Online ISSN 2663-8290 Research Article

Academia Journal of Medicine
Vol. 9, No. 2, July–December 2026

Digital Workflow in Maxillofacial Trauma Management: CBCT, Virtual Planning, Navigation and 3D Printing

Anusha Sajish[1*], Sumit Bhatt[2], Amit K[3], Sonika K[4], Priyanka Shanker[5] and Saurabh S Simre[6]

[1]*Assistant Professor, Department of Oral & Maxillofacial Surgery, Rajasthan Dental College & Hospital, Nirwan University, Jaipur, Rajasthan-302042*
[2]*PhD Scholar, Assistant Professor, Department of Oral and Maxillofacial Surgery, Rajasthan Dental College & Hospital, Nirwan University, Jaipur, Rajasthan*
[3]*Professor & Head, Department of Oral and Maxillofacial Surgery, Rajasthan Dental College and Hospital, Nirwan University, Jaipur, Rajasthan-302042*
[4]*Assistant Professor, Department of Oral and Maxillofacial Surgery, Rajasthan Dental College and Hospital, Nirwan University, Jaipur, Rajasthan-302042*
[5]*Dental Officer, ECHS Polyclinic, Kaleshwar, Karanprayag, Uttarakhand- 246446*
[6]*Department of Dentistry, Pt. Ram Sumer Shukla Government Medical College, Rudrapur, Uttarakhand- 263153*

* Corresponding author. E-mail: anushanair.cp@gmail.com

https://doi.org/10.48165/ajm.2026.9.02.26

ARTICLE INFO

Keywords:
Maxillofacial trauma
CBCT
Virtual surgical planning
Computer-assisted navigation

ABSTRACT

Maxillofacial trauma often involves complex three-dimensional fractures requiring precise diagnosis and surgical planning. Digital technologies such as CBCT, virtual surgical planning (VSP), computer-assisted navigation, and 3D printing have significantly improved the management of these injuries. CBCT provides detailed three-dimensional visualization of fracture patterns, while VSP enables virtual fracture reduction and surgical simulation. Navigation systems facilitate accurate intraoperative transfer of the planned procedure, and 3D printing allows fabrication of anatomical models, surgical guides, and patient-specific implants. These technologies can improve surgical accuracy, predictability, and facial symmetry while potentially reducing operative time. However, their use is associated with limitations including cost, technical expertise, additional planning time, and limited standardization. This narrative review highlights the integrated role of digital workflow technologies in modern maxillofacial trauma management and discusses their clinical applications, advantages, limitations, and future potential.

INTRODUCTION

Maxillofacial trauma is a complex clinical condition that can result in functional, aesthetic, and psychological consequences. Accurate diagnosis and restoration of the pre-traumatic three-dimensional facial anatomy are essential for successful treatment. Conventional radiographic assessment and freehand surgical techniques may be challenging in complex fractures, particularly involving the orbit, zygomaticomaxillary complex, mandible, and panfacial region.[1]

The rapid development of digital technology has transformed the management of maxillofacial trauma. Computed tomography (CT) and cone-beam computed tomography (CBCT) provide detailed three-dimensional visualization of fracture patterns and anatomical structures. These imaging modalities can be integrated with virtual surgical planning (VSP) to simulate fracture reduction, assess facial symmetry, and plan fixation before surgery. Computer-assisted navigation further enables real-time guidance during fracture reduction and reconstruction, while three-dimensional (3D) printing allows fabrication of anatomical models, surgical guides, patient-specific implants, and prebent fixation plates.[2,3]

The integration of these technologies creates a comprehensive digital workflow, extending from diagnosis and virtual planning to intraoperative execution and postoperative evaluation. This approach can improve surgical precision, predictability, and efficiency, particularly in complex maxillofacial injuries. However, challenges such as cost, technical expertise, planning time, equipment availability, and lack of standardized protocols may limit widespread clinical adoption.[4]

Therefore, this narrative review discusses the evolving role of CBCT, virtual surgical planning, computer-assisted navigation, and 3D printing in maxillofacial trauma management, focusing on their clinical applications, advantages, limitations, and future perspectives

Digital Transformation in Maxillofacial Trauma

The management of maxillofacial trauma has evolved considerably from conventional two-dimensional radiography and freehand surgical techniques toward advanced three-dimensional digital technologies. Conventional radiographs remain useful for initial assessment; however, their ability to accurately demonstrate complex fracture patterns, displacement, and three-dimensional anatomical relationships is limited. The introduction of computed tomography (CT) and cone-beam computed tomography (CBCT) has enabled detailed visualization and three-dimensional reconstruction of the facial skeleton, improving diagnostic accuracy and treatment planning.

