

Evaluation of plethysmographic variability index and hemoglobin monitoring in patients who underwent laparoscopic cholecystectomy

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Abstract. – OBJECTIVE: The aim of the study was to determine the interaction of Pleth Variability Index, Perfusion Index (PI) and Peripheral Blood Hemoglobin (SpHb) values during the surgical phases of laparoscopic cholecystectomy.

PATIENTS AND METHODS: After the approval of the Ethics Committee, the patients who experienced laparoscopic cholecystectomy between October 2020 and January 2021 in our hospital were included in the study. We analyzed peripheral blood hemoglobin, pleth variability index, and the perfusion index values of 87 patients who underwent cholecystectomy. We performed the study with Masimo Radical 7 pulse oximeter probe (Masimo Radical 7; Masimo Corp., Irvine, CA, USA) in this present study.

RESULTS: According to the analysis of our results it has been found that hemoglobin, T5, T6, T7 values were found to be significantly higher than T3, T4, T8 values ($p < 0.05$). The PVI T4 value was the highest within the periods, and it was found to be statistically significantly higher between T5, T6, and T7 values ($p < 0.05$). Close values were detected in PI, T1 and T8 periods. T2 value measured during the period of mechanical ventilator was found to be significantly higher than the in T1, T3, T6 values ($p < 0.05$).

CONCLUSIONS: In this study, we followed the SpHb, SPOC, and ORI values in these steps (T1-T8) and investigated the interaction between them. Knowing the response of monitoring to these conditions is important for the treatments to be performed.

Key Words:

Hemoglobin, Laparoscopic cholecystectomy, Pleth variability index, Pneumoperitoneum, Reverse Trendelenburg.

Introduction

Nowadays, thanks to technological developments, non-invasive monitoring has become a

viable alternative to invasive monitoring. One of the monitors that provides such possibilities is the Masimo Radical-7 Pulse Oximeter probe (Masimo Corp., Irvine, CA, USA). With this device, vital monitoring, such as the Pleth Variability Index (PVI), Perfusion Index (PI), Peripheral Blood Hemoglobin (SpHb), and guiding treatment can be carried out non-invasively. Non-invasive monitoring is especially important for tissue perfusion in patients with cardiac and respiratory diseases and in the follow-up of surgical procedures with bleeding risk¹.

PI is calculated as the ratio of pulsatile to non-pulsatile flow and is used as a quick indicator of microcirculatory changes. The parameters, which provide continuous information about tissue perfusion non-invasively, have become the preferred hemodynamic monitoring method in patient follow-up due to their ease of use. However, several potential factors that alter pleth amplitude, such as spontaneous respiratory activity, arrhythmia, impaired peripheral perfusion, hypothermia, sympathetic tone alteration, and vasoactive drug use, limit the usability of PI and PVI monitoring².

General anesthesia and opioid analgesics increase PI while simultaneously decreasing PVI. PI increases as a result of peripheral vasodilation and decreases in sympathetic tone caused by anesthetic drugs and opioids used in the induction and maintenance of general anesthesia³. The PVI is an indicator of the dynamic alterations in the PI throughout the respiratory cycle and is calculated as $PVI (\%) = [(PI \text{ max} - PI \text{ min}) / PI \text{ max}] \times 100$. The PVI is a useful indicator of fluid management evaluation. It depends on respiratory alterations in arterial pulse pressure⁴. In our study, we aimed to examine the interaction of PVI, PI, and SpHb in the monitoring of the laparoscopic cholecystectomy stages.

Patients and Methods

We analyzed PVI, PI, and SpHb values of 87 patients who underwent cholecystectomy with the Masimo Radical-7 Pulse Oximeter (Masimo Corp., Irvine, CA, USA). The ethical approval for this study was obtained from Malatya Clinical Research Ethics Committee (No. 2021/48).

Exclusion criteria included patients with diabetes mellitus, pulmonary diseases, intracardiac shunts, valvular heart disease, peripheral vascular disease, arrhythmias, uncompensated cardiac disease, respiratory disease, chronic renal dysfunction, or age below 18 or older than 70. We included participants who were American Society of Anesthesiologists status I and II who were also scheduled for elective laparoscopic cholecystectomy under general anesthesia aged between 18 and 70 years old. The patients were taken to the operating room after eight hours of fasting. Standard monitoring, including non-invasive blood pressure (NIBP), three-lead electrocardiography (ECG) and pulse oximetry were applied to the patients. The Masimo Radical-7 Pulse Oximeter probe was attached to the index finger of the right hand and protected from light.

