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Outcomes of Injectable Bone Substitute in the Management of Mandibular Condylar Fractures

Vasileiou S[1*], Berger L[2] and Parn K[3]

[1]*Department of Oral and Maxillofacial Surgery, Aristotle University of Thessaloniki, Thessaloniki, Greece*
[2]*Department of Orthopaedic Surgery, Medical University of Vienna, Vienna, Austria*
[3]*Department of Radiology, Tallinn University of Technology, Tallinn, Estonia*

ABSTRACT

Background: Mandibular condylar fractures are among the most common facial skeletal injuries, and their management is divided between closed, non-surgical treatment and open reduction and internal fixation (ORIF), with comminuted or bone-deficient fracture patterns posing particular fixation challenges. Injectable calcium phosphate cements and bioactive glass have an established role in augmenting comminuted fracture fixation elsewhere in the skeleton and in general maxillofacial bone regeneration. Objective: This narrative review synthesizes the published literature on injectable bone substitute materials and on comparative outcomes of open versus closed condylar fracture treatment, to assess the evidence base for using such materials in condylar fracture management. Methods: We reviewed studies and systematic reviews describing the composition and mechanism of injectable calcium phosphate cements, hydroxyapatite cements, and bioactive glass; analogous orthopedic and maxillofacial clinical outcome studies of these materials; and comparative and meta-analytic studies of open versus closed treatment of mandibular condylar fractures, including associated surgical complications. Findings: Injectable bone substitutes reduce screw penetration and support fixation in comminuted metaphyseal fractures elsewhere in the skeleton and achieve favorable functional outcomes when used for articular fracture augmentation, while open treatment of condylar fractures generally improves occlusal and some functional parameters relative to closed treatment at the cost of a modest, largely transient risk of facial nerve injury. No dedicated clinical outcome studies of injectable bone substitute augmentation specifically within condylar fracture fixation were identified. Conclusions: Injectable bone substitutes represent a biologically plausible but clinically unproven adjunct for comminuted or bone-deficient mandibular condylar fractures, warranting prospective evaluation rather than routine adoption.

Keywords: *mandibular condylar fracture; injectable bone substitute; calcium phosphate cement; bioactive glass; open reduction internal fixation*

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Corresponding Author: *Sofia Vasileiou*

E-mail Address: *sofia.vasileiou@auth.edu*

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Introduction

Fractures of the mandibular condyle are among the most frequently encountered injuries of the facial skeleton, and their management remains one of the most contested areas in oral and maxillofacial trauma surgery. The condyle occupies a biomechanically privileged but surgically demanding position, articulating within the glenoid fossa and governing both vertical ramus height and the rotational and translational movements required for normal mastication, speech, and occlusal function. Because the fragment is small, often displaced or overlapping, and situated close to the facial nerve and the external auditory canal, condylar fractures have historically been treated by closed, non-surgical means—maxillomandibular fixation followed by functional rehabilitation—even as open reduction and internal fixation (ORIF) has become the default standard for fractures elsewhere in the mandible [1,2]. The debate between open and closed management has generated a large comparative literature examining occlusion, maximum interincisal opening, mandibular symmetry, and patient-reported temporomandibular joint (TMJ) function, and this evidence base continues to evolve as surgical technique, imaging, and fixation hardware improve [3,4,5,6,7,8].

A parallel and comparatively younger strand of investigation concerns the use of injectable bone substitute materials—calcium phosphate cements, hydroxyapatite cements, and bioactive glass putties—as adjuncts to fracture fixation in comminuted, osteoporotic, or defect-associated bone injury. These materials were developed originally for orthopedic indications such as tibial plateau and proximal humeral fracture augmentation, where they

fill metaphyseal voids created by fragment elevation and provide interim mechanical support while remodeling proceeds [9,10,11,12]. Their osteoconductive and, in some bioactive glass formulations, bioactive properties have subsequently drawn interest in craniomaxillofacial reconstruction, where hydroxyapatite and calcium phosphate cements have been used to contour and fill cranial and facial skeletal defects since the 1990s [13], and where bioactive glass has accumulated a substantial body of evidence in alveolar, periodontal, and maxillofacial bone regeneration [14,15,16,17]. The mandibular condyle—small, cancellous, frequently comminuted in high-energy trauma, and difficult to rigidly plate—represents a plausible, if still underexplored, target for such augmentation strategies, particularly in condylar head and comminuted subcondylar fractures where bone stock is insufficient to support conventional plate-and-screw fixation alone.

