MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
SUMY STATE UNIVERSITY
ACADEMIC AND RESEARCH MEDICAL INSTITUTE

Eastern Ukrainian Medical Journal

116, Kharkivska st., Sumy 40007, Ukraine
e-mail: eumj@med.sumdu.edu.ua
eumj.med.sumdu.edu.ua
ISSN: 2663-5909 (print)/2664-4231 (online)

How to cite: Yehorov R, Kopchak A, Kaniura O, Kryshchuk M. Computer simulation of traumatic mandibular fractures in children of different ages. *East Ukr Med J.* 2026;14(2):521-531. DOI: https://doi.org/10.21272/eumj.2026;14(2);521-531

ABSTRACT

Rostyslav Yehorov
https://orcid.org/0000-0003-4705-7576
Department of Surgical Dentistry and Maxillofacial Surgery of Pediatric Age, Bogomolets National Medical University, Kyiv, Ukraine

Andrii Kopchak
https://orcid.org/0000-0002-3272-4658
Department of Maxillo-Facial Surgery and Innovative Dentistry of Bogomolets National Medical University, Kyiv, Ukraine

Oleksandr Kaniura
https://orcid.org/0000-0002-6926-6283
Department of Orthodontics and Prosthodontics Propaedeutics of Bogomolets National Medical University, Kyiv, Ukraine

Mykola Kryshchuk
https://orcid.org/0000-0002-0662-9147
Department of Dynamics and Strength of Machines and Strength of Materials, Igor Sikorsky KPI, Kyiv, Ukraine

COMPUTER SIMULATION OF TRAUMATIC MANDIBULAR FRACTURES IN CHILDREN OF DIFFERENT AGES

Introduction. The study of the mechanisms of traumatic bone destruction using computer-aided technologies is a pressing problem in modern medicine, particularly in maxillofacial surgery. It has not only diagnostic meaning, but also plays a major role in planning treatment measures.

Materials and methods. The study was aimed at assessing the mechanisms of bone destruction in different age periods. A feature of the applied approach was the reconstruction of simulated lower jaw models based on multispiral computed tomography data of 4 patients aged 2, 6, 9, and 17 years, corresponding to different dentition periods.

Results. When applying force to the chin area, the displacement of the model nodes was greater than when applying force to the body area. They were mainly caused by bending deformation in the area of both condylar processes and reached 3.7 mm for the 17-year-old lower jaw model. When reproducing a traumatic effect on the body of the lower jaw, the maximum displacement was also found in the model of a 17-year-old child and amounted to 2.4 mm, while the smallest displacement was recorded in the 9-year-old lower jaw model, which amounted to 0.8 mm.

Conclusions. When studying the stress-strain state of the lower jaw of pediatric patients under the influence of external traumatic loads, it was found that in all studied age periods, when force is applied to the symphysis area, the stress-strain state of the bone is characterized by the formation of maximum stress concentration in the cortical layer of the bone in the area of the condylar processes.

Calculations of external force extreme values for the studied lower jaw models with a strength limit of 100 MPa indicated that LJ fractures can occur under the impact applied to the chin with an amplitude from 247 N to 266 N for a 2-year-old and 9-year-old jaw models, respectively, and from 145 N – for a 6-year-old jaw model.

Keywords: lower jaw, children, fracture, CT, finite element method, model.

Corresponding author: *Rostyslav Yehorov, Department of Surgical Dentistry and Maxillofacial Surgery of Pediatric Age, Bogomolets National Medical University, Kyiv, Ukraine*
e-mail: dr.egorovr@icloud.com

РЕЗЮМЕ

Ростислав Єгоров
https://orcid.org/0000-0003-4705-7576
кафедра хірургічної стоматології та щелепно-лицевої хірургії дитячого віку НМУ імені О.О. Богомольця, Київ, Україна

Андрій Копчак
https://orcid.org/0000-0002-3272-4658
кафедра щелепно-лицевої хірургії та сучасних стоматологічних технологій Інституту післядипломної освіти НМУ імені О.О. Богомольця, Київ, Україна

Олександр Канюра
https://orcid.org/0000-0002-6926-6283
кафедра ортодонтії та пропедевтики ортопедичної стоматології Національного медичного університету імені О.О. Богомольця, Київ, Україна

Микола Крищук
https://orcid.org/0000-0002-0662-9147
кафедра динаміки і міцності машин та опору матеріалів НТУУ «КПІ імені Ігоря Сікорського», Київ, Україна

ІМІТАЦІЙНЕ КОМП'ЮТЕРНЕ МОДЕЛЮВАННЯ ТРАВМАТИЧНИХ ПЕРЕЛОМІВ НИЖНЬОЇ ЩЕЛЕПИ У ДІТЕЙ РІЗНОГО ВІКУ

Вступ. Вивчення механізмів травматичного руйнування кісток за допомогою комп'ютерних технологій є актуальною темою сучасної медицини і щелепно-лицевої хірургії, зокрема. Воно має не лише діагностичний але й відіграє велику роль в плануванні лікувальних заходів.

Матеріали і методи. Дослідження було спрямовано на вивчення механізмів руйнування кістки в різні вікові періоди. Особливістю застосованого підходу було відтворення імітаційних моделей НЩ у дітей на основі даних мультиспіральних комп'ютерних томограм 4 пацієнтів віком 2, 6, 9 та 17 років, що відповідали різним періодам прикусу.

