

УДК 616.879.235-089

DOI: <http://dx.doi.org/10.20535/2521-1943.2019.85.157907>

Deformation indicators of metacarpal bones fracture fixation

M.S. Shidlovskiy¹ • M.M. Dyman¹ • M.A. Tsygankov²

1 – Igor Sikorsky Kyiv Polytechnic Institute, Kyiv, Ukraine;

2 – National Medical University of A.A. Bohomoltsia, Kyiv, Ukraine

Received: 27 February 2019 / Accepted: 15 March 2019

Abstract. Functional reliability of fixative-bone means was studied for various types of metacarpal fractures depending on the type of fixator and its location. The stiffness characteristics of fracture fixation systems with titanium miniplates were studied, an analysis was performed of the surgical treatment of patients with metacarpal fractures, in which osteosynthesis with needles and external fixation rod apparatus was used, with static and cyclic modes of action of external loads.

When transferring a compressive force to a fragment, the type of fixing means significantly influences the deformation of the osteosynthesis system at all levels of stress; for the most of the measured characteristics, rod devices with external fixation and titanium miniplates of various designs are preferable.

Keywords: osteosynthesis, fracture of metacarpal bones, displacement of fragments, fixation fractures, the stiffness of fixation of fractures, strength of fixation of fractures, metacarpal bones, screws, needles, miniplates, rod apparatus external fixation.

Introduction. Brush injuries reach 30% of injuries of the musculoskeletal system, of which fractures of the metacarpal bones (MB) range from 19% to 35%. One of the most common traumatic injuries is MB fracture. This type of injury most often occurs when punching a hard surface. The most common is a fracture of the neck of the 5th MB, so-called "boxer fracture" (up to 10% of hand bone fractures).

In the surgical treatment of MB fractures [10], several methods are used: fixing with needles, screws (for screw fractures), intramedullary rods, external fixation devices and miniplates with screws. In practice, the treatment method is chosen depending on the "geometry" of the fracture of the metacarpal bone (transverse, oblique, spiral many detrital).

The careful combination of bone fragments and their stable fixation have a crucial significance since the displacement of the debris of the neck and the head of the metacarpal bone can distort the axis finger and cause a significant dysfunction of the hand [7, 10, 5]. Standard fixation systems for this type of fractures, in many cases, does not provide sufficient rigidity and reliability in terms of functional load [4, 5, 6, 8].

Fixation of bone fragments with titanium miniplates of different constructions and with external fixating devices should have not only clinical parameters, but also certain mechanical characteristics, particularly a sufficient hardness and stability during a long-term treatment, which may be accompanied by cyclic loads.

Theoretical calculations levels of stress and strain, which occur in bone fragments and their fixation systems, is a complicated branch of researches first of all, because of the specific mechanical properties of bone tissues (anisotropy, heterogeneity, etc.) and complex configuration of biological objects.

Research on the behavior of fixing natural preparations at real types and levels of stress today is the most reliable and simple way of the estimation of the quality and reliability of these systems.

The purpose of the research is the development of a simulation experiment involving functional load (compression, bending, torsion) and measuring the displacement of MB fragments; - conducting a full-scale experiment on bones with simulated fractures, fixed by various means of osteosynthesis; - study of the deformation characteristics of the fixative-bone means for various types MB fractures depending on the type of fixer and its location; -determination of fixation methods optimal for this type of fracture, establishing functional safety and safety levels in terms of functional reliability.

Materials and research methods. During osteosynthesis of simulated MB fractures, osteosynthesis with metal spokes, titanium miniplates and rod apparatus external fixation was used. Details about tested PC fixers are given in table. 1 (fragments of bone, fastened with needles, for clarity, are shown pulled apart), and fig. 1 shows radiographs of head restraint MB fractures with osteosynthesis of titanium miniplates and spokes.

