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RĪGA STRADIŅŠ UNIVERSITY

Sniedze Mūrniece

Near-infrared Spectroscopy-Based Clinical Algorithm Applicability During Spinal Neurosurgery and Postoperative Cognitive Decline

Summary of the Doctoral Thesis for obtaining
the scientific degree "Doctor of Science (*PhD*)"

Sector Group – Medical and Health Sciences
Sector – Clinical Medicine
Sub-Sector – Anaesthesiology and Resuscitation

Riga, 2023

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The Doctoral Thesis was developed at Rīga Stradiņš University, Riga East Clinical University Hospital “Gaiļezers”, Latvia

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Table of Contents

Abbreviations used in the Thesis

Avg	average
Dx	dextra
EtCO2	end-tidal carbon dioxide
FiO2	fraction of inspired oxygen
Hb	haemoglobin
Hct	haematocrit
LE	laminectomy
MAC	minimal alveolar concentration
MAP	mean systemic arterial pressure
Max	maximum
MDE	microdiscectomy
mmHg	millimetre of mercury
MoCA	Montreal Cognitive Assessment Score
NIRS	near-infrared spectroscopy
O2	oxygen molecule
PaO2	partial pressure of oxygen in arterial blood
PEEP	positive end expiratory pressure
PND	perioperative cognitive disorder
POCD	postoperative cognitive disfunction
rScO2	regional cerebral oxygen saturation
SaO2	arterial oxygen saturation of haemoglobin
SD	standard deviation
Sin	sinistra
Spin Tu	spinal tumour
SpO2	peripheral oxygen saturation

SPSS	Statistical Package for the Social Sciences
TPF	transpedicular fixation
WHO	World Health Organisation

Introduction

Spinal surgery covers a wide range of operations on the spinal column and the underlying tissues and vary from uncomplicated microdiscectomy to surgery of life-threatening spinal fusions and spinal tumours, occasionally with long operation time and large blood loss. It also has been shown over the years that the number of spine surgeries has grown remarkably (Grotle, 2019). At the same time, operating techniques have progressed notably. Minimally invasive procedures with small incisions and a minimum of blood loss are performed, allowing patients to return to their daily activities sooner (Momin, 2020). The operating technique is not the only factor that determines postoperative outcome of the patients, anaesthesia-related factors also should be considered.

Spinal surgery patients are at risk of multiple postoperative complications that may be of neurological origin, such as radicular pain, motor weakness, or surgery-related infections, wound rupture, haematoma, or others (Willhuber, 2019). Several postoperative complications can also be associated with prone positioning, which is used for the majority of spinal surgeries. Prone positioning provides the best surgical conditions regarding visualization of the field. At the same time, prone positioning can promote various physiological changes, such as increased intra-abdominal and thoracic pressures potentially causing multiple organ failure and respiratory changes, postoperative visual loss (Kwee, 2015), motor weakness due to anterior spinal artery hypoperfusion (Bebawy, 2015). Respiratory changes and reduced venous return, causing reduced cardiac output, and not less importantly, intraoperative rotation of the head to the left or right, and/or flexion or extension of the neck, can promote cerebral hypoperfusion and deteriorate delivery of oxygen and substrates to the brain. There are studies showing that elderly patients undergoing spine surgery in the prone position experience cerebral desaturation more than twice as likely as patients in the supine position (Deiner, 2014).

As the organ most in need of a constant oxygen supply, because of a high metabolic activity, the brain consumes approximately 20 % of the oxygen delivered to the body (Rink, 2011). Due to its dependence on autoregulated blood flow with continuous oxygen delivery, hypoxic brain damage can be initiated after only 5 minutes of ischemia (Bebawy, 2015) leading to severe consequences.

Postoperative cognitive dysfunction or decline (POCD) following non-cardiac surgery, affects a number of patients of all ages (Monk, 2008). New-onset cognitive disturbances following a surgical intervention may not only alter postoperative patient recovery (Denault, 2014), but may also result in long-term consequences (Steinmetz, 2009). The exact aetiology of POCD remains unclear. Its pathogenesis is multifactorial, including age, pre-existing comorbidities (cardiac, cerebrovascular), alcohol abuse, and intra- and postoperative complications. While several studies claim that POCD is transient (Abildstrom, 2000), others show significant cognitive impairment even 6 and 8 years after surgery (Selnes, 2008) (Steinmetz, 2009) and even death (McDonagh, 2010).

Despite advances in technology and improved patient safety, the brain remains one of the least monitored organs during surgery. Several methods are available to assess various products of brain metabolism or physiological functions. Jugular bulb cannulation and jugular venous oximetry provide insight into cerebral blood flow and the oxygenation status of the brain. A Clark electrode, inserted directly into the brain parenchyma, shows the oxygenation status of brain tissue. A cerebral microdialysis catheter inserted at the site of injury can measure various biochemical markers, such as glucose, lactate, pyruvate, glutamate, aspartate and potassium (Mahajan, 2013). Unfortunately, all of these methods are highly invasive, which is restricting their use in clinical practice.

Near-infrared spectroscopy (NIRS) has been a well-known technology in medicine since 1977. Jobsis then introduced NIRS for tissue oxygen monitoring (Jobsis, 1977). Cerebral oximeters are non-invasive devices that can be used from the beginning of cardiac surgery or for monitoring traumatic brain injury (Davies, 2015), as well as during abdominal, orthopaedic, urological, gynaecological or thoracic surgical procedures (Nielsen, 2014). Nowadays, NIRS devices, such as cerebral oximeters, are widely used to monitor continuous cerebral oxygen saturation (rScO2) in real time and are widely used to predict brain outcome after cardiac arrest and even to monitor the brain during reanimation (Cournoyer, 2016).

A NIRS-based algorithm is available (Denault, 2014) to help clinicians guide the intraoperative management of patients in cases when cerebral oxygen saturation decreases and active management is required to restore adequate levels and avoid cerebral hypoxia.

Aim of the Thesis

The goal of this Thesis was to evaluate cerebral oxygen saturation in patients undergoing spinal neurosurgery in the prone position using Near-infrared spectroscopy in conjunction with a NIRS-based clinical algorithm, with a further aim of assessing a possible relationship between cerebral oxygenation and a postoperative cognitive decline.

Objectives of the Thesis

1. To determine whether patients undergoing spinal neurosurgery in the prone position experience cerebral desaturation.

2. To evaluate pre- and postoperative cognitive function in patients, who underwent monitoring of regional cerebral oxygen saturation by means of Near-infrared spectroscopy during spinal neurosurgery in the prone position.
3. To determine the value of the NIRS-based clinical algorithm in patients with cerebral desaturation in terms of restoring adequate rScO2 values and postoperative cognitive function.
4. To evaluate the correlation and association of age, haemoglobin, haematocrit, length of surgery, intraoperative blood loss, preoperative and intraoperative systemic MAP, intraoperative end-tidal carbon dioxide, peripheral oxygen saturation and preoperative cognitive function with intraoperative rScO2 values.
5. To identify, whether intraoperative rScO2 values correlate with postoperative cognitive function.
6. To evaluate the usefulness of cerebral oxygen monitoring and a NIRS-based clinical algorithm during spinal surgery with the aim of preventing postoperative cognitive decline.

Hypotheses of the Thesis

Providing adequate cerebral oxygen saturation during spinal neurosurgery in the prone position is essential for avoiding postoperative cognitive decline.

Novelty of the Thesis

A significant number of patients suffer from postoperative cognitive disturbances that impair recovery and return to their daily activities. Apparently, postoperative cognitive decline remains unrecognised unless cognitive monitoring function tools are applied.

Patient safety is one of the most important goals in clinical practice. However, the brain remains one of the least monitored organs intraoperatively.

We have attempted to implement two factors that may improve intraoperative patient safety and avoid postoperative cognitive complications. The first factor is the use of intraoperative cerebral oximetry, which is a non-invasive and easy-to-use method. The second is a tool to assess the patient’s cognitive status using the Montreal Cognitive Assessment Score (MOCA). Our study is one of the few to use cerebral oximetry intraoperatively in spinal surgery patients, and the first to use the MOCA score to assess cognitive function in spinal surgery patients.

1 Materials and Methods

This study was designed as a prospective randomised controlled trial of patients undergoing spinal surgery. Patients were collected between September 2018 and July 2020 in the Clinic of Neurology and Neurosurgery of Riga East Clinical University Hospital “Gaiļezers”. Inclusion criteria were patients aged over 18 years, patients scheduled for spinal surgery performed in the prone position. Exclusion criteria were emergency spinal surgery, patients with known cerebrovascular or psychiatric disease, previous history of stroke, inability to undergo preoperative or postoperative cognitive evaluation (severe pre-or postoperative pain, intake of strong opioid pain medication, intake of sedative medication).

The Research Ethics Committee and Ethics Committee of Rīga Stradiņš University approved the study protocol and the informed consent form (Approval No. 6-2/11/59; No. 85/29.12.2016) (see Annex 1).

The preoperative physical status of the patients was evaluated, blood tests were taken from all patients to obtain haemoglobin (Hb) and haematocrit (Hct) concentrations.

Patients were randomised into a study group and a control group by using a computerised randomization program.

1.1 Anaesthesia and intraoperative patient monitoring

All the patients received general anaesthesia. We induced anaesthesia with fentanyl 0.1–0.2 mg, propofol 1–2 mg/kg and cisatracurium 0.2 mg/kg or atracurium 0.3–0.6 mg/kg for endotracheal intubation. Anaesthesia was maintained with a continuous infusion of fentanyl 0.03–0.06 μg/kg/min, and / or fentanyl boluses 0.05–0.1 mg if heart rate or non-invasive blood pressure raised above 20 % from preoperative values. Cisatracurium continuous infusion

0.06–0.1 mg/kg/h or boluses 0.03–0.2 mg/kg or atracurium continuous infusion 0.3–0.6 mg/kg/h or boluses 0.1–0.2 mg/kg were used when the patient displayed signs of spontaneous breathing. Sevoflurane was kept at minimum alveolar concentration (MAC) 0.6–0.8. Initial tidal volume for mechanical ventilation was set to 7–8 mL/kg. Positive end expiratory pressure (PEEP) of 4–6 cmH2O was used and the fraction of inspired oxygen (FiO2) was 0.5. Ventilation was adjusted to keep end-tidal carbon dioxide (EtCO2) in the range of 35 to 45 mmHg.

Intraoperative variables such as non-invasive mean arterial pressure (MAP) was determined every 5 min. The first MAP values (2 to 3 measurements) measured before induction of anaesthesia, were fixed as preoperative values in the study protocol. Peripheral oxygen saturation (SpO2) and end-tidal carbon dioxide (EtCO2) were documented in the study protocol every 5 min. At the end of the surgery, we recorded the duration of operation and intraoperative blood loss. All the patients were extubated in the operating room.

1.2 Intraoperative cerebral oxygen saturation measurements

In all patients, regional cerebral oxygen saturation was continuously monitored using a near-infrared spectroscopy device (NIRS) INVOS (In Vivo Optical Spectroscopy) 4100 (Covidien, Minneapolis, USA).

After arriving in the operating room before induction of anaesthesia, breathing room air without additional oxygen, two adhesive INVOS rScO2 sensors were placed on the patients’ forehead, one above the right (Dx) and one above the left (Sin) eyebrow. Sensors were connected to the INVOS cerebral oximeter monitor. The preoperative rScO2 values were observed 3–5 minutes with patient breathing room air, at the time-point where they did not change anymore and stayed stable, they were fixed in the study protocol and set as baseline rScO2 values. By establishing baseline rScO2 values, INVOS further tracked the changes in rScO2 values for the left (Sin) and the right side (Dx), respectively, showing the raise or drop from baseline rScO2 values in percentage. Then, regional cerebral oxygen saturation values were registered in the study protocol every 5 minutes as single point measurements.

All the measurements noted in the study protocol, were described as follows: PreOp (Preoperative) values – fixed after the patient had arrived in the operating room, before induction of anaesthesia; Sup (Supine) values – fixed at the time and after the induction of anaesthesia when the patient was still lying supine; Prone values – fixed when the patient was lying in the prone position; Sup2 (Supine) values – fixed at the end of the surgery when the patient was turned back to the supine position.

1.3 NIRS-based intervention algorithm

In the study group intraoperative rScO2 values were kept within a range of 20 % from baseline, or above an absolute rScO2 value of 50 %. As soon as the rScO2 values dropped bilaterally or unilaterally below 20 % from baseline, or below an absolute value of 50 %, the NIRS algorithm was started (Denault, 2014) (see Annex 2). Based on this algorithm, steps are taken in the following order: 1) the position of the head is verified (rotation of the head to the left or right, and / or flexion or extension of the neck are excluded), to rule out mechanical obstruction that could alter cerebral blood and oxygen supply; 2) MAP is increased to maintain cerebral perfusion pressure; 3) systemic oxygenation status is improved if arterial oxygen saturation (SaO2) is low; 4) partial pressure of carbon dioxide (PaO2) is normalised if hypocapnia or hypercapnia is identified; 5) haemoglobin is optimised (according to the algorithm, Hb less than 7–8 g/dL requires red blood cell transfusion); 6) cardiac function is evaluated if the previous steps failed; as a last step, 7) cerebral oxygen consumption should be estimated (convulsions, hyperthermia) (Denault, 2014). Since the algorithm was created for cardiac surgery patients, it also included a step in which central aortic and superior vena cava catheters were inspected. Our algorithm was adapted for use in spinal surgery patients. If rScO2 values did not raise above the threshold values after the two first steps, an arterial blood gas sample would be taken to evaluate SaO2, PaCO2 or Hb level.

Control group patients received standard intraoperative anaesthetic management, rScO2 was monitored blindly, and the investigator was kept unaware about the NIRS results. If MAP dropped below 65 mmHg (Van Diepen, 2017), excessive bleeding was excluded and when indicated, Ephedrine boluses were administered. If SpO2 dropped under 94 %, inspired oxygen concentration was raised above 50 % (Kane, 2013). If haemorrhage of more than 500 ml occurred, arterial blood gas analyses was performed to detect Hb levels and to evaluate the necessity for a blood transfusion. A haemoglobin concentration below 7 to 8 g/dL during haemorrhage was considered a trigger for transfusion (Kozek-Langenecker, 2017).

