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# Innovations and Emerging Trends in Oral and Maxillofacial Surgery: A Comprehensive Review

**Dr. Ramandeep Singh Brar[1], Dr. Jasmine[*2], Dhanashree Jadhav[3], Dr. Noaman Kazi[4], Dr. Ankush Chavan[5], Dr. Mohan D. Deshpande[6]**

[1]Professor and Head, Department of Oral & Maxillofacial Surgery, Dasmesh Institute of Research and Dental Sciences, Faridkot

[2]Associate Professor, Department of Oral & Maxillofacial Surgery, Dasmesh Institute of Research and Dental Sciences, Faridkot

[3]Head of Department of Dentistry, Bharat Ratna Atal Bihari Vajpayee Medical College, Pune

[4]Associate Professor, Department of Oral & Maxillofacial Surgery, M.A. Rangoonwala College of Dental Sciences and Research Centre, Pune

[5]Assistant Professor, Department of Oral & Maxillofacial Surgery, Nair Hospital Dental College, Mumbai

[6]Associate Professor, Department of Oral & Maxillofacial Surgery, Nair Hospital Dental College, Mumbai

***Corresponding Author:**

Dr. JasmineSobana R

## ABSTRACT

Over the last decade, oral and maxillofacial surgery (OMFS) has shifted from artisan, freehand techniques to digitally planned, image-guided, biologically informed care. Cone-beam CT (CBCT) now anchors diagnostics; intraoral scanning (IOS) streamlines impressions; and virtual surgical planning (VSP) with CAD/CAM and additive manufacturing improves geometric fidelity while often reducing operative time. Patient-specific implants, dynamic navigation, arthroscopy, sialendoscopy, and piezoelectric osteotomy have lowered morbidity. Regenerative options—including calcium-phosphate ceramics, bioactive glass, autogenous dentin derivatives, platelet concentrates, and selective rhBMP-2—have reduced donor-site burden. Patient-reported outcomes (PROMs) increasingly define success. This review synthesizes evidence and implementation guidance for Indian public institutions, emphasizing standardization, validation (including AI), point-of-care manufacturing, and equitable access.

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## 1. INTRODUCTION: FROM FREEHAND TO PLANNED, FROM CUTTING TO CONSERVING

Clinical decision-making in oral and maxillofacial surgery (OMFS) has shifted decisively from plate-bending, wafer-guided "feel" to virtual rehearsals, guide-assisted osteotomies, and patient-specific fixation. Typical contemporary pathways begin with cone-beam computed tomography (CBCT), frequently merged with an intraoral scan (IOS) to create a coherent three-dimensional record that drives diagnosis, planning, and the manufacture of surgical guides and plates. Deviations that previously resided in the realm of surgical intuition are now measured in millimetres and degrees. In parallel, success is increasingly defined by patient-reported outcomes—pain, swelling, mastication and speech, daytime sleepiness, appearance, confidence, and time to return to study or work—captured with validated instruments such as FACE-Q and CLEFT-Q (PROMs).[1], [2].[3]

This practice-oriented review synthesizes evidence across four pillars: (i) digital integration (CBCT, IOS, virtual surgical planning [VSP]/CAD-CAM/3D printing, and early but useful AI); (ii) biomaterials and regenerative concepts; (iii) minimally invasive techniques and intraoperative guidance; and (iv) patient-centred outcomes and pathways relevant to public-sector services in India. Emphasis is placed on operational details that help departments move from demonstration projects to routine, auditable service.

## 2. DIGITAL INTEGRATION

### 2.1 CBCT: the three-dimensional backbone

Authoritative guidance from the American Academy of Oral and Maxillofacial Radiology (AAOMR) remains the reference for implant imaging selection criteria, emphasizing when cross-sectional imaging is appropriate, how to justify dose, and the importance of trained interpretation.[4]. The AAE–AAOMR joint statement similarly clarifies focused indications in endodontics and reinforces "as low as diagnostically acceptable" principles[5]. Translating these guidance documents into routine practice requires structured protocols rather than "scan first, think later." In practical terms, field of view (FOV) should be limited to the region of interest; voxel size chosen to match the clinical task (for example, ≤0.2 mm for implant site characterisation); metal and motion artefacts anticipated and mitigated; and reports should explicitly describe inferior alveolar canal variants and mental loop, sinus septa and lateral wall thickness, and ostium patency.[4], [5]

**Why this matters for outcomes:** Systematic reviews demonstrate higher sensitivity of CBCT compared to periapical radiography for detecting apical periodontitis and several endodontic complications, with downstream implications for how success rates are reported [6], [7], [8], [9]. If a department moves from 2D to 3D endpoints without stating that change, apparent "success" can drop simply because the detection method has improved.