Результати. При прикладанні сили на ділянці підборіддя переміщення вузлів моделі було більшим ніж при дії сили на ділянці тіла. Вони були зумовлені переважно деформацією згину на ділянці обох виросткових відростків і сягали 3,7 мм для моделі НЩ пацієнта 17 років. При відтворенні травматичної дії на тіло нижньої щелепи - бічний удар, максимальне переміщення також було виявлено в моделі 17 річної дитини та склало 2,4 мм, а найменше зафіксоване в моделі 9 річної дитини, яке склало 0,8 мм.

Висновки. При дослідженні НДС НЩ пацієнтів дитячого віку під дією зовнішніх травматичних навантажень встановлено, що в усіх досліджених вікових періодах при прикладанні сили на ділянці симфізу НДС кістки характеризується утворенням зон максимальної концентрації напруження в кортикальному шарі кістки на ділянці виросткових відростків.

Обчислення екстремальних величин травмувальної сили для досліджених моделей НЩ при завданій границі міцності у 100МПа встановило, що переломи можуть виникати при ударі в підборіддя з амплітудою від 247Н до 266Н відповідно для віку щелеп 2 і 9 років та 145Н для 6 років.

Ключові слова: нижня щелепа, діти, перелом, КТ, метод скінченних елементів, модель.

Автор, відповідальний за листування*: Ростислав Єгоров, кафедра хірургічної стоматології та щелепно-лицевої хірургії дитячого віку НМУ імені О.О. Богомольця*
e-mail: dr.egorovr@icloud.com

ABBREVIATIONS

FEM – finite element method, LJ – lower jaw, MSCT – multispiral computed tomograms, SSS – stress-strain state

INTRODUCTION

The study of the mechanisms of traumatic bone destruction under the influence of external forces is a pressing problem of modern medicine and, in particular, maxillofacial surgery. It has not only diagnostic, forensic, and preventive meaning, but also plays a major role in planning treatment measures and organizing medical care for patients [1]. There is a large body of research conducted in this field, starting with the classic works of the first half of the 20th century, but most of them have inherent limitations due to the subject matter of the study itself. For bioethical reasons, direct experiments with bone destruction in humans are fundamentally impossible. Experiments on animals and biomimetics do not allow direct application of the results obtained to patients due to significant differences in the functional anatomy of human and animal bones, with these differences being greatest for the facial skull. The use of cadaveric material, which is the gold standard for such studies in biomechanics, also has its drawbacks, associated with age-related and postmortem changes in tissues, difficulties in obtaining and storing the samples, and the complexity of trauma modeling, taking into account different functional states. Particularly problematic from this point of view is the analysis of the mechanisms of traumatic bone fractures in children, because they differ greatly in size, shape, internal structure, and architectonics, as well as in physical and mechanical properties compared to adult patients [2].

An alternative to full-scale experiments in studying the biomechanics of human bones is the use of modern computational modeling methods and advanced computational tools, such as the finite element method (FEM) [3]. The advantage of FEM is that a discrete model with complex geometry and heterogeneous biomechanical properties of materials allows obtaining a larger amount of important information compared to physical models [4].FEM is an important element of preclinical testing of new technologies and materials in the biomedical field, making it possible to perform simulations without involving patients or conducting animal tests. There are well-known works on the study of trauma biomechanics and osteosynthesis of facial bones using FEM, which prove the accuracy and adequacy of modern computer models. However, in the literature available to us, there are no publications using this approach that are devoted to the study of lower jaw (LJ) injury mechanisms in children. Factors that can influence bone destruction in children of different ages due to external forces include differences in the LJ anatomy; the presence of temporary and/or permanent teeth and primordia; increased bone elasticity; phases of active growth, etc. [5].

The works of Khonsari R.H. et al. devoted to the stress-strain state (SSS) of the facial skeleton bones in children of different ages under functional load indicated significant, both quantitative and qualitative differences compared to the adult population [6, 7, 8]. This does not allow extrapolating the results of studies involving fully formed LJ models to pediatric patients. Thus, it necessitates a more in-depth study using improved models that reproduce the age characteristics of children's bones.

The objective of the study was to examine the features of the SSS in the child's LJ at different ages under the influence of traumatic factors and to determine the most probable zones of bone destruction based on the area of force application and the direction of the external force vector.

METHODS AND MATERIALS

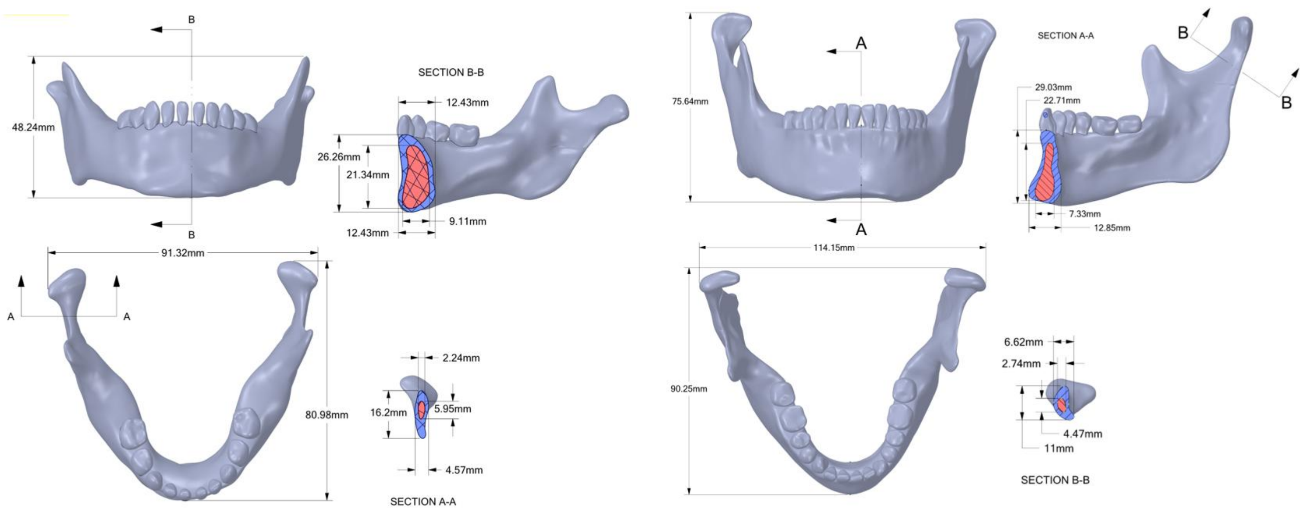
The study of the biomechanical behavior of the LJ under the influence of external traumatic factors was conducted in a model experiment using information technologies and CAD/CAE systems. The study was aimed at assessing the mechanisms of bone destruction in different age periods and explaining the differences in location and types of traumatic fractures that are characteristic of children of different age groups. A feature of the applied approach was the reproduction of simulation models of the LJ in children, which corresponded to different age periods in terms of their anatomical structure and properties, but were subjected to the same external traumatic load. The working hypothesis was that differences in LJ anatomical shape, architectonics, and biomechanical properties in children of different ages significantly affect the characteristics of bone deformation and destruction under the influence of external factors.

