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Medical Imaging in Oral Implantology: Current Status and Practical Recommendations.

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ABSTRACT

Dental Implantology is an exciting and rapidly advancing restorative field, and as with any surgical technique involving manipulation of bone, medical imaging is an invaluable tool for the implantologist. Imaging of the implant sites is required in the diagnostic, surgical, prosthetic and follow-up stages of treatment. However, the side-effects of ionizing radiation associated with medical imaging coupled with an increasing risk of exposure to natural radiation weigh heavily against the choice of imaging modality that is to be used. An informed choice regarding the correct imaging modality at each stage of treatment is therefore of prime importance in the successful treatment of the patient. This review examines the various medical and dental imaging modalities available to the implantologist and attempts to provide a guide for the selection of imaging tool at various stages of treatment to ensure that all required structures are clearly visualized while exposing the patient to the minimal effective dose of radiation throughout the treatment and also inthe follow-up stages.

INTRODUCTION

The rehabilitation of the Stomatognathic system of patients involves a complex dynamic of diagnosis, treatment and follow-up. In all three realms of the rehabilitation process, the clinician must rely on observable systemic and local clinical findings as well as support from Radiology and laboratory data.

Implantology is a rapidly advancingtreatment option in occlusal rehabilitation of partially dentate and edentulous patients. The implantologist has to therefore to be up-to-date with advancingdiagnostic and treatment procedures and technology for successful treatment and for the benefits of the patient. Failure to do so would put the practitioner at a greater risk of failed treatment outcomes and malpractice liabilities [1, 2].

The Need for Imaging in Oral Implantology

One can safely state that “Imaging is required at every stage of treatment” in the field of Oral Implantology. Literature has very clearly shown us that failure to employ the correct modality of diagnostic imaging i.e. one that does not reveal critical structures or bony conditions [3,4,5,6] or utilize the same in the follow-up phase [7] can have disastrous consequences for the patient. (Figure 1)

Frederikson [8] in the early days of oral implantology outlined the ideal requirements for an imaging modality that could be used in diagnosis and treatment planning of a case for dental implantology. His guidelines still hold good today and serve as a valuable tool in the selection of an imaging modality. However an analysis of his guidelines will bring the implantologist to the conclusion that “No single treatment modality is ideal for all phases of site selection and fixture evaluation – A Combination of Techniques is necessary”

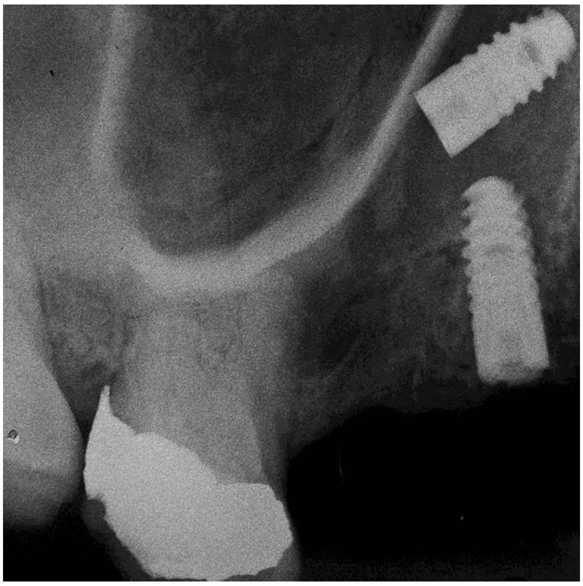

Figure 1: Accidental Migration of the Implant into the maxillary sinus, during an indirect sinus lift possibly due to failure to estimate bone quality and quantity at the floor of the sinus.