Digital technologies have also transformed the surgical management of facial fractures. Three-dimensional imaging can be integrated with virtual surgical planning (VSP) to visualize fracture segments, simulate reduction, assess facial symmetry, and plan fixation before surgery. Computer-assisted navigation allows the virtual plan to be transferred to the operating field, while 3D printing can produce anatomical models, surgical guides, and patient-specific implants. These technologies are particularly valuable in complex orbital, zygomaticomaxillary, midface, mandibular, and panfacial injuries.

An integrated digital workflow connects these technologies into a continuous process, beginning with CT/CBCT image acquisition and 3D reconstruction, followed by virtual planning and fracture reduction, intraoperative navigation or 3D-printed guide-assisted surgery, and postoperative assessment. This approach facilitates more predictable and precise reconstruction of pre-traumatic anatomy and improves communication between the surgeon, radiologist, and technical team. Thus, digital workflow represents a shift from isolated technological applications toward a coordinated, patient-specific approach to modern maxillofacial trauma management **(Fig 1)**.[3-5]

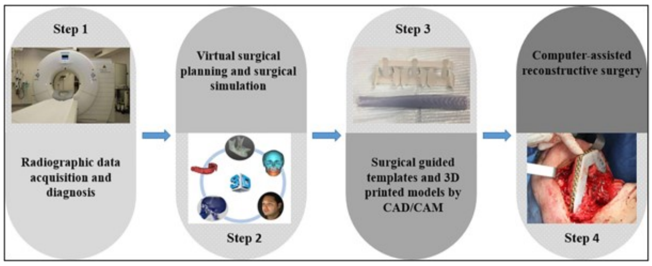

Figure 1: Integrated Digital Workflow in Maxillofacial Trauma Management

CBCT and 3D Imaging in Maxillofacial Trauma

Cone-beam computed tomography has become an important component of modern maxillofacial trauma assessment because of its ability to provide high-resolution three-dimensional images of the craniofacial skeleton. Conventional two-dimensional radiographs may provide limited information regarding the exact location and displacement of fracture fragments because of anatomical superimposition. CBCT overcomes many of these limitations by allowing multiplanar visualization in axial, coronal, and sagittal planes, as well as three-dimensional reconstruction of the facial skeleton.[6,7]

Principles and Applications of CBCT

CBCT uses a cone-shaped X-ray beam and a rotating detector to acquire multiple projections around the patient, which are subsequently reconstructed into a three-dimensional volumetric dataset. The acquired data can be reviewed in different planes and manipulated using dedicated software. In maxillofacial trauma, CBCT is particularly useful when detailed evaluation of osseous structures is required, including assessment of fracture lines, fragment displacement, cortical disruption, and involvement of important anatomical landmarks.[8]

Assessment of Fracture Patterns and Displacement

Three-dimensional imaging provides a better understanding of the morphology and spatial relationship of fracture segments. This is particularly important in comminuted, displaced, and complex fractures, where conventional radiographs may not adequately demonstrate the extent of injury. CBCT can help identify the number and orientation of fracture fragments, degree of displacement, and involvement of adjacent anatomical structures. Accurate visualization of these features assists surgeons in selecting appropriate reduction and fixation strategies.[8]

Evaluation of Different Maxillofacial Fractures

CBCT has applications across a wide range of maxillofacial injuries. In **orbital fractures**, it can demonstrate defects of the orbital floor and walls and help evaluate their relationship with the orbit and infraorbital canal. In zygomaticomaxillary complex fractures, three-dimensional imaging facilitates assessment of fracture involvement at the zygomatic arch, orbital rim, frontozygomatic region, and maxillary buttress. In mandibular fractures, CBCT provides detailed information regarding fracture location, displacement, tooth involvement, and the relationship of the fracture to the inferior alveolar canal. In midface and panfacial trauma, CT-based three-dimensional reconstruction is particularly valuable for understanding the overall pattern of skeletal disruption and planning sequential reconstruction.