**Everyday OMFS touchpoints:** CBCT adds the greatest value where risk mapping determines access or technique—high-risk third molars (inferior alveolar canal proximity and variants), sinus evaluation before augmentation (septa, lateral wall, ostium), orthognathic planning, and oncologic work-ups.[4]

### 2.2 Intraoral scanning (IOS): comfort plus workflow

Across fixed prosthodontic and implant workflows, IOS reduces chair time and improves patient comfort while providing accuracy comparable to conventional impressions for appropriate indications (single units, short spans, disciplined scan paths, verified scan-body seating). Patient preference reliably favours digital impressions, while clinicians benefit from seamless hand-off to laboratories and VSP platforms.[10]

**Precision is not "plug-and-play."** A 2024 systematic review details how scan-body geometry/material, arch length, implant angulation, surface reflectivity, and scanner type influence trueness and precision—necessitating scanner-specific protocols, lighting standards, and QA checklists to avoid drift.[11] Three practical tips make noticeable differences in public clinics: (i) a standardised scan path (palatal/lingual, then occlusal, then buccal) to minimise stitching errors; (ii) mandatory macroscopic or periapical confirmation of scan-body seating before scanning; and (iii) periodic trueness checks against a reference model, recorded in a scanner QA log.[10], [11]

**Full-arch and edentulous nuances:** Full-arch trueness remains more challenging than short spans due to accumulated stitching error, soft-tissue mobility, and reflective surfaces. For complete-arch implant frameworks, scanner choice, scan-body design, and ambient lighting control are particularly consequential.[11] Where full-arch trueness cannot be guaranteed, departments may adopt a hybrid pathway (IOS for quadrants; conventional impressions when a threshold of uncertainty is crossed), thereby matching technology to indication without dogma.

### 2.3 VSP, CAD/CAM, and 3D printing: operating twice, cutting once

Across orthognathics and craniomaxillofacial reconstruction, VSP improves geometric fidelity compared with conventional methods and, in multiple series and meta-analyses, reduces operative time—especially in multi-segment or complex movements[12]. Accuracy metrics commonly reported include linear deviations (<2 mm) and angular deviations (<4°), with waferless, guide-and-plate protocols enabling independent maxillary positioning. Cost analyses in head-and-neck reconstruction suggest VSP is often cost-saving or cost-neutral, largely through reduced operating-room time and length of stay; in-house planning/printing typically enhances affordability and turnaround by avoiding vendor fees and delays.[13]

**Patient-specific implants (PSIs).** Long-term clinical series for 3D-printed titanium PSIs report reliable integration, accurate contour restoration, and acceptable complication rates after oncologic or traumatic defects[14]. PSIs tend to be most advantageous when complex three-dimensional contours, occlusal relationships, or limited exposure favour precisely pre-formed solutions. Orthognathic teams increasingly deploy PSI plates with cutting guides to execute planned movements while preserving condylar seating; verification jigs provide intraoperative checks in midline, yaw, and pitch.[12], [13], [14]

**Service design for Indian public institutions.** A modest point-of-care (POC) lab capable of printing splints and cutting guides (and prototyping plates) can shorten vendor-dependent timelines, increase surgeon control, and unlock savings through reduced OR minutes—benefits aligned with cost literature[13].

### 2.4 Early—but useful—AI

Artificial intelligence has become pragmatic where repetitive digital tasks bottleneck care. External-test studies demonstrate high performance for automated mandibular canal segmentation on CBCT and for classifying the third-molar–canal relationship—both crucial for safer third-molar surgery and posterior implant planning[15],[16]. In clinical implementation, a "human-in-the-loop" workflow limits risk: cross-sectional spot-checks at the mental foramen/lingula, deliberate searches for bifid/accessory canals, overlay of predicted masks on raw greyscale to detect drift, and audit-traced edits before locking the plan.[16], 17]

### 2.5 Interoperability, data governance, and audit culture

Digital care works only if data move cleanly and securely. DICOM export from CBCT units, lossless STL handling, and consistent file-naming conventions prevent silent errors downstream (e.g., version mismatches between planning and printed guides). Access logs, role-based permissions, and regular backups satisfy governance requirements and reassure hospital IT teams. For teaching hospitals, anonymised case libraries—curated with consent and tagged with outcome fields—double as training assets for residents and as seeds for multi-centre registries. Audit templates should be simple: "planning-to-execution deviation," "guide seating issues," "re-print required," and "time in theatre saved" are metrics clinicians engage with and administrators understand.

