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Biomechanical Rationale and Surgical Strategies for Mandibular Condylar Process Fractures: A Review of Computational and Clinical Evidence

Musayev Shamshodbek Shukhratovich
PhD, associate professor
Department of Maxillofacial Surgery
Tashkent State Medical University,
Shomurodov Kakhramon Erkinovich
DSc, Professor
Department of Maxillofacial Surgery,
Tashkent State Medical University,
Tashkent, Uzbekistan
Fayziyev Bakhtiyor Ravshanovich
PhD, associate professor.
Department of Maxillofacial Surgery,
Tashkent State Medical University,
Tashkent, Uzbekistan,

Abstract.
Mandibular condylar process fractures represent one of the most complex and controversial areas in maxillofacial trauma surgery, accounting for approximately 25-35% of all mandibular fractures. The anatomical complexity of the temporomandibular joint (TMJ) region, combined with the critical functional requirements for mastication, speech, and jaw mobility, makes the management of condylar fractures particularly challenging for surgeons. The condylar process serves as a crucial biomechanical pivot point, transmitting masticatory forces while enabling complex three-dimensional mandibular movements, which necessitates a thorough understanding of both mechanical principles and surgical techniques for optimal treatment outcomes.

Keywords: Mandibular condyle, fracture fixation, biomechanics, finite element analysis, review.

Introduction

Fractures of the mandibular condylar process represent one of the most common and technically challenging injuries in maxillofacial trauma, accounting for 25% to 35% of all mandibular fractures [1, 2]. Epidemiological studies consistently demonstrate a bimodal distribution, with peak incidence in young adult males (20-40 years) due to interpersonal violence and road traffic accidents, and a second peak in elderly females resulting from low-energy falls [3,4]. The unique anatomical and functional characteristics of the temporomandibular complex-comprising the condylar head, articular disc, capsule, and lateral pterygoid muscle insertion-create a biomechanically demanding environment where even minor malreduction can lead to significant morbidity [5].

The lateral pterygoid muscle exerts a mean traction force of 50-100 N on the condylar fragment during mandibular function, creating a displacing moment that complicates fracture healing [6]. When this force is inadequately neutralized, the result is typically anteromedial displacement of the proximal fragment, leading to malunion, facial asymmetry, and debilitating functional impairment [7]. Furthermore, the intra-articular nature of high condylar fractures introduces the risk of osteochondral damage, disc displacement, and ultimately post-traumatic osteoarthritis or ankylosis [8].

Historically, the management of condylar fractures has been dominated by a longstanding controversy between closed treatment (maxillomandibular fixation) and open reduction with internal fixation [9]. For much of the 20th century, closed treatment was favored due to concerns about surgical access, facial nerve injury, and avascular necrosis of the proximal fragment [10].

However, accumulating evidence over the past three decades has demonstrated that closed treatment of displaced fractures in adults frequently results in suboptimal outcomes, including malocclusion, restricted mouth opening, and progressive degenerative changes [11,12].

The paradigm shift toward open treatment has been facilitated by several concurrent advances. First, the development of specialized low-profile titanium osteosynthesis systems has enabled stable fixation even in anatomically constrained regions [13]. Second, improved surgical approaches-particularly the retromandibular anteroparotid and endoscopic-assisted techniques-have dramatically reduced the risk of iatrogenic facial nerve injury [14]. Third, and perhaps most significantly, the application of computational biomechanics, especially finite element analysis, has provided unprecedented insights into the mechanical behavior of different fixation constructs under physiological loading conditions [15].

Finite element analysis allows investigators to simulate stress distribution patterns, identify areas of strain concentration, and predict the likelihood of implant failure or bone resorption without the ethical and practical constraints of in vivo testing [16]. These computational models have revealed, for example, that the commonly used single miniplate in condylar neck fractures concentrates von Mises stresses at the screw-neck junction-a finding that correlates with clinical observations of plate fracture at this precise location [17].

Research Methodology

A structured literature search was conducted in PubMed/MEDLINE, Scopus, and Web of Science databases for articles published between January 2010 and March 2025. The search strategy employed a combination of Medical Subject Headings (MeSH) and keywords: ("mandibular condyle"[Mesh] OR "condylar process" OR "subcondylar") AND ("fractures, bone"[Mesh] OR "fracture") AND ("fracture fixation, internal"[Mesh] OR "open reduction" OR "ORIF" OR "osteosynthesis") AND ("biomechanical phenomena"[Mesh] OR "biomechanics" OR "finite element analysis" OR "FEA" OR "computational modeling").

