Original article
https://doi.org/10.18019/1028-4427-2024-30-1-67-75

Comparison of bone age assessment methods using a hand radiography in patients with active growth plate and anteromedial knee instability

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Abstract

Background Bone age is essential for pediatric patients with active growth zones and anteromedial instability to facilitate optimal treatment strategy and minimize postoperative complications. However, many people are unaware of various tools for determining bone age, including classical methods and modern machine learning techniques.

The objective was to show and compare different methods for calculating bone age and determining surgical strategy for patients with anteromedial instability of the knee joint.

Material and methods All-Inside anterior cruciate ligament reconstruction was performed for 20 patients. Wrist radiographs were performed for bone age assessment using the "point scoring system" of Tanner and Whitehouse and the "atlas matching" method of Greulich and Pyle. Machine learning programs were used in addition to standard bone age assessments.

Results The findings showed an average difference of 21 months (80 %) in a group of 20 individuals with bone age ahead of the passport age and an average difference of 18 months (20 %) in patients with retarded bone age.

Discussion The findings showed the difference between chronological and bone age and could be encountered in scientific articles on endocrinology and pediatrics. No scientific studies on the use of the methods could be found in the specialty “trauma and orthopaedics”.

Conclusion Bone age assessment, prediction of children's target height are essential for surgical treatment of patients with open growth plates.

Keywords: bone age, children, all-inside, ACL reconstruction, active growth plate, artificial intelligence

For citation: Ivanov IaA, Minninkov DS, Gushchina DA, Yeltsin AG. Comparison of bone age assessment methods using a hand radiography in patients with active growth plate and anteromedial knee instability. *Genij Ortopedii*. 2024;30(1):67-75. doi: 10.18019/1028-4427-2024-30-1-67-75

INTRODUCTION

Anterior cruciate ligament reconstruction (ACLR) in children with open growth plates is an area of controversy [1]. The incidence of pediatric injury is increasing due to increased sports participation and recreational activities [2, 3]. Issues associated with ACL ruptures are the choice of surgical or conservative treatment [4]; a risk of intraoperative injury to the growth plates [5] and, as a consequence, the search for the optimal surgical technique. The article is based on the dissertation of Ivanov Y.A. "Damage to the pediatric anterior cruciate ligament. Diagnosis and treatment", 05.26.2022 FSBI National Medical Research Center for Traumatology and Orthopaedics named after. N.N. Priorov, Ministry of Health of the Russian Federation.

The objective was to show and compare different methods for calculating bone age and determining surgical strategy for patients with anteromedial instability of the knee joint.

MATERIAL AND METHODS

The patients and volunteers who participated in the clinical study gave written consent. The study was performed in accordance with the principles of the Declaration of Helsinki of the World Medical Association (as amended in 2013). The study was approved by the ethics committee (02/04/2021, No. 1-2021). The following criteria were identified for selecting patients for surgical treatment using the all-inside method: age from 10 to 16 years, complete ACL rupture first identified with imaging, severe anteromedial instability. The study did not include patients with additional injuries to the posterior cruciate ligament (PCL), collateral ligaments, or fracture of the intercondylar tubercle.

The gender information was reported with no obvious correlations or differences found with the parameter. There were 6 (30 % of the total) female patients. Our clinical department provides surgical treatment for patients with ACL ruptures using all-inside all epiphyseal and all-inside partial transphyseal techniques. The main difference of this technique is that the channels are formed up to the growth zone in both bones (all-inside all epiphyseal) or in the femur up to the growth zone, and in the tibia through the growth zone (all-inside partial transphyseal).

An all-inside, all-epiphyseal ACL reconstruction technique involves drilling bone tunnels contained completely within the epiphyses of the skeletally immature knee. Partial transphyseal anterior cruciate ligament (ACL) reconstruction suggests the femoral tunnel placed in the distal femoral epiphysis whereas the tibial tunnel placed in a transphyseal fashion medial to the tibial tubercle. There have been 20 patients treated for anteromedial instability. Radiography of the hand was produced for the patients to determine bone age [6]. The Knee Injury and Osteoarthritis Outcome Score for Children (KOOS-Child) and the Pediatric International Knee Documentation Committee (Pedi-IKDC) Subjective Knee Evaluation Form were used to evaluate functional status. The Tanner and Whitehouse method, a bone-specific scoring system (TW2.1975) [7] and the Atlas of Greulich and Pyle (Greulich W.W. and Pyle S.I., 1959) [8] were used to evaluate skeletal age (Fig. 1).