3D Reconstruction and Anatomical Visualization: A major advantage of digital imaging is the ability to convert volumetric datasets into three-dimensional virtual models. Through segmentation, different anatomical structures and fracture fragments can be identified and digitally manipulated. The reconstructed model allows visualization of the patient's facial skeleton from different perspectives and can be used to evaluate facial asymmetry and simulate fracture reduction. These datasets can subsequently be transferred to virtual surgical planning (VSP), computer-assisted navigation systems, and 3D-printing platforms, creating a direct connection between diagnosis and surgical treatment.

Advantages of CBCT and 3D Imaging

The major advantages include improved visualization of complex fracture anatomy, multiplanar assessment, accurate identification of fracture displacement, better understanding of three-dimensional anatomical relationships, and improved preoperative planning. Digital datasets can also be stored, shared, and integrated with other computer-assisted technologies. This facilitates multidisciplinary communication and enables patient-specific surgical strategies.

Limitations

Despite its advantages, CBCT has certain limitations. Radiation exposure, although generally lower than conventional medical CT for many dental applications, remains an important consideration. CBCT also provides relatively limited soft-tissue information compared with medical CT and may be affected by artifacts from metallic restorations or fixation materials. Image quality can also vary depending on the scanning protocol and patient movement. Furthermore, advanced 3D reconstruction and segmentation require appropriate software, technical expertise, and additional resources, which may limit accessibility in resource-constrained settings.

Overall, CBCT and 3D imaging form the foundation of the digital workflow in maxillofacial trauma, providing the anatomical data required for virtual planning, navigation, and 3D printing. Their integration with subsequent digital technologies allows a transition from conventional image-based diagnosis toward more precise and patient-specific trauma management.[6,7]

Virtual Surgical Planning (VSP):

Virtual surgical planning has become an important component of digital maxillofacial trauma management, allowing surgical procedures to be planned on a three-dimensional virtual model before entering the operating room. VSP begins with the acquisition of high-resolution CT/CBCT datasets, which are imported into specialized software for image processing and segmentation. Bone, teeth, orbital structures, and individual fracture fragments can be digitally separated to create an accurate three-dimensional representation of the patient's facial skeleton.[9]

Acquisition and Segmentation of Imaging Data

The quality of VSP depends largely on the quality of the initial CT/CBCT dataset. The acquired DICOM data are imported into planning software, where segmentation is performed to distinguish bone and other relevant anatomical structures. In complex trauma, individual fracture segments can be isolated and manipulated independently. Accurate segmentation is essential because errors at this stage can affect subsequent virtual reduction and surgical execution.[10-11]

3D Reconstruction of the Facial Skeleton

Following segmentation, a three-dimensional virtual model of the craniofacial skeleton is generated. The model can be rotated, enlarged, and viewed from different angles, allowing detailed assessment of fracture morphology and displacement. In unilateral injuries, the unaffected side can also serve as a reference for restoring the anatomy of the fractured side.

Virtual Fracture Reduction

One of the major advantages of VSP is the ability to perform virtual fracture reduction before surgery. Displaced fracture segments can be digitally repositioned according to anatomical landmarks, occlusion, and facial symmetry. In selected unilateral fractures, mirroring of the unaffected side can provide a useful template for reconstructing the injured region. This allows the surgeon to evaluate the proposed reduction and identify potential difficulties before the procedure.

