Influence of intra-abdominal pressure on the amplitude of fluctuations of cerebral hemoglobin concentration in the respiratory band

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Abstract: An intra-abdominal pressure (IAP) is correlated with cerebral perfusion, in a mechanism of reducing venous outflow. The elevated intra-abdominal pressure leads to an increase in the intracranial pressure and a decrease in the cerebral perfusion pressure. We studied the relationship between the IAP and the cerebral oxygenation with the use of the near infrared spectroscopy technique during a gynecological surgery. The changes in hemoglobin concentrations were analyzed in the time-frequency domain in the frequency band related to respiration. The measurements were carried out in 15 subjects who underwent laparoscopic surgery. During the laparoscopy, the intra-abdominal cavity was insufflated with CO₂, which caused a controlled increase in the IAP. It was observed that the amplitudes of respiration-related waves present in hemoglobin concentration signals show an increase of 1.5 to 8.5 times during elevation of the IAP by 15 mmHg.

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1. Introduction

The intra-abdominal pressure (IAP) is a quasi-steady state pressure within the abdominal cavity determined by flexible and non-flexible abdominal wall. In healthy subjects the IAP varies between 5 and 7 mmHg [1], while in the intra-abdominal hypertension (IAH) and the abdominal compartment syndrome (ACS) it is more than 12 mmHg and 20 mmHg, respectively. It has been observed that the IAH decreases venous return to the heart via pressing on intra-abdominal veins and increasing the intrathoracic pressure what causes pressure on intrathoracic veins. IAH-dependent blood venous stasis is responsible for the increase in pressure on jugular veins and/or epidural venous plexus [2,3] causing reduction in venous outflow [4] and may be correlated with cerebral perfusion disorders [5]. It was reported that the elevated intra-abdominal pressure leads to increase in the intracranial pressure (ICP) [6] and decrease in the cerebral perfusion pressure [7,8]. Furthermore, long lasting disorders in cerebral circulation following the elevated IAP may lead to silent brain ischemia, which can be serious problem in sedated critically ill patients [9]. Thus, the increased IAP is connected with a bad recovery prognosis and may cause severe complications in patients treated in an intensive care unit increasing their mortality. Moreover, mortality resulting from untreated ACS is close to 100% [10].

In addition, the matter is complicated by the fact that the measurement of the intra-abdominal pressure requires invasive, catheter-based method. On the other hand, the assessment of the cerebral perfusion requires non-bedside, non-continuous methods based on bulky instrumentation (e.g. CT or MRI) or is limited to assessment of blood flow in large
cerebral arteries (the transcranial Doppler ultrasound technique). The optical methods might fill the need for continuous, bedside monitoring of cerebral perfusion at the microvascular level. We will show that, the optical method can be used for the assessment of cerebral perfusion changes related to changes in intra-abdominal pressure.

Recently, we studied whether the methods based on near-infrared spectroscopy combined with an injection of the exogenous optical contrast agent may be useful in assessment of brain perfusion disorders in post-traumatic brain injury patients treated in intensive care units [11,12]. These methods can be applied at the bedside. However, they need application of a contrast agent, thus, do not represent non-invasive alternative to other advanced medical imaging techniques. In the present paper we will analyze whether the non-invasive monitoring of signals of oxy- and deoxyhemoglobin concentrations and their fluctuations may contribute to the assessment of cerebral disorders related to the increase in IAP.

We will present the results of monitoring hemoglobin concentration changes as well as the tissue oxygen saturation in the brain cortex during the elective gynecological laparoscopy with the IAP = 15 mmHg. The surgery involves controlled increase in the IAP which is caused by insufflation of the abdominal cavity with CO2. The hemoglobin concentration changes were assessed based on measurements with the use of the time-resolved near infrared spectroscopy. The changes in hemoglobin concentration were analyzed in time-frequency domain with particular emphasis on fluctuations in the signals related to respiration. It will be shown that amplitudes of respiration-related waves present in hemoglobin concentration signals increase during controlled elevation of the IAP. This observation may contribute to better understanding the mechanism of reduction of the venous outflow from the brain and may lead to the development of a novel technique for monitoring of this phenomena.

