УДК 616.727.2-007.281 DOI: 10.21823/2311-2905-2019-25-1-52-64

# Algorithm for Evaluation of Bipolar Defects in Anterior Instability of the Shoulder

V.V. Khominets, R.V. Gladkov, I.S. Zheleznyak, A.S. Grankin, D.A. Volov, A.A. Emelyantsev

*Kirov Military Medical Academy, St. Petersburg, Russian Federation*

**Abstract**

***Purpose of the study*** — to justify the algorithm for evaluation of bipolar defects in anterior shoulder instrability using the most accurate, statistically significant and reproducible methods which would make the algorithm applicable in practical surgery. ***Materials and Methods.*** The authors established 4 groups with 6 patients in each with shoulder instability, group distribution was based on glenoid defect size: small (<15%), moderate (15–19%), large (20–25%) and massive (>25%). All 24 patients underwent 3D-CT, 3D VIBE MRI and shoulder arthroscopy. Measurements were taken by 7 specialists 5 of whom measured defect during arthroscopy. Glenoid defect was measured by linear and sectional relation methods. Pico method on 3D-CT was taken as the „golden standard". Accuracy was verified by analysis of variance with post-hoc comparison. Reproducibility was evaluated by intraclass correlation coefficient. ***Results.*** All groups excluding the one with massive glenoid defects demonstrated significant differences from the model ($p \leq 0.05$) for measurements during arthroscopy and examinations by 3D-CT and 3D VIBE MRI. Restrospective analysis confirmed the least accuracy and the worst reproducibility of visual evaluation of glenoid defects less than 25%. Sectional relation method on 3D-CT had the maximum accuracy and reproducibility in all groups (PE = 1.29%±2.39%, ICC = 0.756–0.856), excluding the group with massive defects, where researched measurement methods had close accuracy when applied on 3D-CT, 3D VIBE MRI and during arthroscopy. Linear relation method on 3D-CT overestimated the defect volume at 2.1–7.9% and demonstrated less reliable reproducibility (PE = 3.22%±5.31%, ICC = 0.612–0.621). The highest error (up to 7.9%) was demonstrated by linear method in case of borderline defects in the III group of 20–25%. Insufficient conformity of results for linear (ICC = 0.42) method and moderate conformity for sectional (ICC = 0.62) method were observed during comparison of 3D VIBE MRI with 3D-CT. MRI underestimated the value of small defects and overestimated large defects. Reproducibility of measurements on 3D-CT by different operators was moderate for visual (ICC = 0.594) and linear methods (ICC = 0.621) and good for sectional method (ICC = 0.756). Reproducibility of measurements by each operator also was moderate for visual and linear methods (ICC = 0.553 и ICC = 0.612) and good for sectional method (ICC = 0.856). The authors suggested an algorithm for selection of examination method and measurements for defects of articular surfaces which also considers the main factors of prognosis and risk of recurrent instability. ***Conclusion.*** Sectional relation method on 3D-CT is the most precise and reproducible method of glenoid defect measurements used in the clinical practice. MRI use without CT is inadmissible for bipolar defects of borderline size. Suggested algorithm allows not to make CT examination at extreme ISIS values and increases the share of osteoplastic surgeries due to identification of off-track injuries with glenoid defects of borderline size (15–25%).

**Keywords:** anterior shoulder instability, bipolar defects, glenoid bone defect, Hill-Sachs defect, Bankart surgery.

**Cite as:** Khominets V.V., Zheleznyak I.S., Gladkov R.V., Grankin A.S., Volov D.A., Emelyantsev A.A. [Algorithm for Evaluation of Bipolar Defects in Anterior Instability of the Shoulder]. *Travmatologiya i ortopediya Rossii* [Traumatology and Orthopedics of Russia]. 2019;25(1):52-64. (In Russ.). DOI: 10.21823/2311-2905-2019-25-1-52-64.

*Roman V. Gladkov*; e-mail: dr.gladkov@gmail.com

Received: 04.12.2018. Accepted for publication: 03.03.2019.

## Introductions

Bone defect in the anterior section of articular process of scapula is the risk factor for recurrent instability after soft tissue stabilization of the shoulder joint and can be an indication for osteoplastic surgery [1, 2]. Multiple studies were dedicated to the identification of glenoid defect size critical for postoperative stability of shoulder joint, and the resulting values are ranging from 20 to 27% [3–7].

However, J.S. Shaha et al. in 2015 reported that defects of smaller size (over 13,5% of transverse diameter of the glenoid) were often followed by insatisfactory functional outcomes in absence of recurrent shoulder dislocations [8]. Scientific research focused on combination of injuries of articular process of scapula and humeral head — bipolar defects. N. Yamamoto et al. in 2007 defined a concept of glenoid track to evaluate the impact of bipolar defects on shoulder joint stability which determined the contemporary approach to the choice of surgical stabilization of shoulder joint [9]. As a consequence we need a more precise method to measure the defect while taking into account the bipolar defects of shoulder articular surfaces allows significantly extend the indications for more traumatic osteoplastic procedure.

Currently there is no universal measurement technique to evaluate size of the defect in articular process of scapula and there are many variances of measurements using 2D-CT, 3D-CT, MRI and visual examination during arthroscopy [10–16].

Glenoid defect volume is estimated by ratio of linear dimensions or areas of injured and intact sections. Incircle model is used most often to measure linear dimensions as well as the squre area while such method allows to avoid laborious application of not always accessible specialized software for calculation of area for irregular shapes of glenoid. Linear and area-dependent versions of incircle method are most applicable for practical work: conventional linear relation and sectional relation method, respectively. Results of linear and area-dependent measurements can significantly differ in patients with defects of various shape. Higher demands for precise measurements of bone defects require to compare the accuracy and reliability (reproducibility) of linear and sectional relation methods as well as direct measurements during arthroscopy to identify the precise and least labour-consuming method for each patient.

Conventionally bone defects are measured on CT, however, there are publications evaluating measurements accuracy on MRI which in any case is needed to evaluate soft tissue lesions. MRI measurements of bone injuries would allow to avoid time and costs for additional CT as well as decrese radiation exposure of the patient in the cases when uncertainty in measurements by MRI is not critical.

N. Magarelli et al. proved the efficiency of MRI measurements by Pico method [17]. S. Gyftopoulos et al. as well as P.E. Huijsmans et al. compared the dimensions of simulated defects in articular processes in cadavers using linear version of incircle method and obtained the maximum deviation of MRI from CT of 1,3% deficite of bone mass [18, 19]. Nontheless L.G. Friedman et al. found out only the moderate correlation of accuracy of MRI findings, second to CT, and relative statistical significance of results using linear version of incircle method on MRI [20].

