Radiographic Imaging in Dentistry: New Diagnostic Horizon with Recent Advancements

Akash Kumar Baranwal[1], Adit Srivastava[2,*]

[1]Service Senior Resident, [2]Reader, Faculty of Dental Sciences, Institute of Medical Sciences, Banaras Hindu University, Varanasi

***Corresponding Author:**
Email: dr.adit69@gmail.com

Abstract

Dentistry has come through many advances in all its branches over the last few decades. With such advancements, the accurate diagnostic tools, specially imaging methods, have become very much necessary. From the initial film based intra-oral periapical X-rays, advanced radiographic techniques like computed tomography, cone beam computed tomography, magnetic resonance imaging and ultrasound have also proved their importance in current dentistry. The three-dimensional imaging systems have resulted in easier assessment of complex cranio-facial tissues and accurate diagnosis of various lesions at early stages. This present paper is about to review the recent advancements in radiographic imaging technology and their applications in various perspectives of dentistry.

Key Words: Radiographic imaging, 3-D imaging, Computed Tomography, Digital imaging

Introduction

Since the discovery of the x-rays, conventional radiographic methods are still being used widely in dentistry. Categorically, the radiographic imaging methods used in dentistry can be divides as: intraoral and extra-oral, analogue and digital, ionizing and non-ionizing imaging and two-dimensional (2-D) and three-dimensional (3-D) imaging.

Usually, the 2-D conventional radiographs suffice for most dental radiographic needs and they are used as an accessory diagnostic aid for the clinical examination by assessing the teeth anatomy and supporting bone to reveal caries, periodontal and periapical diseases, and other osseous structures.

Since these radiographs produce a 2-D image of a 3-D object, the interpretation of tooth with its adjacent anatomical structures cannot be done precisely which limits its diagnostic accuracy[1]. Only the mesio-distal and apico-coronal plane of the structure is assessed, while the buccal-lingual plane remains unable to assess[2]. The other drawbacks also involve the superimposition of anatomical structures surrounding the teeth leading to anatomical noise, appearance of less severe bone destruction than its actual condition, and inability to assess the soft- tissue to hard-tissue relationships.

Considering the abovementioned drawbacks of 2-D imaging, the cases of diagnostic dilemma and treatment planning of special cases desire advanced 3-D imaging techniques. Till date, the advancements of imaging modalities have produced a new horizon for the diagnosis and treatment planning in dentistry. Therefore, the present review article is about to highlight the recent radiographic imaging advancements with their basics, benefits, applications in various fields of dentistry including their limitations.

Radiovisiography (RVG): The radiovisiography (RVG) was the very first imaging system introduced in digital dental radiography[3]. Digital radiography is a technique which produces radiographic image using a sensor with solid-state technology, breaking it into electronic pieces, displaying and storing the image using software in computer system.

Three types of digital radiography systems have been promoted in dental imaging: (1) CCD-Charge-Coupled Device (direct system); (2) CMOS-Complementary Metal Oxide Semiconductor (direct system); and (3) PSP-photo-stimulable phosphor (indirect system). Radiation dose reduction (up to 80%, when compared with conventional plain film radiography) is considered to be one of the most advantageous outcomes of digital radiography[4]. The dose reduction for intraoral digital x-ray has been reported in the range of 50% -60%[5,6] when compared to E-speed film and for extra-oral digital x-ray, it is found up to 50% -70%, when compared to film-screen combinations.[7,8]

Other advantageous features involve the short processing time (image can be seen more quickly on the screen), no need of darkroom, chemical processing and its associated errors. Also, this system contain the ability of manipulating the image produced such as contrast, density, sharpness and image orientation, without generating extra radiation exposure to the patient and operator as well.

Computed Tomography (CT): CT utilizes a narrow fan-shaped X-ray beam and multiple exposures around an object to assess its anatomical structures enabling the clinician to observe the morphologic features and pathology in three- dimensions[9] so that it can also measure the bucco-lingual extent of the lesions overcoming the drawback of 2-D imaging.

CT scanner system is containing a radiographic tube connected to a series of scintillation detectors or ionization chambers. The patient is moved inside the circular aperture in the centre of the gantry. The tube head and reciprocal detectors within the gantry either rotate synchronously around the patient, or the detectors may form a continuous ring around the patient and the X-ray tube may move in a circle within the detector ring.