This narrative review synthesizes the published literature relevant to injectable bone substitute use in mandibular condylar fracture management across four domains: the materials science and preclinical and analogous-fracture clinical evidence for injectable calcium phosphate and bioactive glass bone substitutes; the comparative functional and occlusal outcomes of open versus closed treatment of condylar fractures, which define the clinical context into which any adjunctive material must be integrated; the surgical approaches and complications, particularly facial nerve injury, that shape the risk-benefit calculus of ORIF and any augmentation performed at the time of surgery; and the current state and gaps in clinical translation of injectable bone substitutes specifically within condylar fracture care.

Injectable Bone Substitutes: Materials, Mechanisms, and Preclinical Evidence

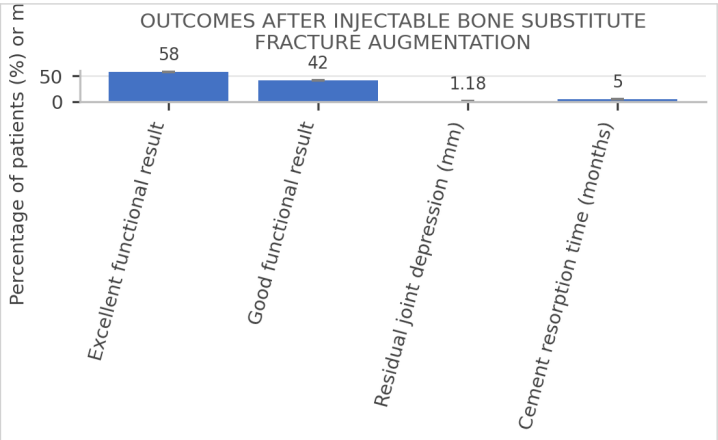
Injectable bone substitutes are broadly divided into calcium phosphate–based cements, which set in situ through a dissolution–precipitation reaction into a nanocrystalline apatite or brushite matrix, and bioactive glass formulations, which are silicate- or borate-based glasses that undergo surface ion exchange and hydroxycarbonate apatite layer formation on contact with physiological fluid. Larsson and Bauer's foundational review of injectable calcium phosphate cement for fracture fixation described the appeal of these materials as combining injectability—allowing percutaneous or minimally invasive delivery into a metaphyseal defect—with compressive strength that, once set, approaches that of cancellous bone, making them well suited to filling voids left after elevation of depressed articular fragments [9]. Low and colleagues' review of calcium phosphate–based composites extended this picture by cataloguing the range of polymeric, protein, and ceramic additives used to tune the injectability, setting time, resorption rate, and mechanical performance of these cements for bone substitute applications [18]. Larsson and Hannink's subsequent survey of commercial injectable bone-graft substitute products reinforced that the field now spans calcium sulfate, calcium phosphate, and composite formulations with differing resorption kinetics and indications, underscoring that "injectable bone substitute" is not a single material but a family of products with distinct handling and biological profiles [10].

Clinical evidence for these materials comes predominantly from long-bone fracture augmentation rather than from the craniomaxillofacial skeleton. Iundusi and colleagues followed 24 patients with depressed tibial plateau fractures treated with reduction and injectable calcium phosphate/sulfate cement (CERAMENT) augmentation for a mean of 44 months, reporting a mean residual joint depression of only 1.18 mm (within a pre-specified 2 mm acceptability threshold), complete radiographic resorption and remodeling of the cement by a mean of 5 months, and functional outcomes rated excellent in 58% and good in 42% of patients, with no reported complications directly attributable to the cement [11]. In a comparable but distinct application, Egol and colleagues showed that intraoperative augmentation of the fracture void with calcium phosphate cement during locked plating of proximal humeral fractures reduced the incidence of secondary screw penetration into the joint compared with plating alone, attributing the effect to the cement's ability to support the subchondral surface against axial loading in osteoporotic or comminuted metaphyseal bone [12]. These two studies illustrate the mechanistic rationale most relevant to condylar fracture surgery: injectable cements can restore load-bearing void volume and buttress fixation hardware in exactly the kind of comminuted, cancellous-bone-deficient fracture pattern that characterizes many condylar head and subcondylar injuries.

Principal injectable and moldable bone substitute material classes referenced in the maxillofacial and analogous orthopedic fracture-augmentation literature.