In the control group, if the rScO2 value dropped by more than 30 % from the individual baseline values, the INVOS system was set to give an alarm, and after all the necessary actions had been taken to restore cerebral oxygenation, the patient was excluded from the study.

1.4 Cognitive evaluation

To evaluate patient cognitive status, we used Montreal Cognitive Assessment (MoCA) test. The test was used in both groups. The first test was performed in the ward during the preoperative visit, 1 to 2 days before surgery. The second test was performed two days after the surgery to avoid any interaction of the intraoperative anaesthetic or acute postoperative pain with the performance of the test. The MoCA test evaluates the following parameters: attention, concentration, executive functions, memory, language, visuo-constructional skills, conceptual thinking, calculation and orientation (MoCA Montreal Cognitive Assessment) (see Annex 3). The MoCA test has been validated in several languages, including Latvian and Russian since these tests have to be performed in the patient’s native language. The test takes approximately 10–15 min to complete. The MoCA test scores range from 0 to 30 points. Postoperative cognitive decline was defined as a reduction in postoperative MoCA test scores compared to preoperative MoCA scores. The MoCA test was performed by one person to ensure that the test was performed in the same manner.

2 Statistical Analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) V.23. Data distribution was tested using the Kolmogorov-Smirnov test. Groups were compared using the t-test for parametric data and the Mann-Whitney test for non-parametric data. Values were presented as the mean ± standard deviation (SD).

Statistical significance was assumed at $p < 0.05$. The Kruskal-Wallis test was performed to determine the p value between three or four patient groups.

Repeated measurements during different phases of a surgery were analysed using repeated measures ANOVA (and Huynh-Feldt correction if the sphericity assumption was violated) in JASP Version 0.11.1.

Spearman's rank correlation coefficient and significance was used to describe correlations between variables. A positive correlation means that as one variable is increasing, the other variable is also increasing. A negative correlation coefficient means that as the value of one variable is going up, the value for the other is decreasing. The Spearman's rho correlation coefficient $\rho = 1$ shows the perfect correlation; $\rho = 0.02$ – a very low correlation; $\rho = 0.2–0.4$ – a low correlation that may warrant further investigation; $\rho = 0.4–0.6$ – a reasonable correlation; $\rho = 0.6–0.8$ – a high correlation; and $\rho = 0.8–1.0$ – a very high correlation.

3 Results

In the present study, a total of 64 adult neurosurgical patients were included – 37 (57.8 %) women and 27 (42.2 %) men, aged 55 ± 15 (mean ± SD) years. Forty-two patients belonged to the study group (21 (50 %) women and 21 (50 %) men; mean age 56 ± 13 years), and 22 patients belonged to the control group patients (16 (72.7 %) women and 6 (27.3 %) men; mean age 53 ± 17 years), p = 0.7 (Table 3.1).

Table 3.1

Per cent patient distribution by age groups – in study group, control group and in all study patients together

Age	**Study group**		**Control group**		**Total**	
	n	**%**	**n**	**%**	**n**	**%**
18–30	0	0	4	18	4	6
31–40	4	10	2	9	6	9
41–50	10	24	3	14	13	20
51–60	15	36	2	9	17	27
61–70	6	14	9	41	15	23
71–80	5	12	2	9	7	11
81–90	2	5	0	0	2	3
91–100	0	0	0	0	0	0

* n – number of patients

One patient of the control group patient was excluded from the study because the regional cerebral oxygen saturation values dropped by more than 30 % from the patient’s individual baseline values and the INVOS device alarm was activated, which initiated the necessary actions to restore cerebral oxygenation.

3.1 Type of surgery

Patients underwent the following spinal surgeries in the prone position: 6 patients (9.4 %) had laminectomy (LE), 28 patients (43.8 %) had minimal invasive microdiscectomy (MDE), 12 patients (18.8 %) had spinal tumour evacuation (Spin Tu) and 18 patients (28.1 %) underwent transpedicular spinal fixation (TPF).

The distribution between study and control group is shown in Figure 3.1.

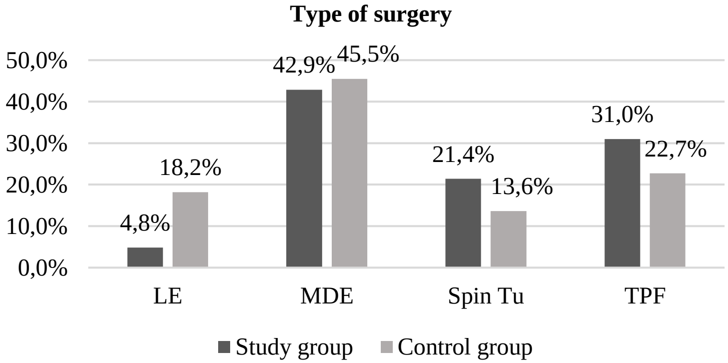

Figure 3.1 **Type of the surgery performed in the study and control groups**

LE – laminectomy, MDE – microdiscectomy, Spin Tu – spinal tumour evacuation, TPF – transpedicular fixation.

3.2 Preoperative laboratory tests

Before the operation standard preoperative laboratory tests were made to determine preoperative haemoglobin und haematocrit level. The mean Hb was 14 ± 2 mg/dl in the study group and 13 ± 1 mg/dl in the control group (p = 0.06). Similarly, there was no significant difference in the mean Hct value between the study and control groups (Table 3.2).

Table 3.2

Mean Hb (mg/dl) and Hct (%) level in study group, control group patients and in all study patients together (mean ± SD)

Indicator	Study group		Control group		p value	Total	
	Mean	SD	Mean	SD		Mean	SD
Hb (mg/dl)	14	2	13	1	0.06	14	2
Hct (%)	42	4	40	4	0.1	41	4

3.3 Duration of the operation

The mean duration of the operation was 116 ± 16 min for all the patients. In the study group, the mean operation time was 128 ± 42 min compared to 104 ± 49 min in the control group. The operation time in the study group was significantly longer than the operation time in the control group with a p value of 0.028.

3.4 Intraoperative blood loss

At the end of the surgery, the mean blood loss was 236 ± 10 ml in total in all study patients. The mean intraoperative blood loss did not show any significant differences between the groups and was 245 ± 97 ml in the study group and 220 ± 115 ml in the control group (p = 0.262).

3.5 Preoperative and intraoperative non-invasive measurements

3.5.1 Mean systemic non-invasive arterial blood pressure (MAP)

The preoperative MAP of 103 ± 10 mmHg in the study group was significantly higher than that of 93 ± 9 mmHg in the control group (p = 0.001). The following intraoperatively measured MAP values, presented as mean, minimum, and maximum values after the intubation with the patient lying supine, during the surgery with the patient lying in the prone position, and at the end of the surgery when the patient was again in the supine position, did not show any statistical differences between the groups, as displayed in Table 3.3.

Table 3.3

The average (Avg), minimum (Min) and maximum (Max) mean systemic arterial pressure in millimetre of mercury (mmHg) in the study group, control group patients and in total (mean ± SD)*

Indicator	**Study group**		**Control group**		**p value**	**Total**	
	Mean	**SD**	**Mean**	**SD**		**Mean**	**SD**
Avg MAP PreOp (mmHg)	103	10	93	9	**0.001**	100	11
Avg MAP Sup (mmHg)	88	15	85	16	0.287	87	16
Min MAP Sup (mmHg)	77	19	78	17	0.477	77	18
Max MAP Sup (mmHg)	101	25	90	18	0.092	97	23
Avg MAP Prone (mmHg)	82	9	80	7	0.466	81	9
Min MAP Prone (mmHg)	65	13	69	8	0.436	66	12
Max MAP Prone (mmHg)	102	17	96	10	0.204	100	15
Avg MAP Sup2 (mmHg)	90	14	87	12	0.440	89	13
Min MAP Sup2 (mmHg)	81	19	82	14	0.851	82	17
Max MAP Sup2 (mmHg)	97	18	92	13	0.286	95	16

* Preoperative (PreOp), after the intubation with patient lying supine (Sup), in the prone position (Prone), at the end of the surgery when patient was turned again supine (Sup2).

In the study group, the MAP analysis using repeated measures ANOVA with Huynh-Feldt correction shows that there is a significant difference between at least two phases ($p < 0.001$).

The post-hoc analysis shows that the difference is among Prone, Supine, Supine 2 and the Preoperative values; and between Prone and Supine 2 (p = 0.005) (Table 3.4).

Table 3.4

The repeated MAP measures ANOVA and post-hoc analysis in the study group

Operation stage	**Operation stage**	**Mean difference**	**SE**	**t**	**p value**
PreOp	Prone	20.27	1.619	12.517	< 0.001
PreOp	Sup	15.216	2.581	5.894	< 0.001
PreOp	Sup2	13.324	2.674	4.983	< 0.001
Prone	Sup2	−6.946	2.057	−3.376	0.005

* Preoperative (PreOp), after the intubation with patient lying supine (Sup), in the prone position (Prone), at the end of the surgery when patient was turned again supine (Sup2), standard error (SE), t-test (t).

In the control group the MAP analysis using repeated measures ANOVA with Huynh-Feldt correction shows that there is a significant difference between at least two phases (p = 0.009).

The post-hoc analysis shows that the difference is among Prone, Supine and the Preoperative values; and between Prone and Supine 2 (p = 0.04) (Table 3.5).

Table 3.5

The repeated measures ANOVA and post-hoc analysis for MAP in the control group

Operation stage	**Operation stage**	**Mean difference**	**SE**	**t**	**p value**
PreOp	Prone	13.65	2.269	6.016	< 0.001
PreOp	Sup	9	3.039	2.961	0.04
Prone	Sup2	−7.25	2.489	−2.913	0.04

* Preoperative (PreOp), after the intubation with patient lying supine (Sup), in the prone position (Prone), at the end of the surgery when patient was turned again supine (Sup2), standard error (SE), t-test (t).

3.5.2 Cerebral oximetry measurements

Regional cerebral oximetry (rScO2) was determined pre- and intraoperatively in all patients of the study. Distribution of data between the study group and the control group and the levels of statistical significance are shown in Table 3.6. The rScO2 values are also presented separately for values measured above the right (Dx) and the left (Sin) cerebral hemisphere, respectively.

Table 3.6

Preoperative (Preop) and average (Avg), minimum (Min), maximum (Max) rScO2 values in percentage above right (Dx) and left cerebral hemisphere (Sin) in the study group, the control group and in the total patient population (mean ± SD) *

Indicator	**Study group**		**Control group**		**p value**	**Total**	
	Mean	**SD**	**Mean**	**SD**		**Mean**	**SD**
Preop rScO2 Dx (%)	71	9	75	9	**0.047**	73	9
Preop rScO2 Sin (%)	72	10	76	9	0.141	73	10
Avg Sup rScO2 Dx (%)	78	11	80	12	0.412	79	11
Min Sup rScO2 Dx (%)	77	11	78	12	0.578	77	11
Max Sup rScO2 Dx (%)	80	11	82	12	0.571	81	11
Avg Sup rScO2 Sin (%)	79	11	79	11	0.806	79	11
Min Sup rScO2 Sin (%)	76	11	77	10	0.702	76	11
Max Sup rScO2 Sin (%)	81	11	81	12	0.898	81	11
Avg Prone rScO2 Dx (%)	77	8	82	9	**0.010**	79	8
Min Prone rScO2 Dx (%)	71	9	78	10	**0.004**	74	10
Max Prone rScO2 Dx (%)	83	7	86	8	0.143	84	8
Avg Prone rScO2 Sin (%)	77	8	82	7	**0.017**	79	8
Min Prone rScO2 Sin (%)	73	9	79	8	**0.012**	75	9
Max Prone rScO2 Sin (%)	82	8	86	7	0.105	84	8
Avg Sup2 rScO2 Dx (%)	77	9	81	10	0.051	78	10
Min Sup2 rScO2 Dx (%)	75	10	80	10	0.051	77	10
Max Sup2 rScO2 Dx (%)	78	9	83	10	0.067	80	9
Avg Sup2 rScO2 Sin (%)	77	10	81	9	0.054	78	10
Min Sup2 rScO2 Sin (%)	75	11	80	9	0.078	76	11
Max Sup2 rScO2 Sin (%)	78	9	83	10	0.058	80	9

* After the intubation with patient lying supine (Sup), in the prone position (Prone), at the end of the surgery when patient was turned supine (Sup2) again.

We found a significantly lower preoperative mean rScO2 Dx in the study group as compared to the control group. We also observed that the average and minimal rScO2 values above the right and the left cerebral hemisphere with the patient lying in the prone position were statistically higher in the control group (Table 3.6).

Study group

Regional cerebral oxygenation above the right cerebral hemisphere (rScO2 Dx) analysis using repeated measures ANOVA with Huynh-Feldt correction shows that there is a significant difference between at least two phases ($p < 0.001$).

The post-hoc analysis shows that the difference is among prone, sup1, sup2 and the preop values (Table 3.7).

Table 3.7

The repeated measures ANOVA and post-hoc analysis for rScO2 Dx in the study group

Operation stage	Operation stage	Mean difference	SE	p value
PreOp	Prone	−5.919	1.254	< 0.001
PreOp	Sup	−7.865	1.235	< 0.001
PreOp	Sup2	−5.459	1.167	< 0.001

* Preoperative (PreOp), after the intubation with patient lying supine (Sup), in the prone position (Prone), at the end of the surgery when patient was turned again supine (Sup2), standard error (SE).

Regional cerebral oxygenation above the left cerebral hemisphere (rScO2 Sin) analysis using repeated measures ANOVA with Huynh-Feldt correction showed that there was a significant difference between at least two phases ($p < 0.001$).

The post-hoc analysis showed that the difference was among prone, sup1, sup2 and the preop values (Table 3.8).

Table 3.8

The repeated measures ANOVA and post-hoc analysis for rScO2 Sin in the study group

Operation stage	**Operation stage**	**Mean difference**	**SE**	**p value**
PreOp	Prone	−6.056	1.186	< 0.001
PreOp	Sup	−7.611	1.172	< 0.001
PreOp	Sup2	−4.694	1.162	0.001

* Preoperative (PreOp), after the intubation with patient lying supine (Sup), in the prone position (Prone), at the end of the surgery when patient was turned again supine (Sup2), standard error (SE).