Three minutes of preoxygenation were performed. Anesthesia induction was maintained *via* thiopental sodium (4-6 mg/kg) and fentanyl (1-1.5 mcg/kg) intravenously. Neuromuscular block was carried out with rocuronium (0.6-1.2 mg/kg). Lung ventilation was maintained after intubation with proper endotracheal tube, and respiratory rate was set in order to provide an end-tidal carbon dioxide (EtCO₂) of 30-35 mmHg. Anesthesia was provided with sevoflurane (1.5-2 Minimal Alveolar Concentration (MAC) in a 50% O₂-air mixture (fresh gas flow 4-liter) tidal volume of 6-8 mL × kg⁻¹ and/or an airway plateau pressure that was not passing over 35 cmH₂O. The respiratory rate was fixed at 12, with an I:E ratio of 1:2 and positive end-expiratory pressure (PEEP) of 5 cmH₂O. Maintenance fluid was performed according to the 4-2-1 law. Crystalloid was used for infusion. Anesthesia stages, table positions and surgical steps were determined from T1 to T8. T1 indicates pre-induction time, T2 represents after intubation time, T3 represents after pneumoperitoneum time, T4 indicates after reverse Trendelenburg position time, T5 represents after cholecystectomy time, T6 represents after correction of the reverse Trendelenburg position time, T7 is after desufflation, and T8 represents after extubation time. Systolic blood pressure (SBP), mean blood pressure (MAP), diastolic blood pressure (DBP), heart rate (HR), oxy-

gen saturation (SpO₂), end tidal CO₂ (EtCO₂), PI, PVI, peripheral blood oxygen content (SPOC) (ml/dL), peripheral blood hemoglobin (SpHb) (g/L), oxygen reserve index (ORI), tidal volume (Vt), PEEP, frequency plateau pressure peak pressure (Ppeak), and intra-abdominal pressure (IAP) values were measured by the laparoscopy device and recorded.

Reverse Trendelenburg position was applied to the patients with an angle of 25-30°. The patients were administered meperidine 0.5 mg/kg intravenously after intubation and 0.5 mg/kg tramadol after cholecystectomy. Demographic data, total bleeding volume, volume of fluid administered, operating times, anesthesia, and reverse Trendelenburg angle variables were recorded. The mean bleeding volume was 21 (10-35) mL in our patients.

In the statistical power analysis, when $\alpha = 0.05$ and 1-B (power) = 0.80, at least 76 subjects were required for the mean change in mean blood pressure to be 12 mmHg (OR 3% mean change in PVI). Considering possible data losses, 87 cases were included in our study. Skewness and kurtosis values were checked in the normality tests of the data. Changes of quantitative variables with respect to time were analyzed with the repeated measures ANOVA test, and the relationship between them was analyzed with Pearson correlation analysis. Data analysis was performed using the IBM SPSS version 20.0 statistical program (SPSS Corp., Armonk, NY, USA). A *p*-value of < 0.05 was considered statistically significant.

Results

Demographics and surgical time were presented in Table I. When HGB values were examined, no difference was observed between T1 and T8 values. T5, T6, T7 values were found to be significantly higher than T3, T4, T8 values ($p < 0.05$) (Figure 1). The lowest values were observed in the T4 period throughout the surgeries. Since ORI was 0 in T1 and T8 periods, it was not included in the statistical calculation. ORI T2 value was found to be significantly higher than the values in T3, T4, T5, T6, T7 periods ($p < 0.05$). The lowest values between periods were observed in the T4 period. MAP T1, T2, T4, T8 values were found to be significantly higher than T5, T6, T7 values ($p < 0.05$) (Figure 2). In addition, a positive and statistically significant relationship was found between MAP T8 value and PVI T8 value in our study ($p < 0.05$) (Figure 2, 4). Close values were

Table I. Demographic and pre-operative data.

