Journal of Clinical Neuroscience 88 (2021) 135–141

Contents lists available at ScienceDirect

Journal of Clinical Neuroscience

journal homepage: www.elsevier.com/locate/jocn

Experimental study

Effects of exogenous factors on spatial accuracy in neurosurgery

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ARTICLE INFO

Article history:
Received 22 November 2020
Accepted 23 March 2021

Keywords:
Microsurgery
Surgical manipulation accuracy
Caffeine
Physical activity
Hand support
Night shift

ABSTRACT

The study aimed to assess the effect of exogenous factors such as surgeon posture, surgical instrument length, fatigue after a night shift, exercise and caffeine consumption on the spatial accuracy of neurosurgical manipulations. For the evaluation and simulation of neurosurgical manipulations, a testing device developed by the authors was used. The experimental results were compared using nonparametric analysis (Wilcoxon test) and multivariate analysis, which was performed using mixed models. The results were considered statistically significant at $p < 0.05$. The study included 11 first-year neurosurgery residents who met the inclusion criteria. Hand support in the sitting position (Wilcoxon test p value = 0.0033), caffeine consumption (p = 0.0058) and the length of the microsurgical instrument (p = 0.0032) had statistically significant influences on the spatial accuracy of surgical manipulations (univariate analysis). The spatial accuracy did not significantly depend on the type of standing position (Wilcoxon test p value = 0.2860), whether the surgeon was standing/sitting (p = 0.1029), fatigue following a night shift (p = 0.3281), or physical exertion prior to surgery (p = 0.2845).

When conducting the multivariate analysis, the spatial accuracy significantly depended on the test subject ($p < 0.0001$), the use of support during the test (p = 0.0001), and the length of the microsurgical instrument (p = 0.0397). To increase the spatial accuracy of microsurgical manipulations, hand support and shorter tools should be used. Caffeine consumption in high doses should also be avoided prior to surgery.

1. Introduction

Spatial accuracy (or movement accuracy) is referred to as the subject's ability to perform a motor action in exact accordance with the spatial characteristics determined in the task [1,2].

Microsurgical manipulations involve a combination of targeted and coordinated actions. The spatial accuracy of microsurgical manipulations is one of the most critical factors in successful surgical interventions, as with uncontrolled and inaccurate movements, microsurgical instruments can damage the tissues and important vessels within the operating field. The surgeon's manual precision may be one of the most important factors affecting the outcome of a microsurgical intervention.

In the literature, the following exogenous factors are usually analyzed as the most likely to influence microsurgical techniques: use of beta blockers [3], wrist support [4], listening to music in the operating room [5,6], length of surgical instruments [7], sleep deprivation [8], exercise [9], caffeine intake [10], alcohol consumption [11,12], and number of surgical gloves worn [13]. Despite a significant number of studies analyzing the listed factors, the vast majority of them were conducted using general surgical simulators and models. Most of the articles also concentrated on the dependence of hand tremor on the factors described above. The parameter that ultimately affects the result of a surgical manipulation, however, is its spatial accuracy.

In the present work, a study of the hypothetical influence of five exogenous factors on the spatial accuracy of neurosurgical manipulations was conducted.

2. Materials and methods

All procedures performed in this study were approved by the ethics committee of our neurosurgical center and conducted in accordance with the 1964 Helsinki Declaration and its later amendments.

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https://doi.org/10.1016/j.jocn.2021.03.039
0967-5868/

Study design: one-group experiment (Fig. 1).

To minimize the influence of prior microsurgical experience, the following inclusion criteria were used: surgeon age from 22 to 27 years, first year of residency in microsurgery, no previous long (more than 1 month) microsurgical training, and voluntary informed consent.

The exclusion criteria were as follows: experience playing musical instruments, prolonged (more than 6 months) dexterity training of the muscles of the hand and forearm, cardiovascular pathology, and allergic reaction to caffeine.

To assess spatial accuracy and simulate microsurgical manipulations, a device (Fig. 2) designed specifically for these purposes (patent for invention No. RU2679297C1) [14] and surgical microscope (Carl Zeiss) were used.

The body of the device and its limiting frame imitated both the trepanation window and the surgical corridor, at the bottom of which the surgical target was located.

As first year residents, all subjects underwent a 2-week course in general microsurgical instrument handling skills. Afterwards, each participant was involved in the training phase of the research on the device in a baseline experiment settings (Experiment №1).