Material class	Setting mechanism	Reported clinical role	Key reference
Injectable calcium phosphate cement	Dissolution-precipitation into nanocrystalline apatite/brushite	Metaphyseal void filling and fixation buttressing (tibial plateau, proximal humerus)	Larsson & Bauer 2002; Iundusi et al. 2015; Egol et al. 2012
Calcium phosphate composites	Ceramic-polymer/protein composite setting	Tunable injectability, resorption rate, and mechanical strength	Low et al. 2010; Larsson & Hannink 2011
Hydroxyapatite cement	In situ moldable apatite cement	Craniofacial contour and skeletal defect repair	Friedman & Costantino 1997
Bioactive glass	Surface ion exchange, hydroxycarbonate apatite layer formation	Alveolar, periodontal, sinus, and maxillofacial bone regeneration	Profeta & Huppa 2016; Saghiri et al. 2025; Naaz 2026
Doped/composite calcium phosphate for jaw regeneration	Ceramic setting with bioactive dopants	Investigational maxillomandibular bone regeneration	Mostafavi Moghaddam et al. 2025

Functional and radiographic outcome distribution three years after injectable calcium phosphate/sulfate cement (CERAMENT) augmentation of depressed tibial plateau fractures, the most complete outcome dataset available for an injectable bone substitute used to augment comminuted, cancellous-bone-deficient articular fracture fixation, the fracture pattern most analogous to comminuted mandibular condylar injuries (Iundusi et al., 2015).



Within the craniomaxillofacial skeleton specifically, hydroxyapatite cement was introduced by Friedman and Costantino for the repair of craniofacial contour and skeletal defects, exploiting its capacity to be molded intraoperatively and to set in situ into a material with a mineral composition similar to bone [13]. Bioactive glass has accumulated the largest body of maxillofacial evidence among injectable and particulate bone substitutes: Profeta and Huppa's review catalogued its use across alveolar ridge preservation, sinus augmentation, and periodontal and peri-implant defect grafting in oral and maxillofacial surgery, attributing its osteostimulative behavior to the formation of a bioactive hydroxycarbonate apatite layer that supports osteoblast attachment and mineralization [14]. More recent syntheses have reinforced this picture: Saghiri and colleagues' systematic review and meta-analysis of bioactive glass against traditional autogenous and allogeneic bone grafts in maxillofacial reconstruction found comparable or favorable radiographic bone fill and complication profiles for bioactive glass across the pooled clinical literature, while Naaz's review of NovaBone-type bioactive glass formulations detailed mechanisms of action, handling properties, and reported clinical outcomes specifically in oral bone regeneration [16,15]. Mostafavi Moghaddam and colleagues' bench-to-bedside review of calcium phosphate materials for maxillomandibular bone regeneration similarly emphasized ongoing innovation in composite and doped calcium phosphate formulations intended to improve handling, resorption matching, and osteoinductive potential for jaw reconstruction, again without reporting condylar-fracture-specific outcome data [17]. Taken together, this literature establishes a coherent materials rationale and an orthopedic and general maxillofacial clinical evidence base for injectable bone substitutes, but it also makes clear that dedicated outcome data in mandibular condylar fracture surgery specifically remain sparse, with the condylar application still resting largely on extrapolation from these analogous settings.

Open versus Closed Reduction of Mandibular Condylar Fractures: Functional and Occlusal Outcomes

Any adjunctive role for injectable bone substitutes in condylar fracture surgery must be considered against the backdrop of the open-versus-closed treatment debate, since bone substitute augmentation is, by definition, an intraoperative maneuver applicable only to the open treatment arm. The single most frequently cited prospective randomized comparison, by Singh and colleagues, randomized patients with unilateral mandibular subcondylar fractures to open or closed treatment and found that both approaches achieved good functional results, with open reduction associated with more rapid and complete restoration of the pre-injury occlusal relationship and mandibular movement, though closed treatment avoided the morbidity of a surgical approach [3]. A subsequent Pakistani cohort study by Asim and colleagues, comparing open and closed treatment of unilateral condylar fractures at six months, reported significantly greater maximum mouth opening in the open group (36.39 ± 4.72 mm) than the closed group (33.74 ± 4.72 mm) and less residual mandibular deviation on opening (0.48 ± 0.99 mm versus 1.09 ± 1.60 mm), while occlusal disturbance scores were similar between groups, leading the authors to conclude that open treatment yields superior functional mobility outcomes even when occlusal results are comparable [19].