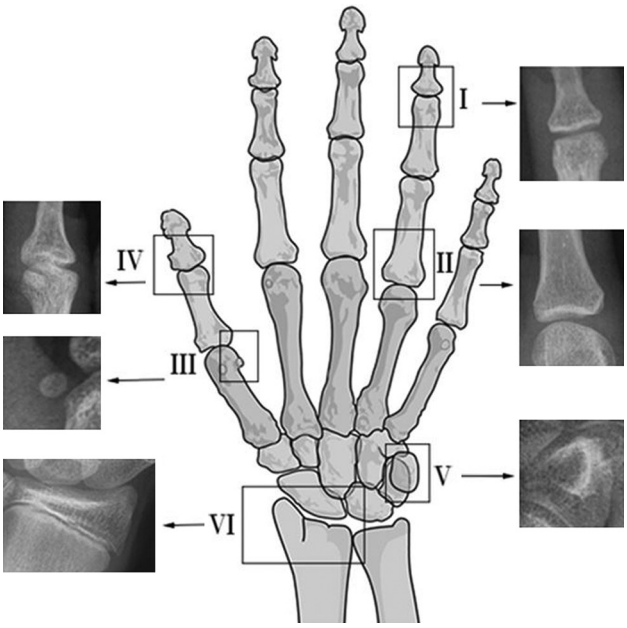

Fig. 1 Growth plates closing at different times in males (can be used as a reference manual): I – 15.5 years, II – 16 years, III – 13 years, IV – 15 years, V – 12.5 years, VI – 14 years old (author's drawing)

In addition to conventional standard methods bone age assessment can be produced using machine learning techniques [9, 10]. There are combined algorithms for bone age assessment based on the use of various neural network models, which helps improve the accuracy of assessment [10, 11]. The data

obtained from the neural network analysis were consistent with the data of the BoneXpert© [12], Auxology© (Pfizer) reconstruction and manual calculations using the Greulich – Pyle Atlas and the Tanner – Whitehouse method.

RESULTS

Patient data analysis was conducted to compare different methods of bone age assessment and expected height, major differences were identified. These data may be useful for orthopaedic surgeons when choosing a surgical treatment technique for patients with open growth plates (Table 1).

Table 1

Data for determining bone age and expected height of patients using machine learning programs

Patient	Software	Gender	Age	Height, cm	Mother's height, cm	Father's height, cm	Bone age	Expected height
1	TW2	m	11	161	170	183	12	183
	Auxology						13.1	183
	BoneXpert						13.6	182.8
	BAA						13.9	180.8
2	TW2	m	12.1	170	164	186	13	181.5
	Auxology						14.8	181.5
	BoneXpert						13.83	187.1
	BAA						13.11	184.5
3	TW2	f	13.3	150	154	178	14.5	159.5
	Auxology						13.9	159.5
	BoneXpert						15.36	152.3
	BAA						13.1	153.4
4	TW2	m	13.5	170	162	168	14	171.5
	Auxology						15.3	171.5
	BoneXpert						14.25	180.9
	BAA						14.11	176.5
5	TW2	m	14	181	173	175	16.5	180.5
	Auxology						15.8	180.5
	BoneXpert						16.35	184.6
	BAA						16.6	183.8
6	TW2	f	15.3	164	168	175	17.5	165
	Auxology						16	165
	BoneXpert						17.1	165.7
	BAA						15.6	165.4
7	TW2	m	15	178	165	170	15.8	174
	Auxology						17	175
	BoneXpert						17.3	179.5
	BAA						17.6	
8	TW2	m	16.7	175	168	180	17	180.5
	Auxology						16.20	180.5
	BoneXpert						17.44	176.5
	BAA						17	
9	TW2	m	17	172	165	170	17	174
	Auxology						16.4	175
	BoneXpert						16.54	174.8
	BAA						16.5	177
10	TW2	f	14	164	175	170	16	166
	Auxology						14.1	166
	BoneXpert						17	164.9
	BAA						14	164

Note: Table 1 and Figure 2 present the most representative data from 10 patients.

