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Ie. V. Shumynskyi, A. V. Kopchak, M.D

O. Bogomolets National Medical University
Institute of Postgraduate Education
Kyiv, Ukraine

CLINICAL AND ANATOMICAL FEATURES OF MAXILLARY FRACTURES IN PATIENTS WITH DIFFERENT TYPES OF ITS PNEUMATIZATION

ABSTRACT
The individual anatomy of the midfacial bones characterize features of their fractures and complicates the process of treatment and rehabilitation of patients with traumatic injuries.
Aim. *Study relationship between the clinical and radiological characteristics of maxillary fractures and the features of its structure, according to the degree of pneumatization.*
Materials and methods. *The values of the number of fracture lines, the number of fragments, the frequency of defect formation in the areas of buttresses, the Facial Injury Severity Scale in patients with different values of the pneumatization index (PI) were analyzed and compared.*
Results. *The pneumatic type of midfacial bones characterized by an increase in the degree of fragmentation and defect formation of the buttresses in comparison with the normal type (66 % and 58 %, respectively, p>0.999).*
Conclusions. *The characteristics of midfacial bones fracture depends on the peculiarities of its architectonics and PI, which must be taken into account when planning surgical treatment.*
Keywords: *pneumatization index, FISS, maxillary fractures, midface bones, Le Fort.*

Є. В. Шуминський, А. В. Копчак, д. мед. н.

Національний Медичний Університет
ім О. О. Богомольця
Інститут Післядипломної Освіти
м. Київ, Україна

КЛІНІКО-АНАТОМІЧНІ ОСОБЛИВОСТІ ПЕРЕЛОМІВ ВЕРХНЬОЇ ЩЕЛЕПИ У ПАЦІЄНТІВ ІЗ РІЗНИМ ТИПОМ ЇЇ ПНЕВМАТИЗАЦІЇ

АНОТАЦІЯ
Індивідуальна анатомія кісток середньої зони обличчя (КСЗО) позначається на особливостях їх руйнування та ускладнює процес лікування та реабілітації пацієнтів із травматичними переломами.
Мета. *Вивчення взаємозв’язків між клініко-рентгенологічними характеристиками переломів верхньої щелепи (ВЩ) та особливостями її будови, зокрема ступенем пневматизації.*
Матеріали і методи. *Проаналізовано та порівняно значення кількості щілин переломів, кількості уламків, частоту утворення дефектів на ділянках контрфорсів, показник Facial Injury Severity Scale у пацієнтів із різним значенням індексу пневматизації (ІП).*
Результати. *Пневматичний тип будови КСЗО характеризується збільшенням ступеня фрагментації та утворенням дефектів контрфорсів ВЩ у порівнянні з нормальним типом будови (66 % та 58 % відповідно, p>0,999).*
Висновки. *Характеристики переломів ВЩ залежать від особливостей її архітектоніки, а саме від ІП, що необхідно враховувати при плануванні лікувальних заходів.*
Ключові слова: *індекс пневматизації, FISS, переломи верхньої щелепи, кістки середньої зони обличчя, Ле Фор.*

The upper jaw (UJ) is a paired bone that has a complex and variable anatomical shape with 4 processes and a complex surface relief. The upper jaws of a person are motionlessly connected to other bones of the midface (zygomatic, nasal, lacrimal, palatine, as well as ethmoid bone and vomer), forming a single functional system, perceives, redistributes and transmits chewing pressure to the bones of the base and vault of the skull. This is provided mainly due to areas of thickened and compacted bone, forming 3 horizontal and 3 vertical buttresses. The vertical buttresses include the nasofrontal, zygomatic and alar-palatal, they determine the position of the upper dentition and provide the transfer of the vertical component of the chewing load on the bones of the base and calvarium. Horizontal buttresses – palatine (lower), middle (formed by the bone tissue of the inferior orbital edge, zygomatic bone and zygomatic arch, and upper (including the superciliary arches and the bridge of the nose), provide a redistribution of loads between the vertical buttresses and the right and left halves of the face, as well as compensate for the horizontal component of the force of closing teeth. From a mechanical point of view, midface buttresses (MFB) create a complex spatial truss system capable of withstanding significant loads acting at different angles. In addition, it provides soft tissue support and determines the height, width and outer contour of the face. [12,15].

Among the important functions of the bones of the middle zone of the face (BMZF), the authors distinguish a protective one, indicating that the bones of the middle zone of the face can absorb the mechanical energy of the action of the traumatic factor, protecting the structures of the base of the skull and the brain. In this case, the MFB buttresses can experience destruction, and, often, multi-shrapnel fragmentation [15].

Fractures of the MFB bones, including fractures of the upper jaw (FUJ), account for 70 % of all fractures of the bones of the facial skull in patients with cranio-maxillofacial trauma [2].

The authors classify FUJ as one of the most complex types of facial fractures. A feature of this type of injury is a significant individual variability in the nature of the fracture, its topographic characteristics and clinical manifestations. According to the literature, the structure of FUJ has changed significantly, due to a change in the nature of injury and an increase in the frequency of high-energy injuries associated with road traffic accidents, man-made disasters and accidents at work, gunshot wounds, etc. [14].

Despite a significant change in approaches to the diagnosis and treatment of traumatic fractures of the upper jaw, which took place in recent decades, to this day their most used classification remains the Rene Le Fort classification, proposed more than 100 years ago. This classification defines the main «lines of least resistance», according to the experimentally defined types of fracture, is simple and straightforward, but at the same time does not provide sufficient information to describe the nature of the fracture and to fully plan treatment measures in most clinical cases. (Donat TL,1998; Erol B, 2004; Mohajerani SH, 2011, Catapano J, 2010; Ahmad Z, 2012; Salvolini U. 2002; Chen WJ, 2006; Fraioli R, 2008). Already at the time of its creation, it was obvious that this classification is rather arbitrary: it does not allow assessing the real nature of the destruction of vertical and horizontal buttresses, especially in the case of multi-fragment fractures, and often underestimates the real severity of damage, which is a complex combination of fractures of the zygomatic, nasal ethmoidal complex and orbits with damage to the upper jaws (including in atypical localization zones) [6, 8, 14].