Control group

Regional cerebral oxygenation above the right and left cerebral hemispheres (rScO2 Dx and rScO2 Sin) analysis using repeated measures ANOVA with Huynh-Feldt correction showed that there was a significant difference between at least two phases (both $p < 0.001$).

The post-hoc analysis showed that the difference was among prone, sup1, sup2 and the preop values (Tables 3.9 and 3.10).

Table 3.9

The repeated measures ANOVA and post-hoc analysis for rScO2 Dx in the control group

Operation stage	**Operation stage**	**Mean difference**	**SE**	**p value**
PreOp	Prone	−6.706	1.439	0.002
PreOp	Sup	−6.353	1.447	0.002
PreOp	Sup2	−6.059	1.598	0.006

* Preoperative (PreOp), after the intubation with patient lying supine (Sup), in the prone position (Prone), at the end of the surgery when patient was turned again supine (Sup2), standard error (SE).

Table 3.10

The repeated measures ANOVA and post-hoc analysis for rScO2 Sin in the control group

Operation stage	Operation stage	Mean difference	SE	p value
PreOp	Prone	−6.824	1.493	0.002
PreOp	Sup	−5.412	1.401	0.007
PreOp	Sup2	−5.588	1.683	0.017

* Preoperative (PreOp), after the intubation with patient lying supine (Sup), in the prone position (Prone), at the end of the surgery when patient was turned again supine (Sup2), standard error (SE).

3.5.3 Peripheral oxygen saturation (SpO2)

Table 3.11 shows the peripheral oxygen saturation measured by pulse oximetry (SpO2) at the same time-points as the variables presented above, i.e. sampled preoperatively in the operating room, with the patients breathing room air before induction of anaesthesia and lying supine, and in the prone position, and at the end of the surgery when the patients were turned back into the supine position.

Table 3.11

Average (Avg), minimum (Min), maximum (Max) SpO2 values presented as percentages in the study group, the control group and in total patient population, respectively (mean ± SD)*

Indicator	Study group		Control group		p value	Total	
	Mean	SD	Mean	SD		Mean	SD
Avg PreOp SpO2 (%)	99.07	1.47	97.73	2.41	<u>0.026</u>	98.61	1.94
Avg SpO2 Sup (%)	99.77	0.58	99.15	1.42	0.059	99.56	0.99
Min SpO2 Sup (%)	99.49	1.23	99.10	1.45	0.183	99.36	1.31
Max SpO2 Sup (%)	99.92	0.27	99.25	1.41	0.017	99.69	0.90
Avg SpO2 Prone (%)	99.93	0.46	99.82	0.50	0.089	99.89	0.48
Min SpO2 Prone (%)	99.76	1.25	99.59	0.96	0.078	99.70	1.15
Max SpO2 Prone (%)	100.00	0	99.91	0.29	<u>0.049</u>	99.97	0.18

Table 3.11 continued

Indicator	Study group		Control group		p value	Total	
	Mean	SD	Mean	SD		Mean	SD
Avg SpO2 Sup2 (%)	99.88	0.44	99.20	1.41	0.008	99.65	0.95
Min SpO2 Sup2 (%)	99.69	1.14	99.05	1.65	0.016	99.47	1.36
Max SpO2 Sup2 (%)	100	0	99.41	1.33	0.001	99.80	0.82

* Preoperatively (Preop), after the intubation with the patients lying supine (Sup), in the prone position (Prone), at the end of the surgery when the patients were turned supine again (Sup2).

3.5.4 End-tidal expired carbon dioxide (EtCO2)

End-tidal expired carbon dioxide measurements after intubation in the supine position, in the prone position and at the end of the surgery in supine position before extubation are shown in Table 3.12.

Table 3.12

Average (Avg), minimum (Min) and maximum (Max) EtCO2 values in millimetre of mercury in the study group, in the control group and in the patients in total (mean ± SD)*

Indicator	Study group		Control group		p value	Total	
	Mean	SD	Mean	SD		Mean	SD
Avg EtCO2 Sup (mmHg)	34	4	35	2	0.657	34	4
Min EtCO2 Sup (mmHg)	33	4	35	2	0.467	34	4
Max EtCO2 Sup (mmHg)	35	4	35	3	0.830	35	4
Avg EtCO2 Prone (mmHg)	35	2	34	2	0.236	35	2
Min EtCO2 Prone (mmHg)	33	3	33	2	0.744	33	3
Max EtCO2 Prone (mmHg)	37	2	36	2	**0.027**	37	2

Table 3.12 continued

Indicator	Study group		Control group		p value	Total	
	Mean	SD	Mean	SD		Mean	SD
Avg EtCO2 Sup2 (mmHg)	35	3	35	3	0.600	35	3
Min EtCO2 Sup2 (mmHg)	35	3	35	3	0.682	35	3
Max EtCO2 Sup2 (mmHg)	35	3	35	3	0.564	35	3

* After the intubation with patients lying supine (Sup) and in the prone position (Prone), at the end of the surgery when the patients were turned supine (Sup2) again.

3.6 Patient demographic parameters and intraoperative measurements based on the type of the surgery performed

Statistically significant differences among patients based on the type of the surgery (LE, MDE, Spinal Tu evacuation, TPF) were observed in the following parameters and measurements:

- age,
- intraoperative blood loss,
- duration of the operation,
- minimal value of the rScO2 above the right cerebral hemisphere in the supine position, and average rScO2 value above the left cerebral hemisphere in the supine position after the intubation.

Patients in the LE group were the oldest (73 ± 7 years), and those in the MDE group were the youngest (48 ± 13 years), p = 0.001.

Intraoperative blood loss was statistically the highest during TPF operations, and it was 311 ± 98 ml with the p value < 0.000.

In terms of operation time, the longest operation time was observed in the Spinal Tumour evacuation group, which was 163 ± 54 min compared to LE – 103 ± 39 min, MDE – 100 ± 31 min and TPF – 126 ± 42 min (p = 0.004).

When analysing patient rScO2 measurements based on the type of surgery, the only statistically significant differences observed were as follows: the minimal value of rScO2 above the right cerebral hemisphere with the patient lying supine at the start of surgery was the highest in the MDE group (rScO2 82 ± 10 %, p = 0.043) and the average rScO2 value over the left cerebral hemisphere with the patient lying supine at the start of surgery was also the highest in the MDE group (rScO2 83±9 %, p = 0.44) (Table 3.13).

Table 3.13

Age, preoperative and intraoperative values measured in the laminectomy (LE), microdiscectomy (MDE), spinal tumour (Spin Tu) and transpedicular fixation (TPF) group (mean ± SD)*

Indicator	**LE**		**MDE**		**Spin Tu**		**TPF**		**p value**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Age (years)	73	7	48	13	58	11	56	16	**0.001**
Intraoperative blood loss (ml)	192	107	184	82	271	81	311	98	**0.000**
Hb (mg/dl)	13	1	14	2	14	1	13	2	0.072
Hct (%)	39	4	42	3	40	3	40	5	0.173
Duration of the operation (min)	103	39	100	31	163	54	126	42	**0.004**
PreOp rScO2 Dx (%)	73	5	75	9	74	10	69	11	0.356
Avg Sup rScO2 Dx (%)	77	7	84	9	76	14	75	11	0.063
Min Sup rScO2 Dx (%)	76	7	82	10	73	14	73	11	**0.043**
Max Sup rScO2 Dx (%)	78	7	86	9	78	14	77	12	**0.050**
PreOp rScO2 Sin (%)	72	9	75	9	75	11	70	10	0.270
Avg Sup rScO2 Sin (%)	72	9	83	9	77	13	76	11	**0.044**
Min Sup rScO2 Sin (%)	71	9	81	10	73	12	74	10	0.080
Max Sup rScO2 Sin (%)	73	8	85	9	79	14	78	12	**0.050**

Table 3.13 continued

Indicator	**LE**		**MDE**		**Spin Tu**		**TPF**		**p value**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Avg Prone rScO2 Dx (%)	78	7	81	8	77	11	77	8	0.425
Min Prone rScO2 Dx (%)	73	8	77	9	71	13	71	8	0.268
Max Prone rScO2 Dx (%)	82	7	86	6	83	9	81	8	0.159
Avg Prone rScO2 Sin (%)	75	6	81	7	77	10	78	8	0.287
Min Prone rScO2 Sin (%)	71	9	78	8	74	13	73	9	0.246
Max Prone rScO2 Sin (%)	79	5	86	7	83	9	83	9	0.244
Avg Sup2 rScO2 Dx (%)	78	7	81	7	76	13	75	11	0.192
Min Sup2 rScO2 Dx (%)	77	6	80	8	74	14	74	11	0.355
Max Sup2 rScO2 Dx (%)	78	7	84	7	78	12	76	10	0.080
Avg Sup2 rScO2 Sin (%)	73	7	81	7	77	14	76	11	0.174
Min Sup2 rScO2 Sin (%)	72	8	79	8	75	15	75	12	0.326
Max Sup2 rScO2 Sin (%)	74	7	83	7	79	12	78	10	0.093
MAP PreOp (mmHg)	94	4	99	12	103	12	100	10	0.434
Avg MAP Sup (mmHg)	80	19	87	16	87	13	88	17	0.861
Min MAP Sup (mmHg)	71	19	81	15	68	25	80	17	0.421
Max MAP Sup (mmHg)	88	22	94	23	105	23	100	23	0.345
Avg MAP Prone (mmHg)	75	9	81	8	85	8	81	9	0.217
Min MAP Prone (mmHg)	62	11	68	8	69	7	63	18	0.461
Max MAP Prone (mmHg)	94	7	98	15	107	16	102	16	0.348

Table 3.13 continued

Indicator	LE		MDE		Spin Tu		TPF		p value
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Avg MAP Sup2 (mmHg)	80	12	90	13	94	10	86	16	0.187
Min MAP Sup2 (mmHg)	77	13	84	12	82	29	79	16	0.392
Max MAP Sup2 (mmHg)	83	12	96	16	101	6	95	21	0.061
Avg CO2 Sup (mmHg)	34	4	35	3	33	5	34	3	0.977
Min CO2 Sup (mmHg)	34	5	35	3	32	6	34	3	0.731
Max CO2 Sup (mmHg)	35	3	35	4	34	4	36	4	0.958
Avg EtCO2 Prone (mmHg)	34	2	35	2	35	3	35	2	0.334
Min EtCO2 Prone (mmHg)	32	2	34	2	32	4	33	3	0.482
Max EtCO2 Prone (mmHg)	35	3	37	2	37	2	37	2	0.178
SpO2 PreOp (%)	99	2	99	2	99	2	99	2	0.817
Avg SpO2 Sup (%)	100	1	100	1	99	1	100	1	0.873
Min SpO2 Sup (%)	100	1	99	1	99	2	99	1	0.909
Max SpO2 Sup (%)	100	1	100	1	100	0	100	1	0.960
Avg SpO2 Prone (%)	100	0	100	0	100	1	100	0	0.903
Min SpO2 Prone (%)	100	0	100	1	99	2	100	0	0.782
Max SpO2 Prone (%)	100	0	100	0	100	0	100	0	0.817
Avg SpO2 Sup2 (%)	98	2	100	1	100	0	100	1	0.403
Min SpO2 Sup2 (%)	98	2	99	1	100	1	100	1	0.486
Max SpO2 Sup2 (%)	98	2	100	0	100	0	100	0	0.070

* Age (years), intraoperative blood loss (ml), Hb (mg/dl), Hct (%), duration of the operation (min), preoperative values and values after the intubation with patient lying supine (Sup), in the prone position (Prone), at the end of the surgery when patient was turned again supine (Sup2) of the rScO2 in percentage above right (Dx) and left (Sin) cerebral hemisphere, MAP, EtCO2, SpO2; Avg – average, Min – minimum, Max – maximum.

3.7 MOCA Test

When analysing our MOCA cognitive test results, we found statistically significant differences in MOCA preoperative evaluation points between the study and control groups: MOCA preoperative points in the study group were 25 ± 2 and 26 ± 2 in the control group (p = 0.034). (Table 3.14).

Table 3.14

Montreal Cognitive Assessment Score in the study group, control group patients and in total (mean ± SD)*

Indicator	Study group		Control group		p value	Total	
	Mean	SD	Mean	SD		Mean	SD
MOCA PreOp	25	2	26	2	**<u>0.034</u>**	26	2
MOCA PostOp	26	2	26	2	0.919	26	2

* preoperative (PreOp) and postoperative (PostOp) points

No relevant differences in MOCA points, neither preoperatively nor postoperatively, were observed when comparing patients based on the type of operation performed (Table 3.15).

Table 3.15

Montreal Cognitive Assessment Score in the laminectomy (LE), microdiscectomy (MDE), spinal tumour (Spin Tu) and transpedicular fixation (TPF) group (mean ± SD)*

Indicator	LE		MDE		Spin Tu		TPF		p value
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
MOCA PreOp	25	1	26	3	26	2	26	2	0.766
MOCA PostOp	25	1	26	2	25	2	26	2	0.124

* Preoperative (PreOp) and postoperative (PostOp) points.

3.8 Intraoperative cerebral oxygen desaturation

In our study, intraoperative cerebral desaturation occurred in three patients – two in the study group and one in the control group. The desaturation time was between 5 to 8 minutes in all three patients.

Study group

In the study group, cerebral oxygen saturation in two patients dropped by 20 % from their individual baseline values and a drop under the absolute value of rScO2 of 50 % was registered. The NIRS-based intervention algorithm was used.

Patient 1 was a 54 years old woman, undergoing spinal tumour evacuation. The preoperatively determined baseline values were rScO2 of 68 % above the right cerebral hemisphere and 69 % above the left one. An intraoperative rScO2 drop for 29 % from baseline values and under the absolute value of 50 % (bilaterally) was observed with the minimal rScO2 value of 48 % while lying in the prone position. According to the NIRS-based intervention algorithm, neutral head positioning was provided as a first step; however, no changes in rScO2 were observed. As a next step, the patient received a dose of ephedrine 10 mg intravenously to raise the mean arterial blood pressure. During the cerebral desaturation period, the MAP was over 95 mmHg, which was 24 % lower than the preoperatively measured baseline value. After the second step, rScO2 values increased above 50 %, then above the baseline, and no further intervention was necessary.