Imaging Modalities at the Disposal of the Implantologist

Currently the imaging modalities that are available for use may be summarized as:

1. 2-Dimentional Imaging (Plain Film and Digital)

    a. Intraoral Radiography
    b. Cephalometric Radiography (Cranial Teleradiography)
    c. Panoramic Radiography
    d. Conventional Film Tomography

2. 3-Dimensional Imaging

    a. Computed Tomography (CT)

        i. Conventional CT
        ii. Cone Beam CT (CBCT)
        iii. Magnetic Resonance Imaging (MRI)

The Intra-Oral Radiograph or the periapical radiograph (IOPA) is a readily available, quick, chair-side modality. Its value in the surgical and post-operative follow-up stages has been well documented. In the hands of a skilled clinician, the Standardized periapical radiograph [9] using a long cone paralleling technique [10] is capable of delivering accurate images in terms of longitudinal measurement of bone height and implant lengths. However the critical landmarks are such as the mandibular canal and maxillary sinus are generally not visible in the small field of the radiograph.

Table 1 – Overview of Effective Radiation Doses in Implant Diagnostic Imaging

Imaging Modality	Effective Dose(μSv)
Intra-Oral Periapical (IOPA)[43]	5-35
Panoramic [33]	6.2 μSv ; 5 to 14 μSv (Digital) 10 μSv; 16 to 21 μSv (film)
Transverse Slices [33]	3 to 12 μSv
3D Computed Tomography (Low Dose) [33]	150 to 610 μSv
3D Cone Beam Volumetric Imaging (CBVT/CBCT)[33]	20 to 599 μSv

Orthopantomography (OPG)or Panoramic Radiographs (PA)provides a wide, overall view of the dentition or residual ridges of both the maxilla and mandible with a small radiation dose (Table 1). Beason et al [11] reported that 95% of dentists took panoramic radiographs as a pre-surgical assessment radiograph. Sakakura et al [12] reported that 80% of dentists took Panoramic Radiographs either as a single examination or in combination with peri-apical radiographs.

The image is however, subject to magnification errors in the vertical plane,distortion in the horizontal plane.True image data may not represent the actual dimensions at a particular location. The data may also be inconsistent between different positions in the arch.

The panoramic radiograph is particularly of use in treatment planning and post-surgical evaluation of cases where multiple implants have been placed, however it must be remembered that panoramic radiographs possess limitations for assessing implant sites when used alone [13]. Immediate post-surgical evaluation and follow-up for zygomatic implants can be accomplished only with the panoramic radiograph.

Table 2 – Public Exposure to Natural Radiation [49]

Source of exposure		Annual Effective Dose (mSv)	
		Average	Typical Range
Cosmic Radiation	Direct Ionizing and Photon Component	0.28	
	Neutron Component	0.10	
	Cosmogenic Radionucelotides	0.01	
	Total Cosmic and Cosmogenic	0.39	0.3-1.01
External Terrestrial Radiation	Outdoors	0.07	
	Indoors	0.41	
	Total External Terrestrial Radiation	0.48	0.3-1.0i
Inhalation	Uranium and Thorium Series	0.006	
	Radon (222Rn)	1.15	
	Thoron (220Rn)	0.1	
	Total Inhalation Exposure	1.26	0.2-10ii
Ingestion	40K	0.17	
	Uranium and Thorium Series	0.12	
	Total Ingestion Exposure	0.29	0.2-1.0iii
Total		204	1.0-13

Cephalometric Radiography or Cranial Teleradiography gives information on the mandibular symphysis for central edentulous areas, including angulations and vestibule-lingual thickness. Preoperative frontal and profile cranial radiography images are useful prior to bone grafting allowing precise evaluation of the donor site, including cranial vault thickness and bone volume at the symphysis [14]. In addition it also provides information on the inclination of the maxillary and mandibular alveolar processes, and on their vertical and facial-lingual dimensions in the mid-sagittal plane.

Conventional Tomography is useful for planning single or multiple implants in a single quadrant [15]. In the image obtained, structures of interest are relatively sharp allowing for a linear measurement of width and height to critical structures and have been shown to be acceptable for dental implant planning [16]. Image detail of surrounding structures may not be sharp due to slight patient movement or superimposition of adjacent structures. The use of a metal marker is a necessity for panoramic machine to accurately position the slices. However some authors argue that in the present day, conventional tomography is not of diagnostic value in dental implantology [17].

Computed Tomography (CT) [18,19]. Despite its limitations – high radiation dose, appropriate dental software not always being available, high cost and beam artifacts and scatter from metal restorations, CT has established itself as the gold standard in dental implant imaging [10].

