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Orthognathic surgery past, present, and future

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ABSTRACT
Orthognathic surgery has been performed for over two centuries with the first procedure occurring in the 1860s. It was not until the late 1950s with the pioneering work of Obwegeser that the modern orthognathic surgery era began. From the beginning, oral surgeons and orthodontists have worked in parallel fashion; advances in both disciplines have led to what is now routinely performed. New and exciting developments are underway not only in diagnosis but also in treatment planning with computer aided surgical simulation and the use of artificial intelligence (AI) to enhance patient treatment outcomes. The purpose of this article is to briefly review the history of orthognathic surgery, to examine the present status and to highlight emerging technologies and advancements.

The early days
Historical perspectives: orthognathic surgery
Given the nature of anaesthesia, it often surprises those new to orthognathic surgery that the first operation was performed in the 1860s (Figure 1). Though the surgical goal was not to modify the patient’s occlusion, it represented the first reported instance of maxillary or mandibular surgery. At the time of the procedure, only ether anaesthesia was available; neither local anaesthetics nor antibiotics existed. The patient underwent what is now known as a LeFort I osteotomy [1] to access a nasopharyngeal carcinoma. The operation was a success, and the tumour was removed; however, it was also a failure due to the patient dying from complications shortly post-operatively.

After this initial foray, few surgical procedures in the jaw were performed until the 1910s and 1920s. At the time, the biological basis for maxillary osteotomy was unknown and surgeons feared the maxilla would slough if cut and repositioned. Wassmund performed what is now known as a total maxillary osteotomy, and rather than moving it during the operation, the patient was allowed to heal for approximately one week before applying orthopaedic traction to obtain the desired maxillary position. Köle later performed dental extraction of the maxillary first premolar and using the extraction site as a ‘safe’ spot for surgical access incised, mobilised and subsequently set the anterior portion of the maxilla posteriorly.

Among the early surgical challenges was the absence of anaesthesia which necessitated surgeons operate quickly to avoid excessive blood loss and to minimize patient discomfort. Other challenges included high rates of infection due to the large number of oral bacteria. With the discovery of penicillin [2] and subsequent large-scale manufacture and distribution [3], post-operative infections became manageable.

Most of the early attempts at mandibular surgery focused on ramal osteotomy or body ostectomy procedures. Ramal procedures included ‘C’, ‘L’ and inverted ‘L’ osteotomy designs with each attempting to set the dentate portion of the mandible posteriorly. Body ostectomy instead focused solely on the dentate portion of the jaw. Surgeons extracted one or more teeth and then set the anterior portion of the jaw posteriorly into the extraction site. The most convenient body ostectomy location was the first premolar region, which allowed for setback of the mandibular canine–canine region. Results were mixed, and orthodontics was rarely performed before, during, or after the surgical procedure. Mandibular advancements were not performed and were thought to be impossible.

Modern orthognathic era
Orthognathic surgery was revolutionized in 1957 [4] when Trauner and Obwegeser reported on the sagittal split ramus osteotomy (SSRO), a major advancement in surgical technique. This new surgical design utilized an osteotomy to initiate and propagate a controlled fracture to create opposing areas of medullary bone for enhanced bone healing. Shortly after their report, the procedure was introduced to the US oral and maxillofacial surgery community at Walter Reed Army Medical Center. Additional benefits included the ability to not only perform mandibular setback but also advancement.
Shortly after, other improvements in mandibular setback procedures were developed [5,6]. Rather than performing body ostectomy, a new approach, the introral vertical ramus osteotomy (IVRO) or transoral vertical ramus ostectomy (TVRO) was developed. The osteotomy extended inferiorly from the sigmoid notch to the gonial angle accessed from the lateral aspect of the ramus. Care was required to remain posterior to lingula to avoid the inferior alveolar neurovascular bundle. The dentate (distal) segment is setback with the proximal (ramal) segment positioned laterally with the bony segments held in position with wire osteosynthesis. Later to improve the TMJ response, Hall and colleagues developed the condylotomy, creating a smaller proximal segment with intentional inferior positioning to create an increased joint space. Unlike the IVRO, the condylotomy was often performed unilaterally using the occlusion on the unoperated side as a vertical ‘stop’.

