Genij Ortopedii. 2021. Vol. 27, no. 6. P. 813-820.

Review article

https://doi.org/10.18019/1028-4427-2021-27-6-813-820

Artificial intelligence for predicting various conditions in spine surgery: a systematic review

V.S. Pereverzev✉, A.I. Kazmin, M.L. Sazhnev, A.A. Panteleev, S.V. Kolesov

National Priorov Medical Research Center of Traumatology and Orthopedics, Moscow, Russian Federation

Corresponding author: Vladimir S. Pereverzev, vcpereverz@gmail.com

Abstract

Introduction Artificial intelligence (AI) includes software systems combined with applied methods and algorithms which main feature is the ability to solve intellectual problems. One of the most popular trend of AI application is the prognosis of various situations, evaluation of any digital information with an attempt to give a conclusion and analysis of different data with a search for hidden patterns. **Study design** Systematic review. **Purpose** To assess current possibilities of artificial intelligence (AI) for predicting unfavorable conditions in spine surgery that require medical care, and future development prospects in this area. **Materials and methods** Until June 2020 we performed a search using the Protocol (PRISMA) "Preferred Reporting Parameters for Systematic Reviews and Meta-analyzes" and keywords for articles in Medline, Scopus and eLIBRARY intended to summarize the available data on algorithms for predicting any pathological conditions in spine surgery that require medical intervention using artificial intelligence technologies. **Results** 20 publications were selected for systematic review, which presented data on the application of artificial intelligence, machine learning and neural networks to predict any condition in spine surgery. According to the review, the data obtained indicate that AI can be successfully used to optimize prognosis in various diseases of the spine. Therefore, the application of AI in the clinical practice of the spine surgeons can improve treatment results. **Conclusion** The promotion of artificial intelligence application in medicine is inevitable. Currently AI shows good results in the area of making clinical decisions by the surgeons and the ability to predict treatment results depending on certain factors. It is imperative that spinal surgeons should realize the potential of these new technologies. Nevertheless, some factors that determine the clinical application of artificial intelligence, i.e. the ability to consider the context of a patient's history, are difficult to calculate mathematically and, so far, are difficult for an algorithmic approach. Eventually, the doctors will continue to play a vital role in patients' treatment, and artificial intelligence will not depreciate their clinical skills, but make them even more important.

Keywords: artificial intelligence, systematic review, machine learning, spine surgeons, neural networks in spine surgery, prognosis in spine surgery

For citation: Pereverzev V.S., Kazmin A.I., Sazhnev M.L., Panteleev A.A., Kolesov S.V. Artificial intelligence for predicting various conditions in spine surgery: a systematic review. *Genij Ortopedii*, 2021, vol. 27, no 6, pp. 813-820. https://doi.org/10.18019/1028-4427-2021-27-6-813-820.

INTRODUCTION

The capabilities of machine learning and artificial intelligence are growing faster today than ever before. Significant advances in information processing allow for an unprecedented level of accuracy in the analysis of large databases [1]. This can be seen in the use of electronic medical documentation with increased quantity and quality of available information to enable medical personnel analyze and understand the factors that can contribute to improvement of the quality of patient care [2]. Information systems, Big Data ("big data" is a term that is commonly used to call huge amounts of information with a complex heterogeneous and/or unspecific structure) and artificial intelligence (AI) can help in this situation. AI includes various software systems, methods, algorithms featuring the ability to solve intellectual problems in the way a person thinking about their solution would do. Prediction of different situations, evaluation of digital information with an attempt to give a conclusion, analysis of electronic data and data mining are most popular AI applications [1]. AI has gained huge popularity: search engines, a car navigator and many other things that have imperceptibly become part of our daily life. AI-based research is also being conducted in many areas of medicine and shows great prospects in improving the effectiveness of clinical approach, personalization, management and scientific activity [3]. Image interpretation is the most popular area of AI research. AI helps to increase the specialist's diagnostic accuracy and prevent errors, but it does not replace a radiologist. Neural network patterns have been applied to different conditions including diagnosis of the patient's bone age, vertebral fractures, bone mineral density, etc. [4]. This review is aimed at summarizing existing data concerning algorithms for predicting different pathological conditions in spinal surgery that require medical intervention using artificial intelligence technologies.

Research design is a systematic review.

The aim was to evaluate the current capabilities of artificial intelligence (AI) for predicting adverse events in spinal surgery that would require medical care, and future prospects for development in the area.

MATERIAL AND METHODS

Using the protocol (PRISMA) "Preferred reporting parameters for systematic reviews and meta-analysis" [5], a detailed search of original articles was conducted in the Medline, Scopus and eLibrary databases. Publications brought out up to June 2020 were reviewed using combinations of search queries in English and Russian "Artificial Intelligence in spine surgery", "Artificial Intelligence in Spinal Diseases", "Spinal prognosis", "artificial intelligence in spinal surgery", "prognosis in spinal surgery", "prediction", "neural networks", "artificial intelligence". Keywords were defined in reference with the probability of being mentioned in the title or summary of the relevant publications. The articles were first selected by the title and then studied in detail. An additional search was performed using links from identified contributions. Articles reporting the use of artificial intelligence, machine learning, neural networks in the surgical treatment of spinal diseases and prediction in spinal surgery were accepted for consideration.

