**INTRODUCTION**

In all facets of dentistry, maxillofacial imaging should be considered an interface between patient history, clinical examination, definitive diagnosis and treatment. Imaging necessitates keen observation and interpretation for the betterment of the individual patient. With the rapid emergence of, and better access to, maxillofacial Cone Beam Computed Tomography (CBCT) and the increasing availability of diagnostic virtual simulation software, the clinical relevance of diagnostic information provided by using these modalities should be examined. Technology incorporating ionizing radiation should never be a matter of "routine", as each imaging procedure must undergo a risk-benefit analysis such that "Radiological examination(s) shall be carried out only if it is likely that the information obtained will be useful for the management of the patient."

**SUMMARY**

Maxillofacial Cone Beam Computed Tomography (CBCT) provides dentists with a cost efficient volumetric imaging modality and, together with Digital Imaging and Communications in Medicine (DICOM) compliant software, has significantly contributed to pre-surgical assessment of alveolar bone prior to dental implant surgery. Accurate two- and three-dimensional interactive images provide visualization of existing osseous anatomy important in developing and planning prosthetic treatment options. An increasing reliance of prosthetic design and implant fixture placement on imaging also facilitates consideration of increasingly more complex treatment options. Even more important than greater adoption of this innovative technology during the last 10 years has been a clinical practice paradigm shift from "bone-based" to "prosthetically driven" implant dentistry. More diverse treatment options, including bone augmentation procedures and surgical guidance, requiring higher degrees of accuracy and clinical confidence, are now converging consensus towards the use of CBCT as an essential diagnostic prerequisite for dental implant surgery.

**THE GOALS OF PRESURGICAL DENTAL IMPLANT IMAGING**

Successful dental implant rehabilitation requires accurate preoperative surgical planning. The use of specific imaging to assist planning is based on professional judgment – the individual clinician’s need for information supplemental to that already obtained from clinical examination to formulate a diagnosis. This need will depend on the skill, competence, knowledge and experience of the clinician. Specific considerations should include clinical complexity, regional anatomic considerations, potential risk of complications and esthetic considerations in the location of implants. The SAC Classification System (Dawson & Chen 2009) provides an excellent clinically based approach to the categorization of both surgical and restorative difficulty in implant dentistry. Within this framework, the use of imaging modalities for presurgical dental implant planning should be adequate to provide information supportive of the following five imaging goals.
1. Establish the morphologic characteristics of the residual alveolar ridge

The morphology of the residual alveolar ridge (RAR) includes considerations of bone volume and quality. Vertical bone height, horizontal width and edentulous saddle length determine the amount of bone volume available for implant fixture placement. This information is necessary to correlate the available bone dimensions with the selection of the number and physical dimensions of the implant. Moderate deficiencies in horizontal and vertical bone may be corrected by augmentation procedures at the time of the osteotomy and implant placement, whereas severe deficiencies will require prior surgical procedures, such as ridge augmentation (Fig. 1). Similarly, excessive or irregular vertical or horizontal bone may require pre-prosthetic or simultaneous alveoplasty (Fig. 2). The average discrepancy between actual and radiographic measurements for intraoral and panoramic imaging is approximately 14% (range, 8–24%) and 23.5% (range, 5–39%), respectively. Jacobs & van Steenberghe 1998, Klinger et al. 1989, Sonick et al. 1994). For CBCT imaging, despite the limited number and methodological inconsistencies of ex vivo studies, CBCT measurement error (range, 0.09% to 2.4%) provides clinically acceptable sub-millimeter levels of accuracy for linear measurement and appears to be the most accurate and reliable tool for implant planning with regard to implant planning (Kobayashi et al. 2004; Suomalainen et al. 2008; Loubele et al. 2008; Vyve-Goutel et al. 2008). CBCT is at least as accurate and, in some circumstances, may be more accurate than multi-slice (MSCT) (Table 1).

