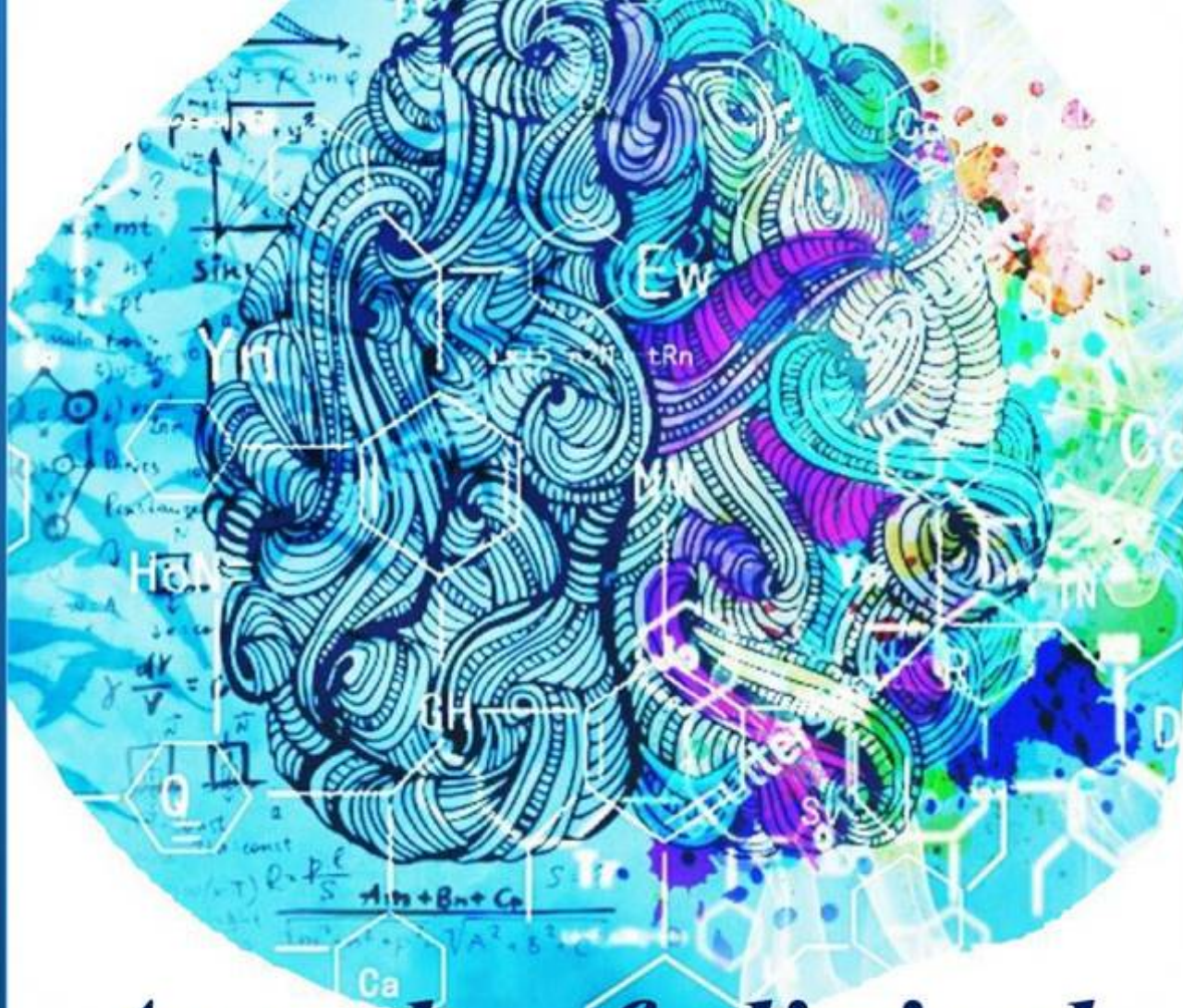


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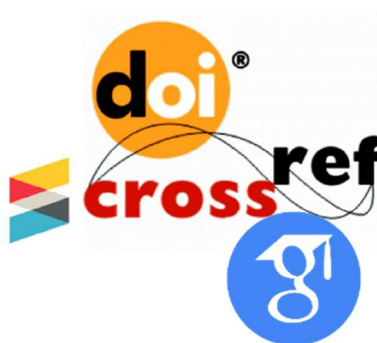
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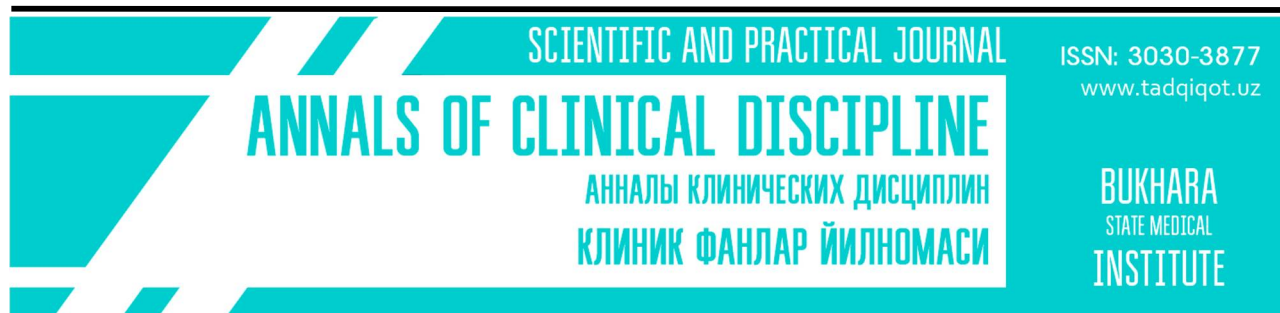
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BIOMECHANICAL PATTERNS AND CLINICAL CHARACTERISTICS OF COMBINED MAXILLOFACIAL TRAUMA: A RETROSPECTIVE ANALYSIS

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Abstract. Maxillofacial trauma is a major clinical challenge associated with complex injury patterns and increasing diagnostic demands. To evaluate epidemiological trends, clinical characteristics, and diagnostic approaches in patients with maxillofacial trauma. A retrospective multicenter study was conducted on 566 surgically treated patients with maxillofacial fractures between 2015 and 2025. Demographic data, injury mechanisms, fracture characteristics, injury severity, and imaging modalities were analyzed. The incidence of maxillofacial trauma increased during the study period, with road traffic accidents and falls from height representing the most common causes of severe injuries. Clinical examination remained the primary diagnostic tool; however, the use of advanced imaging modalities, particularly