During the training phase, each subject was instructed and performed the experiment №1 up to 10 times. The results of the training were recorded. It was noted that each subject's performance reached the plateau of the learning curve, which was assessed visually by the "attempt-result" graph at three consecutive points, i.e., for most subjects, the results of the 8th, 9th, and 10th attempts were approximately at the same level. We found a maximum of 10 ten-times in training was enough to see the plateau in the learning curve and ensure the same initial level of learning for the subjects. The subjects then underwent a testing phase in which they sequentially performed experiments according to the research plan (Fig. 1).

The spatial characteristics of the task (size of the trepanation window and surgical corridor) were the same for all participants in the experiment and as close as possible to the real intraoperative setting – a neurosurgical intervention using the burr hole technique [15].

The participants were required to perform an incision on a simulated arachnoid membrane of the brain around an artificial model of a brain artery using microsurgical scissors through a trepanation window measuring 1.0 by 1.0 cm and a 3.5-cm long surgical corridor (Fig. 3).

During performance of the task, it was necessary to minimize the number of times the microscissors touched the limiting frame of the device that simulated the surgical corridor (in real intraoperative settings, the surgical corridor is formed by brain tissue, blood vessels and nerves). The testing device automatically counted the number of times the microscissors touched the limiting frame. The final parameter, characterizing the spatial accuracy in the experiment, was the number of registered "touches" (errors) of the device frame.

2.1. Testing

Each of the study participants performed the experiments listed below, between which there was an interval of at least 24 h to eliminate the influence of fatigue on the study results. Duration of each experiment for a particular participant was the same. The nondominant hand, except for the experiments in the standing position, rested on the table.

1. *Assessment of spatial accuracy with the surgeon in the sitting position and hands resting on the device*

Subjects performed a microsurgical manipulation using straight microsurgical scissors (Aesculap FD030R, (Melsungen, Germany) total length 165 mm) with their hands resting on the device.

2. *Assessment of spatial accuracy with the surgeon in the sitting position without hand support*

The design of the experiment was similar to that described above; however, the subject's arms were extended forward and did not rest on any supports in any of the joints.

3. *Experiment using a longer microsurgical instrument*

The design of the experiment was the same as that of experiment №1, but the manipulations were performed using straight microscissors that had a total length of 225 mm (Aesculap FD037R).

