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Finite element analysis of the stress-strain state of 3D computer generated imaging of reverse total shoulder endoprostheses

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Objective. To conduct a finite element analysis of the stress-strain state (STS) of the elements of the shoulder joint after implantation reverse shoulder endoprostheses. Material and methods. After 3D-scanning of the composite model of the scapula and humerus, geometric models of the shoulder joint were built in the SolidWorks 2019 SP 1.0 program, followed by mathematical modeling and FEA. For the comparative analysis of the STS of the «bone – reverse endoprosthesis» system, three-dimensional models of two types of reverse shoulder endoprostheses were created, which were then transformed into a finite-element model and implanted into the developed three-dimensional mathematical model of the shoulder joint without cement. The STS calculations of the elements of endoprostheses were carried out for two positions: abduction 90° and flexion 90° with a load of 5 kg. Results. Compared to the healthy shoulder joint, models with reverse shoulder endoprosthesis have significantly different contact stresses and contact areas. It was established that the maximum stress in the details of the contact parts of the endoprosthesis when retracted at an angle of 90° did not exceed +1.78 MPa, when bending +5.8 MPa. The maximum stresses on the liner during shoulder abduction are +8.6 MPa, the minimum –7.38 MPa, during flexion +2.3 MPa and –2.45 MPa, respectively. It has been proven that the contact areas of the hemisphere and inserts of both reverse endoprostheses during abduction and flexion of the limb by 90° are significantly larger (573 mm^2 vs. 1809–2081 mm^2) when compared with a healthy shoulder joint, while changes in the area between the endoprostheses are insignificant and equal to 2...3 %. Conclusions. Analysis of the STS load of elements of reverse shoulder endoprosthesis showed that the greatest stresses occur in the contact zones. It has been proven that the maximum stresses on the contact structures of endoprostheses are less than on the head of a healthy joint, but the contact area during implantation of a reversible endoprosthesis of the shoulder joint increases significantly (more than 3 times).

Мета. Провести скінченно-елементний аналіз (СЕА) напружено-деформованого стану (НДС) елементів плечового суглоба та імплантатів двох типів реверсивних ендопротезів плечового суглоба. Матеріал і методи. Після 3D-сканування композитної моделі лопатки та протеза плечової кістки, побудовано геометричну модель плечового суглоба в програмі SolidWorks 2019 SP 1.0 із наступним математичним моделюванням й аналізом НДС. Для порівняльного аналізу НДС системи «кістка – реверсивний ендопротез» створено тривимірні моделі двох типів реверсивних тотальних ендопротезів плечової кістки, які трансформовано в скінченно-елементі моделі й імплантовано в розроблену тривимірну модель плечового суглоба без цементу. Проведено розрахунки НДС елементів ендопротезів плечового суглоба для двох положень: абдукція 90° та згинання 90° з навантаженням 5 кг. Результати. Порівняно зі здоровим плечовим суглобом, моделі з реверсивними тотальними ендопротезами плечового суглоба мають значно інші контактні напруження та площі контакту. Встановлено, максимальне напруження в деталях контактних частин ендопротеза за відведення під кутом 90° не перевищувало +1,78 МПа, згинання +5,8 МПа. Максимальні напруження на вкладці за абдукції плеча +8,6 МПА, мінімальні –7,38 МПа, під час згинання відповідно +2,3 МПа та –2,45 МПа. Доведено, що контактні площі гемісфери та вкладки обох реверсивних ендопротезів за абдукції та згинання кінцівки на 90° значно більше (573 мм^2 проти 1809–2081 мм^2) порівняно зі здоровим плечовим суглобом, при цьому зміни площі між ендопротезами незначні та дорівнюють 2–3 %. Висновки. Аналіз НДС навантаження елементів реверсивних тотальних ендопротезів показав, що найбільші напруження виникають у їхніх контактних зонах. Доведено, що максимальні напруження на контактних структурах ендопротезів менше ніж на головці здорового суглоба, але площа контакту в разі імплантації реверсивного ендопротеза плечового суглоба значно збільшується (більше ніж у 3 рази). Ключові слова. Плечовий суглоб, реверсивний ендопротез, скінченно-елементний аналіз, тривимірне моделювання.