Due to the still unresolved concern for maxillary viability, Bell performed animal studies [7–9] demonstrating that the maxilla could be cut free, and subsequently that it could be simultaneously repositioned. Later investigations demonstrated that the maxillary artery could be ligated to prevent adverse bleeding events related to inadvertent transection. Jacobs [10] demonstrated that the maxilla could be sectioned acutely (two, three, four piece) for transverse or vertical changes. When only transverse correction was needed, expansion appliances were paired with surgical mobilization (SARPE/SARME) [11]. With both maxillary and mandibular osteotomies now possible, surgeons could fully address all three planes of space for the dentofacial deformity patient.

Surgical stability remained uncertain and unpredictable using wire fixation. Patients exhibited relapse (a return of one or both jaws to the pre-operative position), prolapse (continued movement of one or both jaws in the same direction as the surgery) or completely new positions of one or both jaws. To address this challenge, rigid internal fixation [12–14] (RIF) consisting of titanium bone plates and/or titanium bone screws was developed. With plates, only a single cortex of bone is required (monocortical screws). Without plates, both the buccal and lingual cortices are needed (bicortical). Investigators at UNC have closely examined and reported a hierarchy of stability [15] noting that averages are misleading due to case clusters (Figure 2). Patients with stable results tended to be very stable, while unstable patients were very unstable. To better contextualize the data, they broadly classified procedures as stable (0–2 mm post-operative change), stable with rigid fixation (0–2 mm WITH plates and screws; more with wire fixation), problematic (2–4 mm changes) and unstable (>4 mm change). Despite their work, it remains difficult to predict who will be stable given large patient variability.

**Current status**

Following these pioneering achievements, the discipline entered a ‘steady’ state. Surgeons and orthodontists largely agreed on not only the aesthetic paradigms facilitating coordinated diagnosis and treatment planning but also on which patients would benefit most from orthognathic surgery (Figures 3 and 4). Population studies were performed to demonstrate which dental and skeletal characteristics were best treated with combined care. With established surgical techniques and the patient population identified, efforts shifted to optimizing both treatment timing and treatment efficiency.

One aspect of considerable attention was surgical timing within the overall treatment period. Early on, surgery was performed in the absence of orthodontic care. As teams formed, most utilized the paradigm of orthodontics first to remove dental decompensation with surgery in the middle to ‘land’ the case followed by orthodontic finishing and detailing. More recently [17–19] focus has shifted to moving the surgical event earlier in treatment to provide patients with the facial

![Figure 1](image-url)  
**Figure 1.** This orthognathic surgery timeline represents a broad overview and is not meant or intended to convey every advance in the discipline. The landmark or revolutionary events are listed with many more incremental advances that are notably absent.
changes they desire early and simultaneously speed the overall treatment by harnessing the rapid tooth movement that occurs during the post-operative healing period. Dramatic improvement in overall treatment time has been reported (some in 9–12 months), while other treatments remain 18–24 months or more. One aspect of care that has assisted the ‘surgery first’ movement has been the incorporation of temporary anchorage devices (TADs). The orthodontist places traditional orthodontic appliances and either a light or passive wire, the surgeon places the skeleton in the ideal position, and the orthodontist finishes using the TADs to obtain predictable movements due to the skeletal anchorage from the TADs. The range of cases is quite extensive with some very simple cases (often previously aligned dental arches that did not pursue surgical correction) to the very complex with high levels of crowding, open bite, and transverse challenges. Not every case is suitable for surgery first; particularly those with large transverse discrepancy that requires SARPE (i.e. ≥6 mm at the molar).