multidetector computed tomography and cone-beam computed tomography, increased substantially over time. Higher injury severity was associated with more complex fracture patterns and greater treatment burden. Injury mechanism significantly influences fracture severity and clinical complexity in maxillofacial trauma. The increasing adoption of advanced imaging technologies has improved diagnostic assessment and treatment planning, supporting more effective management of facial injuries.

Keywords: maxillofacial trauma; facial fractures; epidemiology; computed tomography; diagnostic imaging; injury severity.

YUZ-JAG‘ SOHASINING QO‘SHMA SHIKASTLANISHLARIDA BIOMEXANIK XUSUSIYATLAR VA KLINIK TAVSIFLAR: RETROSPEKTIV TAHLIL

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Annotatsiya. Yuz-jag‘ sohasining travmatik shikastlanishlari murakkab jarohatlanish turlari va diagnostikaga bo‘lgan talablarning ortib borishi bilan tavsiflanadigan muhim klinik muammo hisoblanadi. Ushbu tadqiqotning maqsadi yuz-jag‘ sohasi travmalariga chalingan bemorlarda epidemiologik tendensiyalarni, klinik xususiyatlarni va diagnostik yondashuvlarni baholashdan iborat edi. 2015–2025-yillar davomida yuz-jag‘ suyaklari sinishlari sababli jarrohlik davolash