Simulation of Osteotomies and Fixation

VSP can also be used to simulate osteotomies, determine the planned position of fracture segments, and select appropriate fixation strategies. The position and orientation of fixation plates can be planned virtually, and the resulting plan can subsequently be transferred to the operating room using patient-specific surgical guides, prebent plates, or computer-assisted navigation. This can be particularly beneficial in complex orbital, midface, zygomaticomaxillary, and panfacial trauma

Assessment of Facial Symmetry and Occlusion

Restoration of facial symmetry and occlusion is an important objective in maxillofacial trauma surgery. VSP allows comparison of the injured anatomy with the unaffected side or with pre-traumatic anatomical references when available. Virtual planning can help assess facial width, projection, orbital position, and skeletal relationships. In mandibular and maxillary injuries, the dental arches and occlusal relationship can also be incorporated into the planning process to facilitate restoration of functional occlusion. [10,11]

Benefits of VSP

The principal advantages of VSP include improved understanding of complex fracture anatomy, enhanced preoperative planning, visualization of the desired surgical outcome, improved communication among the surgical team, and greater surgical predictability. It may also facilitate the use of patient-specific implants and surgical guides and potentially reduce intraoperative decision-making and operative time in selected complex cases. [10,11]

Limitations of VSP

Despite its advantages, VSP has several limitations. It requires specialized software, trained personnel, appropriate imaging data, and additional preoperative planning time. The cost of software, hardware, and associated services may restrict its availability, particularly in resource-limited settings. Errors may occur during image segmentation, virtual manipulation, or transfer of the virtual plan to the patient. Furthermore, severe comminution, intraoperative changes, soft-tissue factors, and unexpected anatomical findings may make exact reproduction of the virtual plan difficult.

Overall, VSP represents a transition from conventional experience-based planning toward a patient-specific, digitally simulated approach. When integrated with CBCT/CT imaging, navigation, and 3D printing, it forms a central component of the modern digital workflow for complex maxillofacial trauma. [10,11]

Computer-Assisted Surgical Navigation

Computer-assisted surgical navigation (CASN) is an advanced technology that provides real-time guidance during maxillofacial trauma surgery. It links the patient's anatomy with preoperative CT/CBCT data and the virtual surgical plan, allowing the surgeon to monitor the position of surgical instruments and fracture segments during the procedure. This is particularly useful in anatomically complex regions where direct visualization is limited, such as the orbit, midface, skull base, and zygomaticomaxillary complex.

Principles of Surgical Navigation

The navigation process generally begins with acquisition of a high-resolution CT/CBCT dataset and preparation of a virtual surgical plan. During surgery, the patient's anatomy is registered with the preoperative 3D dataset using anatomical landmarks or reference markers. A tracking system continuously determines the position of surgical instruments relative to the patient's anatomy. The surgeon can then view the instrument position on axial, coronal, sagittal, or three-dimensional images.

Applications in Maxillofacial Trauma

Navigation is particularly valuable for orbital fractures, where accurate restoration of orbital walls and volume is essential. It can assist in positioning implants and confirming the boundaries of reconstruction. In zygomaticomaxillary complex fractures, navigation can help achieve accurate three-dimensional reduction by providing information about the position of displaced fragments relative to the unaffected facial skeleton.In midface and panfacial trauma, navigation can assist with sequential fracture reduction and restoration of facial width, projection, and symmetry. It may also be

Table 1

Table 1: Clinical Applications of Digital Workflow in Maxillofacial Trauma	
Trauma	**Digital Application**
Orbital fractures	VSP, orbital volume analysis, navigation, PSI
Zygomaticomaxillary complex fractures	3D reconstruction, VSP, navigation
Mandibular fractures	Virtual reduction, occlusal planning, surgical guides
Midface fractures	VSP, navigation, 3D-printed models
Panfacial fractures	Comprehensive virtual planning and navigation
Comminuted fractures	3D models, patient-specific guides/implants

useful in complex or comminuted fractures where conventional anatomical landmarks are distorted or difficult to identify

Integration with Virtual Surgical Planning

The major advantage of navigation is its ability to transfer the preoperative virtual plan into the operating room. The surgeon can compare the actual position of fracture segments with the planned position during surgery. This creates a continuous digital pathway from CT/CBCT imaging → virtual planning → intraoperative navigation → surgical reconstruction.[11,12]

Advantages

Real-time intraoperative guidance

Improved localization of anatomical structures

More accurate fracture reduction

Assistance in restoring facial symmetry

Useful in complex and comminuted fractures

Helps verify implant and reconstruction positioning

Reduces dependence on limited intraoperative visualization

Facilitates execution of the virtual surgical plan

Limitations

Navigation systems have several limitations, including high equipment costs, requirement for specialized training, additional setup time, and registration errors. Patient movement, changes in anatomy during surgery, and inaccurate registration can reduce navigation accuracy. The system also provides guidance rather than physically correcting the fracture, and therefore remains dependent on the surgeon's judgment and surgical skills.