In spiral CT, the patient is moved continuously through the rotating gantry and image data are obtained as a "spiral" or "helix" rather than in the form of a series of slices[10]. When comparing to CT scanners, spiral scanners result in better multiplanar image reconstructions, decreased exposure time (12 s vs 5 min), and a diminished radiation dose (up to 75%).[11]

Current CT scanners are called multi-slice CT scanners as they contain linear array of multiple detectors (up to 64 rows) that simultaneously acquires tomographic data at different slice locations. The benefits of it include decreased scan time, reduced artifacts, and improved resolution (up to 0.4 mm isotropic voxel).[11]

CT results in high contrast resolution and has ability to differentiate the tissues with < 1% physical density difference compared to 10% required for conventional radiography[11]. CT images have less noise (i.e., they are less grainy), which results from superior collimation of the emerging beam in CT machines.[9]

CT has been proven as gold standard imaging technique for interpretation of the maxillofacial skeleton structures. It helps in diagnosing the complex facial fractures, like those involving the frontal sinus, naso-ethmoidal region[12], and the orbits[13]. It also detects undisplaced fractures of the mandible and the condyle, which are not generally seen on panoramic radiographs.

CT scan has also been proved helpful in determining vertical root fracture or split teeth which cannot be very obvious on periapical radiographs, since CT has not been found sensitive to beam orientation unlike conventional x-ray methods[14]. CT is also able to detect multiple extra root canals and chronic apical periodontitis at early and established stages that can be observed as periodontal space widening with small osteolytic reaction around the root apices.[15]

Spiral CT may help in interpretation of the close relationship between maxillary sinus disease and adjacent periodontal defects and their treatment[16]. Also, CT scan can accurately differentiate between intrinsic and extrinsic salivary tumors and is used for tumor's staging.[17]

LIMITATIONS OF CT:

The disadvantages of CT imaging include high radiation exposure, high costs of the scans and scatter because of metallic objects. It has poor resolution compared to conventional radiographs.

Tuned Aperture Computed Tomography (TACT): TACT is comparatively a simple, faster method for reconstructing tomographic images, introduced by Webber and colleagues[18]. It utilizes the mechanism of tomosynthesis and optical-aperture theory[19,20]. TACT needs 2-D periapical radiographs obtained from different projection angles as base images and allows retrospective creation of longitudinal tomographic slices (TACT-S) lining up in the Z axis of the concerned area. It generally results true 3-D data from any number of arbitrarily oriented 2-D projections.

The overall radiation dose of TACT is usually within double to that of a conventional periapical X-ray and the resolution has been found similar with 2-D radiographs. Also, it does not produce artifacts like starburst patterns as seen with metallic restorations in case of CT.

TACT produces more accurate imaging for assessing non- destructive osseous changes within the healing bony lesions. It has also been proved that TACT can be a better option for analyzing trauma-induced radicular fractures and mandibular fractures[21]. TACT can also be alternative to CT for pre-surgical implant assessment[22]. However, TACT is still at trial phase but thought to be a effective imaging technique for the future dentistry.

Cone Beam Computed Tomography (CBCT): This technique uses a cone-shaped X-ray beam centered on a 2-D detector. It performs 360˚ rotation around the object and generates a series of 2-D images which are reconstructed in 3-D using a modification of the original cone-beam algorithm. Radiation dose of one CBCT scan equals 3-20% that of a conventional CT scan, depending on the equipment used and the area scanned.[11]

X-ray tubes of CBCT cost very less when compared to conventional CT. Images results in isotropic voxels that can be as small as 0.125 mm. CBCT provides a high spatial resolution of bone and teeth which permits definite understanding of the relationship of the adjacent structures.

CBCT has wide applications in dentistry. High resolution of CBCT imaging determines variety of cysts, tumors, infections, developmental anomalies and traumatic injuries involving the maxillo-facial tissues plus evaluating dental and osseous disease in the jaws and temporo-mandibular joints and treatment planning for dental implants. CBCT is categorized into large, medium, and limited volume units based on the size of their field of view (FOV).

Smaller scan volumes have higher resolution images and low effective radiation dose. Size of the concerned area exposed to radiation is the principal demerit of large FOV imaging[23]. Large FOV units are very helpful in analyzing the maxillofacial trauma, orthodontic diagnosis and treatment planning, temporo-mandibular joint (TMJ) and pathologies of the jaws.

Medium FOV is used for assessing the mandibulo-maxillary imaging and for pre-implant planning and pathological conditions while Small FOV units (limited FOVs) are suitable for dento-alveolar imaging and are most beneficial for endodontic implementations.[24]

Limitations of CBCT: CBCT has the problem of scattering and beam hardening artifacts caused by high density structure[25] which diminishes the contrast and limits the imaging of soft tissues. Therefore, CBCT is primarily indicated for imaging hard tissues[26]. Also, CBCT cannot be helpful in detecting bone density because of distortion of Hounsfield Units. CBCT has lengthy scan times (15-20 sec) and they need the person to stay completely firmed.

Magnetic Resonance Imaging (MRI): MRI scan is a specialized imaging technique without ionizing radiation. Most MRI machines are graded on the strength of the magnet, measured in Tesla units, which is the equivalent of 20000 times the magnetic field strength of Earth. MRI units contain the range of 1.5 to 3 Tesla units for in vivo utilization.