The percentile table (Fig. 2) presents the data of 10 patients including the number, the method for bone age assessment and expected height, the height of the patient and parents, gender and age. The table also shows the data obtained to allow analysis and comparison of assessment methods. Predictably, this is the most difficult question. The use of the growth formula has a large error of 5 cm, which is of key importance in the choice of surgical treatment strategy. A height percentile chart can be helpful, but as the child grows, expected height may also change to the lower side.

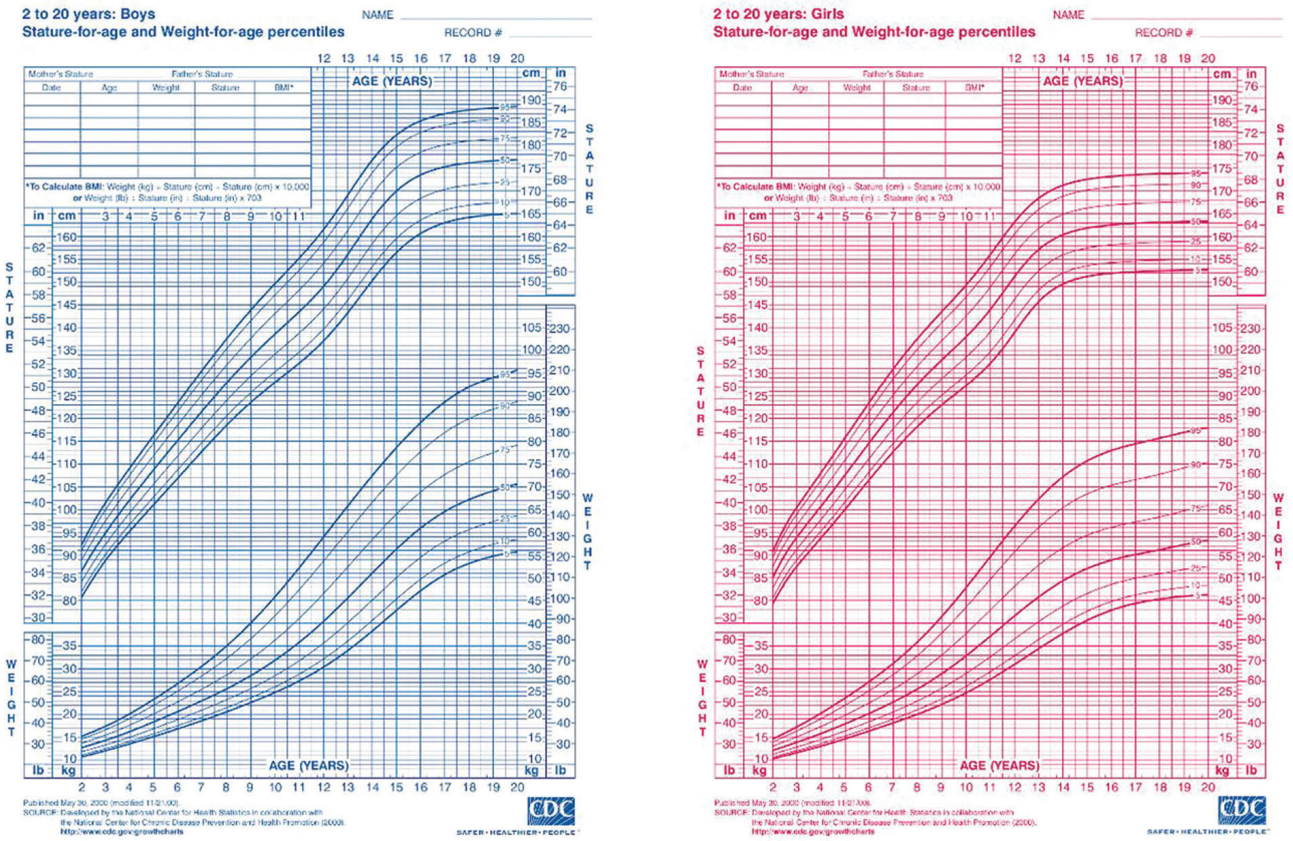

Fig. 2 Percentile table for height and weight for pediatric males and females aged 2 to 20 years

The results of the study in a group of 20 people showed an average difference of 21 months (80 %) in patients with bone age ahead of the passport age, and an average difference of 18 months (20 %) and in patients with delayed bone age.