Representative comparative studies of open versus closed treatment of mandibular condylar fractures cited in this review.

Study	Design	Comparison	Principal finding
Singh et al. 2010	Prospective randomized study	Open vs closed, unilateral subcondylar	Open treatment achieved faster, more complete occlusal and movement restoration
Asim et al. 2018	Comparative cohort, 6-month follow-up	Open vs closed, unilateral condylar	Mouth opening 36.39±4.72 mm (open) vs 33.74±4.72 mm (closed); deviation 0.48±0.99 mm vs 1.09±1.60 mm
Jazayeri et al. 2023	Systematic review and meta-analysis (14 studies, 1507 records screened)	ORIF vs closed	ORIF reduced TMJ pain and malocclusion, improved lateral excursion; higher infection/nerve-injury risk
Shobha et al. 2024	Systematic review and meta-analysis (9 studies, 384 patients)	ORIF (n=197) vs closed (n=187)	Maximum interincisal opening SMD 0.80 (95% CI 0.21-1.39, p=0.008) favoring closed reduction; laterotrusion/protrusion not significant
Sharif et al. 2021 (Cochrane)	Systematic review	ORIF vs closed	Trial evidence remains limited in quantity and quality; uncertain which patients benefit most from surgery

Meta-analytic syntheses have generally supported a functional advantage for ORIF while highlighting the trade-offs involved. Jazayeri and colleagues' systematic review and meta-analysis, drawing on 14 studies identified from an initial pool of 1,507 records, found that ORIF significantly reduced TMJ pain, improved lateral excursive jaw movement, and decreased the incidence of malocclusion relative to closed treatment, while also carrying an increased risk of postoperative infection and facial nerve injury—benefits and harms that must be weighed against one another in individual patients [4]. Li and colleagues' meta-analysis focused specifically on unilateral extracapsular condylar fractures and likewise reported outcome measures favoring open treatment on several functional parameters, while noting substantial heterogeneity in surgical technique and outcome reporting across the pooled trials [5]. By contrast, Shobha and colleagues' more recent systematic review and

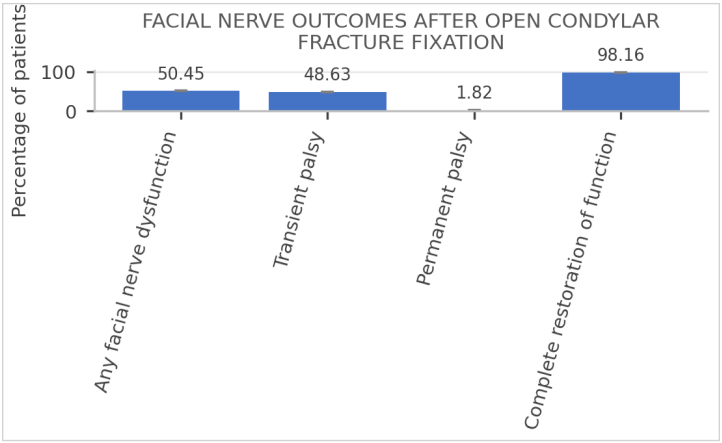
meta-analysis, pooling nine studies and 384 patients (197 treated by ORIF and 187 by closed reduction), found that maximum interincisal opening was significantly greater in the closed reduction group (standardized mean difference 0.80, 95% CI 0.21–1.39, p = 0.008), with no significant between-group difference in laterotrusive or protrusive movement, illustrating that the direction and magnitude of functional advantage reported in the literature is sensitive to the specific studies pooled and the substantial heterogeneity (I^2 = 84–91%) that characterizes this evidence base [6]. Bera and colleagues' three-arm meta-analysis comparing closed, open, and endoscopically assisted management reached a broadly similar conclusion, that outcome differences between modalities are real but modest and heavily influenced by fracture level, displacement, and surgeon experience, and cautioned against over-interpreting any single pooled effect size given the methodological heterogeneity of the underlying trials [7]. The 2021 update of the Cochrane systematic review on interventions for mandibular condyle fractures echoed this caution at the highest level of evidence synthesis, concluding that the trial evidence comparing open and closed approaches remains limited in quantity and quality, with substantial uncertainty about which patients benefit most from surgical intervention [8]. Youssef and colleagues' recent evidence-based indications review attempted to resolve some of this uncertainty by proposing fracture-level- and displacement-based algorithms for selecting ORIF, concluding that lateral pole and marked displacement or dislocation are the indications with the most consistent evidence supporting an open approach [2].