o'tkazilgan 566 nafar bemorni qamrab olgan retrospektiv ko'p markazli tadqiqot amalga oshirildi. Demografik ko'rsatkichlar, travma mexanizmlari, sinishlarning xususiyatlari, shikastlanish og'irligi va diagnostik tasvirlash usullari tahlil qilindi. Tadqiqot davrida yuz-jag' travmalari uchrashish chastotasining ortishi kuzatildi, bunda yo'l-transport hodisalari va balandlikdan yiqilish og'ir jarohatlarning eng ko'p uchraydigan sabablari bo'ldi. Klinik ko'rik asosiy diagnostik usul bo'lib qolgan bo'lsa-da, multispiral kompyuter tomografiyasi va konus-nurli kompyuter tomografiyasi kabi zamonaviy tasvirlash usullaridan foydalanish sezilarli darajada oshdi. Shikastlanishning yuqori darajasi murakkabroq sinish turlari va davolash yuklamasining ortishi bilan bog'liq edi. Travma mexanizmi yuz-jag' sohasi shikastlanishlarining og'irligi va klinik murakkabligiga sezilarli ta'sir ko'rsatadi. Zamonaviy tasvirlash texnologiyalarining keng joriy etilishi diagnostika aniqligini va davolashni rejalashtirish sifatini yaxshilashga xizmat qiladi.

Kalit so'zlar: yuz-jag' travmasi; yuz suyaklari sinishlari; epidemiologiya; kompyuter tomografiyasi; radiologik diagnostika; shikastlanish og'irligi.

БИОМЕХАНИЧЕСКИЕ ОСОБЕННОСТИ И КЛИНИЧЕСКИЕ ХАРАКТЕРИСТИКИ СОЧЕТАННЫХ ТРАВМ ЧЕЛЮСТНО-ЛИЦЕВОЙ ОБЛАСТИ: РЕТРОСПЕКТИВНЫЙ АНАЛИЗ

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Аннотация. Травмы челюстно-лицевой области представляют собой серьезную клиническую проблему, характеризующуюся сложными паттернами повреждений и возрастающими требованиями к диагностике. Целью исследования являлась оценка эпидемиологических тенденций, клинических характеристик и диагностических подходов у пациентов с травмами челюстно-лицевой области. Проведено ретроспективное многоцентровое исследование, включившее 566 пациентов с переломами лицевого скелета, которым было выполнено хирургическое лечение в период с 2015 по 2025 гг. Анализировались демографические показатели, механизмы травмы, характеристики переломов, тяжесть повреждений и применяемые методы визуализации. За исследуемый период отмечено увеличение частоты травм челюстно-лицевой области, при этом дорожно-транспортные происшествия и падения с высоты являлись наиболее частыми причинами тяжелых повреждений. Клиническое обследование оставалось основным методом диагностики, однако использование современных методов визуализации, особенно мультиспиральной компьютерной томографии и конусно-лучевой компьютерной томографии, существенно возросло. Более высокая тяжесть травмы ассоциировалась с более сложными паттернами переломов и большей нагрузкой на систему лечения. Механизм травмы оказывает значительное влияние на тяжесть повреждений и клиническую сложность травм челюстно-лицевой области. Расширение применения современных технологий визуализации способствует повышению точности диагностики и улучшению планирования лечения.

Ключевые слова: травмы челюстно-лицевой области; переломы лицевого скелета; эпидемиология; компьютерная томография; лучевая диагностика; тяжесть травмы.

Introduction. Maxillofacial trauma represents a major public health concern worldwide, accounting for a substantial proportion of injuries resulting from road traffic accidents, falls, sports-related incidents, interpersonal violence, and occupational accidents [1,2]. Owing to the complex anatomical structure of the craniofacial region and its close relationship with the brain, visual apparatus, and upper airway, injuries to the facial skeleton frequently occur in combination with traumatic damage to other body systems [3]. Such combined injuries are associated with increased morbidity, prolonged hospitalization, functional impairment, aesthetic deformities, and significant socioeconomic consequences [4].

