Internal Carotid Artery Blood Flow Response to Anaesthesia, Pneumoperitoneum and Head-Up Tilt During Laparoscopic Cholecystectomy: A Clinical Study

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Background: Control of cerebral blood flow (CBF) is complex and is only beginning to be elucidated. There is paucity of information on how implementation of pneumoperitoneum and head-up tilt under general anaesthesia affects CBF. This study was designed to observe changes that occur in the internal carotid artery (ICA) blood flow with pneumoperitoneum and head-up position and corelate these changes with changes in cardiac output in patients undergoing laparoscopic cholecystectomy.

Methods: ICA blood velocity and diameter was measured by Doppler ultrasound in 35 ASA grade I and II patients undergoing laparoscopic cholecystectomy, at four time points: awake, after anaesthesia induction, after induction of pneumoperitoneum, and after head-up tilt; and ICA blood flow was calculated. Simultaneously, heart rate, blood pressure, and end-tidal carbon dioxide ($ETCO_2$) were recorded, and cardiac output was calculated.

Results: ICA blood flow decreased upon anesthesia induction from 164 mL/minute to 151 ml/minute ($p>0.05$). ICA blood flow increased with pneumoperitoneum (from 164 mL/minute to 179ml/minute $p= 0.04$). Head-up tilt resulted in decrease in ICA blood flow (from 164 mL/minute to 151ml/ minute, $P = 0.09$).

Conclusion: ICA blood flow significantly increased after the creation of pneumoperitoneum in patients undergoing elective laparoscopic cholecystectomy under general anaesthesia. Induction of anaesthesia and head-up tilt, however, did not have any significant change in ICA blood flow. We suggest that ICA blood flow during anaesthesia is influenced by an interplay of actions of anaesthetic agents, positive pressure ventilation and patient position besides the changes in blood pressure, $ETCO_2$ and cardiac output.

Keywords: ICA blood flow, laparoscopic cholecystectomy, cerebral blood flow, end tidal carbon dioxide, general anaesthesia.

Introduction

Control of cerebral blood flow (CBF) is complex and is only beginning to be elucidated[1]. Numerous cardiorespiratory alterations generated by general anaesthesia and mechanical ventilation may affect CBF and surgical procedures may exacerbate these changes.[2]

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Laparoscopic cholecystectomy is a common abdominal surgery conducted under general anaesthesia. Anaesthetic management for laparoscopic cholecystectomy can be challenging as it involves the creation of pneumoperitoneum and placing the patient in reverse Trendelenburg position (head-up tilt). Artificial pneumoperitoneum affects the patient's cardiovascular and respiratory physiology complicating CBF management. The mechanical effect of pneumoperitoneum involves compression of the inferior vena cava, causing reduction in the venous return, resulting in decreased cardiac output and increased central venous pressure[3]. Reverse Trendelenburg position decreases the preload on the heart, and thereby decreasing the venous return resulting in hypotension. Carbon dioxide used for insufflation for the creation of pneumoperitoneum increases the systemic vascular resistance (SVR). Positive end expiratory pressure (PEEP) is employed to counteract the effects of ventilation/ perfusion (V/Q) mismatch that occur due to the creation of pneumoperitoneum[3]. PEEP along with head up tilt improves respiratory mechanics but hinders venous return to the heart. Hypocapnia may aggravate cerebral hypoperfusion in the context of hypovolemia and hypotension, as the cerebral vasculature is particularly reactive to PaCO2.

CBF is not routinely monitored directly in clinical anesthetic practice and its optimization has traditionally rested on indirect measurements like arterial blood pressure and arterial blood gases (ABG). Several studies have been conducted on the alterations in haemodynamics in patients undergoing laparoscopic cholecystectomy in response to pneumoperitoneum and head-up tilt, but there is paucity of information on how implementation of pneumoperitoneum and head-up tilt under general anaesthesia affects the CBF[4]. This study was designed to observe the changes that occur in internal carotid artery (ICA) blood flow with implementation of pneumoperitoneum and head-up position during laparoscopic cholecystectomy.