Surgical Approaches, Complications, and the Rationale for Bone Substitute Augmentation

The decision to pursue ORIF is inseparable from consideration of the surgical approach used to access the condyle and the complications associated with it, since these factors directly shape whether and how an injectable bone substitute could be delivered at the time of fixation. Boffano and colleagues' review of surgical treatment options for condylar head fractures specifically—the subset of injuries most likely to be comminuted, intracapsular, and poorly amenable to conventional plate-and-screw fixation—outlined a spectrum of techniques from minifragment screw fixation to condylar reconstruction and, in severely comminuted or unreconstructable cases, alloplastic replacement, noting that bone stock deficiency and fragment comminution are recurring technical obstacles that limit the applicability of standard fixation hardware [1]. It is precisely in this comminuted subset that an injectable bone substitute has the clearest theoretical role: filling voids left by bone loss or fragmentation, providing scaffolding to support small fixation screws in cancellous condylar bone, and potentially reducing the risk of secondary displacement during healing, by direct analogy with the mechanism demonstrated by Egol and colleagues in comminuted proximal humeral metaphyseal fractures [12].

Complication data from condylar ORIF series further frame the risk-benefit calculation relevant to any additional intraoperative augmentation step. Shi, Patil, and Gupta's retrospective study of the retromandibular transparotid approach found that facial nerve injury, while common in the immediate postoperative period, was overwhelmingly transient, with complete recovery in all affected patients within 8 to 24 weeks, and identified condylar neck fracture level, fracture-dislocation, and limited surgeon experience as the principal risk factors for nerve dysfunction [20]. Agier and colleagues' larger, more recent series of 329 patients undergoing open rigid internal fixation reported a comparable pattern at greater granularity: 50.45% of patients showed some sign of facial nerve dysfunction postoperatively, of whom the great majority (48.63% of the total cohort) had transient palsy and only 1.82% sustained permanent injury, with 98.16% of all affected patients achieving complete restoration of function during follow-up (29% immediately, rising to 84% by five months and 94% by six months); female sex, bilateral condylar fractures, longer operative time, and preauricular (rather than retromandibular) approach were independently associated with a higher likelihood of dysfunction [21]. These figures indicate that the additional morbidity of the open approach required to place an injectable bone substitute is, in most cases, self-limited, but they also reinforce that operative time and surgical complexity—both of which could in principle be increased by an additional augmentation step—are themselves risk factors for nerve injury, a consideration that any protocol incorporating intraoperative cement or glass delivery into condylar fracture surgery would need to address explicitly.

Facial nerve dysfunction outcomes after open rigid internal fixation of mandibular condylar process fractures via surgical approaches exposing the nerve, among 329 patients (Agier et al., 2025), illustrating that the additional operative morbidity relevant to any intraoperative augmentation step is common but overwhelmingly transient.



Clinical Translation of Injectable Bone Substitutes in Condylar Fracture Management

Synthesizing the materials and clinical literatures reviewed above exposes both the promise and the current evidentiary limits of injectable bone substitutes in mandibular condylar fracture care. On the materials side, calcium phosphate cements and bioactive glass formulations have well-characterized setting chemistries, handling properties, and resorption behavior, and have demonstrated favorable outcomes when used to augment comminuted or void-associated fractures in the appendicular skeleton and to support bone regeneration elsewhere in the maxillofacial skeleton [9,18,10,11,12,13,14,16,15,17]. On the clinical treatment side, a substantial and still-evolving comparative literature has established that ORIF of condylar fractures generally improves occlusal and some functional outcomes relative to closed treatment, particularly for lateral pole, displaced, and dislocated fracture patterns, while carrying finite and largely reversible risks of infection and facial nerve injury that are themselves modulated by surgical approach, operative duration, and surgeon experience [3,19,4,5,6,7,8,2,20,21].

