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(Review Article)

The impact of digital imaging and computer-assisted surgery in oral surgery: A narrative review

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Abstract

Digital imaging and computer-assisted surgery (CASS) have ushered in a new era in oral surgery, offering manifold advantages in terms of precision, efficiency, and patient well-being. This narrative review delves into the profound impact of these technologies across various facets of oral surgery, encompassing diagnostics, treatment planning, intraoperative guidance, and postoperative evaluation. We examine the evolution of digital imaging modalities, notably cone beam computed tomography (CBCT), and their seamless integration with computer-assisted tools for meticulous surgical interventions. Furthermore, we explore the benefits conferred by virtual surgical planning (VSP) and 3D printing in refining preoperative strategizing and surgical execution. Additionally, we underscore the pivotal role played by navigation systems and robotic assistance in heightening surgical accuracy and mitigating complications. Notwithstanding the remarkable advantages, we also address the inherent challenges and limitations associated with digital imaging and CASS, including cost considerations, learning curves, and potential errors. Despite these hurdles, the widespread adoption of digital technologies in oral surgery has substantially revolutionized clinical practices, culminating in more predictable outcomes and heightened patient satisfaction. Lastly, we contemplate future avenues for research aimed at optimizing the integration of digital imaging and computer-assisted techniques in oral surgical procedures.

Keywords: Digital Imaging; Computer-Assisted Surgery; Oral Surgery; Cone Beam Computed Tomography; Virtual Surgical Planning; Navigation Systems; 3D Printing; Robotic Assistance; Patient Outcomes

1. Introduction

The realm of oral surgery has undergone a paradigm shift with the advent of digital imaging and computer-assisted surgery (CAS), ushering in a new era of precision, efficiency, and patient-centric care. Over recent decades, digital technologies have reshaped traditional approaches to diagnosis, treatment planning, and surgical interventions in oral and maxillofacial surgery (OMFS). Key among these advancements is cone beam computed tomography (CBCT), offering high-resolution three-dimensional (3D) images of the maxillofacial region with reduced radiation exposure compared to conventional computed tomography (CT) scans [1]. Additionally, intraoral scanners have facilitated non-invasive acquisition of digital impressions, while 3D printing technology has enabled the fabrication of patient-specific surgical guides and implants, enhancing surgical precision [2][3]. CAS encompasses a range of technologies that enhance surgical precision and efficiency, including preoperative planning software for virtual simulations and intraoperative navigation systems for real-time guidance. Such technologies find applications across various oral surgical procedures, from dental implant placement to orthognathic surgery and maxillofacial reconstructions [4].

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While digital workflows offer numerous advantages, including improved diagnostic accuracy, enhanced treatment planning capabilities, and reduced radiation exposure, they also present challenges such as initial capital investment and the need for specialized training. Looking ahead, the field of oral surgery stands poised for further advancements driven by emerging technologies. Artificial intelligence (AI) holds promise in automating tasks such as image segmentation and treatment planning, while augmented reality (AR) systems have the potential to overlay digital information onto the surgical field, enhancing intraoperative guidance and visualization. Moreover, personalized treatment planning based on patient-specific anatomical and genetic information heralds a new era of precision medicine in oral surgery [5,6].

2. The evolution of digital technologies

The evolution of digital technologies in oral surgery has been transformative, ushering in a new era of precision and efficiency in diagnosis, treatment planning, and surgical interventions. Among the most significant advancements is the widespread adoption of cone beam computed tomography (CBCT) imaging, which provides high-resolution three-dimensional (3D) images of the maxillofacial region [7]

