

FEASIBILITY OF SAFE POSTERIOR C1–2 TRANSARTICULAR SCREW FIXATION: CT MORPHOMETRIC STUDY

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Background. C1–2 transarticular fixation according to the F. Magerl technique is one of the most reliable methods of C1–2 screw stabilization. An important aspect of the precise placement of implants during transarticular fixation under X-ray control is the use of correct selection of start- and end-points of the installation trajectory. At certain values of the height and width of C2 isthmus some screw installation trajectories may be accompanied by a zero probability of vertebral artery damage that might be due to the screw malposition.

Aim. To evaluate CT morphometric characteristics of the C2 vertebra to assess the possibility of safe C1–2 transarticular fixation.

Materials and methods. The analysis performed was based on the data obtained from 7672 patients having admitted with suspected injury to the N.V. Sklifosovsky Research Institute of Emergency Medicine during the period from 01.01.2019 to 31.07.2019. The study involved 6 neurosurgeons and 6 medical doctors of the X-ray diagnostics department. The measurements were carried out in 2 stages. Each parameter (isthmus height – IstH, isthmus width – IstHw, lateral mass height – LmH) was measured 2 times. In case of high intraclass correlation, the mean value of the measurements was calculated, which was included in the final analysis.

Results. The intraclass correlation coefficient for all measurements approached an excellent correlation values and was 0.852 (95 % CI 0.844–0.860). Morphometric characteristics were calculated basing on data from 795 patients. The IstH value was 7.45 ± 1.66 , IstHw 8.56 ± 1.48 , LmH 5.56 ± 1.84 mm. In men, the transarticular fixation was significantly more likely to be performed without injury of the vertebral artery (in 66.1 % of cases; χ^2 -test, $p < 0.000001$), whereas in women – only in 29.9 % of cases.

Conclusions. The results obtained suggest that percutaneous bilateral transarticular fixation with the use of posterior spinolaminar point and middle of the atlas anterior arch as landmarks potentially serves as a method of choice in 88.3 % of patients. Of all patients with normal anatomy of C2 isthmus, men are twice more likely to undergo transarticular fixation without damage of vertebral artery than women, the probability exceeds 66 %. However, the risk of injury of this blood vessel in other patients does not exceed 2.3 %, which is comparable with outcomes of other methods of C1–2 screw stabilization.

Keywords: C2 isthmus, morphometric study, C1–2 fusion

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BACKGROUND

C1–2 transarticular fixation (TAF) according to the F. Magerl and P.S. Seemann technique serves as a reliable method of screw stabilization of these vertebrae (Fig. 1) [1]. According to the latest published meta-analyses, this technique is comparable to the Goel–Harms method (A. Goel, J. Harms) in terms of frequency of formation of spondylolysis and implant-associated complications [2, 3]. TAF is also highly sensitive to such aspects of surgery as rigidity of head immobilization during screws installation, type

of implants, localization of the muscle tunnel for screws installation and method of intraoperative visualization. Meta-analysis [2] has demonstrated that the accuracy of installing screws under biplane fluoroscopic control is identical to that employed under neuronavigation. The most important aspect of the precise implants placement during TAF under X-ray control is the correct choice of the trajectory start- and end-points. Simulation study [4] has demonstrated that at certain values of height and width of C2 isthmus some screw installation trajectories (Fig. 2) may be

