Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 32s (2025)
https://www.jneonatalsurg.com
OPEN ACCESS

Recent Advances in Surgical Orthodontics: A Narrative Review

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Cite this paper as: Saloni Dhuppad, Amit Handa, Shraddha Manojkumar Jadhav, Saba Anjum Siddiqui Fareedoddin, Dipali Raghunath Mane, Himanshu Shrivastava, Aditi Sarda, Reader, (2025) Recent Advances in Surgical Orthodontics: A Narrative Review. *Journal of Neonatal Surgery*, 14 (32s), 8292-8295.

ABSTRACT
Surgical orthodontics has witnessed significant advancements over the last decade, with innovations spanning diagnostic imaging, virtual surgical planning (VSP), additive manufacturing, patient-specific implants (PSIs), navigation and augmented reality (AR), the surgery-first approach (SFA), aligner integration, airway-centered planning, and perioperative management strategies such as enhanced recovery after surgery (ERAS) and tranexamic acid (TXA). These developments collectively improve surgical accuracy, efficiency, stability, and patient-centered outcomes. This review synthesizes the current literature on seven key advances in surgical orthodontics, highlighting their clinical applications, limitations, and future research priorities.

Keywords: *Orthognathic surgery, surgical orthodontics, digital planning, aligners, patient-specific implants, ERAS, airway*

1. INTRODUCTION

Orthognathic surgery is an indispensable treatment modality for patients with moderate to severe dentofacial deformities that cannot be managed by orthodontic treatment alone. Historically, planning was based on two-dimensional cephalometry and dental model surgery, followed by manual fabrication of splints. While effective, these methods were limited in three-dimensional (3D) accuracy, soft tissue prediction, and intraoperative reproducibility, which affected treatment outcomes and patient satisfaction[1].

Over the last two decades, surgical orthodontics has undergone transformative changes, with the integration of digital technology, minimally invasive instrumentation, biologic strategies, and patient-centered protocols. Virtual surgical planning (VSP), 3D printing, and CAD/CAM splints have enhanced preoperative accuracy, while intraoperative aids such as patient-specific implants (PSIs) and augmented reality (AR) navigation improve precision during surgery[2–4]. Parallel developments such as the surgery-first approach (SFA), skeletal anchorage devices, and integration of clear aligners have shortened treatment time and improved esthetic outcomes[5–7]. In addition, airway-centered planning, especially maxillomandibular advancement (MMA) for obstructive sleep apnea (OSA), has gained prominence[8]. Biologically driven innovations such as piezosurgery enhance tissue preservation, while perioperative strategies including ERAS protocols and the use of tranexamic acid (TXA) improve recovery and reduce morbidity[9–11].

This narrative review explores seven key advances in surgical orthodontics, elaborating their clinical impact, evidence base, and integration into modern practice.

2. SEVEN KEY ADVANCES IN SURGICAL ORTHODONTICS

1. Virtual Surgical Planning (VSP) and 3D Printing

VSP integrates CBCT, 3D facial scans, and digital dental models to simulate jaw movements in all three planes. Compared with conventional planning, VSP demonstrates higher accuracy, improved prediction of soft tissue outcomes, and reduced intraoperative time[12]. CAD/CAM technology allows fabrication of precise surgical splints and osteotomy guides, enhancing reproducibility and reducing surgical error[13]. Furthermore, additive manufacturing enables customized splints, bone grafts, and osteosynthesis devices.

2. Patient-Specific Implants (PSIs) and Osteosynthesis

PSIs, produced via CAD/CAM and 3D printing, provide customized fixation that aligns precisely with preoperative planning. Their advantages include reduced intraoperative plate bending, improved symmetry in complex deformities, and shorter operative times[14]. Recent studies show significant accuracy improvements in mandibular asymmetry corrections and complex bimaxillary movements, although cost and manufacturing time remain limitations[15].

3. Navigation and Augmented Reality (AR) in Surgery

Dynamic navigation and AR integrate intraoperative imaging with the preoperative plan, allowing real-time visualization of osteotomy lines and repositioning accuracy[16]. Early trials show error margins of <2 mm, comparable to CAD/CAM splints, with potential superiority in complex or revision cases. While not yet mainstream due to equipment cost, AR systems hold promise for teaching, precision, and patient safety[17].