Surgical treatment of MFB fractures is based on the restoration of the buttress system to its premorbid state by methods of open reduction and internal fixation [3, 5]. So, the study of the features of the destruction of this system in different types of fractures is of particular relevance.

A series of works on biomechanics and forensic medicine considered the features of the destruction of the bones of the midface zone in order to describe and explain the significant variety of types and forms of fractures of this localization. In experiments (Nahum, 1976; Hodgson, 1967) on cadaveric material, it was found that the nature of bone damage depends on the absolute value of the applied load, its distribution over the surface, the rate of force application and the duration of its action. It was found that bone tissue is able to withstand significant loads for short periods of time, however, the limit values of the load sharply decrease with an increase in the duration of its action [11].

D. Hampson (1995) pointed out that the ability of the bones of the face to resist mechanical damage is different and characterized by a wide range of individual values with a certain distribution of probabilities / risks. Moreover, according to Nyquist et al., 1986, the average force required for the occurrence of a fracture of the upper jaw was the highest among all bones of the facial skull and exceeded 1100 N. With age, as osteoporosis and osteopenia develop (70-80 years), the strength of the facial bones decreases by 20-30 % compared to the physiological maximum, which is observed at the age of 20-30 (Yamada and Evans, 1970). In addition, the absolute strength of the skull bones in men is higher than in women [11].

Another factor that affects the features of bone destruction is their anatomical structure, which determines the typical fracture zones. The authors point out that the individual anatomy of the bones of the midface zone affects / influences the features of their destruction, at the same time this issue is practically not studied and is considered mainly at the level of hypotheses [10].

From research in the field of orthopedics and traumatology, it is known that the destruction of bones depends on its physical and mechanical properties, geometric shape and internal structure, which determine the characteristics of the distribution of stresses and deformations under the action of traumatic factors. With the development of numerical methods of analysis (in particular, the finite element method), systemic studies of these issues on simulation computer models have become possible. Regarding MFB, there are works that studied the features of fracture biomechanics on finite element models for explosive fractures of the orbit, fractures of the facial complex and, to a lesser extent, for the upper jaw. The main problem in this case was the severity of adequate reproduction geometry of bone structures [16, 17].

MFB bones are known to have a complex and variable shape. Connecting with each other, they participate in the formation of the orbit, nasal cavity, infratemporal and palatine fossa, containing in the middle large air cavities (paranasal sinuses) and bony canals in which vessels and nerves pass. Anthropometrically, 4 types of faces according to Seago are distinguished with different sizes and ratios of bone structures, which significantly affect their biomechanical behavior [13].

Another equally important factor is the degree of pneumatization, which determines the architectonics of the bone in this area. In the pneumatic type of bone structure MFB, the internally bony air cavities are well expressed and form large bays, extending to the alveolar process, the body of the zygomatic bone, etc. At the same time, the bone tissue becomes thinner, and its density increases. In the sclerotic type, the air cavities have a smaller volume, and the bone structures become thicker, although their density and mineral saturation may decrease at the same time. According to the ratio of the volume of bone tissue and air cavities (pneumatization index – PI) Malanchuk et al. There are 3 main types of MFB bone structure. PI value ≤ 0.9 corresponds to the pneumatic type of bone structure MFB, the value in the range of 0.9-1.5 to normal, and ≥ 1.5 to sclerotic [4].

A decrease in the thickness of bone tissue in the area of the buttresses with an increase in pneumatization, qualitatively changes the distribution of stresses and deformations during trauma, theoretically can affect the clinical and anatomical characteristics of the fracture and complicate the process of treatment and rehabilitation of patients with traumatic fractures of the upper jaw and MFB bones. At the same time, in the literature, the issues of the relationship between the type of fracture and the features of the anatomical structure of the bones of the MFB are practically not studied, which determines the relevance of this work.

The aim of the study was to study the relationship between the clinical and radiological characteristics of fractures of the upper jaw and the features of its anatomical structure, in particular the degree of pneumatization.

Materials and methods. General characteristics of clinical material, inclusion and exclusion criteria. The material of the study was 37 patients with multiple traumatic fractures of the bones of the midface zone (32 men and 5 women aged 19 to 73 years, the average age was 38.2±15.9 years), who were inpatient treatment in the departments of neurosurgery and polytrauma of Kiev City Clinical Emergency Hospital. The inclusion criteria for the study were the presence of at least one of the types of fractures of the upper jaw according to Le Fort (I, II or III) in a patient with fractures of the facial skull, written consent to participate in the study, complete documentation of the case, computed tomography (CT) scan in the preoperative period and after surgery.

The exclusion criteria were patients with gunshot fractures of the bones of the facial skull, patients' age under 18, poor quality of CT, noncompliance with medical recommendations and lack of interaction with a doctor in the postoperative period, patient refusal to participate in the study.

All patients were examined according to the standard scheme, which included the collection of anamnesis, clinical and laboratory examination with the determination of general and local status, as well as a multispiral CT scan on a 128 Philips Ingenuity CT 128 shear device with a 0.67 mm slice thickness on admission and the next day after surgical intervention. When establishing a diagnosis based on clinical and radiological data, the nature of the destruction of the upper jaw was described in detail, the characteristics of fractures of the zygomatic and nasoetmoidal complexes, Glabella areas, the upper edges of the orbits and its walls, if any occurred in combination with fractures of the upper jaw, were additionally studied [1]. The severity of maxillofacial injury was determined using the Facial Injury Severity Scale (FISS) in the comparison groups [7].

For a more accurate determination of the nature of the fractures, the classification system proposed by T. Donat 1998 was used, according to which 3 vertical buttresses (V1 – naso-frontal / nasomaxillary; V2 – zygomatic-maxillary; V3 – pterygomaxillary) and 3 horizontal buttresses (H1 – superciliary arches and nose bridge; H2 – inferior orbital edge, zygomatic bone and zygomatic arch; H3 – alveolar process of the upper jaw) are determined. Horizontal buttresses were additionally divided into central (c) and lateral (l) segments (section), and vertical buttresses – into upper (s) and lower (i) segments [12]. At each of the defined sites (segments), the number of fracture cracks and, accordingly, bone fragments were determined to determine the degree of their fragmentation, then the total number of fracture cracks, fragments in each patient was determined by summing pre-determined values, and the total number of fracture cracks in the nasomaxillary (naso-frontal) buttress area and zygomatic-alveolar ridge on the right and left – areas V1i, V2i, belonging to the anatomical structures of the upper jaw proper, which are subject to osteosynthesis were determined separately (fixation of fragments in the V3 zone is not carried out, therefore it was excluded by calculations). The average number of fracture cracks / fragments was determined per 1 buttress, and the number of buttresses that were fragmented was also determined. Further analysis did not take into account the features of destruction of the walls of the orbit and maxillary sinus, as well as the magnitude and nature of the displacement of fragments.

