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Retrospective Assessment of Factors Affecting Carboxyhemoglobin Levels in Patients Undergoing Robotic Surgery

Robotik Cerrahi Uygulanan Hastalarda Karboksihemoglobin Düzeylerini Etkileyen Faktörlerin Retrospektif Olarak Değerlendirilmesi

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ABSTRACT

Objective: Electrocautery in laparoscopic surgeries converts abdominal carbon dioxide gas into carbon monoxide, which binds to hemoglobin with a higher affinity than oxygen and can impair oxygen transport and lead to hypoxia. This study aimed to assess changes in carboxyhemoglobin (COHb) levels and investigate the factors affecting COHb levels in patients undergoing robotic surgery.

Methods: Forty-two patients were included in this retrospective study. Patient demographics, anesthetic used, airway pressures, and COHb levels at different time points (baseline COHb-1st hour COHb-post-pneumoperitoneum COHb-postoperative care unit COHb-deltaCOHb) were considered. Age, gender, American Society of Anesthesiology (ASA) physical score, body mass index, smoking status, surgery type, anesthesia type, patient position, fresh gas flow (FGF), insufflation, and airway pressures, which may have an effect on COHb levels, were compared.

Results: No significant relationship was found between COHb levels at all measured time points and factors such as gender, ASA scores, surgery type, anesthesia type, position, FGF, insufflation pressure, and airway pressure. Smokers had significantly higher COHb levels than passive smokers, non-smokers, and ex-smokers at baseline (p=0.003), 1st hour (p=0.006), and post-pneumoperitoneum COHb (p=0.009) levels.

Conclusion: Long surgery time, use of different types of anesthetics, and low FGF does not increase the risk of elevated COHb levels. Hence, different anesthetic drugs and low FGF, regardless of the position of the patient or the length of the procedure, can be used in robotic surgery without increasing the risk.

Keywords: Robot-assisted surgery, carbon monoxide, carboxyhemoglobin, robotic surgery

ÖZ

Amaç: Laparoskopik ameliyatlarda elektrokoter, abdominal karbondioksit gazını, hemoglobine oksijenden daha yüksek afiniteyle bağlanan ve oksijen taşınmasını bozarak hipoksiye yol açabilen karbon monoksite dönüştürür. Bu çalışmada robotik cerrahi uygulanan hastalarda karboksihemoglobin (COHb) düzeyindeki değişikliklerin değerlendirilmesi ve COHb düzeyini etkileyen faktörlerin araştırılması amaçlandı.

Yöntemler: Bu retrospektif çalışmaya 42 hasta dahil edildi. Hasta demografik özellikleri, kullanılan anestezikler, hava yolu basınçları ve farklı zaman noktalarındaki COHb düzeyleri (başlangıç COHb-1. saat COHb-pnömoperiton sonrası COHb-ameliyat sonrası bakım ünitesi COHb-deltaCOHb) dikkate alındı. COHb düzeylerine etki edebilecek yaş, cinsiyet, Amerikan Anesteziyoloji Derneği (ASA) fizik skoru, vücut kitle indeksi, sigara içme durumu, ameliyat türü, anestezi türü, hasta pozisyonu, taze gaz akışı (FGF), insuflasyon ve hava yolu basınçları karşılaştırıldı.

Bulgular: Ölçülen tüm zaman noktalarındaki COHb düzeyleri ile cinsiyet, ASA skorları, ameliyat tipi, anestezi tipi, pozisyon, FGF, insuflasyon basıncı ve hava yolu basıncı gibi faktörler arasında anlamlı bir ilişki bulunamadı. Sigara içenlerde başlangıçta (p=0,003), 1. saatte (p=0,006) ve pnömoperiton sonrası (p=0,009) COHb düzeyleri pasif içicilere, sigara içmeyenlere ve sigarayı bırakmış kişilere göre anlamlı derecede yüksekti.

Sonuç: Ameliyat süresinin uzun olması, farklı türde anesteziklerin kullanılması ve FGF'nin düşük olması COHb yüksekliği riskini artırmaz. Dolayısıyla robotik cerrahide hastanın pozisyonuna ve işlemin uzunluğuna bakılmaksızın farklı anestezik ilaçlar ve düşük FGF riski artırmadan kullanılabilir.