Choice of surgical stabilization procedure of shoulder joint in patients in the present study is based on identification of Instability Severity Index Seore (ISIS) (Boileau P., 2006) with detalisation of value and biomechanical significance of bipolar bone defects in accordance with the concept of glenoid track. At extreme values of ISIS (less than 3 and above 6) additional CT examination is not mandatory while the choice of surgery is conditioned by the body of of factors identified during collection of medical history, patient examination, X-ray and MRI examinations. Cases with intermediate ISIS values (from 3 to 6) demand a more detailed approach with precise measurement of articular surfaces defects and calculation of the track of articular process of scapula.

**Purpose of the study** — to justify the algorithm for evaluation of bipolar defects in anterior shoulder instrability using the most accurate, statistically significant and reproducible methods which would make the algorithm applicable in practical surgery.

## Materials and Methods

To identify the most accurate and reproducible measurements of bone defects of articular surfaces the authors established 4 groups of patients with anterior posttraumatic shoulder instability, each of the group included 6 patients with small (<15%), moderate (15–19%), large (20–25%) and massive (>25%) glenoid defects. Patients included 4 women and 20 men. Mean age was 20,2 years (from 19 to 49 years). Shoulder instability was chronic in all patients and accompanied by 2–17 episondes of dislocation. Prior to the study no patients underwent surgery on the shoulder joint. Time between CT, MRI and following arthroscopy did not exceed 10 days. Exclusion criteria were osteoarthrosis signs, inflammatory arthropathy and defects in results of radiological examinations which complicated the measurements.

All 24 patients underwent CT with 3D reconstruction of shoulder joint, 3D VIBE MRI and shoulder arthroscopy. Articular surfaces were evaluated on axial, curvilinear and VRT images on en-face plane in such a manner where glenoid articular surface was directed towards the operator. 3D VIBE MRI was performed on Siemens Magnetom Symphony, Philips Ingenia, GE Optima MR450w with magnetic field induction of 1.5T.

Measurement results were imported into software application Inobitec DICOM Viewer with the option of direct measurement of area for outlined shape of random irregular form. During 3D VIBE reconstruction on MR images in oblique sagittal en-face view the incircle was drawn upon intact posterior and inferior glenoid outline, during 3D-CT reconstruction — on intact articular process of contralateral limb, then transferred to the affected joint and positioned along intact posterior and inferior outline of articular process. This algorithm was repeatedly described in literature [21, 22]. Glenoid outline in anterior damaged compartment and part of incircle in intact comparments were marked by point set, obtaining the square area of articular surface calculated in application taking into account precise geometry of defect outlines. Obtained square area of articular surface was compared with the incircle area, thus obtaining the amount of bone defect in the articular process of scapula (area-dependent Pico method) [23]. Obtained defect dimensions on 3D-CT were considered as a standard while the present method takes into consideration the irregular form of the bony defect (Fig. 1a).

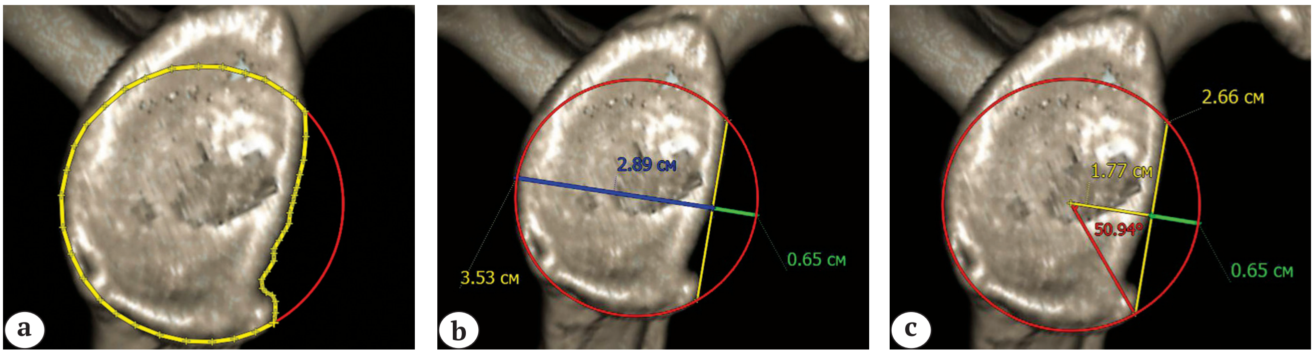


**Fig. 1.** Incircle methods for calculation of defect dimensions in anterior part of articular process of scapula:
a — area-dependent standard Pico method using special software (13.1%);
b — linear relation method (18.4%);
c — area-dependent sectional relation method (12.7%)

Measurements were taken by 7 operators, 5 of whom measured defect during arthroscopy. Each operator measured defects by linear and area-dependent versions of incircle method: conventional method of linear relation and sectional relation, respectively. Linear relation method (patent № 2661717) stipulates plotting a long chord linking intersection points of incircle with the border of articular surface in superior and inferior margins of the defect. Then an incircle diameter was drawn at right angle to long chord and found the ratio of chord height (linear dimensions of the defect) to the incircle diameter (relative linear dimensions of the defect) (Fig. 1b).

Sectional relation method allows to calculate the ratio of bone defect square area to incircle area without labour-consuming direct measurements. To do so the area of incircle segment corresponding to defect of anterior glenoid part is calculated. Drawing of incirle, long chord and diameter perpendicular to chord was made similarly to linear method, then square area of segment was calculated by formula:

$$S_{segm} = R^2 \arcsin(L/2R) — L(R\text{-}h)/2,$$

based values of incircle radius (R), length (L) and chord height (h) obtained from software.

Circle square area was calculated as

$$S_{cirl.} = \varpi R^2.$$

Then the bone loss percentage was identified by the ratio of $S_{segm.}/\ S_{cirl.}$ — relative area-dependent defect dimensions (Fig. 1c). Computerization was made in Microsoft Excel.

Linear glenoid defect dimensions were measured also during arthroscopy by method of Burkhart S.S. and De Beer J.F. referring to the area of thinned cartilage taken as the center of intact articular process of scapula [24] (Fig. 2).