RESULTS

Initially, 64 articles were found in the Medline, Scopus and eLibrary databases. One of them was published neither in English nor in Russian, four more were excluded due to duplication. Of the 59, 26 were withdrawn because they did not meet the inclusion criteria. Another six were excluded due to insufficient information about the use of applications for prediction. Abstracts (n = 4) and letters from editors (n = 3) were not in the inclusion criteria. Finally, 20 articles were included in the review, the selection stages are shown in Figure 1. A summary of the search is presented in Table 1. A large number of the selected articles reported back pain and degenerative lesions of the spine. There are support systems for making clinical decisions and recommendations for the diagnosis and treatment of pain in the lumbar spine. The approach allows systematization of the current status of the patient, and the development of such systems would help the doctor to identify an adequate treatment strategy. This is the advantage over making a decision alone. There will be the possibility to appropriately distribute the number of services performed and increase their accessibility to the population.

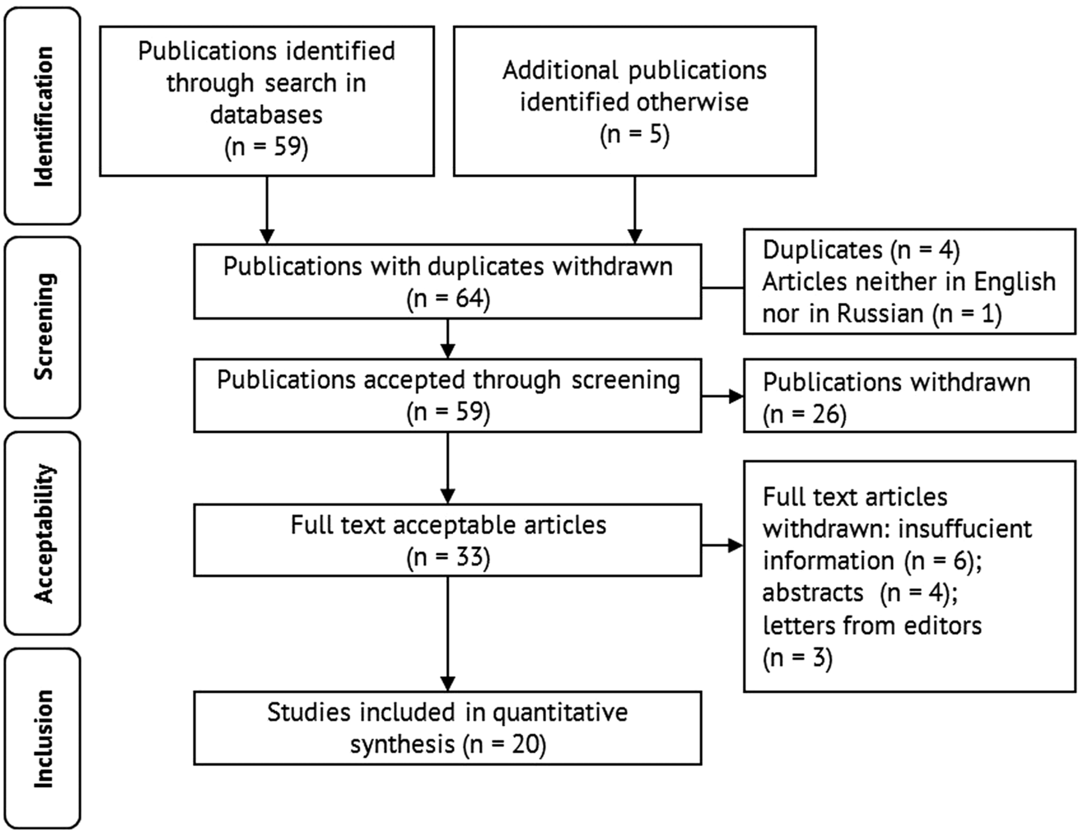

Fig. 1 Stages of search and selection of literary sources for systematic review

Table 1

List of publications on prediction in spinal surgery using artificial intelligence