✉ M.S. Shidlovskiy

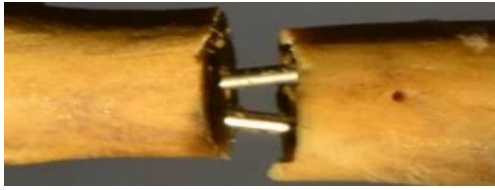



n_shidlovsky@ukr.net

✉ M.M. Dyman

mrs_d@ukr.net

Table 1

Information about proven methods of fixation of the metacarpal bones

System of osteosynthesis	Abbreviation	Auxiliary elements	Figure
1. Needles	N	needles Ø 1.2 mm	
2. Titanium miniplate	TM	screws Ø 1.7 mm	
3. Titanium miniplate with additional fixation elements	TMa	screws Ø 1.7 mm	
4. Rod apparatus external fixation	AEF	rods Ø 2.5 mm	

Samples preparation for testing. Fracture modeling, their fixation, and experiments were performed on intact chicken thigh bones. Preliminary tests showed that the stiffness characteristics of these bones used for research differ little from the human MB. So stiffness of intact chicken thigh bones during compression stays in the range of 417 N/mm to 588 N/mm. Compression tests of an intact human MB showed the value of this characteristic (442±31) N/mm. The possibility of using chicken thighs in the experiment with means of fixation of fractures is based also on the coincidence of geometric sizes of preparations with natural bones.



a



b



Fig. 1. Radiographs of the fractures of the metacarpal bones (a) with osteosynthesis of titanium miniplates (b, c) and needles (d, e)

On the epiphyses of the examined bones before testing hard heads made from Protacryl-M plastic were formed, which are designed to fix specimens on the desktop testing machine (lower heads in Fig. 2) and the transfer of force to the bone during load (top heads in Fig. 2). Such approach eliminates samples' additional movements which occur in the places of fixation while the load is applied to them and allows to measure only bones and fixation systems deformations [11].

Geometric characteristics of samples (distances from points of load to places of attachment) are given in Table 2.

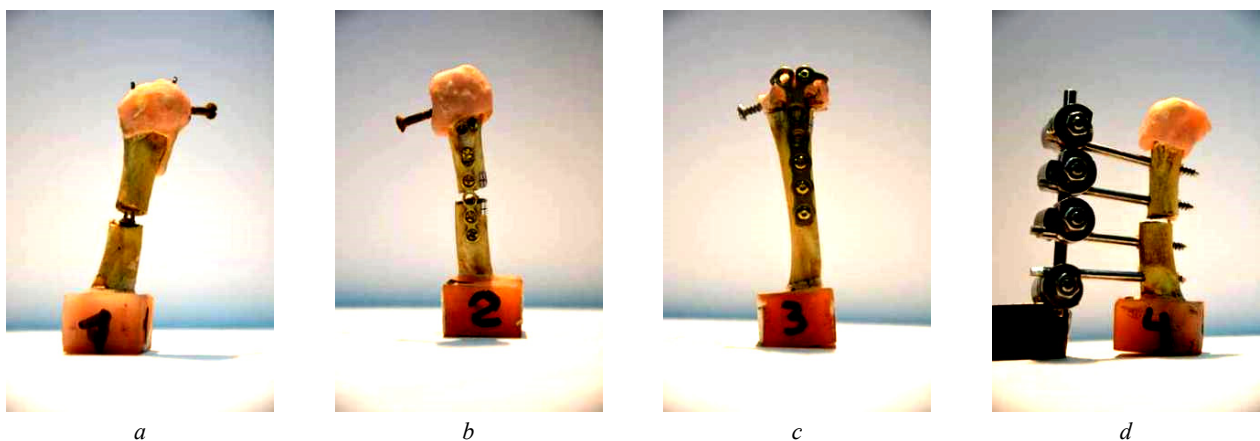


Fig. 2. Models of OS systems of metacarpal bones, subjected to tests, with fixings in the epiphysis with the spokes (a), titanium miniplate (b), titanium miniplates with additional fixation elements (c) and rod apparatus external fixation (d)

Table 2

Geometric characteristics of the tested samples

Type of loading	Geometric characteristics	OS systems			
		N	TM	TMa	AEF
		Size, mm			
Compression	The distance from the point of application of the load to the place of attachment of the bone	60	60	64	60
	The distance from the point of application of the load to the place of attachment of the bone	50	48	60	55
Bending	The distance from the point of application of the load to the bone fracture site	27	24	8	30
	The distance from the point of application of the load to the longitudinal axis of the bone	18	18	16	18
Rotation	The distance from the point of application of the load to the place of attachment of the bone	50	48	60	55