Keywords. Shoulder joint, total shoulder replacement, finite element analysis, 3D-imaging

Introduction

Finite element analysis (FEA) as one of the research tools in biomechanics was first used by W. Brekelmans [1]. Currently, due to the development of computer technologies and the improvement of mathematical modeling, FEA is a generally recognized effective and non-invasive method of analysis of new implants based on obtaining data on the distribution of deformations and stresses [2-6].

Most fractures of the proximal part of the humerus (FPPH) are known to occur in elderly patients with osteoporosis [7]. Fixation of implants in the proximal part of the humerus against the background of osteoporosis is a difficult task for surgeons. Reversible total shoulder arthroplasty (RTSA) is one of the methods of surgical treatment of patients with fragmented FPPH against the background of osteoporosis [8]. However, FEA assessment requires correct setting of boundary conditions, which is not easy due to the complex structure of the shoulder joint, taking into account all the muscles and ligaments acting together. Since the stability of the shoulder joint is mostly provided by soft tissues, the authors [9–10] were among the first to include the main rotational muscles in the 3D model in addition to the bones, but they were considered as passive structures. Most FEA studies simplified the mathematical model of shoulder joints, ignoring the interaction of muscles, ligaments, bones and other surrounding structures [11–12]. In our opinion, muscles should be considered as dynamic structures, which will allow optimal determination of the resulting movement and contact zones of the artificial endoprosthesis of the shoulder joint.

Purpose. To develop a mathematical model of the shoulder joint taking into account the muscles and their attachment, to conduct a comparative analysis of the stress-strain state (SSS) of the elements of the shoulder joint in normal conditions and after implantation of two types of reversible endoprostheses of the shoulder joint.

Material and methods

For three-dimensional modeling of the shoulder joint after 3D scanning of the composite model of the scapula and humerus of the Swedish company [13], geometric models were built in the SolidWorks 2019 SP 1.0 environment with mathematical modeling and SSS analysis in the ANSYS 2022 R2 application software package (Licences belong to Ontic Ltd 01159718, serial N 0000-0001-5371-9527, ANSYS, Inc., Canonsburg, PA, USA) [14]. The research was conducted on the basis of: 3D scanning of bones and creation of 3D models, analysis, generalization of results and conclusions based on the developments of the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Sciences of Ukraine. Physical and mechanical properties of the layers of the model and the 3D model itself were taken from the studies [15–19].

For the comparative analysis of the SSS of the «bone – implant» system, three-dimensional models of reversible total endoprostheses of the humerus were created, which were then transformed into finite element models (FEM) and built into the developed three-dimensional mathematical model of the shoulder joint [15] without cement (Fig. 1).

The developed FEA uses a Tetra10 element with ten nodes, the number of elements is 530,094, the number of nodes is 784,700, and the average linear size of the elements is 2 mm. Calculations of SSS elements of two reversible total endoprostheses of the shoulder joint were carried out for two positions: abduction 90° and flexion 90° with a load of 5 kg (Figs. 2, 3).

The scheme of applied elastic elements is shown in Fig. 4. The characteristics of the materials of the components of reversible endoprostheses are given in Table 1 [21–24].

Statistical analysis of the data was performed directly in the ANSYS software package and with the help of the Mathcad software package (version 15.0). The comparison was made by the non-parametric Wilcoxon test.

Results and their discussion

Calculations showed that depending on the angle and direction of abduction of the limb, the distribution of maximum and minimum principal stresses for

Table 1

Physico-mechanical properties of materials of reversible total endoprostheses models

Tissue type	Density, kg/m^3	Young's modulus E, GPa	Poisson's ratio ν	Tensile strength limit, σ+, MPa	Compressive strength limit, σ-, MPa
Porous titanium	4 354	0,61	0,34	170	105
UHMWPE	930	0,60	0,46	21	48
CoCr alloy	8 400	0,20	0,29	1 100	800