## 3. BIOMATERIALS AND REGENERATIVE STRATEGIES

### 3.1 Alloplasts that behave biologically

Autogenous bone remains the benchmark for osteogenesis/osteoinduction; however, donor-site morbidity and limited volume sustain the search for reliable substitutes. Contemporary materials science supports calcium-phosphate ceramics and bioactive glasses in many maxillofacial indications when combined with membranes and stable fixation.[18], [19]

**What is new in chemistry and architecture?** Calcium-phosphate ceramics can be engineered as hydroxyapatite (HA), β-tricalcium phosphate (β-TCP), or biphasic compositions (BCP), with porosity and interconnectivity tuned to balance strength and resorption kinetics[18]. Bioactive glasses (e.g., 45S5-type) release biologically active ions (e.g., Ca, Si) that modulate osteogenesis and antimicrobial behaviour; newer polymer-glass composites aim to improve handling and mouldability without sacrificing ion release[19]. From a surgical perspective, these design choices matter most when load bearing is minimal and when the defect geometry is contained (e.g., sinus floor, alveolar ridges with intact walls).

**Membranes and fixation:** barrier membranes (collagen, PTFE) remain essential for guided bone regeneration (GBR); the more the graft relies on space maintenance rather than osteoinduction, the more fixation (tacks, pins, screws) is needed to prevent micromovement that otherwise collapses porosity and sabotages angiogenesis.

**Posterior maxilla choices.** Where vertical bone is limited, high-level evidence indicates that both sinus floor elevation (lateral or crestal) and short implants can achieve high survival when patient selection and technique are disciplined; selection should be individualised by residual bone height, systemic risk factors, morbidity, cost, and patient preference regarding staged care.[20].[21],[22]. The clinical implication is a tiered decision tree: (i) if residual bone height is adequate and anatomy favourable, select short implants to avoid grafting; (ii) if height is borderline and sinus anatomy straightforward, consider crestal elevation; (iii) if height is insufficient and septa or thin lateral walls complicate access, lateral window with piezo assistance may minimise membrane injury while permitting controlled graft placement.[20].[21],[22].

#### 3.1.1 Autogenous tooth/dentin-derived graft

Autogenous tooth/dentin—as particulate graft or demineralised dentin matrix—has emerged as a pragmatic option in resource-constrained systems. Systematic reviews report favourable histomorphometry and ridge-dimension maintenance relative to spontaneous healing, and competitive outcomes versus xenografts/alloplasts for indicated defects.[23], [24]

### 3.2 Platelet concentrates (PRF/PRP/CGF)

Autologous platelet concentrates are mainstream adjuncts in sockets, sinus grafts, peri-implant defects, and soft-tissue procedures. A recent umbrella review and indication-specific syntheses support earlier soft-tissue healing and radiographic bone fill for defined indications, while highlighting heterogeneity in tubes, spins (g-force/time), and handling.[26]

### 3.3 rhBMP-2: potent, selective, expensive

Recombinant human BMP-2 remains a powerful osteoinductive tool for segmental defects and salvage scenarios. Contemporary maxillofacial reviews emphasise judicious, consent-rich use because dose and carrier influence oedema and other adverse effects; cost constraints in public systems argue for reserving rhBMP-2 where alternatives are unlikely to succeed biologically.[27]

## 4. MINIMALLY INVASIVE OMFS AND IMAGE GUIDANCE

### 4.1 Arthroscopy and sialendoscopy

Arthroscopy for internal derangements yields meaningful improvements in pain and function with low morbidity in experienced hands, facilitating earlier return to routine compared with early open procedures in appropriately selected cases.[7] The maturation of optics and instrumentation has reduced the learning curve; nevertheless, programme quality still hinges on patient selection and disciplined post-operative physiotherapy.