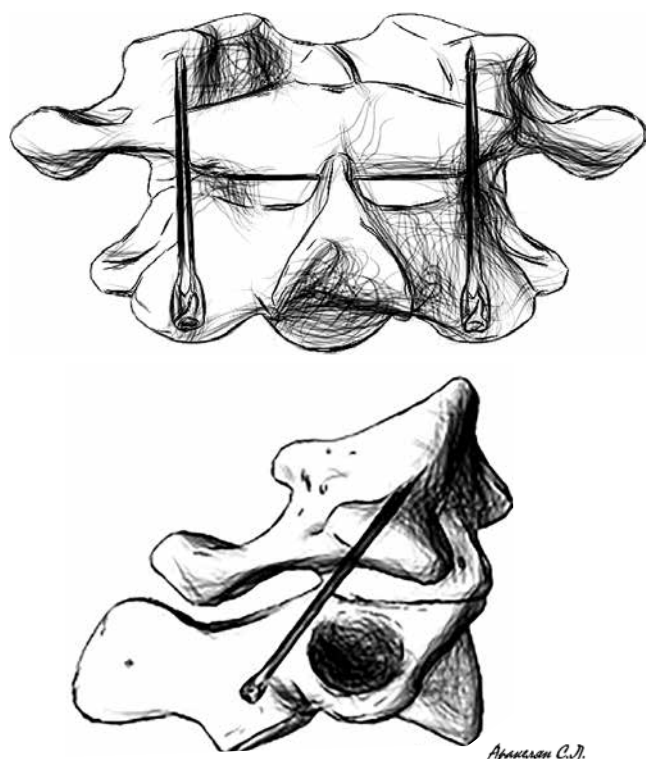


Fig. 1. Scheme of C1–2 posterior transarticular fixation (Fig. made by neurosurgeon S. L. Arakelyan)

accompanied by a zero probability of vertebral artery (VA) damage that might be due to the screw malposition. The possibility of minimally invasive TAF surgery along with its safety makes this technique preferable in some patients during surgical intervention to C1–2 vertebrae.

The aim of the study was to evaluate the CT morphometric characteristics of C2 vertebra to assess feasibility of safe C1–2 vertebrae fixation.

MATERIALS AND METHODS

Objects of research

The present work is a retrospective morphometric single – center study. The object of the study was the computer tomography (CT) data of the cervical spine. As we employed completely depersonalized data, the patients' informed consent to participate the study was not required. A continuous sampling of patients admitted to the hospital for the period from 01.01.2019 to 31.07.2019 was carried out. The inclusion criteria in the study were as follows:

- admission of a patient in an emergency with a suspected injury;
- availability of cervical spine CT with slices thickness of 0.5 mm.

The exclusion criteria were as follows:

- the patient's age is less than 15 years;
- developmental anomaly of craniovertebral level;
- C2 fracture;
- previously performed intervention on C1–2 vertebrae;
- metal artifacts in the craniovertebral region.

Researchers

Six neurosurgeons and 6 medical doctors of the X-ray diagnostics department took part in the morphometric study. Before starting the work, a briefing was held that included training to measure of the required parameters in several patients who did not participate in the study. Also, all participants were provided with methodological recommendations for measurement of the parameters to be studied in the present work.

Measurements

The measurements were carried out using the RadiAnt DICOM Viewer 2021.2.2 software (Medixant, Republic of Poland). In the mode of MPR multiplanar reconstruction, the measurements included estimation of height of the C2 isthmus (IsthH), its width (IsthW) and height of C2 lateral mass in the region of VA furrow (IntH) (Fig. 3).

In accordance with the classification by M. H. Nogueira-Barbosa and H. L. Defino [5], the 4 types of C2 isthmus could be recognized (Fig. 4). Type I corresponds to the normal values. Type IIa is accompanied by a decrease in the IsthH and IsthW values – less than 5 mm. In case of type IIb, there is a decrease in LmH – below 2.5 mm. In case of type IIc, there is a decrease in all 3 parameters listed above.

Our previous study [4] has shown that the safest trajectory for screw installing is directed from the posterior spinolaminar point towards the middle of tubercle of atlas anterior arch (see Fig. 2). With such screw installation having 4 mm in diameter, the VA damage was not registered if IsthH is more than 6.6 mm and IsthW is more than 7.6 mm [4]. The risk of VA damage was 2.3 % in patients with IsthH size of 5.0–6.59 mm and IsthW size of 5.0–7.59 mm.

All the patients were equally distributed among the researchers for the analysis. The measurements were carried out in 2 stages. After the first stage, a random exchange of patients between researchers with repeated measurement was performed. Thus, each patient was examined twice by different specialists. In the case of high intraclass correlation coefficient (ICC) between the expert responses for 2 measurements of single parameter, the mean value was calculated and that mean value was taken in the final analysis.