"Computerized tomography provides a more accurate visualization of anatomic structures without superimposition and allows for a continuous view of surface topography while preserving the soft tissue detail" [20]. (Figure 2)

Computed Tomography has been found to be of immense use in the pre-surgical (diagnostic) stage [21, 22] especially where bone augmentation procedures and the need for the visualization of critical structures such as the maxillary sinus [23], and inferior alveolar nerve is critical. CT has also proven itself in the follow-up of grafted sites [24, 25]. The implantologist must remember that CT is of no value in the assessment of the integration of the implant as a radiolucent band is usually present around the implant on CT Images [10].

Figure 2 – CT-Scan data providing continuous viewing of diagnostic data in a case with deficient bone and pnematized sinus.

Data from the DICOM image generated from the machine allows for digital planning [26] and digital mock surgeries to be performed aiding in selection of implant fixtures and generation of CAD-CAM surgical stents.

Cone Bean Computed Tomography(CBCT):CBCT allows the creation in “real time” of images not only in the axial plane but also 2-dimensional (2D) images in the coronal, saggital and even oblique or curved image planes - a process referred to as multiplanar reformation (MPR). In addition, CBCT data are amenable to reformation in a volume, rather than a slice, providing 3-dimensional (3D) information while simultaneously reducing the radiation dose on the patient [27,28,29,30,31,32]. The superior radiographic information for high contrast structures in pre-surgical planning using CBCT over Computed Tomography and Orthopantomography has been well documented [33, 34,35].CBCT has also been advocated for sinus graft assessment and Bone Block Graft assessment [36]. However, obtaining bone density readings from the CBCT data is difficult as the technique does not use Hounsfields.

Dental Cone Beam CT Units are now available that are the sizes of present day Panoramic Radiograph machines, generally allowing the unit to have both – sensors for panoramic radiography and the Cone Beam CT in one machine. The patient isallowed to sit or stand based on the construction of the machine and manufacturer.

Magnetic Resonance Imaging (MRI) measures spin-down rates of photons in the body within a magnetic field and provides enhanced imaging contrast between soft tissue structures. The lack of ionizing radiation is a promising advantage of MRI.

MRI, when compared with CT, has been reported to be reliable in respect to bone measurements for dental implant planning [37]. However, studies by other authors havestated that MRI has been shown to have only a potential for pre-implant imaging due to the limited bone information generated [38, 39] and large costs to the patient.

Hubálková H et al [40, 41] and Costa AL et al [42] have reported that orthodontic wires, dental implants and metallic restorations do produce artefacts on the MRI image that may even render the resultant image useless, but do not pose a threat to a patient undergoing an MRI examination.

The Dental Implant Radiology Prescription – Factors to be considered

Radiological diagnosis for treatment planning as well as effective evaluation during surgical and prosthetic phases,and future continuous evaluation of the treated patient is the prime requirement in the treatment of patients with osseointegrated supported prosthesis.

A prescription for radiographs in the treatment should be made keeping in mind the guidelines put forward by Frederikson [8], the requirement at each stage and the effective dose of radiation that the patient would be exposed to at the end of the treatment process and follow-up appointments.

The recommended annual dose limits of radiation for the general public has been cited as 5mSv for infrequent exposure and 1mSv for non-continuous exposure. A 50mSv limit has been cited for the lens of the eye, skins and extremities[43]. Normal radiographic diagnostic procedures, even the periapical radiograph result in a comparatively large dose of radiation to the patient. Table 1 [43, 44] outlines the effective radiation doses for various imaging modalities in implant dentistry.

A significant point that one should remember is that the rehabilitation with osseointegrated supported prosthesis is a procedure which could very well take months to complete. In this time frame, the patient would possibly be exposed to a number of other natural and man-made sources of radiation [45,46,47,48] the largest of which would be from medical imaging for a non-dental condition which may arise during the course of the implant treatment. It therefore becomes imperative that these external sources be factored into the radiology prescription at every point of implant treatment. Table 2 lists the public exposure to Natural Radiation [49].