The features of the surgical intervention were analyzed, including the number of fixators installed, the need to remove bone fragments in the area of the buttresses, as well as the anatomical and functional result obtained. The influence of the architectonics of the MFB bones on the efficiency and complexity of surgical interventions and the stability of the fixation system over time was determined.

To determine the type of structure of the bones of the face, three-dimensional computer models of the bones and air cavities of the MFB were constructed.. Licensed software Mimics 12.1 was used for processing CT images (Materialise, Belgium).

Construction and analysis of 3D models. Computer models were created based on data from preoperative CT scans of patients included in the study. The orientation of the tomographic slices is based on the standardized CT protocol of the facial skull. Bone models included the entire volume of bone tissue and were within the radiographic density range of 250 to 3071 Hounsfield units (HU). The limits of the model were: in the frontal plane - above the level of the location of Glabella, below - the level of the apex of the alveolar process of the upper jaw. In the sagittal plane: in front - the most prominent point of the alveolar process of the upper jaw, behind - the level of the extreme point Lamina medialis processus pterygoideus ossis sphenoidalis. The crown parts of the teeth were not included in the model. Air cavity models were created in the X-ray range from – 452 to – 1024 HU within the previously specified spatial limits (corresponding to the bone model). Thus, the model of the paranasal cavities included both maxillary, ethmoid, part of the frontal sinus, part of the main sinus, and the nasal cavity.

Considering the fact that the models were created on the basis of CT data of patients with fractures of the MFB bones, the volume of the air cavities was reduced due to mucosal edema, the presence of blood clots, foreign bodies (hemostatic tampons, probes). Therefore, when creating a model of the air cavities, its limits were manually corrected using tools for working with a "mask" to achieve a ratio between bone tissue and air cavities, which adequately reflects the patient's inherent premorbid architectonics. The MFB sinus and nasal cavity models were combined into a single two-piece model. The volume of bone tissue and air cavities was determined and the pneumatization index was calculated [4].

Depending on the type of bone structure of the MFB, according to the PI, CT of the patients were divided into 3 groups. The first group included patients with pneumatic type of structure, the PI level was less than 0.9. The second group included patients with a normal type of bone structure MFB, in which the PI level ranged from 0.9 to 1.5. The third included patients with the sclerotic type, the PI level was more than 1.5.

When conducting statistical analysis, the nature of the distribution of quantitative indicators in the groups was determined by the Shapiro-Wilk test. To present data in the case of a normal distribution, the mean value (M) and standard deviation (±SD) were determined, in the case of the distribution of indicators according to a law other than normal, the median values (Me) and the interquartile range (Q_I-Q_{III}) were determined. The determination of disagreement on these parameters in the comparison groups was carried out using the Student's or Mann-Whitney test. To determine the presence of a relationship between the indicators, the Spearman rank correlation index was calculated. For qualitative signs, the frequency of their manifestation was calculated (%). Comparison of qualitative features was carried out according to Fisher's exact test. When analyzing by the method of constructing logistic regression models, low values of PI (PI≤0.9) and affiliation to group I related to the case (resulting sign Y=1) because this is associated with an increase in pneumatization of the sinuses and thinning of bone tissue in the areas of the buttress. To predict the risk of a low PI value, univariate and multivariate logistic regression models were used. The selection of significant features was carried out according to the Akaike information criterion (AIC). To assess the quality of forecasting, the method of constructing curves of the operating characteristics of the model (ROC-curves) and the calculation of the area under curve (AUC) with an estimate of 95 % of the possible interval (95 % PBI) were used. With the selected optimal decision-making threshold, the model calculated the indicators of its sensitivity and specificity. The assessment of the influence of factor signs on the risk of a low IP value was carried out according to the odds ratio (OR), its 95 % of PBI was calculated. The critical level of significance is assumed to be 0.05 for the two-sided critical region. The analysis was carried out using the statistical package EZR v.1.54 (graphical user interface for R statistical software version 4.0.3, R Foundation for Statistical Computing, Vienna, Austria) [9].

Results. According to the results of calculating the models, the volume of the MFB bones ranged from 63 cm^3 to 154.5 cm^3 and averaged 101.2±22.1 cm^3. The volume of the air cavities ranged from 87 cm^3 to 186.5 cm^3 and averaged 129.4±21.9 cm^3. The PI value varied and ranged from 0.68-1.79. The distribution of patients depending on the degree of pneumatization was as follows. The pneumatic type of structure MFB (PI less than 0.9; group I) had 11 patients (29.7 %). Normal type of structure (PI from 0.9 to 1.5) – 24 patients (64.9 %). Sclerotic type of structure (PI more than 1.5) – 2 patients (5.4 %). Despite a very small number of patients with a sclerotic type of structure, for further analysis, they were combined into one group with normal type patients (group II). Cases of symmetric bilateral fractures of various levels for Le Fort were found in 63.6 % in group I and in 46.1 % in group II. Unilateral fractures were identified in 9 % in group I and 15.3 % in group II. Bilateral fractures at different levels in 27.4 % in group I and 38.6 % in group 2. FUJ in 28.5 % and 31.8 % were combined with fractures of the mandible, the walls of the frontal sinus, and fractures of the skull base in groups I and II, respectively. In the case of fractures of the upper jaw at different levels according to the Le Fort classification, the severe of the two types of fractures present was taken into account. The data on the number of different types of fractures of the upper jaw in groups are shown in figure 1.