Similarly, where implants are planned for the anterior segment in edentulous mandibles, the inter-foramina distance measured on panoramic images is approximately 10% less than the inter-foramina distance measured on cross-sectional CBCT images (Lagravère et al. 2006, 2008; Mah et al. 2008). CBCT = MSCT

2. Determine the orientation of the residual alveolar ridge

The orientation and resorptive topography of the alveolar-basal bone complex should be assessed to determine deviations of the RAR that compromise alignment of the implant fixture with respect to the prosthetic plan, particularly in the mandible (Fig. 4) and anterior maxilla (Fig. 5). Several ridge defect classification systems have been proposed. Seibert (1983) classified ridge deficiencies into three broad categories of bone volume tissue loss; buccolingual, apico-coronal, and a combination of both. Cawood and Howell (1988) described the cross-section morphologic progression of edentulous jaw atrophy. Lekholm and Zarb’s classification (1985) is still important in patients with systemic conditions that influence bone density and can be considered a risk factor for osseointegration, such as osteoporosis (Toskali et al. 2009). While density gray levels measured in a specific dental CBCT unit are not equivalent to HU, several techniques and devices are currently being investigated to derive HU from gray levels in dental cone CBCT (Lagravère et al. 2006, 2008; Mah et al. 2010) (Fig. 3).

### Table 1: Summary of measurement error (% mm) reported in selected articles comparing accuracy of CBCT and MSCT measurements on cross-sectional images.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Modality Mean or Range</th>
<th>Statistical Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kobayashi et al.</td>
<td>2004</td>
<td>1.4% (0.1–5.2%)</td>
<td>CBCT = MSCT</td>
</tr>
<tr>
<td>Suomalainen et al.</td>
<td>2008</td>
<td>2.3–4.7%</td>
<td>CBCT = MSCT</td>
</tr>
<tr>
<td>Loubele et al.*</td>
<td>2008</td>
<td>2.2%</td>
<td>CBCT = MSCT</td>
</tr>
<tr>
<td>Vyve-Goutel et al.*</td>
<td>2008</td>
<td>2.4 ± 1.5% [H] 1 ± 10% [B]</td>
<td>---</td>
</tr>
<tr>
<td>Fatemitabar and Nikgoo*</td>
<td>2010</td>
<td>0.36 ± 0.39 mm [B] 0.37 ± 0.33 mm [P] 0.54 ± 0.45 mm [H]</td>
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<td>---</td>
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</tr>
<tr>
<td>MSCT</td>
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</tr>
<tr>
<td>CBCT</td>
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*CBCT: Cone beam computed tomography; MSCT: Multi-slice computed tomography; **converted from absolute measurement error values (mm); ***absolute measurement error (mm); NA: not applicable; H: alveolar bone height; B: alveolar bone width; P: palatal alveolar height

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Fig. 1: Cured multi-planar reformatted (MPR) “simulated panoramic” image (A) of a totally edentulous maxilla with radiopaque markers identifying potential implant fixture sites demonstrating mild (incipient to moderate) resorption of the residual alveolar ridge. Sequential 1-mm-thick cross-sectional images at the left incisor (B) and left canine (C) demonstrate additional severe horizontal deficiency requiring augmentation prior to implant placement.
subdivided into 5 (small), 1 (medium), and L (large) subcategories. They also described treatment options based on this HVC classification. Tinti and Parma-Benfenati (2003) introduced a clinical classification of bone defects. They categorized the “envelope of bone” into excludes the parameter of bone, wounds, fenestrations, deficiencies, horizontal ridge deficiencies, and vertical ridge deficiencies. The SAC system of bone volume assessment (Chen et al. 2009) provides clinicians with a simple classification of ridge deficiency incorporating both horizontal and vertical bone deficiencies. Bone volume is classified as: 1) Sufficient, 2) Deficient horizontally but allowing simultaneous augmentation, 3) Deficient horizontally requiring hard tissue augmentation and the appropriate selection of implant type and size.