Authors	Year	Country	Condition	Patients/ review	Purpose	Conclusion/result
Dickey J.P. et al. [7]	2002	USA	Low-back pain	9	To investigate the relationship between intervertebral motion, intravertebral deformation and pain in chronic low-back pain patients	The neural network model showed a strong relationship between observed and predicted pain. Neural networks are able to effectively describe relationships between pain and vertebral motion in chronic low-back pain patients
Hill J.C. et al. [6]	2008	UK	Nonspecific back pain	500	To develop and validate a tool that screens for back pain prognostic indicators relevant to initial decision making in primary care	Offered is a screening tool, which is a promising instrument for identifying subgroups of patients to guide the provision of early secondary prevention in primary care. Further work will establish whether allocation to treatment subgroups using the tool, linked with targeting treatment
Parsaeian M. et al. [8]	2012	Iran	Low back pain	17295	Compare empirically predictive ability of an artificial neural network with a logistic regression in prediction of low back pain	Based on these three criteria, artificial neural network would give better performance than logistic regression. Although, the difference is statistically significant, it does not seem to be clinically significant
Papić M. et al. [9]	2016	Serbia	Lumbar disc herniation	145	Predict the return to work after operative treatment of lumbar disc herniation	The predictive modeling indicated at the most decisive risk factors in prolongation of work absence: psychosocial factors, mobility of the spine and structural changes of facet joints and professional factors including standing, sitting and microclimate
Lafage R. et al. [10]	2018	USA	Sagittal alignment	Review	Planning and prediction of postoperative sagittal alignment using self-learning computers	Integrating newer technology can change the current way of planning/simulating surgery. The use of powerful computer-assisted tools that are able to integrate several parameters and learn from experience can change the traditional way of selecting treatment pathways and counseling patients. However, there is still much work to be done to reach a desired level as noted in other orthopedic fields, such as hip surgery. Many of these tools already exist in non-medical fields and their adaptation to spine surgery is of considerable interest.
Arvind V. et al. [11]	2018	USA	Cervical discectomy	14615	Demonstrate the performance of machine learning models in predicting postoperative complications following anterior cervical discectomy and fusion	Artificial neural network and logistic regression algorithms outperform ASA physical status classification for predicting individual postoperative complications. Additionally, neural networks have greater sensitivity than LR when predicting mortality and wound complications. With the growing size of medical data, the training of machine learning on these large datasets promises to improve risk prognostication, with the ability of continuously learning making them excellent tools in complex clinical scenarios
Karhade A.V et al. [12]	2018	USA	Degenerative diseases of the lumbar spine	26364	Use of machine learning for the development of an open-access web application for preoperative prediction of non-standard indications in surgery during planned operations for degenerative diseases of the lumbar spine	The frequency of non-standard indications in 26,364 patients who underwent elective surgery for degenerative diseases of the lumbar disc was 9.28 %. Machine learning algorithms have shown promising results in internal validation for preoperative prediction of non-standard indications
Karhade A.V. et al. [13]	2018	USA	Spinal chordoma	265	Develop machine learning models for survival prediction and deploy them as open access web applications as a proof of concept for machine learning in rare nervous system lesions	The analysis of patients with spinal chordoma demonstrated that machine learning models can be developed for survival prediction in rare pathologies and have the potential to serve as the basis for creation of decision support tools in the future
Kim J.S. et al. [14]	2018	USA	Posterior lumbar spine fusion	22629	Train and validate machine learning models to identify risk factors for complications following posterior lumbar spine fusion.	Machine learning in the form of logistic regression were more accurate than benchmark ASA scores for identifying risk factors of developing complications following posterior lumbar spine fusion, suggesting they are potentially great tools for risk factor analysis in spine surgery
Ghogawala Z. et al. [15]	2019	USA	Degenerative spondylolisthesis	Review	Review of advanced computing technologies, artificial intelligence in particular and the related field of machine learning, for modeling and prediction based on factors influencing surgeons' decision-making, and develop approaches to creating diagnostic recommendations that can be applied in practice for clinical scenarios that would lead to improved surgical results	Recent developments in computing power, along with efforts to collect digital medical data, suggest that artificial intelligence technology can be used to predict which patients can develop instability after laminectomy, and to ensure optimal selection of patients for the use of implants in the lumbar spine

Table 1 continued

List of publications on prediction in spinal surgery using artificial intelligence