	Minimum	Maximum	Mean	Std. Deviation
Age (years)	18	68	46.3	14.728
Height (cm)	150	178	163.3	6.729
Weight (kg)	52	110	79	12.307
Intraoperative crystalloids (ml)	750	1890	1016	187.1
Preoperative hemoglobin	9.60	16.70	13.5	1.29121
Preoperative hematocrit	31.5000	48.9000	40.6	3.3381991
Duration of surgery (min)	32	141	53.1	18.4
Duration of anaesthesia (min)	40	152	61.4	18.9
Bleeding (ml)	55	135	79	83

68 of our patients were female and 19 were male. According to the ASA (American Society of Anesthesiologists) classification, 28 patients were ASA1, and 59 patients were ASA 2.

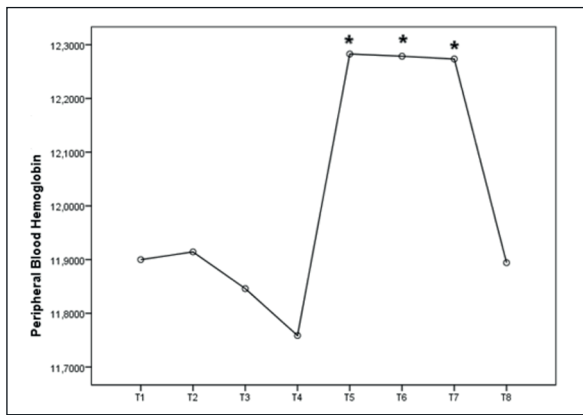


Figure 1. Peripheral Blood Hemoglobin (SpHb). T5 p -value = 0.001 ($*p < 0.05$), T6 p -value = 0.019 ($*p < 0.05$), T7 p -value = 0.012 ($*p < 0.05$).

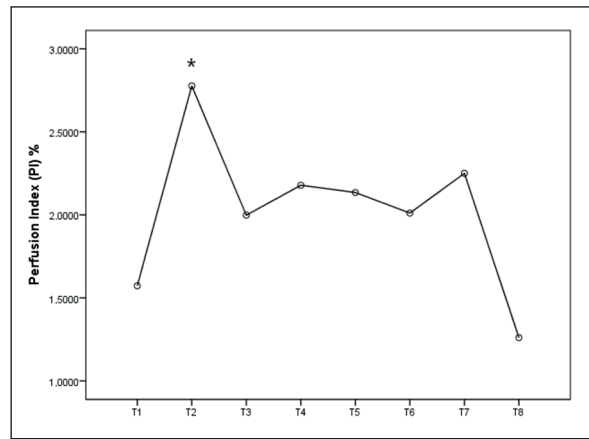


Figure 3. Perfusion Index (PI). T2 p -value = 0.001 ($*p < 0.05$).

seen in PI T1 and T8 periods. T2 value during the period of being connected to mechanical ventilator was found to be significantly higher than the values in T1, T3, T6 periods ($p < 0.05$) (Figure

3). The PVI T4 value was the highest within the periods, and it was found to be statistically significantly higher between T5, T6, and T7 values ($p < 0.05$) (Figure 4). When SPOC values were ex-

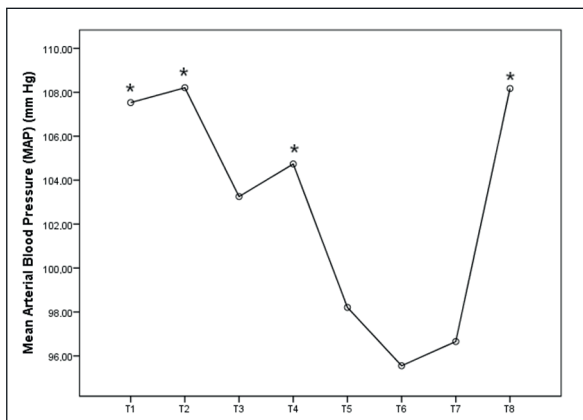


Figure 2. Mean Blood Pressure (MAP). T1 p -value = 0.030 ($*p < 0.05$), T2 p -value = 0.042 ($*p < 0.05$), T4 p -value = 0.002 ($*p < 0.05$), T8 p -value = 0.001 ($*p < 0.05$).