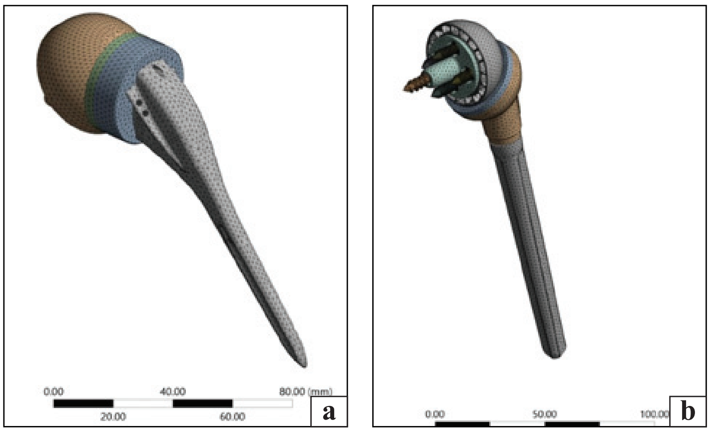

Fig. 1. General FEA view of a reversible total endoprosthesis of the shoulder joint: a) UNIC Reverse Evolutis, France [21]; b) proposed by the authors [25]

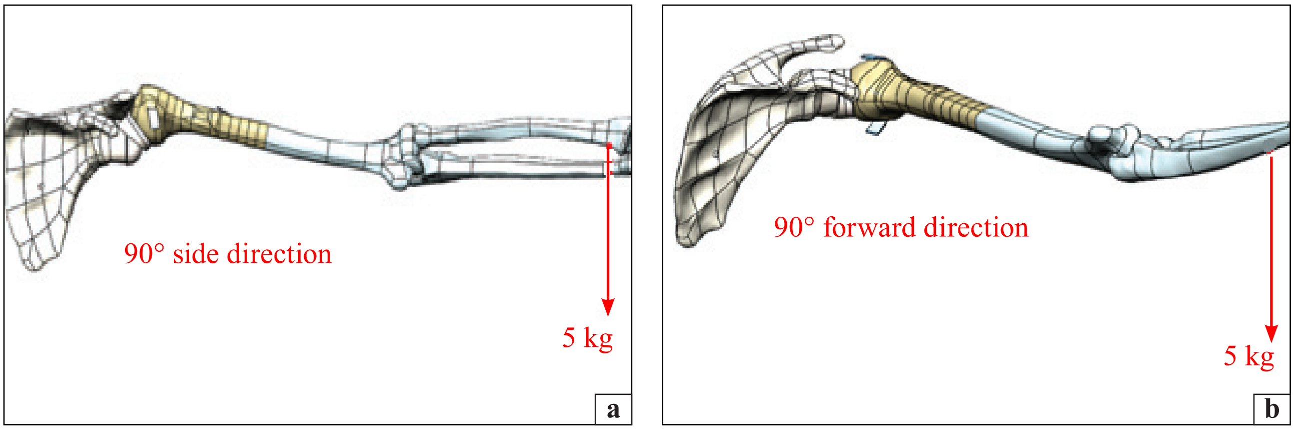

Fig. 2. Shoulder joint: kinematic model and loading scheme: a) abduction up to 90°; b) bending up to 90° with a load of 5 kg

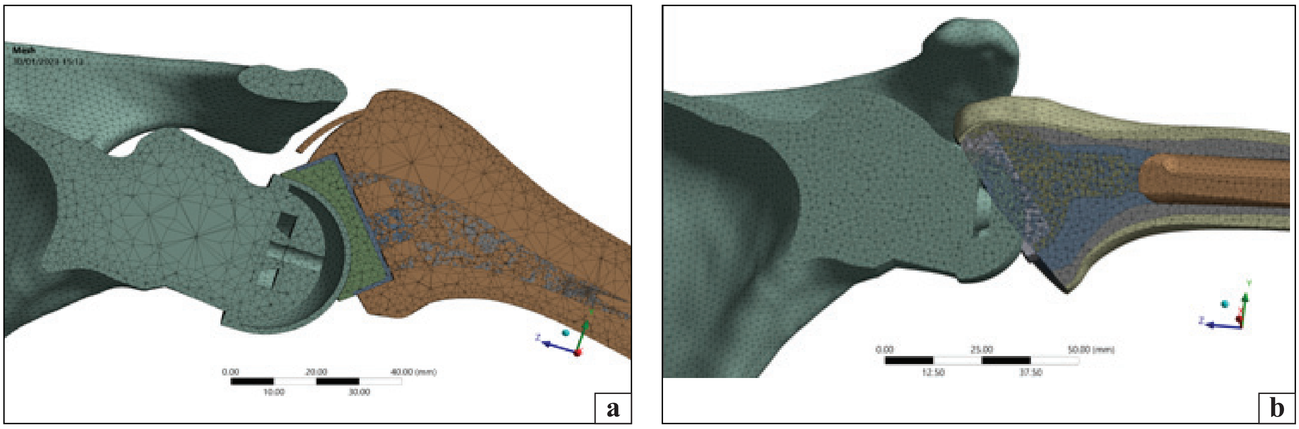

Fig. 3. FEA diagrams of the shoulder joint with reversible total endoprosthesis of the shoulder joint for the calculated case of shoulder abduction (abduction) by 90° from: a) UNIC Reverse Evolutis, France [21]; b) proposed by the authors [25]