Materials and Methods

The study was conducted on 35 ASA I and II patients after obtaining approval from the institutional ethics committee (MGMCH/IEC/JPR/2020 /83) and registration with the Clinical Trial Registry - CTRI/2021/07/ 035076. ASA grade III/IV/V patients with hyperlipidaemia, known coronary artery disease, hypertension, cerebrovascular disease, diabetes mellitus, and Patients on beta blockers or on statin therapy were excluded from the study.

All consenting patients underwent thorough pre-anaesthetic check-ups. Standard ASA I monitoring was done. End-tidal carbon dioxide ($ETCO_2$) monitoring was started before the induction of the anaesthesia. General anaesthesia was induced with Midazolam 1 mg, glycopyrrolate 0.2 mg, fentanyl 2 µg/kg, and propofol 2 mg/kg. Vecuronium 0.1 mg/kg was used to facilitate orotracheal intubation. Maintenance of anaesthesia was achieved by top-ups of vecuronium and isoflurane in 40% oxygen in air on controlled ventilation maintaining eucapnia. Patients were extubated at the end of the surgery with Neostigmine and Glycopyrrolate.

Internal carotid artery blood flow was recorded using a linear probe (6-13 Mhz) and an Ultrasound machine (FUJIFILM Sonosite, Inc. Bothell, Washington USA). ICA diameter was measured using the calliper at the maximum diameter of the intima keeping probe in short axis [5]. ICA velocity was recorded by tracing Doppler graph manually.

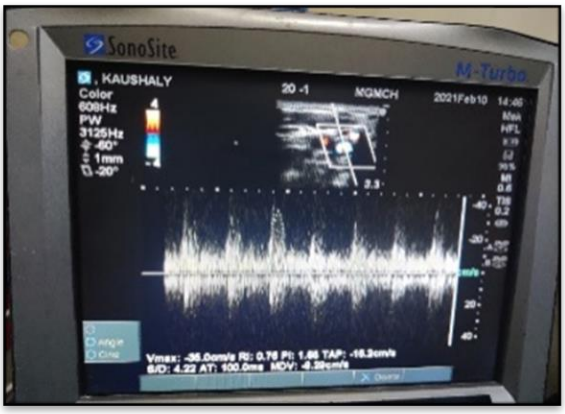


Figure 4: *Tracing of the internal carotid artery (ICA) velocity by doppler*

All the observations were recorded at the following time points (Figure 4 and 5). `

1. Awake just before the induction of anaesthesia, with the patient in supine position. (Time point A)

2. Two minutes after the induction of anaesthesia, with the patient in supine position. (Time point B)

3. Two minutes after creating pneumoperitoneum, with the patient in supine position. (Time point C)

4. Two minutes after giving 10-20˚ head-up tilt. (Time point D).

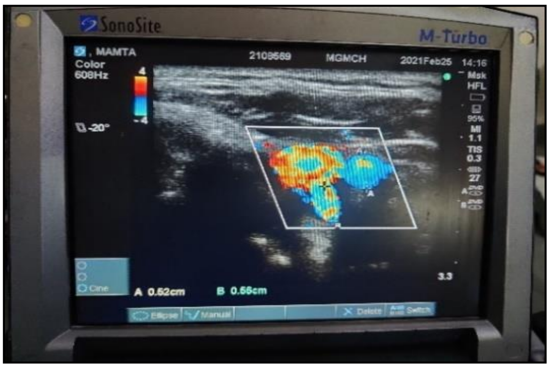


Figure 5: *Measurement of the internal carotid artery (ICA) diameter with a calliper*

ICA blood flow was calculated by substituting the values of diameter (D) and the velocity (V) in the formula $\pi D^2 V/4$ and then multiplying this value by 60 to obtain flow in mL/min.