Authors	Year	Country	Condition	Patients/ review	Purpose	Conclusion/result
Ames C.P. et al. [16]	2019	Multicenter.	Adult spinal deformity	570	Apply artificial intelligence -based hierarchical clustering as a step toward a classification scheme that optimizes overall quality, value, and safety for adult spinal deformity surgery	Unsupervised hierarchical clustering can identify data patterns that may augment preoperative decision-making through construction of a 2-year risk-benefit grid. In addition to creating a novel AI-based ASD classification, pattern identification may facilitate treatment optimization by educating surgeons on which treatment patterns yield optimal improvement with lowest risk
Joshi R.S. et al. [17]	2019	USA	Adult spinal deformity	Review	Overview of prediction models and machine learning for the treatment of adult spinal deformity	The studies reflect the common efforts of surgeons and mathematicians from all over the world to develop adult scoliosis surgery in the modern technological age. The ability to use advanced computational methods will significantly affect patient care. Remaining at the forefront of technological advances, spinal surgeons will continue to strive to provide patients with the most useful data in order to optimize the process of preoperative visits to clinics and make doctor-patient decisions. The next steps will be the further development of artificial intelligence technology, its application directly for clinical decision-making and ensuring the availability of technology for surgeons. In achieving this, adult scoliosis surgery has really begun to embrace the era of personalized medicine
Han S.S. et al. [18]	2019	USA	Spine surgery	1 106 234	To develop and evaluate a set of predictive models for common adverse events after spine surgery	Presented is a set of predictive models for AEs following spine surgery that account for patient-, diagnosis-, and procedure-related factors which can contribute to patient-counseling, accurate risk adjustment
Bertsimas D. et al. [19]	2019	USA	Pediatric cervical spine injuries	Without/ with injury 9533/ 119	To develop highly accurate clinical decision rules to predict pediatric cervical spine injuries using machine learning methods	This study developed a decision rule that achieves high injury identification while reducing unnecessary imaging. It demonstrates the value of machine learning in improving clinical decision protocols for pediatric trauma
Schwartz J.T. et al. [2]	2019	USA	Spine surgery	Review	Examine the current state of machine learning using electronic medical records as it applies to spine surgery	Electronic medical records represent a rich source of medical data, and machine learning algorithms may be able to successfully use the data for applications in spinal surgery. Progress has already been made in using machine learning algorithms to read radiographs, generate reports, and predict clinical outcomes with impressive results
Staartjes V.E. et al. [20]	2019	The Netherlands	Microdiscectomy of lumbar disc herniation	422	To evaluate the feasibility of deriving robust deep learning-based predictive analytics from single-center, single-surgeon data	The study demonstrates that generating personalized and robust deep learning-based analytics for outcome prediction is feasible even with limited amounts of center-specific data. With prospective validation, the ability to preoperatively and reliably inform patients about the likelihood of symptom improvement could prove useful in patient counselling and shared decision-making
Weber K.A. et al. [21]	2019	USA	Muscle fat infiltration following injury to cervical spine	39	Automatic quantitative assessment of muscle infiltration by adipose tissue after whiplash injury to the cervical spine	Neural network models may improve the efficiency and objectivity of muscle measures allowing for the quantitative monitoring of muscle properties in disorders of and beyond the cervical spine
Ryu S.M. et al. [22]	2020	South Korea Корея	Spino-pelvic chondrosarcoma	1088	To predict survival following a spino-pelvic chondrosarcoma diagnosis	This study is the first to analyze population-level data using artificial neural network ML algorithms for the role and outcomes of surgical resection and radiation therapy in spino-pelvic chondrosarcoma
Azimi P. et al. [23]	2020	Multicenter	Spinal diseases	Review	To identify the role of artificial neural networks in spinal diseases	The evidence suggests that artificial neural networks can be successfully used for optimizing the diagnosis, prognosis and outcome prediction in spinal diseases. Therefore, incorporation of ANNs into spine clinical practice may improve clinical decision making
Hopkins B.S. et al. [24	2020	USA	Surgical site infection after posterior spinal fusions	4046	To predict surgical site infection after posterior spinal fusions using artificial intelligence	Machine learning and artificial intelligence are relevant and impressive tools that should be employed in the clinical decision making for patients. The variables with the largest model weights were primarily comorbidity related with the exception of multilevel fusion. Further study is needed, however, in order to draw any definitive conclusions

In 2019 Ghogawala Z. Et al. suggested that most patients with lumbar spondylolisthesis are treated with a fusion, which is much more costly compared with laminectomy alone at least in the short term. The data published on degenerative lumbar spondylolisthesis suggest that most patients can be successfully treated only with decompression in the lumbar spine, and the number of patients who develop instability at the level of surgery in the long term is insignificant. The instability that can be treated successfully with lumbar fusion. Recent developments in computing power along with efforts to capture digital medical data suggest that AI technology might be used to predict which patients would develop delayed instability after lumbar laminectomy and permit optimal selection of patients for lumbar instrumented fusion. Not all patients with degenerative spondylolisthesis need lumbar fusion [25]. A larger database is required to create an algorithm for solutions in order to determine the optimal indications for a particular approach [15]. There is a study that first demonstrated the use of unsupervised learning through artificial intelligence based hierarchical clustering as a step toward a classification scheme that optimizes overall quality for adult spinal deformity surgery [16].

The initiative was taken over by Joshi R.S. et al. (2019), who combined their work with the development of a prediction tool for assessing the risk of adult spinal deformity surgery to predict complications, repeated intervention and specific results of improving the quality of life for up to 2 years based on patient-specific variables [17]. Validation of the results of the studies will lead to the widespread use of similar decision-making tools for spinal surgeons. A set of prediction models for adverse factors following spine surgery can account for patient-, diagnosis-, and procedure-related factors which can contribute to patient-counseling, accurate risk adjustment, and accurate quality metrics [18]. Neural networks were examined in the ability to predict lower back pain in order to automatically predict and identify risk factors for complications following posterior lumbar spine fusion [14], and to develop and evaluate the selection of prognostic models of common adverse events after spinal surgery [18]. Bertsimas D. et al. (2019) leveraged machine learning methods to develop highly accurate clinical decision rules to predict pediatric cervical spine injuries [19]. It demonstrates the role of machine learning in improving clinical decision protocols for pediatric trauma. Preoperative prediction of prolonged postoperative opioid prescription can help identify candidates for increased surveillance after lumbar disc herniation surgery [26]. Patient-centered explanations of predictions can enhance both shared decision-making and quality of care.