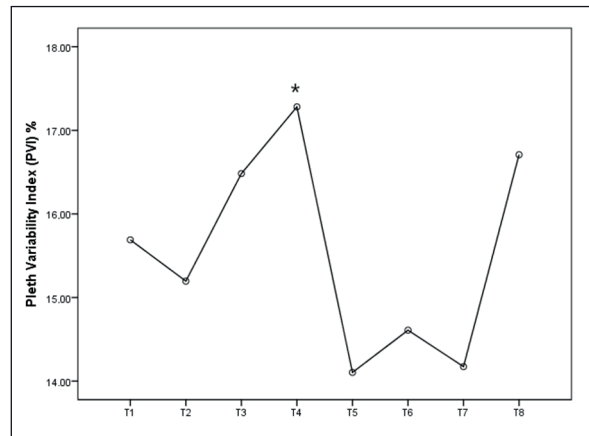


Figure 4. Pleth Variability Index (PVI). T4 p -value = 0.001 ($*p < 0.05$).

amed, no difference was observed between T1 and T8 values. A statistically significant correlation was found between the T7 period, in which the highest value was observed, and the T1, T3, T4, and T8 values ($p < 0.05$). Intraoperative monitoring results were given in Table II.

Discussion

Thanks to developing technologies, much monitoring can be done non-invasively. PVI, PI, SPOC, SpHb, and ORI can be easily monitored with the Masimo Radical-7 Pulse Oximeter probe (Masimo Corp., Irvine, CA, USA). This device gives clinicians information regarding patient hemoglobin oxygenation PI and liquid volume. It is important to know the patient positions during surgery when such monitoring is used as well as the interactions with the medications given.

Today, hemodynamic monitoring includes static parameters, such as central venous pressure and pulmonary capillary end pressure, as well as dynamic parameters, such as stroke volume change and pulse pressure change⁵. To maintain patient safety, it is essential to possess the anesthetic methods and all possible perioperative physiological alterations⁶. Hemodynamic monitoring and optimal fluid treatment are the keystone treatment in order to improve outcomes and allow patients to tolerate the surgical procedure⁷.

The working principle of the PI includes measuring changes in finger peripheral perfusion using a pulse oximeter⁸. Intravenous fluid administration has an important purpose for patients undergoing surgical procedures. Hypovolemia may cause reduced circulatory volume, resulting in reduced oxygen distribution and finally causing organ dysfunction and shock⁹. The plethysmographic variability index (PVI) provides continuous, noninvasive dynamic follow-up of circulating blood volume and lately has been declared to determine fluid resuscitation¹⁰. PVI is an indicator of the dynamic alterations in the PI that develop during respiratory cycles¹¹. The PVI is a useful method because of its advantages, including being noninvasive, using an easy-to-place sensor, and its maintenance of continuous bedside measurement¹². PI and PVI are ratios of nonpulsatile current (AC) to pulsatile current (DC) in the capillary bed.

PI (%) is equal to $[AC / DC] \times 100$. Using the maximum and minimum PI, PVI can be calculated as follows: $PVI (\%) = [(PI_{max} - PI_{min}) / PI_{max}] \times$

100. PVI provides dynamic automatic measurements during the respiratory cycle. It works with a noninvasive oximetry probe attached to a finger or ear oximetry probe. PVI noninvasively measured with a pulse oximetry probe is a dynamic and plethysmographic method for intravascular volume assessment, and its clinical usage is increasing because of its ease of use, continuous monitoring, and independence from the user⁵. PI increases as a result of peripheral vasodilation and decreased sympathetic tone caused by anesthetic drugs and opioids used in the induction and maintenance of general anesthesia³.

In our study, as reported in the literature, PVI decreased while PI increased after anesthesia induction (Figures 3 and 4). One of the dynamic parameters used to predict fluid response in mechanically ventilated patients is the PVI, which is obtained by continuously and automatically calculating the pulse oximetry plethysmographic waveform variability during the respiratory cycle.