Clinical instance

The patient's chronological age was 13.5 years at the time of admission, height was 168 cm. The mean KOOS subscale scores were: pain 69; symptoms 68; activities of daily living (ADL) 65; sport 54 [13, 14]. Pedi-IKDC [15] scored 68. The patient was diagnosed with rupture of the anterior cruciate ligament (Fig. 3), anteromedial instability of the knee joint. The initial knee injury was caused by a fall from a bicycle. The patient sustained another injury during boxing training and developed knee instability. Bone age assessment was produced for the patient to minimize the risk and choose the optimal ACL reconstruction technique. Estimation of skeletal maturity indicated bone age of 14.5 years with the Greulich-Pyle and Tanner-Whitehouse method, 14.2 years with Auxology© (Pfizer) reconstruction, 14.3 years with BoneXpert© (Fig. 4), 14.9 years with Bone Age Analyzer. The patient's predicted height based on hand and wrist radiograph was 175 cm. The patient's target height predicted by parental heights was 170.5 cm. The patient's peak active growth was 12.5 years. Based on the findings, surgical treatment included arthroscopic revision, debridement and ACL plastic surgery using the all-inside partial transphyseal technique. Postoperative period

was uneventful. During a after surgery, The range of motion in the knee joint was 180-100 degrees at a 6-month follow-up. No pain, no swelling observed. KOOS-Child questionnaire scores: pain 78; symptom 93; ADL 91; sport 82. Pedi-IKDC scored 74.

Fig. 3 MRI scan of the knee joint in the sagittal plane. The white arrow shows the anterior cruciate ligament rupture

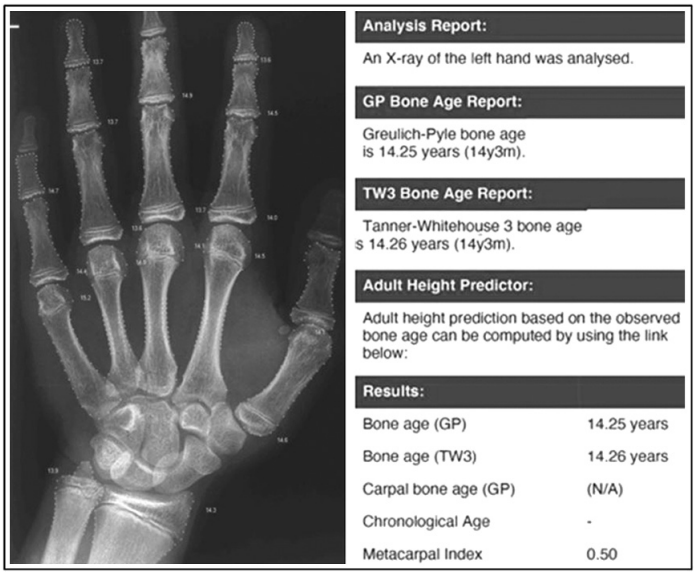

Fig. 4 Bone age calculated from an X-ray of the patient's hand using BoneXpert software

Bone age and predicted height of the patient were measured in the clinical case. Bone age was 1 year ahead of chronological (passport) age. The patient's height was 168 cm (with a target height of 175 cm), and stage IV of the Tanner Sexual Maturity Rating indicated sexual maturation. Position of bone canals in the tibia and femur, physeal injury, presence/absence of angular deformities (Fig. 5) and graft integrity (Fig. 6) were examined with radiographs and MRI scans of the knee joint at 12 months.

Bone age and expected height were calculated again using the BoneXpert software (Fig. 7). The calculations showed 11/2 year difference with the passport age (passport age 14 years, bone age 15.5 years). The height was 172 cm, and the expected height decreased to 174 cm suggesting completed growth.