Table 2

Maximum and minimum stresses in elements of endoprostheses in 90° abduction position and contact area

Calculation of SSS for the model	Maximum stresses, MPa		Minimum stresses, MPa		Contact area, mm^2
	for 90° abduction on the hemisphere	for 90° abduction on the tab	for 90° abduction on the hemisphere	for 90° abduction on the tab	
UNIC Reverse Evolutis, France	1.78	8.60	–6.75	–7.38	1 809.48
Reversible total endoprosthesis proposed by the authors	1.22	0.12	–2.20	–0.12	1 948.24

the hemisphere of endoprostheses and inserts of endoprostheses has a non-linear nature. Reverse endoprosthetic repair of the shoulder joint is accompanied by a change in the directions of the resulting force vectors that occur during the work of the muscles surrounding the shoulder joint, the distance between the places of attachment of elastic connections changes compared to a healthy shoulder joint, which results in a change in the kinematics of the shoulder joint.

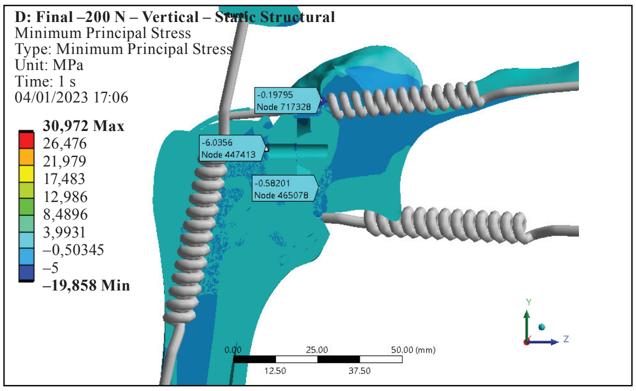

Fig. 4. Example of SSS calculation of the «bone – reversible shoulder endoprosthesis» model with elastic elements imitating muscles

Tables 2, 3 show the minimum and maximum stresses in the elements of endoprostheses in the position of 90° abduction, 90° flexion and the contact area, as well as a healthy shoulder. Figures 5, 6 demonstrate examples of stress visualization.

The maximum stress in the contact parts of the endoprosthesis during abduction at an angle of 90° did not exceed +1.78 MPa, during bending +5.8 MPa. The maximum stresses on the tab during shoulder abduction are +8.6 MPa, the minimum stresses on the tab reach –7.38 MPa, +2.3 MPa and –2.45 MPa during flexion, respectively (see Table 2).

Assessment of the obtained data showed that the contact areas of the hemisphere and the tabs of both reversible endoprostheses during abduction and flexion of the limb to 90° are significantly larger compared to the healthy shoulder joint [15] (Table 3), while the changes in the area between the endoprostheses are insignificant and equal to 2–3 %.

We believe, firstly, that an increase in the contact area leads to the prevention of dislocation of the endoprosthesis due to an increase in the movement of the contact surfaces one relative to the other (1897.93–2081.60 mm^2 vs. 573 mm^2 in a healthy joint).