Reconstruction of the three-dimensional geometry of a child's lower jaw in simulation computer models. Three-dimensional solid LJ models were created using the software codes of 3D Slicer [X1], Autodesk Meshmixer [X2], and Ansys 12.1 [X3].

The spatial geometry of the jaw was reconstructed based on multispiral computed tomography (MSCT) data from 4 patients aged 2, 6, 9, and 17 years, which corresponded to 4 different periods: primary, early mixed, mixed, and permanent dentition. To create simulation models, MSCTs of patients with no signs of LJ disease/traumatic injuries were selected, whose anthropometric parameters corresponded to the age standards. The main cephalometric indices of the selected jaws are given in Table 1, and their geometric features are presented in Figure 1.

Table 1 – Anthropometric parameters of the LJ models

Parameter	Child's age			
	2 years	6 years	9 years	17 years
Co-Co	91.7 mm	107.1 mm	107.8 mm	123.7 mm
PO-GO	61.8 mm	77 mm	77.9 mm	87.1 mm
GO-COsup	49.3 mm	45.6 mm	48.8 mm	64 mm
Gonian angle	129.7°	120.1°	120.9°	121.9°



A B

Figure 1 – Anatomical differences in LJ shape in children of different ages reproduced in 2-year-old (a) and 17-year-old (b) models

MSCT data in DICOM format was imported into 3D Slicer for further segmentation. Separate masks were created and modified for the cortical and cancellous layers of the LJ, as well as for the teeth and primordia located in the jaw (Fig. 2). The created models neglected the structural and mechanical features of the periodontal ligament and tooth follicles as insignificant.

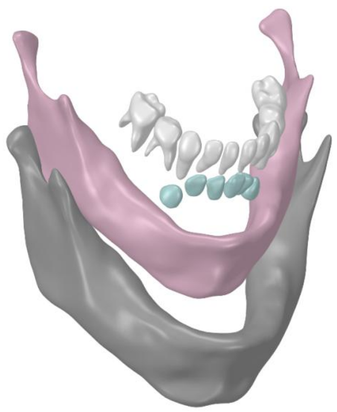


Figure 2 – Multi-component lower jaw model of a 2-year-old child in assembly mode

The geometry of these anatomical structures is very complex, their mechanical properties are not well understood, so this approximation of the model helped reduce the number of errors and inconsistencies during computer simulation.

The created surface polygonal models were exported as STL files to the Autodesk Meshmixer software package, where they were checked for geometry errors with subsequent correction when creating volumes. To reproduce the action of an external traumatic force, an absolutely rigid body with an area of 10 mm^2 was modeled in the form of a round plate 1 mm thick and was placed on the outer surface of the chin and the lateral surface of the simulated jaw models. These locations are typical areas of external force exertion during trauma. Surface models of the LJ structures using Boolean operations were combined by mating and connecting into multi-component assemblies with realistic three-dimensional geometry reproduction and imported into the Ansys Workbench Mechanical software for further numerical calculation.

Finite element mesh decomposition, loading, and material properties.

Preprocessing of models was performed in the Ansys 12.1 software environment (USA). For each simulation model of children's jaws, the volumes of the corresponding bone and tooth structural elements were created, followed by the assignment of the biomechanical elastic properties.

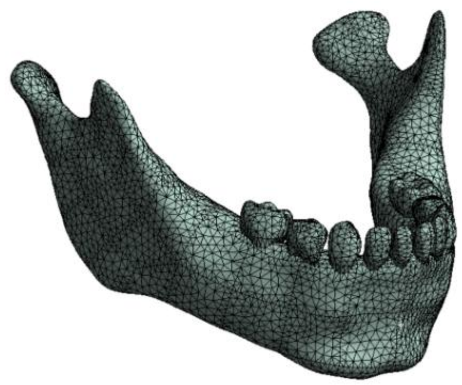
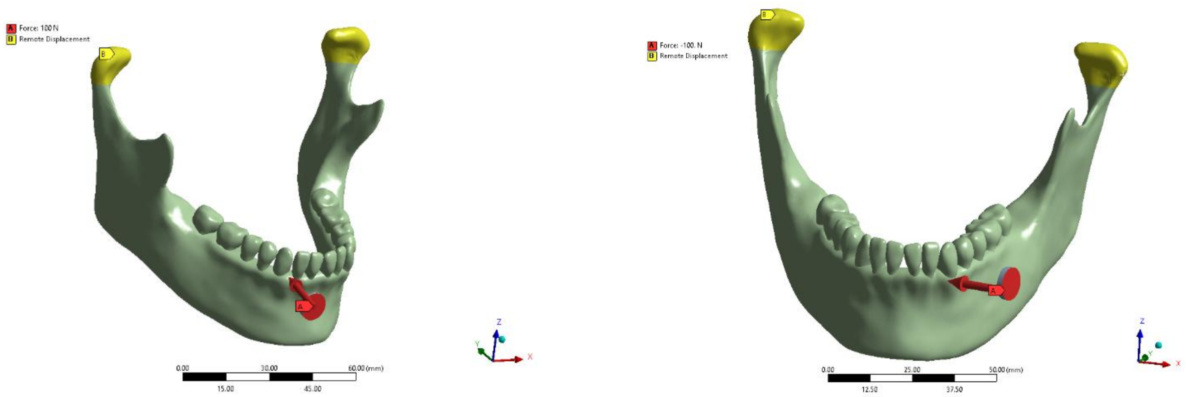