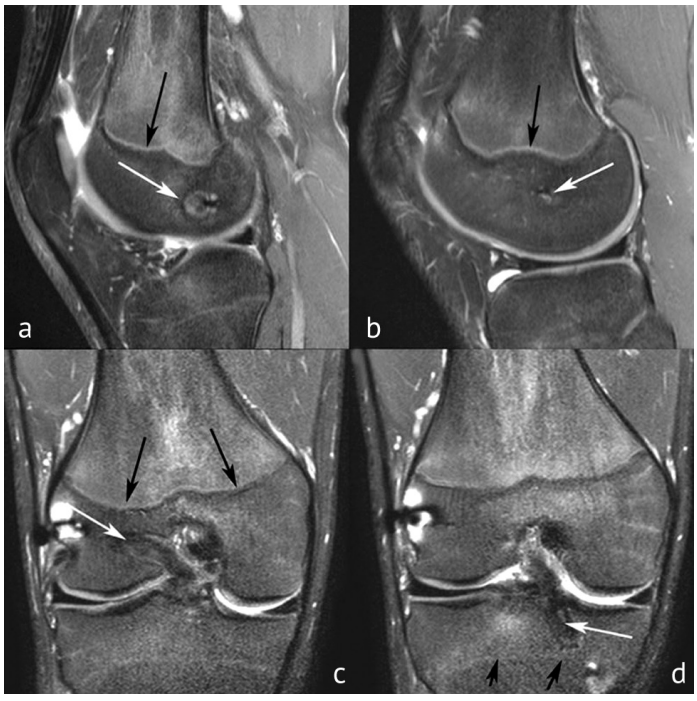

Fig. 5 MRI sagittal view of the knee joint (*a* and *b*) at 12-month follow-up showing the location of the canal in the lateral condyle of the femur (white arrows) relative to the growth plate (black arrows). MRI coronal view (*c* and *d*) shows the location of the canals in the femur and tibia (white arrows) relative to the growth plates (black arrows)

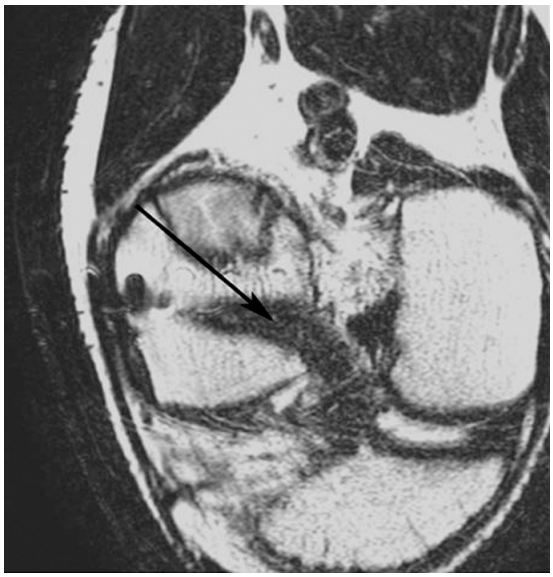

Fig. 6 MRI view of the knee at 12 months of surgery. The black arrow shows the integrity of the graft

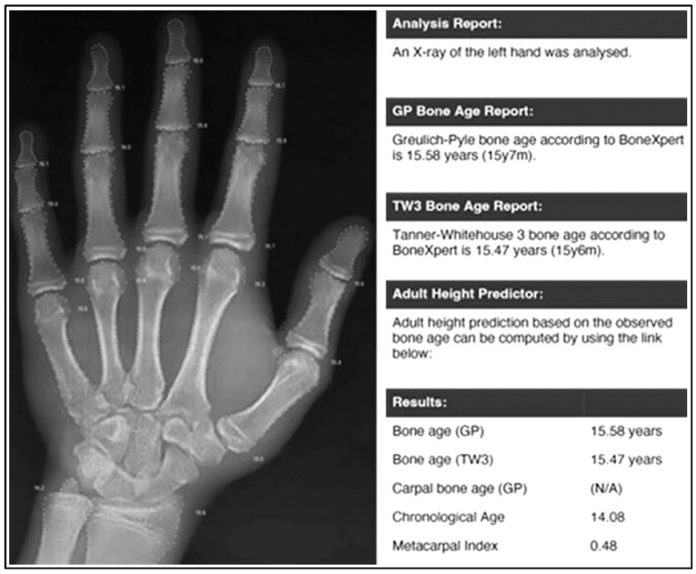

Fig. 7 Bone age calculated from a radiograph of the patient's hand using the BoneXpert software at 12 months of surgery