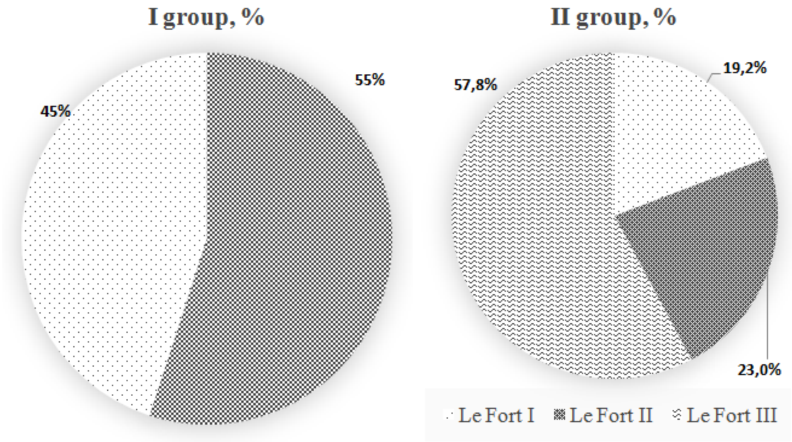

Fig. 1. Distribution of types of fractures of the upper jaw according to the classification of Rene Le Fort in the comparison groups.

There were no significant differences in this parameter in patients in the comparison groups ($p>0.05$).

The FISS score ranged from 1 to 13.Median values for the severity of maxillofacial injury are presented in table 1 and figure 2 There was no statistically significant difference in the severity of maxillofacial trauma in patients of groups I and II ($p=0.471$). The indicators for which the study was also conducted among patients in the comparison groups, presented in table 1.

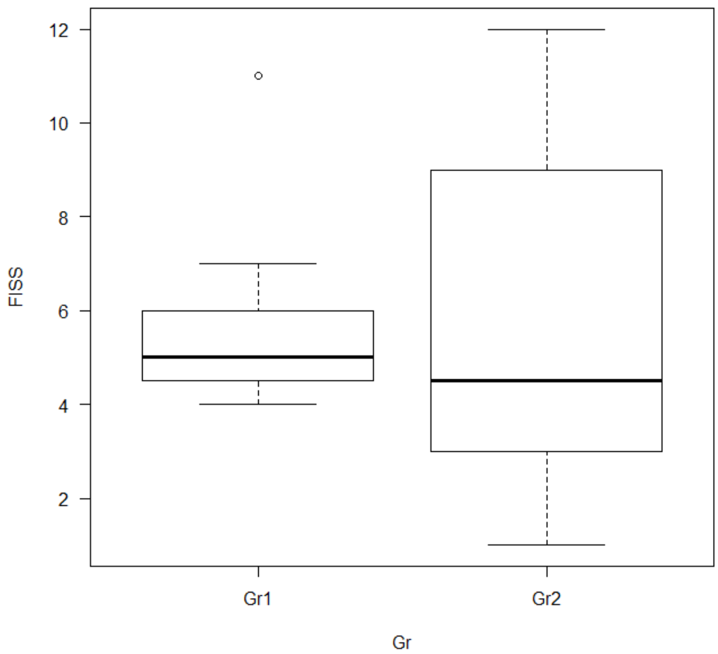

Fig. 2 Median values, first and third quartiles of the severity of maxillofacial trauma in groups.

Table 1

The value of clinical and tomographic parameters in patients with maxillary fractures, depending on the degree of pneumatization of the MFB

Indicator / Group		PI≤0,9 I group (n=11)	PI≥0,9 II group (n=26)	Significance level of differences between groups, p
FISS Me (QI÷QIII)		5 (4.5÷6)	4.5 (3÷8.5)	0.471
Total number of fracture slits M ± SD		13.09 ±5,61	10.19±4.19	0.091
The total number of fracture slits on all buttresses	<15	8 (73 %)	22 (85 %)	0.403
	≥15	3 (27 %)	4 (15 %)	
The total number of fracture slits in the area of the naso-frontal and zygomatic-maxillary buttresses (areas V1i /V2i,) M± SD		5.09±1.37	4.46±1.55	0.253
Average number of damaged vertical buttresses of the upper jaw per 1 patient (areas V1i/V2i, excluding area V3) Me (QI÷QIII)		4 (4÷4)	3 (3÷4)	0.004
The total number of fracture slits on all buttresses	<5	4 (36.3 %)	13 (50 %)	0.495
	≥5	7 (63.7 %)	13 (50 %)	
Average number of fracture slits per broken vertical buttress of the upper jaw (areas V1i and V2i) M±SD		1.36±0.53	1,34 ± 0,55	0.853
The frequency of formation of defects in the vertical buttresses of the upper jaw with a lot of splintery fragmentation (number of defects / number of damaged buttresses)		4 з 6 (66 %)	7 з 12 (58 %)	>0.999

The total number of fracture slits in different areas of the MFB ranged from 2 to 26. There was no difference in the average number of fracture slits on buttresses in group I and group II (p=0.091). The result is shown in table 1 and figure 3.

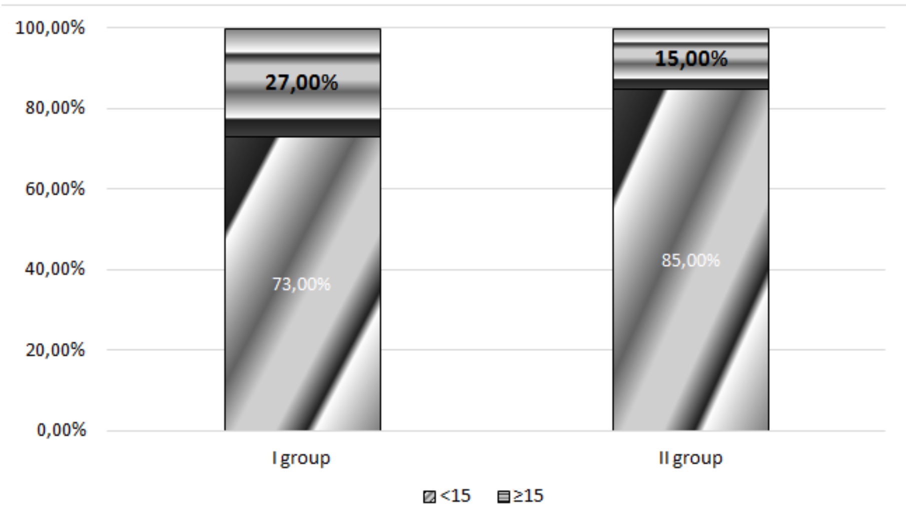

Fig. 3. Distribution of patients by the number of fracture cracks in groups. The black color indicates the number of patients with up to 15 fracture slits. White indicates patients with 15 fracture slits or more.