Figure 3 – Finite element mesh for a 3D lower jaw model of a 2-year-old child. The model consists of 83863 tetrahedral elements and 151761 nodes

To create four discrete models of jaws of different ages, 10-node tetrahedral finite elements with quadratic approximation of functions were used, which we considered optimal for representing objects with complex geometry and surface curvature profiles. The mesh density (optimal number of nodes and finite elements) in the created discrete models was controlled by a convergence test of the obtained results (Fig. 3).

To conduct experiments, calculation schemes were developed for different types of LJ (Fig. 4). Discrete jaw models were rigidly fixed at the articular surfaces of the right and left heads of the LJ. According to Malanchuk V.O. et al. (2013) and Shilovsky M.S. et al. (2009), the elastic limit of the jaw cortical layer is in the range from 75 MPa to 140 MPa [9, 10]. For pediatric cortical bone, this figure is somewhat lower and more variable. Öhman C. (2011) defines this parameter in the range from 50 to 170 MPa depending on the mineral saturation of the bone, with an average value of about 100 MPa [11]. We applied an external force of 100 N to an absolutely rigid round plate located in the chin area or the lateral surface of the jaw body. The amplitude and direction of the force load vector in traumatic injuries of children's jaws were selected based on literature data [12, 13].

The study of the jaw SSS was conducted in a quasi-static formulation of application problems of biomechanics. In total, 8 simulation models of biomechanical systems were created, which reproduced 4 anatomical structures corresponding to different ages and 2 types of loading that differed in the area of application and the direction of the traumatic force vector.



a **b**

Figure 4 – Calculation schemes for assessing the bearing capacity of the jaw model under traumatic force loads of 100 N: chin - a, lateral surface - b

The physical and mechanical parameters of the biomechanical characteristics of bone tissue were determined based on empirical relationships between bone mineral (radiographic) density and the modulus of elasticity [12, 14] with regard to age differences in average values for the cortical and cancellous layers (Table 2). To simplify the calculation, bone tissue was defined as continuous, homogeneous (within the cortical and cancellous layers), linearly elastic, and isotropic tissue. These simplifications are acceptable and are used in most modern biomechanical studies [X1-X2] based on the use of FEM. The teeth were reconstructed in a simulation model with averaged mechanical characteristics given in Table 2, in accordance with the recommendations of modern literature sources [15, 16].

Table 2 – Age differences in mean values for the cortical and cancellous layers of the LJ

Age, years	Material type	Radiological density, HU	Tissue modulus of elasticity, MPa	Poisson's ratio	Static strength, MPa
2	Cortical bone	1350	6500	0.27	≤100
	Cancellous bone	210	800	0.29	≤13.8
6	Cortical bone	1500	8500	0.27	≤100
	Cancellous bone	260	800	0.29	≤13.8
9	Cortical bone	1600	10500	0.27	≤100
	Cancellous bone	350	800	0.29	≤13.8
17	Cortical bone	1900	12500	0.27	≤100
	Cancellous bone	500	800	0.29	≤13.8
	Teeth		14700	0.4	-

After checking the finite element meshes for defects and optimizing them according to quality criteria [x4], convergence assessment and verification of numerical calculations of the SSS models were performed. The integral deformation capacity of the LJ models was determined as the maximum displacement of the model nodes under the reproduced loading conditions; the nature of stress and deformation distribution in the bone tissue was described, and their gradients were estimated. LJ strength under given loading conditions was assessed by the maximum value of the Mises equivalent stress in the bone tissue, comparing it with the maximum permissible values.

RESULTS

Under traumatic force influence, the LJs were subjected to a complex stress-strain state, which included tension, compression, shear, bending, and torsion. When applying force to the chin area, the displacement of the model nodes was greater than when applying force to the body area. They were mainly caused by bending deformation in the area of both condylar processes and reached 3.7 mm for the 17-year-old LJ model (Table 3).

Table 3 – Characteristics of the deformation, stress state, and load-bearing capacity of the LJ models under the traumatic force applied to different areas of the jaw

	2-year-old model E = 6500 MPa		6-year-old model E = 8500 MPa		9-year-old model E = 10500 MPa		17-year-old model E = 12500 MPa	
Area of force application	Frontal area	Lateral area	Frontal area	Lateral area	Frontal area	Lateral area	Frontal area	Lateral area
Load force (N)	100							
Maximum Mises stress (MPa) in the global model	37.5	44.9	68.6	59.0	40.4	45.7	101.4	70.4
Maximum displacement (mm)	1.8	1.2	1.9	1.4	0.9	0.8	3.7	2.4
Load-bearing capacity*(N)	266	222	145	169	247	219	98	142

**Note: the limiting value of the traumatic force of the LJ model*

When applying a traumatic force to the chin area, the lowest indicator was observed for a 9-year-old model and was 0.9 mm, but regardless of the child's age and the magnitude of the maximum displacement of the model's nodes, the distribution of deformations for this type of load was characterized by a high level of symmetry.