2. Methods

This prospective observational study was conducted in adult women assessed in the American Society of Anesthesiologists in category I or II, undergoing the elective gynecological laparoscopy under general anesthesia. This study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board and the Bioethical Committee for Human Studies of the Medical University of Lublin, Poland (KE-0254/220/2016). Written informed consent was obtained from all participants. Patients with history of cerebral diseases were excluded. Additionally, patients, who required massive fluid resuscitation due to an intra-operative bleeding were also excluded. The studies were registered at ClinicalTrials.gov on 17/07/2018 under ID NCT03640741.

2.1 Anesthesia

A day before surgery patients received the oral premedication with the estazolam (Polfa, Poland) at the dose of 2 mg. Just before the induction of anesthesia, the patients were routinely monitored with the pulse-oximetry (SpO2), the intermittent arterial blood pressure measurement and the continuous electrocardiography for the heart rate (HR) monitoring. The urinary bladder was catheterized in all patients before anesthesia induction.

A single dose of the fentanyl (Polfa, Poland) and the propofol (AstraZeneca, United Kingdom) were used for anaesthesia induction. To facilitate the tracheal intubation, a bolus of 0.1 mg/kg body weight of the vecuronium bromide (Organon, France) was administered to all patients; the amount was titrated to maintain an adequate level of muscle relaxation. All patients were mechanically ventilated using the intermittent positive pressure ventilation (IPPV) with the mixture of oxygen and air with ratio 60:40% and at the fixed tidal volume of 5–6 ml/kg body weight. The respiration rate was adjusted to maintain the end-tidal CO2 between 35 - 40 mmHg with the peak respiratory pressure lower than 30 cmH2O. The fraction of inspired oxygen (FiO2) was adjusted to maintain the peripheral blood saturation (SpO2) between 97 – 100%. In cases requiring increased ventilation, the respiratory rate was increased. In these cases however, it did not require the increase in the tidal volume. The
resulted respiration rate was between 9 and 12/min and was constant for each subject during the experiment. The respired mixture of gases was monitored with the SpaceLabs monitor (SpaceLabs Healthcare, OSI systems, USA). Anaesthesia was maintained using fractioned dose of the fentanyl and the sevoflurane (ABBVIE, UK). Balanced crystalloids (Sterofundin ISO, Melsulgen, Germany) were used to maintain the mean arterial pressure above 70 mmHg. After the surgery completion, the sevoflurane was discontinued, and the neuromuscular blockade was reversed using a single dose of the atropine (0.5 mg) and the neostigmine (2.5 mg). Patients were extubated upon satisfactory emergence from general anaesthesia and admitted to the postoperative intensive care unit. The postoperative pain was treated with fractionated doses of the paracetamol (Bristol Myers Squibb, Poland).

2.2 Surgery/laparoscopy

After induction of anesthesia, a single-port trocar was inserted into the abdominal cavity above the level of the umbilicus. Pneumoperitoneum was induced with the carbon dioxide insufflation until the IAP reached 15 mmHg (typically during 2-5 minutes). After induction of anesthesia the intra-abdominal pressure was measured in the urinary bladder (Kron method) and next it was measured directly in the peritoneal cavity during the surgery. After the pneumoperitoneum was performed, a 10 mm 0° optic was introduced into the orifice corresponding to the port. Surgery was performed in Trendelenburg position at –25 to –30 degrees, to produce the gravitational displacement of viscera away from the surgical site. Arms were arranged along the body and legs in lithotomy position. The surgical procedure was as follows:

• induction of anesthesia,
• intubation of the subject,
• start of the insufflation of abdominal cavity with CO₂ – gradual increase in intra-abdominal pressure,
• stop of the insufflation of abdominal cavity,
• moving the patient into Trendelenburg position,
• surgical procedure (an uterus removal, a polyps removal, a biopsy),
• release of CO₂ - quick decrease in the IAP
• waking up the patient.