Overall, computer-assisted navigation serves as an important bridge between virtual planning and actual surgical execution, particularly in complex maxillofacial trauma. Its integration with 3D imaging, VSP, and 3D printing has the potential to improve the accuracy and predictability of reconstructive procedures.

Three-Dimensional Printing in Maxillofacial Trauma

Three-dimensional (3D) printing has emerged as a valuable component of digital maxillofacial trauma management. CT/CBCT-derived data can be converted into physical anatomical models that provide a direct representation of complex fracture patterns. These models can assist in preoperative planning, fracture simulation, and patient education.[13]

3D printing can also be used to fabricate patient-specific surgical guides, occlusal splints, prebent fixation plates, and customized implants. In complex orbital, zygomaticomaxillary, mandibular, and panfacial fractures, these applications may improve surgical accuracy and facilitate restoration of pre-traumatic anatomy.[14]

The major advantages include improved visualization, patient-specific planning, and potentially reduced operative time. However, high cost, printing time, technical expertise, material limitations, and accessibility remain important challenges. Overall, 3D printing complements CBCT, virtual surgical planning, and navigation to create a more precise and individualized digital workflow in maxillofacial trauma.[13-15 table 1]

Advantages of Digital Workflow

Improved anatomical visualization

Greater surgical precision

Better restoration of facial symmetry

Improved preoperative planning

Reduced intraoperative uncertainty

Potential reduction in operative time

Enhanced surgical predictability

Better communication and patient education

Limitations and Challenges

High initial cost

Requirement for specialized software and equipment

Learning curve

Additional planning time

Registration and navigation errors

CBCT/CT radiation considerations

Difficulty with severely comminuted fractures

Limited accessibility in resource-constrained settings

Lack of standardized protocols and long-term evidence

Future Perspectives

The future of digital maxillofacial trauma management lies in the integration of artificial intelligence, augmented reality, robotics, advanced 3D printing, and patient-specific implants. AI-assisted fracture segmentation and automated virtual planning may further improve accuracy and reduce planning time. Greater accessibility, standardization, and cost reduction are expected to support wider clinical adoption

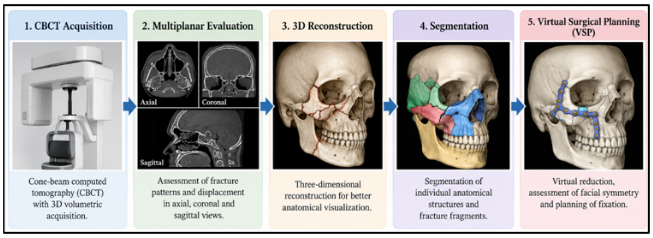

Figure 2: Role of CBCT in the Digital Workflow of Maxillofacial Trauma: From Three-Dimensional Imaging to Virtual Surgical Planning

CONCLUSION

The integration of CBCT, virtual surgical planning, computer-assisted navigation, and 3D printing has transformed the management of complex maxillofacial trauma. These technologies improve anatomical visualization, surgical planning, accuracy, and predictability. Despite limitations related to cost, expertise, and standardization, an integrated digital workflow represents a promising approach toward precise, efficient, and patient-specific trauma reconstruction.

REFERENCES

Bavestrello Piccini, G., Sfondrini, D., Tomulescu, S. A., Esposito, C., Piccioni, A., Caputo, G., Voza, A., Zanza, C., Longhitano, Y., & Savioli, G. (2026). Modern management of maxillofacial trauma in the emergency department. *World Journal of Emergency Medicine, 17*(1), 15–27.