2.1. Cone Beam Computed Tomography (CBCT)

Cone beam computed tomography (CBCT) has emerged as a pivotal tool in oral surgery, offering detailed 3D imaging of the maxillofacial region. Recent studies emphasize the role of CBCT in enhancing preoperative assessment and treatment planning accuracy. For instance, research by Naitoh et al. (2021) highlights the utility of CBCT in precisely evaluating the anatomical structures relevant to dental implant placement, thus minimizing the risk of surgical complications [8,9] Furthermore, CBCT has been instrumental in optimizing the management of complex maxillofacial fractures, as demonstrated by studies such as the one conducted by Kihara et al. (2020), which underscored the value of CBCT in delineating fracture patterns and guiding surgical interventions . The integration of advanced CBCT technologies, such as dual-energy CBCT, has further enhanced the diagnostic capabilities of this imaging modality, enabling improved visualization of soft tissues and bone pathology [10]. Figure 1

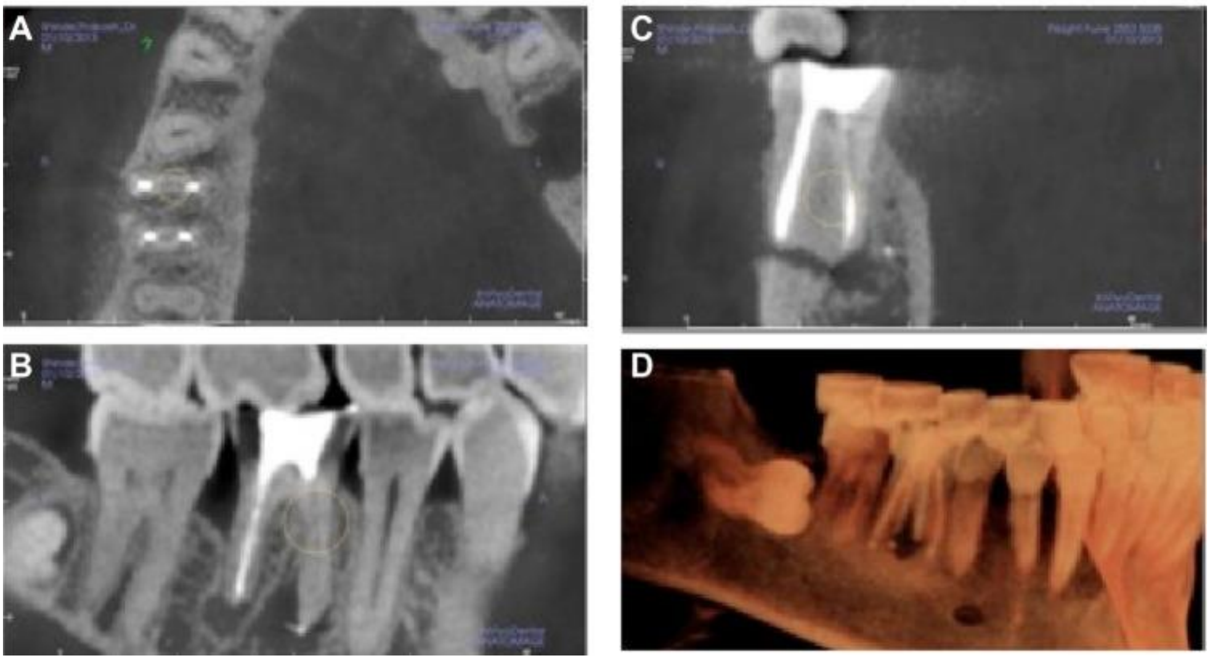

Figure 1 CBCT image showing the missed canal in the mandibular molar

Notes: Images courtesy of Dr Niranjan Vatkar, endodontist, Pune, India. (A) Missed canal seen on axial view. (B) Sagittal view showing large radiolucent lesion with mandibular first molar. (C) Cross sectional view showing missed canal. (D) 3D reconstruction showing osteolytic lesion with mandibular first molar.

