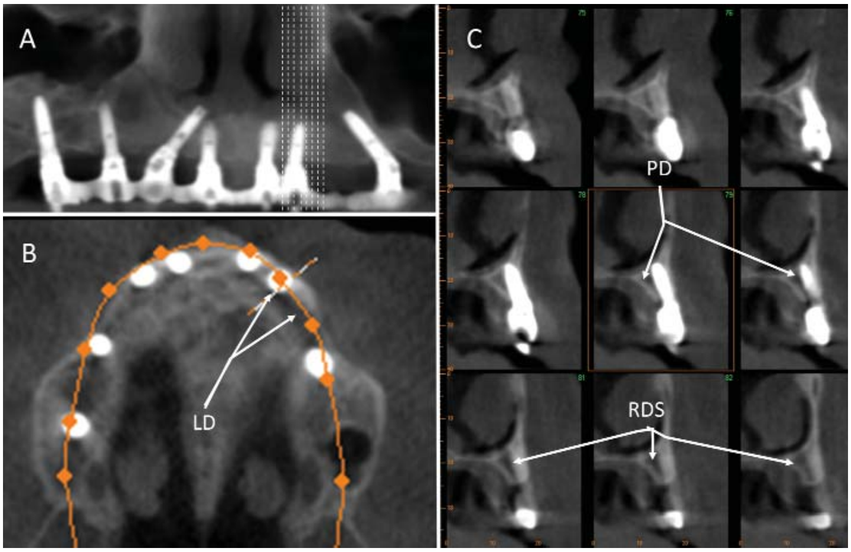

Figure 9. In this case, the patient presents for assessment of the maxillary left anterior with suspected ailing or failing implant fixture(s). The reformatted medium thickness "panoramic" image (A) with location of cross-sectional images (white hashed lines) and 0.4mm axial image with the panoramic spline (orange)(B) show multiple implant fixtures. The axial image demonstrates an area of relative low density (LD) of the alveolar bone palatal and immediately posterior to the fixture placed at the left maxillary canine site. On cross-sectional images (C), the photon starvation (PS) presents as a peri-implant defect (PD) on the palatal aspect of the adjacent anterior implant and a reduced radiodensity "shadow" (RDS) on the palatal aspect of the alveolar crest - all features are artifacts.

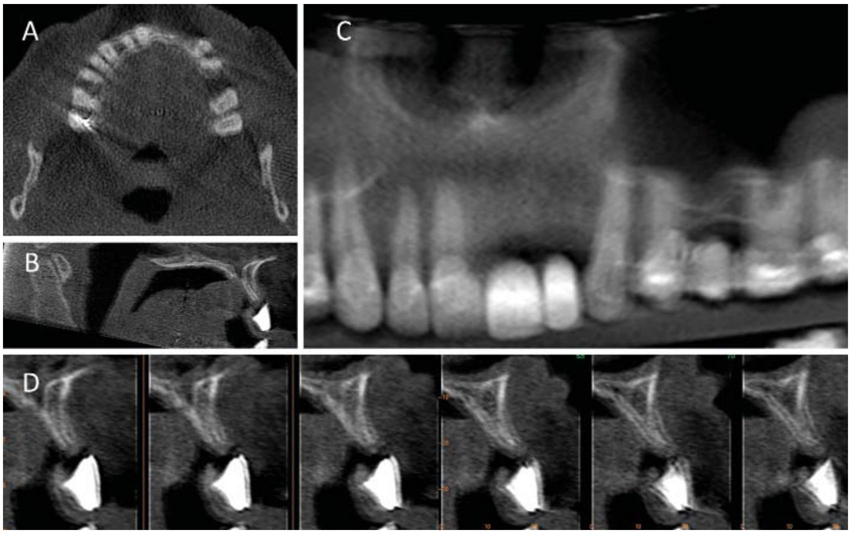

Figure 10. Example of presentation of motion artifact in axial (A), sagittal (B), reformatted "panoramic" (C) and 1mm cross-sectional images demonstrating double contour of cortical borders.