Anahtar Sözcükler: Robot destekli cerrahi, karbonmonoksit, karboksihemoglobin, robotik cerrahi

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INTRODUCTION

Carbon monoxide (CO) is an odorless gas that can significantly affect multiple organs and tissues in the body (1). CO exposure may occur under various circumstances, especially from sources such as car exhaust, smoking, and malfunctioning heating systems. Anesthesiologists should be especially cautious about the possibility of CO exposure during general endotracheal anesthesia. Because conventional carbon dioxide (CO_2) absorbents break down volatile anesthetic drugs, CO is typically produced within the anesthesia breathing circuit. The type of volatile agent used, anesthetic concentration, absorbent temperature, patient CO_2 production, chemical composition of the CO_2 absorbent used, and water content within the absorbent are significant factors that influence the level of CO production during anesthesia (2,3).

During various laparoscopic surgeries, the use of cautery can change abdominal CO_2 gas into CO gas. Peritoneal absorption can increase carboxyhemoglobin (COHb) levels. It has been noted that intra-abdominal CO levels can reach dangerous amounts although COHb levels can rise to considerable but non-risky values (4).

COHb evaluation is a test that determines the amount of CO bonded with hemoglobin in the blood. Therefore, the proportion of total blood hemoglobin was used to indicate COHb levels.

Robotic surgery is a minimally invasive procedure that allows surgeons to perform complex procedures with greater supervision, precision, and flexibility than regular surgery (5). Compared with conventional surgery, robotic surgery has many benefits, including smaller incisions, less blood loss, less discomfort, shorter hospital stays, and faster recovery times. In addition, it permits greater precision in actions and better vision of the surgical site, both of which can improve patient outcomes (6). Because robotic surgery is a modification of laparoscopic surgery, it necessitates the use of CO_2 pneumoperitoneum for intra-abdominal pathologies (6). Similar to laparoscopic surgery, CO_2 gas is inflated into the abdomen to create a closed chamber that allows intra-abdominal vision.

Although laparoscopic surgeries have been investigated for the conversion of abdominal CO_2 to CO and their impact on COHb levels, robotic surgeries have not been investigated. Our hypothesis is that prolonged pneumoperitoneum durations during robotic procedures, which are longer than those during laparoscopic procedures, would result in more CO_2 insufflation and, ultimately, higher COHb levels. Therefore, the goal of this study was to assess changes in COHb levels and investigate the factors affecting COHb levels in patients undergoing robotic surgery.

MATERIALS AND METHODS

The records of patients aged 18 years who underwent elective robotic surgery in the robotic operating room of the Gazi University Faculty of Medicine between December 2021 and December 2022 were retrospectively evaluated following the approval of the Gazi University Local Ethics Committee (approval number: 2023-259, date: 21.02.2023). Preoperative anesthesia evaluation, intraoperative anesthesia follow-up forms, and laboratory parameters of the patients included in the study were obtained from the hospital information system.

Patients with chronic obstructive pulmonary disease, restrictive pulmonary disease, a history of pulmonary infection in the last month, hematologic disease, allergy to the drugs used, pregnancy, or thoracic or ear-nose-throat (ENT) surgery were excluded. Patients for whom anesthesia forms and blood gas analyses were not accessible retrospectively were excluded from the study to ensure the consistency of the data.

Age, gender, weight, height, comorbid diseases, American Society of Anesthesiology (ASA) physical score, and smoking history were recorded from the preoperative anesthesia evaluation forms. Anesthetic agents used in the maintenance of anesthesia, type and duration of surgery, surgical position, insufflation and airway pressures, end-tidal carbon dioxide ($ETCO_2$) levels, and fresh gas flow (FGF) values were obtained from the anesthesia forms. The blood gas analyses used in the perioperative follow-up were systematically classified as post-induction, first hour, post-pneumoperitoneum, and postoperative care unit. pH, partial oxygen pressure, partial CO_2 pressure, hemoglobin, hematocrit, oxygen saturation, COHb, potassium, sodium, calcium, glucose, lactate, and bicarbonate levels were recorded.

In blood gas analysis, COHb values are obtained using spectrometric measurement method similar to those used in our hospital. We used COHb values measured during perioperative blood gas analysis follow-ups.

Alterations in COHb levels, the difference in postanesthesia care unit (PACU) COHb levels from baseline measurements (referred to as deltaCOHb), and the relationship between COHb levels at the time of measurement and age, gender, ASA scores, body mass index (BMI), smoking status, surgery type, anesthesia type, position, FGF, insufflation pressures, and airway pressures were assessed.