Abbreviation: CBCT, cone-beam computed tomography

2.2. Intraoral Scanners

Intraoral scanners have revolutionized the process of dental impression-making, offering numerous advantages in terms of accuracy, efficiency, and patient comfort. Recent research by Joda et al. (2021) underscores the superior accuracy of digital impressions obtained using intraoral scanners compared to conventional impression techniques [11]. This enhanced accuracy translates into improved fitting and longevity of dental restorations, contributing to better patient outcomes. Moreover, intraoral scanners have facilitated seamless integration with computer-aided design and computer-aided manufacturing (CAD/CAM) systems, enabling efficient fabrication of custom-made surgical guides, prosthetic restorations, and orthodontic appliances [12]. The study by Joda et al. (2021) further highlights the potential of intraoral scanners to streamline digital workflows in oral surgical practice, leading to improved treatment efficiency and patient satisfaction [13].

2.3. 3D Printing Technology

3D printing technology has revolutionized the fabrication of patient-specific surgical guides, implants, and anatomical models, offering unprecedented customization and precision in oral surgery. Recent studies have demonstrated the clinical efficacy of 3D-printed surgical guides in enhancing the accuracy and predictability of implant placement procedures. For example, research by Vásquez et al. (2020) evaluated the accuracy of 3D-printed surgical guides for dental implant placement and found them to be highly precise, with minimal deviations from planned implant positions. Moreover, 3D printing technology has facilitated the development of innovative implant designs tailored to specific patient needs, as highlighted by studies such as the one conducted by Sun et al. (2021), which explored the use of patient-specific implants in mandibular reconstruction surgeries The study demonstrated favorable outcomes in terms of implant stability, functional restoration, and patient satisfaction 14,15]

2.4. Digital Workflows and Communication

Digital workflows have transformed communication and collaboration in oral surgical practice, facilitating seamless data exchange and interdisciplinary teamwork. Recent research emphasizes the importance of digital communication platforms in enhancing treatment planning efficiency and patient engagement. For instance, a study by Lim et al. (2021) investigated the use of teledentistry for preoperative assessment and postoperative monitoring of oral surgery patients [16]. The study demonstrated the feasibility and effectiveness of teledentistry in facilitating remote consultations, reducing unnecessary clinic visits, and optimizing patient care [17]. Furthermore, digital communication platforms have enabled real-time collaboration between clinicians and dental technicians, leading to more accurate and timely fabrication of custom-made surgical guides and prosthetic restorations [18]. This streamlined workflow improves treatment efficiency and patient satisfaction while reducing the risk of errors associated with traditional communication methods [19].

Computer-assisted surgery (CAS) encompasses a variety of applications in oral surgery, leveraging digital technologies to enhance precision, efficiency, and patient outcomes. Some key applications of CAS in oral surgery include[20]:

2.5. Preoperative Planning

CAS facilitates detailed preoperative planning by providing virtual simulations of surgical procedures based on patient-specific anatomical data obtained from imaging modalities such as cone beam computed tomography (CBCT) scans. Surgeons can use specialized software to visualize anatomical structures, assess bone quality and quantity, and plan optimal implant placement or reconstructive procedures. By precisely positioning virtual implants or simulating osteotomies, CAS allows surgeons to anticipate potential challenges and develop comprehensive surgical plans.

2.6. Implant Placement

One of the primary applications of CAS in oral surgery is the precise placement of dental implants. CAS enables surgeons to create virtual implant templates or guides based on preoperative planning, which serve as navigational aids during surgery. These surgical guides provide real-time feedback and guidance to ensure accurate implant placement according to the predetermined plan, minimizing the risk of errors and complications. Additionally, CAS allows for the integration of intraoperative imaging modalities, such as fluoroscopy or optical tracking systems, to further enhance implant placement accuracy.[21,22]

2.7. Orthognathic Surgery

CAS plays a valuable role in orthognathic surgery, which involves correcting congenital or acquired deformities of the jawbones to improve function and facial aesthetics. By precisely planning osteotomies and repositioning the maxilla and mandible, CAS helps achieve optimal skeletal relationships and facial harmony. Virtual surgical planning software allows surgeons to visualize and simulate the desired surgical outcomes, facilitating communication with patients and interdisciplinary collaboration. During surgery, CAS provides real-time guidance and verification to ensure accurate execution of the planned movements, leading to improved surgical outcomes and patient satisfaction.