When reproducing a traumatic effect on the body of the lower jaw (a lateral impact), the maximum displacement was also found in the model of a 17-year-old child and amounted to 2.4 mm, while the smallest displacement was recorded in the model of a 9-year-old child, which amounted to 0.8 mm. The deformation of the LJ was asymmetric and more complex. Clinically, differences in the magnitude of maximum deformation can be explained by differences in bone geometry and elasticity, the presence of tooth buds, and different thicknesses of the cortical layer (Fig. 5, 6). In real conditions, jaw deformation can be significantly influenced by the surrounding soft tissues – periosteum, fascia, ligaments, various muscle groups, which were not studied in this research.

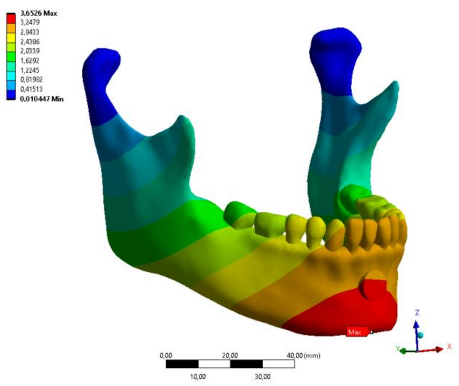


Figure 5 – Displacement of nodes of the discrete LJ model under load applied to the chin area

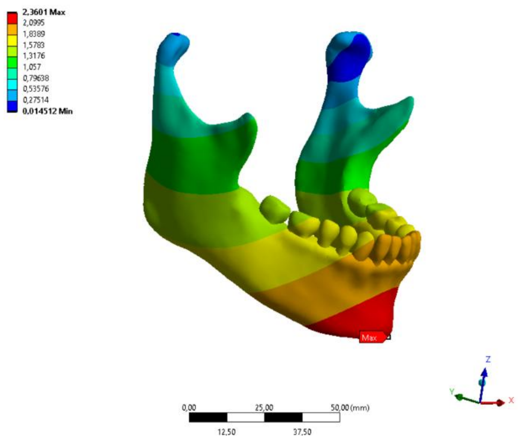


Figure 6 – Displacement of nodes of the discrete LJ model under load applied to the lateral surface

The distribution of Mises equivalent stress in the studied models turned out to be complex and uneven and was characterized by areas of local concentration, corresponding to places of potential bone destruction and fractures occurrence under the action of a traumatic force (Fig. 7, 8).

Maximum stress gradients in all models were located in the bone areas close to the point of force application and in the area of the condylar neck (CN) (on both sides, when applying force to the chin area, and mainly from the contralateral side, when applying force to the body area).

Although the general SSS patterns in all models were similar, certain qualitative differences were noted in different age periods, and the maximum value of the equivalent stress of the biomechanical system differed significantly. Thus, when a traumatic force was applied to the chin area, the distribution of stress and strain was relatively symmetrical, with areas of maximum load concentration at the base of the condylar process, on the inner side, somewhat closer to the posterior edge of the ramus. On the outer surface of the LJ ramus, the stress in the local concentration zones was 1.5 times less. When applying a traumatic force to the LJ body, the area of maximum stress concentration was observed in the middle of the base of the condylar process from its inner side, while the load on the side of force application (on the area of the jaw body close to the traumatic force site and on the ramus area) was approximately 4 times less.

When applying load to the chin area in the 6-year-old model, the greatest stress also occurred in the area of the condylar processes, with the areas of maximum stress concentration shifting closer to the neck of the condylar process and forming high gradients on the outer surface, closer to the notch, and on the inner surface of the posterior edge. With asymmetric loading, the largest stress amplitudes were recorded on the outer surfaces of the base and neck of the contralateral condylar process.

With symmetrical loading in the 9-year-old model, the highest stress concentration occurred in the area of the condylar process neck along the outer surface of the LJ ramus. At the base of the condylar process, the stress concentration was 1.5–2 times less. When a load was applied to a body area, the highest stress occurred at the base of the condylar process on the side opposite to the force application.

The 17-year-old LJ model, under the conditions of applying force to the chin, was characterized by a shift of the areas of maximum stress concentration upwards to the lateral pole of the LJ head and an increase in stress absolute magnitude to critical values. However, when applying force unilaterally, the stress appeared to be greater on the load side only in this model. The most tense area was also the LJ ramus.

In all models, the areas of the condylar processes were the most loaded, which actually reproduces the conditions for indirect fractures occurrence during impacts and falls, which are typical for the pediatric population. It can be assumed that reproducing other boundary conditions corresponding to the teeth occlusion at the time of injury will change the nature of the LJ SSS, including an increase in the stress concentration directly in the area of force application (the mechanism of direct fractures).

