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Cone Beam Computed Tomography and Virtual Cloning: A Review

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Abstract

With the use of technologies, dental office workflow is moving toward a more efficient and cost-effective approach. Digitalization of dental records and computer-assisted imaging techniques have simplified workflow. Innovation and introduction of cone beam computed tomography, proface (facial three-dimensional [3D] soft-tissue capture), intraoral scan, planning software, and 3D printers has changed the dental profession. Clinical practice uses virtual workflows, and digital dentistry is a new development. The purpose of this article is to update the dental professionals with different available technologies for the creation of a virtual patient and digital tools that can be used for diagnosis, treatment planning, and follow-up of patients. The advantages of digital dentistry and future scope are highlighted in this article.

Keywords
- intraoral scanners
- facial scanning
- virtual patient
- digital dentistry
- cone beam computed tomography

Introduction

With the advent of cone beam computed tomography (CBCT), dental office workflow is constantly evolving toward an efficient and cost-effective method by using multiple state-of-the-art technologies. These new technologies assist in virtual treatment planning, simulations, and appropriate diagnostic approaches.[1] The digitalization can be applied to all fields of dentistry, especially for the simulation of surgical templates and placement of implants.[2] Digital dentistry is the term given to the inclusion of computer-based assessments for a wide variety of uses, such as collection of patient information, communication, diagnosis, simulation, and treatment planning along with follow-up.[3] Digitalization has improved the diagnosis and management of patients in the following ways: (1) creation of virtual patient dental records; (2) use of computer-assisted imaging methods (clinical information, radiographic information, and virtual scanning images) to diagnose a patient, further creating a concept of the digital patient; (3) virtual simulations using soft-tissue overlays to carry out the treatment plan in vitro; (4) hassle-free state-of-the-art visualization method with more efficiency for implant placements by creating surgical templates for the same. The most important developments in digital dentistry are workflow improvement, better dentist and patient experience, reduced complications, and improved treatment outcome.[4]

Advantages of Digital Dentistry

Integration of all digital technologies facilitates virtual three-dimensional (3D) representation of the patient (►**Fig. 1**). Different techniques are used for superimposing patient data.[5–7] Recent advancements simplified the procedure of digitalization with digital workflows (►**Fig. 2**).[4,6]

In the orthodontic practice, digital models provide several advantages over the traditional approach by creating a virtual simulation and thus aiding in digital manipulation with a reduction in manipulation errors and more efficient storage.[8]

In endodontics, digital workflow enables 3D model creation of the desired tooth from CBCT data and to do further segmentation of the canals, to determine the canal

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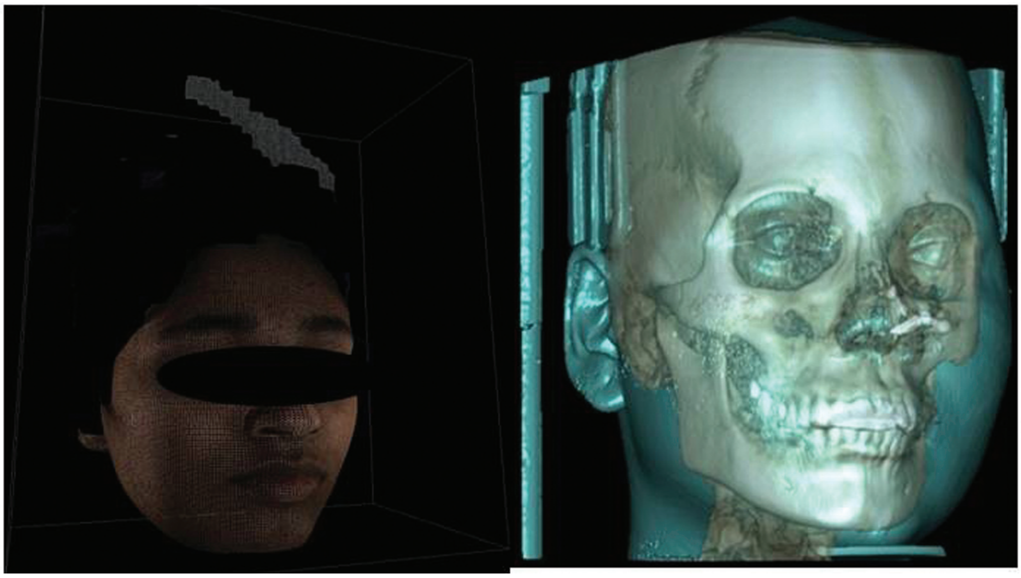

Fig. 1 Virtual patient concept.