The patient’s operation time was higher than the average in the study group and was 270 min compared to 128 ± 42 min in the other study group patients ($p = 0.0001$). The operation time was also longer than the mean operation time measured in the spinal tumour patient group, which was 153.2 ± 44.3 min ($p < 0.001$).

Patient’s preoperative systemic MAP – 124 mmHg – was higher than that measured in the other study group patients (MAP 103 ± 10 mmHg, $p = 0.03$). It was also higher than the preoperative MAP in the other spinal tumour patients with the mean preoperative systemic MAP of 100.9 ± 9.8 mmHg ($p < 0.001$).

The *second study group patient* was a man, 57 years old, undergoing microdiscectomy (at the single level of L4–5) operation. The baseline rScO2 values were as follows: rScO2 Dx 85 % and rScO2 Sin 87 %. During the operation with the patient lying in the prone position, rScO2 values dropped to minimal rScO2 value of 63 % (bilaterally) (by 27 % from patient’s individual baseline values measured preoperatively before intubation). In addition, the second patient did not show any changes in rScO2 values after correct head positioning was achieved. At the time of cerebral desaturation, the MAP decreased to 62 mmHg (baseline MAP value – 104 mmHg), as the next step intravenous ephedrine 10 mg was given. A further decrease in MAP was observed, with the lowest MAP of 56 mmHg. Another 10 mg of ephedrine was administered. Together with the MAP also rScO2 values increased above the threshold values and no further intervention was necessary.

The cognitive function based on the MOCA test points in both study group patients, where NIRS-based interventional algorithm was used, stayed consistent – preoperatively and postoperatively. In *patient 1*, MOCA score preoperatively was 26 points and also postoperatively – 26 points. In *patient 2*, MOCA score preoperatively and postoperatively was 23 points.

Control group

In the control group, cerebral oxygen desaturation was found in one patient. The patient was a 24 years old woman, who underwent a two level transpedicular lumbar spinal fixation after trauma. The preoperative baseline rScO2 values were rScO2 Sin 92 % and rScO2 Dx 87 %. We observed an intraoperative drop of rScO2 by 21 % from baseline value (to rScO2 of 73 % Dx with patient lying in the prone position).

By analysing and comparing this patient’s demographic data and intraoperative measurements, we did not observe any statistically significant differences from the other patients in the control group. Analysing the patient’s measurements retrospectively we saw a MAP decrease at the time when rScO2 decrease was also observed, from baseline 91mmHg to MAP 71mmHg (MAP value decreased by 22 %).

MOCA score in the patient described above decreased by 4 points postoperatively – from MOCA 29 points preoperatively to MOCA 25 points postoperatively, which is defined as postoperative cognitive dysfunction.

3.9 Postoperative cognitive decline and MOCA score

Out of a total of 64 patients included in the study, postoperative cognitive decline was observed in 19 (29.6 %) patients, 9 out of 42 patients (21.4 %) in the study group and 10 out of 22 patients (45.5 %) in the control group.

The following postoperative MOCA score reductions were observed:

- for 1 point – in 8 patients (5 in the study group and 3 in the control group);
- for 2 points – in 7 patients (3 – study group, 4 – control group);
- for 3 points – in 1 patient (1 – control group);
- for 4 points – in 3 patients (1 – study group, 2 – control group).

The statistically significant difference in comparison with other patients, who did not have postoperative MOCA decrease, was observed in the following measurements: the average rScO2 value in the prone position over the left cerebral hemisphere and the maximum EtCO2 value in the supine position (Table 3.16).

Table 3.16

Average (Avg) rScO2 in percentage in the **prone position above left cerebral hemisphere (Sin) and maximum (Max) EtCO2 in millimetre of mercury after the intubation in patient lying supine in the patients where postoperative MOCA score decrease was observed and in the other patients in the study**

Indicator	**Patients with postoperative MOCA score decrease**		**Other patients in the study**		**p value**
	Mean	**SD**	**Mean**	**SD**	
Avg prone rScO2 Sin (%)	82	7	78	8	0.048
Max EtCO2 Sup (mmHg)	37	3	34	4	0.041

We also analysed separately those patients, who had a postoperative decrease in MOCA score of 4 points. No statistically significant differences were observed when compared to all the other patients in the study.

Table 3.17 shows the percentage of patients with a postoperative MOCA score decrease in each MOCA domain.

Table 3.17

The number of patients in percentage (%) that showed postoperative MOCA point decrease analysed within separate MOCA domains in study, control groups and in total

MOCA Domain	**Study group N (%)**	**Control group N (%)**	**p value**	**Total N (%)**
Visuospatial / Executive	13.0	16.7	0.771	14.3
Naming	0	0	–	0
Memory	No points			
Attention	21.7	25.0	0.827	22.9

Table 3.17 continued

MOCA Domain	Study group N (%)	Control group N (%)	p value	Total N (%)
Language	8.7	41.7	**0.021**	20.0
Abstraction	0	8.3	0.160	2.9
Delayed recall	26.1	33.3	0.652	28.6
Orientation	13.0	0	0.191	8.6

3.10 Spearman's rho correlation analysis

Using Spearman's rho rank correlation to analyse all the patients included in the study, we found a negative correlation between intraoperative rScO2 values and patient age, intraoperative blood loss and preoperative MAP value and a positive correlation with preoperative MOCA values (Table 3.18, Figures 3.2–3.5).

Table 3.18

Spearman's rho correlation coefficients ρ between age, intraoperative blood loss, MAP Preoperative, MOCA preoperative score and intraoperative rScO2 values in all study patients

Indicator	Spearman's rho correlation coefficient and p value	Intraoperative rScO2 values
Age	Spearman's rho correlation coefficient (ρ)	−0.352
	p value	0.004
Intraoperative blood loss	Spearman's rho correlation coefficient (ρ)	−0.248
	p value	0.049
MAP Preoperative	Spearman's rho correlation coefficient (ρ)	−0.306
	p value	0.014
MOCA Preoperative	Spearman's rho correlation coefficient (ρ)	0.326
	p value	0.009

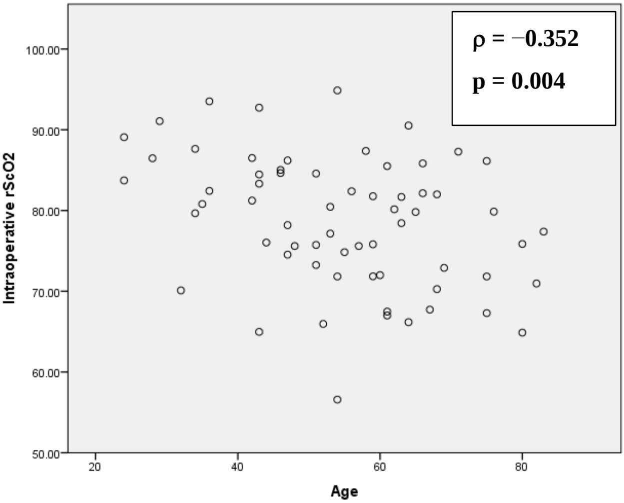

Figure 3.2 **Spearman's rho correlation between age and intraoperative rScO2 values in all study patients**

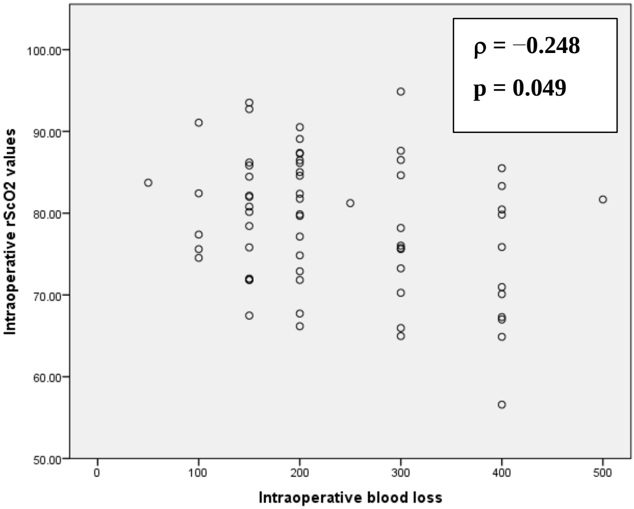

Figure 3.3 **Spearman's rho correlation between intraoperative blood loss and intraoperative rScO2 values in all study patients**

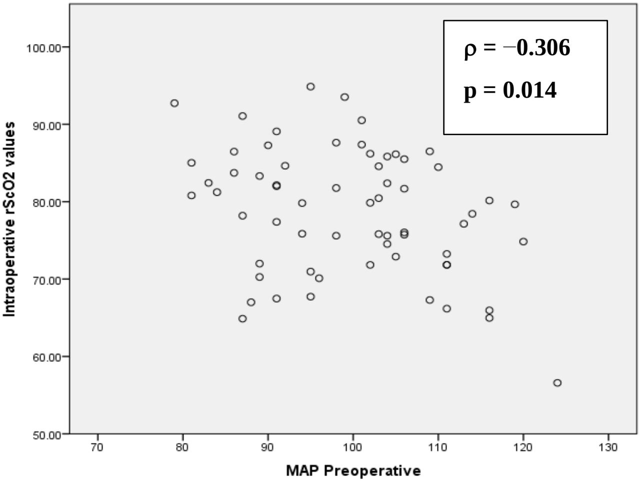

Figure 3.4 **Spearman's rho correlation between MAP Preoperative values and intraoperative rScO2 values in all study patients**

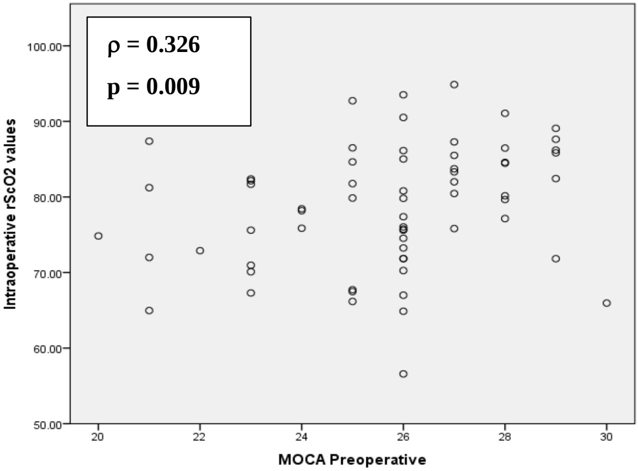

Figure 3.5 **Spearman's rho correlation between MOCA preoperative score and intraoperative rScO2 values in all study patients**

Linear regression showed that factors explaining 28.5 % of the variance in the intraoperative rScO2 values were age (B = −0.134, 95 % CI [−0.266, −0.001], p = 0.048) and preoperative systemic MAP (B = −0.204, 95 % CI [−0.384, −0.024], p = 0.027), controlling for other factors (intraoperative blood loss, Hb, Hct, duration of surgery, intraoperative systemic MAP, EtCO2, SpO2, MOCA score).

We also investigated whether intraoperative rScO2 values correlated with other measured variables separately for the study group and the control group. For the study group, we found a negative correlation between intraoperative rScO2 measurements and preoperative MAP (ρ = −0.354, p = 0.021) (Figure 3.6). In the control group, we found a negative correlation between intraoperative rScO2 and patient age (ρ = −0.655, p = 0.001) (Figure 3.7).

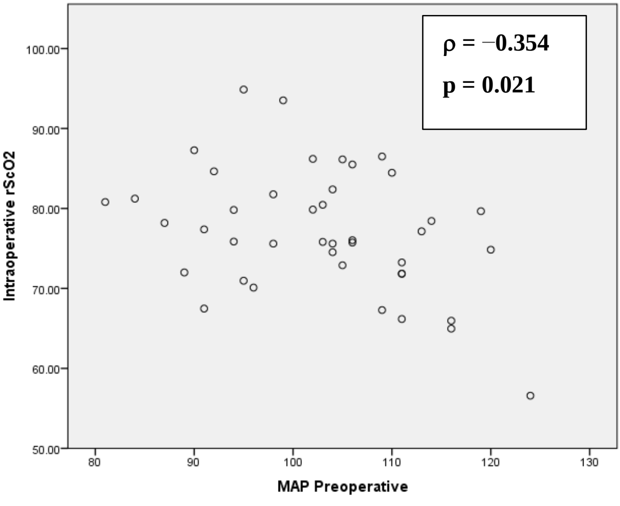

Figure 3.6 **Spearman’s rho correlation between MAP preoperative values and intraoperative rScO2 values in study group patients**

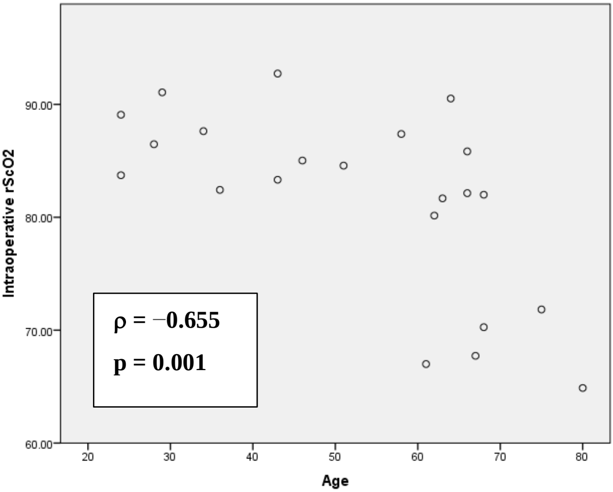

Figure 3.7 **Spearman's rho correlation between age and intraoperative rScO2 values in control group patients**

Postoperative MOCA score did not correlate with intraoperative rScO2 values. However, patients, who had a decrease in rScO2 of > 10 % at any stage of surgery had a lower postoperative median MOCA score. Patients who had a decrease of rScO2 > 10 % had a median postoperative MOCA score of 26.0 (IQR 1.5). Patients who had no decrease or a decrease of < 10 % had a median postoperative MOCA score of 25.5 (IQR 3). This difference was statistically significant (p = 0.02) (Figure 3.8).