Results

All the data were. catalogued.in Excel. Mean (M) and standard deviations (SD) of the measurements were used for statistical analysis. (Table 1) Student t-test was used to test significance across the four time points and the level of significance was set at $p < 0.05$.

35 ASA grade I and II consenting patients (21 females, 14 males) age between 18 and 60 years (44 ± 12.47 mean ±SD ** years), with a mean weight of 64 ±10 kg and mean height of 154±10 cm fulfilling the entry criteria posted for elective laparoscopic cholecystectomy were recruited in the study.

Effects of anaesthesia

Induction of anaesthesia induced a statistically significant reduction from 93 mmHg to 88 mmHg** mm Hg in the MAP (p=0.02).

Heart rate increased by 8% from 82/minute to 89/minute p=0.004). Induction of anaesthesia caused a minimal reduction in the ICA diameter from 0.49 cm ** to 0.48 cm ** (p=0.1), while the ICA blood flow reduced by 8% (from 164 mL/minute to 151 mL/minute). Changes in the ICA blood flow were statistically insignificant.

Table 1: *Cardiovascular, respiratory, and cerebrovascular variables at four different time points during laparoscopic cholecystectomy in 35 American Society Of Anaesthesiologist Physical status I and II patients. (A: before induction of anaesthesia, B: after induction of anaesthesia, C: after creation of pneumoperitoneum, D: after head-up tilt).*

Parameters	Time points							
	A		B		C		D	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Heart rate (beats/minute)	83	11	89	11.6	93	13	85	8.7
Mean arterial pressure MAP (mmHg)	94	7.4	89	8.6	94	10.2	94	10.14
ICA diameter (cm)	0.49	0.07	0.48	0.07	0.53	0.07	0.49	0.08
ICA velocity (cm/s)	14.2	1.9	13.6	2.5	13.4	2.9	13.2	2.7
$ETCO_2$ (mm Hg)	34	2.4	35	3.5	37	3.9	36	3.9
Tidal volume (mL)			415	50	415	21	415	21.3
Blood flow (mL/minute)	165	53.7	152	55.6	180	57.02	162	53.11

Effects of pneumoperitoneum

Insufflation of pneumoperitoneum in supine position caused a reduction in the MAP (from 92 mm Hg to 88 mm Hg) which was statistically insignificant. Heart rate increased by 12% (from 82/minute to 92/minute, P = 0.0001).

Creation of pneumoperitoneum resulted in a 7.5% increase in the ICA diameter (from 0.49 cm to 0.53 cm, p=0.0002) and a 9% increase in the ICA blood flow (from 164mL/min to 179 mL/minute, p=0.04) and increase in $ETCO_2$ (from 34 to 37 mm Hg, P = 0.002) (Tables 1, 2a and 2b).

Effects of head-up tilt

Placing the patient in the reverse Trendelenburg position (head-up tilt) reduced the ICA blood flow as compared to the awake state (164 mL/minute to 151 mL/minute, p=0.09). ICA diameter, heart rate and MAP regained pre-anaesthetic values after the head-up tilt.