When prescribing a radiograph during any of the stages of implant treatment the implantologist must take into account the cumulative amount of radiation that the patient is has been exposed to, the current exposure and what possible exposure he/she may undergo in the near future.

Based on the above considerations, the authorspropose the following guide for the prescription of radiographs over the course of implant treatment. An overview of the guide is given in Tables 3 and 4. Figure 3 provides a schematic work-flow and sequence of the various imaging modalities in the sequence of rehabilitating a patient with animplant-supported-prosthesis.

For diagnostic scenarios which do not involve bone augmentation or sinus lift procedures the implant surgeon would find that the use of panoramic radiographs with diagnostic markers would be more than adequate (Fig 4a). In cases where immediate extraction and placement of implants are indicated, a periapical radiograph with a radiographic marker alongside the tooth indicated for extraction would provide data for calculation of the length and width of the required implant fixture, (Fig 4b) which again could be verified when the tooth is atraumatically removed. Cases involving single implant restorations in the presence of a pneumatized sinus can be successfully diagnosed with a periapical radiograph with a radiographic marker properly positioned. (Fig 4c). Conventional Transverse Slicing or conventional tomography will aid in the determination of the buccal-lingual dimension of bone available in the absence of a CT-Scan. (Fig 4d)

The ideal radiographic marker would be a 5mm (diameter) metal sphere. Other radiographic markers that may be used are Gutta Percha points and barium coated or specially designed radio-opaque teeth [50].

For cases which involve multiple implant fixtures such as a fixed full arch bridge or a removable overdenture, diagnosis is accomplished with a panoramic radiograph containing radiographic markers at the proposed implant sites.Only if difficulty is encountered in locating critical structures such as the mandibular canal or if the sinus is found to be pneumatized is a CBCT or a Dental CT indicated. The CBCT or the Dental CT should be the diagnostic aid of choice when the case requires bone augmentation – both at the donor and recipient sites for the determination of bone volume and density of the donor graft and the bone at the recipient site.

When using radiographic markers are used Computed Tomography, a ball of 2mm diameter has been recommended be used to reduce the amount of scattering that may occur in the image generated. The use of gutta percha markers and radio-opaque teeth also provide the radiologist and technician information about the proposed implant site [48].

Following placement of the graft, a panoramic radiograph with CT scan can be used to confirm the quality of bone grafts in terms of density and homogeneity, perfect integration of the graft with existing bone, and the absence of resorption of the graft or other bone fragments [14, 51].

The consolidation of graft is best visualized by microscopic examination of a specimen of the bone taken prior to delayed placement of the fixture or at the time of loading when a fixture was placed simultaneously the time of graft placement.

No matter how many fixtures are being placed, radiographs for in-surgical navigation must be made using chair side periapical radiographs (preferably digital) for no more than practical reasons – the patient cannot be repeatedly moved to a panoramic machine! Clinical use of paralleling pins would aid in reducing the number of in-surgical navigation radiographs.

Table 3: Radiographic Guide for the Implantologist for cases that Do Not Involve Hard Tissue Grafting

Prosthetic Design	Region	Diagnostic Tool (With Radiographic Markers)	Surgical: In Operative	Surgical: Immediate Post – Surgical	Prosthetic Phase	Follow-up	Estimated Minumum Effective Dose at the End of the 1st Follow-Up Appointment
Single Tooth Replacements	Anterior Maxilla / Mandible	Panoramic (OPG)	IOPA[i]	IOPA[i]	IOPA[i]	IOPA	26.5µSv
	Posterior Maxilla	Panoramic (OPG) orCone Beam CT orConventional Dental CT	IOPA[iv]	Panoramic (OPG)	IOPA	1. Panoramic (OPG)[iii] 2. IOPA[iii]	27.4-50µSv (Using Dental Cone-Beam CT)
	Posterior Mandible		IOPA[iv]	Panoramic (OPG)			
Multiple Fixed / Removable Prosthesis	Anterior Maxilla / Mandible	Panoramic (OPG) orCone Beam CT orConventional Dental CT	IOPA[iv]	Panoramic (OPG)	IOPA	1. Panoramic (OPG) IOPA	27.4-50µSv (Using Dental Cone-Beam CT)
	Posterior Maxilla	Panoramic (OPG) orCone Beam CT orConventional Dental CT	IOPA[iv]	Panoramic (OPG)	IOPA	1. Panoramic (OPG) 2. IOPA	27.4-50µSv (Using Dental Cone-Beam CT)