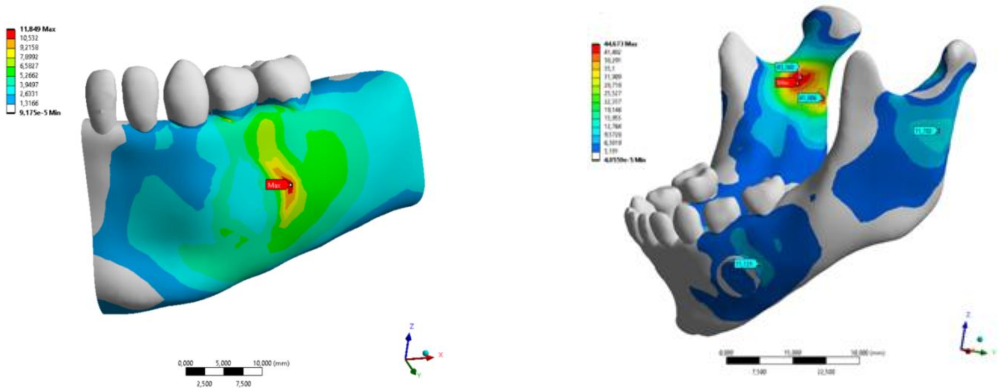


Figure 7 – Areas of maximum stress concentration in the cortical layer of the 2-year LJ model

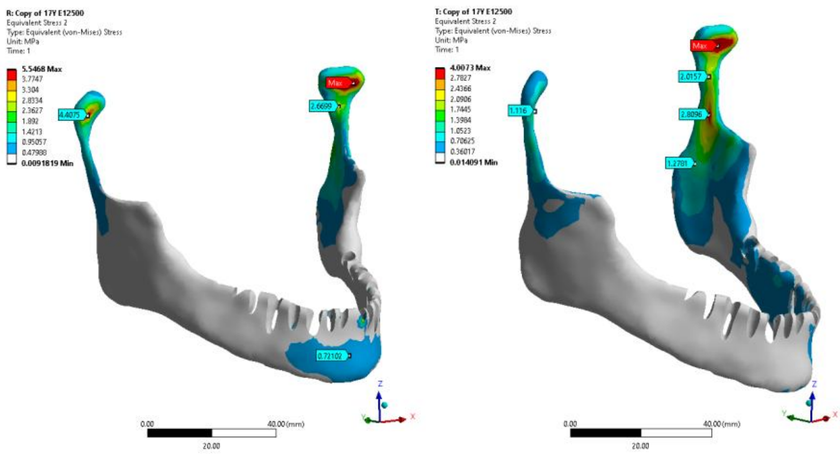


Figure 8 – Distribution of Mises equivalent stress in the cancellous bone layer of the lower jaw during force loading

Interestingly, the area of maximum stress concentration shifts from the base of the condyles upward to the neck and lateral pole of the LJ head along with increasing age and changes in the condyle shape, which explains the higher frequency of high condylar fractures in older age groups compared to younger children.

The magnitude of the tensions in younger children was lower. This, along with the high elasticity of children's bones and a thick layer of periosteum, explains the lower frequency of LJ fractures in early childhood than in older age groups and the high frequency of "greenstick" fractures.

DISCUSSION

An important task of this study was to develop improved simulation computer models of the lower jaw in different dentition periods. They were reconstructed from multispiral computed tomography data of 4 patients aged 2, 6, 9, and 17 years, taking into account the radiographic density and elastic modulus of bone specific to the indicated age groups. Aimed at assessing the LJ SSS under the influence of traumatic factors, this study revealed significant qualitative and quantitative differences in the distribution of stress and deformations in the jaw bone tissue of patients of different ages.

According to numerous publications, the finite element analysis of computer models of biomechanical systems is a proven and effective mathematical method for studying the biomechanical behavior of anatomical structures in a non-invasive way [16].

With advances in software and the performance of personal computers, the number of finite elements (FEs) and nodes used in discrete models has increased. The simplest models were built from several thousand FEs and nodes. Icheri et al. used a cranial geometric model with a total of 2349 FEs, while a 2007 study by Holberg used a skull model with a total of 30,000 FEs and 50,000 nodes. In the study by Ulfah R. et al., 154,808 FEs with 266,047 nodes were used to create a more accurate 3D model of the maxilla. In their study, Zhao B. et al. (2021) created models from 288,103 tetrahedral FEs and 531,921 nodes. In our study, the discrete model consists of a minimum of 83,863 tetrahedral FEs and 151,761 nodes for the 2-year-old child LJ model, which was considered sufficient to reflect the features of the LJ SSS under given loading conditions.

Although comparison of the obtained data with the results of direct experiments is extremely difficult and has significant bioethical limitations, the obtained data correlate with existing clinical experience regarding the peculiarities of LJ fracture localization in different age periods.

During our research, we found that the total system deformation was consistently greater when struck to the chin than to the body, making frontal impacts to the chin less favorable due to a higher risk of indirect fractures. Despite the increase in bone density, the system deformation at an older age (17 years) was greater compared to a younger age, due to anatomical and physiological differences associated with jaw growth and a change in the force arm.

When reproducing the effect of traumatic force on the chin area (symphysis) in the models, the largest stress concentration was noted in the cortical layer of the bone, while the maximum stress value increased with age from 37.5 to 101.4 MPa. There was a tendency for maximum stress concentration to shift from the base of the condylar process to the medial pole of the condylar head. This is confirmed by the increased frequency of indirect fractures of the condylar neck and LJ head when falling on the chin in the age group of 13–17 years.

In cases of simulated traumatic force in the area of the LJ body, the maximum stress in the cortical layer ranged from 44.9 to 70.4 MPa. The tendency for increased stress magnitude with age is nonlinear, which can be explained by changes in jaw anatomical shape and size, the force arm, the presence and location of tooth roots and premordia, and mineral saturation, which affects bone mechanical properties. The combined influence of these factors determined the complex and nonlinear nature of the relationship between the age of the child and the maximum value of equivalent stress under the influence of traumatic factors. The higher bone elasticity in younger children led to lower local stress, which exceeded the limit value only for the 17-year-old jaw model.