In a number of patients, the difference between the values of the same parameter was significant (3 mm or more). They were examined separately by an expert, and if measurement errors were detected, these data were not included in the final analysis. If data from the same patient had errors in estimation of 2 or more parameters, then the patient was completely excluded from further analysis.

Statistical analysis

The data obtained were analyzed using Statistica 10.0 (StatSoft Inc., USA) and IBM SPSS Statistics 23.0 software.

The normality of the data distribution was estimated by the Shapiro–Wilk statistical test (Shapiro–Wilk's W test). Pearson's correlation coefficient (Pearson's r) was used for

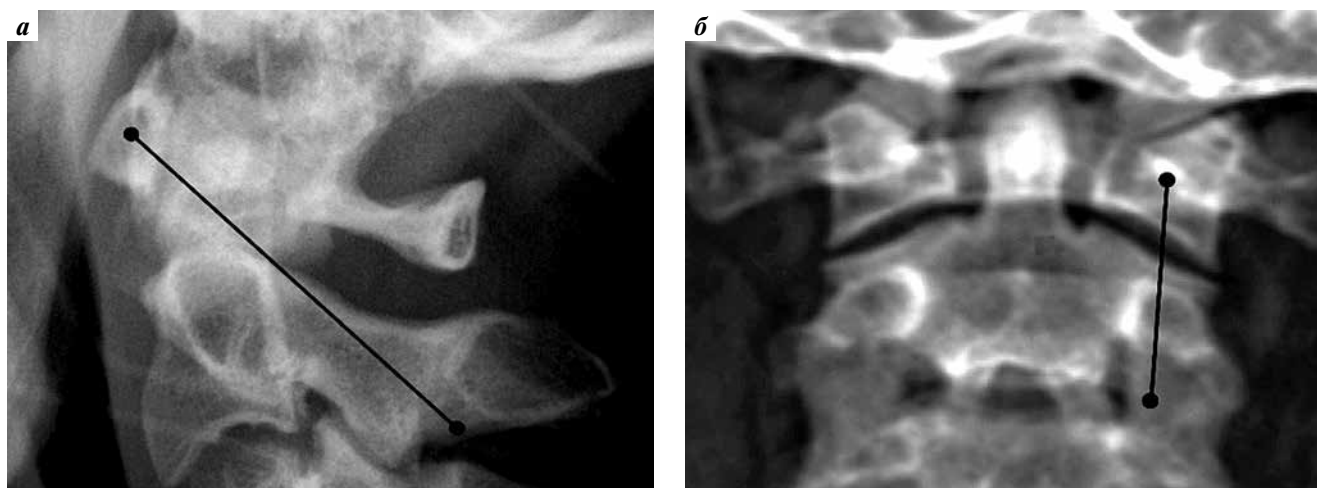


Fig. 2. Roentgenograms in lateral (a) and straight (б) projections demonstrating the safest trajectory of transarticular fixation

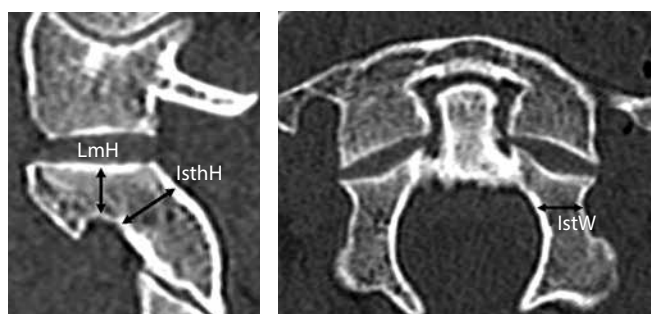


Fig. 3. C2 morphometric parameters: LmH – height of lateral mass; IsthH – height of isthmus; IsthW – width of isthmus