What the literature does not yet provide is a body of dedicated clinical outcome data—randomized or even large comparative

case series—evaluating injectable bone substitute augmentation specifically within mandibular condylar fracture fixation. The rationale for such an application is coherent and is supported indirectly by several converging lines of evidence: the recognition that condylar head and severely comminuted subcondylar fractures are the fracture patterns least amenable to conventional rigid fixation because of insufficient bone stock [1]; the demonstrated capacity of calcium phosphate cement to buttress fixation hardware and reduce secondary displacement in analogous comminuted metaphyseal fractures elsewhere in the skeleton [12,11]; and the accumulating evidence that bioactive glass and calcium phosphate materials are safe, well-tolerated, and osteoconductive when placed within the maxillofacial skeleton for other indications [14,16,17,13]. Translating this rationale into practice will require case series or comparative studies that specifically evaluate injectable bone substitute augmentation of condylar ORIF against conventional plate-and-screw fixation alone, with attention to union rates, maintenance of ramus height, occlusal stability, TMJ function, and complication rates including infection and heterotopic ossification, mirroring the outcome domains already established as clinically meaningful in the broader open-versus-closed condylar fracture literature [6,7]. Until such data accumulate, the use of injectable bone substitutes in condylar fracture management should be regarded as a biologically plausible but clinically unproven extension of a well-established orthopedic and craniomaxillofacial biomaterials evidence base, appropriate for cautious case-by-case consideration in comminuted or bone-deficient fractures rather than as a standard adjunct to ORIF.

Conclusion

Mandibular condylar fractures continue to be managed through a spectrum of open and closed strategies whose comparative functional and occlusal outcomes are increasingly well characterized, if still marked by heterogeneity across studies and by genuine uncertainty about which patients benefit most from surgery [4,6,7,8]. Injectable bone substitutes—calcium phosphate cements, hydroxyapatite cements, and bioactive glass—bring a mature materials science and a supportive body of analogous clinical evidence from orthopedic fracture augmentation and general maxillofacial bone regeneration to the table [9,10,11,12,14,16]. Their specific application to comminuted or bone-deficient mandibular condylar fractures remains a rational but largely untested extension of this evidence base, and it represents an identifiable and tractable direction for future clinical research: prospective series and, ultimately, comparative trials evaluating whether intraoperative injectable bone substitute augmentation improves union, stability, and functional recovery in the condylar fractures least amenable to conventional fixation, without adding meaningfully to the operative time and complication burden that already accompanies open condylar surgery [1,20,21].

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Vasileiou S conceived the review, conducted the literature search, and drafted the manuscript. Berger L contributed to the literature screening and biomechanical and materials framing and critically revised the manuscript for important intellectual content. Parn K contributed additional radiological context and approved the final version for submission.

Ethics Statement

Not applicable. This is a narrative review of previously published literature and did not involve new experimental data, human participants, or animal subjects.

Data Availability

No new data were generated or analyzed for this review. All sources synthesized are cited in the reference list and are available through their original publishers.

References

1. Boffano P, Benech R, Gallesio C, Arcuri F, Benech A (2014) Current opinions on surgical treatment of fractures of the condylar head. Craniomaxillofacial Trauma & Reconstruction, 7(2):92-100, DOI:10.1055/s-0034-1371772.

2. Youssef SALY, Raghoebar II, Helmers R, de Lange J, Dubois L (2025) Redefining and identifying evidence-based indications for open reduction and internal fixation in mandibular condylar fractures: a comprehensive systematic review and evidence analysis. Craniomaxillofacial Trauma & Reconstruction, 18(2):25, DOI:10.3390/cmtr18020025.

3. Singh V, Bhagol A, Goel M, Kumar I, Verma A (2010) Outcomes of open versus closed treatment of mandibular subcondylar fractures: a prospective randomized study. Journal of Oral and Maxillofacial Surgery, 68(6):1304-1309, DOI:10.1016/j.joms.2010.01.001.

4. Jazayeri HE, Lopez J, Khavanin N, Xun H, Lee UK, Best DL, Reategui A, Urata MM, Dorafshar AH (2023) Comparative benefits of open versus closed reduction of condylar fractures: a systematic review and meta-analysis. Plastic and Reconstructive Surgery, 151(4):664e-672e, DOI:10.1097/prs.0000000000010009.

5. Li J, Yang H, Han L (2019) Open versus closed treatment for unilateral mandibular extra-capsular condylar fractures: a meta-analysis. Journal of Cranio-Maxillofacial Surgery, 47(7):1110-1119, DOI:10.1016/j.jcms.2019.03.021.

6. Shobha ES, Nainoor N, Prashanth NT, Rangan V, Malick R, Shetty S (2024) Comparative evaluation of open reduction with internal fixation against closed reduction methods for condylar fracture management: a systematic review and meta-analysis. Journal of Maxillofacial and Oral Surgery, 23(3):475-487, DOI:10.1007/s12663-024-02125-4.