While modern prediction models require working with limited hypotheses, machine learning methods can include many more variables. Information can be a priority and influence decision-making at different levels. The development of powerful computer-assisted methods involves the integration of several sources of information such as radiographic parameters (lying, standing) X-rays, MRI, CT scan, etc., demographic information (age, gender and BMI), and unusual non-osseous parameters (muscle quality, proprioception, gait analysis data). Using machine learning, shape recognition and modeling, in particular, computer methods can predict the balance of the spine and identify suspected pathological zones and compensatory mechanisms and offer adequate surgical solutions [10]. Studies across the electronic medical record data domains of imaging, text, and structured data are reviewed. Discussed applications include clinical prognostication, preoperative planning, diagnostics, and dynamic clinical assistance. The limitations and future challenges including legislation issues for machine learning research using electronic medical records are also discussed [2].

Karhade A.V. et al. (2018) suggested that AI can be successfully used for different spine diseases to verify the diagnosis, prognosis and prediction of results. In addition to that, neural networks are useful for the development of new computational tools for predicting clinical outcomes, the timing of return to work, physical disability, complications, the need for early readmission, the ability to walk, the timing of discharge after spinal surgery [9, 27, 28]. Neural network methods have also been used to develop prediction algorithms for postoperative complications after anterior cervical discectomy and spinal fusion [11] and to assess clinically significant improvement in pain in the lower extremities, back and functional insufficiency after lumbar disc herniation surgery [20] and for automatic quantitative assessment of muscle fat infiltration after whiplash injury of the cervical spine [21]. Further retraining of neural network algorithms, generalization of models, standardization of data in neural networks and focusing on their use as a tool in the clinical practice of a spinal surgeon will increase the efficiency of decision-making [23]. In 2018 Karhade A.V. et al., reviewed patients with spinal chordoma and showed that machine learning models can be developed for survival prediction in rare pathologies [13]. In 2020 Ryu et al. showed that survival neural network machine learning algorithms can be used to predict survival following a spino-pelvic chondrosarcoma diagnosis [22]. In 2020 Hopkins B.S. et al. first published the use of AI for the prediction of risk factors for the development of infectious complications after spinal surgery. The positive prognostic value, showing how well the model predicted the risk of infection, was 92.56 %. The negative prognostic value, demonstrating how well the model predicted the absence of risk of infectious complications, was 98.45 %. The greatest probability of complications was mainly associated with concomitant pathology: chronic heart failure, chronic pulmonary insufficiency, hemiplegia/paraplegia and AIDS/HIV. Males and Whites were less susceptible to infectious complications. In addition to that, individuals who stay in the intensive care unit and have greater Charlson comorbidity index require more attention due to the increased risk of complications [24]. However, in order to draw any definitive conclusions, further research is needed.

DISCUSSION

Single-level lumbar spinal decompression surgery (for stenosis or disc herniation) is one of the most common neurosurgical procedures. The results of a survey 2013 among American Association of Neurological Surgeons indicated a total of 50 % of surgeons who performed wrong-level surgery at least once, and 10 % who performed wrong-side lumbar spine surgery at least once [29]. These figures are comparable with similar data from other authors [30]. Medical errors are the third leading cause of death of patients [31]. The search for new approaches to avoid potential mistakes will significantly improve the quality of care provided to patients. Over the past few years, the number of publications on the use of neural networks in spinal diseases has increased significantly to report diagnosis and prediction. The product of the American company IBM Watson IBM's Watson is the most prominent AI-based system for medicine [32]. Initially, the project was developed to help doctors diagnose oncological diseases and select an effective method of treatment that consequently led to reduced treatment costs. To date, the principle of machine learning has been applied in other fields of medicine (cardiology [33], ophthalmology [34], endocrinology [35], etc.). Research is currently being conducted at our center using the IBM Power AI Vison and a model for recognizing malignant tumors of the bone and joint system is being developed [36]. A number of developments on the use of AI in spinal surgery focus on preoperative assessment, planning, intraoperative care and prediction of results in spinal surgery. A logistic regression model has been successfully developed to predict the results of fusion at the lumbar spine [25]. Weber K.A. et al. have developed a model of a clinical prediction tool to determine the likelihood of improvement in spinal function, back and leg pain in patients with lumbar fixation one year after surgery. This model has shown high accuracy in validation [21]. The same authors have developed prediction models published in open access to allow a doctor and a patient individually or jointly can enter individual demographic data to predict the likelihood of getting a good result during surgery to get fusion at the level of the lumbar spine. In addition, a machine learning tool was developed to predict the long-term postoperative prescription of opiates in patients who had undergone lumbar spine surgery [26]. Karhade et al. (2018) [37, 38] developed a machine learning tool for automatic prediction of mortality in metastatic spinal involvement.

It is suggested that these studies will significantly reduce the treatment costs. Research investments needed to develop prediction systems in the field of artificial intelligence require a lot of technical knowledge and digital infrastructure that are inaccessible to most spinal surgeons. With limited financial resources in a hotel organization, large expenditures on strategic developments in the field of AI are difficult to be justified, when competing with hospital expenditures, in particular. This provides an opportunity for other stakeholders to analyze the progress in the technology. For example, medical equipment supply companies are significantly more interested in the research and promotion of artificial intelligence in medicine, and spinal surgeons are to be involved in the process to ensure adequate implementation of AI.