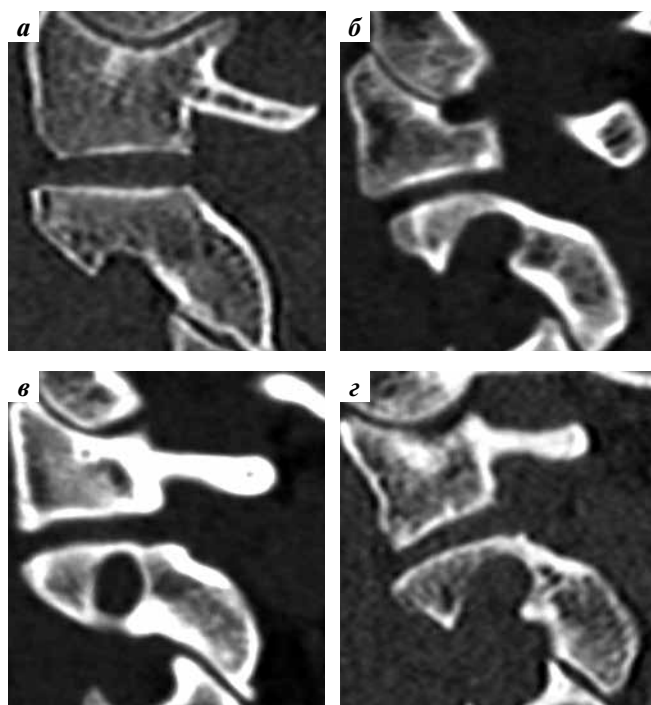


Fig. 4. Variants of vertebral artery passage in isthmus of C2 vertebra (M.H. Nogueira-Barbosa and H.L. Defino [5]), types: a – I; б – IIa; в – IIb; г – IIc

data series with a normal distribution. Spearman's correlation coefficient (Spearman's ρ) was calculated when data distribution differed from normality.

The differences between groups were calculated by the use of the Mann–Whitney U Test and Kruskal–Wallis Test. When comparing the parameters measured in nominal and ordinal scales, the Pearson's chi-squared (Pearson's χ^2 test) was used. The difference between groups was considered statistically significant when $p < 0.05$.

Interexpert agreement was evaluated using the intra-class correlation coefficient (ICC 2.1 – two – way random effects model, absolute agreement); the results were evaluated in accordance with the Landis–Koch system (J.R. Landis, G.G. Koch) [6]. The correlation of responses was considered low at a value less than 0.5, moderate – 0.5–0.75, good – 0.75–0.90, excellent – above 0.9.

RESULTS

Patient selection

For the period from 01.01.2019 to 31.07.2019, there were a total of 7672 patients admitted to an emergency were examined in the CT office of the N.V. Sklifosovsky Research Institute of Emergency Medicine. After applying the inclusion criteria, 853 patients were selected to view of DICOM archives. Of these, 24 patients were excluded from the study due to anomaly of the craniovertebral junction or because of metal structure installed in C2 area.

Results after completion of the second stage of the study were as follows:

- measurement errors were not detected in 683 patients;
- the expert found a measurement error in 1 of the studied parameters so this parameter was excluded from the final analysis; there were 112 such patients;
- measurement errors of 2 or more parameters were detected, therefore these patients were excluded from the study; there were 34 such patients.

Thus, the final analysis of morphometric characteristics included data from 795 patients, and classification of isthmus

part in accordance with the classification of M.H. Nogueira-Barbosa and H.L. Defino included 683 patients.

Assessment of inter-expert consent

The ICC intraclass correlation coefficient for IsthH measurements was 0.786 (95 % CI, 0.765–0.805), for IsthW – 0.763 (95 % CI, 0.738–0.786), for LmH – 0.790 (95 % CI, 0.770–0.808). The overall intra-class correlation for all measurements approached excellent level and was 0.852 (95 % CI, 0.844–0.860). Taking in consideration the high degree of correlation of responses between experts, the results of all 795 patients were taken in the final analysis.

Analysis of C2 parameters

Morphometric characteristics were calculated on the basis of data from 795 patients. Among them there were 514 (64.7 %) men and 281 (35.3 %) women. The mean age was 42.9 (15–93) years.

The mean value of IsthH in the left sections of C2 vertebra was 7.40 ± 1.63 mm, in the right – 7.51 ± 1.70 mm. The total value of IsthH for both sides was 7.45 ± 1.66 mm (Table 1).