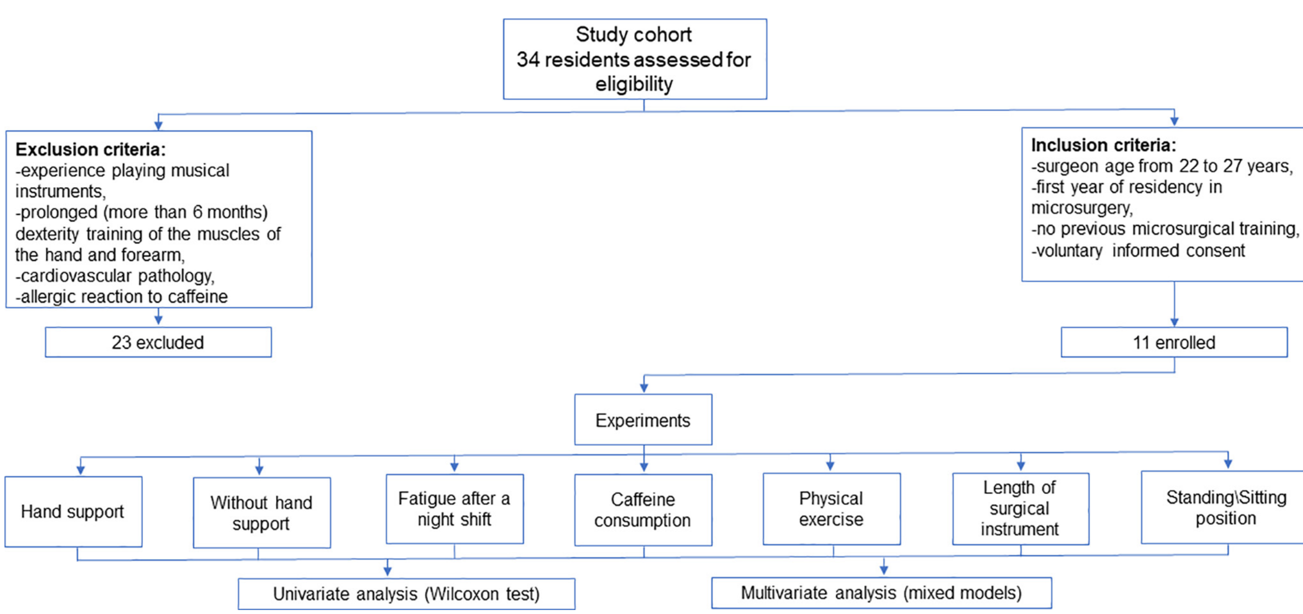

Fig. 1. Study design.

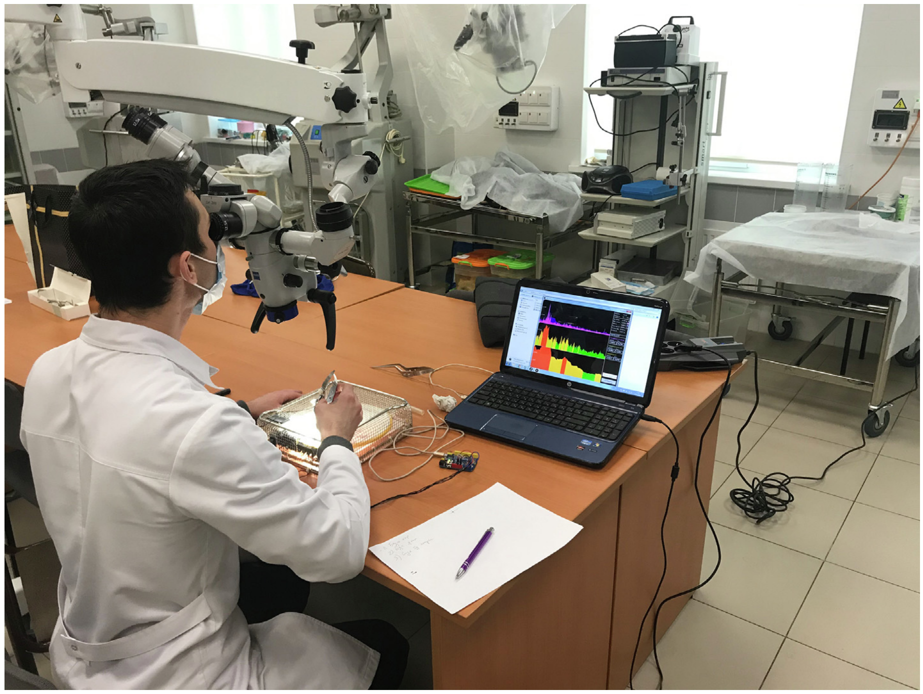

Fig. 2. Assessment of spatial accuracy with the surgeon in the sitting position and hands resting on the device.

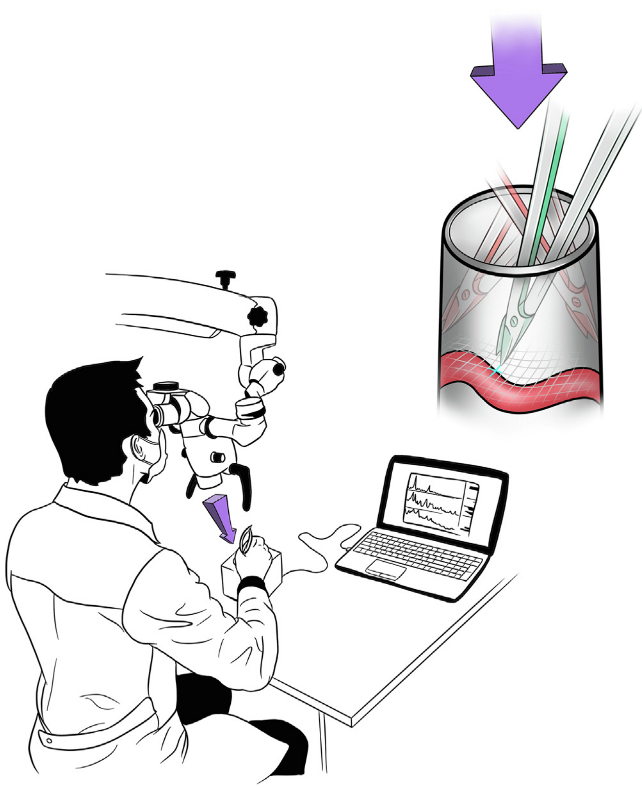

Fig. 3. Schematic representation of the testing process and the surgical target.

