Review Article

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Dentistry Section

DICOM: A Revolution in Facet of Maxillofacial Imaging

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ABSTRACT

Digital Imaging and Communications in Medicine (DICOM) is a paradigm that enables interoperability between health-related digital applications, imaging devices, and Picture Archiving and Communications Systems (PACS). DICOM has its foundation in the USA, established by the American College of Radiology (ACR) and the National Electrical Manufacturers Association (NEMA) in 1983 with the objective of establishing a "gold standard" for monitor and print-copy devices. In 1996, the American Dental Association (ADA) became a member of DICOM, followed by the American Academy of Oral and Maxillofacial Radiology and the American Association of Orthodontics. A working committee specifically for dentistry (WG-22) was initiated in 2003, and in 2005, it was finally adopted as an international standard. Currently, it is internationally recognised as the standard configuration for compatibility between dental radiological images and various scanners and digital X-ray devices. DICOM synchronises network communication and facilitates the exchange of patient data through a transmission protocol. The purpose of the present paper is to emphasise the reliance of digital dentistry on DICOM and its relationship with Three-Dimensional (3D) printing.

Keywords: 3D printing, Picture archiving and communications system, Stereolithography

INTRODUCTION

In dentistry, numerous recent technological advancements have been introduced for the diagnosis of oral and maxillofacial diseases, all of which involve the production of 2D/3D images or graphical representations of data [1]. Since 1983, thanks to the efforts of ACR and NEMA, only medical radiological systems like Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and ultrasound have been able to communicate digitally [2,3]. To ensure efficient digital image handling within specific departments or hospitals and to facilitate coordination between devices, the adoption of a single formatting standard like PACS was highly desirable [2,3].

For the communication of diagnostic images and associated data, DICOM serves as the International Organisation for Standardisation (ISO) through which radiological images are transmitted from digital X-ray machines and scanners, along with the protocol used for transmission, retrieval, and archiving of these images. The DICOM standard has become universally adopted in the field of medicine, including dentistry, for the possession, storage, and display of digital images [4,5].

With the increasing global digitisation of dentistry, incorporating image acquisition techniques such as optical surface scanning, Cone Beam Computed Tomography (CBCT), Computer-Aided Design (CAD)/Computer-Aided Manufacturing (CAM) systems, and Electronic Digital Records (EDRs), dental associations worldwide, including the American Dental Association, have also recognised the importance of embracing the DICOM standard for dentistry [1,6].

Terminologies

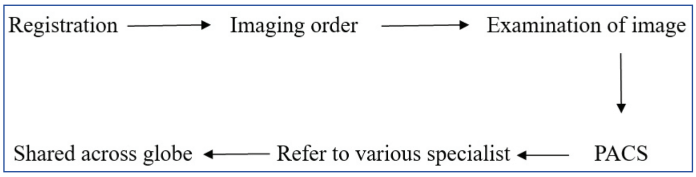
Acquisition modality: In DICOM technology, a dental digital machine is referred to as an acquisition modality [2,3,7].

Acquisition devices: The acquisition devices include CBCT and CAD-CAM systems, which enable periapical, cephalometric, and panoramic imaging. Other acquisition devices used in dentistry include MRI, CT scan, and Ultrasonography (USG) [2,3,7].

Conformance statement: Each acquisition modality contains a "Conformance Statement," which specifies the necessary setup for the X-ray device to facilitate interaction with other components, such as the digital record system or viewing monitor, and other acquisition appliances. DICOM conformance statement is essential for ensuring interoperability between different modalities [2,3,7].

Picture Archiving and Communication System (PACS): It is utilised to manage digital DICOM files. In dentistry, PACS is primarily used in dental clinics, educational centers, and large hospital facilities where data interoperability between departments is required. It also facilitates communication between general physicians and dentists [2,3,7].