The epidemiology and clinical presentation of maxillofacial trauma are strongly influenced by the mechanism of injury. High-energy trauma, particularly road traffic accidents and falls from height, often produces complex fracture patterns involving multiple anatomical regions of the facial skeleton, whereas sports-related injuries are more frequently associated with localized fractures and soft-tissue damage [5,6]. Variations in impact direction, velocity, energy transfer, and contact surface characteristics generate distinct biomechanical loading conditions that determine fracture location, severity, and associated injuries [7]. Understanding these biomechanical mechanisms is therefore essential for accurate diagnosis, risk assessment, treatment planning, and outcome prediction.

Despite advances in imaging technologies, including multidetector computed tomography (MSCT), cone-beam computed tomography (CBCT), three-dimensional reconstruction, and computer-assisted surgical planning, diagnostic challenges remain common in patients with combined maxillofacial trauma [8]. Concomitant traumatic brain injury, cervical spine injury, or multisystem trauma may obscure clinical manifestations of facial fractures, resulting in delayed diagnosis and suboptimal treatment [9]. Furthermore, traditional clinical assessment is primarily descriptive and often fails to adequately explain the relationship between injury mechanism and resulting fracture patterns.

Recent developments in biomechanical modeling and finite element analysis (FEA) have provided new opportunities to investigate the mechanical behavior of craniofacial structures under traumatic loading conditions [10,11]. These approaches enable the identification of stress concentration zones, prediction of fracture-prone regions, and evaluation of the influence of impact characteristics on injury severity. However, studies integrating clinical observations with biomechanical analysis in large cohorts of patients remain limited, particularly for combined maxillofacial trauma [12].

A comprehensive understanding of the relationship between injury mechanism, biomechanical characteristics, and clinical manifestations may improve diagnostic accuracy, facilitate individualized treatment strategies, and support the development of preventive measures. Moreover, the identification of mechanism-specific injury patterns could contribute to more effective resource allocation and clinical decision-making in emergency and trauma care settings.

Therefore, the aim of the present study was to investigate the biomechanical patterns of combined maxillofacial trauma and determine their influence on clinical presentation, diagnostic findings, and treatment outcomes. Specifically, we analyzed fracture distribution, injury severity, and clinical characteristics among patients with maxillofacial trauma resulting from road traffic accidents, falls from height, sports injuries, and multifactorial trauma mechanisms, and explored the relationship between injury biomechanics and observed clinical outcomes in a cohort of 566 surgically treated patients.

Materials and Methods. Study design and patient population

This retrospective multicenter study analyzed patients treated for maxillofacial trauma between January 2015 and December 2025 at three tertiary referral centers specializing in craniofacial injury management, including the Republican Research Center for Emergency Medicine and its Tashkent City Branch, Tashkent State Medical University, and the Republican Specialized Scientific and Practical Medical Center of Otorhinolaryngology and Head and Neck Diseases. The study protocol was approved by the institutional ethics committee and conducted in accordance with the principles of the Declaration of Helsinki.

A total of 1,284 patient records were initially screened. After exclusion of patients with incomplete clinical documentation, unavailable computed tomography (CT) data, isolated soft-tissue injuries, conservative treatment, or incomplete follow-up information, 566 patients with surgically treated maxillofacial fractures were included in the final analysis. All included patients underwent open reduction and internal fixation under general anesthesia and had complete preoperative imaging records available for review. Patient demographic characteristics, mechanism of injury, fracture localization, injury severity, treatment characteristics, and clinical outcomes were extracted from electronic medical records.

Clinical and radiological assessment

Upon admission, all patients underwent a standardized clinical and radiological evaluation. Clinical assessment included documentation of age, sex, injury mechanism, associated injuries, neurological status, and fracture characteristics. Fracture severity was quantified using the Facial Injury Severity Scale (FISS). Panfacial fractures were defined as injuries involving the upper, middle, and lower thirds of the facial skeleton.