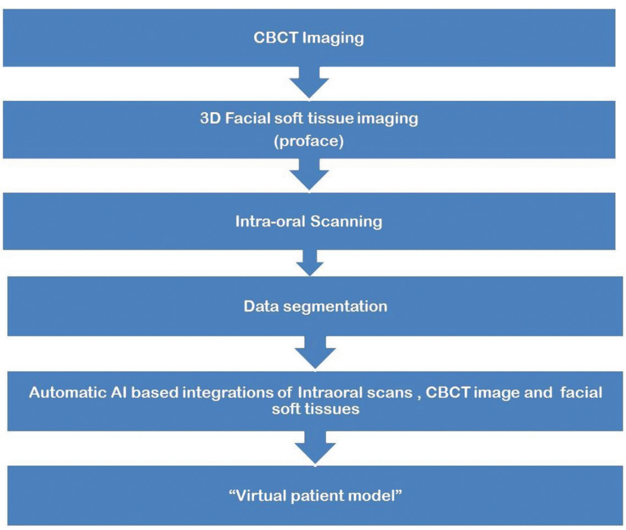

Fig. 2 "Virtual patient model" concept on integration of cone beam computed radiography (CBCT), intraoral scans along with proface.[4]

curvatures, and to create a virtual simulation of the whole endodontic procedure in the virtual setup (with the help of digital files). Clinicians will be benefitted as there will be a clear understanding of the complexities of the anatomy of the tooth and will aid in practicing minimally invasive procedures.[9,10]

In restorative and prosthetic dentistry, fabrication of the crown and/or bridge with rehabilitation and denture fabrication could be undertaken without much hassle to the patient with the digital workflow method as compared with multiple visits in the traditional workflow.[11,12]

Digital Radiography and CBCT

Ionizing radiations are prominent tools to view the anatomic or pathologic structures of the patient.[13] CBCT enables the dentist to view the maxillofacial structures, for diagnosis of dentoalveolar pathology, and aids in planning dental treatments.

With the advent of implants in dentistry, simulation of the implant placements has been reinforced with an ability to be accurately depicted on both the maxillary and mandibular arches. However, the quality depends predominantly on pixel resolution. The diagnostic quality of CBCT is determined by the following factors: (1) machine-oriented properties, which include focal spot, voxel size, the field of view (FOV), kilovoltage peak, and milliamperage; (2) patient-related properties such as the density of skeletal structures and restoration in teeth, patient stability, and positioning; and (3) augmented software for interpretation (designing and data manipulation, 3D augmentation of images, and integrating Digital Imaging and Communications in Medicine [DICOM]-based datasets from independent CBCT units).[14,15]

Currently, ~279 CBCT devices are registered in the global market with wide-ranging technical parameters.[16] The majority of the devices currently available offer a variable radiation dose.[17] Each CBCT unit has the tube voltage (kVp) and tube current (mA) preconfigured and the radiologist alters the technical parameters to get a high-quality image as per the ALADAIP principle (as low as diagnostically acceptable being indication-oriented and patient-specific).[18] Back in 1998, the initial CBCT device, NewTom 9000 (Quantitative Radiology, Verona, Italy), came into the field of dentomaxillofacial radiology.[19] The CBCT units have undergone multiple updates and further advancements, and now high-quality images can be drawn out of low doses within a limited FOV. Artificial intelligence (AI) in the form of reconstruction algorithms with segmentation and integration of images as a constant development in the past decade has allowed a greater flex toward reduction in effective radiation dosage using a 3D imaging modality.[20,21]

Segmentation of images: The segmentation of the 3D images obtained within an area of interest congregates as