As can be seen from the figure 3, the frequency of cases with the number of fracture slits in all parts of the buttresses more than 15 in the I group was 12 % higher than in group II, therefore the degree of fragmentation of the facial skull in persons with pneumatic type was higher, although in this number observations, these differences were not statistically significant (p>0.05). Figure 4 shows the difference between the degree of fragmentation and the size of the MFB fragments in patients with the same types of fractures.

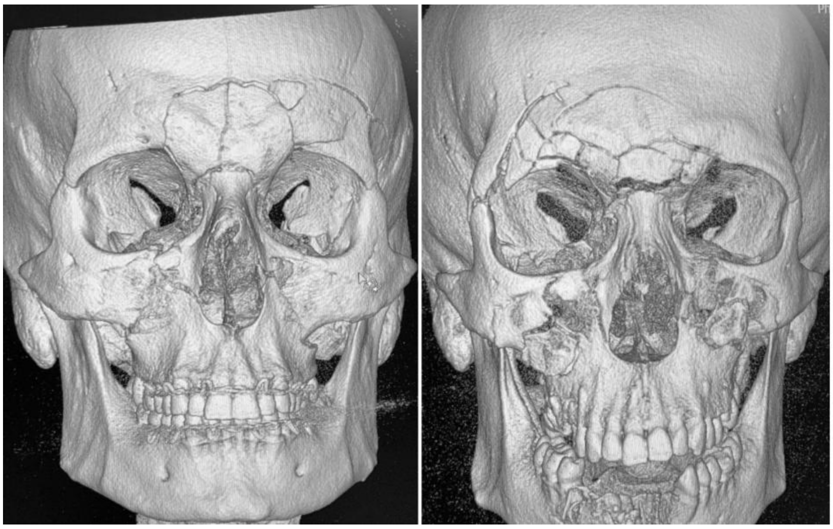

Fig. 4. 3-D reconstructions of tomographic images of patients with the same types of fractures in 2 groups are presented. Patient of group II on the left, PI = 1.38. Patient of group I on the right, PI = 0.86.

The total number of fracture slits in the area of the naso-frontal and zygomatic-alveolar buttresses (zones V1i and V2i,) per patient in the first group was also greater. So more than 5 fracture slits in this area in group I were found in 64 % of patients, in group II in 50 % of patients (p=0.495), in some cases this indicator reached 8 fracture slits, which reflected fragmentation of the vertical buttresses (Fig. 5).

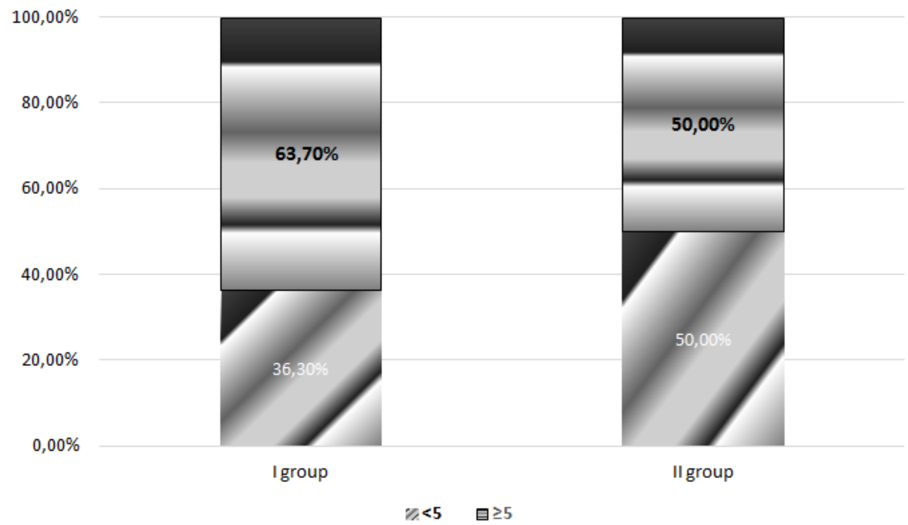

Fig. 5. Distribution of patients by the number of fracture slits in the areas of the nasolabial and zygomatic-maxillary buttresses in groups. The blue color indicates the number of patients with up to 5 fracture slits. Orange indicates patients with 5 fracture slits or more.

The median value of the number of damaged vertical buttresses of the upper jaw per 1 patient in the first group was higher (p=0.004) than in group II. So in group I, each buttress of zone V1i and V2i was broken, excluding zone V3 (Table 1).

Multiple fragmentation of the upper jaw was accompanied by the need to remove non-viable fragments during surgery with the formation of defects in the area of vertical buttresses, which was observed in the first group in 4 out of 6 operated patients (66 % of cases), in group II in 7 out of 12 operated patients – 58 % (p>0.05). This made it difficult to reposition large fragments of MFB bones, and made fixation technically difficult and less predictable.

Considering the significant variability of MFB fractures and the relatively small number of observations during the analysis, there was no statistically significant difference in indicators of the comparison groups (p>0.05).

However, when conducting a correlation analysis using a correlation matrix, a weak negative association was found between the PI and the number of fracture slits in the nasal buttress region (r=-0.347, p=0.038) and a weakly positive correlation between the PI and the number of fracture cracks in the zygomatic region. arcs (r=0.385, p=0.020). So with an increase in pneumatization, the degree of fragmentation of the buttresses of the upper jaw tended to increase, and the degree of fragmentation of the zygomatic arch decreased.

For further analysis, PI values ≤0.9, which belonged to group I patients (pneumatic type), were considered a conditional risk group with the potential for complications in the postoperative period. To identify the relationship between the classification of the patient to group I and the severity of maxillofacial trauma, a method of constructing and analyzing multifactor models of logistic regression was used.