Radiological assessment was performed using multidetector computed tomography (MSCT) with three-dimensional reconstruction. Cone-beam computed tomography (CBCT) was additionally used when detailed evaluation of maxillofacial structures was required. Fractures were classified according to anatomical location, including mandibular, maxillary, zygomaticomaxillary, orbital, nasal, frontal, and panfacial fractures. Imaging findings were independently reviewed by experienced maxillofacial surgeons and radiologists.

Based on the mechanism of injury, patients were categorized into four groups: road traffic accidents, falls from height, sports-related injuries, and multifactorial trauma. Fracture patterns, injury severity, duration of hospitalization, operative time, and treatment outcomes were compared among these groups.

Bone density and microstructural analysis

Quantitative evaluation of craniofacial bone characteristics was performed using Mimics software version 14.0 (Materialise HQ, Leuven, Belgium). Three-dimensional reconstructions generated from CT datasets were used to assess bone mineral density and microstructural organization of different anatomical regions of the facial skeleton. Bone density was measured in Hounsfield units (HU), while microstructural parameters including bone volume fraction (BV/TV), trabecular thickness (Tb.Th), trabecular separation (Tb.Sp), trabecular number (Tb.N), connectivity density (Conn.D), and porosity were analyzed in representative regions of interest. Comparative analyses were performed for the frontal bone, zygomatic bone, maxilla, mandible, orbital complex, and nasal bones.

Biomechanical modeling

Finite element analysis (FEA) was performed using Mechanical Finder software (Research Center for Computational Mechanics, Tokyo, Japan). Patient-specific three-dimensional craniofacial models were reconstructed from CT images and converted into finite element meshes. Simulated impact scenarios were designed to reproduce frontal, lateral, and oblique traumatic loading conditions with impact velocities ranging from 5 to 10 m/s.

The biomechanical response of craniofacial structures was evaluated by calculating stress distribution, acceleration, pressure transmission, and Head Injury Criterion (HIC) values. Regions of maximal stress concentration and predicted fracture susceptibility were identified and subsequently compared with clinically observed fracture patterns. This approach enabled assessment of the relationship between injury mechanism, force transmission pathways, and resulting clinical manifestations.

Statistical analysis. Statistical analyses were performed using SPSS software (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean $\pm$ standard deviation, whereas categorical variables were reported as frequencies and percentages. Comparisons between injury mechanism groups were performed using one-way analysis of variance (ANOVA) for continuous variables and the chi-square test for categorical variables. Associations between biomechanical parameters, fracture patterns, and clinical outcomes were evaluated using correlation and regression analyses where appropriate. A p-value < 0.05 was considered statistically significant.

Results. Epidemiological trends and utilization of diagnostic methods

Analysis of annual case distribution demonstrated a progressive increase in the incidence of maxillofacial trauma throughout the study period. The number of recorded cases increased from 32 in 2014 to a peak of 73 in 2023, corresponding to a 128.1% increase over the observation period. Following this peak, a decline was observed, with 54 cases recorded in 2024 and further reductions in 2025 and 2026. Despite this decrease, incidence levels remained substantially higher than those reported at the beginning of the study period (Figure 1A).

Evaluation of diagnostic approaches revealed significant changes in imaging utilization over time (Figure 1B). Clinical examination remained the most frequently employed diagnostic modality throughout the study period, increasing from 32 cases in 2015 to 73 cases in 2024 before declining to 54 cases in 2025. Conventional radiography demonstrated a gradual reduction in use, decreasing from 24–28 examinations annually during the early years of the study to 14 examinations in 2025. Similarly, orthopantomography (OPG) showed a modest decline over time.

In contrast, advanced imaging modalities exhibited a marked increase in utilization. The use of multidetector computed tomography (MSCT) increased steadily from 13 cases in 2015 to 62 cases in 2024, reflecting its growing importance in the evaluation of complex facial fractures. Cone-beam computed tomography (CBCT) also demonstrated progressive adoption, particularly after 2020. Three-dimensional reconstruction and artificial intelligence-assisted diagnostic technologies were introduced during the later stages of the study period and showed continuous growth, indicating increasing integration of digital technologies into maxillofacial trauma management.

