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Recent Advances in Dental Imaging

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Abstract **Review Article**

There have been considerable advances in the field of dentistry in the past few decades. Such advances have led to better imaging tools for more accurate diagnosis and comprehensive treatment planning. Conventional radiographs with 2-dimensional (2D) imaging methods such as periapical radiographs, lateral cephalograms, and panoramic cephalograms have been used since a long time. Earlier such radiographs were recorded with film-based radiographic technique. These radiographs have been shifted to digital radiography with the advances in technology, which has led to a substantial decrease in the time required for procedures for image processing, viewing, and storage. Recently, the 3-dimensional (3D) radiographs such as Computed Tomography (CT) and Cone-beam computed tomography (CBCT) have changed the landscape of dental imaging. This paper discusses in detail the current available methods of dental imaging.

Keywords: Digital imaging; Cone-beam computed tomography (CBCT); Computed Tomography (CT); 2-dimensional (2D) radiography, 3-dimensional (3D) radiography.

INTRODUCTION

One of the greatest discoveries in the medical field, X-rays, was discovered accidentally by William Roentgen in 1895. Since then, x-rays or radiographic imaging has played an important role in the field of dentistry. In a broad sense, the dental imaging techniques can be divided in to two main categories: Intraoral radiographs and Extraoral radiographs [1]. The imaging techniques can use either ionizing radiation or non-ionizing radiation.

2-Dimensional (2D) Imaging

Radiographs used in the earlier days in the dental and medical field consisted mainly of 2D radiographs. 2D radiographs can be useful in obtaining the required information for most cases in dentistry. The main purpose of the radiographic imaging in dentistry has been to supplement and aid the clinical diagnosis of conditions. Mainly, the dental imaging such as peraiapical radiographs could be useful in examining the dental structures such as enamel, dentin, pulp, periodontal ligament and alveolar bone structures [2]. In addition, the root morphology, root anatomy, root resorption and periapical lesions can be easily identified in the periapical radiographs. However, there are limitations in two-dimensional radiography. One such limitation is the superimposition of overlying structures. As the structures of head and neck are three-dimensional and the 2D radiographs provide the 2D images of such 3D structures, the images of overlying structures are also recorded while recording the radiograph of the region of interest [2, 3]. This leads to difficulty in accurately identifying the landmarks for the structures of interest. In addition, there is loss of spatial information in the third dimension.

Film-based and digital radiography

The conventional 2D radiographs were based on film-based radiographic technique. In the film-based radiographic technique, the radiographs have to be processed in the darkroom, and careful handling of images with chemicals such as developing agent and fixing agent. These procedures lead to processing errors in the final evaluation of 2D radiographs [4]. The introduction of digital imaging has been substantial in overcoming the disadvantages of the conventional film-based radiography. With digital imaging, there is no need for chemicals and dark room for the recording, acquisition, and processing of radiographs. In addition to reducing processing errors, digital imaging has made the dental radiographic imaging easier and faster.

Panoramic radiography

Panoramic radiograph is commonly recorded as a part of the comprehensive diagnostic workup. Panoramic radiography is a specialized radiographic technique with a large field of view in which the 3-dimensional structures of head and neck such as maxilla, mandible, and orbits are projected on a flat plane in 2-dimensions. Because of the large field of view, panoramic radiographs also allow the imaging of temporomandibular structures along with the jaws [5]. Panoramic radiograph is utilized as a screening tool for the assessment of the teeth, dentoalveolar structures, bone level, impactions, and for evaluation of dental implants. However, there are downsides to panoramic radiograph imaging similar to the periapical radiographic imaging. The disadvantages are due to magnification and distortion which do not allow the precise measurements. Due to this reason, the evaluation of side effects of orthodontic treatment such as root resorption can be inaccurate in 2D radiographs [6]. In addition, panoramic radiograph does not allow the evaluation of the fine minute anatomic details due to poor resolution [7].

Lateral cephalometric radiography

Lateral cephalometric radiographs provide a radiographic image of the lateral side of the head in a side-view [8]. It enables the identification of the relationship of maxilla, mandible and cranial structures. A cephalometric radiograph is used by dentists, and orthodontists to identify the relation of the maxillary and mandibular dentition to the jaws, the relation of maxilla to mandible, relation of maxilla and mandible to the cranial base [10]. A cephalometric radiograph allows the assessment of skeletal, dental, soft-tissues of the head and neck. Because of the large field of view of a cephalometric radiograph, it can be used for evaluation of the skeletal maturation of the patient by assessment of the cervical vertebrae maturation (CVM). However, it has inherent disadvantages of a 2-dimensional radiograph such as magnification and distortion, difficulty in identification of landmarks due to superimposition of overlying structures [11]. In addition, the positional errors while recording the lateral cephalometric radiograph can lead to errors in accurate assessment of the head and neck structures such as the length of maxilla, mandible, and assessment of cervical vertebral maturation (CVM) [12].