Partial Volume Averaging

This is a feature of both conventional fan and CBCT imaging. It occurs when the selected voxel resolution of the scan is greater than the spatial or contrast resolution of the object to be imaged. In this case, the pixel is not representative of the tissue or boundary however becomes a weighted average of the different CT values. The wide range of grey scales present within particular tissues in CBCT in areas where there is thin bone and contributes to this phenomena such that the intensity value of a particular structure is overwhelmed by the grey scale values of the structures either side of this and is effectively "washed out". This is important in recognizing two current limitations of CBCT imaging for implant therapy. The first is that 3D shaded surface models from CBCT are more prone to surface defects

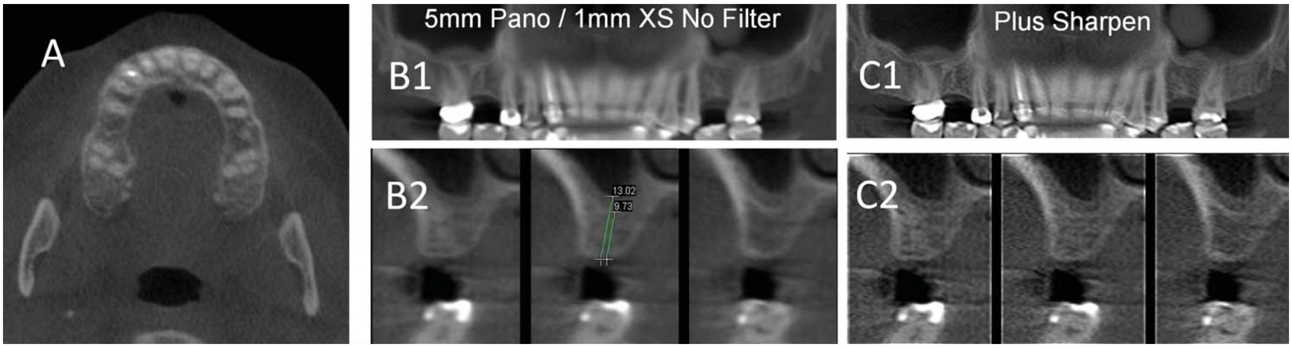

Figure 11. Demonstration of the effect of sharpen enhancement on clarity of images in patient with motion. Axial image (A) demonstrates unsharpness of image due to motion. Reformatted "panoramic" (B1) and associated cross-sectional images (B2) without enhancement provides images where measurements are difficult to precisely measure, particularly surfaces which are poorly corticated and associated with mucosa (e.g. floor of the maxillary sinus). Similar images B2 and C2) show greater clarity and definition, suitable for accurate measurements, when sharpen algorithms are applied.