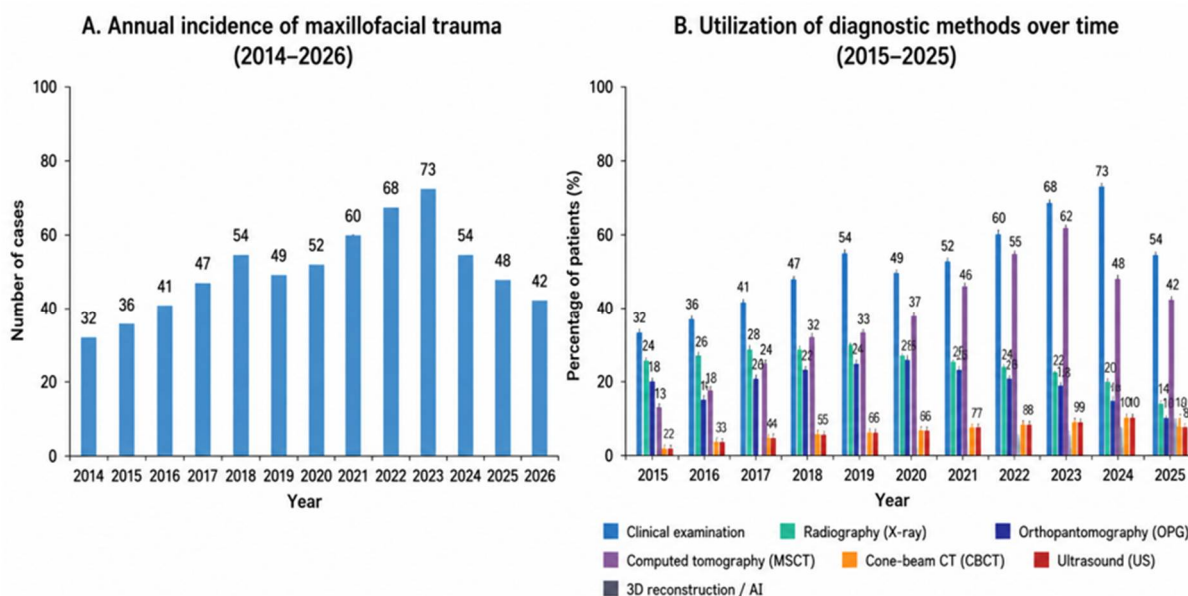


Figure 1. Trends in maxillofacial trauma incidence and diagnostic imaging practices over the study period. (A) Annual number of maxillofacial trauma cases. (B) Utilization of diagnostic methods from 2015 to 2025, demonstrating increasing adoption of advanced imaging technologies and digital diagnostic tools.

Clinical and radiological characteristics

Among the 566 surgically treated patients included in the study, road traffic accidents and falls from height represented the predominant mechanisms of injury, accounting for the majority of severe fracture patterns. Clinical assessment revealed substantial variability in fracture distribution according to injury mechanism. High-energy trauma was frequently associated with multifocal and panfacial injuries, whereas sports-related trauma more commonly resulted in isolated fractures.

Radiological evaluation using MSCT and three-dimensional reconstruction enabled accurate characterization of fracture morphology and anatomical distribution. Fractures of the midface were the most frequently encountered injuries, particularly involving the zygomaticomaxillary complex and orbital region. Mandibular fractures were predominantly localized to the body, angle, and condylar regions. Panfacial fractures were identified in a substantial proportion of patients exposed to high-energy trauma mechanisms, including road traffic accidents and multifactorial injuries.

The severity of injury, assessed using the Facial Injury Severity Scale (FISS), was significantly greater among patients presenting with panfacial fractures than among those with isolated injuries. Higher FISS scores were associated with prolonged hospitalization and increased operative duration. Patients requiring surgical procedures exceeding 120 minutes demonstrated significantly greater injury severity compared with those undergoing shorter interventions.

Similarly, extended hospital stays were associated with more extensive fracture patterns and increased anatomical involvement.