**Historical perspectives: orthodontics**

**The early days**

The founding of orthodontics is largely attributed to Edward Hartley Angle [20]. (Figure 5) Diagnostic tools were limited to dental study models, photographs, and clinical examination. Later, cephalometric analysis enabled objective measures to be employed. Downs published one of the earlier analyses [21] including the novel ‘wigglegram’ which presented the information in a pictorial fashion. At this time, views on craniofacial

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**Figure 2.** Developed by UNC, the hierarchy of stability illustrates the varying degrees of stability and success for the various surgical movements. Among the more stable procedures are maxilla up and maxilla forward. This stability then declines progressively to the least stable procedures including maxilla inferior repositioning, mandible back, and maxillary transverse expansion [15].

**Overjet:**
- 7mm or greater (4% of the population)
- ≥3mm or greater (0.5% of the population)

**Open bite:**
- 3mm or greater (0.6% of the population)

**Total Need:**
*Estimated to be about 5% of those seeking orthodontic care*

**Figure 3.** The third national health and nutrition examination survey 1988–1994 (NHANES III) highlights the prevalence of characteristics for the most severe occlusal deviations from ideal [16].
growth varied with many thinking growth were immutable and surgical movement of the jaws was not routinely considered or even conceived. These limitations forced early practitioners to focus on optimizing the position of the teeth within the respective jaws.

In early orthodontic care, it was assumed that placing the dentition in the proper position within the respective jaws would create beauty and harmony. However, when jaw position(s) were nonideal, dental compensations had to be performed; however, the amount of compensation needed was unclear. Steiner developed ‘chevrons’ [22] which proposed adjusting incisor angulations based upon specific jaw position anomalies. Tweed made similar compensations using the Tweed triangle (FMA, FMIA, and IMPA). As mandibular plane increased, the other two measures had to compensate accordingly with the IMPA being the most adjustable. Orthodontic camouflage attempts may have satisfied cephalometric paradigms but often left unsatisfactory facial aesthetics. Unsuccessful outcomes led to the term ‘envelope of discrepancy’, which was proposed to assist orthodontists and surgeons to appreciate the limits of safe orthodontic and surgical movements. The intent was both disciplines should recognize when planned movements were likely to be successful and could be performed versus when planned movements were likely to be unsuccessful and should be avoided (Figure 6). Just because orthodontic movements might be possible, didn’t mean that the movements were free of complications or should be performed. To further assist, Burstone prioritized the integument or soft-tissue profile in treatment planning [23]. His soft tissue evaluation efforts were adopted, expanded, and became popularized by many others [24–26] and later led to a wide range of specific soft tissue focused cephalometric analyses.

Simultaneously, improved orthodontic mechanics were developed utilizing an engineering/Newtonian physics perspective. Tweed, Gugino, Ricketts and Burstone [28–33] were leaders in this movement, with both Ricketts and Burstone pioneering ways to treat

**Figure 5.** This orthodontic history and advances timeline represents a broad overview and is not meant or intended to convey every advance in the discipline. The landmark or revolutionary events are listed with many more incremental advances that are notably absent.

**Figure 6.** Envelope of discrepancy describes the historical amount of movement that orthodontists can consider possible by themselves, with extraction/growth, and with surgery. The envelope of movement is considered larger for the mandible particularly when surgical movements are considered [27].
the dental arch in segments rather than as a continuous unit [34]. This new approach enabled orthodontists to better complement and coordinate with surgical desires to obtain differential lateral, vertical, or sagittal movements.

**Modern orthodontics**

Orthodontic appliances and techniques have undergone tremendous evolution and enhancement since Angle. Two primary wire slot sizes (18 or 22) are available as are multiple bracket styles (single wing, twin, self-ligating) as well as materials (stainless steel, porcelain). Even more notable are the wide variety of wire materials ranging from Elgilo and stainless steel in the beginning to now, including various forms of nickel titanium alloys, improvements in stainless steel, titanium molybdenum alloy (beta titanium) and even formable versions of nickel titanium composite. Each has improved the orthodontist’s ability to deliver optimal force systems to achieve the planned tooth movement. Recently, novel bracket-free novel treatment approaches were developed using clear aligners.