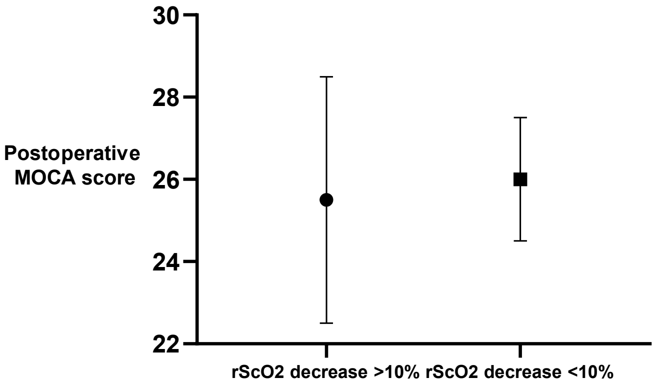

Figure 3.8 **Median postoperative MOCA score in patients with intraoperative rScO2 decrease > 10 % and in patients with no decrease or rScO2 decrease < 10 %**

4 Discussion

Spinal surgery is a medical field covering a wide range of different operations performed on the spinal column and the surrounding tissues. The type of operation, the surgical technique, the operation time, the intraoperative blood loss, the professional skills of the medical staff and other relevant factors determine the intraoperative management and the postoperative outcome. Spinal surgery is a complex area of medicine that is challenging for both clinicians and researchers. We aimed to find out whether cerebral desaturation can occur during spinal surgery in the prone position, and the potential usefulness of a near-infrared spectroscopy -based clinical algorithm. We also speculated whether cerebral desaturation was associated with a postoperative cognitive decline. In particular, we sought to identify which factors would influence cerebral oxygenation in patients undergoing spinal surgery, such as patient age, preoperative haemoglobin and haematocrit levels, end-tidal carbon dioxide concentration, peripheral arterial oxygen saturation, intraoperative blood loss and the duration of the surgery. Our working hypothesis was that providing adequate cerebral oxygen saturation during spinal neurosurgery in the prone position is essential to prevent POCD.

Several recent studies have elucidated the monitoring of cerebral oxygen saturation by using NIRS devices – cerebral oximeters. As non-invasive devices, they have gained popularity in many different fields of surgery as well as in various conditions requiring treatment in the ICU, including both adult and pediatric patient populations. A limited number of studies have focused specifically on monitoring cerebral oxygenation using NIRS devices intraoperatively during spinal surgery and only a few studies have evaluated cognitive function as part of the postoperative outcome (Trafidlo, 2015).

4.1 Age

Age plays a significant role in terms of intraoperative cerebral desaturation. Elderly patients suffer from intraoperative cerebral desaturation, often due to reduced physiological reserves (Casati, 2005). Recent studies have shown that higher age is associated with a reduction of intraoperative rScO2 (Tobias, 2008; Burkhart, 2011). Almost 20 %–40 % of elderly patients experience cerebral desaturation during non-cardiac surgery (Casati, 2005; Papadopoulos, 2012; Deiner, 2014) and elderly people make up more than 30 % of all patients requiring anaesthesia for surgeries (Casati, 2005). The age at which patients are included in the elderly patient population varies from study to study. Sixty-five years and older is the most commonly used definition. In our study, we included adult patients aged 18 years and above, with a mean age of 55 ± 15 years (mean ± SD). Patients aged 61 and older accounted for 64 % of the study population. In our study, intraoperative cerebral desaturation of more than 20 % from baseline, or an absolute drop in rScO2 to below 50 % was observed in three patients. Two of them were 54 and 57 years old and the third patient was only 24 years old, showing that even young patients can experience a significant drop in rScO2 during surgery.

As mentioned above (Casati, 2005; Deiner, 2014; Papadopoulos, 2012) patients at the age of 65 years and older show lower intraoperative rScO2 values. In contrast, we observed significantly higher average and minimal intraoperative rScO2 values over both cerebral hemispheres in the prone position in the control group, in which the majority of the patients were aged 61–70 years. At the same time, most of the patients in the study group (36 %) were in the age group of 51–60 years but presented with lower rScO2 values in the prone position.

Generally, our study predicts a negative correlation between patient age and intraoperative rScO2 values ($\rho = -0.352$, $p = 0.004$), which is consistent with the studies mentioned above (Casati, 2005; Deiner, 2014; Papadopoulos, 2012). This raises the question of what is the cut-off age, at which increased attention should be paid to the possibility of an intraoperative cerebral desaturation. In addition, the fact that three patients in our study with significant intraoperative cerebral desaturation were notably younger than 65 years, made us analyse and look for other factors that could potentially cause cerebral desaturation.

4.2 Mean arterial blood pressure (MAP), the choice of vasoconstrictors

Mean arterial blood pressure is a crucial factor in the assurance of adequate cerebral perfusion pressure, including appropriate cerebral oxygen delivery. As stated in the intraoperative NIRS algorithm (Denault, 2007; Trafidlo, 2015), the evaluation of MAP is the second step after verifying head position if cerebral desaturation occurs. Based on the cerebral autoregulation, proper brain tissue perfusion remains constant in a range of 50–150 mmHg (van den Brule, 2018). The recommended MAP, which ensures the best organ perfusion, including the brain, is 65 mmHg (Van Diepen, 2017). Intraoperative hypotension is defined as an absolute MAP < 65 mmHg or relative MAP decrease under 20 % or more from baseline (Meng, 2018). In our study MAP at the time of cerebral desaturation in one of our study group patients was lower than 65 mmHg (56–62 mmHg). In the other study group patient, MAP was 24 % lower than baseline at the time of cerebral desaturation. Both patients received ephedrine boluses and rScO2 raised above the threshold values, confirming the importance of arterial blood pressure in maintaining adequate cerebral saturation.

The choice of vasoconstrictors that increase MAP and preserve rScO2 has been discussed in several studies. Previous studies have shown that ephedrine, which was used in our patients, increases MAP but does not decrease (or even increase) rScO2, as compared, for example, with phenylephrine where MAP increases at the same level, but rScO2 decreases significantly (Vanpeteghem, 2020; Koch, 2020; Nissen, 2010).

On the other hand, other patients with a MAP < 65 mmHg or MAP values lower than 20 % below baseline did not show cerebral desaturation. The question of interest is – whether a MAP of 65 mmHg can be accepted as a standard value regarding the appropriate cerebral perfusion and therefore oxygen delivery, or whether an individual MAP- threshold should be aimed at? Moreover, which MAP value should be considered as baseline, the one measured at the time of preoperative patient visit, or the one measured in the operating room before induction of anaesthesia? In the preoperative check, MAP is not always measured. On the other hand, blood pressure measured immediately before the operation is strongly influenced by preoperative stress and intake of antihypertensive drugs and other medicines. Zhang and colleagues (Zhang, 2021) showed that cerebral oximetry itself can be used to identify optimal MAP intraoperative range to ensure adequate cerebral autoregulation. Their study showed that optimal MAP targets for elderly patients (≥ 65 years) were between 67.8 ± 8.9 and 116.4 ± 10.5 mmHg, and for middle aged patients (45–64 years) between 71.2 ± 12.5 and 111.3 ± 8.9 mmHg (Zhang, 2021). In our patient population mean intraoperative arterial blood pressure varied from 66 ± 12 to 100 ± 15 mmHg, which was consistent with the findings of Zhang et al., although the values in our study were derived from all age groups.

The importance of preoperative blood pressure management is already well known, as patients with hypertension have increased risk of postoperative complications, such as cardiovascular events, neurologic deficits or even death

(Varon, 2008). We detected significantly higher preoperative MAP in our study group patients compared to control group patients. At the same time in the study group patients, we observed lower preoperative rScO2 values and lower rScO2 values in the prone position. A negative correlation was found between preoperative MAP and intraoperative rScO2 values. The same finding was observed in our one study group patient, where significant cerebral desaturation occurred. In this one study group patient, preoperative MAP was remarkably higher than the group average and intraoperative cerebral desaturation was observed. Studies evaluating preoperative variables affecting intraoperative rScO2 measurements do not mention MAP as one of them (Thiele, 2020). To our knowledge, no studies have specifically investigated preoperative blood pressure in relation to intraoperative cerebral oxygenation. In contrast to Varon et al. (Varon, 2008), no correlation was found between preoperative or intraoperative MAP and postoperative outcome – cognitive function – in our study.

Our study showed that blood pressure plays an important role in maintaining adequate cerebral saturation levels intraoperatively. In their study, Jo et al. suggest that the brain could be used as an index organ for overall hemodynamic stability (Jo, 2020). And the same as in our study, Jo et al. also demonstrate that changes in MAP correlate with rScO2, although the correlation is weak (Jo, 2020). At the same time, in our case no correlation was found between MAP and postoperative cognitive function. The exact role of MAP in maintaining adequate cerebral oxygenation should be debated. Are there absolute MAP levels that require intervention and how should they be managed?

4.3 Hb, Hct, intraoperative blood loss

Blood is the main carrier of haemoglobin, and Hb is the main molecule involved in O2 transport. It is therefore useful to discuss Hb, Hct and intraoperative blood loss in relation to cerebral oxygen saturation.

Haemoglobin has been shown to be significantly associated with cerebral rScO2 values, and a linear relationship can be seen with lower Hb levels corresponding to lower rScO2 values (Ookawara, 2020). According to the World Health Organization, anaemia is defined as haemoglobin < 13 mg/dl for men and < 12 mg/dl for non-pregnant women (WHO, 2011). Poor postoperative outcomes have been described in patients with different preoperative haemoglobin levels – 10 mg/dl, 11 mg/dl and 12 mg/dl, although it is still debatable whether they are caused by low haemoglobin levels or other factors (Van Straten, 2009). In our study, we did not find any correlation between preoperative haemoglobin or haematocrit levels and intraoperative rScO2 values or postoperative outcome – cognitive function. That can be explained by the fact that the mean preoperative haemoglobin and haematocrit levels in the study and control group were in the normal range and the patients were not anaemic based on the WHO definition. That also corresponded to the study by Shayan et al. (Shayan, 2022), in which perioperative neurocognitive disorder (PND) was investigated in relation to anaemia. In that study, no correlation between postoperative cognitive performance one month after the surgery and preoperative anaemia was found (Shayan, 2022). To our knowledge, there are no studies, where Hb or Hct levels were analysed in regard to intraoperative rScO2 or postoperative outcomes in spinal surgery patients.

The same linear relationship as for Hb and rScO2 can also be seen for blood loss and rScO2. Torella et al. (Torella, 2004) noticed that cerebral oxygen saturation decreases proportionally to blood loss. This is consistent with our finding of a negative correlation between intraoperative blood loss and cerebral oxygenation. However, Torrella and colleagues observed a remarkably higher median blood loss of 650 ml (400–1800 ml) (Torella, 2004) compared to a mean intraoperative blood loss of 236 ± 103 ml (100–500 ml) in our study material as a whole.

4.4 The length of operation

The length of surgery has been described as a factor in terms of postoperative complications. It has been shown that postoperative complications (surgical site infection, wound dehiscence, bleeding, pneumonia, urinary tract infection, renal failure, sepsis, cardiac complications) double with operative time that exceeds two or more hours (Cheng, 2018). Prolonged surgery time has also been considered as a risk factor for postoperative cognitive decline (Rundshagen, 2014; Borozdina, 2018). When we looked separately at the patients that presented with POCD, we found the same trend as in the above studies. The mean duration of surgery for patients with POCD was 130 ± 44 min, compared to 115 ± 46 min in patients with no POCD. Although the findings were not significantly different.

4.5 Cerebral oxygenation during spinal surgery in prone position

Authors also have evaluated whether changes in cerebral oxygenation can be seen only during spinal surgery in the prone position or in the position in general. Deiner et al. showed, as in our current study, that patients experience cerebral desaturation when undergoing surgery in the prone position (Deiner, 2014). Their study compared elderly patients (≥ 68 years) who underwent surgery in the prone position with patients who underwent surgery lying supine. The researchers observed that cerebral desaturation was related to the prone position, as patients operated in the prone position were twice as likely to experience a cerebral saturation than those operated in the supine position (Deiner, 2014). In our patients, we observed higher average and minimal cerebral oxygenation values in the prone position over both cerebral hemispheres in the control group when compared to the study group. The majority of patients in the control group (41 %) were aged 61–70 years. At the same time, most of the patients in the study group were younger – between 51 and 60 years old.

A few years ago, Andersen and colleagues (Andersen, 2014) demonstrated the importance of neutral head position for maintaining cerebral oxygenation in the prone position, since rotation of the head to the right or left and / or flexion or extension of the neck can cause a decrease in rScO2. In our study, correction of head position was performed as the first measure against cerebral desaturation, as correct head positioning is also the first step in the NIRS-based clinical algorithm (Denault, 2014; Trafidlo, 2015). In our cases, no improvement in rScO2 values was seen after repeated confirmation of correct, neutral head position.

4.6 Postoperative cognitive decline

In the present study, we aimed at investigating whether intraoperative cerebral desaturation leads to postoperative cognitive disturbances by evaluating preoperative and postoperative patient cognitive status using the MOCA test. We observed a decrease in postoperative MOCA scores in 19 patients that accounted for 29,6 % or almost one third of the total patient population. Moreover, postoperative cognitive decline was observed in almost a half of the patients in the control group (45.5 %), where rScO2 was monitored blindly compared to 21.4 % patients in the study group. In the same way, more patients in the control group presented a decrease in the MOCA score of 4, 3 and 2 points, whereas in the study group, the majority of patients showed MOCA score decrease by only 1 or 2 points postoperatively. The largest difference between the groups was observed in the MOCA language domain, where 41.7 % of the patients in the control group showed postoperative decline compared to only 8.7 % of the patients in the study group. This finding is difficult to explain because centres responsible for the language, are located in different areas of the brain (Broca's, Wernicke’s areas). What we did find in the control group was a negative correlation between intraoperative rScO2 values and patient age, showing that the aging brain is more dependent on the adequate oxygen delivery.