The data we obtained can help solve the inverse problem and calculate the critical load required for bone destruction and the formation of indirect fractures in children of different ages. This value is rather hypothetical, due to the lack of reliable data on the ultimate strength of bone tissue in children. However, assuming the maximum permissible equivalent stress for the cortical bone layer to be 100 N, which is a standard in orthopedic and traumatological studies, we have established that probable damage to the outer surface of heterogeneous bone structures of the LJ model may initially occur to the cortical tissues of the condylar process under traumatic force applied to the chin area with an amplitude 247 N to 266 N for 2-year-old and 9-year-old jaw models, respectively, and 145 N – for 6-year-old jaw model. However, in a 17-year-old jaw bone model, initial damage may occur in the chin and lateral condylar process regions under 98 N of force, which is fully consistent with the increased frequency of indirect fractures in older age groups.

CONCLUSIONS

1. When studying the stress-strain state of the lower jaw in pediatric patients under the influence of external traumatic loads, it was found that in all studied age periods, when force is applied to the symphysis area, the stress-strain state of the bone is characterized by the formation of maximum stress concentration in the cortical bone layer in the area of the condylar processes. When a traumatic force is applied to the LJ body, maximum stress occurs on the lateral side of the condylar base in all models, except for the model of a 17-year-old child's jaw, where the maximum stress concentration occurs on the side of force application. The maximum displacement of the model nodes (maximum deformation of the system) in all age groups was by 11.6–30.57% greater when applying force to the chin area compared to the LJ body area.

2. For the models of LJ corresponding to different ages, there were inherent differences in the distribution of stress and strains, which consisted in a nonlinear increase in the equivalent stress value with age from 37.5 (for a 2-year-old child model) to 101.4 MPa in (for a 17-year-old child model) with force impact on the chin area and from 44.9 to 70.4 MPa with force impact on the body area. At the same time, with increasing age, the area of maximum stress concentration in the condylar process shifted from the base to the neck and lateral pole of the LJ head.

3. Calculations of external force extreme values in the chin area for the studied models indicated that LJ fractures can occur under the traumatic force with an amplitude from 247 N to 266 N for a 2-year-old and 9-year-old jaw models, respectively, and from 145 N – for a 6-year-old jaw model. For a 17-year-old jaw bone model, initial damage may occur to the chin area at force loads of 98 N.

4. When applying external force to the body area, it has been established that LJ fractures can occur when a force with an amplitude of 142 N to 222 N is applied for 17 years and 2 years, respectively.

5. The results obtained during the study of the patterns of stress-strain states of simulated models of injuries in four children's jaws of different ages using

modern information technologies and the finite element method can be considered as a basis for an in-depth study of injury mechanisms (including in forensic examination) and the development of strategies for the prevention and treatment of traumatic jaw fractures and functional rehabilitation regimens in children, depending on the nature of the injury and the child's age.

ETHICAL CONSIDERATIONS

The study was conducted without involving human subjects.

AUTHOR CONTRIBUTIONS

Rostyslav Yehorov – collection of material, writing of the text, analysis of the obtained data.
Andrii Kopchak – concept and design, text writing.
Oleksandr Kaniura – concept and design, editing.
Mykola Kryshchuk – collection of material, analysis of the obtained data.

FUNDING

This research was carried out without grant support. The study was carried out within the framework of the research project "Interdisciplinary approaches to the diagnosis and treatment of surgical dental diseases of the maxillofacial area in children" of the Department of Surgical Dentistry and Maxillofacial Surgery of Pediatric Age, Bogomolets National Medical University. State registration code: 0122U000494.

CONFLICT OF INTEREST

The authors declare that they have no actual or potential conflict of interest regarding the results of this work. All authors guarantee that they have not received any remuneration in any form that could influence the results of the work.

ARTIFICIAL INTELLIGENCE DISCLOSURE

The authors confirm that no artificial intelligence technologies were used during the writing or editing of the manuscript.

REFERENCES

1. Lisiak-Myszke M, Marciniak D, Bieliński M, Sobczak H, Garbacewicz Ł, Drogoszewska B. Application of Finite Element Analysis in Oral and Maxillofacial Surgery-A Literature Review. Materials (Basel). 2020 Jul 9;13(14):3063. https://doi.org/10.3390/ma13143063. PMID: 32659947; PMCID: PMC7411758.
2. Arora L, Bhardwaj S, Hashmi GS, Anwar SF, Rahman SA. Finite Element Analysis (FEA) of Perpendicular Plating Versus Conventional Plating in Mandibular Symphysis Fracture. J Maxillofac Oral Surg. 2020 Mar;19(1):143-148. https://doi.org/10.1007/s12663-019-01244-7. Epub 2019 May 27. PMID: 31988578; PMCID: PMC6954911.
3. Santos LS, Rossi AC, Freire AR, Matoso RI, Caria PH, Prado FB. Finite-element analysis of 3 situations of trauma in the human edentulous mandible. J Oral Maxillofac Surg. 2015 Apr;73(4):683-91. https://doi.org/10.1016/j.joms.2014.10.014. Epub 2014 Oct 22. PMID: 25577458.
4. Mańkowski J, Piękoś J, Dominiak K, Klukowski P, Fotek M, Zawisza M, Żach P. A Mandible with the Temporomandibular Joint-A New FEM Model Dedicated to Strength and Fatigue Calculations of Bonding Elements Used in Fracture and Defect Surgery. Materials (Basel). 2021 Sep 2;14(17):5031. https://doi.org/10.3390/ma14175031. PMID: 34501120; PMCID: PMC8434464.
5. Pandya H, Patel H, Vithalani S, Bhavsar B, Shah U, Chunawala A. Finite Element Analysis of New Modified Three-dimensional Strut Miniplate versus Conventional Plating in Mandibular Symphysis and Angle Fractures - An *In vitro* Study. Ann Maxillofac Surg. 2024 Jan-Jun;14(1):71-75. https://doi.org/10.4103/ams.ams_205_23. Epub 2024 May 8. PMID: 39184404; PMCID: PMC11340833.
6. Morice A, Taverne M, Eché S, Griffon L, Fauroux B, Leboulanger N, Couloigner V, Baujat G, Cormier-Daire V, Picard A, Legeai-Mallet L, Kadlub N, Khonsari RH. Craniofacial growth and function in achondroplasia: a multimodal 3D study on 15 patients. Orphanet J Rare Dis. 2023 Apr 18;18(1):88. https://doi.org/10.1186/s13023-023-02664-y. PMID: 37072824; PMCID: PMC10114380.
7. Bloch K, Geoffroy M, Taverne M, van de Lande L, O'Sullivan E, Liang C, Paternoster G, Moazen M, Laporte S, Khonsari RH. New diagnostic criteria for metopic ridges and trigonocephaly: a 3D geometric