In our opinion, AI should be considered as a tool to help doctors provide quality medical care, as well as a new implant, visualization or navigation method. When implementing and using AI, it is important to make sure that these developments are aimed at improving the quality of medical care rather than increasing the profits of sponsors and developers. Clinicians should recognize that the successful use of machine learning methods can improve the treatment results of patients suffering from spine diseases. The data obtained indicate that AI can be successfully used to optimize the prognosis for different spine diseases. Therefore, the use of AI for spine diseases can improve the outcomes in clinical practice.

CONCLUSION

Promotion of artificial intelligence in medicine is inevitably destined. AI has shown good results in the clinical decision-making and the ability to predict the treatment results depending on certain factors. Spinal surgeons need to embrace the potential of these new technologies. However, some factors involved in the clinical application of artificial intelligence, such as the capacity to recognize the contexture of a patient's medical history, are difficult for calculations, and therefore are difficult for an algorithmic approach.

Ultimately, doctors will continue to play a vital role in management of patients, and artificial intelligence would be unable to devalue their clinical skills, and will make them even more important.

REFERENCES

1. Gusev A.V., Dobridniuk S.L. Iskusstvennyi intellekt v meditsine i zdravookhranenii [Artificial intelligence in medicine and healthcare]. *Informatsionnoe Obshchestvo*, 2017, no. 4-5, pp. 78-93. (in Russian)
2. Schwartz J.T., Gao M., Geng E.A., Mody K.S., Mikhail C.M., Cho S.K. Applications of Machine Learning Using Electronic Medical Records in Spine Surgery. *Neurospine*, 2019, vol. 16, no. 4, pp. 643-653. DOI: 10.14245/ns.1938386.193.
3. Panchmatia J.R., Visenio M.R., Panch T. The role of artificial intelligence in orthopaedic surgery. *Br. J. Hosp. Med*. (Lond), 2018, vol. 79, no. 12, pp. 676-681. DOI: 10.12968/hmed.2018.79.12.676.
4. Gyftopoulos S., Lin D., Knoll F., Doshi A.M., Rodrigues T.C., Recht M.P. Artificial Intelligence in Musculoskeletal Imaging: Current Status and Future Directions. *AJR Am. J. Roentgenol*., 2019, vol. 213, no. 3, pp. 506-513. DOI: 10.2214/AJR.19.21117.
5. Knobloch K., Yoon U., Vogt P.M. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement and publication bias. *J. Craniomaxillofac. Surg*., 2011, vol. 39, no. 2, pp. 91-92. DOI: 10.1016/j.jcms.2010.11.001.
6. Hill J.C., Dunn K.M., Lewis M., Mullis R., Main C.J., Foster N.E., Hay E.M. A primary care back pain screening tool: identifying patient subgroups for initial treatment. *Arthritis Rheum*., 2008, vol. 59, no. 5, pp. 632-641. DOI: 10.1002/art.23563.
7. Dickey J.P., Pierrynowski M.R., Bednar D.A., Yang S.X. Relationship between pain and vertebral motion in chronic low-back pain subjects. *Clin. Biomech*. (Bristol, Avon), 2002, vol. 17, no. 5, pp. 345-352. DOI: 10.1016/s0268-0033(02)00032-3.
8. Parsaeian M., Mohammad K., Mahmoudi M., Zeraati H. Comparison of logistic regression and artificial neural network in low back pain prediction: second national health survey. *Iran J. Public Health*, 2012, vol. 41, no. 6, pp. 86-92. PMCID: PMC3469002.
9. Papić M., Brdar S., Papić V., Lončar-Turukalo T. Return to Work after Lumbar Microdiscectomy – Personalizing Approach through Predictive Modeling. *Stud. Health Technol. Inform*., 2016, vol. 224, pp. 181-183.
10. Lafage R., Pesenti S., Lafage V., Schwab F.J. Self-learning computers for surgical planning and prediction of postoperative alignment. *Eur. Spine J*., 2018, vol. 27, no. Suppl 1, pp. 123-128. DOI: 10.1007/s00586-018-5497-0.
11. Arvind V., Kim J.S., Oermann E.K., Kaji D., Cho S.K. Predicting Surgical Complications in Adult Patients Undergoing Anterior Cervical Discectomy and Fusion Using Machine Learning. *Neurospine*, 2018, vol. 15, no. 4, pp. 329-337. DOI: 10.14245/ns.1836248.124.