Ways to load samples. Prepared samples were fixated on the testing machine's desktop with clamps. Fixating samples on the desktop with different orientation relative to the direction of the load made it possible to conduct tests in compression, bending and torsion (Fig. 3a, 3b and 3c respectively). To create a torsion effect on a plastic head attached to the distal MB epiphysis, a steel kernel, perpendicular to the longitudinal axis of the bone, was fixed. Through it, at a

distance of 16-18 mm from the longitudinal axis of the bone the load was applied. To eliminate bending during torsion, a fluoroplastic film with a low friction coefficient was put under the plastic head (Fig. 3c), which does not interfere with the action torque.

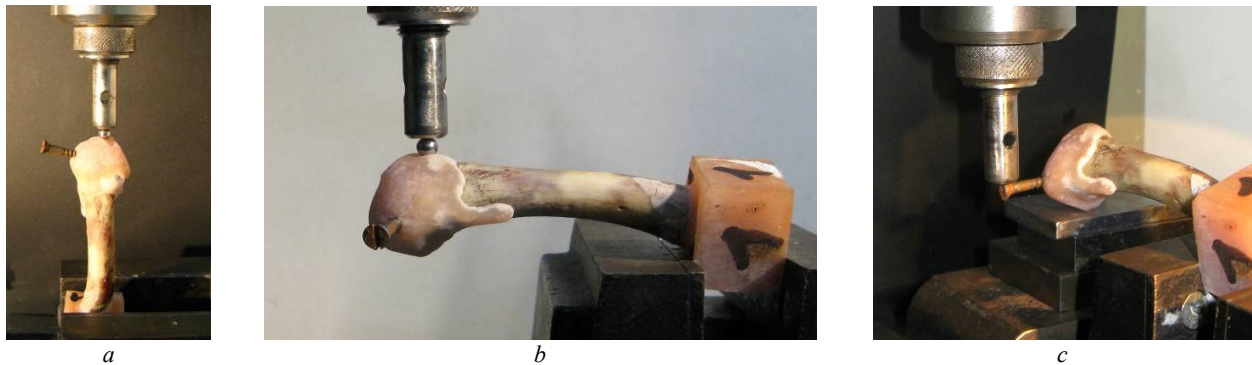


Fig. 3. Compression tests of the metacarpal bone (a), bending (b) and torsion (c)

The force applied to the specimen in the tests for compression and bending (Fig. 3a, 3b) was transmitted along using a steel ball. To prevent the occurrence of the cortical layer's local deformations, a layer of Protacril-M plastic was put at the point of contact on the surface of the bone. For loading specimen, the TIRA-test 2151 test machine was used [11].

Registration of displacements and recording of the deformation diagram in the coordinates "load P - movement Δ " (Fig. 4) was performed using the measuring system of the test machines with an accuracy of 0.1 N and 0.01 mm. Initially, intact samples were tested with small (no more than 0.5 mm) deformations, which is caused by the need to save samples in intact condition for further testing. After fractures fixation modeling, the tests were repeated with deformations up to 1.0 ... 1.2 mm.