Trafidlo et al. (Trafidlo, 2015) also investigated spinal surgery patients operated in the prone position and showed that in the group without NIRS monitoring, more patients presented with postoperative cognitive deficiencies. Many studies have shown that patients after cardiac and non-cardiac surgery suffer from postoperative cognitive decline or dysfunction (van Dijk, 2000; Jensen, 2006; Newman, 2007). To our knowledge, Trafidlo et al. (Trafidlo, 2015) is the only study so far that has monitored cerebral oxygen saturation during spinal surgery and analysed it in relation to postoperative cognitive outcome. There are studies describing POCD as a transient postoperative disturbance (Rundshagen, 2014). Other studies show that POCD can significantly impair postoperative recovery and even increase postoperative mortality (Monk, 2008; Steinmetz, 2009). Unlike delirium, POCD can stay unrecognised unless preoperative and postoperative neurophysiological tests are used.

Zorrilla-Vaca et al. (Zorilla-Vaca, 2018) performed a meta-analysis and found that the incidence of POCD is reduced when cerebral oximetry-guided intraoperative management is applied. Based on the findings of the latter investigators, the thresholds for interventions were most commonly either rScO2 < 75 % of baseline, or an absolute value of rScO2 < 55–60 % (Zorilla-Vaca, 2018). We used the NIRS-based intraoperative intervention algorithm of Denault et al. (Denault, 2014), which has been adapted to non-cardiac surgery by Trafidlo et al. (Trafidlo, 2015). Based on these algorithms, the threshold for intervention is a drop in rScO2 of 20 % or more from baseline (unilaterally or bilaterally) or rScO2 < 50 %. Zorilla-Vaca and colleagues also found and described that neurological deficits are more likely to occur with an rScO2 reduction of more than 30 % (Zorilla-Vaca, 2018). This lead us to the question as to whether a drop in rScO2 of 20 % below baseline may represent a clinically significant desaturation. In addition, it is still not strictly defined whether rScO2 baseline values should be determined preoperatively in the patient breathing room air (Dworschak, 2012) or with supplemental oxygen (Heringlake, 2011). In our study, we set the baseline values according to Dworschak et al. (Dworschak, 2012) with patients breathing room air. We observed that the two patients in our study group, who experienced a drop in rScO2 of 20 % or more below baseline and a drop in rScO2 below 50 %, which were eliminated, had no postoperative cognitive decline, and vice versa – the patient in our control group, who experienced cerebral desaturation, but no interventions were applied, was found to have POCD. Furthermore, patients who had an intraoperative decrease in rScO2 of > 10 % had a lower median postoperative MOCA score. Therefore, our study results were in line with the findings of Green et al., who affirmed that both a 20 % rScO2 decline from baseline values is significant and that in clinical practice steps should be taken beforehand to limit a smaller decrease, for example, of 10 % (Green, 2017). Lin et al. in their study also suggest that cerebral oxygen saturation decrease already over 11 % could be used as a potential predictor to postoperative neurocognitive impairment (Lin, 2013). In addition, it has been advised to use cerebral oximetry as a trend monitor, tracking changes in saturation, rather than using absolute rScO2 values (Bickler, 2013).

In our patients, the time spent in cerebral desaturation was from 5 to 8 minutes. Based on brain physiology, hypoxic brain damage can occur as early as 5 min of hypoxia (Barash, 2015). Therefore, if cerebral desaturation is detected, intervention must not be delayed. Literature data regarding this issue are very contradictory. While one study shows that POCD develops as early as < 5 min exposure to cerebral oxygenation values of < 65 % (Tang, 2012), other studies claim that the time of the cerebral desaturation should be 2 hours to result in neurological impairment (Kurth, 2009). It should be noted that the latter study was conducted on piglets.

The brain is the primary endpoint for many anaesthetics, and anaesthesia has therefore been recognised as one of the risk factors for postoperative neurological disorders (Casati, 2005). Nevertheless, the brain is one of the least monitored organs intraoperatively. The aim of the intraoperative monitoring of cerebral oxygenation saturation is to detect harmful physiological events that can lead to brain damage (Mahajan, 2013) and to prevent them. Several studies have shown that patients suffer from postoperative cognitive decline or dysfunction following cardiac and non-cardiac surgery (van Dijk, 2000; Jensen, 2006; Newman, 2007). Some studies describe POCD as transient postoperative disturbance (Rundshagen, 2014), whereas other studies show that POCD can significantly impair postoperative recovery and even increase postoperative mortality (Monk, 2008; Steinmetz, 2009).

Cerebral oximeters are non-invasive devices, that provide continuous real-time monitoring of cerebral oxygenation. Intraoperative monitoring of cerebral oxygenation should be applied together with NIRS-based intraoperative intervention algorithm, as simple interventions may provide clear benefits.

4.7 Strengths and limitations

In recent studies, researchers have assessed cerebral oxygenation intraoperatively during non-cardiac surgery (Moerman, 2015; Nielsen, 2014). In some of the latter studies, the cerebral oximeters were applied in patients who undergoing surgery in the prone position (Andersen, 2014; Deiner, 2014) . In addition, an intraoperative NIRS-based clinical algorithm was used (Denault, 2007; Tosch, 2016). It has been demonstrated that patients, experiencing intraoperative cerebral desaturation, suffer from various postoperative complications (Goldman, 2004; Murkin, 2007) including POCD

(Zorilla-Vaca, 2018). However, to our knowledge, only one study has included intraoperative monitoring of cerebral oxygenation and evaluated postoperative cognitive outcome after spinal surgery (Trafidlo, 2015). Thus, Trafidlo et al. evaluated POCD by using different neurocognitive tests, such as N-back Test, Trail Making Test A and B, Stroop Colour-Word Interference Test Part 1 and 2 and others (Trafidlo, 2015). Our aim was to show, that there is a simple test, such as MOCA, that can evaluate cognitive function in a short period of time during preoperative and postoperative patient evaluation. The MOCA test is easy to use. It is available in several languages and covers a wide range of cognitive domains, such as short-term memory, visuo-spatial abilities, executive functions, attention, concentration, working memory, language, and orientation to time and place (MoCA Montreal Cognitive Assessment). In our opinion, it is important to use easy applicable tests to monitor cognitive function and detect POCD, which take little time and are understandable to patients (in their native language). Recently, Soehle at el. have also suggested that cognitive evaluation tests should take only a couple of minutes, without requiring excessive staff training in order to be implemented in clinical practice (Soehle, 2022). The discussion could arise regarding the fact that the same MOCA test was used to evaluate patient cognitive status preoperatively and postoperatively and could lead to a learning effect. Unfortunately, there was no other option to avoid this, as there is only one version of MOCA test available that is validated in Latvian and Russian.

Another limitation of our study was that patients with postoperative cognitive decline were not inspected repeatedly after the surgery. The cognitive function was evaluated only once after surgery, and no other possible postoperative complications were assessed. Nor any intraoperative PaO2 or PaCO2 measurements were taken to minimize invasive manipulations, although they would show changes in oxygen and carbon dioxide concentrations more accurately than SpO2 and EtCO2. In the current study, we also did not analyse patient comorbidities as a factor that could influence intraoperative cerebral saturation or postoperative cognitive decline. Another limitation of the study is the number of patients included in the study due to the limited budget available for the study and the high cost of cerebral oximetry electrodes.

Conclusions

1. Patients undergoing various spinal surgeries in the prone position may experience intraoperative cerebral desaturation and rScO2 values below 20 % of individual baseline values or a drop in rScO2 below the absolute value of 50 %. Otherwise, intraoperative cerebral desaturation will remain unrecognised unless cerebral oximeters are used and cerebral oxygenation is monitored.
2. In the control group, where rScO2 was monitored blindly and no NIRS algorithm was applied, 45.5 % of patients showed postoperative cognitive decline compared to the study group, where postoperative cognitive decline was observed in 21.4 % of patients. More patients in the control group showed larger postoperative MOCA point decrease (2, 3 and 4 points) compared to the study group, where most of the patients presented with postoperative MOCA score decrease of 1–2 points.
3. No postoperative cognitive decline was observed in patients, in whom intraoperative regional cerebral oxygen saturation was monitored and cerebral desaturation was treated according to the NIRS-algorithm. In patient in whom intraoperative regional cerebral oxygenation was monitored blindly, cerebral desaturation was detected, but the NIRS algorithm was not applied, postoperative cognitive decline was noticed.
4. A statistically significant negative correlation was found between intraoperative rScO2 values and age, intraoperative blood loss and preoperative mean arterial blood pressure. In addition, a positive correlation was observed between intraoperative rScO2 and preoperative MOCA score.
5. Postoperative MOCA score was not correlated with intraoperative rScO2 values. However, patients with an intraoperative decrease in rScO2 of > 10 % had a lower postoperative median MOCA score.

6. During spinal neurosurgery in the prone position, cerebral oximetry combined with a NIRS-based clinical algorithm gives valuable information about cerebral oxygenation and prevents postoperative cognitive decline. Ensuring adequate cerebral oxygen saturation is essential for patient safety.

Publications

Articles

1. Murniece, S., Soehle, M., Vanags, I., Mamaja, B. 2020. Regional cerebral oxygen saturation monitoring during spinal surgery in order to identify patients at risk. Applied Sciences; 10(6), 2069; https://doi.org/10.3390/app10062069
2. Murniece, S., Soehle, M., Vanags, I., Mamaja, B. 2019. Near-infrared spectroscopy based clinical algorithm applicability during spinal neurosurgery and postoperative cognitive disturbances. *Medicina;* 55(5), 179; https://doi.org/10.3390/medicina55050179
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Presentations at international conferences

1. Murniece, S. Cerebral oxygen saturation monitoring and near-infrared spectroscopy based clinical algorithm applicability during spinal neurosurgery. 10th Baltanest. 07.–08.10.2021, Virtual Event. (Oral presentation)
2. Murniece, S., Soehle, M., Vanags, I., Mamaja, B. Regional oxygen saturation monitoring during spinal surgery in order to identify patients at risk for cerebral desaturation. Euroanaesthesia 2020. 28.–30.11.2020, Virtual Event (Poster presentation)
3. Murniece, S., Vanags, I., Soehle, M., Mamaja, B. The value of a near infrared spectroscopy based clinical algorithm in patients undergoing spinal surgery and its relation to postoperative cognitive decline. Euroanaesthesia 2019. 01.–03.06.2019, Vienna, Austria (Poster presentation)
4. Berezovskis, R., Murniece, S., Mamaja, B. Postoperative cognitive dysfunction in patients undergoing spinal neurosurgery. Euroanaesthesia 2019. 01.–03.06.2019, Vienna, Austria (Poster presentation)

5. Murniece, S., Soehle, M., Vanags, I., Mamaja, B. NIRS-based intraoperative patient management during spinal neurosurgery in prone position and postoperative cognitive disturbances. Update on Neuro-Anaesthesia and Neuro-Intensive Care, Interdisciplinary neuroscience. 07.-09.11.2018, Brussels, Belgium (Oral presentation, nominated for best abstract)
6. Murniece, S., Vanags, I., Soehle, M., Mamaja, B. Near-infrared spectroscopy based clinical algorithm applicability during spinal neurosurgery in prone position to avoid postoperative cognitive dysfunction. 9th International Baltic Congress of Anaesthesiology. Intensive Care and Pain Management, 25.–27.10.2018, Vilnius, Lithuania (Poster presentation)
7. Berezovskis, R., Murniece, S., Mamaja, B. Postoperative cognitive dysfunction after spinal neurosurgery in prone position. 9th International Baltic Congress of Anaesthesiology, Intensive Care and Pain Management. 25.–27.10. 2018, Vilnius, Lithuania (Poster presentation)
8. Murniece, S., Vanags, I., Mamaja, B. Intraoperative regional cerebral oxygen saturation monitoring using near infrared spectroscopy device during spinal neurosurgery in prone position and postoperative cognitive dysfunction. Euroanaesthesia 2018. 02.–04.06.2018, Copenhagen, Denmark. Thesis book: European Journal of Anaesthesiology, 2018; 35(56):162 (Oral presentation)
9. Murniece, S., Stepanovs, J., Vanags, I., Mamaja, B. Prone positions influence on regional cerebral oxygen saturation in patients undergoing spinal neurosurgery. 13th International Conference on Neurology and Neurosurgery. 19.–21.06.2017, Paris, France. Thesis book: Journal of Neurophysiology; 8 (4), 37. DOI: 10.4172/2155-9562-C1-052 (Oral presentation)
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Presentations at the local conferences in Latvia

1. Murniece, S, Soehle, M., Vanags, I., Mamaja, B. Cerebral oximetry guided intraoperative algorithm relation to postoperative cognitive function in spinal surgery patients. RSU conference "Knowledge for use in practice". 01.-05.04.2019, Riga, Latvia. (Poster presentation)

2. Berezovskis, R., Mūrniece, S., Mamaja, B. Development of postoperative cognitive dysfunction after spinal neurosurgery. RSU conference "Knowledge for use in practice", 01.–05.04.2019. Riga, Latvia. (Poster presentation)
3. Murniece, S., Vanags, I., Mamaja, B. Prone position, intraoperative cerebral oxygenation monitoring and postoperative cognitive dysfunction. RSU Scientific conference 2018. 22.–23.03.2018, Riga, Latvia. Thesis book: p86 (Poster presentation)
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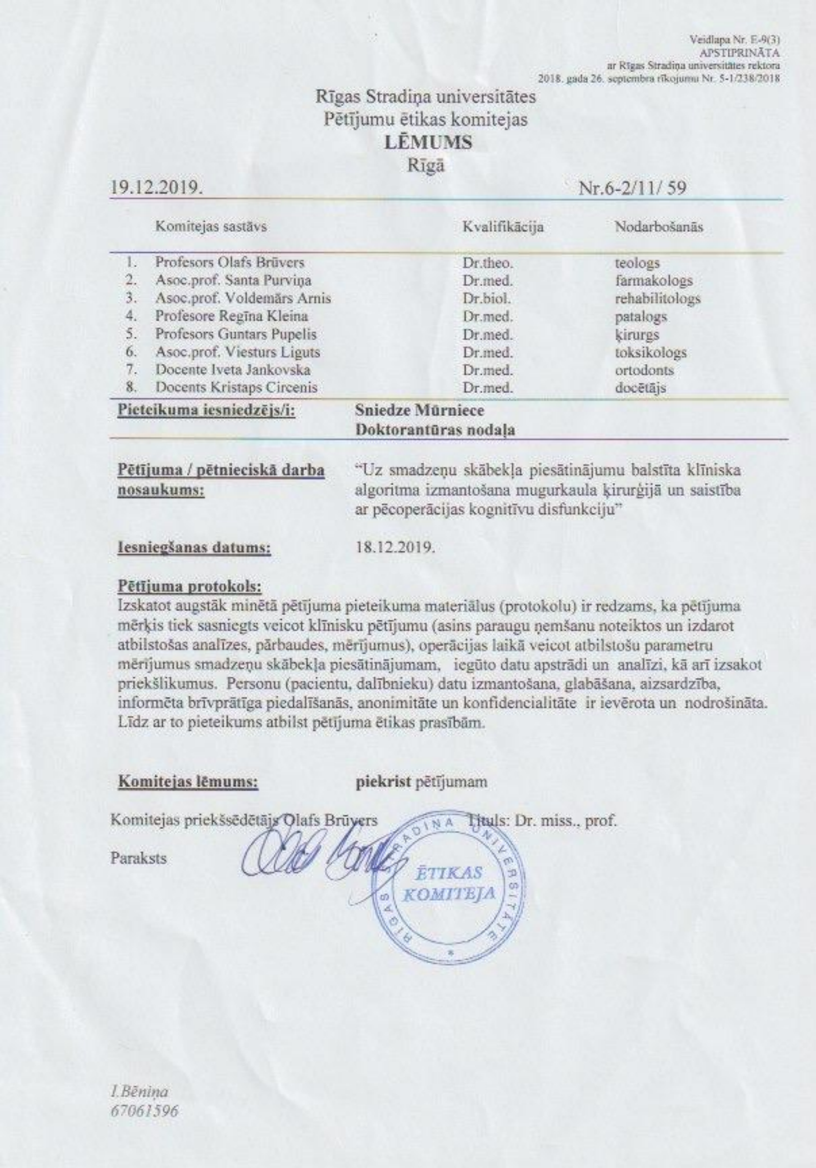
Annexes