4. *Physical exercise experiments*

In these experiments, the subject was asked to perform the maximum possible number of push-ups prior to testing. Then, the participant performed a microsurgical task at intervals of 10, 60, and 280 min after finishing strength training.

5. *Experiments comparing the surgeon's hand position while standing*

The subject performed a microsurgical manipulation on a testing device using microsurgical scissors (Aesculap FD030R, total length 165 mm) and the most popular hand positions:

a. The fingers rested on the testing device.
b. The arms were held at the sides of the body and bent at the elbows.
c. The arms were extended forward without support.

6. *Assessment of the effects of fatigue after a night shift*

At 9.00–9.30 a.m. after the end of a 24-hour shift with a total sleep duration of no more than 4 h per shift, the subjects were tested.

7. *Experiment with caffeine consumption*

Prior to the experiment, participants excluded caffeine-containing drinks (tea, coffee, energy drinks) from their diet for 7 days. Before testing, the subjects consumed caffeine at a dose of 1.34 mg per 1 kg of body weight. Thirty minutes after consuming caffeine, the subjects performed a microsurgical manipulation using short microscissors (Aesculap FD030R) with their hands resting on the device in the sitting position.

2.2. Statistical analysis

All statistical studies were conducted using STATISTICA software (version 13.0, Dell Corp., Texas, USA). In a pairwise comparison with the use of one-way analysis, experiment No. 1 was used as the reference experiment for experiments 2, 3, 4, 6, and 7. The results of experiments 5 were compared separately.

For the purposes of exploratory analysis, a mixed-effects model, including the "number of errors" as the dependent variable, "test subject" as the random effect, and "position", "hand support", "tool length", "caffeine consumption", and "physical exercise " as fixed effects, was created. The coefficient of determination (R^2) was equal to 0.344.

P-values <0.05 were considered statistically significant.

3. Results

The study included 11 neurosurgery residents (8 males and 3 females) with an average age of 23.9 years (23–26).

The results (Fig. 4) demonstrated that, with univariate analysis (Table 1), the surgical spatial accuracy was significantly affected by hand support in the sitting position (Wilcoxon test p-value = 0.0033), caffeine consumption (p = 0.0058) and the length of the microsurgical instrument (p = 0.0032).

When conducting the multivariate analysis, the spatial accuracy significantly depended on the test subject (p < 0.0001), the use of support during the test (p = 0.0001), and the length of the microsurgical instrument (p = 0.0397) (Table 2).

4. Discussion

Spatial accuracy is one of the main criteria affecting the effectiveness of any surgical manipulation, as well as an integral criterion for mastering manual precision. The effectiveness of manual techniques in microsurgical interventions is largely determined by the ability of the microsurgeon to perform spatially precise motor activities using microsurgical instruments.

The current literature data are somewhat contradictory, and no consensus exists regarding the effects of different factors (exogenous or endogenous) on the physiology of precise manipulations in microsurgery.

4.1. Caffeine consumption

According to different studies, 50% [16] to 90% [17] of healthcare personnel consume caffeine in various forms (e.g., coffee, tea, and energy drinks) during and after night shifts, which tends to increase physiological resting tremors [18]. However, the dose of caffeine that increases resting tremor probably varies significantly from individual to individual and depends on the duration of caffeine consumption. In one study, it was shown that caffeine (5 mg/kg) significantly increased tremor in participating subjects [19], while in another study, the authors determined that more than 300 mg caffeine has a negative effect [20].

A number of studies have demonstrated the negative effect of caffeine on surgical techniques [10,21,22], while other studies have not reached such a conclusion [18]. According to the results of our study, in the univariate analysis, the use of caffeine significantly influenced the spatial accuracy of microsurgical manipulations. Multivariate analysis using a mixed-effects model did not reveal a statistically significant effect, which may be due to the small number of observations. It is likely that the effects of caffeine are highly individual, which leads to conflicting research results.

4.2. Exercise

There is a strong belief among physicians of microsurgical specialties that it is necessary, if possible, to avoid physical exertion before surgery.