3. Identify local anatomic or pathologic conditions within the RAR limiting implant placement

The clinician should be extremely familiar with internal anatomic features of both jaws that can compromise and limit implant fixture placement or risk involvement of adjacent structures. Often these features are not easily identified or localized by clinical examination or conventional radiographic imaging. In the maxilla, the regions that require additional assessment include the incisor region (e.g. nasopalatine fossa and canal, nasal fossa) and the premolar region (e.g. mental foramen and canal) and molar region (e.g. submandibular gland fossa, inferior alveolar or (mandibular) canal containing the neurovascular bundle (Fig. 7) all present with anatomic variations that potentially restrict implant placement. Anatomic anomalies may also be present (Fig. 8). Numerous local pathologies may prevent, restrict or modify implant placement such as retained root tips, sinus disease (Fig. 9) or adjacent inflammatory processes.

4. Identify regional secondary conditions that may influence implant placement

Imaging enables detection of regional anatomic conditions or pathology of other structural elements of the maxillofacial region which may have important ramifications in the overall timing and sequencing of treatment phases. Imaging of the temporomandibular joint in particular, especially in patients who provide a positive clinical history (e.g. temporomandibular dysfunction) or present with changes in vertical dimension, changing occlusal relationships or unusual extraction patterns (e.g. unilateral sequential tooth loss after multiple root canal fillings) can sometimes direct the clinician to potential etiologies for maxillo-mandibular occlusal instability (Fig. 10). Such early identification can alert the clinician to treatment decisions regarding implant loading protocols and post-prosthetic occlusal protection. Other imaging findings distant to the osteotomy site may not directly influence any aspect of implant therapy, however do have important implications for the overall health of the patient (Fig. 11).

5. Correlate imaging findings to the prosthetic plan

Treatment planning for a potential implant site involves interplay of considerations of both surgical and prosthetic requirements. The previous four goals have been directed towards the premise that the “bone sets the tone” indeed numerous authors have proposed surgically desirable parameters for implant placement in regard to residual alveolar ridge anatomy for the mandible (Greenstein & Cavallaro 2007; DeBalso et al. 1994; Greenstein & Tarnow 2006; Misch et al. 2005; Misch et al. 2006; Dawson and Chen 2009). These include a minimum of: 1) 1 mm of alveolar bone on both buccal and lingual sides of the implant, 2) 2 mm of bone separating the implant from any adjacent anatomic structures such as the mandibular canal and surrounding tooth roots, 3) 3 mm

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**Fig. 5:** Curved MPR “simulated panoramic” image (A) of a partially dentate maxilla with an anterior edentulous diastema. The left maxillary sinus is obliterated by soft tissue relative hyper-density. Sequential contiguous 1-mm cross-sectional images (C) confirm the horizontal deficiency and reduction in available alveolar width due to the large nasopalatine canal.

**Fig. 6:** Curved MPR “simulated panoramic” image (A) of a partially dentate maxilla missing a single right maxillary central incisor. Initial clinical and radiographic assessment indicates adequate bone volume. 0.4-mm axial reference image (B) demonstrates a large nasopalatine fossa and canal resulting in severe horizontal deficiency compromising available bone volume. Sequential contiguous 1-mm cross-sectional images (C) confirm the horizontal deficiency and large nasopalatine canal as well as the irregular topography of the healing alveolar crest.

**Fig. 7:** Left posterior mandibular cross-sections (molar region) (A) show marked horizontal deficiency (large nasopalatine fossa and canal) and reduced vertical atrophy of the residual alveolar ridge in the anterior mandibular edentulous boundary region. Sequential contiguous 1-mm cross-sectional images (B) confirm marked horizontal deficiency and unusual/irregular shape with buccal cortical concavity extending throughout the alveolus necessitating consideration of prior bone augmentation.

**Fig. 8:** 21-year old male presents with congenital oligodontia involving multiple mandibular anterior teeth. The left axial (D) and coronal (E) images show marked horizontal and vertical bone atrophy at the site involved. The left axial (D) and coronal (E) images show marked horizontal and vertical bone atrophy at the site involved. The left axial (D) and coronal (E) images show marked horizontal and vertical bone atrophy at the site involved. The left axial (D) and coronal (E) images show marked horizontal and vertical bone atrophy at the site involved.