The initial search yielded 847 potentially relevant articles. After removal of duplicates and screening of titles and abstracts, 97 full-text articles were assessed for eligibility. Twenty-eight studies met all inclusion criteria and were included in the final synthesis. These comprised 12 biomechanical investigations (6 finite element analyses, 6 experimental mechanical tests on cadaveric or synthetic models) and 16 clinical studies (including 4 systematic reviews/meta-analyses, 5 prospective cohorts, and 7 retrospective series).

Results and Discussion

The present review synthesizes evidence from 28 studies spanning experimental biomechanics, computational modeling, and clinical outcomes to provide a comprehensive framework for surgical decision-making in condylar process fractures. The central finding is that fixation strategy must be tailored to fracture level based on fundamental biomechanical principles: load-sharing constructs for the well-vascularized but anatomically constrained condylar head, and load-bearing constructs for the highly stressed condylar neck.

The superiority of lag screw osteosynthesis in condylar head fractures is now supported by both biomechanical and clinical evidence. From a mechanical perspective, screws provide interfragmentary compression that eliminates micromotion-a prerequisite for primary bone healing . The absence of a plate avoids stress shielding and allows physiological loading of the subchondral bone, which may explain the low rates of avascular necrosis observed clinically.Biologically, the minimal dissection required for screw placement preserves the tenuous blood supply to the condylar head, which enters primarily through the lateral pterygoid attachment and capsular reflections. Plates, by contrast, require periosteal stripping that may compromise this already fragile circulation.

For condylar neck fractures, the biomechanical imperative is resistance to the displacing force of the lateral pterygoid muscle. The lateral pterygoid inserts on the pterygoid fovea of the condylar neck and, during contraction, generates a moment that tends to rotate the proximal fragment anteromedially [6]. A single plate, regardless of its thickness, acts as a cantilever subjected to high bending moments. Finite element analyses consistently demonstrate stress concentration at the screw-plate interface nearest the fracture line-precisely the location where clinical plate fractures are observed [17].

Double plates, or three-dimensionally configured single plates such as the delta plate, create a stable construct that resists rotation by providing fixation in orthogonal planes. This principle-two-point fixation to resist rotational forces-is well established in orthopedic surgery for metaphyseal fractures [4,9].

The clinical translation of these biomechanical principles is evident in the superior functional outcomes reported with double-plate fixation. Although randomized trials directly comparing single versus double plates are lacking, the consistency of findings across biomechanical studies and the logical progression from mechanical principles to clinical practice support the recommendation for two-point fixation whenever anatomically feasible.

Conclusion

The surgical management of mandibular condylar process fractures has evolved substantially over the past two decades, transitioning from a historically conservative approach to an evidence-based paradigm grounded in biomechanical principles. This review synthesizes computational, experimental, and clinical evidence to demonstrate that optimal outcomes require fracture-level specific strategies. For condylar head fractures, lag screw osteosynthesis provides superior biomechanical stability while preserving the tenuous blood supply, resulting in excellent long-term function with minimal risk of avascular necrosis. The addition of disc repair when indicated addresses the soft tissue component of these injuries and may prevent post-traumatic osteoarthritis. For condylar neck fractures, the biomechanical imperative to resist lateral pterygoid traction mandates two-point fixation, achieved either by double miniplates or three-dimensionally configured single plates. Finite element analyses consistently demonstrate that single straight plates concentrate stress at the screw-neck junction, predisposing to fatigue failure. The clinical translation of these findings is evident in superior functional outcomes with double-plate constructs.

The retromandibular anteroparotid approach has emerged as the optimal access for neck fractures, offering excellent visualization with minimal risk to the facial nerve. Endoscopic assistance provides comparable outcomes with the advantage of scarless surgery, though it requires specialized training and equipment. Despite these advances, significant knowledge gaps remain. The role of patient-specific computational modeling in preoperative planning, the optimal management of the articular disc, and the long-term fate of these injuries over decades all require further investigation. The integration of biomechanical principles into surgical decision-making, however, has already improved outcomes and will continue to guide innovation in this challenging area of maxillofacial trauma.

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