Measuments in all 24 patients were made by 7 specialists including 2 orthopaedic surgeons, 2 radiologists and 3 residents. All data was depersonalized in respect of diagnosis and surgery plan prior to measurements. Single-factor variance analysis with consequent a posteriory analysis inclyding post-hoc tests and means comparison by Tukey's method (Tukey's Honest Significant Difference test) was used to compare accuracy of linear relation and sectional relation methods among themselves and with the standard as well as measuments on 3D VIBE MRI and 3D-CT. Significance level of $\alpha = 0.05$ was used for calculation of sufficient statistical power to achieve the effect size of 0.48.

Measurement reproducibility was evaluated by interclass correlation coefficient (One-Way Random ICC(1)); $p \leq 0.05$ was used to determine statistical significance. ICC ≥0.75 was considered as good match, from 0.5 to 0.75 — as moderate, and less than

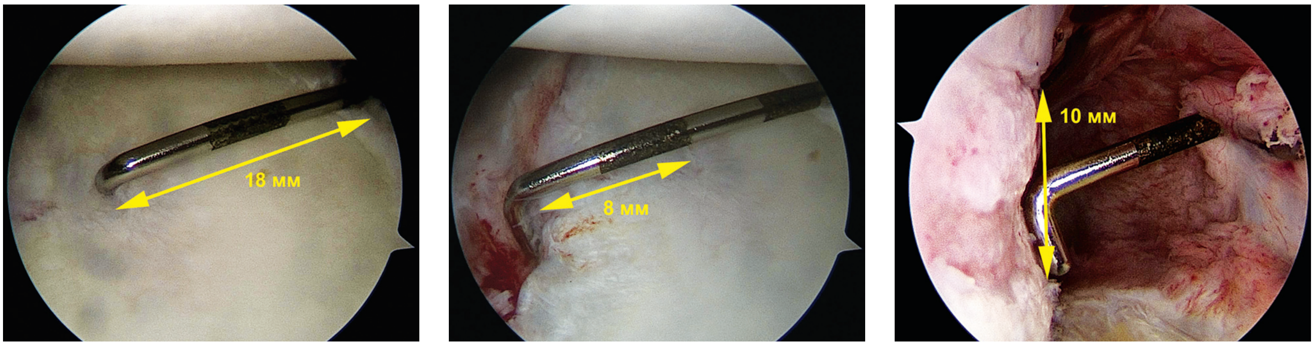


**Fig. 2.** Visual measurement of the defect of articular process (28%) and humeral head (10 mm) during arthroscopy

0.5 — as weak. Obtained measurements were divided into 4 groups depending on dimensions of bony defect to identify its impact on measurement accuracy by each method: with small (<15%), moderate (15–19%), large (20–25%) and massive (>25%) defects of scapula. ICC for earch operator was also calculated to assess correspondence rate of measurements by various methods on 3D VIBE MRI with results of the model method on 3D-CT. Linear regression analysis was used to evaluate the trend and rate of relation of measurements on 3D VIBE MRI and 3D-CT. Besides, the authors compared mean percentage errors of studied measurement methods by each operator in respect of model values.

Track of Hill-Sachs defect was evaluated in all cases on 3D-CT by measuring the diameter of intact glenoid (D), linear dimensions of glenoid defect at affected joint (d) and difference from the medial border of Hill-Sachs defect to the site of infraspinatus tendon attachment on humeral head (HSI — Hill-Sachs interval). Hill-Sachs interval is formed by the defect itself (HS) and bone bridge (BB) between the defect and infraspinatus tendon attachment (HSI = HS+BB). S. Gyftopoulos et al. reported that HSI measurement can be performed without loss of accuracy on axial MRI images [25]. Then the width of glenoid tack (GT) was calculated: GT = 0.83D-d. If width of glenoid track exceeded the value of Hill-Sachs interval the defect was considered biomechanically unfavorable — “off-track”, while in case of HSI<GT the defect was “on-track” (Fig. 3).

## Results

All groups, excluding the group with massive glenoid defects, demonstrated statistically significant differences (*p*≤0,05) between results of glenoid defect measurements and calculations between various methods as compared to the model (Table 1). Post-hoc analysis revealed significant differences in results of visual measurements of glenoid defect during arthroscopy from the model in 12 out of 24 patients in groups I=III. Sectional relation method on 3D-CT was the most accurate and reproducible in all groups (mean percentage error PE = 1.29±2.39%, ICC = 0.75–0.85), excluding the group with massive defects, when the studied methods had close accuracy during application on 3D-CT, 3D VIBE MRI and arthroscopy. Values from linear relation method significantly differed from the standard in all groups, except for the group of massive defects, and always exceeded the values of sectional relation method, while linear model doesn’t take into account the radial shape of articular process. Linear method on 3D-CT overestimated the

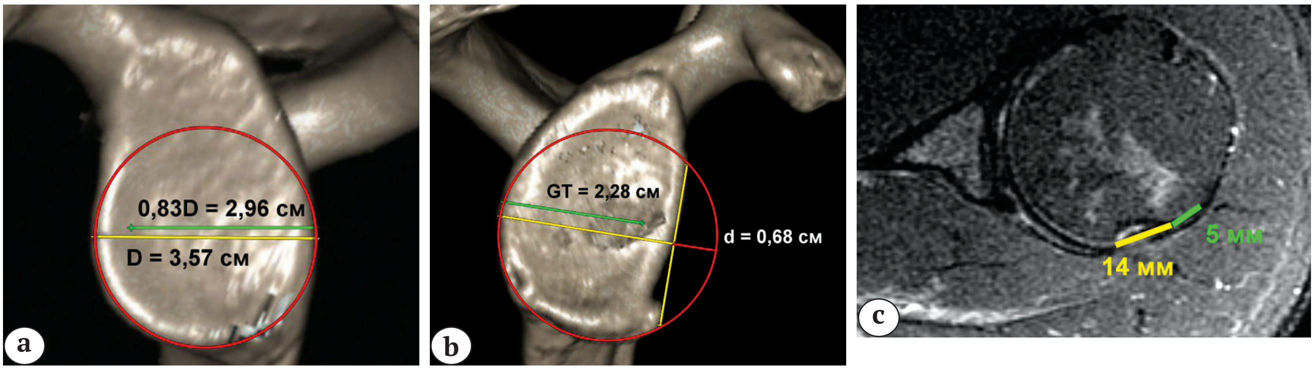


**Fig. 3.** Evaluation of track for articular process of scapula in bipolar injuries of shoulder joint:
a — measurement of diameter of intact glenoid (D = 3.57 cm);
b — calculation of defect width (d = 0.68 cm) and glenoid track (GT = 2.28 cm); c — MRI measurement of Hill-Sachs interval (HSI = 1.9 cm) including the defect itself (HS = 14 mm) and bony bridge (BB = 5 mm). Based on the fact that glenoid track is wider than Hill-Sachs interval (GT>HSI) the bipolar lesion was considered “on-track”

amount of lesion at 2.1–7.9% and had less reliable reproducibility (PE = 3.22±5.31%, ICC = 0.61–0.62). Besides, the biggest error (up to 7.9%) the linear method demonstrated in cases of borderline glenoid defects — in group III with large defects (20–25%).