Table 4: Radiographic Guide for the Implantologist for cases that Involve Hard Tissue Grafting

Prosthetic Design	Region	Diagnostic Tool (With Radiographic Markers)	Surgical: In Operative	Surgical: Immediate Post – Surgical	Surgical: Evaluation of Graft	Prosthetic Phase	Follow-up	Estimated Minumum Effective Dose at the End of the 1st Follow-Up Appointment
Single Tooth Replacements	Anterior Maxilla / Mandible	Cone Beam CT orConventional Dental CT	IOPA	IOPA	Panoramic (OPG)	IOPA	IOPA	56.2 µSv (Using Dental Cone-Beam CT)
	Posterior Maxilla	Panoramic (OPG) orCone Beam CT orConventional Dental CT	IOPA	Panoramic (OPG)	Panoramic (OPG)	IOPA	1. Panoramic (OPG) 2. IOPA	33.6-48.62 µSv (Using Dental Cone-Beam CT)
	Posterior Mandible		IOPA	Panoramic (OPG)	Panoramic (OPG)			
Multiple Fixed / Removable Prosthesis	Anterior Maxilla / Mandible	Panoramic (OPG) orCone Beam CT orConventional Dental CT	IOPA	Panoramic (OPG)	Panoramic (OPG))	IOPA	1. Panoramic (OPG) 2. IOPA	33.6-48.62 µSv (Using Dental Cone-Beam CT)
	Posterior Maxilla Posterior Mandible	Panoramic (OPG) orCone Beam CT orConventional Dental CT Conventional Dental CT	IOPA	Panoramic (OPG)	Panoramic (OPG)	IOPA	1. Panoramic (OPG) 2. IOPA	33.6-48.62 µSv (Using Dental Cone-Beam CT)

[i]Depending on radionuclide composition of soil and building material
[ii]Depending on indoor accumulation of radon gas
[iii]Depending on radionuclide composition of foods and drinking water
[iv]To evaluate direction of osteotomy and proximity to nearby structures
[v]For Immediate Post-Surgical Evaluation and final surgical placement
[vi]to ensure accurate fit of the prosthesis at the abutment-implant junction and the prosthesis -abutment junction
[vii]For General evaluation of the fixtures and prosthesis
[viii]For a specific evaluation of pathology around any of the implants.

During the prosthetic phase, single implant fixtures are examined for pathologies and osseointegration using periapical radiographs. A true test of osseointegration would be a clinical examination of the fixture (E.g.: use of the Osstel Diagnostic device), Multiple implants should be examined using a panoramic radiograph. A conventional film based technique is recommended to avoid confusion due to mach band effects seen on digital radiographs (Fig 5). Examination of the fit of the prosthetic restoration should always be examined with periapical radiographs to avoid errors due to magnification and distortions seen on the panoramic film.

During the follow-up phase single implant restorations may be examined with peri-apical radiographs and multiple fixtures with panoramic radiographs keeping in mind the mach band effect that may occur in a digital radiograph. If reasonable doubt arises on the condition of one or more fixtures on the panoramic radiograph, periapical radiographs may be made of the fixtures in question. Zygomatic Implants should be mandatorily evaluated with panoramic radiographs.

Figures 6 and 7show typical sequence of radiographs in the rehabilitation of a patient with implant supported restorations.