For IsthW, the mean value on the left was 8.68 ± 1.45 mm, on the right – 8.43 ± 1.50 mm. The total IsthW value for both sides was 8.56 ± 1.48 mm.

For the C2, mean LmH on the left was 5.42 ± 1.79 mm, on the right – 5.70 ± 1.87 mm. In general, the LmH for both sides was 5.56 ± 1.84 mm.

The statistical analysis revealed no correlation between age and IsthH ($r = 0.012$, $p > 0.05$) as well as between age and LmH ($r = -0.05$, $p > 0.05$). A very weak negative correlation between age and IsthW was revealed ($r = -0.08$, $p < 0.00001$). When analyzing the distribution by sex, the measured parameters of C2 vertebra in men were significantly higher than in women (Mann–Whitney test, $p < 0.0001$) (Fig. 5).

The results of patients' distribution according to the classification by M.H. Nogueira-Barbosa and H.L. Defino are presented in Table 2. The procedure of TAF for C1–2 vertebrae has contraindication for patients with types IIa and IIc. Therefore, the TAF evaluation of both sides was possible in 602 (88.3 %) patients, only of one side – in 59 (8.6 %) patients. It was impossible to perform TAF due to the anatomical features of C2 vertebra in 22 (3.2 %) patients. The relationship between the type of C2 isthmus and the age was not revealed (Kruskal–Wallis's test, $p = 0.38$). In men, the normal anatomy of C2 isthmus that made possible TAF of both sides was significantly more frequent than in women (χ^2 test, $p < 0.00001$).

Out of 585 patients with normal anatomy of C2 isthmus, it was possible to perform completely safe TAF in 319 (54.5 %) observations on both sides and in 153 (26.2 %) – only on one side. In the remaining 113 (19.3 %) patients, the risk of VA damage was 2.3 %. There was no significant relationship between age and probability of safe TAF (Kruskal–Wallis's test, $p = 0.78$). In men, the feasibility to perform TAF without VA injury was significantly more frequent (χ^2 test, $p < 0.000001$). So, in men, it could be performed on both sides in 2 out of 3 (66.1 %) observations, whereas in women – only in 29.9 %.

DISCUSSION

The question of choosing the method of C1–2 vertebrae stabilization after traumatic injuries of C1–2 vertebrae still remains unresolved. Under certain conditions, the TAF has significant advantages over other stabilization methods. Thus, the minimum number of implants installed and the absence of connectors allows implementation of various options to reduce intervention invasion: the use of intermuscular accesses [7], as well as various options for percutaneous intervention [8, 9]. Application of such minimally

Table 1. Calculated morphometric parameters of C2 vertebra: data from other authors and from our present study

Parameter	S. Raut et al. [10]	M.H. Nogueira-Barbosa, H.L. Defino [5]	The data obtained in this study (I.S. Lvov et al.)
IsthH on the left, mm	—	7.73 ± 1.75	7.40 ± 1.63
M	6.00 ± 1.10	8.19 ± 1.71	7.85 ± 1.57
F	5.77 ± 1.23	7.02 ± 1.58	6.55 ± 1.39
IsthH on the right, mm	—	8.23 ± 1.72	7.51 ± 1.70
M	5.90 ± 1.22	8.59 ± 1.66	7.91 ± 1.65
F	6.11 ± 1.04	7.66 ± 1.70	6.77 ± 1.51
IsthW on the left, mm	—	7.77 ± 1.33	8.68 ± 1.45
M	5.95 ± 1.13	8.20 ± 1.03	9.08 ± 1.39
F	5.70 ± 1.18	7.11 ± 1.47	7.94 ± 1.27
IsthW on the right, mm	—	7.75 ± 1.23	8.43 ± 1.50
M	5.78 ± 0.93	8.03 ± 1.10	8.83 ± 1.42
F	5.84 ± 0.95	7.31 ± 1.31	7.71 ± 1.38
LmH on the left, mm	—	—	5.42 ± 1.79
LmH on the right, mm	—	—	5.70 ± 1.87

Note. Morphometric parameters of C2 vertebra: IsthH – isthmus height; IsthW – isthmus width; LmH – lateral mass height.