MRI principle is based on behavior of hydrogen atoms (consisting of one proton and one electron) within a strong magnetic field which is used to generate the MR image. This forces the nuclei of many atoms in the body to align themselves with the magnetic field. The machine implies a radiofrequency pulse to depolarize the atoms and the energy that is emerging from the body is utilized and used to generate the MR image by a computer. The MRI has high contrast sensitivity to soft tissue differences as hydrogen is found in abundance in soft tissue, but is lacking in most hard tissues and this is the main reason behind MRI replacing the CT for soft tissues imaging.[27]

MRI provides the best resolution of tissues with low inherent contrast. Some cases of squamous cell carcinoma of the tongue can only be detected with MRI. The main use of MRI in dentistry is for investigation of soft-tissue lesions in salivary glands, TMJ and tumor staging.

Also, it seems to be ideal for assessment of internal derangement of TMJ. MRI can also detect joint effusions, synovitis, erosions and associated bone marrow edema. Odontogenic cysts and tumors can be differentiated better on MRI than on CT. It also helps in detecting the soft tissue diseases like neoplasia, involving tongue, cheek, salivary glands, neck and lymph nodes.[28]

MRI can also precisely differentiate between solid and cystic lesions on the basis of signal characteristics and enhancement patterns. It also permits accurate differentiation between the keratocystic odontogenic tumor (KCOT) and other odontogenic lesions.[29]

A recent introduction in MRI technology is called SWeep Imaging with Fourier Transform to assess the dental structures. It can simultaneously image both hard and soft dental tissues with high resolution with less scan time[30]. It can also detect the extent of carious lesions and simultaneously find the pulpal tissue condition, whether reversible and irreversible pulpitis, which can influence the treatment planning.[31]

Limitations of MRI: MRI is usually not supposed to be used in patients with cardiac pacemakers, implantable defibrillators, some artificial heart valves, cerebral aneurysm clips, or ferrous foreign bodies in the eye. Metallic dental restorations can generate artifacts producing a major diagnostic problem in CT examinations of malignant tumors in the maxillofacial region.[32,33]

Claustrophobic patients should not be positioned in the close confines of an MRI machine. Other drawback of MRI includes long scanning time and much expensive compared to other conventional radiographic methods. [34]

Ultrasound: Ultrasound (US) is a non-invasive, cost-effective and painless imaging technique. Unlike X-rays, it is devoid of harmful ionizing radiation. US can be utilized for both hard and soft tissue assessment.

US principles depend on the reflection of sound waves (echoes) with a frequency outside the human range (1-20 kHz), at the interface of tissues which have different acoustic properties. Ultrasonic waves are generated by the piezoelectric mechanism within a transducer (probe). US waves transmit energy, as X-ray does, but it needs a medium for its transmission, unlike X-rays which pass readily through a vacuum. The transducer detects the echoes and transforms them into an electrical signal and finally, a real-time black, white and shades of grey picture are viewed on a computer screen.[35]

US can be an important and alternative diagnostic method when MRI is contra-indicated in conditions like cardiac pacemakers, claustrophobia and metallic prostheses. US is used to diagnose fractures of the orbital margin and nasal bone, zygomatic arch, and the anterior wall of the frontal sinus. It can also be helpful in assessing the patients with mid-facial fracture. Ultrasonography also determines extra-capsular sub-condylar fractures.

US can differentiate solid and cystic lesions in the parotid gland. It also detects sialoliths in parotid, submandibular and sublingual salivary glands. These appear as echo-dense spots with a characteristic acoustic shadow[36]. US have ability to define the internal muscle structures more clearly than CT. It can also asses the muscles thickness which can be an important criteria for follow-up examination of inflammatory soft tissue conditions of the head and neck region and superficial tissue lesions of the maxillofacial region.[37] US is a valuable diagnostic aid in assessing the pathological nature (granuloma vs cysts) of periapical diseases[38,39]. It has been found helpful in guided fine-needle aspiration, tongue cancer thickness assessment, and evaluating metastasis to cervical lymph nodes.[40]

Limitations of Ultrasound: The limitations of US include inability in diagnosing displaced fractures, complex maxillofacial fractures, posterior orbital floor fractures and intra-capsular mandibular condyle fractures due to overlapping of zygomatic arch[41]. US are restricted by bone and therefore it can be indicated only if there is a bony defect over the lesion through which ultrasonic waves can traverse.[42]

Conclusion

Excellent advances have been made for betterment of radiographic imaging systems since their introduction and it seems that their needs will be increasing in the future. Definite use and accurate interpretation of appropriate imaging technology will help to detect lesions or pathologies at very early stages. Dentists must know in detail about the working principles, requirements, benefits, drawbacks and hazardous effects of these systems for proper utilization.

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