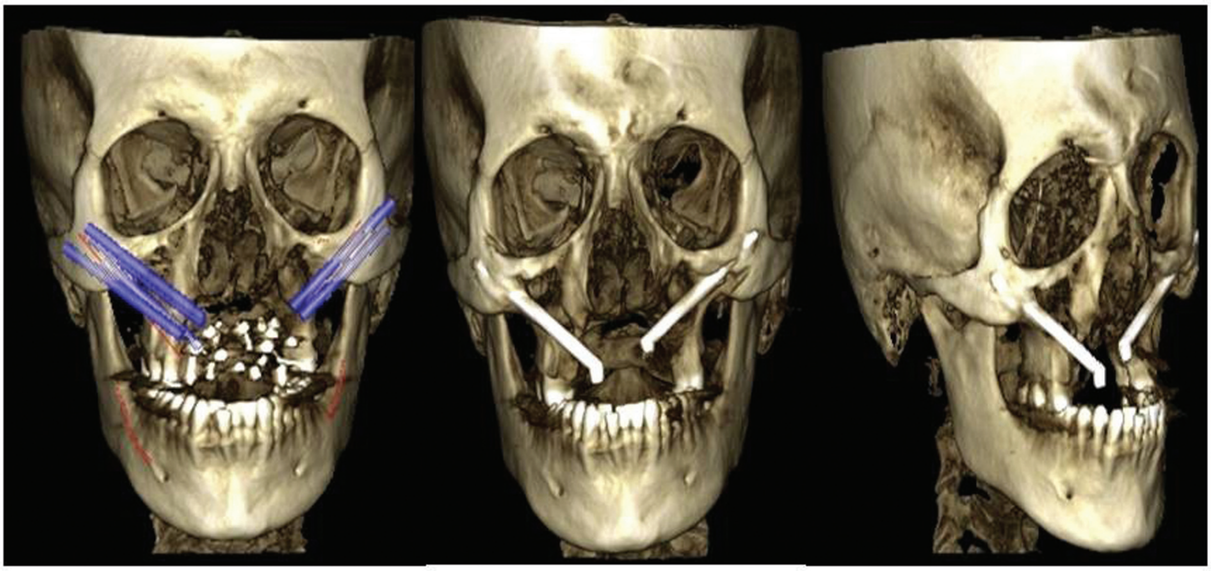

Fig. 3 Virtual patient simulation pre- and post-titanium reconstruction plates.

the second critical step for the digital workflow method, as a computer-aided procedure either by using a maximum intensity projection or by calculating the integral projection.[22]

Intraoral image acquisition using intraoral scanners (IOS): Advancements in CBCT imaging has come a long way from its inception in clinical settings to produce detailed and accurate bone tissue segmentation. Certain drawbacks of inadequate information related to dentogingival tissues, bite registration anomaly, and failure in recording interocclusal relationships could not be ruled out.[23] Artifacts such as patient motion–related metal artifacts during dental implant procedures further deteriorate the accuracy of the 3D image of the dentogingival region. The conventional workflow technique was primarily based on preparing stone casted models for the diagnosis and treatment planning. The conventional technique has risk of inaccuracies such as mold instability in the form of dimensional changes seen during the transition of the chemicals in room temperature settings.[23] IOS have proven to be a boon within the digital workflow space for a more real-time and accurate surface reproduction and to overcome shortcomings of the convention workflow. The main applications of IOS have been for designing onlays/inlays, denture frameworks, cleft obturators, veneers and crowns in restorative dentistry, rendering customized arch wires, fixed and removable appliance fabrication, aligners along with indirect bonding trays in orthodontics, guided simulation of surgical templates in implantology, and simulation guides for maxillofacial reconstructive procedures[24] (►**Figs. 3** and **4**).

Digital Clone

Digital clone is integration of volumetric scans of CBCT along with overlaying proface and intraoral scans.

Facial scanners: Optical scanning technology using 3D face scanners helps study facial morphology. This noninvasive technique has several advantages such as open data format, real skin color texture, less scanning time, and the ability to merge with CBCT volumetric data. Laser scanners and white light scanners are two types of facial scanners.[14]

Virtual representation of the realistic soft-tissue overlay is essential in the treatment planning, outcome determination in terms of aesthetics, in the field of orthodontics, maxillofacial reconstructive surgeries, implant, prosthodontic rehabilitation, and certain restorative procedures involving the anterior teeth.[25]

Registration and integration of images: The ultimate step is for integration and registration of 3D images obtained with superimposition of acquired 3D images of the dentomaxillofacial skeleton, including anatomical and pathological structures, teeth, and soft-tissue facial region for the creation of a 3D virtually augmented clinical model (also known as virtual patient) in a digital workflow method.[26]

A method used primarily for the interactive attachment of the segmented CBCT images along with the intraoral scanned imageries where both the images are matched at the same teeth surface and/or the anatomical region of interest to create a registration has been referred to as surface matching, which gets affected sometimes by the metals and artifacts in cases of restorations and orthodontic appliances.[27] Few authors have reportedly raised the need for integration of intraoral reference devices with possible fiducial markers or the integration of the titanium markers onto the gingival region as to clear the way and further mitigate the inaccuracies in the registration process, which is thought to be a time-gobbling process.[28] Few authors have suggested that for a double-scan voxel-based registration, which is considered to be a low compared resolution CBCT acquisition method of the dentomaxillofacial field of region, segmented and integrated with the teeth required from comparatively a high-resolution volumetric CBCT image acquitted further on to obtain an amplified virtual patient model.[29]