Limitations of 2D Imaging

The head and neck structures have to be represented in 2-dimensions instead of three-dimensions in 2D radiography [13]. As 2D radiographs provide a 2-dimensional image of 3-dimensional objects, the relationship of the structures with each other cannot be analyzed accurately. This leads to reduced diagnostic potential of a 2D radiograph compared to 3D radiographs. The head and neck structures can be evaluated in either two of the three planes i.e. sagittal, coronal, or axial planes, but not all three. The anatomy of maxillofacial skeleton is complex and thus, 2D radiographs are not able to accurate reproduce the intricate 3D anatomy [14]. This leads to inaccurate assessment of the effect of treatment on dental alveolar structures such as root resorption, cervical vertebrae maturation, and length of jaws [6]. When compared to measurements on dry skull, it has been reported that 2D radiographs show reduced levels of bone damage than actually present [15].

Thus, due to all these disadvantages of 2D radiographic imaging, 3D imaging was introduced in the dental field. The introduction of computed tomography in the medicine led to the development of 3-diemnsinoal imaging in the dental field [16]. Cone-beam Computed tomography (CBCT) was developed for dental evaluation of the head and neck structures. CBCT revolutionized the radiographic imaging for dentists, and specialists such as periodontists, orthodontists, oral and maxillofacial surgeons, oral radiologists, and other dental specialists.

3D Imaging

Computed Tomography (CT)

Computed tomography (CT) was introduced by Godfrey Hounsfield in 1972. CT uses a narrow fan-shaped radiographic beam [17]. The radiographic tube in a CT scanner is connected to a series of scintillation detectors. Multiple exposures are made during the CT scan around an object to record the inner structures [18]. This allows the clinicians to assess the morphology and pathologic features in 3-dimensions. CT scanners are useful for CT angiography and cardiac imaging. However, the disadvantage of CT is that it is expensive and it has limited application in maxillofacial diagnosis.

CT radiographic technique has the advantage of higher accuracy. However, there is high radiation with CT radiographic technique. Other disadvantages of CT radiographic technique are scatter radiation with metallic objects and decreased application in the diagnosis of dental fractures such as tiny fissures as such fractures are beyond the resolution of CT [19]. This may result in false-negative measurements. Thus, 3D radiographic imaging technique has been modified for dental field which resulted in the development of Cone-beam Computed Tomography (CBCT).

Cone-Beam Computed Tomography (CBCT)

Cone-Beam Computed Tomography radiographic technique is performed with a cone-shaped x-ray beam. A series of images in the axial plane are recorded and re-constructed by applying the reconstruction algorithms for CBCT. The reconstruction algorithm for cone-beam computed tomography was developed by Aboudara *et al*. in 1984 [14]. Many modifications of the reconstruction algorithms are available now for the CBCT. The main advantage of

CBCT is that the radiation dosage of CBCT is 3% to 20% lower than conventional CT scan. The dose of CBCT varies according to the x-ray recording machine and the field of view (fov).

Endodontics

CBCT has been useful in the field of endodontics. It has been shown that CBCT is valuable in the diagnosis of periapical lesions [20, 21]. A CBCT-based periapical index (CBCTPAI) was introduced by Estrela *et al.* for the purpose of assessment of periapical lesions before and after endodontic treatment. CBCT allows the differential diagnosis of the periapical cyst and periapical granulomas by the measurement of density [22]. With CBCT, the assessment of the radiographic structures can be performed in different planes. Thus, it allows the evaluation of vertical root fractures as opposed to periapical radiographs.

For most applications, limited volume CBCT is used in endodontics [23]. The limited volume CBCT has increased resolution which results in more accuracy for procedures pertaining to endodontics such as the length of the root canals, the anatomy of root canals, and presence of accessory canals. Moreover, the limited volume CBCT results in decreased radiation to the patient.