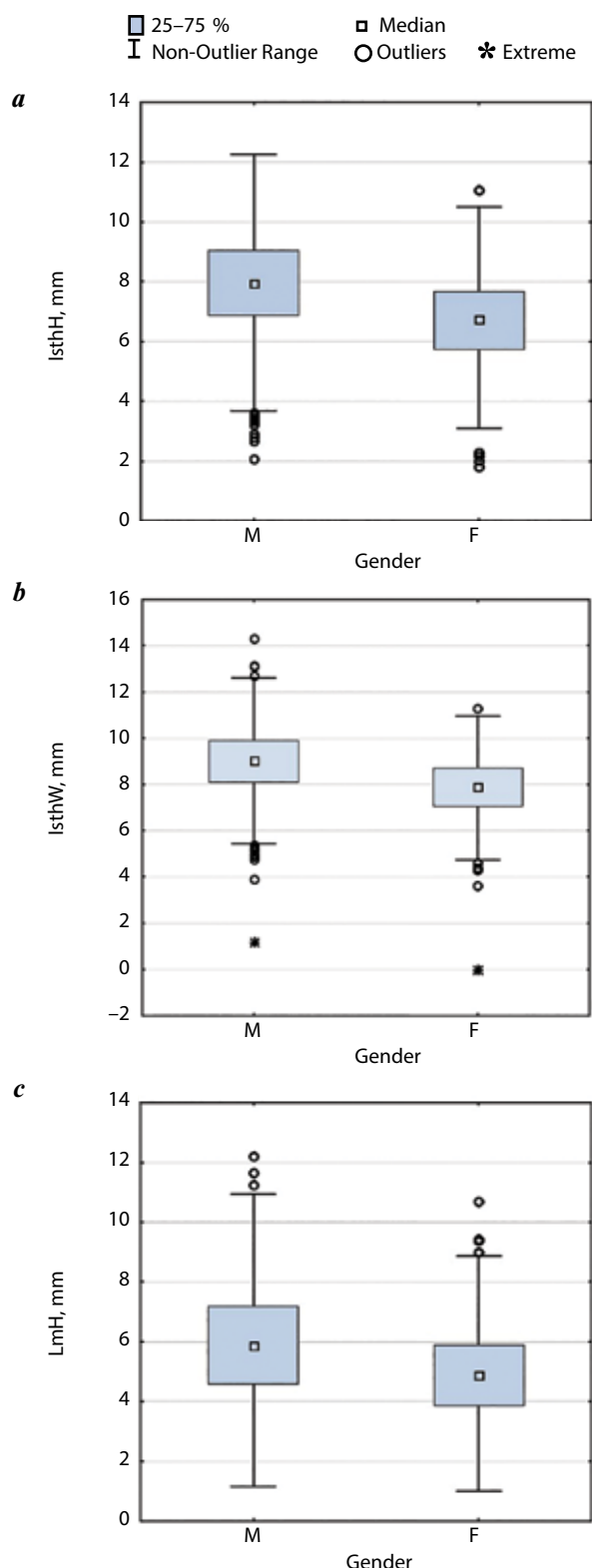


Fig. 5. Dimensions of evaluated morphometric parameters of the C2 vertebra depending on the patient's gender: a – isthmus height (IsthH); b – isthmus width (IsthW); c – lateral mass height (LmH)

invasive techniques can significantly lower by several times the amount of blood loss and anesthesia duration. Currently, the most controversial and debated aspect is the

Table 2. Distribution of patients depending on different types of left and right C2 isthmus (according to classification by M.H. Nogueira-Barbosa and H.L. Defino [5])

Left C2 isthmus, types	Right C2 isthmus, types				
	I	IIa	IIb	IIc	Total
I	585	17	7	6	615
IIa	26	14	0	3	43
IIb	7	1	3	3	14
IIc	5	1	1	4	11
Total	623	33	11	16	683

safety of TAF implementation. Its most formidable complication is the malposition of the screw in VA direction. The simulation study [4] has clearly demonstrated the possibility of percutaneous technique employing radiological landmarks only. At the same time, TAF safety may correspond to or exceed that of the classical methods of F. Magerl or Goel–Harms if a certain X-ray trajectory is selected. The main goal of our study is to determine the pool of patients to whom such a TAF could be applied.