The increasing challenges of high compliance orthodontic treatment plans for patients with underlying jaw base discrepancy led to the development of temporary anchorage devices (TADs), which were modifications of surgical fixation screws. When properly utilized, TADs enhance desired orthodontic tooth movement while simultaneously minimizing undesirable responses elsewhere in the arch. Careful planning must be done because unfortunately TADs can also more efficiently perform adverse tooth movements beyond the so-called envelope of discrepancy previously mentioned.

**Future: Pt 1: orthodontic improvements blur orthognathic surgery needs**

The effectiveness of TADs has blurred the line between surgery and dental compensation in all three planes of space. TADs can reportedly obtain transverse maxillary expansion in skeletally mature individuals [35–37] with some dramatic changes [36]. Akyalcin et al. have suggested guidelines for traditional RPE, MARPE, and SARPE based on skeletal maturity and the magnitude of expansion required. Mild-to-moderate amounts of expansion in young adults (20–30s) can be successfully obtained with TAD supported rapid palatal expanders (MARPE) [38]. Larger amounts of skeletal expansion or more mature patients benefit from the MARPE appliance with simultaneous surgical mobilization. As investigations continue, a better understanding of the most appropriate appliance design and level of invasiveness will become clearer.

In the sagittal plane, several teams have reported that TAD supported skeletal movement, particularly maxillary protraction [39–44]. The protocol involves placement of subperiosteal bone anchored plates (BAMP) to protract the maxilla. Purists will state that this remains a surgical approach, albeit a less invasive one. The premise harks back to earlier animal studies [45] where endosseous implants were placed in the zygoma for protraction similar to Auxhausen’s early surgical concept. With BAMP, the amount of maxillary skeletal movement is greater than orthopaedic appliances alone; in animal studies BAMPs showed clear sutural disruption, however the maxilla cannot be moved as far or as predictably as with LeFort osteotomies. In addition, the effect is quite variable, some patients exhibit significant maxillary/midface protraction, while others demonstrate mandibular retrusion. How an individual patient will respond remains unpredictable. Efforts are now underway to use BAMP in cleft and other craniofacial patients, where stability is a large concern with traditional orthognathic surgery [46]. Stability is still being examined, and a better understanding will become available as studies conclude.

With the success of BAMP for Class III malocclusion, others have hypothesized that similar effects might be observed with bone-anchored mandibular protrusion appliances [47,48]. To date, results are mixed, and studies are small with only one randomized clinical trial. Further examination is required prior to formulating conclusions.

Vertically, TADs have been used with varying degrees of success in both the growing and nongrowing patient populations. The most successful group [49,50] demonstrated that moderate skeletal dysplasia can be appropriately and successfully treated with TADs to intrude the posterior maxillary and/or mandibular dentition. There is notable skeletal improvement with the mandible rotating anteriorly and superiorly; however, the results are substantially less than the amount of bite closure rotation occurring with orthognathic surgery [51]. Clearly, a role for TAD facilitated vertical control exists and the professions must achieve consensus that balances the risk benefit ratio of both procedures to determine the most appropriate treatment plan for each individual patient.

**Future: Pt 2: digital treatment planning, artificial intelligence, and data science**

For severe skeletal dysplasia cases, orthognathic surgery remains the ideal treatment approach. However, traditional orthognathic surgery treatment planning is time consuming and fraught with potential error due to the many steps involved [52]. Full records including cephalometric tracings, models and facebow must be obtained. After performing the cephalometric prediction, one must complete the model mounting, model surgery and splint fabrication. Each step creates the opportunity for a small error, which can become additive. Improving not only the efficiency but also the predictability and simplicity of surgical treatment
planning would be a major enhancement to both orthodontists and surgeons.