7. Bera RN, Kumar JA, Kanojia S, Boojar FMA, Chauhan N, Hirani MS (2021) How far we have come with the management of

condylar fractures? A meta-analysis of closed versus open versus endoscopic management. Journal of Maxillofacial and Oral Surgery, 21(3):888-903, DOI:10.1007/s12663-021-01587-0.

8. Sharif MO, Fedorowicz Z, Drews P, Nasser M, Dorri M, Newton T, Oliver R (2021) Interventions for the treatment of fractures of the mandibular condyle. Cochrane Database of Systematic Reviews, Issue 12:CD006538, DOI:10.1002/14651858.CD006538.pub2.

9. Larsson S, Bauer TW (2002) Use of injectable calcium phosphate cement for fracture fixation: a review. Clinical Orthopaedics and Related Research, 395:23-32, DOI:10.1097/00003086-200202000-00004.

10. Larsson S, Hannink G (2011) Injectable bone-graft substitutes: current products, their characteristics and indications, and new developments. Injury, 42(Suppl 2):S30-S34, DOI:10.1016/j.injury.2011.06.013.

11. Iundusi R, Gasbarra E, D'Arienzo M, Piccioli A, Tarantino U (2015) Augmentation of tibial plateau fractures with an injectable bone substitute: CERAMENT. Three year follow-up from a prospective study. BMC Musculoskeletal Disorders, 16:115, DOI:10.1186/s12891-015-0574-6.

12. Egol KA, Sugi MT, Ong CC, Montero N, Davidovitch R, Zuckerman JD (2012) Fracture site augmentation with calcium phosphate cement reduces screw penetration after open reduction-internal fixation of proximal humeral fractures. Journal of Shoulder and Elbow Surgery, 21(6):741-748, DOI:10.1016/j.jse.2011.09.017.

13. Friedman CD, Costantino PD (1997) Repair of craniofacial defects with hydroxyapatite cement. Journal of Oral and Maxillofacial Surgery, 55(12):1449-1451, DOI:10.1016/S0278-2391(97)90648-0.

14. Profeta AC, Huppa C (2016) Bioactive-glass in oral and maxillofacial surgery. Craniomaxillofacial Trauma & Reconstruction, 9(1):1-14, DOI:10.1055/s-0035-1551543.

15. Naaz R (2026) NovaBone bioactive glass for oral bone regeneration: mechanisms, innovations, and clinical outcomes. Cureus, 18(5):e108789, DOI:10.7759/cureus.108789.

16. Saghiri MA, Saini RS, Okshah A, Binduhayyim RIH, Heboyan A, Muradyan AA (2025) Efficacy of bioactive glass versus traditional bone grafts in maxillofacial reconstruction: a systematic review and meta-analysis of clinical outcomes. Cell Transplantation, 34, DOI:10.1177/09636897251379572.

17. Mostafavi Moghaddam SA, Mojtahedi H, Bahador A, Kamali Hakim L, Tebyaniyan H (2025) Clinical advances in calcium phosphate for maxillomandibular bone regeneration: from bench to bedside. Ceramics, 8(4):129, DOI:10.3390/ceramics8040129.

18. Low KL, Tan SH, Zein SHS, Roether JA, Mourino V, Boccaccini AR (2010) Calcium phosphate-based composites as injectable bone substitute materials. Journal of Biomedical Materials Research Part B: Applied Biomaterials, 94B(1):273-286, DOI:10.1002/jbm.b.31619.

19. Asim MA, Ibrahim MW, Javed MU, Zahra R, Qayyum MU (2018) Functional outcomes of open versus closed treatment of unilateral mandibular condylar fractures. Journal of Ayub Medical College Abbottabad, 31(1):67-71.

20. Shi D, Patil PM, Gupta R (2015) Facial nerve injuries associated with the retromandibular transparotid approach for reduction and fixation of mandibular condyle fractures. Journal of Cranio-Maxillofacial Surgery, 43(3):402-407, DOI:10.1016/j.jcms.2014.12.009.

21. Agier P, Kozakiewicz M, Tyszkiewicz S, Gabryelczak I (2025) Risk of permanent dysfunction of facial nerves after open rigid internal fixation in the treatment of mandibular condylar process fracture. Medical Sciences, 13(3):121, DOI:10.3390/medsci13030121.