Annex 1

The Rīga Stradiņš University

Research Ethics Committee approval



Veidlapa Nr. E-9(3)
APSTIPRINĀTA
ar Rīgas Stradiņa universitātes rektora
2018. gada 26. septembra rīkojumu Nr. 5-1/238/2018

Rīgas Stradiņa universitātes
Pētījumu ētikas komitejas
LĒMUMS
Rīgā

19.12.2019. Nr.6-2/11/ 59

Komitejas sastāvs	Kvalifikācija	Nodarbošanās
1. Profesors Olafs Brūvers	Dr.theo.	teologs
2. Asoc.prof. Santa Purviņa	Dr.med.	farmakologs
3. Asoc.prof. Voldemārs Arnis	Dr.biol.	rehabilitologs
4. Profesore Regīna Kleina	Dr.med.	patalogs
5. Profesors Guntars Pupelis	Dr.med.	ķirurgs
6. Asoc.prof. Viesturs Liguts	Dr.med.	toksikologs
7. Docente Iveta Jankovska	Dr.med.	ortodonts
8. Docents Kristaps Circenis	Dr.med.	docētājs

Pieteikuma iesniedzējs/i: **Sniedze Mūrniece**
Doktorantūras nodaļa

Pētījuma / pētnieciskā darba nosaukums: "Uz smadzeņu skābekļa piesātinājumu balstīta klīniska algoritma izmantošana mugurkaula ķirurģijā un saistība ar pēcoperācijas kognitīvu disfunkciju"

Iesniegšanas datums: 18.12.2019.

Pētījuma protokols:
Izskatot augstāk minētā pētījuma pieteikuma materiālus (protokolu) ir redzams, ka pētījuma mērķis tiek sasniegts veicot klīnisku pētījumu (asins paraugu ņemšanu noteiktos un izdarot atbilstošas analīzes, pārbaudes, mērījumus), operācijas laikā veicot atbilstošu parametru mērījumus smadzeņu skābekļa piesātinājumam, iegūto datu apstrādi un analīzi, kā arī izsakot priekšlikumus. Personu (pacientu, dalībnieku) datu izmantošana, glabāšana, aizsardzība, informēta brīvprātīga piedalīšanās, anonimitāte un konfidencialitāte ir ievērota un nodrošināta. Līdz ar to pieteikums atbilst pētījuma ētikas prasībām.

Komitejas lēmums: **piekrist** pētījumam

Komitejas priekšsēdētājs Olafs Brūvers Tituls: Dr. miss., prof.

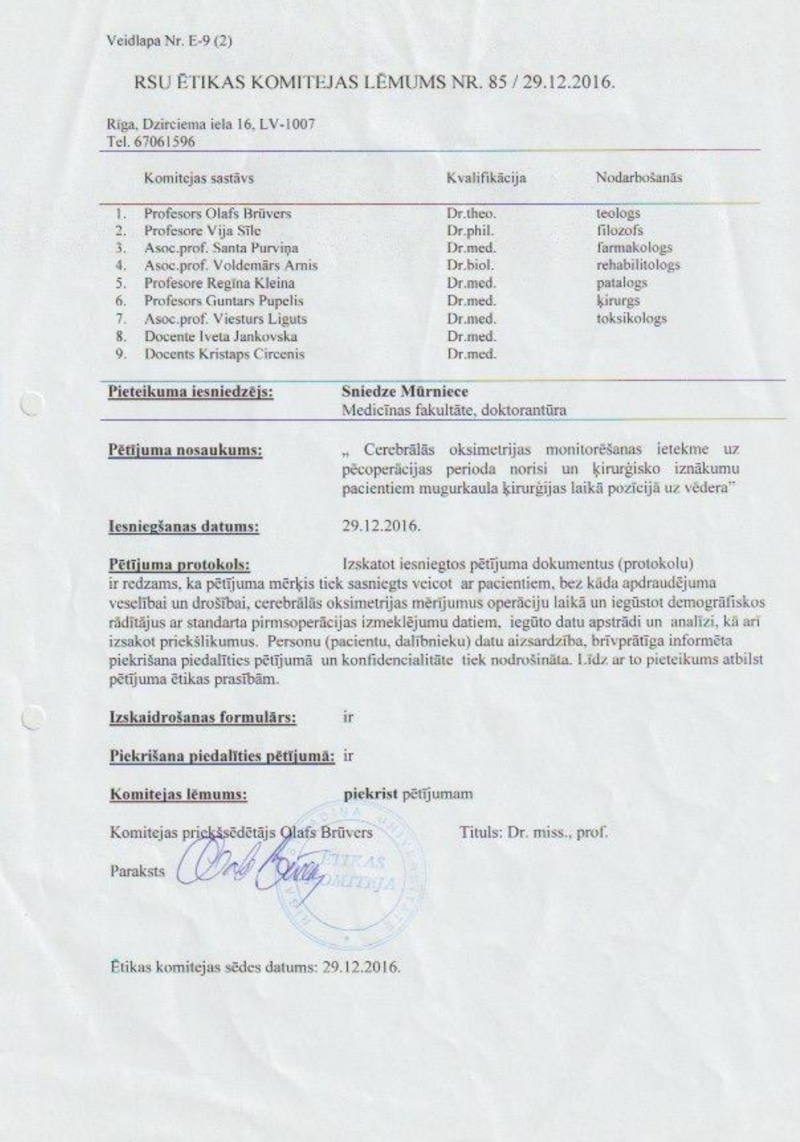
Paraksts

ĒTIKAS KOMITEJA

I.Bēniņa
67061596

The Rīga Stradiņš University

Ethics Committee approval



Veidlapa Nr. E-9 (2)

RSU ĒTIKAS KOMITEJAS LĒMUMS NR. 85 / 29.12.2016.

Rīga, Dzirciema iela 16, LV-1007
Tel. 67061596

	Komitejas sastāvs	Kvalifikācija	Nodarbošanās
1.	Profesors Olafs Brūvers	Dr.theo.	teologs
2.	Profesore Vija Sīle	Dr.phil.	filozofs
3.	Asoc.prof. Santa Purviņa	Dr.med.	farmakologs
4.	Asoc.prof. Voldemārs Arnis	Dr.biol.	rehabilitologs
5.	Profesore Regīna Kleina	Dr.med.	patalogs
6.	Profesors Guntars Pupelis	Dr.med.	ķirurgs
7.	Asoc.prof. Viesturs Liguts	Dr.med.	toksikologs
8.	Docente Iveta Jankovska	Dr.med.	
9.	Docents Kristaps Circenis	Dr.med.	

Pieteikuma iesniedzējs: **Sniedze Mūrniece**
Medicīnas fakultāte, doktorantūra

Pētījuma nosaukums: „ Cerebrālās oksimetrijas monitorēšanas ietekme uz pēcoperācijas perioda norisi un ķirurģisko iznākumu pacientiem mugurkaula ķirurģijas laikā pozīcijā uz vēdera"

Iesniegšanas datums: 29.12.2016.

Pētījuma protokols: Izskatot iesniegtos pētījuma dokumentus (protokolu) ir redzams, ka pētījuma mērķis tiek sasniegts veicot ar pacientiem, bez kāda apdraudējuma veselībai un drošībai, cerebrālās oksimetrijas mērījumus operāciju laikā un iegūstot demogrāfiskos rādītājus ar standarta pirmsoperācijas izmeklējumu datiem, iegūto datu apstrādi un analīzi, kā arī izsakot priekšlikumus. Personu (pacientu, dalībnieku) datu aizsardzība, brīvprātīga informēta piekrišana piedalīties pētījumā un konfidencialitāte tiek nodrošināta. Līdz ar to pieteikums atbilst pētījuma ētikas prasībām.

Izskaidrošanas formulārs: ir

Piekrišana piedalīties pētījumā: ir

Komitejas lēmums: **piekrist** pētījumam

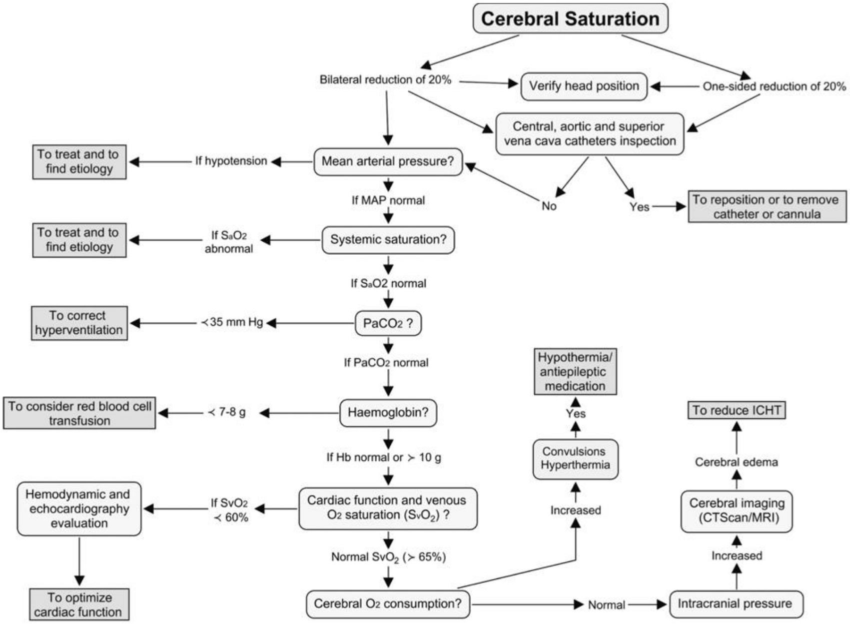
Komitejas priekšsēdētājs Olafs Brūvers Tituls: Dr. miss., prof.

Paraksts

ĒTIKAS KOMITEJA

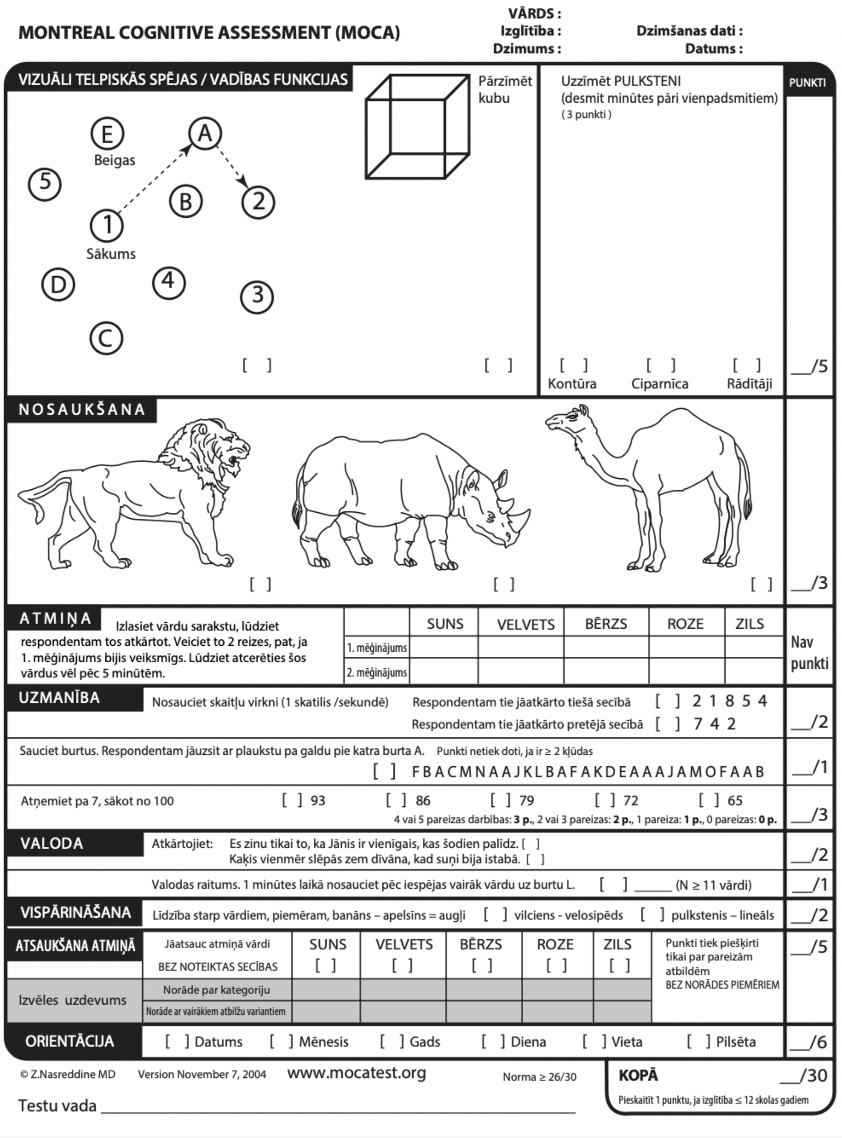
Ētikas komitejas sēdes datums: 29.12.2016.