12. Karhade A.V., Bongers M.E.R., Groot O.Q., Cha T.D., Doorly T.P., Fogel H.A., Hershman S.H., Tobert D.G., Srivastava S.D., Bono C.M., Kang J.D., Harris M.B., Schwab J.H. Development of machine learning and natural language processing algorithms for preoperative prediction and automated identification of intraoperative vascular injury in anterior lumbar spine surgery. *Spine J*., 2020, S1529-9430(20)30135-2. DOI: 10.1016/j.spinee.2020.04.001.
13. Karhade A.V., Thio Q., Ogink P., Kim J., Lozano-Calderon S., Raskin K., Schwab J.H. Development of Machine Learning Algorithms for Prediction of 5-Year Spinal Chordoma Survival. *World Neurosurg*., 2018, vol. 119, pp. e842-e847. DOI: 10.1016/j.wneu.2018.07.276.
14. Kim J.S., Merrill R.K., Arvind V., Kaji D., Pasik S.D., Nwachukwu C.C., Vargas L., Osman N.S., Oermann E.K., Caridi J.M., Cho S.K. Examining the Ability of Artificial Neural Networks Machine Learning Models to Accurately Predict Complications Following Posterior Lumbar Spine Fusion. *Spine* (Phila Pa 1976), 2018, vol. 43, no. 12, pp. 853-860. DOI: 10.1097/BRS.0000000000002442.
15. Ghogawala Z., Dunbar M.R., Essa I. Lumbar spondylolisthesis: modern registries and the development of artificial intelligence. *J. Neurosurg. Spine*, 2019, vol. 30, no. 6, pp. 729-735. DOI: 10.3171/2019.2.SPINE18751.
16. Ames C.P., Smith J.S., Pellisé F., Kelly M., Alanay A., Acaroğlu E., Pérez-Grueso F.J.S., Kleinstück F., Obeid I., Vila-Casademunt A., Shaffrey C.I. Jr., Burton D., Lafage V., Schwab F., Shaffrey C.I. Sr., Bess S., Serra-Burriel M.; European Spine Study Group, International Spine Study Group. Artificial Intelligence Based Hierarchical Clustering of Patient Types and Intervention Categories in Adult Spinal Deformity Surgery: Towards a New Classification Scheme that Predicts Quality and Value. *Spine* (Phila Pa 1976), 2019, vol. 44, no. 13, pp. 915-926. DOI: 10.1097/BRS.0000000000002974.
17. Joshi R.S., Haddad A.F., Lau D., Ames C.P. Artificial Intelligence for Adult Spinal Deformity. *Neurospine*, 2019, vol. 16, no. 4, pp. 686-694. DOI: 10.14245/ns.1938414.207.
18. Han S.S., Azad T.D., Suarez P.A., Ratliff J.K. A machine learning approach for predictive models of adverse events following spine surgery. *Spine J*., 2019, vol. 19, no. 11, pp. 1772-1781. DOI: 10.1016/j.spinee.2019.06.018.
19. Bertsimas D., Masiakos P.T., Mylonas K.S., Wiberg H. Prediction of cervical spine injury in young pediatric patients: an optimal trees artificial intelligence approach. *J. Pediatr. Surg*., 2019, vol. 54, no. 11, pp. 2353-2357. DOI: 10.1016/j.jpedsurg.2019.03.007.
20. Staartjes V.E., de Wispelaere M.P., Vandertop W.P., Schröder M.L. Deep learning-based preoperative predictive analytics for patient-reported outcomes following lumbar discectomy: feasibility of center-specific modeling. *Spine J*., 2019, vol. 19, no. 5, pp. 853-861. DOI: 10.1016/j.spinee.2018.11.009.
21. Weber K.A., Smith A.C., Wasielewski M., Eghtesad K., Upadhyayula P.A., Wintermark M., Hastie T.J., Parrish T.B., Mackey S., Elliott J.M. Deep Learning Convolutional Neural Networks for the Automatic Quantification of Muscle Fat Infiltration Following Whiplash Injury. *Sci. Rep*., 2019, vol. 9, no. 1, pp. 7973. DOI: 10.1038/s41598-019-44416-8.
22. Ryu S.M., Seo S.W., Lee S.H. Novel prognostication of patients with spinal and pelvic chondrosarcoma using deep survival neural networks. *BMC Med. Inform. Decis. Mak*., 2020, vol. 20, no. 1, pp. 3. DOI: 10.1186/s12911-019-1008-4.
23. Azimi P., Yazdanian T., Benzel E.C., Aghaei H.N., Azhari S., Sadeghi S., Montazeri A. A Review on the Use of Artificial Intelligence in Spinal Diseases. *Asian Spine J*., 2020, vol. 14, no. 4, pp. 543-571. DOI: 10.31616/asj.2020.0147.
24. Hopkins B.S., Mazmudar A., Driscoll C., Svet M., Goergen J., Kelsten M., Shlobin N.A., Kesavabhotla K., Smith Z.A., Dahdaleh N.S. Using artificial intelligence (AI) to predict postoperative surgical site infection: A retrospective cohort of 4046 posterior spinal fusions. *Clin. Neurol. Neurosurg*., 2020, vol. 192, pp. 105718. DOI: 10.1016/j.clineuro.2020.105718.