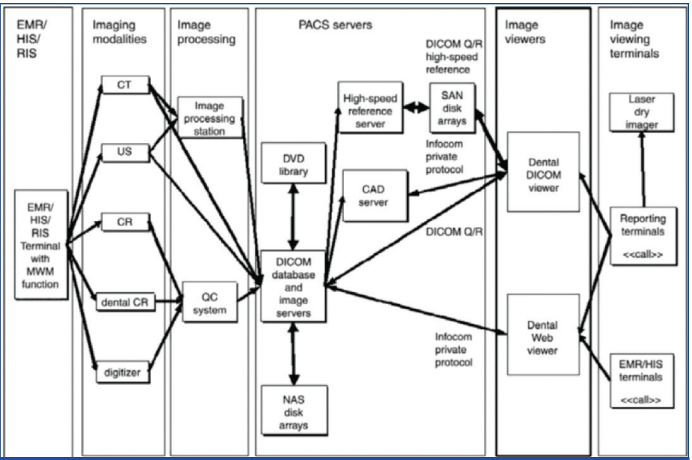
DICOM acts as a glue that binds various medical imaging systems together [2]. Within the complete digital medical space, DICOM objects are generated and transmitted over computer networks [2,3]. For radiographic examinations, the patient's data is first registered, followed by the imaging order from the system, and finally, the image is captured. Images are circulated across the globe and accessed by various devices, each assigned its own IP address and Application Entity (AE) by DICOM. DICOM uses Transmission Control Protocol (TCP) and the Internet Protocol (IP) for communication. Each AE is assigned its own name known as the Application Entity Title (AET) [2,3,7]. Picture archiving and communication systems have further evolved to enable comprehensive storage and retrieval of digital DICOM images [Table/Fig-1] [8].



Features of DICOM

Primary features:

1. Load and display DICOM images using specific files or directories. This feature enables users to import DICOM files into the software by specifying their location [4].
2. Query and retrieve images from the archive. This feature allows users to search for DICOM images based on parameters such as patient name, date of birth, and modality, which are stored in the database [4,9].
3. Multi-window view (layout) that allows synchronous display of multiple images (approximately 16 images) on a single screen [4,9].



[Table/Fig-1]: Components of a hospital DICOM PACS [3].
Source: EBM Technologies

4. Length measurements in mm/cm, which enable users to calculate distances between two points on a DICOM image in centimetres or millimetres.
5. Magnifier that allows users to enlarge DICOM images for better visualisation according to their convenience [4,9].
6. Patient information, such as patient name and date, can be viewed along with the corresponding DICOM image using the "show patient and study information" feature.
7. PACS connectivity is a special feature that enables users to transmit and register DICOM files into the central system. The DICOM viewer retrieves all the necessary details from PACS to display the images whenever needed.
8. With the advent of CBCT, the Multi-Planar Reconstruction (MPR) feature becomes of utmost importance. It allows the formation of images in the sagittal, coronal, or oblique planes [4,9].

Auxiliary Features

Annotation text: This feature enables users to attach 'user-defined' text to the DICOM image by marking a region. Colour inversion allows the user to change the colour of a DICOM image for analytical purposes [4,9]. Although it's a digital era in dentistry, this feature of importing Joint Photographic Experts Group (JPEG) images is important for those who can scan a radiographic film to import and view that image in JPEG format in the DICOM viewer. The ability to compare multiple series side by side allows users to simultaneously view and compare multiple series of images [4,9].

Usage of DICOM in Dentistry

In orthodontics, planning the treatment prior to its implementation is important, and for that, imaging of the craniofacial region is needed. Orthodontic patient evaluation includes 2-D imaging methods to evaluate craniofacial structures [3]. Cone Beam Computed Tomography (CBCT), an innovative technology in digital dentistry, provides 3-D views of the craniofacial area, improving diagnosis, treatment options, final treatment results, and outcome measure assessment. In orthodontics, when CBCT is used, DICOM is associated with it on various parameters for quantitative exploration and 3-D surgical projection [3]. Many software programs are currently available to convert CBCT DICOM images along various planes to visualise a specific region of interest [3].

Oral surgeons use DICOM-based files in clinical pre-surgical planning to provide information regarding general anatomy and to delineate the extent of pathology [3]. With CBCT, DICOM files can identify pathologies that can be measured in three dimensions, evaluated for relative bone density, and assessed in terms of relative volume. Additionally, the CBCT DICOM imaging curriculum may help in the analysis and management of sleep apnea, airway obstruction, snoring, and the shape and contours of upper airway passages. These can be examined in three dimensions and used to measure airway volume, thus providing potential for 'virtual endoscopy' [3].

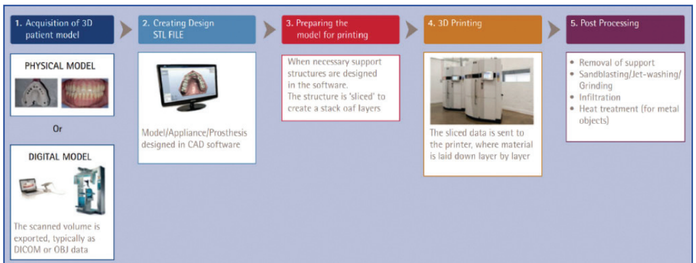
In the era of dental implants, bone volume and bone quality are elements of specific interest in establishing the prime location for positioning dental implants for successful results. CBCT is required to determine this parameter, and data transport between workstations follows the DICOM standard formalities [10].