At the same time, participating in long surgical interventions is impossible without general and profession-specific endurance, which can only be achieved through regular athletic training.

In most studies related to this issue, authors draw conclusions about the negative impact of physical exercise on surgical techniques [9,23–25].

We did not find statistically significant differences between the participants' baseline spatial accuracy and that after exercise. Possible reasons for the lack of a previously described effect could be related to a relatively low level of exertion during exercise and rapid recovery of the participants in our study.

4.3. Sleep deprivation

Night shifts and sleep deprivation are an integral part of any doctor's life and can ultimately cause psychological (mixed anxiety and depression disorder) and physiological disorders [26,27].

Obviously, sleep deprivation and general fatigue are not an advantage for an operating surgeon. However, the question is, how critical are they for surgical efficiency and microsurgical technique accuracy?

Among available studies related to this topic, some have shown that sleep deprivation has statistically significant negative effects on surgical technique precision [11,28–36] while other studies have not found such a correlation [37–44].The results of our study

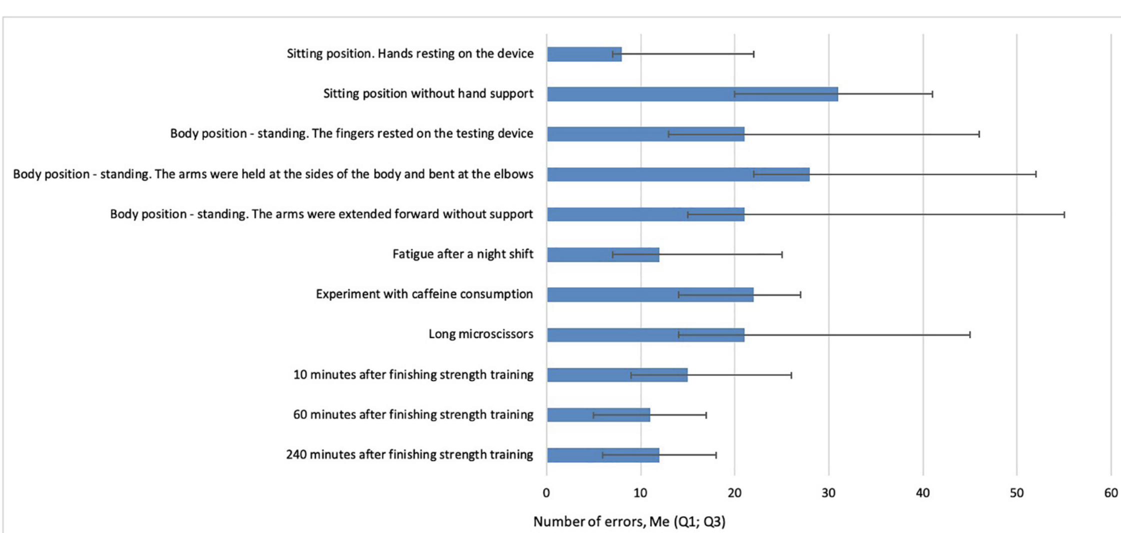

Fig. 4. Boxplots showing the number of errors across experiments (bars represent median, whiskers represent quartiles).

Table 1
Results of the experiments and univariate analysis.

№	Experiment	Number of errors, Me (Q1; Q3)	Pairwise comparison, reference experiment №	p-value
№1.	Sitting position. Hands resting on the device.	8 (7; 22)	–	–
№2.	Sitting position without hand support.	31 (20; 41)	№1	**0.0033**
№3	Long microscissors.	21 (14; 45)	№1	**0.0032**
№4	a. Sitting position. Hands resting on the device 10 min after finishing strength training.	15 (9; 26)	№1	0.2845
	b. Sitting position. Hands resting on the device 60 min after finishing strength training.	11 (5; 17)		0.5633
	c. Sitting position. Hands resting on the device 240 min after finishing strength training.	12 (6; 18)		0.3081
№5	a. Standing position. The fingers rested on the testing device.	21 (13; 46)	№5b	0.2860
	b. Standing position. The arms were held at the sides of the body and bent at the elbows.	28 (22; 52)	№5c	0.9645
	c. Standing position. The arms were extended forward without support.	21 (15; 55)	№5a	0.6103
№6	Fatigue after a night shift.	12 (7; 25)	№1	0.3281
№7	Experiment with caffeine consumption.	22 (14; 27)	№1	**0.0058**
	Comparing the surgeon's position (standing/sitting).		№1 with №5a	0.1029
			№2 with №5c	1.0000

Me – median; Q1 – lower quartile; Q3 – upper quartile.
Boldface values are statistically significant.