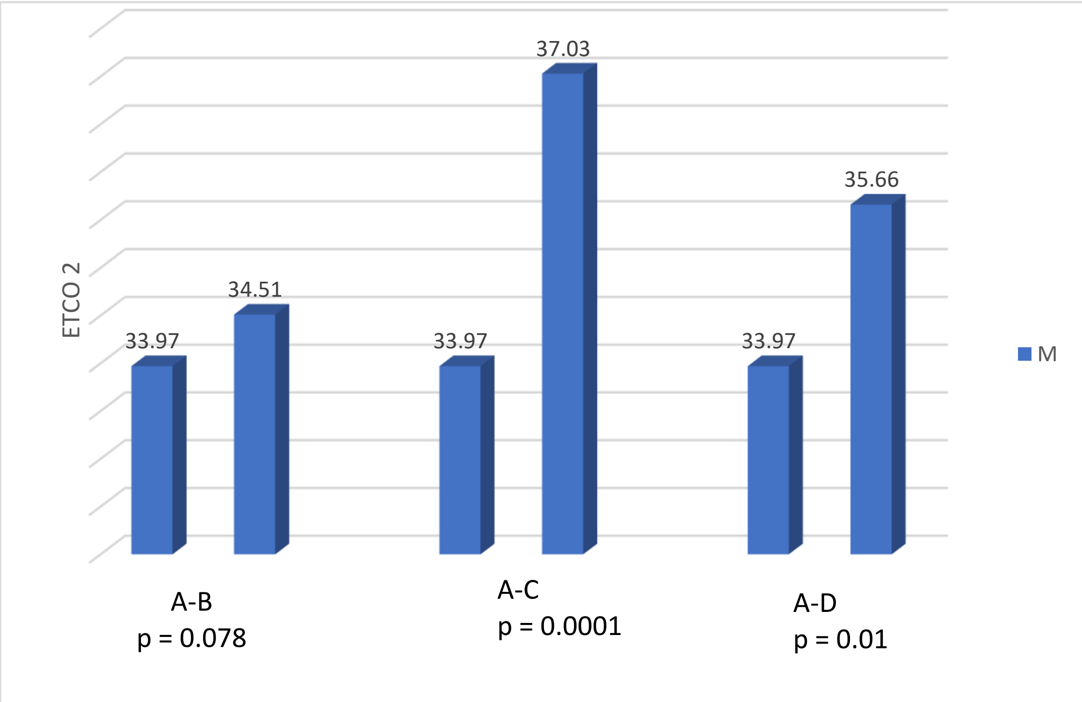


Figure I: *Representing Mean and significance of ETCO2 (end-tidal carbon dioxide) between time points A-B, A-C and A-D (A: before induction of anaesthesia, B: After induction of anaesthesia, C: after creation of pneumoperitoneum, D: after head-up tilt).*