*Table 1*

**Variance analysis of measurements for the defect of articular process of scapula**

| Patients | Glenoid defect measurement by standard Pico method, % | Average glenoid defect volume, % | Significant differences of variance analysis results for the studied and standard methods, *p** |
|---|---|---|---|
| Group I (<15%) | | | |
| Patient 1 | 5.2 | 7.3 | 0.001 |
| Patient 2 | 6.1 | 9.4 | <0.001 |
| Patient 3 | 7.1 | 9.3 | <0.001 |
| Patient 4 | 11.3 | 14.5 | <0.001 |
| Patient 5 | 13.1 | 14.5 | 0.023 |
| Patient 6 | 11.2 | 11.7 | 0.415 |
| Group II (15–19%) | | | |
| Patient 1 | 18.5 | 18.9 | 0.507 |
| Patient 2 | 15.1 | 18.1 | <0.001 |
| Patient 3 | 17.3 | 19.12 | 0.003 |
| Patient 4 | 17.5 | 18.62 | <0.001 |
| Patient 5 | 18.9 | 19.6 | 0.082 |
| Patient 6 | 16.4 | 21.2 | 0.001 |
| Group III (20–25%) | | | |
| Patient 1 | 20.5 | 25.0 | 0.001 |
| Patient 2 | 21.1 | 25.7 | <0.001 |
| Patient 3 | 24.8 | 20.5 | 0.001 |
| Patient 4 | 21.3 | 24.6 | <0.001 |
| Patient 5 | 23.8 | 18.04 | 0.032 |
| Patient 6 | 20.2 | 23.7 | 0.001 |
| Group IV (>25%) | | | |
| Patient 1 | 31.5 | 31.9 | 0.854 |
| Patient 2 | 28.2 | 29.1 | 0.468 |
| Patient 3 | 31.2 | 32.1 | 0.592 |
| Patient 4 | 25.8 | 26.7 | 0.469 |
| Patient 5 | 26.6 | 26.3 | 0.432 |
| Patient 6 | 30.4 | 31.0 | 0.992 |

* — statistically significant difference at $p \leq 0.05$.

Measurement reproducibility by various operators was moderate for visual (ICC = 0.594) and linear method (ICC = 0.621), and reliable for sectional method (ICC = 0.756). Measurements reproducibility by each surgeon was also moderate for visual and linear methods (ICC = 0.553 and ICC = 0.621), and reliable for sectional method (ICC = 0.856).

Overall interclass correlation (ICC) between 3D VIBE MRI and the standard 3D-CT in application of linear method for all operators was 0.413 which proves poor correlation of glenoid defect measurements by linear method on 3D VIBE MRI and the standard area-dependent method on 3D-CT. Results of application of sectional relation method on MRI demonstrated somewhat more reliable correlation with the standard: interclass correlation for sectional method was 0.623.

Additional glenoid defect measurements on 3D VIBE MRI by the model method were performed for quantitative description of correlation between 3D VIBE MRI and 3D-CT. Mean glenoid defect dimensions measured by the model method on 3D VIBE MRI was 24.16±10.3%. When analyzing the correspondence of results obtained by the model measurement methods, a regression line was drawn on 3D VIBE MRI and 3D-CT using linea regression analysis and its inclination (angle factor) was identified: value of increased defect volume according to 3D-CT at increase of defect volume per unit of measure (1%) according to 3D VIBE MRI. Angle factor was significantly difference from 1 and was 0.29 ($p \leq 0.001$) which means that defect dimensions on 3D VIBE MRI exceeded standard in case of defect volume above average and below the standard — in defects less than average value. Change of defect size according to 3D VIBE MRI was 1%, according to 3D-CT the defect size will change average at 0.29%. Small number of cases did not allow to maintain the conditions of linear model application, however, the obtained results correspond to the data of G.M. Friedman et al. reported for large samples [20].

Thus, during comparison of 3D VIBE MRI and 3D-CT the authors observed poor match of results for linear method (ICC = 0.412) and moderate match for sectional method (ICC = 0.623). At the same time in groups with small size of glenoid defects (about mean) we can expect underestimation of their dimensions on MRI, but in the groups with large defects — overestimation.

Percentage error of each measurement is represented by a difference between a value obtained by studied method and by the model measurement on the same glenoid. Average volume of glenoid defect by the standard measurement on 3D-CT was 25.45±8.71% (ranging 9–42%). Mean percentage errors (±SD standard mean error) for dimensions of articular process defect are given in percentage and were obtained in result of measurements on 3D VIBE MRI and 3D-CT by linear and sectional relation methods as compared to the model dimensions (Table 2).

*Table 2*

**Average measurement results for defects of articular process of scapula for all operators and mean errors in respect of the standard values**

| Method | Average defect volume, % | Mean error (PE, %) |
|---|---|---|
| Linear method on 3D-CT | 24.08± 8.22 | 3.22%±5.31 |
| Linear method on 3D VIBE MRI | 23.89± 9.08 | 4.86%±4.12 |
| Sectional method on 3D-CT | 25.84± 7.12 | 1.29%±2.39 |
| Sectional method on 3D VIBE MRI | 24.12± 7.21 | 3.94%±3.11 |

The model value — 25.45±8.71%.

Error value in respect of the model on 3D VIBE MRI was 4.86±4.12% for linear relation method and 3.94±3.11% — for sectional method, while error on 3D-CT was 3.22±5.31% and 1.29±2.39% for linear and sectional methods, respectively. 3D VIBE MRI resulted in loss of accuracy as compared to 3D-CT was from — 1.16% to 0.7% for linear method and from — 2.09% to 1.2% for sectional method, CI 95%.

The highest error (2.7–8.5%) was reported for linear relation method on 3D VIBE MRI for borderline glenoid defects — in group 20–25%. The similar results was obtained after the same measurement method on 3D-CT — error in group of 20–25% was the most significant: 2.3–6.9%, though it was slightly less than at MRI measurements. The least deviation from the standard values in all groups was obtained at sectional method on 3D-CT (0.4–3.1%). During measurements on 3D VIBE MRI by sectional method the error did not exceed 4.6% excluding the group with borderline defect dimensions (Table 3).