NIRS-based clinical algorithm (Denault, 2014)



Annex 3

Montreal cognitive assessment test (MoCA) in Latvian, Russian and English



MONTREAL COGNITIVE ASSESSMENT (MOCA)

VĀRDS :
Izglītība : **Dzimšanas dati :**
Dzimums : **Datums :**

VIZUĀLI TELPISKĀS SPĒJAS / VADĪBAS FUNKCIJAS

Pārzīmēt kubu

Uzzīmēt PULKSTENI (desmit minūtes pāri vienpadsmitiem) (3 punkti)

[ ] [ ] [ ] Kontūra [ ] Ciparnīca [ ] Rādītāji

PUNKTI ___/5

NOSAUKŠANA

[ ] [ ] [ ] ___/3

ATMIŅA Izlasiet vārdu sarakstu, lūdziet respondentam tos atkārtot. Veiciet to 2 reizes, pat, ja 1. mēģinājums bijis veiksmīgs. Lūdziet atcerēties šos vārdus vēl pēc 5 minūtēm.

	SUNS	VELVETS	BĒRZS	ROZE	ZILS
1. mēģinājums					
2. mēģinājums					

Nav punkti

UZMANĪBA Nosauciet skaitļu virkni (1 skatilis /sekundē)
Respondentam tie jāatkārto tiešā secībā [ ] 2 1 8 5 4
Respondentam tie jāatkārto pretējā secībā [ ] 7 4 2 ___/2

Sauciet burtus. Respondentam jāuzsit ar plaukstu pa galdu pie katra burta A. Punkti netiek doti, ja ir ≥ 2 kļūdas
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B ___/1

Atņemiet pa 7, sākot no 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 vai 5 pareizas darbības: **3 p.**, 2 vai 3 pareizas: **2 p.**, 1 pareiza: **1 p.**, 0 pareizas: **0 p.** ___/3

VALODA Atkārtojiet: Es zinu tikai to, ka Jānis ir vienīgais, kas šodien palīdz. [ ]
Kaķis vienmēr slēpās zem dīvāna, kad suņi bija istabā. [ ] ___/2

Valodas raitums. 1 minūtes laikā nosauciet pēc iespējas vairāk vārdu uz burtu L. [ ] _____ (N ≥ 11 vārdi) ___/1

VISPĀRINĀŠANA Līdzība starp vārdiem, piemēram, banāns – apelsīns = augļi [ ] vilciens - velosipēds [ ] pulkstenis – lineāls ___/2

ATSAUKŠANA ATMIŅĀ	Jāatsauc atmiņā vārdi BEZ NOTEIKTAS SECĪBAS	SUNS [ ]	VELVETS [ ]	BĒRZS [ ]	ROZE [ ]	ZILS [ ]	Punkti tiek piešķirti tikai par pareizām atbildēm BEZ NORĀDES PIEMĒRIEM	___/5
Izvēles uzdevums	Norāde par kategoriju							
	Norāde ar vairākiem atbilžu variantiem							

ORIENTĀCIJA [ ] Datums [ ] Mēnesis [ ] Gads [ ] Diena [ ] Vieta [ ] Pilsēta ___/6

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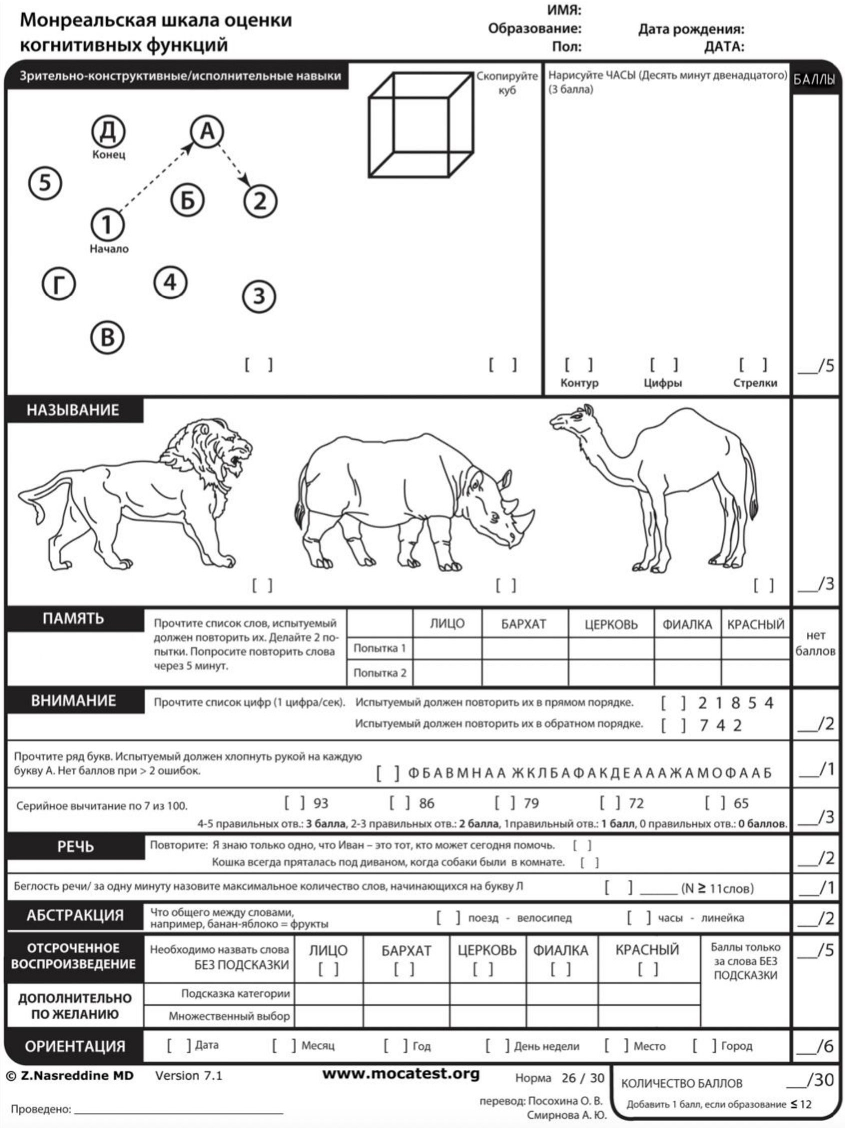
KOPĀ ___/30
Pieskaitīt 1 punktu, ja izglītība ≤ 12 skolas gadiem

Testu vada ______________________________

Annex 3 continued



Монреальская шкала оценки когнитивных функций

ИМЯ:
Образование:
Пол:
Дата рождения:
ДАТА:

Зрительно-конструктивные/исполнительные навыки

[ ]

Скопируйте куб [ ]

Нарисуйте ЧАСЫ (Десять минут двенадцатого) (3 балла)

[ ] Контур [ ] Цифры [ ] Стрелки

БАЛЛЫ ___/5

НАЗЫВАНИЕ

[ ] [ ] [ ] ___/3

ПАМЯТЬ

Прочтите список слов, испытуемый должен повторить их. Делайте 2 попытки. Попросите повторить слова через 5 минут.

	ЛИЦО	БАРХАТ	ЦЕРКОВЬ	ФИАЛКА	КРАСНЫЙ
Попытка 1					
Попытка 2					

нет баллов

ВНИМАНИЕ

Прочтите список цифр (1 цифра/сек). Испытуемый должен повторить их в прямом порядке. [ ] 2 1 8 5 4

Испытуемый должен повторить их в обратном порядке. [ ] 7 4 2 ___/2

Прочтите ряд букв. Испытуемый должен хлопнуть рукой на каждую букву А. Нет баллов при > 2 ошибок. [ ] ФБАВМНАА ЖКЛБАФАКДЕАААЖАМОФААБ ___/1

Серийное вычитание по 7 из 100. [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65

4-5 правильных отв.: **3 балла**, 2-3 правильных отв.: **2 балла**, 1правильный отв.: **1 балл**, 0 правильных отв.: **0 баллов.** ___/3

РЕЧЬ

Повторите: Я знаю только одно, что Иван – это тот, кто может сегодня помочь. [ ]

Кошка всегда пряталась под диваном, когда собаки были в комнате. [ ] ___/2

Беглость речи/ за одну минуту назовите максимальное количество слов, начинающихся на букву Л [ ] _____ (N ≥ 11слов) ___/1

АБСТРАКЦИЯ

Что общего между словами, например, банан-яблоко = фрукты [ ] поезд - велосипед [ ] часы - линейка ___/2

		ЛИЦО	БАРХАТ	ЦЕРКОВЬ	ФИАЛКА	КРАСНЫЙ	
ОТСРОЧЕННОЕ ВОСПРОИЗВЕДЕНИЕ	Необходимо назвать слова БЕЗ ПОДСКАЗКИ	[ ]	[ ]	[ ]	[ ]	[ ]	Баллы только за слова БЕЗ ПОДСКАЗКИ
ДОПОЛНИТЕЛЬНО ПО ЖЕЛАНИЮ	Подсказка категории						
	Множественный выбор						

___/5

ОРИЕНТАЦИЯ

[ ] Дата [ ] Месяц [ ] Год [ ] День недели [ ] Место [ ] Город ___/6

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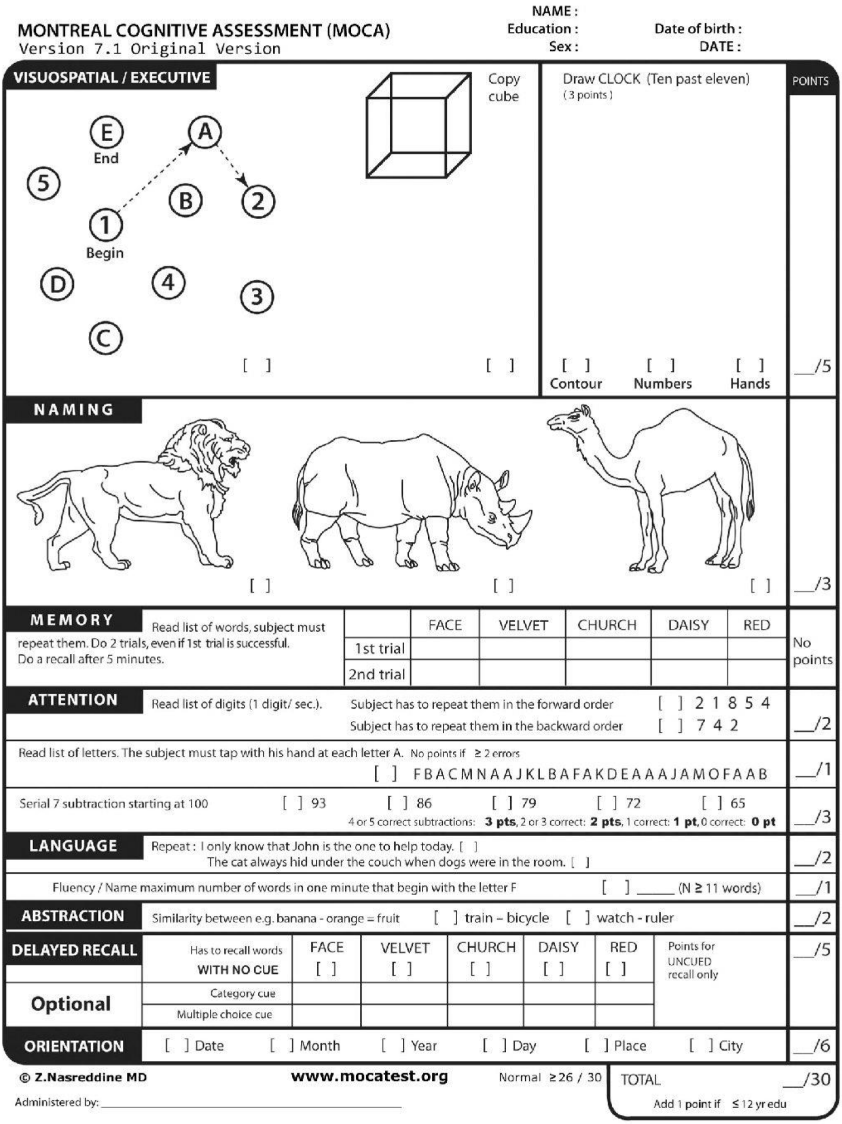
КОЛИЧЕСТВО БАЛЛОВ ___/30

Добавить 1 балл, если образование ≤ 12

Проведено: ______________________________

перевод: Посохина О. В.
Смирнова А. Ю.



MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.1 Original Version

NAME :
Education :
Sex :
Date of birth :
DATE :

VISUOSPATIAL / EXECUTIVE [ ]	Copy cube [ ]	Draw CLOCK (Ten past eleven) (3 points) [ ] Contour [ ] Numbers [ ] Hands		POINTS ___/5
NAMING	[ ]	[ ]	[ ]	___/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).

Subject has to repeat them in the forward order [ ] 2 1 8 5 4
Subject has to repeat them in the backward order [ ] 7 4 2 ___/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] FBACMNAAJKLBAFAKDEAAAJAMOFAAB ___/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 or 5 correct subtractions: **3 pts,** 2 or 3 correct: **2 pts,** 1 correct: **1 pt,** 0 correct: **0 pt** ___/3

LANGUAGE Repeat : I only know that John is the one to help today. [ ]
The cat always hid under the couch when dogs were in the room. [ ] ___/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] _____ (N ≥ 11 words) ___/1

ABSTRACTION Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler ___/2

DELAYED RECALL	Has to recall words **WITH NO CUE**	FACE [ ]	VELVET [ ]	CHURCH [ ]	DAISY [ ]	RED [ ]	Points for UNCUED recall only	___/5
Optional	Category cue							
	Multiple choice cue							

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City ___/6

© Z.Nasreddine MD **www.mocatest.org** Normal ≥26 / 30 TOTAL ___/30
Add 1 point if ≤ 12 yr edu

Administered by: ______________________________