4. Surgery-First Approach (SFA) and Skeletal Anchorage Devices

The SFA eliminates presurgical orthodontic decompensation, delivering immediate esthetic improvement and reducing overall treatment time by up to 30–40%[18]. Temporary anchorage devices (TADs) play a pivotal role in postoperative tooth movement control, ensuring stability and facilitating challenging mechanics such as molar intrusion or torque correction[19]. While meta-analyses confirm comparable stability to conventional approaches, careful case selection is essential to prevent relapse[20].

5. Integration of Clear Aligners in Orthognathic Protocols

Clear aligners are increasingly used for pre- and post-surgical orthodontics, providing improved esthetics, comfort, and periodontal health compared to fixed appliances[21]. Studies demonstrate comparable occlusal and skeletal outcomes, though aligners require meticulous digital staging and auxiliaries for complex movements[22]. Combined with VSP, aligner integration allows seamless digital workflows and enhanced patient satisfaction[23].

6. Airway-Centered Orthognathic Surgery and OSA Management

Maxillomandibular advancement (MMA) has emerged as the most effective surgical treatment for moderate to severe OSA, with success rates exceeding 80%[24]. In addition to functional benefits, airway-centered planning integrates CBCT-based volumetric analysis into routine orthognathic workflows, aligning esthetic and airway goals. Recent studies also report significant improvements in quality of life, daytime sleepiness, and cardiovascular outcomes post-MMA[25].

7. Piezosurgery and Perioperative Strategies (ERAS and TXA)

Piezoelectric osteotomy allows selective bone cutting with reduced risk of injury to adjacent soft tissues, nerves, and vessels. Benefits include decreased blood loss, improved postoperative comfort, and enhanced neurosensory recovery[26]. Complementary perioperative strategies—particularly ERAS protocols—reduce opioid use, shorten hospital stays, and improve recovery[27]. Prophylactic use of TXA has proven effective in minimizing intraoperative bleeding without increasing thromboembolic risk[28].

3. DISCUSSION

The last decade has redefined surgical orthodontics by shifting from conventional model surgery to digitally driven, patient-specific, and biologically favorable approaches. Each of the seven advances brings unique advantages, yet adoption varies based on institutional resources, training, and patient selection.

Planning domain: VSP and CAD/CAM splints have become standard in many centers, demonstrating superior geometric accuracy and efficiency[12,13]. Their integration with PSIs represents the pinnacle of personalization, particularly in complex asymmetry, though questions remain regarding cost-effectiveness and long-term outcomes[14,15]. Navigation and AR expand these benefits into the operating theatre, allowing real-time accuracy and reducing reliance on splints[16,17].

Execution domain: The surgery-first approach, supported by skeletal anchorage, reduces treatment duration and improves psychosocial outcomes, though it demands precise biomechanics and strict retention to mitigate relapse[18–20]. Similarly, aligner integration reflects a patient-centered evolution, offering comparable results with superior comfort and hygiene[21–23].

Functional expansion: Airway-centered orthognathics, particularly MMA for OSA, illustrates the expansion of surgical orthodontics beyond esthetics and occlusion, into systemic health and sleep medicine[24,25]. This represents a paradigm shift, emphasizing interdisciplinary collaboration with pulmonologists and sleep specialists.

Biologic and perioperative advances: Piezosurgery demonstrates tangible improvements in safety and comfort[26]. ERAS pathways and TXA use highlight the importance of perioperative medicine, focusing on recovery quality, reduced blood loss, and patient satisfaction[27,28].

While these advances represent significant progress, challenges persist. Cost, access disparities, and steep learning curves limit universal adoption. Long-term evidence on stability, neurosensory recovery, and cost-effectiveness remains incomplete. Future priorities include randomized trials comparing digital versus conventional workflows, registries capturing PROMs and airway outcomes, and AI-driven prediction tools to further personalize surgical orthodontics[29–33].

Overall, surgical orthodontics has entered a new era where precision, efficiency, function, and patient experience converge. The clinician's responsibility is to integrate innovations judiciously, ensuring evidence-based, ethical, and equitable practice.

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