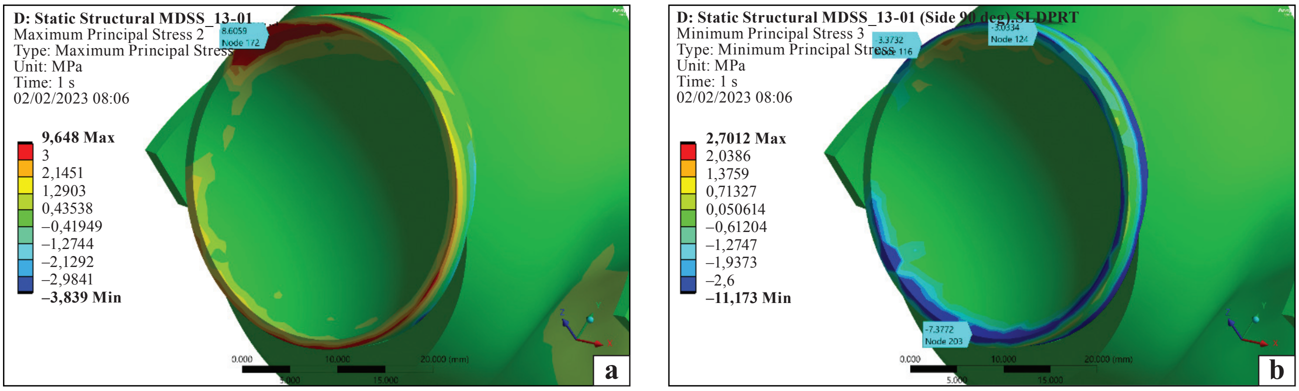

Fig. 5. SSS of the reversible total endoprosthesis of the shoulder joint, UNIC Reverse Evolutis, France in the 90° abduction position: a) maximum stresses on the tab; b) minimum stresses on the tab

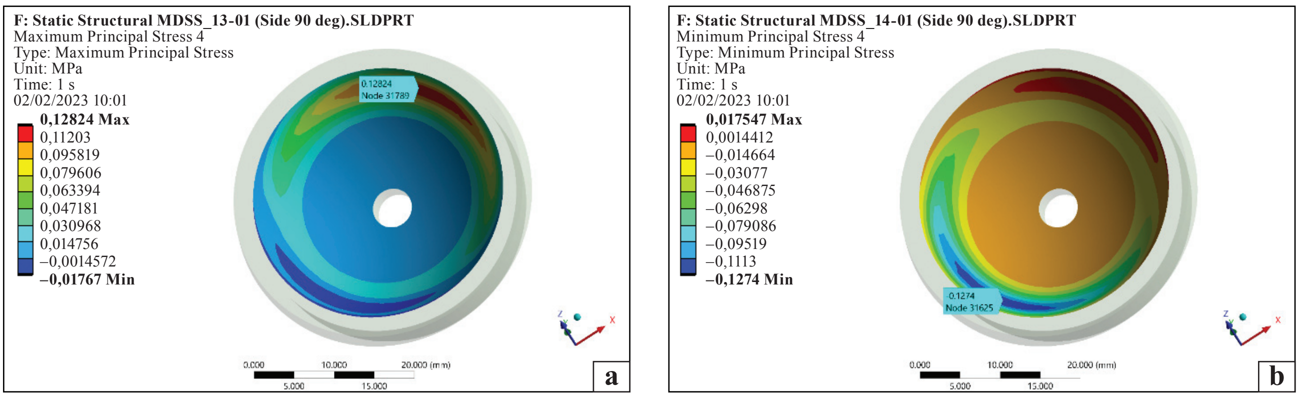

Fig. 6. SSS of the reversible total endoprosthesis of the shoulder joint proposed by the authors in the 90° abduction position: a) maximum stresses on the tab; b) minimum stresses on the tab

Table 3

Maximum and minimum stresses in elements of endoprostheses and a healthy shoulder joint during flexion of the shoulder to 90° and contact area

Calculation of SSS for the model	Maximum stresses, MPa			Minimum stresses, MPa			Contact area, mm^2
	on the hemisphere for bending the shoulder up to 90°	on the tab for bending the shoulder up to 90°	at a shoulder abduction angle of 90°	on the hemisphere for bending the shoulder up to 90°	on the tab for bending the shoulder up to 90°	at a shoulder abduction angle of 90°	
UNIC Reverse Evolutis, France	2.20	2.30	—	–3.60	–2.45	—	1897.93
Reversible total endoprosthesis proposed by the authors	5.80	0.12	—	–2.45	–0.13	—	2081.60
Articular cartilage of the head of the humerus	—	—	+13.8	—	—	–3.58	573
Articular cartilage of the glenoid cavity of the scapula	—	—	+3.62	—	—	—	—

Secondly, in the case of a change in the center of rotation (its medialization occurs in reversible endoprostheses), the muscles around the shoulder joint are stretched and lengthened during reversible total endoprosthesis, so the maximum stresses on the contact structures of endoprostheses are less than on the head of a healthy joint [15] (Tables 2, 3). Thus, technical features of the reversible total endoprosthesis proposed by the authors make it possible to obtain a sufficient contact area, but with a decrease in the maximum and minimum stresses on the contacting surfaces. An increase in the contact area, on the other hand, leads to a limitation of the range of motion compared to a healthy shoulder joint [15, 20, 21, 26, 27].