After the surgery all devices were removed, one port was used for the postoperative drainage, and then the umbilical incision was closed in layers, including the peritoneum, the anodesma, the subcutaneous tissue, and the subcuticular layer, using reabsorbable sutures.

2.3 Subjects

Seventeen women were included. However two were excluded from further analysis, the first one due to the strong movement artifacts prior to increase in the IAP and the second one due to the technical problems with data acquisition. Finally 15 women were studied. In all subjects, the mean IAP measured just after the anesthesia induction ranged between 0 and 1 mmHg. The intra-peritoneal CO₂ insufflation was uncomplicated. The patients data and diagnostic procedures are given in Table 1.

The optodes of the time-resolved near infrared spectroscopy (trNIRS) system were positioned on the forehead of the subject, symmetrically on left and right hemisphere (channel 1 and 2 respectively). Optical signals were measured during the whole procedure.
| Subject number | Age  | Weight [kg] | Height [m] | Procedure/Diagnosis                  | Volume of CO₂ [liter] insufflated into peritoneal cavity for induction of increase in the IAP of 15 mmHg |
|----------------|------|-------------|------------|--------------------------------------|--------------------------------------------------------------------------------------------------|
| 1              | 32   | 90          | 172        | sterilitas                           | 3.1                                                                                               |
| 2              | 28   | 72          | 174        | cystis ovarii sin                     |                                                                                                   |
| 3              | 36   | 66          | 168        | myoma uteri                          | 3.1                                                                                               |
| 4              | 33   | 50          | 162        | sterilitas                           | 3.2                                                                                               |
| 5              | 38   | 60          | 164        | ovarian cyst                          | 4.5                                                                                               |
| 6              | 31   | 54          | 165        | ovarian cyst                          | 3.8                                                                                               |
| 7              | 27   | 71          | 163        | uterine fibroids                     | 4.3                                                                                               |
| 8              | 28   | 53          | 164        | ovarian cyst                          | 3.3                                                                                               |
| 9              | 40   | 50          | 162        | ovarian cyst                          | 4.1                                                                                               |
| 10             | 42   | 53          | 160        | ovarian cyst                          | 3.6                                                                                               |
| 11             | 37   | 85          | 165        | ovarian cyst                          | 3.1                                                                                               |
| 12             | 29   | 75          | 167        | ovarian cyst                          | 4.1                                                                                               |
| 13             | 81   | 66          | 166        | ovarian cyst                          | 2.9                                                                                               |
| 14             | 43   | 67          | 166        | uterine fibroids                     | 3                                                                                                  |
| 15             | 37   | 85          | 165        | sterilitas                           | 2.6                                                                                               |
| 16             | 34   | 60          | 160        | sterilitas                           | 2.1                                                                                               |
| 17             | 33   | 62          | 169        | sterilitas                           | 2.1                                                                                               |

### 2.4 Measurement system

We applied the custom-made, 2-channel, time-resolved near infrared spectroscopy system [13,14]. The measurement system utilized semiconductor pulsed laser heads (Picoquant, Germany) operating at 2 wavelengths, 690 nm and 830 nm and controlled using SEPIA 2 current driver (Picoquant, Germany). The light pulses, generated with repetition rate of 64 MHz, were delivered into a human head with the use of bifurcated fibers (ThorLabs, USA) of diameter of 400 µm and length of 2 m. Furthermore, diffusely reflected photons were collected in reflectance geometry using 2 m long liquid light guides (Newport, USA), of diameter of 3 mm, combined with Hybrid PMTs (Becker&Hickl, Germany). The source fibers and detecting light guides were fixed on the surface of the head using the Coban self adhesive bandage (3M, USA) and in-house 3D-printed plastic holder with the interoptode separation of 3 cm. The light was coupled into and from the head using prisms, thus the fibers and the liquid light guides were positioned parallel to surface of the head. The power of light emitted into the tissue was 3 mW. The distributions of time of flight of photons (DTOF) at each wavelength and for each channel were acquired with the sampling frequency of 10 Hz using two TCSPC boards (SPC 130 Becker&Hickl, Germany) mounted in MAGMA PCI driver. The synchronization pulses from the SEPIA driver were delivered to the TCSPC electronics. The data from the TCSPC boards was recorded through Express Card Interface on the laptop PC using the Becker&Hickl software. The collection time of each DTOF was 90 ms. The instrumental response function (IRF) was measured within each measurement session. Full width at half maximum of the IRF was around 400 ps.
2.5 Data analysis