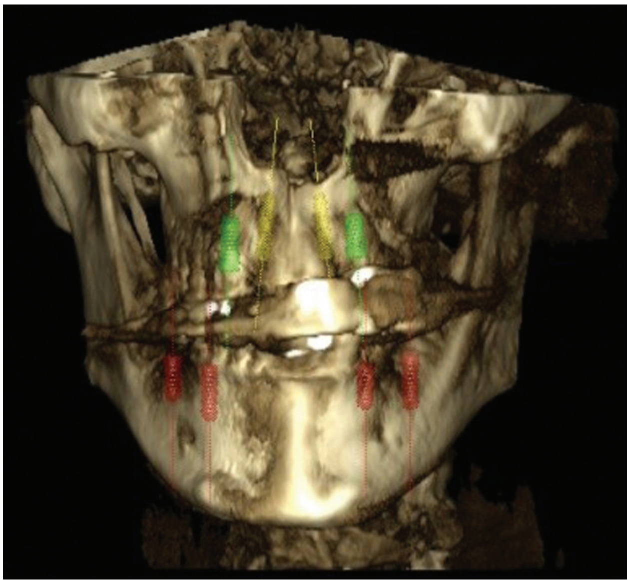

Fig. 4 Implant-guided simulation for full mouth rehabilitation.

3D printing of the implant guides and surgical planes: 3D printing, also known as additive manufacturing (AM), rapid prototyping, layered manufacturing or solid free form fabrication is a process that is computer controlled to create a 3D object by adding multiple layers of material one after the other. The idea behind this innovation is that the manufacturing equipment uses the geometric data to build each layer separately and sequentially to get the final desired product (►**Fig. 5**). But the printing requires a virtual design of the object. The ultimate design obtained is then ready to be fed into the 3D printer via USB, SD, or Wi-Fi modes, and finally the 3D object is acquired based on the configuration and type of printer used.[30]

The advantages of 3D printing technology over CAD/CAM are the following[31]:

- Mono blocks used in the milling process are often wasted due to unused portions, which are discarded as recycling of the same is also not feasible.
- Heavy abrasion and wearing of the milling tools affect their cycling time.
- Microscopic ceramic cracks could be induced during the process of milling due to the brittle nature of the ceramics.

Patient Monitoring

Low-dose 3D CBCT has been a reliable and integrated diagnostic modality for different dentomaxillofacial applications, including implant site assessment, periodontal disease, treatment plans for orthodontic impactions, and complex endodontic treatments. 3D CBCT follow-up is suggested for possible depiction of peri-implantitis, implant failure, healing of periapical pathosis, depiction of the biomaterial behavior, monitoring after sinus augmentations, to determine the outcome of cleft palate graft outcomes, and to invigorate the rate of condylar changes with possible erosion or decalcification.[32–35]

Because of its complexities in acquiring 2D images, digital subtraction radiography (DSR) is used less often as a research tool. DSR is an image processing tool that subtracts two successive images over a time period to determine the changes between them. However, poor geometric reproducibility limits the efficacy drastically with a contrast change.[13]

Finally, from assessing the periapical lesion healing or extraction socket remodeling, root resorption, or bone grafting, current research findings have also suggested and supported the critical consideration of 3D volumetric follow-up as the 3D approach semiautomatically generates the volumetric datasets of severely resorbed alveolar sockets more precisely than the traditional 2D approach.[2]

Future Scope and Consideration

The following further advancements should be considered as a futuristic approach for a more simplistic and reliable digital workflow method for not only diagnosing and treating with simulation but also predicting the treatment outcome and a possible follow-up:

- AI-based automatic segmentation of dentomaxillofacial structures in the form of neural network digital algorithms further enhances virtual diagnosis and treatment planning.
- The algorithm segmentation techniques of AI by standardizing the proposed scanning parameters with workflow-specific guidelines and training AI algorithms with a larger dataset to augment the precision.
- Automatically processed AI-based fusion digital algorithms for the registration of facial soft-tissue data along with the teeth surface onto the virtually segmented skull without any mechanical interruption or possession of the region of interest.
- Further introduction of AI-based navigation-assisted surgeries with the help of dental robots as already introduced with YOMI will prove to be more efficient with haptic guidance and precision, also saving time for both the patient and the operator. Dental robotics with assisted AI technology will be the future perspective not only in implant surgeries but also in orthognathic surgeries, facial reconstruction, and guided minimally invasive procedures.