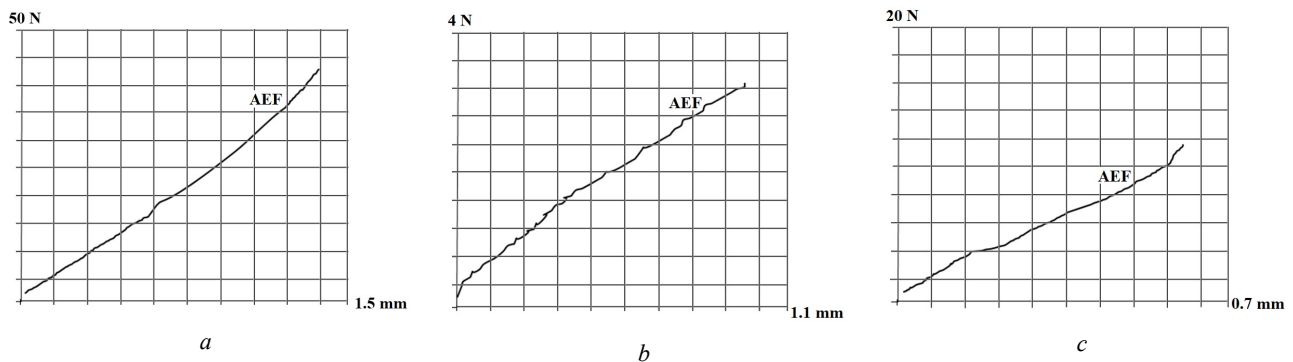


Fig. 4. Typical deformation diagrams constructed in the coordinate system "Load, N - deformation, mm", metacarpal bones at fracture, fixed external fixation device, under the action of compression (a), bend (b) and torsion (c)

Test results and analysis

The effect of one-time short-term loads. Deformations were determined and diagrams of specimen deformation under compression, bending and torsion load recorded. For further analysis convenience, instead of the absolute values of the load P and deformation Δ normalized deformations $\delta = \Delta / P$ and the values inversed to normalized deformations (stiffness of systems), $C = P / \Delta$.

These characteristics sufficiently enough reflect the biomechanical properties of linear systems in which the deformations are directly proportional to the load (Fig. 4).

The results of measurements and calculations are placed in the summary table. 3, where the confidence intervals calculated from the results of 3 ... 5 measurements with a normal distribution law of experimental data with a 95% confidence level. Graphically this data are presented on fig. 5.

As can be seen from the data presented, under the action of compressive loads, the most rigidity is the fixing system with the titanium miniplate "TM". With bend and torsion fixation with "AEF" has a significant advantage in terms of rigidity. The least rigidity of all tested systems is observed under the action of bending loads.

To compare the rigidity characteristics of various MB-fixation systems, the ratio of the stiffness of intact bones C_i to the tightening of bones with fractures and fixation systems C_f were calculated. Results in the form of coefficients of change in stiffness $\psi = C_i / C_f$ are placed in the table. 4, and in fig. 6, these coefficients are presented graphically.

Table 3

The results of measuring the deformation and roughness of various methods fixation of metacarpal fractures

Type of fixation	Intact bones		Bones with fractures and fixation systems	
	Reduced deformation $\delta \cdot 10^3, \text{mm/N}$	Stiffness $C, \text{N/mm}$	Reduced deformation $\delta \cdot 10^3, \text{mm/N}$	Stiffness $C, \text{N/mm}$
COMPRESSION				
1 (N)	2.17 ± 0.17	461 ± 32	42.37 ± 3.09	23.6 ± 2.10
2 (TM)	2.38 ± 0.15	417 ± 29	11.39 ± 0.79	87.8 ± 6.16
3 (TMa)	2.47 ± 0.17	405 ± 41	53.24 ± 3.72	18.8 ± 1.35
4 (EFA)	2.36 ± 0.19	417 ± 30	31.60 ± 2.21	31.6 ± 2.30
BENDING				
1 (N)	30.56 ± 2.14	33 ± 2.31	935.18 ± 65.46	1.07 ± 0.07
2 (TM)	48.39 ± 3.38	21 ± 1.47	652.47 ± 45.67	1.53 ± 0.10
3 (TMa)	54.07 ± 3.80	19 ± 1.33	562.96 ± 39.40	1.78 ± 0.13
4 (EFA)	40.74 ± 2.85	25 ± 1.75	282.64 ± 19.78	3.54 ± 0.25
ROTATION				
1 (N)	31.43 ± 2.20	32 ± 2.25	166.36 ± 11.64	6.01 ± 0.45
2 (TM)	58.87 ± 4.12	17 ± 1.19	209.26 ± 14.64	4.78 ± 0.34
3 (TMa)	18.40 ± 1.40	54 ± 3.78	213.88 ± 14.97	4.68 ± 0.32
4 (EFA)	23.33 ± 1.63	44 ± 3.08	47.31 ± 3.31	21.1 ± 1.47

As can be seen from the presented data, under the action of compressive loads, the fixation system with titanium miniplates «TM» has the greatest rigidity. Bending and torsion fixation with using «EFA» has a significant advantage in terms of rigidity. Smallest stiffness of all tested systems is observed under the action of bending loads.