**Fig. 9:** Curved MPR “simulated panoramic” image (A) of a partially dentate maxilla missing multiple teeth in the right posterior free-end edentulous space and left-bound edentulous area. Note that the entire right maxillary sinus is obliterated by soft tissue relative hyper-density. Sequential contiguous 1-mm cross-sectional images (B) demonstrate that this soft tissue material fills the right maxillary sinus completely and surrounds the right maxillary sinus. While this is most likely acute sinusitis, CBCT imaging is non-specific and other imaging protocols and post-prosthetic occlusal instability. The right axial (D) and coronal (E) images show marked horizontal and vertical bone atrophy at the site involved. The left axial (D) and coronal (E) images show marked horizontal and vertical bone atrophy at the site involved. The left axial (D) and coronal (E) images show marked horizontal and vertical bone atrophy at the site involved. The left axial (D) and coronal (E) images show marked horizontal and vertical bone atrophy at the site involved.

**Fig. 10:** 20mm MPR “simulated panoramic” image (A) of partially dentate maxillary arch with severely atrophic residual alveolar ridge in the anterior edentulous regions bilaterally taken for assessment of the maxillary sinuses prior to sinus lift and bone augmentation. On the floor of the right maxillary sinus in the region of the first molar there is a dome-shaped soft tissue relative hyper-density consistent with a small antral mucocele/pseudocyst. Note however the moderate right and severe left dento-alveolar atrophy and reducible degenerative joint disease. The stability of the final implant base prosthesis is augmented, in part, on controlling and stabilizing the occlusion. However in patients with active/serious temporomandibular joint disease the condition should be treated by an oto-rhinolaryngologist.
of bone separating adjacent implants and 4) 5 mm of alveolar bone mesial to the mental foramen to avoid the anterior loop of the mental nerve (2 mm mesial to the furthest radiographic extent of the mental nerve). Prosthetic evaluation involves a thorough clinical examination and analysis of diagnostic casts with final placement resulting from integrating prosthetic requirements with surgical reality. Perhaps the most important and, as yet, underutilized goal of imaging is to enable translation of prosthetic planning to the surgical site. Imaging radiographic templates with radiopaque markers provides an excellent method of facilitating this by assisting the clinician in visualizing prosthetic aspects of the proposed implant site to the prosthetic ideal. Numerous authors have reviewed the efficacy and utility of various imaging technologies in providing diagnostic and assessment purposes. The use of ionizing radiation for implant assessment purposes should always be subject to an individual risk/benefit analysis such that each imaging examination be subject to an individual risk/benefit analysis. Recommendations based on the literature, without regard for anatomic structures. A variety of DICOM-compliant software is now available, both with and without CAD/CAM options, allowing virtual implant placement. Imaging strategies can provide visualization of complex implant “simulations.”

**IMAGING STRATEGIES**

Table 2: Subjective comparison of the relative efficacy of available imaging technologies in providing diagnostic information for implant therapy.

<table>
<thead>
<tr>
<th>Imaging Goal</th>
<th>Specific Objective</th>
<th>Introral</th>
<th>Extroral</th>
<th>Cross-sectional</th>
<th>CBCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periapical Panoramic Cephalometric Tomography CBCT</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Morphology of the RAR</td>
<td>Vertical bone height</td>
<td>+++</td>
<td>++</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td></td>
<td>Horizontal bone height</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Edentulous saddle width</td>
<td>++</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Orientation of the RAR</td>
<td>Bone quality</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Cross-sectional</td>
<td>-</td>
<td>-</td>
<td>e (anterior only)</td>
<td>-</td>
</tr>
<tr>
<td>Identify possible bone volume</td>
<td>Acacia</td>
<td>+++</td>
<td>++</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pathology</td>
<td>+++</td>
<td>++</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Identify second ary conditions</td>
<td>TMJ, CA calcifications</td>
<td>+++</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Correlate imaging findings to the prosthetic plan</td>
<td>Radiographic template</td>
<td>++</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Virtual implant/prosthesis</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Image-guided surgery</td>
<td>-</td>
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</tbody>
</table>