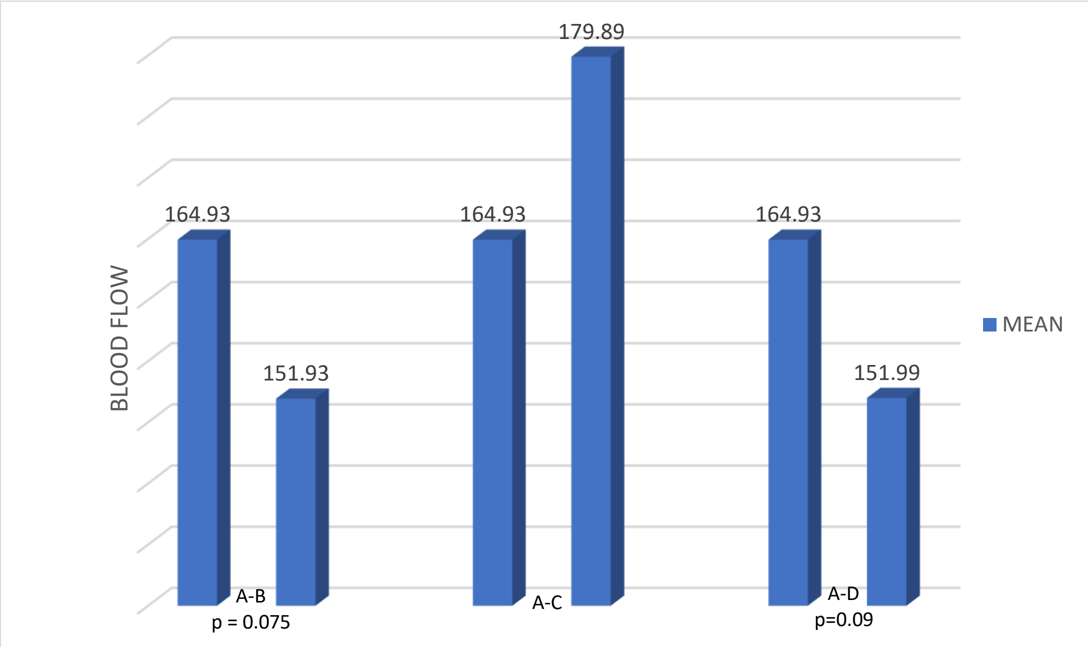
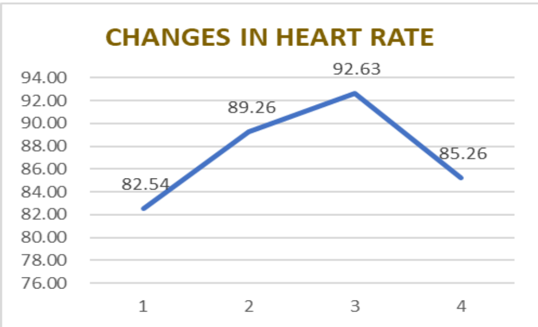
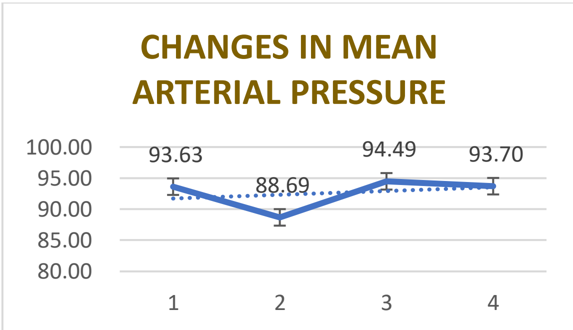
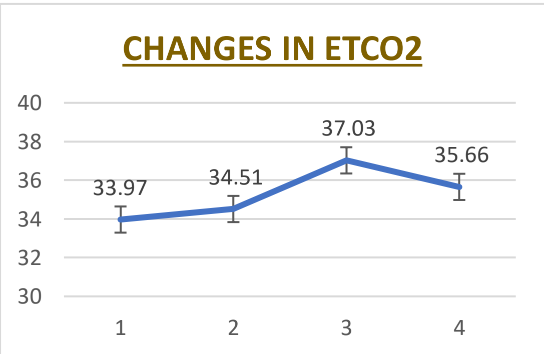
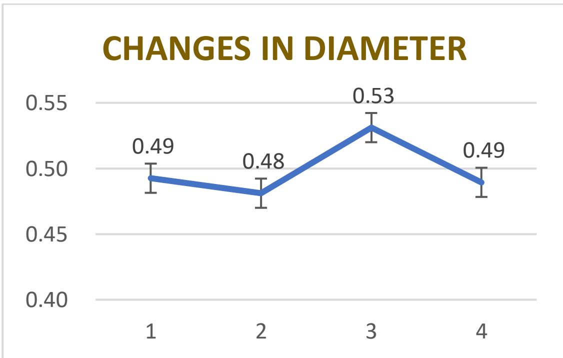


Figure 2: *Representing Mean and significance of changes in Internal carotid artery blood flow at interval A-b, A-C and A-D (A: before induction, B: After induction, C: after creation of pneumoperitoneum, D: after head-up tilt).*