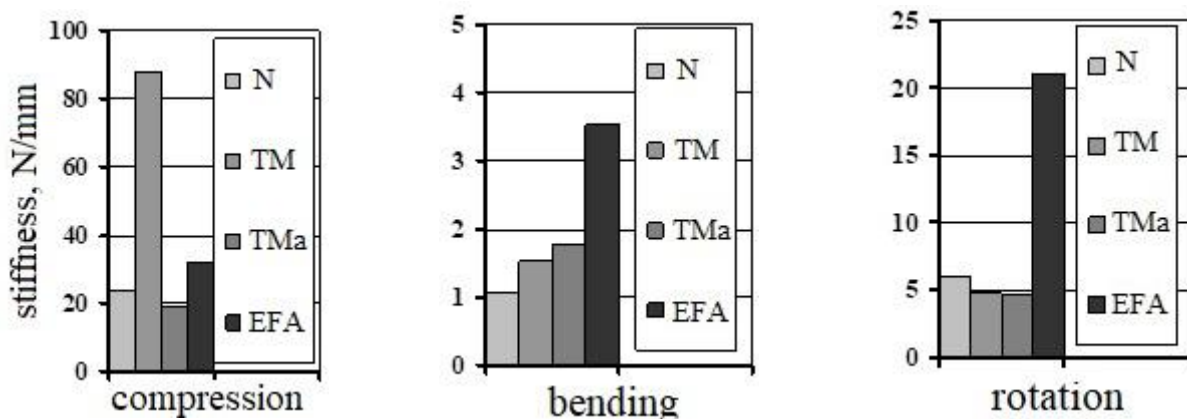
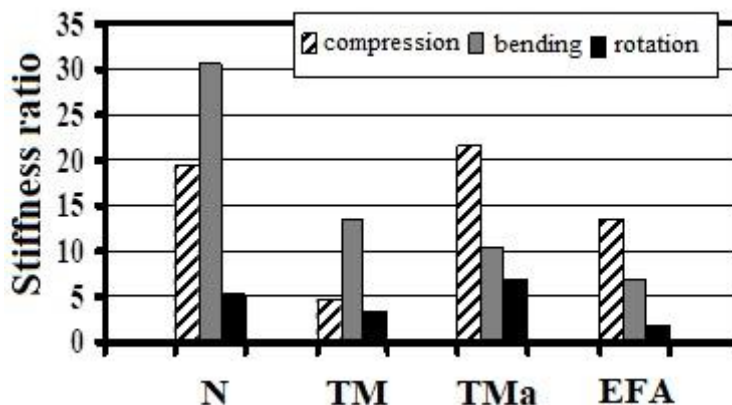


Fig. 5. Comparison of the stiffness of various systems of fixation of fractures of the metacarpal bones compression, bending and torsion

Reduced bone stiffness due to fractures and anchoring different ways

Type of fixation	Stiffness ratio of intact and damaged bones $\psi = C_i / C_F$		
	Compression	Bending	Rotation
1 (N)	19.5	30.6	5.29
2 (TM)	4.79	13.5	3.55
3 (TMa)	21.6	10.4	11.6
4 (EFA)	13.4	6.94	2.03

Fig. 6. Ratio of stiffness of intact and damaged bones $\psi = C_i / C_F$

The slightest change in stiffness under the action of compression and torsion is registered with application of fixation «TM» and «EFA», and under the action of bending loads using «EFA» and «TMa». This allows us to recommend the systems «EFA», «TM» and «TMa» for use in the fixation of the metacarpal bones fractures.

Long-term cyclic loads. The change in stiffness of the osteosynthesis systems is investigated under the action of cyclic loads that mimic the effects on the bone compound factor physical exercise. The following program was implemented for cyclic loading of the sample [11, 12, 13]: deformation of the sample at a rate of 0.5 mm/min until the occurrence of a force P_{MAX} ; sample exposure at this load for 1s; sample unloading at the same speed up to P_{MIN} ; sample exposure at this load for 1s. After that, the cycle was repeated. The maximum number of cycles for each sample is 10.

