Review Article

3D Imaging in Orthodontics - A Narrative Review

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ABSTRACT

Three-dimensional (3D) technology has been widely used in orthodontics in recent years. Conventional computed and cone-beam computerized tomography (CT/CBCT), ultrasonography (USG), magnetic resonance imaging, and surface scanning, intraoral scanning are some of the 3D technologies in orthodontics. The purpose of this article is to review the currently available orthodontic appliances which utilizes 3D technology such as the principles in 3D imaging and its possible applications of 3D facial imaging in orthodontics, the different techniques of 3D imaging of the teeth as well as the recent efforts to create the "virtual orthodontic patient" with the help of 3D soft- and hard-tissue data. This article is basically a brief narrative review of some of the commercially available 3D-based technologies in orthodontics.

Keywords: Three-dimensional, cone beam computed tomography, clinical use, computed tomography, intraoral scanners, magnetic resonance imaging

INTRODUCTION

The modern digital era has started with access to significantly many new diagnostic information. With advancing digital technology from two-dimensional (2D) to three-dimensional (3D), the more and more information will be available and with this information, orthodontics will excel to next level, enhancing the scope.[1]

Progress in 3D imaging has significantly increased in the past two decades and has found many applications in orthodontics and also in oral and maxillofacial surgery. In 3D imaging system, the anatomical data are assembled by utilizing diagnostic imaging equipment, it will be processed by a computer and then the image will be displayed on a 2D monitor showing the illusion of depth. The image will appear in 3D with the depth perception. The implementation of 3D imaging in orthodontics includes various pre- and post-orthodontic assessments of dentoskeletal relationships and facial esthetics, examining orthodontic outcomes with regard to soft and hard tissues, 3D treatment planning, also 3D soft- and hard-tissue prediction of treatment result outcomes. Other benefits of utilizing 3D models in orthodontics are three-dimensionally fabricated custom made archwires, archiving 3D dental, facial and skeletal records for in-treatment planning, research, and medico legal purposes.

Along with computed tomography (CT), other 3D tools also offer undeniable possibilities that allow clinicians to acquire 3D scans. 3D scanning of the human face and dentition within seconds has greatly replaced the photographs and dental casts. These tools allow us to examine soft and hard tissues in an infinite variety of ways with resolution near microscopy.[2]

According to Quintero *et al.*, there are several reasons for limited validity of 2D cephalometry's scientific method and its applications,[3] like the representation of a 3D object as 2D is a conventional head film. The structures are displaced vertically and horizontally in proportion to their distances from the film or recording plane.[4] Accurate assessment of structures away from the mid sagittal plane is impossible, because facial symmetry is rare and because of relative image displacement of right and left sides.[5] Significant radiographic projection errors are related to image acquisition, magnification, distortion, also the errors in positioning of patient and projective distortion inherent to the film/patient/focus geometric relationships.[5]

Manual collection of data and cephalometric analyses processing have revealed low accuracy and precision. Manual tracings of anatomic structures used for cephalometric analysis incorporates intra and inter-observer errors. Furthermore, the conventional analyses utilize linear and angular measurements defined in a coordinate system that varies across patients and in longitudinal assessments.[5]

Errors in landmark identification due to lack of well-defined anatomic outlines, hard lines and shadows, landmark locations are poorly described in at least one of the planes of space that depends

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on head orientation and observer experience.[6]

Therefore, the aim of the present narrative review is to summarize the various 3D imaging system, its daily application in orthodontic practices for diagnosing and treatment planning.

3D IMAGING MODALITIES

Some of the 3D imaging methods can be summarized as follows:

- Conventional computed and cone-beam computerized tomography (CT/CBCT)
- USG
- Magnetic resonance imaging (MRI) and surface scanning
- Intraoral scanning.

CT

The first clinical CT scanner was introduced by Sir Godfrey N Hounsfield in 1967.[7]

CT imaging, also known as computerized axial tomography imaging, uses spiral X-ray equipment [Figure 1] to generate cross sectional images of the body. A fan beam shaped X-ray source [Figure 2] and solid-state detectors are mounted on a rotating gantry while it advances. The image of the patient is obtained slice by slice usually in an axial plane. Images interpretation is done by assembling the slices to get multiple 2D representation. Stacking multiple 2D slices together leads to the formation of 3D illustrations. Since CT is expensive and subjects the patient to a high radiation dose, CBCT was introduced to overcome these limitations.[8]