Average diameter of articular process of scapula measured on 3D-CT of intact limb was 30,7 mm and demonstrated insignificant variance between study groups. Average width of glenoid track decreased with increase of defect from group I to IV. Hill-Sachs interval value (HSI) was somewhat lower in the groups with large and massive defects. In the group with massive defects all lesions had “off-track” pattern. Naturally that in the group with lesion of articular process of scapula less than 15% the quantity of off-track defects on humeral head was also the least and amounted to 33.3%, while 83.3% of large and 66,7% of medium glenoid defects were accompanied by off-track Hill-Sachs defects. Thus, isolated repair of capsule-labral complex in 11 (61.1%) out of 18 patients from our sample with glenoid defect less than 25% would have been accompanied by a high risk of recurrent instability due to wedging of defects on the humeral head and on articular process of scapula in abduction and external rotation of the shoulder.

## Discussion

The easiest and faster way to measure the defect size of articular process of scapula is to perform it during the arthroscopy. Analysis of accuracy of arthroscopic measurement of glenoid defect has confirmed the possible application of this medhod. However, in defects positioned at an angle towards the longitudinal axis of glenoid the measurements demonstrate significant error due to the wide-angle view via arthroscope which complicates the selection of correct direction for measurements [26, 27].

The analysis demonstrated statistically significant variances from the standard measurement made under visual control during arthroscopy ($p<0.05$). Sectional method demonstrated higher accuracy and reproducibility than conventional linear relation method on 3D-CT as well as on 3D VIBE MRI. The exception was the group with massive lesions of articular surface of scapula (more than 25%) where all study methods including visua and all calculation methods had the

*Table 3*

**Mean errors of measurements by studied methods for defects of articular process of scapula with various size vs standard values, %**

| Glenoid defect | Linear method on 3D-CT | Linear method on 3D VIBE MRI | Sectional method on 3D-CT | Sectional method on 3D VIBE MRI |
|---|---|---|---|---|
| Group I (<15%) | 3.2±1.3 | 2.9±2.1 | 1.2±1.0 | 3.1±3.1 |
| Group II (15–19%) | 2.9±1.4 | 5.2±6.3 | 0.4±1.1 | 4.2±1.3 |
| Group III (20–25%) | 4.6±2.3 | 5.8±2.9 | 2.7±2.4 | 4.9±0.4 |
| Group IV (>25%) | 2.2±1.9 | 4.3±1.4 | 0.9±1.1 | 3.9±3.1 |

The model value — 25.45±8.71%.

similar results without statistically significant differences. In the group with borderline defect dimensions (20–25%) the authors observed the higher overestimation of results at application of linear relation method on 3D-CT and on 3D VIBE MRI.

More reliable reproducibility of measurements was observed with sectional method. Comparison of 3D VIBE MRI with 3D-CT revealed a moderate match of results for linear method and more reliable match for sectional method. 3D VIBE MRI underestimated glenoid defect size in groups with defects less than average, and overestimated in groups with larger defects.

Exact measuring of bone defects of articular surfaces is the key to determine indication for plastic (Bankart) or osteoplastic (Latarjet) surgery for shoulder joint stabilization. The most common is the method of linear relations, first of all due to simplicity and usability in practical surgery. However, geometrically such approach is accompanied by substancial revaluation of measurements while it calculates the area of square but nor circular shape [28].

There are some publications presenting results of special software application allowing to separate glenoid defect insde of incircle and to automatically calculate the defect area [12, 29, 30]. Practically such program approach automatically implements the method suggested by P. Baudi and named after Italian phisolopher Pico della Mirandola [31]. Pico method has the maximum accuracy and reproducibility among all measurements of glenoid bone defects however it requires rather labor-consuming and lengthy process of marking irregular line of bone defect and did not become commonly used.

To simplify the measurements G.D. Dumont et al. suggested to mark the border of bone defect as chord on the incircle and to calculate the area of obtained segment basing on angle at center generated by the chord [11]. Further evoluation of area-dependent measurement resulted in elaboration of sectional relation method when the square of bone defect is calculated basing on chord length in the majority of software for analysis of CT and MRI examinations [32].

The authors compared accuracy and reproducibility of the most widely used linear relation method and sectional relation method — based on measuring of defect area, however, more accessible and simple than direct measuring by special software. Match of calculatated results to the model was set as criteria. The study was conduced in patient groups with defects of various size. Group distribution was based on criteria most often used in surgical algorithms (<15%, 15–19%, 20–25% и >25%). Measurements were taken by experienced radiologists as well as practicing orthopaedic surgeons and clinical residents, meaning specialists of different experience and qualifications. Obtained results were analyzed also for reproducibility properties.

Choice of research method is widely discussed in the scientific literature. Measurement accuracy on X-rays, MRI, 2D-CT and 3D-CT are studies. J.Y. Bishop et al. concluded in their study on the maximum accuracy of 3D-CT which was confirmed by other researchers [10, 14, 33]. 2D-CT measurements did not provide reliable outcomes due to strong dependency on direction and position of the section. Inevitable rotational displacements in sagittal plane during axial images construction results in measurement errors up to 5.2% [34].

Many publications are dedicated to study of MRI examinations for evaluation of bone defects in articular surfaces of shoulder joint, though giving controversial results [17–20, 35]. Data obtained by the authors of the present research prove moderate correspondence of measurement results of glenoid defect by linear relation method on 3D VIBE MRI to the model area-dependent method on 3D-CT. Somewhat more reliable correlation with model were demonstrated by 3D VIBE MRI measurements by sectional relation method. Despite the fact that MRI application for calculation of glenoid defect doesn't have the same accuracy as 3D-CT, area-dependent measurements on MRI allow to avoid additional CT scanning of the patient in cases where defect size is not borderline (near to critical values) — for patients with ISIS above 6 or less than 3. Preceding research demonstrated promising outlook of MRI for measuring of bone defects on cadavers, however, the data of the present study confirm only moderate correspondence of results (ICC = 0.623), second to 3D-CT. One of the possible explanations is the application of the more accurate area-dependent method of measurements, while previous researchers used the linear relation method. Besides the different results can be the consequence of clinical pattern of the study in contrast to cadaver measurements in previous publications. Posttraumatic bone defects as compared to simulated osteotomy defects have irregular shape and irrefular borders which makes it more difficult to mark and measure and measurement results deviate more for posttraumatic defects. At collation of MRI with CT the contours are less distinct and angles are less acute which also deteriorates the result.