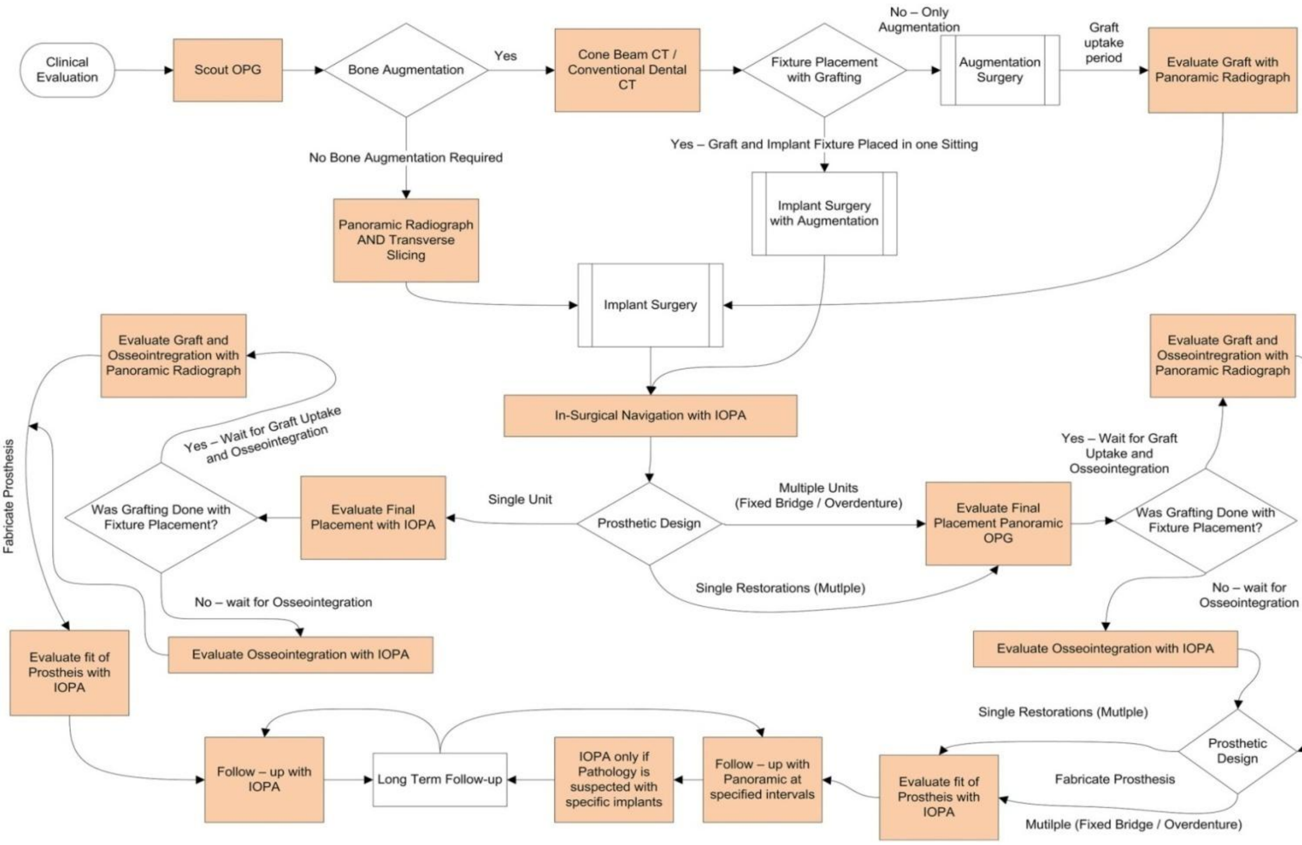

Figure 3: A general Sequential flow of radiographs in the treatment of a patient with implant-supported-prosthesis