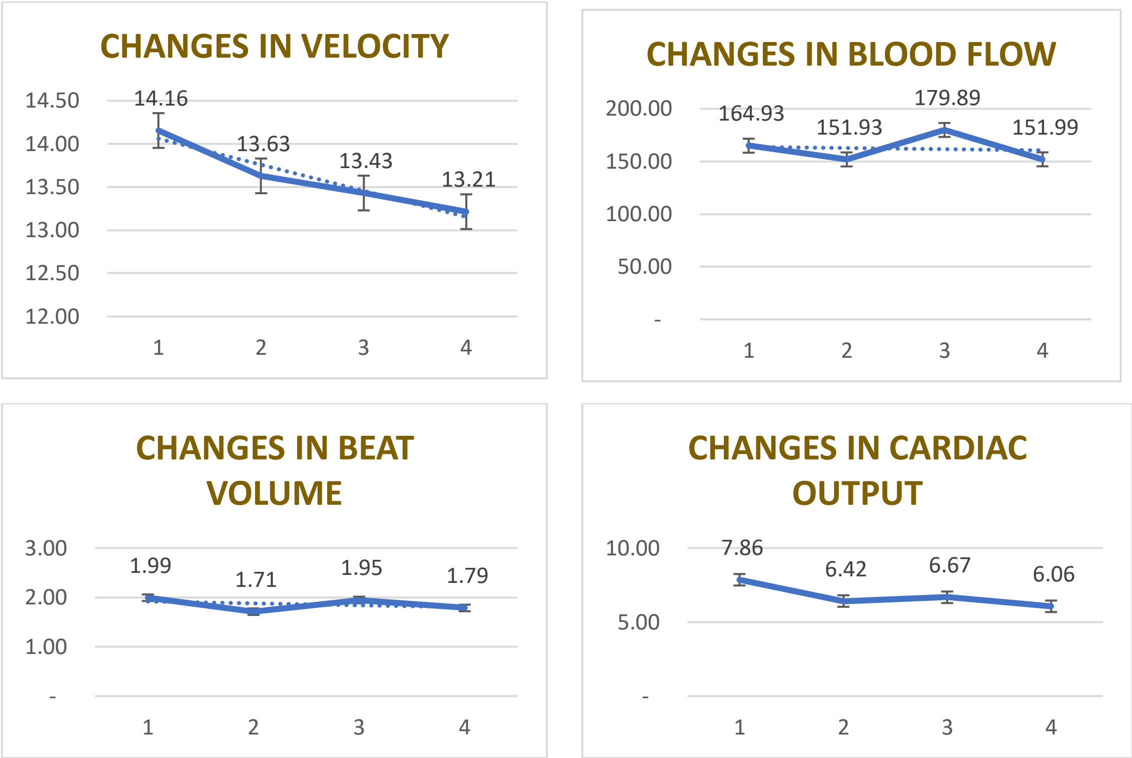


Figure 6: *graphs representing trend followed by observed and derived parameters at studied time points – before induction (1), 2 minutes after induction (2), 2 minutes after pneumoperitoneum (3) and 2 minutes after head-up tilt (4).*

Discussion

We performed this study on 35 adult patients belonging to ASA class I and II undergoing elective laparoscopic cholecystectomy to study the internal carotid artery (ICA) blood flow changes that may occur intraoperatively non-invasively using an Ultrasound machine. A study conducted by Skytioti[4] in 2019 underpinned this research. Existing literature holds autoregulation to be responsible for constant cerebral blood flow (CBF), recent studies have suggested CBF to be more "pressure passive"[5]. Anaesthetic agents, anaesthetic techniques, effects of mechanical ventilation, arterial / exhaled carbon dioxide tension, the effect of patient positioning during surgery and various surgical procedures themselves per se may result in cardiorespiratory effects and other direct changes affecting the CBF.

Many studies have been conducted on how anaesthetic drugs affect cerebral metabolism and intra-cranial pressure[6,7,8]. Since CBF is not routinely monitored directly in clinical anaesthetic practice, its optimization has traditionally rested on indirect measurements like arterial blood pressure and arterial blood gases[9].

CBF is maintained with anterior and posterior circulations that anastomose into the circle of Willis (CoW). ICA joins CoW via the anterior circulation and contributes 70% of the arterial flow to the brain[10]. The cerebrovascular reactivity of the ICA is more compared to the external carotid artery and the vertebral artery[11].