Thus, to obtain the complete information on soft tissues injuries of unstable shoulder joint and precise size of defect of articular process of scapula we need MRI and 3D-CT. Conclusions of the authors match the conclusions of R.K. Lee et al. in terms that despite good correlation of results of various measurements on MRI and CT, 3D-CT still exceeds MRI for glenoid defects [36].

Obtained results justified the algorithm for selection of research method and evaluation of biomechanical relations of bipolar defects of articular surfaces in anterior shoulder instability. To determine surgical tactics the instability index is calculated on ISIS scale considering factors most significant for prognosing of recurrent instability. Instability index is calculated by level and pattern of physical activity of the patient, age and signs of hyperlaxity of ligamentous complex as well as radiological signs of articular lesions. Besides, all patients need MRI to identify objective signs of shoulder joint instability and define morphological substratum.

When instability index is not exceeding 3 the describes volume of preoperative examination is sufficient for selecting the soft tissue stabilization of shoulder joint (Fig. 4).

At extreme instability index above 6 the osteoplastic surgery is required. Defect of the shoulder head demands additional remplissage in case of off-track Hill-Sachs lesion. Track in patients with high instability index can be defined by MRI while it doesn't need high accuracy due to already made decision on osteoplastic surgery.

Intermediate values of instability index (from 3 to 6) need more precise calculations of bipolar defect size which is feasible only by 3D-CT. While the more accurate Pico method requires special software and laborious measurements, it's replacement by sectional relation method is possible according to obtained results. In case of defect of articular process of scapula less than 15% irrespective of track of Hill-Sachs lesion in patients with intermediate istability index it's possible to perform soft tissues stabilizing surgery supplemented by remplissage in cases of off-track Hill-Sachs defect. In case of large glenoid defects (over 15%) the choice of surgery is determined by bipolar injuries, and presence of off-track Hill-Sachs lesion demands mandatory osteoplastic stabilization of shoulder joint.

Choice of defect size of 15% as a critical value is based on outcomes of biomechanical bench study of R.U. Hartzler, P.J. Denard and S.S. Burkhart who concluded that Bankart surgery supplemented by remplissage on the model with 15% glenoid defect and with unfavorable off-track Hill-Sachs allows to reliably avoid wedging of Hill-Sachs with anterior border of injured glenoid [37].

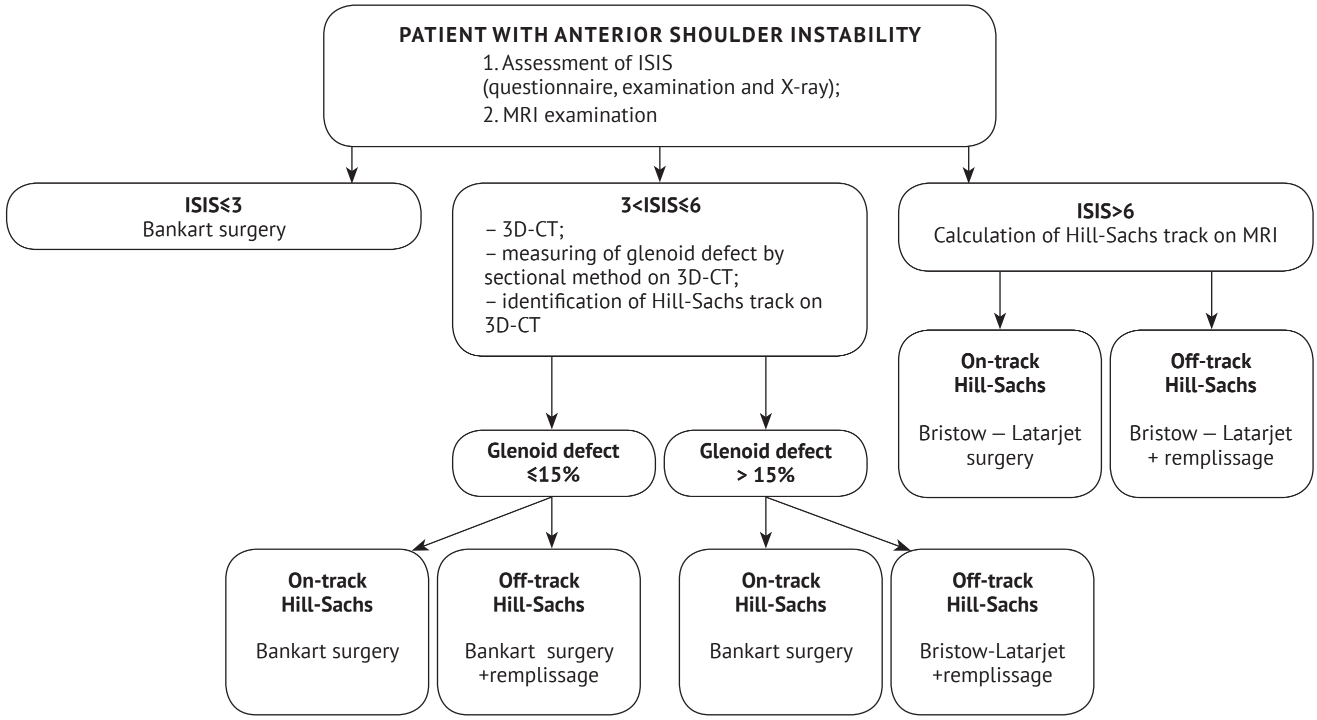


**Fig. 4.** Algorithm of examination and surgical treatment of patients with anterior shoulder instability

## Conclusion

Sectional relation method on oblique-sagittal 3D-CT view is the most accurate and reproducible method for evaluation of defect size of articular process of scapula which doesn't require lengthy and laborious marking of irregular defect contour and therefore applicable in practical surgery.

Measurements during arthroscopy significantly differed from the model excluding the group of patients with massive glenoid defects. MRI measurements allow to avoid additional CT examination, however, accuracy and reliability of obtained results is less, and the higher error (up to 8.5%) of MRI measurements was observed in borderline glenoid defects when accuracy of measurements is of key importance for selection of surgical procedure. Thus, MRI use without CT is not permissible in bipolar defect of borderline size.

Suggested algorithm allows to avoid CT in patients with extreme values of ISIS and accompanied by increase of overall share of performed osteoplastic stabilizing procedures. Above mentioned occurs due to identification of prognostic unfavorable off-track Hill-Sachs lesions in patients with glenoid defects of borderline size (15–25%).