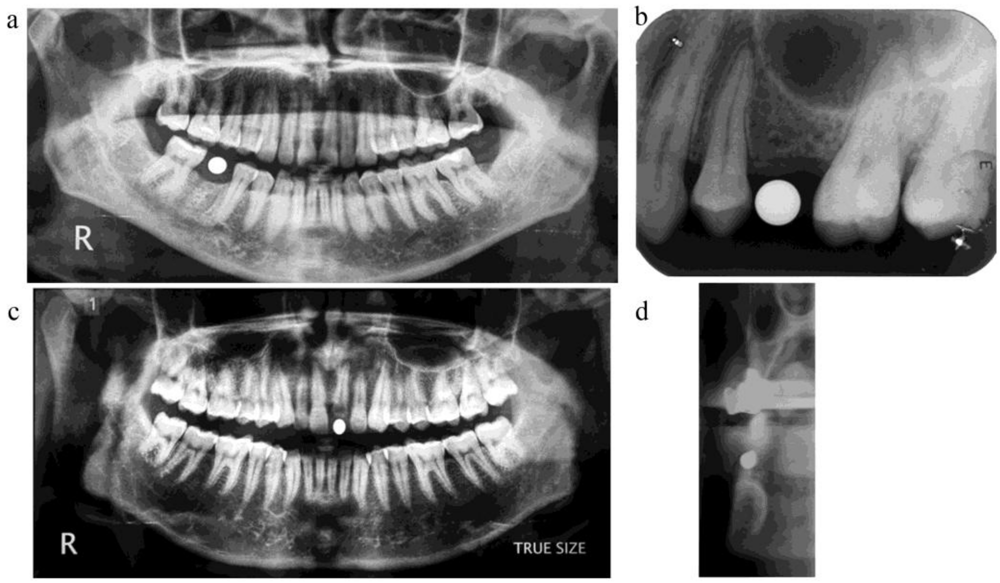

Figure 4: Use of Diagnostic Markers. a – Use on a panoramic radiograph. b – on a periapical radiograph to determine available bone height from the sinus floor. c – adjacent to tooth indicated for immediate extraction and implant placement, to determine implant length. d – In conventional tomography to aid in determination of bucco-lingual dimension and distance from the mandibular canal.

Figure 5: Mach Band Effect: Radiolucent Halo's around two healthy implants and metallic restorations