Analysis of the SSS load of elements of two types of reversible total endoprosthesis models showed that the greatest stresses occur in the contact zones of the endoprostheses. The obtained results of numerical modeling of SSS in elements of endoprostheses were compared to allowable stresses for materials. It was determined that depending on the direction of movement, the tension changes non-linearly.

Computer simulation of RTSA has been shown to facilitate the assessment of muscle and joint loading that cannot currently be measured noninvasively *in vivo*. Modeling and simulation of RTSA played a crucial role in implant positioning and improvement of surgical technique [28, 29]. Today, most modeling and simulation tools require a high level of knowledge and are mostly limited to a research environment [30, 31].

We believe that the correct evaluation of the analysis of stresses and deformations occurring in the structural elements of the endoprosthesis of the shoulder joint and its surrounding bones largely depends on muscle modeling and requires a model capable of accurately and reliably predicting muscle movement in automated conditions. Numerous researchers approach this problem in different ways. Thus, the authors [8] built a 3D model of the shoulder joint and analyzed it using the FEA method. The peculiarity of their model is the construction of four muscles of the rotator cuff and three bundles of the deltoid muscle in the form of a «string of pearls». The muscle bundles consisted of 15 rigid spheres connected by linear elastic springs and attached to the bones. The free ends of the muscle bundles were pulled to the place of insertion, after which shoulder movements were performed. The FEA model showed good qualitative agreement with previously published results for abduction, bending, and axial rotation before and after RTSA.

The developed three-dimensional models of «bone – reversible endoprosthesis» taking into account the muscles and their interaction with bones and the results obtained after the SSS analysis can be used in the future for the introduction of new and more effective treatment methods, including new designs of shoulder joint endoprostheses.

Conclusions

Analysis of the stress-strain state of elements of two types of reversible total endoprosthesis models showed that the greatest stresses occur in the contact zones of the endoprostheses. The obtained results of the numerical simulation of the stress-strain state in elements of endoprostheses are significantly less with permissible stresses for materials. It was determined that depending on the direction of movement, the tension changes non-linearly.

The three-dimensional model «bone – reversible endoprosthesis» developed by us with the introduction of elastic elements imitating the muscles surrounding the shoulder joint made it possible to stabilize the models and evaluate the stress distribution in the structural elements of endoprostheses using the finite element analysis method.

It has been proven that the maximum contact stresses in reversible endoprostheses are less compared to a healthy shoulder joint, but the contact area during implantation of a reversible endoprosthesis of the shoulder joint increases significantly (more than 3 times).

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Conflict of interest. The authors declare no conflict of interest.