When choosing the optimal threshold for decision making based on the ROC curve of a one-factor model for predicting the risk of a low value of the PI coefficient by the number of fracture slits in the area of the nasal-frontal buttress, it was found that all patients with a low PI value have >1 fracture slits in the area of the nasal-frontal buttress, and ≤1 fracture slits in patients with high PI (> 0.9). Figure 6 shows the performance curve of the test, AUC = 0.69 (95 % PBI 0.52-0.83). With the selected test threshold, it demonstrates the following predictive properties: Sensitivity 100 %, Specificity 34.6 %.

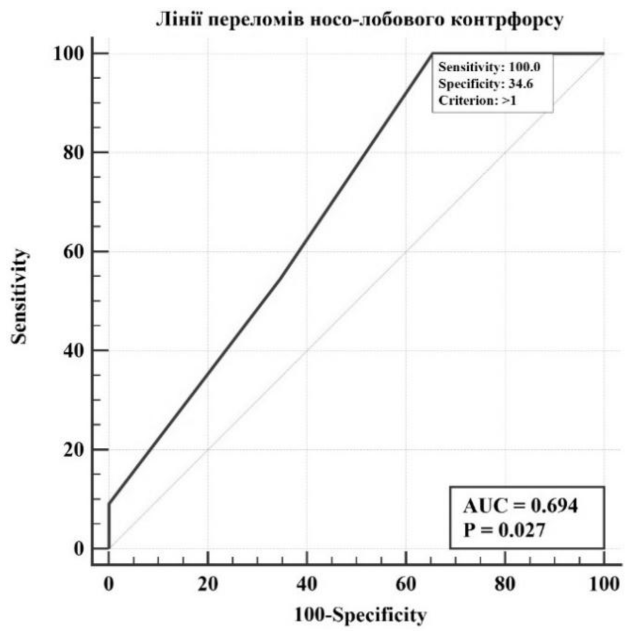

Fig. 6. The curve of the operating characteristics of the test for predicting the risk of a low value of the PI coefficient of the one-factor model according to the number of fracture slits in the area of the nasolabial buttress.

Table 2

Coefficients of a four-factor logistic regression model for predicting the risk of a low PI value

Factor sign	Model coefficient value, b±m	The level of significance of the difference between the coefficient of the model and 0, p	Odds ratio indicator, OR (95% PBI)
FISS	-0.92±0.50	0.063	0.40 (0.15–1.06)
Total number of fracture slits	0.82±0.37	0.027	2.3 (1.1–4.7)
The number of fragments of the zygomatic arch	-2.84±1.51	0.060	0.06 (0.01–1.12)
The number of fragments of the zygomatic-maxillary buttress	-1.91±0.92	0.038	0.15 (0.02–0.90)

To identify a set of indicators of the severity of maxillofacial trauma and other signs associated with a low PI value among 15 factor signs, 4 significant variables were selected using the AIC method. These included indicators of the severity of maxillofacial trauma FISS, the total number of fracture cracks in the areas of buttresses, the number of debris in the area of the zygomatic-alveolar ridge and zygomatic arch. Based on the selected risk factors, a four-factor model of logistic regression for predicting the risk of a low PI value was built (the analysis of the model coefficients is presented in table 2).

The proposed model with high accuracy (AUC = 0.89 (95 % PBI 0.78-0.99)) predicts the risk of low PI value, figure 7 shows the curve of the operational characteristics of the model.

This is a confirmation of the influence (relationship) of pneumatization of the MFB bones and such characteristics of the fracture as the overall degree of fragmentation and the number of fragments in the area of the zygomatic arch and zygomatic-alveolar ridge.

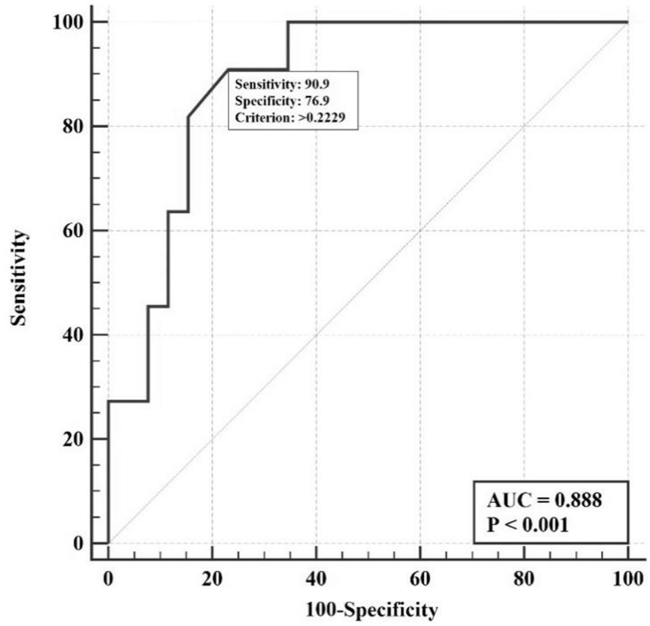

Fig.7. Operating characteristics curve of a 4-factor model for predicting the risk of a low value of the PI coefficient.

When choosing the optimal threshold of the model (Y>0.223), the sensitivity of the model is 90.9 % (95 % PBI 58.7 % – 99.8 %), and the specificity is 76.9 % (95 % PBI 56.4 % – 91 %), the predictability of a positive model result is 62.5 % (95 % PBI 44.6 % – 77.5 %), the predictability of a negative model result is 95.2 % (95 % PBI 75.3 % – 99.2 %).

Discussion. Fractures of the MFB bones are quite diverse in their clinical and anatomical characteristics, which is due to differences in the direction, duration of action, the magnitude and area of application of the force of the traumatic agent, and also depends on the characteristics of the individual anatomy, internal structure and physical and mechanical properties of bone structures [5]. They are accompanied by the destruction of a complex system of vertical and horizontal buttresses, and the fracture slit can run both along the typical lines of least resistance described by Le Fort, and deviate from them, causing complex fragmentation with the formation of fragments of different sizes and shapes. Grayson Roumeliotis found that in high-energy trauma, an increase in the energy of the traumatic factor not only leads to greater fragmentation at the lesion site, but also qualitatively changes the topography of the fracture gap [14]. It is known that the characteristics and localization of the fracture determine the volume of surgical treatment and its complexity, affect the integral effectiveness of therapeutic and rehabilitation measures, the course of the postoperative period, and the frequency of complications. With multifragment fragmentation, which often occurs as a result of high-energy trauma, with reduced resistance (strength) of bone tissue, individual bone fragments lose their viability and connection with soft tissues. The formation of defects in the buttress section creates unfavorable biomechanical conditions in the areas that receive functional loads, reduces the possibilities for redistribution of stresses between the fixator and the bone, and, as a result, reduces the effectiveness of surgical interventions and increases the risk of secondary displacements and irreversible deformations of the fixator.