The results of experiments and calculations are presented in Fig.7.

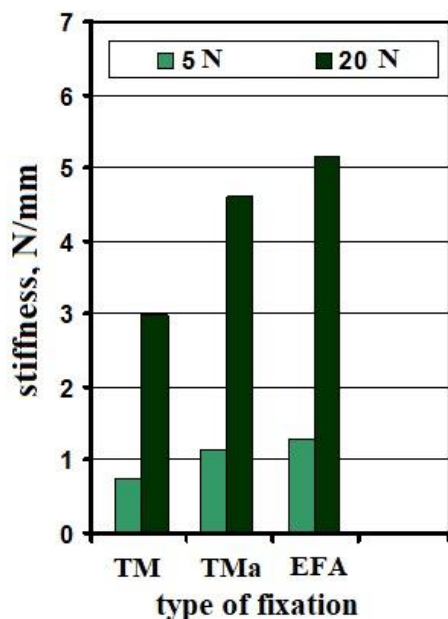


Fig. 7. Stiffness of various ways of fixing the metacarpal bone with cyclic loads

Conclusions

1. Under the action of one-time compressive loads, the system has the greatest rigidity using fixation with titanium miniplates, and during bending and torsion, it was using the external fixation device. The most dangerous types of stress in terms of the stability of bone deformities with a fracture and an established fixture is bending loads.

2. Compared to intact bone, the slightest change in stiffness under compression and the torsion is registered when using fixing with miniplates and rod apparatus, under the action of bending loads - when using a rod apparatus and titanium miniplates

3. Under the action of cyclic loads, the rigidity itself is observed in the rod apparatus.

4. For most of the measured characteristics, rod devices of an external fixings and titanium miniplates are preferable.

Деформаційні показники фіксації переломів п'ясних кісток

М.С. Шидловський, М.М. Димань, М.А. Циганков

Анотація. Досліджено функціональну надійність засобів фіксатор-кістка при різних типах переломів п'ясних кісток в залежності від типу фіксатора та його розташування. Вивчені характеристики жорсткості систем фіксації переломів з титановими мініпластинами, був проведений аналіз оперативного лікування хворих з переломами п'ясних кісток, при якому застосовувався металоостеосинтез спицями та стрижневий апарат зовнішньої фіксації, при статичних та циклічних режимах дії зовнішніх навантажень.

При передачі стискаючого зусилля на відламок тип фіксуючих засобів суттєво впливає на деформації системи остеосинтезу при всіх рівнях навантаження; за більшістю вимірних характеристик перевагу мають стрижневі апарати зовнішньої фіксації та титанові мініпластини різних конструкцій.

Ключові слова: остеосинтез, металоостеосинтез, підголівчатий перелом п'ясних кісток, зміщення уламків, фіксація переломів, жорсткість фіксації переломів, міцність фіксації переломів, п'ясна кістка, гвинти, спиці, мініпластина, стрижневий апарат зовнішньої фіксації.

Деформационные показатели фиксации переломов пястных костей

Н.С. Шидловский, М.М. Дымань, М.А. Циганков

Аннотация. В статье исследована функциональная надежность средств фиксатор-кость при разных типах переломов пястных костей в зависимости от типа фиксатора и его расположения. Изучены характеристики жесткости систем фиксации переломов с титановыми минипластинами, был проведен анализ оперативного лечения больных с переломами пястных костей, при котором применялся металоостеосинтез спицами и стержневой аппарат внешней фиксации, при статичных и циклических режимах действия внешних нагрузок.

При передаче сжимающего усилия на обломок тип фиксирующих средств существенно влияет на деформации системы остеосинтеза при всех уровнях нагрузки; за большинством измеренных характеристик преимущество имеют стержневые аппараты внешней фиксации и титановые минипластины разных конструкций.