The data analysis was carried out in Matlab environment (version R2016b, MathWorks, USA). The oxyhemoglobin and deoxyhemoglobin concentration changes were calculated with the use of the modified Beer-Lambert law using Eq. (1) and Eq. (2) [15].

\[
\Delta A_1 = (\varepsilon_{HbO2}^A \Delta C_{HbO2} + \varepsilon_{Hb}^A \Delta C_{Hb}) < l >_{A1}
\]

\[
\Delta A_2 = (\varepsilon_{HbO2}^B \Delta C_{HbO2} + \varepsilon_{Hb}^B \Delta C_{Hb}) < l >_{A2}
\]

where: \(\Delta A_{1,2}\) are light attenuations expressed as \(-\log(I/I_0)\) (\(I_0\) is measured light intensity and \(I_0\) is a baseline), \(\varepsilon_{HbO2}, \varepsilon_{Hb}\) are wavelength-dependent extinction coefficient for oxygenated and deoxygenated hemoglobin, respectively [16]. The \(\Delta C_{HbO2}\) and \(\Delta C_{Hb}\) are changes in oxygenated and deoxygenated hemoglobin concentration. The optical pathlengths \(<l>_{A1}\) and \(<l>_{A2}\) were estimated from the mean time of flight of photons, the 1st statistical moment of the DTOF [17] with consideration of the influence of the IRF and the refractive index of the tissue \(n = 1.4\).

The measured optical signals were affected by movement artifacts caused by the surgical procedure. Moreover, the amplitude of respiratory related fluctuations recorded in optical signals measured on the head is in general low [18]. Thus, respiratory-related fluctuations were not visible in higher order statistical moments of DTOFs, which we previously used successfully for the assessment of signals related to changes in absorption located in deeper tissue compartments [13]. Therefore, the approach based on statistical moments [19] allowing to eliminate the contamination of superficial layers failed.

Tissue oxygen saturation (StO₂) was calculated according to Eq. (3) and Eq. (4) [20] using absorption coefficients assessed for 2 wavelengths based on the analysis of statistical moments of distribution of time of flight of photons [17].

\[
S_{O2} = \frac{\mu'_{A1}^{HbO2} - \mu'_{Hb}^{HbO2}}{\mu'_{HbO2}^{HbO2} - \mu'_{Hb}^{HbO2}} \frac{\mu'_{A2}^{HbO2} - \mu'_{Hb}^{HbO2}}{\mu'_{HbO2}^{HbO2} - \mu'_{Hb}^{HbO2}}
\]

\[
\mu'_{A1} = \frac{\mu'_{HbO2}^{HbO2}}{\mu'_{Hb}^{HbO2}}
\]

Furthermore, the hemoglobin concentration changes were analyzed using the Matlab’s spectrogram function which allows to visualize time-frequency distributions of the power spectral density. The spectrogram was calculated for 256-samples-long periods (25.6 s long) with overlap of 8 samples (0.8 s long). Moreover, time series of the power spectral density (PSD) at the frequency, that corresponds to the maximum amplitude in respiration band, i.e. 0.2-0.35 Hz, were plotted. This frequency follows the respiratory rate of the subject.