In the dental implantation workflow, a visual replica of the affected teeth is initially created to visualise the postoperative outcome of the surgery with the patient. An impression of the patient's teeth is taken, and a cast is poured, which is then sent to a dental laboratory. With additional information, the laboratory creates a visual model known as the 'Wax Up' [11]. Nowadays, this entire workflow is simplified with the invention of CAD/CAM technology, where the patient's tooth is scanned, and the information is sent to the laboratory via a DICOM file. The patient's teeth cast can also be scanned by either the dentist or the laboratory technician, which leads to the next step of implant placement planning [11]. Implant templates are selected and virtually positioned in the patient's images, with various modifications made using available tools and markers. The scanning template is then prepared for processing, becoming the surgical template. It is used to drill the holes for the implants according to the predetermined position inside the patient's mouth during the surgery, and this entire process requires DICOM, known as the 'gold standard' [11].

DICOM is essential for effective medical image management, data analytics, and controlling Artificial Intelligence (AI) algorithms. Choosing the modern web-driven framework of DICOM over traditional synchronous transmission frameworks helps enhance access to information and simplifies implementation [6]. The DICOM standard allows web-based exchange of detailed information through the Web Access to DICOM Objects (WADO) extension, supporting in-hospital workflows and enabling the sharing of DICOM files over the internet. It provides an organised and standardised representation of medical image data, allowing effortless exchange between systems, devices, and apparatus from different vendors or manufacturers [6].

3D Printing

The term '3D printing' describes a manufacturing approach that builds an object layer by layer, also known as additive manufacturing. It can also be referred to as rapid prototyping. Recent developments in optical scan technology, especially Cone Beam Computed Tomography (CBCT), have revolutionised the field of 3D printing. These advancements have provided us with easy access to volumetric data, which can be converted into a 3D model [Table/Fig-2] [12].



[Table/Fig-2]: A 3D printing process [13].
Source: 3D printing in dentistry. British Dental Journal. 2015;219(11):521-29

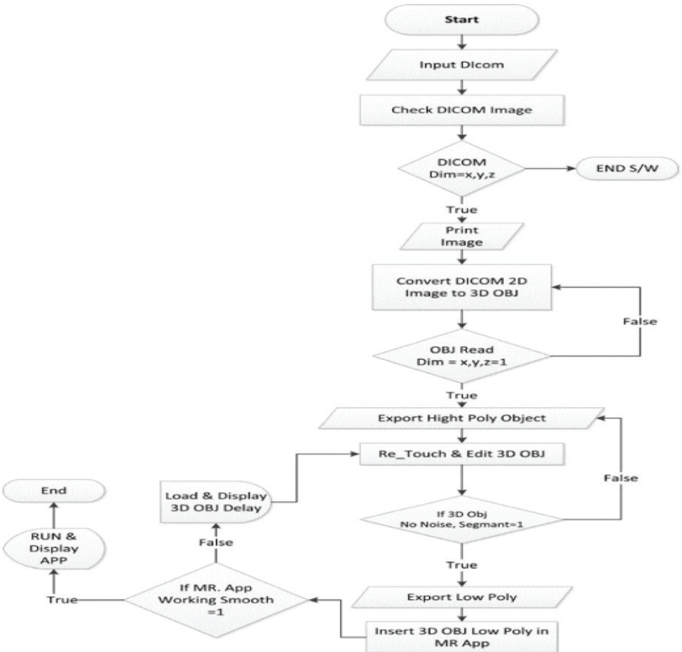
DICOM and 3D Printing

The workflow of the entire process can be divided into three steps [Table/Fig-3]:

Step 1 involves obtaining a 3D volume image of the patient as a DICOM image file [13].

Step 2 involves fragmenting the anatomical framework from the surrounding image and transporting it to the virtual 3D model using the STL file format. Fragmenting osseous structures and soft tissue is typically straightforward in most cases. However, generating an accurate STL replica can be challenging in a few instances for two reasons. Firstly, thin osseous structures (such as bone around the orbital floor or nasal cavity) and fine tissue spaces (such as the upper and lower joint chamber between the temporal bone and the mandible) may not be clearly represented in the STL replica. Secondly, various artifacts (such as metal artifacts and beam hardening from dental prostheses) can reduce image readability and interfere with the fragmentation process [13,14].