Weiss, R., 2nd, & Read-Fuller, A. (2019). Cone beam computed tomography in oral and maxillofacial surgery: An evidence-based review. *Dentistry Journal, 7*(2), 52.

Antonelli, A., Bennardo, F., & Giudice, A. (2024). Breakthroughs in oral and maxillofacial surgery. *Journal of Clinical Medicine, 13*(3), 685.

Rana, M., Sakkas, A., Zimmermann, M., Kostyuk, M., & Schwarz, G. (2026). Artificial intelligence in oral and maxillofacial surgery: Integrating clinical innovation and workflow optimization. *Journal of Clinical Medicine, 15*(2), 427.

van den Dries, S., He, P., & Panchal, N. (2026). The expanding role of virtual surgical planning in maxillofacial trauma management. *Dental Clinics of North America, 70*(3), 703–723.

Kaasalainen, T., Ekholm, M., Siiskonen, T., & Kortesniemi, M. (2021). Dental cone beam CT: An updated review. *Physica Medica, 88*, 193–217.

Theodoridis, C., Damaskos, S., & Angelopoulos, C. (2024). Frequency and clinical significance of incidental findings on CBCT imaging: A retrospective analysis of full-volume scans. *Journal of Oral and Maxillofacial Research, 15*(1), e5.

Baccher, S., Gowdar, I. M., Guruprasad, Y., Solanki, R. N., Medhi, R., Shah, M. J., & Mehta, D. N. (2024). CBCT: A comprehensive overview of its applications and clinical significance in dentistry. *Journal of Pharmacy and Bioallied Sciences, 16*(Suppl. 3), S1923–S1925.

Zoabi, A., Redenski, I., Oren, D., Kasem, A., Zigron, A., Daoud, S., Moskovich, L., Kablan, F., & Srouji, S. (2022). 3D printing and virtual surgical planning in oral and maxillofacial surgery. *Journal of Clinical Medicine, 11*(9), 2385.

Lassausaie, A., Sesqué, A., Barthélémy, I., & Depeyre, A. (2020). Virtual surgery planning and three-dimensional printing template for osteotomy of the zygoma to correct untreated zygomaticomaxillary complex fracture. *Journal of Craniofacial Surgery, 31*(4), 1142–1145.

Longeac, M., Depeyre, A., Pereira, B., Barthelemy, I., & Pham Dang, N. (2021). Virtual surgical planning and three-dimensional printing for the treatment of comminuted zygomaticomaxillary complex fracture. *Journal of Stomatology, Oral and Maxillofacial Surgery, 122*(4), 386–390.

Kupfer, P., Cheng, A., Patel, A., Amundson, M., Dierks, E. J., & Bell, R. B. (2017). Virtual surgical planning and intraoperative imaging in management of ballistic facial and mandibular condylar injuries. *Atlas of the Oral and Maxillofacial Surgery Clinics of North America, 25*(1), 17–23.

King, B. J., Park, E. P., Christensen, B. J., & Danrad, R. (2018). On-site 3-dimensional printing and preoperative adaptation decrease operative time for mandibular fracture repair. *Journal of Oral and Maxillofacial Surgery, 76*(9), 1950.e1–1950.e8.

Xue, R., Lai, Q., Sun, S., Lai, L., Tang, X., Ci, J., Zhang, Z., & Wang, Y. (2019). Application of three-dimensional printing technology for improved orbital-maxillary-zygomatic reconstruction. *Journal of Craniofacial Surgery, 30*(2), e127–e131.

Manmadhachary, A., Aditya Mohan, A., & Haranadha Reddy, M. (2021). Manufacturing of customized implants for orbital fractures using 3D printing. *Bioprinting, 21*, e00118.

How to Cite this Article: Sajish A., Bhatt S., K A., K S., Shanker P., S Simre S.. (2026). Digital Workflow in Maxillofacial Trauma Management: CBCT, Virtual Planning, Navigation and 3D Printing. *Academia Journal of Medicine*, ***9***(2), 152-157. https://doi.org/10.48165/ajm.2026.9.02.26