In salivary obstruction, sialendoscopy has transformed care. Large pooled analyses and long-term series report high stone-clearance success and low rates of gland loss and major complications, establishing endoscopy as the first-line, gland-preserving approach for most obstructive disorders.[28]

### 4.2 Piezoelectric osteotomy

Piezoelectric surgery—ultrasonic micro-vibrations that selectively cut mineralised tissues—has become a preferred approach for membrane-sparing sinus windows and high-risk third molars where soft-tissue protection is paramount. Recent systematic reviews of third-molar extraction show reductions in postoperative pain, swelling, and trismus with piezo compared with rotary techniques, albeit with longer osteotomy times—an outpatient-appropriate trade-off.[15]

**Sinus augmentation nuance:** Evidence on Schneiderian membrane perforation during sinus lifts is mixed; published series and reviews suggest lower perforation odds with piezo-created windows in some hands, while randomised data find broadly similar rates compared with rotary burs.[15],[20] The safest practice pairs piezo windows with meticulous elevation technique, appropriate curette selection, and respect for anatomic risk factors (thin membranes, septa, smoking). Departments should explicitly teach "abort and stage" thresholds to junior staff to avoid forcing an elevation when vision or control is compromised.

### 4.3 Dynamic navigation and mixed reality

Computer-assisted navigation now spans the OMFS spectrum—implants, foreign-body removal, complex lesions, orbital floors and medial walls—with target registration errors commonly around 1 mm when registration and calibration are rigorous.[29] Prospective and comparative clinical studies demonstrate clinically acceptable accuracy of dynamic navigation relative to planned positions and greater consistency than freehand placement, albeit with setup time and cost considerations.[30], [31], [32]

Beyond implantology, navigation is particularly helpful for accessing posterior-medial orbital floor fractures through minimal incisions, localising radiopaque foreign bodies near the skull base, and guiding osteotomies around critical structures in recurrent odontogenic tumours; real-time visualisation of instruments against the plan improves whole-team anticipation and speed.[29],[33] Mixed-reality overlays are clinically feasible but remain adjunctive until robust comparative outcomes mature.

## 5. PATIENT-CENTRED OUTCOMES (PROMS/PREMS) AND PERI-OPERATIVE PATHWAYS

PROMs have become integral to evaluation in orthognathic and craniofacial surgery. The FACE-Q (Craniofacial) and CLEFT-Q instruments provide validated scales for appearance, function, and psychosocial domains across languages and contexts, enabling routine capture of outcomes that matter to patients.[1],[2] Orthognathic systematic reviews consistently document quality-of-life gains after surgery, complementing radiographic success metrics.[2] For obstructive sleep apnoea (OSA), maxillomandibular advancement (MMA) improves polysomnographic indices and yields meaningful PROM improvements—daytime sleepiness (Epworth), disease-specific quality of life (e.g., FOSQ), and high overall satisfaction—with neurosensory effects generally transient.[3]

PROMs naturally dovetail with the AAOMS Parameters of Care (ParCare 2023) and the AAOMS Office-Based Anaesthesia White Paper, which emphasise standardised assessment, consent, documentation, and crisis readiness through simulation and drills.[9],[34] ParCare-aligned checklists, OBEAM-style drills, and routine PROM capture can harmonise safety and quality across multi-site public teaching clinics and support accreditation readiness.[9],[34]

## 6. IMPLEMENTATION FOR INDIA: SKILLS, SYSTEMS, AND EQUITY

### 6.1 Skills and curricula

Graduates require fluency in classical OMFS (anatomy, occlusion, flaps, microsurgery) and in the digital language (DICOM handling, segmentation QA, registration error sources, scan-body idiosyncrasies, basic statistics for audit, and AI verification). Simulation is central—orthognathic VSP rehearsals; sedation/anaesthesia crisis drills; dry-lab guided-surgery sessions that make failure modes explicit (guide warpage, seating errors).[9],[34] Assessment can be competency-based: a resident should demonstrate (and be signed off for) each node in the digital chain (CBCT prescription and justification, IOS accuracy checks, VSP review participation, theatre execution with guide verification).

### 6.2 Systems and operating models

Building a reliable human-in-the-loop pipeline begins with a CBCT protocol (FOV/voxel/dose justification), an IOS checklist (scan-body fit, scan path, lighting), and a VSP design review in which OMFS, orthodontics/prosthodontics, radiology, and biomedical engineering confirm occlusion, midlines, condylar seating, soft-tissue expectations, and fixation strategy.