DISCUSSION

The findings showed a difference between chronological and bone age. These studies are normally reported in journals of endocrinology and pediatrics, and there are no reported on the use of these methods in the journals of traumatology and orthopaedics. There is a predictable sequence of development and progression of ossification centers in healthy children. An age is characterized by specific radiological findings indicating a stage of maturation. Skeletal maturity assessment is a more accurate indicator of human body maturation than chronological age. Final height can be predicted with more reliability using bone age [6]. Two methods were used in the series to determine bone age of patients: bone-specific scoring system of Tanner and Whitehouse (TW2.1975) [7] and the Atlas of Greulich and Pyle (Greulich W.W. and Pyle S.I., 1959) [8]. The TW2 method is based on accurate measurements of each bone and on the assessment of numerical scores with the sum of the scores facilitating the assessment of overall skeletal maturity. In the Greulich and Pyle method, BA is evaluated by comparing the radiograph of the patient with the nearest standard radiograph in the atlas; thus, this method reflects the maturity level of all bones in the hand and wrist.

Bone age can be estimated using machine learning methods [9, 10] as a promising trend in the field. The Bone Age Analyzer program, developed by specialists from Belarus [10, 11], is a combined algorithm for bone age assessment based on the use of neural network models to improve the accuracy. The data obtained from the neural network analysis are in line with the data obtained using the BoneXpert© [12], Auxology© (Pfizer) programs and manual calculations using the Greulich-Pyle Atlas and the Tanner-Whitehouse method. It is important to note that opinions of a radiologist, trauma surgeon and pediatric endocrinologist may differ, since the assessment methods may be somewhat subjective and be associated with specific specialty [16, 17]. However, the use of combined algorithms for bone age assessment based on neural networks helps reduce the subjectivity and improve the accuracy of measurements. When using the there were no difficulties with the use of Auxology© software (Pfizer) [18, 19].

There are many methods for bone age assessment, and advanced techniques are based on the use of neural networks and machine learning. This simplifies the calculation process reducing the role of the human factor. The availability of such methods is currently limited. For example, the well-known BoneXpert© program [12] may not be available to the Russian doctors due to its high

cost. However, there are hopes that developments from allied countries and Russian innovations will become more accessible in the future and will positively effect the use of the methods [20-30]. We evaluated stages of patients' sexual maturation using the Tanner Sexual Maturity Rating, which helped to track development during puberty assessing the bone age of children to determine growth patterns. In our series, we used data that required no specific statistical processing. We used mandatory questionnaires including KOOS-Child and Pedi-IKDC, which are widely used in pediatric trauma and orthopaedic practice worldwide. The questionnaires have been validated and culturally adapted in Russian for use in children with various knee pathologies.

CONCLUSION

Age characteristics and bone age assessment are essential for predicted and target growth of patients with open growth plates undergoing surgical treatment. Bone age assessments help determine the maturity of bones and growth plates, which play a crucial role in bone growth and function. In our series, the patient had not yet completed his growth, so passing channels through the growth plates could affect the integrity and the function. The *all inside partial transphyseal* technique was practical in the case. The *all inside all epiphyseal* technique should be used for large expected growth rates (> 5 cm < 10 cm) to minimize the risk of injury to growth plates. If the expected height is greater than 10 cm of the actual height, then surgical treatment may be further delayed by the need for a more beneficial effect. Introduction of implants can lead to uneven load distribution and cause curvature of the skeleton and functional impairment.

The patient's bone age assessment and projected height are essential for preoperative planning. A variety of methods can be used for assessing bone maturation, and will help the doctor to choose an adequate surgical treatment which can be further delayed for a more favorable outcome. The main bone age assessment methods are the Greulich-Pyle and Tanner-Whitehouse based on the level of maturity for 20 selected regions of interest in specific bones of the wrist and hand. The Auxology© software and the analogues can facilitate the choice of the most effective surgical treatment and help to avoid possible complications associated with injury to growth plates.

Conflict of interest *The authors declared no potential conflicts of interest with respect to the authorship and/or publication of this article.*

Funding *The authors received no financial support for the research and/or authorship of this article.*

Ethical review *The study was carried out in accordance with the principles of the Declaration of Helsinki of the World Medical Association (as amended in 2013). The study was approved by the ethics committee. (04.02.2021, No. 1-2021).*

Informed consent *Patients or their legal representatives and volunteers who participated in the clinical study gave written consent.*

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The article was submitted 09.03.2023; approved after reviewing 16.05.2023; accepted for publication 01.12.2023.

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Gushchina D.A. – data collection.

Yeltsin A.G. – data collection, text editing.