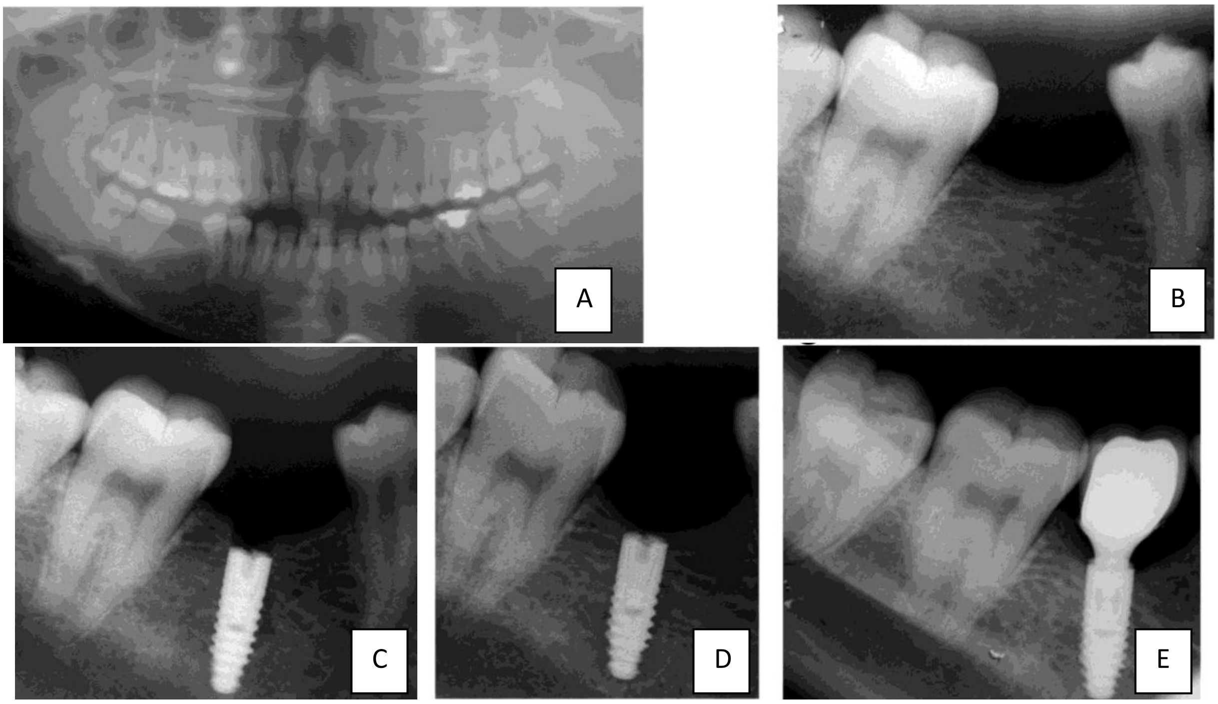

Figure 6: Sequence of Radiographs for treatment of loss of a single tooth with a dental implant: a- Scout OPG, b- Pre-Operative Peri-apical Radiograph. c- Immediate Post-Operative IOPA, d- IOPA prior to prosthetic phase to evaluate osseointegration. e- Post Cementation peri-apical radiograph.

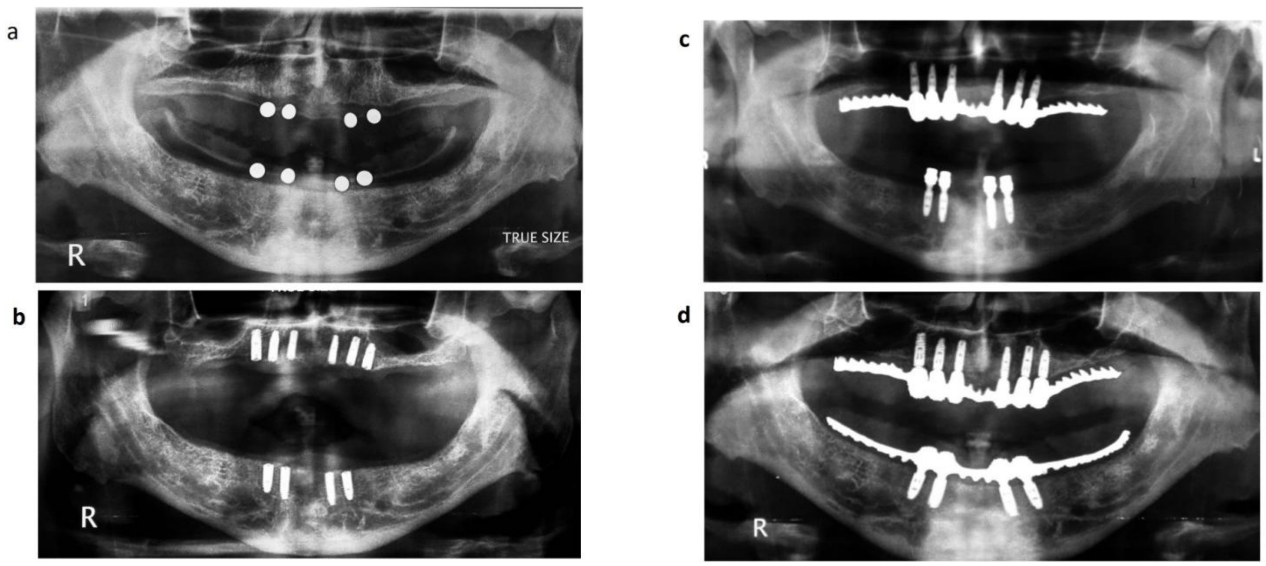

Figure 7: Sequence of Radiographs for treatment of a completely edentulous patient with dental implants. a- Pre-operative panoramic radiograph with diagnostic markers. b – Post Operative. c and d – Evaluation of Prosthetics

CONCLUSION

James Hunter said "Treat the patient not the X-Ray"

An imaging modalityshould be considered only a thorough clinical diagnosis of the case at hand and after ensuring that the expertise is available to provide accurate assessment with that particular modality. This ensures that the patient is not put in harm's way or that the imaging modality be unwarranted for that case. Advances in the field of medical imaging, both new and diversification of existing modalities [52], will no doubt provide better visualization of structures for diagnosis, planning and treatment of the patient with possibly lower health risks for the patients and operators

A complete dental oral implant treatment is therefore complete only when the correct imaging modality is employed for the particular phase of the treatment.

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Conflict of Interest (all authors)

There are no financial or other relations that could lead to a conflict of interest.

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