**POC design/printing:** where feasible, an in-house lab—at minimum for splints and cutting guides, with plate prototyping—can shave days off vendor timelines (especially in oncology) and may be cost-neutral or cost-saving via reductions in OR minutes and length of stay [13],[14]. Required elements include: (i) two resin printers to ensure redundancy; (ii) validated biocompatible resins with lot tracking; (iii) curing and cleaning stations with SOPs; (iv) a design control log (case number, designer, version history, reviewer sign-off); and (v) theatre-side “fit check” jigs to detect errors before incision.

### 6.3 Equity and access

Digital care risks widening disparities if technologies cluster only in tertiary centres. State dental colleges and public hospitals can pool CBCT/IOS access, share segmentation teams across campuses, and publish outcomes with PROMs to permit comparison. On materials, match biology to budget: autogenous dentin or validated alloplasts where BMP-2 is unaffordable; piezo and endoscopy where morbidity savings matter most; and short implants as alternatives to sinus grafting when anatomy allows.[19],[22],[27],[28]

**Tele-planning and spoke–hub networks:** a low-bandwidth tele-planning model—upload DICOM/STL to a secure server, weekly remote VSP boards, printed guides couriered back—can extend advanced care to peripheral hospitals. Success depends on clear data standards and on named liaisons who police file quality (e.g., CBCT voxel size, truncation artefacts, occlusion capture fidelity).

### 6.4 Measurement and improvement

Quality programmes should track both process and outcome: proportion of cases with documented dose justification; IOS remakes; guide reprints; VSP-to-execution deviation; peri-operative complications; PROMs capture rate; and time-to-return-to-work/school. Publishing these as annual reports—along with case complexity indices—builds public trust and attracts trainees who want disciplined, modern programmes.

## 7. WHAT’S COMING NEXT: REALISTIC EXPECTATIONS

### 7.1 Faster, safer planning (AI-assisted)

AI will continue to shrink segmentation and planning time as models improve for teeth, roots, canals, and complex deformities—provided local validation and explicit clinician oversight identify bias and drift[15],[23]. In the near term, the most reliable gains will remain in segmentation and landmarking rather than in autonomous planning. “Glass-box” models that provide uncertainty maps and editable masks will be easier to govern than opaque classifiers. A sensible adoption sequence is: (i) benign time-savers (teeth segmentation), (ii) risk-critical assistance (canal segmentation with mandatory verification), and (iii) AI-suggested osteotomy paths reviewed by senior surgeons.

### 7.2 Smarter biomaterials

Bioactive glasses and ceramics with tuned ion release, hybrid composites that guide immune responses toward regeneration, and better soft-tissue interfaces are moving from bench to bedside [18,[19]. In practice, the next wave is likely to feature “precision GBR” stacks—combinations of scaffold, membrane, and local biologics tailored to defect geometry and patient risk (e.g., smoker vs non-smoker). Antimicrobial ion release may reduce reliance on systemic antibiotics, aligning surgical practice with antimicrobial stewardship.

### 7.3 Careful translation of cell-based strategies

Mesenchymal-cell-plus-scaffold protocols are likely to find narrow, regulated indications first (e.g., alveolar clefts, select nonunion defects) under multidisciplinary teams. Early human data suggest promise when cells meet engineered microenvironments, but reproducibility and cost remain limiting factors.[9],[34]

## 8. CONCLUSION

OMFS in 2025 differs markedly from a decade earlier: planning is virtual, osteotomies are more conservative, reconstruction increasingly leverages regeneration, and outcomes are judged with the patient's voice alongside the scan. The evidence is strongest for CBCT-led planning under appropriate indications[4],[5], comfort and workflow gains with IOS [4], accuracy improvements (and often shorter operating times) with VSP and guided, patient-specific hardware [12],[13], [14], high success with low morbidity for sialendoscopy [28], better postoperative comfort with piezoelectric osteotomy in third-molar extraction [15], and navigation that brings millimetric confidence to difficult anatomy.[30],[32],[29],[33]. ParCare-aligned anaesthesia pathways and routine PROMs collection further align services with patient priorities.[1], [34]

For public institutions in India, the feasible steps are clear: train teams, build digital pipelines, validate tools locally, and publish honest outcomes—less improvisation, more pre-planned precision; less harvesting, more biology; less paternalism, more partnership. The practical direction is to standardise what works, document it transparently, and share it widely so that equitable, modern OMFS becomes the norm rather than the exception.

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