Technological improvements including cone beam computed tomography (CBCT), digital intraoral scanning, three-dimensional stereolithographic printing (CAD/CAM; STL) and software improvements have revolutionized orthognathic surgery planning. Combining these separate technologies led to a process called computer aided surgical simulation (CASS) or computer aided orthognathic surgery (CAOS) [53–55]. Surgeons can now send digital files (CBCT, models ± scan) to third-party vendors (or in-house) computer technicians who will clean and prepare the data for surgery. The CBCT is oriented and aligned so that the midsagittal reference plane from the clinical exam is the same as the one in the computer model. Once done, the jaw(s) are ‘segmented’ with osteotomies tailored to individual surgeon’s preference. The surgeon then gives the computer technician the anticipated surgical movements needed to model the operative plan which is either approved, rejected or modified until the desired outcome is achieved. Once approved, the interim and final splints can be 3d printed and if desired, cutting and fixation guides fabricated to assure that the surgeon performs the plan as predicted. The new digital workflow lets both do what they do best, the surgeon operates, and the computer technician works with data, making the process more efficient. Rather than spending 6–8 hours for an individual case, the surgeon can complete the process in 15–20 minutes and get enhanced outcomes by being able to visualize the outcome in 3d during the prediction. Problems can be observed more easily and addressed during prediction rather than as a surprise in the operating room. This enhanced digital treatment planning process can be done in real time and can facilitate not only the surgeon and the technician but can also involve the orthodontist either in person with the surgeon or virtually via video conferencing software. Outcome data has shown that surgeons are able to be accurate to <1 mm or 1°.

To further improve treatment planning and outcomes, investigators are beginning to develop artificial intelligence (AI), machine learning (ML) and deep learning (DL) approaches. Gateno and co-workers have reported that providers have poor reproducibility when orienting and aligning CBCT volumes. Likewise, ‘simple’ matters such as clinical midline determination can be 3 mm off before being noticeable to orthodontic practitioners [56] and 4 mm for laypeople [57]. Using large datasets, artificial intelligence (AI) programs can be taught to perform this seemingly simple task better than the operator can do themself [58]. Anatomic landmarks are automatically identified and localized [59,60] with paired right and left structures used to generate both lateral cephalometric and frontal symmetry analysis. Surgical correction is performed by the computer utilizing specific algorithms with operator input (supervised learning) or without (unsupervised learning) [61–63]. Once completed the operator can determine the clinical appropriateness and feasibility of the AI generated approach and accept, modify or reject as necessary. Gateno et al. are the primary developers and to appropriately train the neural network a broader dataset will be needed to provide sufficient data and clinical feedback. Outcomes are beginning to be reported, but broad-based adoption within the profession will take time.

Conclusions

At their inception, surgeons and orthodontists frequently worked in separate but parallel paths to correct skeletal and dental malocclusion and improve facial harmony. As improvements in each discipline occurred independently, providers from both disciplines began to partner with one another improving the results obtained by each discipline on its own. Technological improvements paired with interdisciplinary communication and collaboration improved orthognathic surgery results immensely making treatment not only more predictable but routine. While to some it may appear that the two disciplines may diverge again with orthodontists taking a greater role in skeletal correction using TADs, the exceptional and innovative orthodontic practitioner will recognize the continued need for surgeon – orthodontist collaboration. New technologies are making the diagnosis and treatment planning process easier to navigate and while AI/DL/ML make the process more efficient, truly remarkable results must continue to involve the active and disciplined approach of expert providers. The future of orthognathic surgery is bright and the technological evolutions in both fields complement one another to provide patients with the highest and most accurate level of care to date.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Author contributions

Corresponding author contributed to conception, design, literature review, drafted and critically revised the manuscript. No other authors were part of this paper.
Ethical approval

Approval of the Institutional Review Board was waived since this is a review article, and no patient identification was included.

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