Discussion. The present study investigated epidemiological trends, clinical characteristics, and diagnostic approaches in a cohort of 566 surgically treated patients with maxillofacial trauma. The findings demonstrate a progressive increase in the incidence of maxillofacial injuries over the study period, accompanied by substantial changes in diagnostic practices, particularly the growing utilization of advanced imaging modalities. Furthermore, injury severity and fracture complexity were strongly associated with the mechanism of trauma, emphasizing the importance of understanding biomechanical factors underlying craniofacial injury patterns.

A notable finding of the present study was the continuous increase in the annual incidence of maxillofacial trauma from 2014 to 2023. Similar trends have been reported in both developed and developing countries, where urbanization, increased motor vehicle use, occupational exposure, and participation in high-risk recreational activities have contributed to a growing burden of facial injuries [13,14]. Although a decline was observed during the final years of the study period, the incidence remained substantially higher than that recorded at the beginning of the observation period, suggesting that maxillofacial trauma continues to represent a significant healthcare challenge.

The distribution of injuries observed in our cohort is consistent with previous epidemiological investigations demonstrating that road traffic accidents and falls from height remain among the leading causes of severe facial trauma [3,4]. These mechanisms involve high-energy transfer and are frequently associated with multifocal fractures, panfacial injuries, and concomitant traumatic brain injury. In contrast, sports-related trauma was more commonly associated with isolated fracture patterns and lower injury severity. The observed differences support previous biomechanical studies showing that impact velocity, force direction, and energy dissipation significantly influence fracture morphology and anatomical distribution [15].

An important observation of this study was the increasing adoption of advanced imaging technologies. While clinical examination remained the cornerstone of initial assessment throughout the study period, the utilization of multidetector computed tomography increased substantially. This trend reflects growing recognition of CT imaging as the diagnostic gold standard for complex facial fractures because of its superior ability to identify fracture lines, displacement, comminution, and associated cranial injuries [16]. The progressive implementation of cone-beam computed tomography and three-dimensional reconstruction techniques further improved visualization of complex anatomical structures and facilitated preoperative planning.

The increasing use of digital technologies observed in the present study parallels recent developments in computer-assisted surgery and artificial intelligence applications in maxillofacial trauma. Artificial intelligence-based systems have demonstrated promising capabilities in automated fracture detection, segmentation, and surgical planning, potentially reducing diagnostic errors and improving clinical efficiency [17,18]. Although AI-assisted methods represented only a small proportion of diagnostic procedures during the study period, their steady increase suggests that these technologies are likely to become integral components of future trauma management pathways.

The association between injury severity and treatment burden observed in the current investigation is consistent with previous reports. Patients presenting with higher FISS scores and panfacial fractures required longer operative times and extended hospitalization. Similar relationships have been documented by Bagheri et al. [19] and Catapano et al. [20], who reported that increasing fracture complexity is associated with greater surgical demands, higher complication rates, and prolonged recovery periods. These findings highlight the value of standardized severity assessment systems in predicting resource utilization and optimizing treatment planning.

From a clinical perspective, the present results support a mechanism-based approach to trauma assessment. Knowledge of the injury mechanism provides important information regarding expected fracture patterns and associated injuries. For example, patients involved in high-speed road traffic accidents or falls from height should be considered at elevated risk for panfacial

fractures and intracranial injury, warranting comprehensive radiological evaluation. Such an approach may improve diagnostic accuracy and reduce the risk of missed injuries, particularly in patients with altered consciousness or multiple trauma.

Conclusion. Maxillofacial trauma remains a significant clinical challenge, with an increasing incidence and evolving diagnostic requirements. The present study demonstrated that injury mechanism is closely associated with fracture severity and clinical complexity, with high-energy trauma resulting in more extensive facial injuries. The progressive adoption of advanced imaging modalities, particularly CT-based techniques and three-dimensional reconstruction, has improved diagnostic accuracy and treatment planning. A mechanism-based approach combined with modern imaging technologies may facilitate earlier diagnosis, optimize management strategies, and improve outcomes in patients with maxillofacial trauma.

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