The works devoted to the mechanisms of bone destruction during trauma indicate that the geometric characteristics of bone structures and the peculiarities of their architectonics determine the formation of zones of local concentration of stresses and deformations, the direction of propagation of cracks, and, consequently, the integral nature of the loss of the integrity of the damaged bone (Baitner A, 1999; Normal T, 1990; Zimmermann EA, 2009; Helwig P, 2013) [14]. For the upper jaw, which has an extremely complex anatomical structure, these issues have not been sufficiently studied in separate, mainly experimental studies.

To date, the progress of visualization methods and computer modeling opens up new possibilities in the in vivo study of the anatomy and architectonics of the MFB bones, as well as determining the severity of injury and the degree of fragmentation of bone structures. The gold standard in the diagnosis of facial fractures is multispiral computed tomography, which allows high accuracy to identify damaged areas, and to plan further treatment measures. The use of CT also makes it possible to determine the thickness and density of bone structures, and the topographic and anatomical parameters of the air cavities, based on objective criteria.

In this study, we studied the features of destruction of the upper jaw in patients with concomitant craniofacial trauma, and their association with the degree of pneumatization of the MFB bones. The study group included 37 patients with various types of damage of upper jaw, and to determine pneumatization, an objective indicator – PI (the ratio of the volume of bone structures and air cavities) was used. According to the obtained PI values, the patients who were included in the study mainly had a normal (64.8 %) or pneumatic (29.7 %) type of facial bone structure. Among the studied patients, there were only 2 with a sclerotic type of structure. In this case, the PI values were on the border with the normal type. This can be considered one of the limitations of this work, since the obtained results do not allow us to speak about the features of bone destruction in patients with this type of architectonics.

In the course of the work, a tendency towards an increase in the degree of fragmentation and the severity of injury in patients with pneumatic type of MFB structure was revealed. So the total number of fracture cracks was more than 15 in patients with pneumatic type in 27 % versus 15 % in control (normal and sclerotic type), and the number of fracture cracks in the area of vertical buttresses more than 5 was noted in 63.7 % versus 50 % in control. Thus, an increase in the degree of fragmentation in patients with pneumatic type of bone structure MFB occurred mainly due to an increase in the amount of fragments in the area of the nasal buttress and the zygomatic-alveolar ridge. In this regard, in patients of this group, the number of defects in the area of buttresses, which were formed during open reduction and osteosynthesis, turned out to be 8 % higher.

During the analysis, it was determined that in a given number of observations, in conditions of significant variability of the studied clinical cases, these differences were not statistically significant ($p<0.05$), which requires additional prospective multicenter studies to confirm the revealed pattern.

At the same time, when performing a correlation analysis of the PI with the number of fracture cracks in the region of the nasal-frontal buttress, a negative correlation of weak strength was determined. According to the indices of the one-factor regression model of the number of fracture cracks in the area of the nasal-frontal buttress, it is possible to predict the patient's belonging to the risk group. Provided that there is>1 fracture gap in the buttress section, then the patients belong to the group with a low PI value, and if the number of fracture slits is ≤1, then the patients belong to the group with a high PI value sensitivity is 100 %, but specificity – 34.6 %. When constructing a multivariate regression model(sensitivity 90,9 (95 % PBI 58,7-99,8), specificity 76,9 (95 % PBI 56,4-91)), additional relationships between the IP and the number of fragments in the area of the zygomatic-alveolar ridge and zygomatic arch were established. So, there was a tendency to an increase in the number of fragments in the area of the nasolabial and zygomatic-maxillary buttresses (as well as the total number of bone fragments) and a decrease in the degree of fragmentation of the zygomatic arch with an increase in the pneumatization of the bones of the midface.

It is known that the features of the architectonics of the facial skull and upper jaw, in particular, are formed in the process of onto- and phylogenesis and are quite variable. Thus, the structure of the maxillary cavities correlates with the volume of the nasal cavity, the narrowing of which in ethnic groups living in a cold dry climate is accompanied by an increase in the volume of the maxillary sinuses and vice versa. The authors consider this as an adaptive mechanism that provides adequate warming and humidification of the air (Yokley, 2009; Noback et al., 2011; Holton et al., 2013 Butaric et al., 2010; Holton et al., 2011, 2013; Butaric, 2015; Ito et al., 2015b). Other studies have demonstrated possible relationships between the morphology of external bone structures and internal cavities of the facial skull (Koppe et al., 1999b; Koppe et al., 2005b; Zollikofer et al., 2008, Ito et al., 2015b; but see Ito et al., 2015a). Butaric and Maddux, 2016 and others

(O'Higgins et al., 2006; Smith et al., 2010; Ito and Nishimura, 2016) have demonstrated a relationship between the size, shape and position of the zygomatic bone and the lateral and downward expansion of the maxillary sinus. The shape and size of the maxillary sinus also significantly depends on the vertical dimensions of the face (to a greater extent than on the width or anteroposterior size of the facial skull) [10].

At the same time, regardless of the type of bone structure in the middle zone of the face, they provide effective perception and redistribution of the chewing load. This is achieved by an increase in the density and stiffness of the bone with its thinning in patients with a pneumatic type of structure, as well as a change in the orientation of ostens and trabeculae in the direction of the mean vector of static loads and an increase in the degree of its anisotropy. Such properties of the bone, on the other hand, make it more vulnerable to abnormal loads caused by the action of traumatic factors that cause the fragile nature of its destruction and the creation of numerous areas of local stress concentration with a tendency to splintery fragmentation of the bone in areas close to the air cavities. In normal and sclerotic types, the energy of the traumatic factor is more efficiently transferred by the system of buttresses, which reduces the number of areas experiencing destruction and fragmentation in the zones V1i and V2i according to Donat, at the same time, fragmentation of the junction areas of the facial and cerebral skull increases (in our study, this is the zygomatic arch).