**Competing interests:** the authors declare that they have no competing interests.

**Funding:** the authors have no support or funding to report.

## References

1. Balg F., Boileau P. The instability severity index score. A simple pre-operative score to select patients for arthroscopicor open shoulder stabilisation. *J Bone Joint Surg Br.* 2007;89(11):1470-1477. DOI: 10.1302/0301-620X.89B11.18962.
2. Shin S.J., Koh Y.W., Bui C., Jeong W.K., Akeda M., Cho N.S. et al. What is the critical value of glenoid bone loss at which soft tissue Bankart repair does not restore glenohumeral translation, restricts range of motion, and leads to abnormal humeral head position? *Am J Sports Med.* 2016;44(11):2784-2791. DOI: 10.1177/0363546516656367.
3. Beran M.C., Donaldson C.T., Bishop J.Y. Treatment of chronic glenoid defects in the setting of recurrent anterior shoulder instability: A systematic review. *J Shoulder Elbow Surg.* 2010;19(5):769-780. DOI: 10.1016/j.jse.2010.01.011.
4. Chen A.L., Hunt S.A., Hawkins R.J., Zuckerman J.D. Management of bone loss associated with recurrent

anterior glenohumeral instability. *Am J Sports Med.* 2005;33(6):912-925. DOI: 10.1177/0363546505277074.
5. Lynch J.R., Clinton J.M., Dewing C.B., Warme W.J., Matsen F.A. 3rd. Treatment of osseous defects associated with anterior shoulder instability. *J Shoulder Elbow Surg* 2009;18(2):317-328. DOI: 10.1016/j.jse.2008.10.013.
6. Ochoa E. Jr., Burkhart S.S. Glenohumeral bone defects in the treatment of anterior shoulder instability. *Instr Course Lect.* 2009;58:323-336.
7. Yamamoto N., Itoi E., Abe H., Kikuchi K., Seki N., Minagawa H., Tuoheti Y. Effect of an anterior glenoid defect on anterior shoulder stability: A cadaveric study. *Am J Sports Med.* 2009;37:949-954. DOI: 10.1177/0363546508330139.
8. Shaha J.S., Cook J.B., Song D.J., Rowles D.J., Bottoni C.R., Shaha S.H., Tokish J.M. Redefining «critical» bone loss in shoulder instability: Functional outcomes worsen with "subcritical" bone loss. *Am J Sports Med.* 2015;43(7): 1719-1725. DOI: 10.1177/0363546515578250.
9. Yamamoto N., Itoi E., Abe H., Minagawa H., Seki N., Shimada Y., Okada K. Contact between the glenoid and the humeral head in abduction, external rotation, and horizontal extension: a new concept of glenoid track. *J Shoulder Elbow Surg.* 2007;16(5):649-656. DOI: 10.1016/j.jse.2006.12.012.
10. Bishop J.Y., Jones G.L., Rerko M.A., Donaldson C., MOON Shoulder Group. 3-D CT is the most reliable imaging modality when quantifying glenoid bone loss. *Clin Orthop Relat Res.* 2013;471(4):1251-1256. DOI: 10.1007/s11999-012-2607-x.
11. Dumont G.D., Russell R.D., Browne M.G., Robertson W.J. Area-based determination of bone loss using the glenoid arc angle. *Arthroscopy.* 2012;28(7):1030-1035. DOI: 10.1016/j.arthro.2012.04.147.
12. Hamamoto J.T., Leroux T., Chahla J., et al. Assessment and evaluation of glenoid bone loss. *Arthrosc Tech.* 2016;5(4):e947-e951. DOI: 10.1016/j.eats.2016.04.027.
13. Magarelli N., Milano G., Baudi P., Santagada D.A., Righi P., Spina V. et al. Comparison between 2D and 3D computed tomography evaluation of glenoid bone defect in unilateral anterior gleno-humeral instability. *Radiol Med.* 2012;117(1):102-111. (In English, Italian). DOI: 10.1007/s11547-011-0712-7.
14. Rerko M.A., Pan X., Donaldson C., Jones G.L., Bishop J.Y. Comparison of various imaging techniques to quantify glenoid bone loss in shoulder instability. *J Shoulder Elbow Surg.* 2013;22(4):528-534. DOI: 10.1016/j.jse.2012.05.034.
15. Bakshi N.K., Patel I., Jacobson J.A., Debski R.E., Sekiya J.K. Comparison of 3-dimensional computed tomographybased measurement of glenoid bone loss with arthroscopic defect size estimation in patients with anterior shoulder instability. *Arthroscopy.* 2015;31(10):1880-1885. DOI: 10.1016/j.arthro.2015.03.024.
16. Shin S.J., Jun B.J., Koh Y.W., McGarry M.H., Lee T.Q. Estimation of anterior glenoid bone loss area using the ratio of bone defect length to the distance from posterior glenoid rim to the centre of the glenoid. *Knee Surg Sports Traumatol Arthrosc.* 2018;26(1):48-55. DOI: 10.1007/s00167-016-4312-x.
17. Magarelli N., Milano G., Sergio P., Santagada D.A., Fabbriciani C., Bonomo L. Intra-observer and interobserver reliability of the «pico» computed tomography method for quantification of glenoid bone defect in anterior shoulder instability. *Skeletal Radiol.* 2009;38(11):1071-1075. DOI: 10.1007/s00256-009-0719-5.
18. Gyftopoulos S., Hasan S., Bencardino J., Mayo J., Nayyar S., Babb J., Jazrawi L. Diagnostic accuracy of MRI in the measurement of glenoid bone loss. *AJR Am J Roentgenol.* 2012;199(4):873-878. DOI: 10.2214/AJR.11.7639.
19. Huijsmans P.E., Haen P.S., Kidd M., Dhert W.J., van der Hulst V.P., Willems W.J. Quantification of a glenoid defect with three-dimensional computed tomography and magnetic resonance imaging: a cadaveric study. *J Shoulder Elbow Surg.* 2007;16(6):803-809. DOI: 10.1016/j.jse.2007.02.115.
20. Friedman L.G.M., Ulloa S.A., David T.B., Hussein A.S., Morgan H.J., Miniaci A.A. Glenoid Bone Loss Measurement in Recurrent Shoulder Dislocation. Assessment of Measurement Agreement Between CT and MRI. *Orthop J Sports Med.* 2014;2(9):2325967114549541. DOI: 10.1177/2325967114549541.
21. Sugaya H., Moriishi J., Dohi M., Kon Y., Tsuchiya A. Glenoid rim morphology in recurrent anterior glenohumeral instability. *J Bone Joint Surg Am.* 2003;85-A(5):878-884.
22. Huysmans P.E., Haen P.S., Kidd M., Dhert W.J., Willems J.W. The shape of the inferior part of the glenoid: A cadavericstudy. *J Shoulder Elbow Surg.* 2006;15(6):759-763. DOI: 10.1016/j.jse.2005.09.001.
23. Bois A.J., Fening S.D., Polster J., Jones M.H., Miniaci A. Quantifying glenoid bone loss in anterior shoulder instability: Reliability and accuracy of 2-dimensional and 3-dimensional computed tomography measurement techniques. *Am J Sports Med.* 2012;40(11):2569-2577. DOI: 10.1177/0363546512458247.
24. Burkhart S.S., De Beer J.F. Traumatic glenohumeral bone defects and their relationship to failure of arthroscopicBankart repairs: Significance of the inverted-pear glenoid and the humeral engaging Hill-Sachs lesion. *Arthroscopy.* 2000;16(7):677-694.
25. Gyftopoulos S., Beltran L.S., Bookman J., Rokito A. MRI Evaluation of Bipolar Bone Loss Using the On-Track Off-Track Method: A Feasibility Study. *AJR Am J Roentgenol.* 2015;205(4):848-852. DOI: 10.2214/AJR.14.14266.
26. Detterline A.J., Provencher M.T., Ghodadra N., Bach B.R. Jr, Romeo A.A., Verma N.N. A new arthroscopic technique to determine anterior-inferior glenoid bone loss: Validation of the secant chord theory in a cadaveric model. *Arthroscopy.* 2009;25(11):1249-1256. DOI: 10.1016/j.arthro.2009.05.019.
27. Provencher M.T., Detterline A.J., Ghodadra N., Romeo A.A., Bach B.R. Jr, Cole B.J., Verma N. Measurement of glenoid bone loss: A comparison of measurement error between 45 degrees and 0 degrees bone loss models and with different posterior arthroscopy portal locations. *Am J Sports Med.* 2008;36(6):1132-1138. DOI: 10.1177/0363546508316041.
28. Bhatia S., Saigal A., Frank R.M., Bach B.R. Jr, Cole B.J., Romeo A.A., Verma N.N. Glenoid diameter is an inaccurate method for percent glenoid bone loss quantification: Analysis and techniques for improved accuracy. *Arthroscopy.* 2015;31(4):608-614.e1. DOI: 10.1016/j.arthro.2015.02.020.
29. Barchilon V.S., Kotz E., Barchilon Ben-Av M., Glazer E., Nyska M. A simple method for quantitative evaluation