Conclusion

Advancements such as digital workflow allows merging of the volumetric datasets of both CBCT and facial and intraoral scanners interactively as such data could be valuable for implant-related guided simulations, minor endodontic surgeries (minimally invasive procedures), virtually designed orthognathic surgeries along with simulated occlusal prosthetic try-ins for a possible full mouth rehabilitation. Furthermore, applying AI-based algorithms will further reduce the burden on the clinician by predicting the treatment outcomes quantitatively and qualitatively.

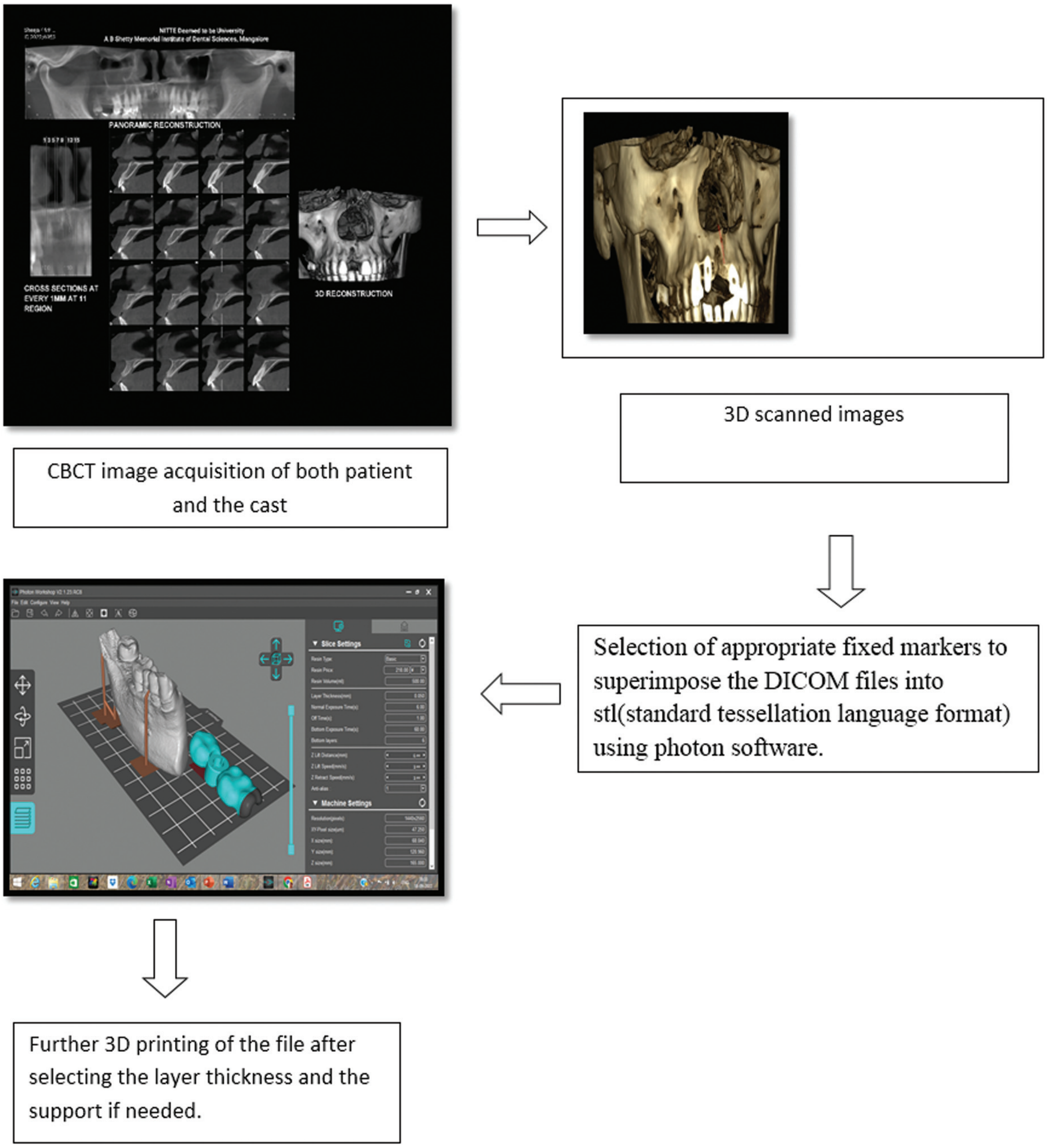

Fig. 5 Flowchart showing the integration of images to create a "virtual implant guide."

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Conflict of Interest
None declared.

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