3. Results

3.1 Tissue oxygen saturation

We analyzed changes in hemoglobin concentrations (the deoxyhemoglobin \(\Delta C_{Hb}\) and the oxyhemoglobin \(\Delta C_{HbO2}\)) as well as the tissue oxygen saturation during increase in the intra-abdominal pressure for all 15 subjects. In Fig. 1 an example of the tissue oxygen saturation, during insufflation of the abdominal cavity, measured for both hemispheres for the subject 3 is presented. The difference in the StO2 between hemispheres might results from physiology and/or anatomy, e.g. difference in skull thickness [21], and is observed in healthy subjects [22] as well.

Furthermore, the mean values of StO₂ for period of 50 s before the start of insufflation with CO₂ and for period of 450 s after the start of insufflation were calculated for 15 subjects.
The distribution of these series (2 values for each subject) were presented in Fig. 2 with the use of the MatLab’s boxplot function in order to account for their statistical significance. The upper and lower sides of the boxes represent 75th and 25th percentiles of samples respectively, while the red line is the median and the whiskers represent interquartile range. We did not observe any repetitive behavior related to changes in the tissue oxygen saturation. The Wilcoxon rank sum test, did not reject the hypothesis, that the medians of StO$_2$ for different periods were equal at 5% level of significance.

![Fig. 1. Time course of the tissue oxygen saturation during the insufflation of abdominal cavity measured in the subject number 3 on the left and right hemisphere (channels 1 and 2, respectively). The start and stop of the CO$_2$ insufflation were marked with red dotted lines.](image1)

![Fig. 2. The summary statistics for 15 patients of mean values of StO$_2$ for periods of 50 s before the start of insufflation with CO$_2$ and 450 s after the start of insufflation with CO$_2$, respectively. The upper and lower sides of the boxes represent 75th and 25th percentiles of samples, while the red line is the median and the whiskers represent interquartile range.](image2)

### 3.2 Pulsatile components

In the next step, in order to analyze physiological fluctuations, the signals of changes in hemoglobin concentration were high-pass filtered below 0.1 Hz. In Fig. 3 and Fig. 4 changes in concentrations of both forms of hemoglobin are presented for the left and right hemisphere for the subjects 3 and 13 respectively. The increase in the amplitude of oscillations can be easily observed, especially for changes in the oxygenated hemoglobin concentration.
Fig. 3. Changes in oxy- and deoxyhemoglobin concentration $\Delta CHbO_2$ and $\Delta CHb$ during the insufflation of the abdominal cavity measured simultaneously in the subject number 3 on the left and right hemisphere (channels 1 and 2 respectively). The start and stop of CO$_2$ insufflation were marked with red dotted lines.

Fig. 4. Changes in oxy- and deoxyhemoglobin concentration $\Delta CHbO_2$ and $\Delta CHb$ during the insufflation of the abdominal cavity measured for the subject number 13 at left and right hemisphere (channels 1 and 2 respectively). The start and stop of CO$_2$ insufflation were marked with red dotted lines.

Furthermore, in Fig. 5 and 6 the time-frequency distributions of the power spectral density of $\Delta CHbO_2$ and $\Delta CHb$ (2 upper panels) signals, acquired respectively for the subjects 3 and 13, assessed at the left and right hemisphere (left and right panels) were presented. Each spectrogram is presented for $\Delta CHbO_2$ and $\Delta CHb$ together with the cross-section over time of the power spectral density at the maximum amplitude in the respiratory band (from 0.2 Hz to 0.35 Hz). The time-series of PSD (bottom panels in Fig. 5 and 6) are presented to visualize the difference in the amplitude of the respiratory components between $\Delta CHbO_2$ and $\Delta CHb$. The amplitude of changes in oscillations in the respiratory band is higher for $\Delta CHbO_2$. The respiration component of $\Delta CHbO_2$ increases after around one minute from the start of the insufflation. The amplitude of the PSD at the respiration related frequency increases by 1.5-8.5 times while the IAP increases. This effect is observed in 11 out of 15 subjects.
Fig. 5. The time-frequency distribution of the power spectral density of $\Delta C_{\text{HbO}_2}$ and $\Delta C_{\text{Hb}}$ for the subject 3 assessed on the left and right hemisphere (channel 1 and channel 2). The time series of the PSD at $f = 0.23$ Hz, which corresponds to the respiratory rate of the subject, are presented in the lower panel. The start and stop of CO$_2$ insufflation were marked with red dotted lines.