2.8. Maxillofacial Reconstruction

In cases of maxillofacial trauma or oncologic resections, CAS enables precise planning and execution of reconstructive procedures. Figure 2,3 Surgeons can use virtual surgical planning to design patient-specific osteotomies, grafts, or implants tailored to the individual's anatomy. CAS facilitates the fabrication of custom-made surgical guides or templates to aid in the accurate transfer of the preoperative plan to the surgical field By optimizing surgical precision and minimizing surgical time, CAS contributes to the restoration of form and function in patients undergoing maxillofacial reconstruction [23,24,25]

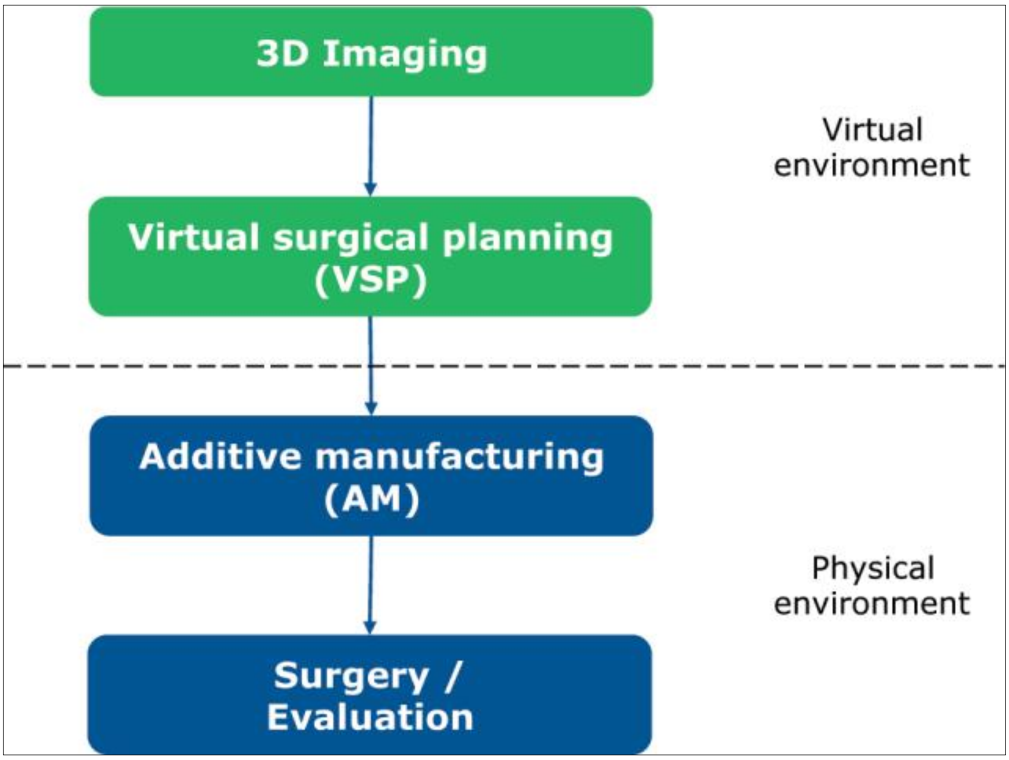

Figure 2 Steps in computer-assisted surgery.[23]