approach. Orphanet J Rare Dis. 2024 May 18;19(1):204. https://doi.org/10.1186/s13023-024-03197-8. PMID: 38762603; PMCID: PMC11102612.

8. Liang C, Marghoub A, Profico A, Buzi C, Didziokas M, van de Lande L, Khonsari RH, Johnson D, O'Higgins P, Moazen M. A physico-mechanical model of postnatal craniofacial growth in human. iScience. 2024 Jul 29;27(9):110617. https://doi.org/10.1016/j.isci.2024.110617. PMID: 39220256; PMCID: PMC11365398.
9. Malanchuk VO, Kryshchuk MH, Kopchak AV. Imitatsiine komp'iuterne modeliuvannia v shchelepno-lytsevii khirurhii. Kyiv: Askaniia; 2013. 350 p.
10. Malanchuk VO, Kopchak AV, Shydlovskyi MS. Mekhanichni vlastyvosti kistkovoi tkanyny ulamkiv nyzhnioi shchelepy pry yii travmatychnomu perelomi. In: Proceedings of the International scientific-practical conference "Innovatsiini tekhnolohii v stomatolohii ta shchelepno-lytsevii khirurhii"; 2009 Oct 30–31; Kharkiv, Ukraine. Kharkiv: 2009. p. 25–28.
11. Öhman C, Baleani M, Pani C, et al. Compressive behaviour of child and adult cortical bone. *Bone*. 2011;49(4):769-776. https://doi.org/10.1016/j.bone.2011.06.035
12. Wong RC, Tideman H, Merkx MA, Jansen J, Goh SM, Liao K. Review of biomechanical models used in studying the biomechanics of reconstructed mandibles. Int J Oral Maxillofac Surg. 2011 Apr;40(4):393-400. https://doi.org/10.1016/j.ijom.2010.11.023. Epub 2010 Dec 30. PMID: 21195588.
13. Vollmer D, Meyer U, Joos U, Vègh A, Piffko J. Experimental and finite element study of a human mandible. J Craniomaxillofac Surg. 2000 Apr;28(2):91-6. https://doi.org/10.1054/jcms.2000.0125. PMID: 10958421.
14. Jung BT, Kim WH, Park B, Lee JH, Kim B, Lee JH. Biomechanical evaluation of unilateral subcondylar fracture of the mandible on the varying materials: A finite element analysis. PLoS One. 2020 Oct 8;15(10):e0240352. https://doi.org/10.1371/journal.pone.0240352. PMID: 33031474; PMCID: PMC7544122.
15. González Del Castillo McGrath M, Araujo-Monsalvo VM, Murayama N, Martínez-Cruz M, Justus-Doczi R, Domínguez-Hernández VM, Ondarza-Rovira R. Mandibular anterior intrusion using miniscrews for skeletal anchorage: A 3-dimensional finite element analysis. Am J Orthod Dentofacial Orthop. 2018 Oct;154(4):469-476. https://doi.org/10.1016/j.ajodo.2018.01.009. PMID: 30268257
16. Pandya H, Patel H, Vithalani S, Bhavsar B, Shah U, Chunawala A. Finite Element Analysis of New Modified Three-dimensional Strut Miniplate versus Conventional Plating in Mandibular Symphysis and Angle Fractures - An *In vitro* Study. Ann Maxillofac Surg. 2024 Jan-Jun;14(1):71-75. https://doi.org/10.4103/ams.ams_205_23. Epub 2024 May 8. PMID: 39184404; PMCID: PMC11340833.

INFORMATION ABOUT THE AUTHORS

Єгоров Ростислав Ігорович, кандидат медичних наук, доцент кафедри хірургічної стоматології та щелепно-лицевої хірургії дитячого віку Національного медичного університету імені О.О. Богомольця, Київ, Україна.

Копчак Андрій Володимирович, доктор медичних наук, професор кафедри завідувач кафедри щелепно-лицевої хірургії та сучасних стоматологічних технологій Національного медичного університету імені О.О. Богомольця, Київ, Україна.

Канюра Олександр Андрійович, проректор з науково-педагогічної та лікувальної роботи, доктор медичних наук, професор кафедри ортодонтії та пропедевтики ортопедичної стоматології Національного медичного університету імені О.О. Богомольця, Київ, Україна.

Крищук Микола Георгієвич, доктор технічних наук, професор кафедри динаміки і міцності машин та опору матеріалів НТУУ «КПІ імені Ігоря Сікорського», Київ, Україна

Received: 17.05.2025

Accepted for publication: 11.07.2025

Published: 23.06.2026