References

1. Brekelmans, W. A. M., Poort, H. W., & Slooff, T. J. J. H. (1972). A New Method to Analyse the Mechanical Behaviour of Skeletal Parts. *Acta Orthopaedica Scandinavica, 43* (5), 301–317. https://doi.org/10.3109/17453677208998949
2. Ye, Y., You, W., Zhu, W., Cui, J., Chen, K., & Wang, D. (2017). The Applications of Finite Element Analysis in Proximal Humeral Fractures. *Computational and Mathematical Methods in Medicine, (2)*, 1–9. https://doi.org/10.1155/2017/4879836
3. Mousa, M. A., Abdullah, J. Y., Jamayet, N. B., El-Anwar, M. I., Ganji, K. K., Alam, M. K., & Husein, A. (2021). Biomechanics in Removable Partial Dentures: A Literature Review of FEA-Based Studies. B*ioMed Research International,* 1–16. https://doi.org/10.1155/2021/5699962
4. Sugano, N., Hamada, H., Uemura, K., Takashima, K., & Nakahara, I. (2022). Numerical analysis evaluation of artificial joints. *Journal of Artificial Organs, 25* (3), 185–190. https://doi.org/10.1007/s10047-022-01345-0
5. Sabesan, V. J., Lima, D. J. L., Yang, Y., Stankard, M. C., Drummond, M., & Liou, W. W. (2020). The role of greater tuberosity healing in reverse shoulder arthroplasty: a finite element analysis. *Journal of Shoulder and Elbow Surgery, 29* (2), 347–354. https://doi.org/10.1016/j.jse.2019.07.022
6. Huang, Y., Ernstbrunner, L., Robinson, D. L., Lee, P. V. S., & Ackland, D. C. (2021). Complications of Reverse Total Shoulder Arthroplasty: A Computational Modelling Perspective. *Journal of Clinical Medicine, 10* (22), 5336. https://doi.org/10.3390/jcm10225336
7. Mellstrand Navarro, C., Brolund, A., Ekholm, C., Heintz, E., Hoxha Ekstrom, E., Josefsson, P. O., Leander, L., Nordstrom, P., Ziden, L., & Stenstrom, K. (2018). Treatment of humerus fractures in the elderly: A systematic review covering effectiveness, safety, economic aspects and evolution of practice. *PLOS ONE, 13* (12), e0207815. https://doi.org/10.1371/journal.pone.0207815
8. Goetti, P., Denard, P. J., Collin, P., Ibrahim, M., Mazzolari, A., & Lädermann, A. (2021). Biomechanics of anatomic and reverse shoulder arthroplasty. *EFORT Open Reviews, 6* (10), 918–931. https://doi.org/10.1302/2058-5241.6.210014
9. Büchler, P., & Farron, A. (2004). Benefits of an anatomical reconstruction of the humeral head during shoulder arthroplasty: a finite element analysis. *Clinical Biomechanics, 19* (1), 16–23. https://doi.org/10.1016/j.clinbiomech.2003.09.009
10. Büchler, P., Ramaniraka, N. A., Rakotomanana, L. R., Iannotti, J. P., & Farron, A. (2002). A finite element model of the shoulder: application to the comparison of normal and osteoarthritic joints. *Clinical Biomechanics, 17* (9–10), 630–639. https://doi.org/10.1016/s0268-0033(02)00106-7
11. Xia, S., Zhang, Y., Wang, X., Wang, Z., Wang, W., Ma, X., & Tian, S. (2015). Computerized Virtual Surgery Planning for ORIF of Proximal Humeral Fractures. *Orthopedics, 38* (5), e428-e433. https://doi.org/10.3928/01477447-20150504-62
12. Webb, J. D., Blemker, S. S., & Delp, S. L. (2012). 3D finite element models of shoulder muscles for computing lines of actions and moment arms. *Computer Methods in Biomechanics and Biomedical Engineering, 17* (8), 829–837. https://doi.org/10.1080/10255842.2012.719605
13. Sawbones: biomechanical test materials: A Division of Pacific Research Laboratories [web source]/Sawbones Europe AB, 2018. Retrieved from: http://www.sawbones.com.
14. Gadala, M. (2020). Finite elements for engineers with Ansys applications. Cambridge, Cambridge University Press.
15. Korzh, M., Makarov, V. ., Smerdov, S., Tankut O., Pidgaiska, O., & Zdanevych, S. (2023). Analysis of the stress-strain state three-dimensional model of a healthy shoulder joint. *ORTHOPAEDICS TRAUMATOLOGY and PROSTHETICS*, (3), 27–36. https://doi.org/10.15674/0030-59872021327-36
16. Lazarev, I. A., Lomko, V. M., Strafun, S. S., & Skiban, M. V. (2018). Comparative analysis of stress-strain changes at the humeral head cartilage in different types of glenoidlabrum injuries. *TRAUMA, 19* (2), 51–59. https://doi.org/10.22141/1608-1706.2.19.2018.130654
17. Zheng, M., Zou, Z., Bartolo, P. J. D. S., Peach, C., & Ren, L. (2016). Finite element models of the human shoulder complex: a review of their clinical implications and modelling techniques. *International Journal for Numerical Methods in Biomedical Engineering, 33* (2), e02777. https://doi.org/10.1002/cnm.2777
18. Gunneswara Rao, T. D. & Andal, M. (2018). Strength of Materials: Fundamentals and Applications. Gunneswara Rao. Cambridge University Press.
19. Singh, D., Rana, A., Jhajhria, S. K., Garg, B., Pandey, P. M., & Kalyanasundaram, D. (2018). Experimental assessment of biomechanical properties in human male elbow bone subjected to bending and compression loads. *Journal of Applied Biomaterials & Functional Materials, 17* (2), 228080001879381. https://doi.org/10.1177/2280800018793816
20. Haering, D., Raison, M., & Begon, M. (2014). Measurement and Description of Three-Dimensional Shoulder Range of Motion With Degrees of Freedom Interactions. *Journal of Biomechanical Engineering, 136* (8). https://doi.org/10.1115/1.4027665
21. Frankle, M., Marberry, S., & Pupello, D. (Eds.). (2016). Reverse Shoulder Arthroplasty: Biomechanics, Clinical Techniques, and Current Technologies. Springer International Publishing. https://doi.org/10.1007/978-3-319-20840-4
22. Falkowska, A., Seweryn, A., & Skrodzki, M. (2020). Strength Properties of a Porous Titanium Alloy Ti6Al4V with Diamond Structure Obtained by Laser Power Bed Fusion (LPBF). *Materials, 13* (22), 5138. https://doi.org/10.3390/ma13225138
23. Zhang, C., Zhang, L., Liu, L., Lv, L., Gao, L., Liu, N., Wang, X., & Ye, J. (2020). Mechanical behavior of a titanium alloy scaffold mimicking trabecular structure. *Journal of Orthopaedic Surgery and Research, 15* (1). https://doi.org/10.1186/s13018-019-1489-y
24. Hussain, M., Naqvi, R. A., Abbas, N., Khan, S. M., Nawaz, S.,