Orthodontics

CBCT has brought about a revolution in the diagnostic aspects in the field of orthodontics and dentofacial orthopedics [8]. CBCT has the advantage of 3-Dimensional imaging in that it shows the head and neck structures in the same ratio as in the patient's mouth without magnification and distortion. It also allows the measurements to be performed in all 3 planes. The angulation of the roots can be observed in a CBCT accurately without superimposition of overlying structures as opposed to a panoramic radiograph [24]. For these reasons, CBCT is a useful tool for accurate and precise measurements of root resorption, as well as growth of dentofacial structures.

The advancement of bonding agents in orthodontics has led to a significant change in the way orthodontics is practiced [25]. The introduction of aligners has been considered to be an important discovery in the field of orthodontics [26, 27]. However, 3D imaging and CBCT have completely revolutionized the diagnostic and treatment planning aspects of orthodontics. In addition to the evaluation of linear measurements of the head and neck structures, CBCT allows the clinician to perform volumetric measurements [6]. Volumetric measurements with CCBT can be performed for the assessment of root volume pre and post-treatment to identify the volume of root resorption with orthodontic treatment. Another such application of CBCT is in the measurement of airway volume [28]. Volumetric assessment of airway can be performed after rapid palatal expansion and mini-screw assisted rapid palatal expansion to analyze the effects of such orthodontic interventions on airway [28]. The dimensional aspects of airway have found to be increased in some studies, however, it has not found to be showing any significant increase in certain other studies [29, 30]. Mehta *et al*. showed using 3D imaging that mini-screw assisted rapid palatal expansion leads to increase in airway volume in the short-term but there was no difference between mini-screw assisted rapid palatal expansion and conventional rapid palatal expansion in the long-term, other than nasopharyngeal volume which was increased with mini-screw assisted rapid palatal expansion [31].

Implants

Dental implants are screw type fixtures inserted into the alveolar bone of the patient for receiving a fixed prosthesis. CBCT has proven to be very useful for the pre-treatment evaluation of the patient prior to placing the dental implants. CBCT is used mainly to identify the amount of bone present in the specific location for the dental implant. In addition to the quantification of the amount of bone, CBCT can also be used to judge the quality of bone by evaluation of the bone density [32]. One of the important advantages of CBCT is the information regarding the location of vital structures so that any damage to such structures can be prevented during the placement of the dental implants. CBCT has also been reported to be useful for intraoperative placement of dental implants [33].

Periodontics

In periodontics, CBCT can be used effectively to identify the bony defects such as intrabony defects, furcation defects, presence of dehiscence and fenestration, as well as periodontal cysts [34]. CBCT can provide a detailed view of the bony structures which is helpful in accurately measuring the bone parameters. Such measurements with CBCT can be made preoperatively to identify the periodontal status of the patient. In addition, CBCT is also a useful tool for evaluation of post-treatment outcomes after periodontal treatment.

Oral and maxillofacial surgery

CBCT has several applications in oral and maxillofacial surgery such as for planning for surgery in 3-dimensions and evaluation and diagnosis of impactions of teeth, cysts, tumors, and implants. One of the major applications of CBCT for oral and maxillofacial surgery is in the diagnosis of fractures and inflammatory conditions of jaws and sinuses. CBCT allows the assessment of non-displaced fractures of condylar head which are difficult to be diagnosed with 2D radiographs [35]. CBCT is also useful for more accurate assessment of cervical vertebrae maturation compared to 2D radiographs such as lateral cephalograms as in 2D radiographs, the positioning errors lead to inaccuracies in CVM measurements [12].

Cervical vertebrae maturation is used for evaluation of the patient's skeletal maturation and diagnosing whether the patient is ready for orthognathic surgery. However, in fractures of the cervical vertebrae, CBCT is not indicated as CBCT requires the patient to be in upright position which will be difficult for a patient with cervical vertebrae fracture.

Limitations of CBCT

The quality of radiographic image with CBCT has disadvantages of scattering and beam hardening artefacts which can result due to structures with increased density like enamel and other radiopaque materials [36]. The resulting scatter radiation can lead to decreased contrast and has negative effects on the soft-tissues in the radiographic image. Thus, CBCT is mainly used for hard-tissues [37]. However, in the recent times with the improvement in the CBCT technology; soft-tissues can be imaged very accurately with CBCT.

CONCLUSIONS

The recent advances in dental imaging have completely changed the way that diagnosis and treatment planning is performed. Conventional 2-dimensional radiographs have been used since long in dentistry. With the help of newer advances such as CBCT, it is possible to identify the head and neck structures in 3-dimensions in dentistry and dental specialties such as endodontics, orthodontics, implants, periodontics, oral and maxillofacial surgery, and other dental specialties.

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