The PI is calculated as the ratio of pulsatile to nonpulsatile flow and is used as a quick indicator of microcirculatory changes². Throughout the surgery, we complied with the isotonic fluid replacement schedule for our patients according to the 4-2-1 rule. We recorded the changes on the monitor in all phases. Cannesson et al¹³ believed that PVI provides a noninvasive, automatic, continued follow-up of fluid responsiveness in mechanically ventilated patients under general anesthesia. Coeckelenbergh et al¹⁴ reported that PVI was a valuable guide for optimal fluid therapy similarly to pulse pressure changes related to length of hospital stay and possibility of postoperative complications in patients, especially after low-to-moderate-risk abdominal surgery. Laparoscopic operations have been the primary procedures of general surgery because of the development of mini-invasive techniques. Generally, artificial pneumoperitoneum is set up with carbon dioxide insufflation, and the intra-abdominal pressure (IAP) is often maintained at 10-15 mmHg. The increase in IAP significantly affects the preload. It is critical to determine the effect of IAP on the volume status of patients who have experienced laparoscopic procedures¹⁵. Although it is commonly considered that laparoscopic procedures are minimally invasive, they are disturbing surgeries because of alterations in IAP, intrathoracic pressure, diaphragm shift, right and left atrial pressure, vascular resistances, cardiac output, and carbon dioxide overload. Additionally, it is believed that nociception stimulates a

Table II. Peroperative hemodynamic data.

	T1		T2		T3		T4		T5		T6		T7		T8	
	Mean	Std. D.	Mean	Std. D.	Mean	Std. D.	Mean	Std. D.	Mean	Std. D.	Mean	Std. D.	Mean	Std. D.	Mean	Std. D.
SBP mmHg	141.1	140	139.2	137	127.7	127	130.8	132	126.5	124	134.7	118	125.3	124	140.6	139
DBP mmHg	83.5	83	90.1	90	96.1	88	88.2	88	80.9	82	83.2	76	78.1	78	86.9	87
MAP mmHg	107.5	108	108.2	109	103.2	105	104.7	102	98.2	101	95.5	93	96.6	95	108.1	109
SpO ₂ %	97	97	99.2	99	98.8	99	98.7	99	98.1	98	98.4	98	98.5	99	96	98
HR beats/min	81.4	81	93	92	84.5	83	83.4	87	80	78	76.9	75	77.1	74	96.8	88
Pplato, cm H ₂ O			14.4	15	17.4	19	17.4	19	17.3	19	15.4	16	14.8	15		
Ppeak, cm H ₂ O			17.5	17	26.1	21	21.3	21	21.4	22	19	19	18.5	18		
Vt ml			513.1	515	515.4	510	514.7	510	513.9	518	515.6	516	521	521		
EtCO ₂ mmHg			33.4	33	32.8	32	33.4	33	34.9	34	35	34	35	35		
IAB mmHg					12.7	13	12.7	13	12.7	13	12.7	13				

Systolic Blood Pressure (SBP), Mean Blood Pressure (MAP), Diastolic Blood Pressure (DBP), Heart Rate (HR), Oxygen Saturation (SpO₂), End tidal co2 (EtCO₂), Pleth Variability Index (PVI), Perfusion Index (PI), Peripheral Blood Oxygen Content (SPOC), Oxygen Reserve Index (ORI), Intra-Abdominal Pressure (IAP), Peripheral Blood Hemoglobin (SpHb), Oxygen Reserve Index (ORI), Tidal Volume (Vt), Positive End-Expiratory Pressure (PEEP), Plateau Pressure (Pplato), Peak Pressure (Ppeak) and Intra-Abdominal Pressure (IAP).

sympathetic activation¹⁶. The reduction in PI and increase in PVI observed during the postoperative period may be due to variations in respiration throughout spontaneous ventilation, residual influences of intravenous or volatile anesthetics, and opioid analgesic agents or to high sympathetic activity originating from postoperative pain¹⁷. Respiratory parameters, including tidal volume, and ventilation rate and type may influence the PI and PVI^{3,17}.

Various hemodynamic and respiratory alterations may occur based on the patient's surgical position¹⁸. The patient's position, pneumoperitoneum, and use of norepinephrine are some limitations of PI and PVI assessment¹⁹. Arslantas et al²⁰ stated that PI increased under general anesthesia, but that PVI did not change. They explained that both the reverse T position and pneumoperitoneum application failed to cause a change in PI but increased PVI. Pneumoperitoneum can stimulate hemodynamic alterations that emerge as reductions in stroke volume, cardiac output, and venous return and an increase in systemic vascular resistance¹⁸. Høiseth et al²¹ and Lui et al²² suggested that the PVI increased and the PI decreases after pneumoperitoneum. In our study, on the one hand, PI and PVI increased after pneumoperitoneum. On the other hand, PI and PVI decreased after the reverse Trendelenburg position (Figures 3 and 4). Donati et al²³ determined that after induction of pneumoperitoneum (end abdominal pressure of 11-15 mmHg while patient was in head-down position), central venous pressure (CVP) rose by 3.7 mmHg, and they assessed the value as insignificant when the systemic vascular resistance (SVR) value was measured by the FloTrac[®]/Vigileo system because of the endoabdominal pressure (10 mmHg) and patients' horizontal position.