Wilson 1996; Meitner & Tallents, 2004) and others have described in the literature (Almog et al. 2001; Burns et al. 1998; Higginbottom & Wilson 1996; Meitner & Talents, 2004) and include outline-type templates, spherical “BB” type markers, wire over-lay type markers, (C) Cylindrical markers. Wilson 1996; Meitner & Tallents, 2004) and others have described in the literature (Almog et al. 2001; Burns et al. 1998; Higginbottom & Wilson 1996; Meitner & Talents, 2004) and include outline-type templates, spherical “BB” type markers, wire over-lay type markers, (C) Cylindrical markers.
Table 4: Summary of selected studies comparing the efficacy of imaging on implant planning decisions.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>PE or FE</th>
<th>No.</th>
<th>Modality</th>
<th>Control</th>
<th>Decision (% where modality made difference)</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schropp et al.</td>
<td>2001</td>
<td>S</td>
<td>46</td>
<td>T pa + P</td>
<td>54%</td>
<td>28%</td>
<td>70%</td>
</tr>
<tr>
<td>Frei et al.</td>
<td>2004</td>
<td>LE, PM</td>
<td>77</td>
<td>T P</td>
<td>0.0%</td>
<td>3%</td>
<td>9%</td>
</tr>
<tr>
<td>Vazquez et al.</td>
<td>2008</td>
<td>LE, PM</td>
<td>2,584</td>
<td>P C</td>
<td>---</td>
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</tbody>
</table>

There is an enormous spectrum of opinion as to the necessity of cross-sectional, and now more specifically CBCT, imaging prior to implant surgery. The value of specific diagnostic imaging modalities can be assessed as to how observations from radiographic images change our diagnosis and subsequent treatment. Studies directly comparing the efficacy of cross-sectional imaging on implant planning decisions are equivocal (Jacobs et al. 1999; Schropp et al. 2001; Diniz et al. 2008; Frei et al. 2004; Vazquez et al. 2008; Schropp et al. 2011) (Table 3) and none provide information specifically on CBCT. Two organizations have provided guidance statements on the use of imaging for implant dentistry, both of which are almost 10 years old. The American Academy of Oral and Maxillofacial Radiology advocate cross-sectional imaging as the method of choice for most implant patients (Tynjälä & Broeks 2000). The European Association for Osseointegration suggests that additional cross-section imaging is indicated only to supplement information obtained from clinical examination and appropriate conventional tomography (Harris et al. 2004). Such indications include the posterior mandible and maxilla when there is less than a 2-mm “safety zone” between anatomic structures and the proposed implant dimensions, to further assess ambiguous anatomic topography, the single tooth replacement implant and cases where imaging is necessary in the anterior, to determine the necessity of CBCT imaging based on pre-operative contribution to diagnostic and surgical value comprising three levels:

1. Level I (LI) - CBCT is an essential and necessary imaging modality providing valuable diagnostic information in most clinical situations. All SAC complex cases should be designated Level I.
2. Level II (LI) - CBCT is a highly desirable imaging modality providing valuable diagnostic information in some clinical situations. All SAC advanced cases should be designated Level II.
3. Level III (LI) - CBCT is an appropriate imaging modality that may contribute to diagnostic information in some clinical situations. All SAC straightforward cases should be designated Level III.

Applying this hierarchy to site specific surgical procedures, the following general and site specific criteria in defining clinical scenarios require a high level of confidence and accuracy in implant placement to fulfill optimal prosthetic design criteria – a demand that is answered most efficiently by CBCT; the imaging modality of choice in the practice of 21st century dental implant surgery.

CONCLUSION

Maxillofacial CBCT acquisition has led to a paradigm shift in the role imaging assumes in dental implant therapy. No other technical innovation within the last decade has supported the concept of prosthodontically driven implant placement than CBCT by assisting in the assessment, supporting the planning and increasingly directed surgical guided implant placement. CBCT has, in effect, brought together the surgical and prosthetic considerations necessary to satisfy esthetic, restorative, and prosthetic criteria, while respecting the surrounding anatomical structures. The clinician must therefore now assume a more dynamic and participatory role in this process. The appropriateness of CBCT imaging however should be based on a risk/benefit analysis. Application of the SAC system for implant case classification provides the clinician with a practical means to determine the necessity of CBCT imaging.
REFERENCES