Step 3 involves 3D printing the concrete 3D replica using "G-code" generation software, which produces the 3D printable data in G-code format [13,14].



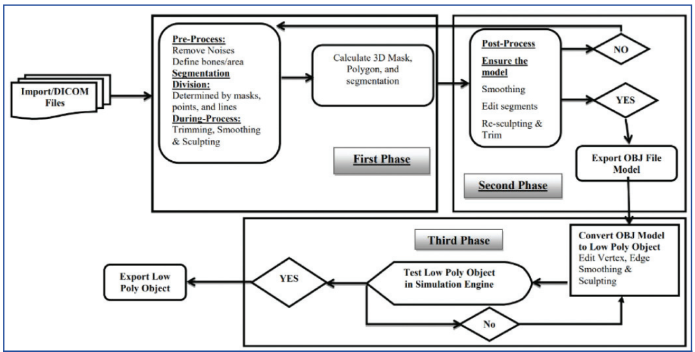
[Table/Fig-3]: DICOM File to 3D Model [15].
Source: WSEAS Transactions on Computers. 2020;19(2):10-20 Doi: 10.37394/23205.2020

Creation of the "3D Model" [Table/Fig-4]

1st Pre and during process phase: Firstly, after incorporating the DICOM file, it has to pass through numerous internal stages. This includes noise removal through preprocessing, defining the area to be modified by drawing a set of points and lines, and finally sculpting, trimming, and smoothing to show precise detailing [15].

2nd Post-process phase: If the final form is identical to the required one, it can be exported as an OBJ file. However, if any discrepancies exist, re-sculpting and trimming should be executed before and after editing [15].

3rd Testing phase: This is the most important phase where the model will be tested, and the OBJ file will be converted into a model. After the final simulation and integration with actual systems, this OBJ file is transformed into a low poly replica using sculpting techniques. The replica is then checked for regularity and the extent of ease of movement within the graphics programs used [15].



[Table/Fig-4]: Block diagram showing transformation steps from DICOM to "3D replica [15].
Source: WSEAS Transactions on Computers. 2020;19(2):10-20. Doi: 10.37394/23205.2020

Advantages of DICOM

Patient's demographic details, such as name, age, sex, birth date, hospital identity number, ethnic group, occupation, referring physician, institution name, and DICOM Unique Identifiers (UIDs), can be easily extracted from the header of a DICOM file when using it in presentations, teaching files, or publications, as patient privacy should be respected [3]. Since DICOM images are relatively large, conversion of these images into other formats takes place either at a diagnostic workstation or at a Web client of a PACS system. This allows the user to store the image displayed in the active window as a JPEG or TIFF file [15]. For Windows® operating system users without DICOM, they can press the "Print Screen" key on the keyboard to capture and save the image. It can then be immediately inserted into a PowerPoint™ slide or saved as a file using image editing software. Interpolation is a mathematical process through which image dimensions can be "scaled" or "resized" using software programs. This process adds or subtracts pixel details to minimise storage space requirements and facilitate on-screen presentations or web pages [2,3,15,16].

The information from a radiological setup is mostly transmitted through an offline channel, namely Compact Disc (CD), for simple transfer and storage. In addition to the DICOM image films, other necessary files are also included on the CD for displaying these images. The CDs typically contain an autorun file, a DICOM viewer, a DICOM directory (DICOMDIR), and a file consisting of the DICOM images, which makes the transfer of DICOM images a bit cumbersome [12]. Unlike other image file configurations such as Joint Photographic Experts Group (JPEG) or Tagged Image File Format (TIFF) files, the individual DICOM image folders cannot be viewed by double-clicking on them directly, as they are not identified by Windows® as image folders [12]. Without a proprietary viewer supplied with DICOM images, these files cannot be viewed on computers. A supplemental software combination called a "DICOM browser" is required, which can depict and display the folder as an image [2,3,15,16].

CONCLUSION(S)

Most of the manual and clinical procedures in dentistry have been replaced by updated software and digital scanners. Digitalisation is undoubtedly going to be the future of dentistry. Therefore, it is important to effectively integrate digital scanning data with verified images. The current need is to anticipate the growth of digitalisation by introducing advanced equipment, such as a CBCT machine with a concurrent face-scanning feature. Currently, it is crucial to condense digital scanning details and integrate them into various software platforms that are easily compatible. This integration is essential for 3D printing, which in turn is necessary in various fields of dentistry.

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