of the missing area of the anterior glenoid in anterior instability of the glenohumeral joint. *Skeletal Radiol.* 2008;37(8):731-736. DOI: 10.1007/s00256-008-0506-8.
30. Nofsinger C., Browning B., Burkhart S.S., Pedowitz R.A. Objective preoperative measurement of anterior glenoid bone loss: A pilot study of a computer-based method using unilateral 3-dimensional computed tomography. *Arthroscopy.* 2011;27(3):322-329. DOI: 10.1016/j.arthro.2010.09.007.
31. Baudi P., Righi P., Bolognesi D., Rivetta S., Rossi Urtoler E., Guicciardi N., Carrara M. How to identify and calculate glenoid bone deficit. *Chir Organi Mov.* 2005;90(2): 145-152. (In English, Italian).
32. Parada S.A., Eichinger J.K., Dumont G.D., Parada C.A., Greenhouse A.R., Provencher M.T. et al. Accuracy and reliability of a simple calculation for measuring glenoid bone loss on 3-dimensional computed tomography scans. *Arthroscopy.* 2018;34(1):84-92. DOI: 10.1016/j.arthro.2017.07.032.
33. Chuang T.Y., Adams C.R., Burkhart S.S. Use of preoperative three-dimensional computed tomography to quantify glenoid bone loss in shoulder instability. *Arthroscopy.* 2008;24(4):376-382. DOI: 10.1016/j.arthro.2007.10.008.
34. Gross D.J., Golijanin P., Dumont G.D., Parada S.A., Vopat B.G., Reinert S.E. et al. The effect of sagittal rotation of the glenoid on axial glenoid width and glenoid version in computed tomography scan imaging. *J Shoulder Elbow Surg.* 2016;25(1):61-68. DOI: 10.1016/j.jse.2015.06.017.
35. Tian C.Y., Shang Y., Zheng Z.Z. Glenoid bone lesions: comparison between 3D VIBE images in MR arthrography and nonarthrographic MSCT. *J Magn Reson Imaging.* 2012;(1):231-236. DOI: 10.1002/jmri.23622.
36. Lee R.K., Griffith J.F., Tong M.M., Sharma N., Yung P. Glenoid bone loss: assessment with MR imaging. *Radiology.* 2013;267(2):496-502.
37. Hartzler R.U., Bui C.N.H., Jeong W.K., Denard P.J., Burkhart S.S., Lee T.Q. et al. Remplissage of an off-track hill-sachs lesion is necessary to restore biomechanical glenohumeral joint stability in a bipolar bone loss model. *Arthroscopy.* 2016;32(12):2466-2476. DOI: 10.1016/j.arthro.2016.04.030.

## INFORMATION ABOUT AUTHORS:

*Vladimir V. Khominets* — Dr. Sci. (Med.), Head of the Department and Clinic of Traumatology and Orthopedics, Kirov Military Medical Academy, St. Petersburg, Russian Federation

*Roman V. Gladkov* — Cand. Sci. (Med.), Lecturer of the Department and Clinic of Traumatology and Orthopedics, Kirov Military Medical Academy, St. Petersburg, Russian Federation

*Igor S. Zheleznyak* — Dr. Sci. (Med.), Head of the Department and Clinic of Radiology and Radiology with a course of ultrasound diagnostics, Kirov Military Medical Academy, St. Petersburg, Russian Federation

*Alexey S. Grankin* — Cand. Sci. (Med.), Resident of the Department and Clinic of Traumatology and Orthopedics, Kirov Military Medical Academy, St. Petersburg, Russian Federation

*Daniil A. Volov* — Resident of the Department and Clinic of Traumatology and Orthopedics, Kirov Military Medical Academy, St. Petersburg, Russian Federation

*Alexandr A. Emelyantsev* — Cand. Sci. (Med.), Lecturer of the Department and Clinic of Radiology and Radiology with a Course of Ultrasound Diagnostics, Kirov Military Medical Academy, St. Petersburg, Russian Federation