Hussain, A., Zahra, N., & Khalid, M. W. (2020). Ultra-High-Molecular-Weight-Polyethylene (UHMWPE) as a Promising Polymer Material for Biomedical Applications: A Concise Review. *Polymers, 12* (2), 323. https://doi.org/10.3390/polym12020323
25. Korzh M. O., Manukyan V. A., Kosyakov O. M., Makarov V. B., Kovalev A. M., Strelnytskyi V. E., Vasiliev V. V., Yermakov V. R., Nikitin Yu. M., Grebennikov K. O., & Chupryna D. O. Reversible total modular endoprosthesis of the shoulder joint. Patent № 147264 UA. (In Ukrainian)
26. Collotte, P., Erickson, J., Vieira, T. D., Domos, P., & Walch, G. (2021). Clinical and radiologic outcomes of eccentric glenosphere versus concentric glenosphere in reverse shoulder arthroplasty. J*ournal of Shoulder and Elbow Surgery, 30* (8), 1899-1906. https://doi.org/10.1016/j.jse.2020.10.032
27. Helmkamp, J. K., Bullock, G. S., Amilo, N. R., Guerrero, E. M., Ledbetter, L. S., Sell, T. C., & Garrigues, G. E. (2018). The clinical and radiographic impact of center of rotation lateralization in reverse shoulder arthroplasty: A systematic review. *Journal of Shoulder and Elbow Surgery, 27* (11), 2099–2107. https://doi.org/10.1016/j.jse.2018.07.007
28. Ingrassia, T., Nigrelli, V., Ricotta, V., Nalbone, L., D'Arienzo, A., D'Arienzo, M., & Porcellini, G. (2019). A new method to evaluate the influence of the glenosphere positioning on stability and range of motion of a reverse shoulder prosthesis. *Injury, 50*, S12–S17. https://doi.org/10.1016/j.injury.2019.01.039
29. Zhang, M., Junaid, S., Gregory, T., Hansen, U., & Cheng, C. (2019). Effect of baseplate positioning on fixation of reverse total shoulder arthroplasty. *Clinical Biomechanics, 62*, 15–22. https://doi.org/10.1016/j.clinbiomech.2018.12.021
30. Ackland, D. C., Robinson, D. L., Wilkosz, A., Wu, W., Richardson, M., Lee, P., & Tse, K. M. (2019). The influence of rotator cuff tears on muscle and joint contact loading after reverse total shoulder arthroplasty. *Journal of Orthopaedic Research, 37* (1), 211–219. https://doi.org/10.1002/jor.24152
31. Glenday, J., Kontaxis, A., Roche, S., & Sivarasu, S. (2019). Effect of humeral tray placement on impingement-free range of motion and muscle moment arms in reverse shoulder arthroplasty. *Clinical Biomechanics, 62*, 136–143. https://doi.org/10.1016/j.clinbiomech.2019.02.002

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FINITE ELEMENT ANALYSIS OF THE STRESS-STRAIN STATE OF 3D COMPUTER GENERATED IMAGING OF REVERSE TOTAL SHOULDER ENDOPROSTHESES

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