Morphometric studies of feasibility of fixing interventions at the craniovertebral level based on CT-reformation data are extremely rare in the literature. To date, only 2 studies have been published in the field of the anatomical features of C2 isthmus during TAF application [5, 10]. These works have significant drawbacks. One of them is the possibility of making a systematic measurement error. All the data were obtained on the basis of only single measurement by a single expert. In the study [5], the authors have evaluated reproducibility of measurements by the same author with an interval of 2 months. In another study [10], the Student paired t-test was similarly used. Nevertheless, the same expert can make a systematic measurement error and repeat it at any time interval. To eliminate errors and inaccuracies, each measurement of each morphometric parameter must be performed 2 times by different experts [11]. Given that there is a high-degree correlation of responses between different experts, the arithmetic mean will approach the true value of the morphometric parameter. Also, in one study [5], a series of CT scans with slice thickness of 3 mm were used that can also produce a significant error in the morphometric parameter during implementation of multiplanar MPR reconstructions.

In our study, all the possible disadvantages that could affect the final result were eliminated. First of all, we formed a complete sample of all emergency patients who did not plan to go to hospital in advance. These patients performed CT not because of any orthopedic or neurological disease and this fact makes it possible to approximate the percentage of the craniovertebral transition anomalies to those actually occurring in the population. Secondly, each the parameter in the study was measured twice and the calculation of intraclass correlation made it possible to identify and eliminate the measurements that could include errors.

Comparing the already published data [5, 10], we note differences in the results. These differences may be due to both the above-mentioned methodology disadvantages and could also depend on difference between patients from different macroregions. Thus, in the study [5] there were patients from Latin American region, in the other [10] – from residents of Asian region, in our study – mainly from those of European region.

As result of the analysis, it was revealed that TAF (bilateral and monolateral) is generally feasible in most incoming patients. This procedure is contraindicated in only 3.2 % of all patients. C2 morphometric parameters in men are higher than in women. The parameters of the C2 isthmus make it possible to perform TAF employing only X-ray landmarks completely safely in 66 % of men and almost in 30 % of women, while the surgery with a risk of VA damage of 2.3 % – in 34 % of men and in 70 % of women. Thus, in our opinion, in the absence of other contraindications (incomplete reduction of atlantoaxial dislocation, need to create a bone fusion in C1–2 intervertebral space, anatomical

features of the neck and chest) and taking into account TAF feasibility and safety, it has proved to be the method of choice for all incoming patients.

CONCLUSIONS

In the present study, the morphometric parameters of isthmus and lateral mass of C2 vertebra were determined for the first time with the minimization of methodological errors and inaccuracies. The results obtained suggest that percutaneous bilateral TAF with the use of the posterior spinolaminar point and the middle of atlas anterior arch as landmarks could potentially be the method of choice in 88.3 % of patients. In 11.7 % of patients, the TAF was impossible to perform unilaterally or on both sides. Of all patients with normal anatomy of C2 isthmus, the probability to perform TAF without VA damage was twice more in men than in women and exceed 66 %. At the same time, the risk of VA injury in other patients does not exceed 2.3 %, that is comparable to the same outcome after implementation of other methods of C1–2 screw stabilization.

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Authors' contributions

I.S. Lvov: research design of the study, data analysis, article writing;
A.A. Grin: research design of the study, scientific editing of the article;
A.E. Talypov: research design of the study, scientific editing of the article;
S.Yu. Roshchin: literature review, data collection and analysis;
V.A. Sharifullin: data collection and analysis;
Z.A. Barbakadze: data collection and analysis;
E.E. Alekhin: data collection and analysis;
A.V. Tupikin: data collection and analysis;
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