Figure 1: The CT equipment and the CBCT equipment

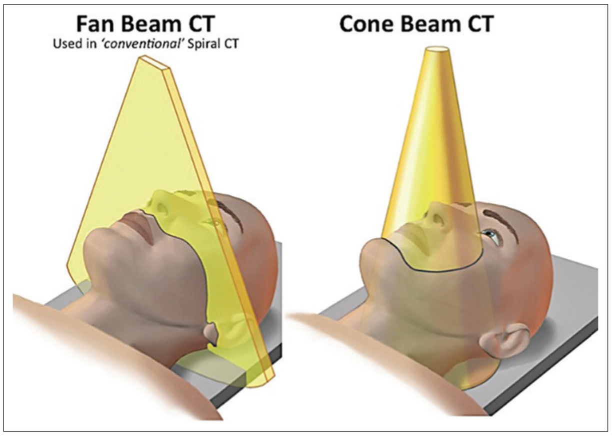

Figure 2: Comparison of basic functioning difference between CT and CBCT technologies

CBCT[9]

The CBCT machine can scan the patient in sitting, standing, and supine position. X-ray source and detector are fixed to rotating gantry [Figure 1] which is used to achieve the desired imaging in CBCT. By the middle of the area of interest onto an X-ray detector on the opposite side, a divergent cone shaped [Figure 2] source of ionizing radiation is directed. Throughout the rotation, multiple (from 150≥ 600) sequential planar projection images of the particular view of the field are captured in a complete or in a partial arc.

Differences between CT and CBCT

Reference	CBCT technology	CT technology
Type of beam	Cone shaped	Fan shaped
Exposure of beam	Volumetric, 3D	2D
Scan time	Rapid scan time (10–70 s)	More scan time, it takes some minutes for scan to complete
Dose	Range 36.5–182.1 µSv	Range: Mandible- 761-3324µSv Maxilla- 104-1202 µSv
Artifacts	More noise and movement artifacts compared to CT; lesser metal artifacts compared to CT	Lesser as compared to CBCT
Soft tissue	Poor soft-tissue contrast	It has bone and soft-tissue windows, making it useful for determining various soft-tissue details

CBCT: Cone-beam computed tomography, 2D: Two-dimensional, CT: Computed tomography

Applications of CBCT in orthodontics

Various applications of CBCT in orthodontics could be broadly covered as: [8]

1. Diagnostic assessments
    - Root form and length
    - Unerupted tooth position
    - Facial asymmetry
    - Clefts and bone defects
    - Pathologies.
2. TMJ assessment
3. Airway
4. Craniofacial morphometrics and cephalometry
5. Orthodontic treatment planning
6. Assessment of treatment outcomes.

Diagnostic assessments[10]

CBCT imaging system exactly determines the labial/lingual relationships, the exact angulation of impacted teeth, and the exact proximity of adjacent roots, crown, and bones and play a very important role in diagnosing and treatment planning.

TMJ assessment[10]

Degenerative changes of TMJ, which play an important role in orthodontics treatment, can be evaluated using follow-up CBCT over an extended period of time. Current software solutions allow the visualization of TMJ osseous elements, isolated (segmented) from other surrounding structures.

Airway[10]

The volume of the airway and the sinuses can be quantified possibly using CBCT filtered images. The location of most constricted airway can be established, and the quantification of axial view of this region can be done.

Craniofacial morphometrics and cephalometry[11]

Several visualization modes of 3D measurements from CBCTs can be made, including volume rendered, shaded surface display, and multiplanar (MPR). Among all, in the MPR mode, point to point measurements made are highly accurate compared to the physical skull measurements.

Orthodontic treatment planning[11]

CBCT provides accurate information regarding the bone volume, bone quality, and location of adjacent structures, which are necessary for proper placement of temporary anchorage devices.

Assessment of treatment outcomes[11]

CBCT is now considered a tool for determining treatment outcomes in patients undergoing maxillary expansion: patients after alveolar bone graft placement and treated cleft lip/palate patients; and those who underwent orthopedic corrections and orthognathic surgery.