Tapar et al¹⁹ analyzed the changes in the PI patients when they were rotated from the supine to the reverse Trendelenburg position (head-up tilt to 45°). They showed that the reverse Trendelenburg position significantly decreased the PI, which was clarified by the reduction in venous return and increased SVR. The Trendelenburg and reverse Trendelenburg positions and pneumoperitoneum used in laparoscopic surgery can affect hemodynamic monitoring parameters by changing intrathoracic pressure²¹. This study reported that PI alterations depend on body positions, with the most significant result occurring in the Trendelenburg position and the least significant during the 45° supine sitting position. This result may be significant in surgical subjects

whose positions may change during a surgical procedure, thus affecting the PI result and requiring a novel baseline to monitor PI¹⁹. There is conflicting information in the literature regarding the effect of pneumoperitoneum and patient position on PI. Liu et al²² showed that while mean arterial pressure (MAP) increased with pneumoperitoneum, PI decreased and PVI increased. After desufflation, PVI value decreased, whereas PI increased. In our patients, MAP increased after pneumoperitoneum and decreased after the reverse Trendelenburg position (Figure 2). Hoiseth et al²¹ showed that PVI increased during pneumoperitoneum in a study investigating the dynamic variables of fluid responsiveness in patients undergoing laparoscopic surgery.

In a study in which epidural analgesia was applied in combination with general anesthesia to eliminate the effects of sympathetic activation triggered by pain in laparoscopic cholecystectomy or colectomy surgery, the results were as follows: PI decreased in 1-5 minutes after pneumoperitoneum, but PVI did not change. After desufflation, PI decreased in 1-5 minutes, and PVI decreased in 4-5 minutes. The researchers reported that because epidural analgesia was applied with general anesthesia, painful stimuli and sympathetic activity were blocked and that this hemodynamic change developed because of only the pneumoperitoneum²⁴. In our patients, after desufflation, PI increased while PVI decreased (Figures 3 and 4).

Arslantaş et al²⁵ reported that the reverse Trendelenburg position and pneumoperitoneum failed to change either the PI or the PVI. In contrast, in morbidly obese patients experiencing general anesthesia, deflation reduced the PVI but did not alter the PI. Additionally, the researchers reported that PI increased and PVI decreased under general anesthesia. Therefore, the PI and PVI both were beneficial hemodynamic parameters in patients under general anesthesia for laparoscopic bariatric surgery. Liu et al²² suggested that stroke volume variation and noninvasive PVI both demonstrated quick and consistent alterations with high intra-abdominal pressure due to the carbon dioxide insufflations. Additionally, they reported that PVI was a highly sensitive indicator of alterations in intra-abdominal pressure²².

Limitations

The small patient sample of this clinical study created a limitation and should be addressed by larger samples in future studies.

Conclusions

Monitoring is essential in anesthesia. With new developing technologies, monitoring has often been noninvasively carried out. This situation eliminates both the necessary procedures for invasive monitoring and the complications that may occur because of these procedures. Despite these advantages, PVI, PI and SpHb, three of these new monitoring systems, are affected by table positions during surgery and conditions, such as pneumoperitoneum. In our study, SpHb decreases at the beginning of the reverse Trendelenburg position and then rises. The MAP decreases after a minimal rise after the reverse Trendelenburg position and returns to its initial values with the end of anesthesia. PI increases significantly after induction of anesthesia and remains high under anesthesia. PVI, on the other hand, decreases after anesthesia induction and reaches its highest value after reverse Trendelenburg position. Monitoring response to these conditions is important for treatments to be performed. Our study's results supported those of existing literature.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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Ethical Statement

Ethical approval was obtained from Malatya Clinical Research Ethics Committee (Ethical Number: 2021/48).

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