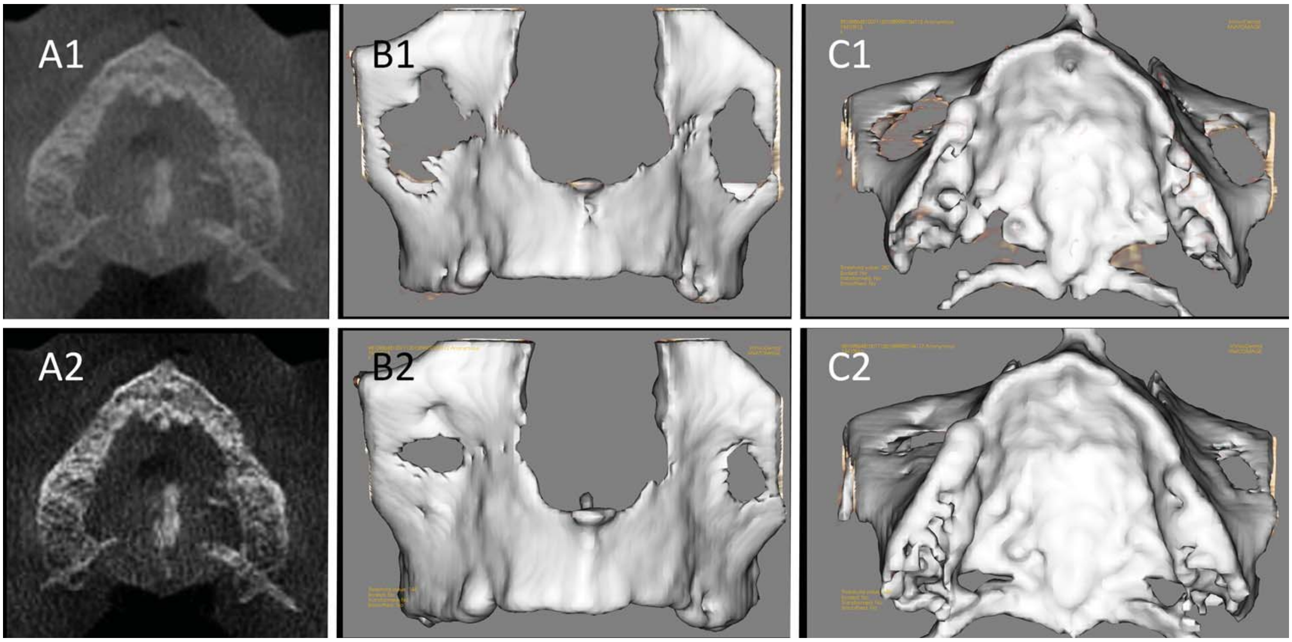

Figure 12. Demonstration of effects of DICOM data enhancement on surface shaded volumetric rendering. Original DICOM axial data (A1) provides shaded surface volumetric renderings with apparent cortical defects as viewed from the frontal (B1) and inferior oblique (C1) aspects. Enhanced DICOM data with edge enhancement and image equalization (A2) provides more representative shaded surface volumetric renderings (B2 - frontal) and (C2 - inferior oblique).

than conventional CT derived models, particularly in the maxillary posterior regions where the bone is the thinnest (Figure 12). As shaded surface models are required for the fabrication of restrictive surgical guides, it is possible that this inherent limitation in contrast resolution could affect the accuracy and reliability of implant placement using guided implant procedures. Numerous techniques are available to minimize these effects including the use of higher exposures (increasing either kVp or mAs), the export of contrast enhanced and filtered DICOM image files and, implementation of algebraic reconstruction techniques - the latter of which is currently only implemented in one CBCT system. The second aspect is that thin cortical bone adjacent titanium implants suffers not only from physics-based effects of beam hardening and streaking artifacts, but when superimposed with partial volume averaging, thin buccal cortical integrity is difficult to distinguish. These features limit the reliability of cross-sectional imaging for the assessment or monitoring of minor peri-fixture osseous change.

About the authors

Professor William Scarfe graduated from the University Of Adelaide School of Dentistry (1982) and was awarded Fellowship in the Royal Australasian College of Dental Surgeons (1986). He completed a certificate in Dental Diagnostic Science and a Masters from the Graduate School at the University of Texas Health Science Center at San Antonio (1992). He is Professor, Radiology and Imaging Science, Dept of Surgical/Hospital Dentistry, The University of Louisville School of Dentistry. Dr Scarfe is Secretary to the Board of the International Association of Dento-Maxillo-Facial Radiology, and Treasurer, American Academy of Oral and Maxillofacial Radiology. He is Scientific Editor of the Radiology Section of Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics (OOOOE).

Professor Allan Farman is President-elect of the American Academy of Oral and Maxillofacial Radiology. He is the voting Representative for the American Dental Association to the International DICOM (Digital Imaging and Communications in Medicine) Standards Committee and Chairs DICOM WG 22 (Dentistry). He is a Past-President of the International Association of DentoMaxilloFacial Radiology, founder and Chair of the international Congress and Exposition on Computed Maxillofacial Imaging and Scientific Editor for the American Academy of Oral and Maxillofacial Radiology. He is author or co-author of 20 books and more than 300 scientific articles.

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