Moreover, we averaged time series of the PSD at the maximum amplitude of oscillations in respiratory band for left and right hemispheres. The averaged time-series were smoothed with the Matlab’s zero-phase digital filter of a window size of 40 samples (4 s). Due to high differences in amplitudes between the subjects, the PSD time-series were first normalized from 0 to 1 and after that, for each distribution the mean value calculated for period between

Fig. 6. The time-frequency distribution of the power spectral density of $\Delta C_{\text{HbO}_2}$ and $\Delta C_{\text{Hb}}$ for the subject 13 assessed on the left and right hemisphere (channel 1 and channel 2). The time series of the PSD at $f = 0.20$ Hz, which corresponds to the respiratory rate of the subject, are presented in the lower panel. The start and stop of CO$_2$ insufflation were marked with red dotted lines.
0 s and 50 s (rest period) was subtracted. The resulted time series for 15 subjects are presented in Fig. 7.

![Fig. 7.](image)

Fig. 7. Distributions of time-series of the power spectral density at the maximum amplitude of oscillations in the respiratory band of changes in $\Delta CHbO_2$ (upper panel), $\Delta CHb$ (lower panel) averaged for left and right hemispheres. The start of CO$_2$ insufflation is marked with red dotted line.

Furthermore, the mean values of the time series between 0 s and 50 s and between 50 s and 450 s i.e., before and after the start of insufflation with CO$_2$ were calculated for 15 subjects. The distribution of these series (2 values for each subject) were presented in Fig. 8 with the use of the MatLab’s boxplot function in order to present the statistical significance of data pre and after the CO$_2$ insufflation. The upper and lower sides of the boxes represent 75th and 25th percentiles of the samples respectively, while the red line is the median and the whiskers represent interquartile range. According to the Wilcoxon rank sum test, the p-values for distributions of the mean PSD for $\Delta CHbO_2$ and $\Delta CHb$ were $p = 0.033$ and $p = 0.020$ respectively. This means, that in both cases, null hypotheses of equal medians were rejected at 5% significance.

![Fig. 8.](image)

Fig. 8. The summary statistics for 15 subjects of mean values of the normalized power spectral density of $\Delta CHbO_2$ and $\Delta CHb$ for time series in range 0 ÷ 50 s and 50 ÷ 450 s i.e., before and after the start of the CO$_2$ insufflation. The upper and lower sides of the boxes represent 75th and 25th percentiles of samples, while the red line is the median and the whiskers represent interquartile range.
4. Discussion

We have carried out measurements of changes in optical signals with the time-resolved near infrared spectroscopy system at 2 hemispheres during the laparoscopy procedure. We have studied changes in the tissue oxygen saturation as well as changes in the hemoglobin concentration and its spectrogram while insufflation of the abdominal cavity with CO2 what increases the intra-abdominal pressure. We did not observe any significant changes in the tissue oxygen saturation while increase in the IAP. This observation is in a good agreement with reports of other authors [23–31] where only small changes (increase or decrease) in the saturation were noted. In 3 out of 8 studies no significant changes in StO2 were reported. The detailed results of estimation of StO2 obtained with the near infrared spectroscopy during the increase in IAP while laparoscopy are presented in Table 2. The results were obtained in subjects of different age and gender.