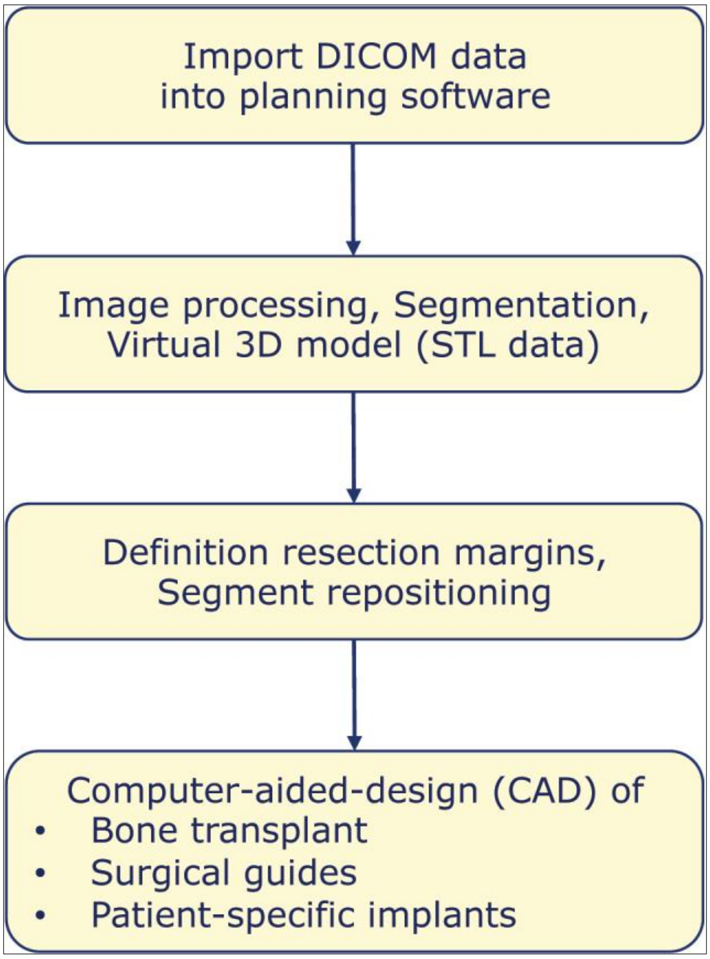

Figure 3 CAD-process in mandibular reconstruction[23]

2.9. Temporomandibular Joint (TMJ) Surgery

CAS is increasingly utilized in temporomandibular joint (TMJ) surgery to address various pathologies, including degenerative joint disease, ankylosis, or trauma. Virtual surgical planning allows for precise assessment of TMJ anatomy and biomechanics, facilitating the selection of appropriate surgical interventions [23]. CAS enables surgeons to simulate osteotomies, condylar repositioning, or joint replacement procedures, ensuring optimal functional outcomes and patient satisfaction [33]. Real-time intraoperative guidance provided by CAS systems enhances the accuracy of surgical maneuvers and helps avoid damage to critical structures surrounding the TMJ [22]

3. Advantages and Challenges of Digital Workflows[26,27]

3.1. Advantages

Enhanced Precision: Digital workflows allow for precise planning and execution of surgical procedures, leading to improved treatment outcomes. Through advanced imaging technologies and computer-aided design (CAD) software, surgeons can visualize anatomical structures in three dimensions, enabling accurate treatment planning and implant placement.

Improved Efficiency: Digital workflows streamline various aspects of oral surgery, reducing chairside time and enhancing patient comfort. Intraoral scanners eliminate the need for traditional impression materials, while CAD/CAM technology enables the fabrication of custom-made surgical guides and prosthetic restorations with greater efficiency and accuracy.

Predictable Outcomes: By simulating surgical procedures in a virtual environment, digital workflows allow surgeons to anticipate potential complications and optimize treatment strategies. Virtual planning enables the assessment of treatment feasibility and the simulation of desired surgical outcomes, leading to more predictable results and reduced surgical risks.

Enhanced Communication: Digital workflows facilitate seamless communication and collaboration among interdisciplinary team members. Digital platforms enable the sharing of patient data, treatment plans, and imaging studies, fostering interdisciplinary teamwork and ensuring comprehensive patient care.

Patient-Centric Care: Digital workflows contribute to a more patient-centered approach to oral surgery. Patients benefit from reduced treatment times, improved treatment outcomes, and enhanced comfort throughout the treatment process. Moreover, digital platforms enable better patient education and engagement, empowering patients to make informed decisions about their oral health.