NONRADIATION IMAGING TECHNIQUES

Ultrasonography

It was first commercially available in 1964. High frequency sound waves are required to produce dynamic images (sonograms) of organs, tissues or blood flow inside the body. Moreover, it utilizes about 20,000 Hz frequency of an ultrasound wave and 2.5–15 MHz of medical ultrasound wave.[12]

Mechanism

When an electric field is applied to an array of piezoelectric crystals located on the transducer surface, an ultrasound wave is generated. Stimulation of electric field will lead to mechanical distortion of the crystals results of which is the vibration and production of sound waves. The sound waves released from the transducer are transmitted into the body, and then the tissue interface reflects it back to the transducer. Which are then transformed into an electric signal, which is then processed and displayed on screen as an image. The total process of transformation of sound waves to electrical energy is called the piezoelectric effect.[13]

Applications

- Widely used in medicine as a diagnostic, therapeutic, and operative tool
- Diagnosis, follow-up and quantification of normal and hypertrophied jaw muscles, salivary gland tumors, soft-tissue cyst, etc.
- Long-term documentation of myofunctional treatment
- Diagnostic tool for dynamic functional analysis of the tongue, and the measurement of soft-tissue thickness for optimal placement of orthodontic miniscrew.[14]

MRI

To produce highly detailed images of human body MRI utilizes the magnetic effects of hydrogen and its interaction with large magnetic field and radio waves. The hydrogen nucleus consists of one proton and it also possesses a remarkable magnetic moment, and it is also found generously in the human body.

The nuclei of the hydrogen atoms tend to spin in one of the two directions [Figure 3a] when the patient is places in a large external magnetic field. These nuclei of hydrogen atom can transit their spin orientation or process from the direction of the magnetic field to the opposite orientation. This transition is

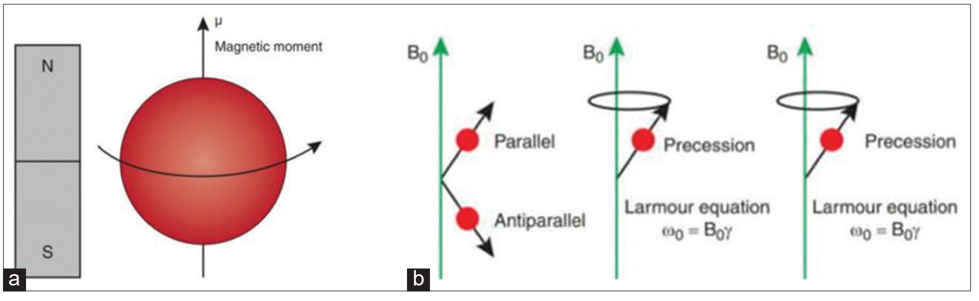

Figure 3: (a) The proton as a tiny bar magnet (b) Single proton in an external magnetic field: precessional frequency; many protons in the magnetic field

caused by releasing a radiofrequency causing the nuclei to spin in other direction. The frequency of energy required to make this transition is specific, and is called the Larmor frequency [Figure 3b].[15]

The energy released by molecules transitioning or processing from the high-energy to low-energy state produces the signal which used to create MRI images.

MRI was first used for imaging the temporomandibular joint by Helms *et al*. in 1984. In the field of orthodontics, the first MRI study of TMJ following Herbst appliance therapy was published in 1998.

APPLICATIONS IN ORTHODONTICS

In the diagnosis of TMJ disorders

MRI has been found more accurate in confirming various disorder of TMJ. MRI has been found as accurate as arthrotomography in confirming disc displacement and more accurate in disclosing gross arthrosis than tomography. Disc perforations are better disclosed by arthrography.

In evaluating the TMJ adaptations following functional appliances

TMJ adaptations following Herbst appliance has been well documented in literature using MRI.[16]

In evaluating the jaw muscles and craniofacial morphology

MRI has been used in several studies for measuring cross-sectional area and volume of the jaw muscles. It has also been used in measuring the muscle volume in response to myofunctional appliance. 3D reconstruction of jaw muscles is possible using software applications.

Intra oral scanner

For many decades, now 3D geometry of dental tissues was registered using conventional impression techniques.[17] The primary disadvantage of these conventional techniques is errors occurring due to expansion of dental stone and volumetric changes of impression materials for which an excellent dental laboratory service is required. Intraoral scanner (IOS) impression techniques [Figure 4] was developed in dental practice to overcome the errors of conventional impression techniques.

Advantages of digital scanning[18]

Improvement in both diagnostic and therapeutic measures, improved case acceptance, faster records submission to laboratories and insurance providers, lesser retakes, reduced storage requirements, reduced chair time, faster laboratory return standardization of office procedures, improved appliance accuracy, better workflow, lower inventory expense, and reduced treatment times.

Patient benefits include more comfort and less anxiety, easier refabrication of lost or broken appliances, reduced chair time as well as potentially reduced treatment time.

IOS technologies

IOS is a medical device consisting of a handheld camera (hardware), a computer, and a software. The IOS objective is to assess the 3D geometry of an object accurately. Standard Tessellation Language (STL) or locked STL is the most widely used digital format. It is open irrespective of the type of imaging technology employed by IOS, all cameras require the projection of light that is then recorded as individual images or video and compiled by the software after recognition of the points of interest (POI).