25. Ghogawala Z., Dunbar M., Essa I. Artificial Intelligence for the Treatment of Lumbar Spondylolisthesis. Neurosurg. *Clin. N. Am*., 2019, vol. 30, no. 3, pp. 383-389. DOI: 10.1016/j.nec.2019.02.012.
26. Karhade A.V., Ogink P.T., Thio Q.C.B.S., Cha T.D., Gormley W.B., Hershman S.H., Smith T.R., Mao J., Schoenfeld A.J., Bono C.M., Schwab J.H. Development of machine learning algorithms for prediction of prolonged opioid prescription after surgery for lumbar disc herniation. *Spine J*., 2019, vol. 19, no. 11, pp. 1764-1771. DOI: 10.1016/j.spinee.2019.06.002.
27. DeVries Z., Hoda M., Rivers C.S., Maher A., Wai E., Moravek D., Stratton A., Kingwell S., Fallah N., Paquet J., Phan P.; RHSCIR Network. Development of an unsupervised machine learning algorithm for the prognostication of walking ability in spinal cord injury patients. *Spine J*., 2020, vol. 20, no. 2, pp. 213-224. DOI: 10.1016/j.spinee.2019.09.007.
28. Karhade A.V., Ogink P., Thio Q., Broekman M., Cha T., Gormley W.B., Hershman S., Peul W.C., Bono C.M., Schwab J.H. Development of machine learning algorithms for prediction of discharge disposition after elective inpatient surgery for lumbar degenerative disc disorders. *Neurosurg. Focus*, 2018, vol. 45, no. 5, pp. E6. DOI: 10.3171/2018.8.FOCUS18340.
29. Meyer B., Gempt J. Stupid mistakes. World Neurosurg., 2013, vol. 79, no. 3-4, pp. 447. DOI: 10.1016/j.wneu.2012.10.044.
30. Mody M.G., Nourbakhsh A., Stahl D.L., Gibbs M., Alfawareh M., Garges K.J. The prevalence of wrong level surgery among spine surgeons. *Spine* (Phila Pa 1976), 2008, vol. 33, no. 2, pp. 194-198. DOI: 10.1097/BRS.0b013e31816043d1.
31. Makary M.A., Daniel M. Medical error – the third leading cause of death in the US. *BMJ*, 2016, vol. 353, pp. i2139. DOI: 10.1136/bmj.i2139.
32. Bakkar N., Kovalik T., Lorenzini I., Spangler S., Lacoste A., Sponaugle K., Ferrante P., Argentinis E., Sattler R., Bowser R. Artificial intelligence in neurodegenerative disease research: use of IBM Watson to identify additional RNA-binding proteins altered in amyotrophic lateral sclerosis. *Acta Neuropathol*., 2018, vol. 135, no. 2, pp. 227-247. DOI: 10.1007/s00401-017-1785-8.
33. Johnson K.W., Torres Soto J., Glicksberg B.S., Shameer K., Miotto R., Ali M., Ashley E., Dudley J.T. Artificial Intelligence in Cardiology. *J. Am. Coll. Cardiol*., 2018, vol. 71, no. 23, pp. 2668-2679. DOI: 10.1016/j.jacc.2018.03.521.
34. Kapoor R., Walters S.P., Al-Aswad L.A. The current state of artificial intelligence in ophthalmology. *Surv. Ophthalmol*., 2019, vol. 64, no. 2, pp. 233-240. DOI: 10.1016/j.survophthal.2018.09.002.
35. Contreras I., Vehi J. Artificial Intelligence for Diabetes Management and Decision Support: Literature Review. *J. Med. Internet. Res*., 2018, vol. 20, no. 5, pp. e10775. DOI: 10.2196/10775.
36. Sergunova K.A., Karpov I.N., Gromov A.I., Morozov A.K., Semenov D.S. Razrabotka apparatno-programmnykh sredstv kontrolia parametrov kachestva diffuzionno-vzveshennykh izobrazhenii dlia povysheniia effektivnosti diagnostiki opukholevykh obrazovanii [Development of hardware and software tools for monitoring the quality parameters of diffusion-weighted images to increase the efficiency of diagnostics of tumor formations]. *Biotekhnosfera*, 2016, no. 5 (47), pp. 9-13. (in Russian)
37. Karhade A.V., Thio Q.C.B.S., Ogink P.T., Shah A.A., Bono C.M., Oh K.S., Saylor P.J., Schoenfeld A.J., Shin J.H., Harris M.B., Schwab J.H. Development of Machine Learning Algorithms for Prediction of 30-Day Mortality After Surgery for Spinal Metastasis. *Neurosurgery*, 2019, vol. 85, no. 1, pp. E83-E91. DOI: 10.1093/neuros/nyy469.
38. Karhade A.V., Thio Q.C.B.S., Ogink P.T., Bono C.M., Ferrone M.L., Oh K.S., Saylor P.J., Schoenfeld A.J., Shin J.H., Harris M.B., Schwab J.H. Predicting 90-Day and 1-Year Mortality in Spinal Metastatic Disease: Development and Internal Validation. *Neurosurgery*, 2019, vol. 85, no. 4, pp. E671-E681. DOI: 10.1093/neuros/nyz070.

The article was submitted 08.07.2020; approved after reviewing 25.09.2021; accepted for publication 19.10.2021.

Information about the authors:

1. Vladimir S. Pereverzev – M.D., vcpereverz@gmail.com;
2. Arkadii I. Kazmin – Candidate of Medical Sciences;
3. Maxim L. Sazhnev – Candidate of Medical Sciences;
4. Andrei A. Panteleev – M.D.;
5. Sergei V. Kolesov – Doctor of Medical Sciences.