3.2. Challenges

Initial Investment: Implementing digital workflows in oral surgery requires significant upfront investment in equipment, software, and training. The cost of intraoral scanners, CAD/CAM systems, and 3D printers can be substantial, particularly for smaller practices with limited financial resources.[24]

Technological Complexity: Digital workflows involve multiple technologies and software platforms, which can be complex and challenging to navigate. Surgeons and dental staff require specialized training to effectively utilize digital imaging systems, CAD/CAM software, and intraoral scanners. Moreover, staying updated with rapidly evolving digital technologies poses ongoing challenges.[23,24]

Data Security and Privacy: The digitalization of patient records and imaging data raises concerns about data security and privacy. Practices must implement robust cybersecurity measures to protect sensitive patient information from unauthorized access, breaches, or cyberattacks. Compliance with regulations such as the Health Insurance Portability and Accountability Act (HIPAA) is essential to safeguard patient confidentiality.[20,25,26]

Integration Issues: Integrating digital workflows into existing practice workflows can pose logistical challenges. Practices may encounter compatibility issues when trying to integrate different digital technologies or software systems. Ensuring seamless interoperability between various components of the digital workflow requires careful planning and coordination.

Workflow Disruption: Transitioning to digital workflows may disrupt established practice workflows and routines. Staff members may require time to adapt to new technologies and workflows, leading to temporary decreases in productivity or efficiency. Practices must allocate resources for training and support to minimize workflow disruptions during the transition period.[25]

Future directions and emerging technologies in oral surgery hold promise for further enhancing patient care and treatment outcomes. One area of development lies in the continued integration of artificial intelligence (AI) and machine learning algorithms into digital workflows. These technologies have the potential to revolutionize treatment planning, image analysis, and decision-making processes by providing clinicians with valuable insights and predictive analytics. Additionally, the refinement of augmented reality (AR) and virtual reality (VR) applications is anticipated to play a significant role in surgical training, patient education, and preoperative planning By offering immersive and interactive experiences, AR and VR technologies can improve spatial awareness, enhance surgical precision, and simulate complex procedures in a risk-free environment.[23,26,27]

Furthermore, the adoption of robotic-assisted surgery is expected to expand, offering increased accuracy and precision in various oral surgical procedures. Robotic systems can assist surgeons in performing delicate tasks with enhanced dexterity and control, leading to improved outcomes and reduced surgical complications.[28 Additionally, advancements in 3D printing technology hold promise for the customization of surgical instruments, implants, and prosthetic devices, thereby optimizing treatment outcomes and patient satisfaction. Custom-designed surgical guides and patient-specific implants can facilitate precise surgical interventions and promote faster recovery times.[29,30]]

Moreover, the convergence of digital technologies with regenerative medicine and tissue engineering is poised to revolutionize oral tissue regeneration and reconstruction. Biomimetic materials, growth factors, and stem cell therapies offer new avenues for enhancing tissue regeneration and promoting wound healing in oral surgery. By harnessing the regenerative potential of biomaterials and biological agents, clinicians can address complex defects and improve the long-term functional and aesthetic outcomes for patients.

4. Conclusion

The integration of digital technologies in oral surgery signifies a profound shift in treatment methodologies, offering a diverse range of advantages from improved precision and efficiency to enhanced patient satisfaction and outcomes. The emergence of artificial intelligence, augmented reality, robotic-assisted surgery, 3D printing, and regenerative medicine heralds a new era of innovation and transformation within the field. These cutting-edge technologies hold immense promise for revolutionizing surgical practices, refining treatment planning processes, and advancing overall patient care. However, their widespread adoption requires addressing challenges such as initial investment expenses, technological intricacies, and seamless integration into existing workflows. As ongoing research and development continue to push the boundaries of possibility, it is crucial for clinicians, researchers, and industry experts to collaborate closely in order to fully harness the potential of digital innovations in oral surgery. By embracing these advancements and utilizing them effectively, oral surgeons can usher in a future where personalized, precision-driven care becomes the norm, ultimately benefiting patients worldwide.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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