Four types of imaging technology are currently employed[18]

1. Triangulation
2. Parallel confocal imaging
3. Active wave front sampling (AWS)/Three-dimensional in-motion video
4. Accordion fringe interferometry (AFI).

Triangulation [Figure 5a]

Laser technology is used to calculate distances from the scanner wand sensor to the object using Pythagorean geometric principles.[18] Optical triangulation uses this principle and often

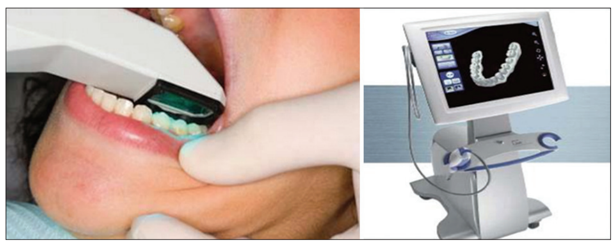

Figure 4: Intraoral scanner (digital) in use and chairside IOS

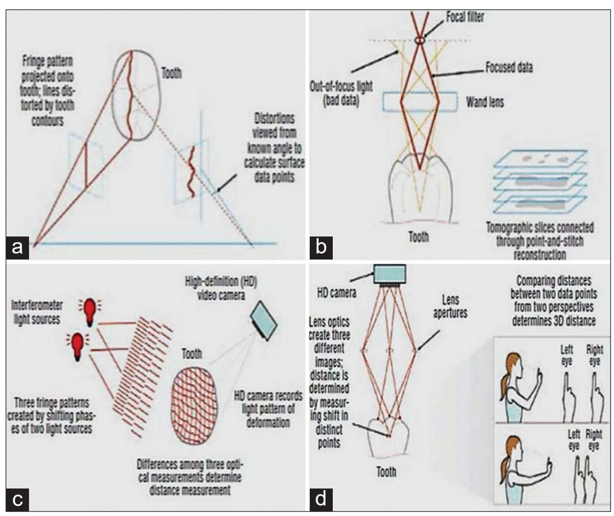

Figure 5: (a) Triangulation technique (b) paralleling confocal technique (c) accordion fringe interferometry (d) active wavelength sampling

measures distances to objects without physically touching them. Triangulation is according to a principle that the position of a point of a triangle (the object) can be calculated knowing the positions and angles of two points of view. It is useful in acquiring data within a few microns from delicate, wet or soft materials, as are found in the oral cavity. These two points of view may be produced by two detectors, a single detector using a prism, or captured at two different points in time.[18]

Parallel confocal technique [Figure 5b]

This technology can be used detect the sharpness area of the image to assess distance to the object that is correlated to the focal length of the lens. It is a technique based on acquisition of focused and defocused images from selected depths. It is used to reconstruct the tooth and it can take successive images by taking at different focuses and aperture values and from different angles around the object. The sharpness area is directly related to the dexterity of the operator who can generate motion blur, and this technique also requires large optics that may lead to difficulties in clinical practice.[18]

AFI [Figure 5c]

AFI is a system which utilizes two beams of laser light that creates three projected patterns — called fringe patterns — that strikes the target surface and takes on new fringe patterns. The distortion in the original pattern is detected by a high-definition video camera, which forms the 3D image.[18]

AWS [Figure 5d]

AWS is a 3D-in-motion technique. It is used in capturing the 3D data in a video sequence and models the data in real time. Because it does not rely on a laser and triangulation techniques, it is thus faster and eliminates the downsides of distortion and optical illusion. It can create an onscreen virtual model almost instantaneously.[18]

AWS is a surface imaging technique, requiring a camera and an off-axis aperture module. The module moves on a circular path around the optical axis and produces a rotation of POI. Distance and depth information are then derived and calculated from the pattern produced by each point.[18]

Uses of IOS

It is used for fabrication of orthodontic study models, customized archwires, and customized fixed appliances (in both labial and lingual versions), as well as indirect bonding trays. In addition, digital technology is also used for diagnostic setups, fabricating aligners and removable orthodontic appliances, and diagnostic procedures in both orthodontic and orthodontic/orthognathic surgical combined treatment.

CONCLUSION

3D devices have an important role to play role in orthodontics for diagnosis, therapeutic treatment planning and prognosis procedures. There are many varieties of techniques that can be used and depending on the kind of analysis each one has different outcomes, reproducing three-dimensionally different tissues and implicating higher or lower risks for the patient. There has been remarkable increase in the use of 3D technology in orthodontics in the recent years.

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