<u>Effects of general anaesthesia</u>

ICA blood flow, diameter and velocity followed a declining trend after the induction of anaesthesia. Our study findings also reported a significant increase in the heart rate and a decline in the MAP. Our results are similar to those of Skytioti[4]. Existing literature has established the effects caused by the anaesthetic agents on the haemodynamic and the CBF[1,7,12]. Reduction in the CBF can be an interplay of both propofol and isoflurane as inhalational agents usually cause a dose-dependent increase in the CBF[1]. A significant increase in the heart rate could have been a combined effect of propofol-induced tachycardia[13], baroreceptor reflex due to hypotension or laryngoscopy-induced sympathetic stimulation. Induction with propofol is invariably associated with decrease in arterial blood pressure but its effect on cardiac output is not consistent[14].

Effects of pneumoperitoneum

The creation of pneumoperitoneum caused increase in the ICA blood flow as compared to the awake state. our findings are at variance with the observations of Skytioti M. et al.[4] This difference can be because of methodology they adopted in terms of adjustments in ventilatory settings to maintain the same value of $ETCO_2$ throughout the period of study. In our study, the average $ETCO_2$, although in clinically acceptable range, increased from 34 mm Hg after induction to 37 mm Hg after the creation of pneumoperitoneum. This may be the cause of the increase in the mean ICA diameter, as carbon dioxide causes cerebral vasodilation as has been shown in previous literature.[15,16]

In a study conducted by Kohei Sato to evaluate 'differential blood flow responses to CO_2 in human internal and external carotid and vertebral arteries', there was an increase in the ICA blood flow in response to increased $PaCO_2$ levels.[17]

Cerebral vasculature is sensitive to carbon dioxide and responds to hypercapnia by dilating and increasing the CBF to ensure sufficient oxygenation for adequate metabolism of the brain. Interpreting the effects of pneumoperitoneum in our study and comparing it with the observations of Skytioti along with the evidence in the contemporary literature, it appears pertinent to maintain a steady state $ETCO_2$ by prudent ventilatory manipulations during laparoscopic cholecystectomy.

Effects on the head

After insufflation, when the patient was placed in the reverse Trendelenburg position, there was a significant decline in the heart rate, mean arterial pressure, ICA diameter and blood flow. Creation of pneumoperitoneum in the horizontal position during surgery, as per study protocol, might have contributed to hemodynamic stability by preventing large reductions in venous return[4]. as the researchers in a previous study have reported a 50% decline in cardiac index after inducing pneumoperitoneum in the reverse Trendelenburg position after 10 minutes.[10]

In our study, ICA blood flow decreased only marginally after head up-tilt as compared to the awake state but decreased significantly after insufflation (p=0.0007). The decrease in the ICA blood flow is in correspondence with a decrease in ICA diameter and a decrease in cardiac output as both factors have a strong correlation with the ICA blood flow. A decrease in ICA diameter can be due to a decrease in the mean $ETCO_2$ from 37 mm Hg to 35 mm Hg which may have caused vasoconstriction of the vessel. Venous return decreases in the head-up position as has been proved in previous studies [17] and hence the reduction in mean arterial pressure can be correlated to decreased venous return which was reflected as decreased cardiac output.

Conclusion

Internal carotid artery (ICA) blood flow significantly increased after the creation of pneumoperitoneum, in patients undergoing elective laparoscopic cholecystectomy under general anaesthesia. Induction of anaesthesia and head-up tilt however did not have any significant effect on the ICA blood flow. Despite maintaining the MAP in the range of autoregulation, changes in the ICA blood flow were independently associated with the changes in $ETCO_2$, however, the changes in $PaCO_2$ were not studied. We hypothesize that cervical extracranial portion of ICA is not merely a passive conduit for distribution of blood to the brain, but it actively and rapidly reacts to the changes in the cardiac output and $ETCO_2$ and also responds in tandem with autoregulation of CBF like its intracranial portion contributing to the formation of the circle of Willis. This hypothesis, however, requires further validation using well-designed controlled studies.

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