Table 2
Results of the multivariate analysis.

Effects	SS	df	MS	F	p
Intercept	11508.14	1	11508.14	46.00	<0.0001
Test subject	8310.85	10	831.08	4.22	**<0.0001**
Position	474.22	1	474.22	2.41	0.1246
Hand support	3154.04	1	3154.04	16.01	**0.0001**
Tool length	860.06	1	860.06	4.37	**0.0397**
Physical exercise	2	1	105.82	0.54	0.4657
Caffeine consumption	492.25	1	492.25	2.50	0.1177

SS- Sum of Squares; Df- Degree of freedom; MS-Mean Square; F-F-statistic.

show no effect of fatigue after 24-hour shifts (with no more than 4 total hours of sleep during a shift) on surgical spatial accuracy.

4.4. Surgeon posture and surgical instrument length

Surgical interventions of long duration are sometimes associated with the need to work while standing with the arms extended without support. In such cases, it is often necessary to use microinstruments up to 20 cm in length. In other cases, it is technically possible to operate in a sitting position and use various types of special devices [45] or the edges of the surgical wound for hand support. The results of the available studies addressing this issue indicate a decrease in the amplitude of tremor when utilizing hand support during surgery [4,21,46]. We have demonstrated a significant effect of the use of hand support in the sitting position and the length of the instrument on the spatial accuracy of the surgical manipulations through both univariate and multivariate analysis.

Some neurosurgeons operate only in the sitting position and use obligatory hand support, while others are constrained in this position, feel their freedom of movement is hindered in such conditions and tend to perform neurosurgery in a standing position. We have not found studies evaluating the effects of a surgeon's position on surgical accuracy, and the results of our study showed no differences in the spatial accuracy based on this factor.

Multivariate analysis of our results also demonstrated that the subject effect was statistically significant for the accuracy of surgical manipulations. More complex and systematic studies of endogenous factors, such as individual metabolic profiles of striated muscle tissue, should be performed to determine the practicality of such an approach. Perhaps in the future, the methods used in athletics and sports medicine for the selection of athletes will find their application in the selection of candidates for microsurgical medical specialties.

4.5. Limitations

The following factors may have influenced the results of the study: the subject factor and learning curve.

The study of the speed and dynamics of the subjects' training was not included in the objectives of the study and full consideration of this effect in the analysis would have required a more cumbersome design with multiple control repetitions, which was difficult to implement within the framework of this work. Nevertheless, we assume that the effect of training can be neglected since all subjects achieved a stable result in the baseline experiment at the training phase.

The factor of the individual subject's impact was addressed with a mixed effects model in the statistical analysis. A greater sample is desired for more robust estimation, therefore, we consider a sample size as a limitation.

Furthermore, the study was performed on a limited series of young neurosurgeons (first year residents), and spatial accuracy was investigated in strictly specified dimensions that are typical for burr hole and keyhole approaches used in neurosurgery.*Practical implications for surgical care*

- Hand support and short microsurgical instruments improve spatial accuracy
- Caffeine consumption in high doses should be avoided prior to surgery
- Moderate physical exercise prior to surgery does not affect spatial accuracy

- Fatigue following a night shift does not influence spatial accuracy
- The type of surgeon posture does not have a significant impact on spatial accuracy

5. Conclusions

Our study suggests that using hand rests and shorter instruments during surgical interventions may result in better spatial accuracy in neurosurgical trainees. It is also advisable to avoid the use of caffeine in large doses before surgery.

Funding

This research was supported by a grant from the Russian Science Foundation(project № 19-75-00058).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to express our sincere gratitude to all the participants for their efforts in this study.

Author contributions

Andrey E. Bykanov: conception and design, data acquisition and analysis, interpretation of the data, drafting of the manuscript for submission.

David I. Pitskhelauri: critical revisions of the manuscript.

Rinat A. Sufianov; Nikita S. Grachev: data acquisition, interpretation of data.

Timur R. Zagidullin, Gleb V. Danilov: statistical analyses.

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