Ключевые слова: остеосинтез, металоостеосинтез, подголовчатый перелом пястных костей, смещения обломков, фиксация переломов, жесткость фиксации переломов, прочность фиксации переломов, пястная кость, винты, спицы, минипластина стержневой аппарат внешней фиксации.

References

- Tannenbaum E.P. Comparison of 2-Dimensional and 3-Dimensional Metacarpal Fracture Plating Constructs Under Cyclic Loading/ E.P. Tannenbaum, G.T. Burns, N.R. Oak, J.N. Lawton // The Journal of Hand Surgery. 6'2017. 6'№42. 6'P. 159-165. <https://doi.org/10.1016/j.jhssa.2017.01.003>
- Cotterell I.H. Metacarpal and Phalangeal Fractures in Athletes / I.H. Cotterell, M.J. Richard // Clinics in Sports Medicine. 6 2015. 6№ 34. 6 P. 69-98. <https://doi.org/10.1016/j.csm.2014.09.009>
- Murison J.C. Metacarpal bone reconstruction by a cementless induced membrane technique / J.C. Murison, G. Pfister, S. Amar, S. Rigal, L. Mathieu // Hand Surgery and Rehabilitation. 2019. Available online
- Brotzman S.B. 5 - Fifth Metacarpal Neck Fracture (Boxer's Fracture) / S.B. Brotzman, T.M. Kidd, M.A. Hardy, S.R. Novotny // Clinical Orthopaedic Rehabilitation. - 2018. - №4. - P. 24-28.
- Zhang X. Reduction of Fifth Metacarpal Neck Fractures With a Kirschner Wire / X. Zhang, X. Huang, X. Shao // The Journal of Hand Surgery. - 2015. - № 40. - P. 1225-1230. <https://doi.org/10.1016/j.jhssa.2015.03.015>
- Jann D. Retrograde fixation of metacarpal fractures with intramedullary cannulated headless compression screws / D. Jann, M. Calcagni, P. Giovanoli, T. Giesen // Hand Surgery and Rehabilitation. - 2018. - № 37. - P. 99-103. <https://doi.org/10.1016/j.hansur.2017.12.005>
- Khan Yaseen F.M. A rare case of floating fifth metacarpal and review of literature / F.M. Khan Yaseen, M.R. Guity, A. Arfa, N. Bagheri // Trauma Case Reports. - 2019. - № 20. Available online
- Duan W. Treatment of comminuted fractures of the base of the thumb metacarpal using a cemented bone-K-wire frame. / W. Duan, X. Zhang, Y. Yu, Z. Zhang, X. Shao, W. Du // Hand Surgery and Rehabilitation. - 2019. - № 38. - P. 44-51.
- Amsallem L. Simplified internal fixation of fifth metacarpal neck fractures / L. Amsallem, J. Pierrart, T. Bihel, J. Sekri, T. Lafosse, E. Masmajejean, D. Delgrande // Orthopaedics & Traumatology: Surgery & Research. - 2018. - № 104. - P.257-260.
- Nemov A. Simulation of mechanical behaviour of the plate for osteosynthesis: loads and computational approach / A. Nemov, M. Zhmaylo, I. Zelinskiy, N. Ermolenko, A. Karandashev, A. Borovkov, V. Khominets, I. Khominets, K. Mamedov, A. Miliaev, A. Grebenyuk // Series on Biomechanics. - 2018. - № 32. - P. 30-37.
- Шидловський Н.С. Методи дослідження деформаційної надійності систем остеосинтеза кінцівок людини / Н.С. Шидловський // Біомедична інженерія. - 2011. - №1. - С. 24-31.
- Шидловський Н.С. Натурні тести систем "більшеберцова кістка з переломом – стержневою апаратом фіксації / Н.С. Шидловський, А.М. Лакша, Д.Е. Шпак // Вісник НТУУ "КПІ", Серія Машинобудування. - 2011. - том 2, № 61. - С. 134–140.
- Шидловський Н.С. Особливості вибору режимів біомеханічних натурних тестів систем остеосинтеза з урахуванням циклічних навантажень / Н.С. Шидловський, А.М. Лакша, М.М. Димань // Літопис травматології та ортопедії. 2014. 6 № 1-2/(29-30). 6 с.115-120.