In addition to the demonstrated tendency towards the formation of less favorable splintery fractures in the area of the vertical buttresses of the upper jaw, the pneumatic type is associated with a number of features that complicate surgical treatment and reduce its effectiveness. Thinning of the bone, its fragmentation and the formation of defects at the site of the fixation installation complicate the reposition, reduce the possibility of redistribution of stresses between the plate and the bone, worsen the conditions for screw fixation. This creates additional risks of disintegration of the fixator-bone system and the development of secondary displacements.

Findings. 1. Clinical and anatomical characteristics of fractures of the upper jaw largely depend on the features of its architectonics, namely, on the ratio of the volume of bone tissue and air cavities.

2. There are associations between the risk of a low PI value and the degree of fragmentation of the nasal buttress (AUC=0.69 (95 % PBI 0.52-0.83)), the total number of fracture cracks, FISS, the degree of fragmentation of the zygomatic-alveolar ridge and facial arch ((AUC=0.89 (95 % PBI 0.78-0.99))

3. During open reposition and osteosynthesis of MFB bones in patients with pneumatic type of structure, defects in the area of vertical buttresses of the upper jaw in group I were formed in 66 % of cases, and in group II in 58 %. The tendency to the formation of splintery fragmentation must be taken into account when planning and implementing treatment and rehabilitation measures.

REFERENCES

1. **Ludi E.K., Rohatgi S., Zygmont M.E., Khosa F., Hanna T.N.** Do Radiologists and Surgeons Speak the Same Language? A Retrospective Review of Facial Trauma. AJR Am J Roentgenol. 2016;207(5):1070-1076. doi: 10.2214/AJR.15.15901. Epub 2016 Aug 24. PMID: 27556232.
2. **Regmi K.P., Tu J., Ge S., Hou C., Hu X,. Li S., Du J.** Retrospective Clinical Study of Maxillary Sagittal Fractures: Predictors of Postoperative outcome, Journal of Oral and Maxillofacial Surgery. 2016:576-583 doi: 10.1016/j.joms.2016.11.012.
3. Lozada K, Kadakia S, Abraham MT, Ducic Y. Complications of Midface Fractures. Facial Plast Surg. 2017 Dec;33(6):557-561. doi: 10.1055/s-0037-1607447. Epub 2017 Dec 1. PMID: 29195235.
4. **Malanchuk V.O., Kopchak A.V., Astapenko O.O., Shuminsky E.V**. Doslidzhennya anatomichnoyi budovy ta arkhitektoniky kistok seredn′oyi zony oblychchya za danymy spiral′noyi komp’yuternoyi tomohrafiyi. Novyny stomatologii. 2016;№2(87):66-70. [in Ukrainian]
5. **McRae M., Frodel J.** Midface fractures. Facial Plast Surg. 2000;16(2):107-13. doi: 10.1055/s-2000-12572. PMID: 11802361.
6. **Le Fort R.** Experimental study of fractures of the upper jaw Parts I and II. Rev Chir Paris. 1901;23:208; translated by Tessier P, and reprinted in Plast Reconstr Surg 1972;50: 497
7. **Bagheri S.C., Dierks E.J., Kademani D., Holmgren E., Bell R.B., Hommer L., Potter B.E**. Application of a facial injury severity scale in craniomaxillofacial trauma. J Oral Maxillofac Surg. 2006 Mar;64(3):408-14. doi: 10.1016/j.joms.2005.11.013. PMID: 16487802
8. **Marciani R.D.** Management of midface fractures: fifty years later. J Oral Maxillofac Surg. 1993 Sep;51(9):960-8. doi: 10.1016/s0278-2391(10)80035-7. PMID: 8355101.
9. **Kanda Y.** Investigation of the freely available easy-to-use software ‘EZR’ for medical statistics. Bone Marrow Transplant. 2013;48:452–458.
10. **Maddux S.D., Butaric L.N.** Zygomaticomaxillary Morphology and Maxillary Sinus Form and Function: How Spatial Constraints Influence Pneumatization Patterns among Modern Humans. Anat Rec (Hoboken). 2017 Jan;300(1):209-225. doi: 10.1002/ar.23447. PMID: 28000407.
11. **Hampson D.** Facial injury: a review of biomechanical studies and test procedures for facial injury assessment. J Biomech. 1995 Jan;28(1):1-7. doi: 10.1016/0021-9290(95)80001-8. PMID: 7852433
12. **Donat T.L., Endress C., Mathog R.H.** Facial fracture classification according to skeletal support mechanisms. Arch Otolaryngol Head Neck Surg. 1998 Dec;124(12):1306-14. doi: 10.1001/archotol.124.12.1306. PMID: 9865751.
13. **Sigaud S.** Le forme humaine C. Sigaud. - Paris, 1914 (Tsytyruetsia no B.A Nykytiuk. Novosty sportyvnoi y medytsynskoi antropolohyy. Nauchno-ynformatsyonnыi sbornyk. M. 1991;2:5-7
14. **Roumeliotis G., Ahluwalia R., Jenkyn T., Yazdani A**. The Le Fort system revisited: Trauma velocity predicts the path of Le Fort I fractures through the lateral buttress. Plast Surg (Oakv). 2015 Spring;23(1):40-2. doi: 10.4172/plastic-surgery.1000899. PMID: 25821772; PMCID: PMC4364145.
15. **Stanley R.B. Jr.** Rigid fixation of fractures of the maxillary complex. Facial Plast Surg. 1990;7(3):176-84. doi:

10.1055/s-2008-1064680. PMID: 2135701.

16. **Tanne K., Miyasaka J., Yamagata Y., Sachdeva R., Tsutsumi .S, Sakuda M.** Three-dimensional model of the human craniofacial skeleton: method and preliminary results using finite element analysis. J Biomed Eng. 1988 May;10(3):246-52. doi: 10.1016/0141-5425(88)90006-4. PMID: 3392976.

17. **Zannoni C., Mantovani R., Viceconti M**. Material properties assignment to finite element models of bone structures: a new method. Med Eng Phys. 1998 Dec;20(10):735-40. doi: 10.1016/s1350-4533(98)00081-2. PMID: 10223642.

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