| Authors          | Patients                                      | NIRS device | Optodes position | IAP change          | StO2 change          |
|------------------|-----------------------------------------------|-------------|------------------|---------------------|----------------------|
| De Waal et al. 2002 [23] | Children                                      | INVOS 3100A | Forehead, right hemisphere | Increase (5 – 8 mmHg) | increased from 61 ± 9 to 70 ± 9 |
| Gipson et al. 2006 [24] | 70 adults for laparoscopic hemorrhaphy, gastric bypass or cholecystectomy | INVOS 3100A | Forehead, right hemisphere | Increase (8 – 12 mmHg) | increased from the baseline in 246 and decreased in 758 of the total of 1004 data points |
| Lee et al. 2006 [25] | 24 female patients                            | INVOS 4100  | NA               | Increase (12 – 15 mmHg) | ± 9.3%               |
| Tsypin et al. 2007 [26] | 64 children, gynecological laparoscopic intervention | Critikon RedOx Monitor 2020 | Forehead | NA | 3% reduction |
| Kupisiak et al. 2011 [27] | 105 laparoscopic cholecystectomy patients      | INVOS 4100  | NA               | NA                  | No significant change |
| Kamagai et al. 2015 [28] | 40 patients undergoing laparoscopic radical prostatectomy | INVOS 5100B | Forehead, left and right hemisphere | Increase (15 mmHg) | Increased from 68.6 ± 4.7% to 74.0 ± 5.0% at 5 minutes after increased IAP |
| Tuna et al. 2016 [29] | 40 children                                   | Critikon RedOx Monitor 2020 | Forehead, left and right hemisphere | Increase (8 - 10 mmHg) | No significant change |
| Pelizzo et al. 2017 [30] | 30 children                                   | NA          | NA               | Increase (8 - 12 mmHg) | 82.0 ± 11.1 (vs baseline 81.3 ± 9.6) |
| Matanes et al. 2018 [31] | 18 women who underwent robotic sacrocolpopexy | INVOS 5100  | Forehead, left and right hemisphere | Drop (from 14 to 10 mmHg) | No significant change |
| Our studies      | 17 woman who underwent laparoscopic procedure | Custom-made time resolved trNIRS | Forehead, left and right hemisphere | Increase (15 mmHg) | No significant change |

We observed, however, the effect of the increase in amplitude of fluctuations of changes in hemoglobin concentration related to the respiratory band during increase in the IAP. The observed increase in the amplitude was larger in the signals of changes in oxygenated
hemoglobin concentration. The amplitude of the PSD at the respiration frequency observed in changes in hemoglobin concentration increased 1.5 to 8.5 times.

This effect is related to the influence of the respiration on the amplitude of fluctuations observed in optical signals which was previously reported in spirometry studies [32,33] and more recently applied in [34]. During breathing, the increased pressure in the lungs leads to modification of the blood flow in venous system, especially big veins, e.g. inferior vena cava, jugular veins. When the intra-abdominal pressure increases, the intrathoracic pressure increases as well. As a consequence the pressure being applied by lungs on veins is higher, resulting in the higher amplitude of fluctuations observed in optical signals (Fig. 9). The changes in amplitudes of hemoglobin concentrations were previously observed in a mechanism of the increase in the expiratory pressure. Elwell et al. [35] reported the increase in the oxygenated hemoglobin concentration while increase in the expiratory pressure up to 20 cmH₂O.

The observed increase in the amplitude of respiratory band fluctuations may be of use for the assessment of venous saturation using method described by Wolf et al. [32] and Franceschini et al. [33]. In these studies, in which the spirometry technique was proposed, only in limited number of subjects the respiratory related fluctuations were successfully monitored, what limits practical usefulness of the proposed technique. An externally induced increase in the intra-abdominal pressure may allow to increase the amplitude of fluctuations in respiratory band, thus, leading to the reliable assessment of the venous saturation. Moreover, the effect described in this paper, caused by the increase in IAP, might be additionally useful in the method of coherent hemodynamics spectroscopy for the assessment of cerebral autoregulation reported by Fantini [36] and Kainerstorfer et al. [37].

Results of the presented study confirm that the oxygenation of the brain is modified due to increase in the abdominal pressure. These results are in line with reports in which relationship between the ICP and the IAP were observed. The NIRS-based technique, which is non-invasive and easy to apply at the bedside, allows to study these relationships indirectly. The observed modification of the cerebral oxygenation related to the increase in the IAP may lead
to significant complications especially in patients with critical brain perfusion disorders treated in the intensive care units.

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