Statistical Analysis

Statistical analyses were conducted using the Statistical Package for Social Sciences (SPSS), version 26.0 for Windows (SPSS Inc. Chicago, USA). Categorical variables were presented as counts and percentages, and continuous variables were reported as mean ± standard deviation. The normal distribution of variables was assessed using the Kolmogorov-Smirnov test. For normally distributed data, comparisons between two groups were performed using the independent t-test, and multiple groups were analyzed using One-Way ANOVA. Non-normally distributed data were compared using the Mann-Whitney U test for the two groups and Kruskal-Wallis test. Spearman's r data analysis was performed to evaluate the correlation. A statistical significance level of $p<0.05$ was set for all analyses.

RESULTS

The study analyzed data from 41 patients between the ages of 24 and 75 years and classified under ASA I-III. Twenty-eight patients were excluded for not meeting the inclusion criteria: 11 underwent thoracic surgery, 7 underwent ENT surgery, and 10 had respiratory disease infection in the past month (Figure 1).

The median duration of surgery was 240 min (interquartile range, 210-300). The baseline demographic and clinical characteristics of the patients are shown in Table 1.

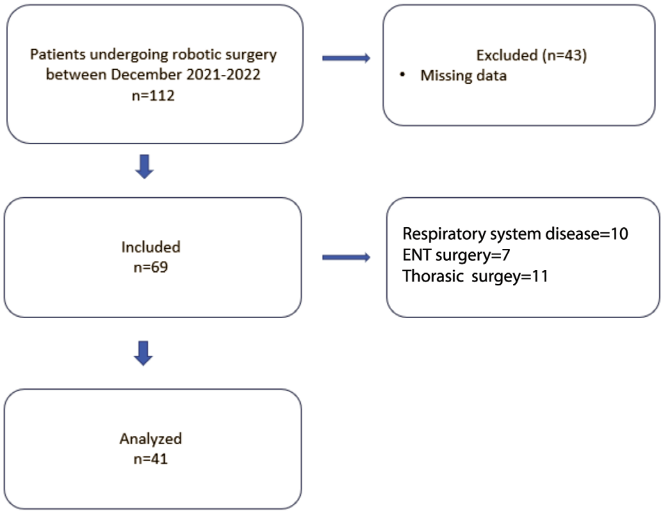

Figure 1. Flowchart of the study.

ENT: Ear-nose-throat.

Only five patients out of the entire patient population had increased COHb levels after surgery. Five patients, on the other hand, showed no change in deltaCOHb. In a large majority of cases (n=31), COHb levels decreased after surgery. The values of $ETCO_2$, partial pressure of CO_2, and COHb are provided in Table 2.

No significant relationship was found between COHb levels at all measured time points and factors such as gender, ASA scores, surgery type, anesthesia type, position, FGF, insufflation pressure, and airway pressure.

Age was found to be correlated with COHb levels, specifically baseline COHb, 1st hour COHb, post-pneumoperitoneum COHb, and deltaCOHb, but not with PACU COHb. Baseline COHb (r=-0.46, p=0.002), 1st hour COHb (r=-0.40, p=0.008), and post-pneumoperitoneum COHb (r=-0.39, p=0.01) were negatively correlated with age. However, there was a positive correlation between deltaCOHb and age (p=0.001, r=0.58).

Spearman's rank correlation analysis demonstrated a positive association between the change in COHb levels (deltaCOHb) and BMI (correlation coefficient, r=0.35, p=0.02) and age (p=0.001, r=0.58). Additionally, a moderate inverse correlation was observed between deltaCOHb and surgical duration (p=0.03, r=-0.34).

There was a significant difference between smoking status and COHb levels. Smokers had significantly higher COHb levels than passive smokers, non-smokers, and ex-smokers at baseline (p=0.003), 1st hour (p=0.006), and post-pneumoperitoneum COHb (p=0.009) levels. COHb change was also statistically significant in smokers compared with that in the other groups (p=0.001). COHb levels decreased more in smokers toward the end of surgery. No difference was observed in the PACU COHb levels. The COHb levels of the patients according to smoking status are shown in Table 3.

DISCUSSION

CO poisoning has historically been suggested to be caused by exposure of the patient to smoke from lasers and electrodesiccation during laparoscopic surgery (4). This retrospective study contributes to our understanding of COHb levels in robotic surgery by revealing several findings. First, our results provide additional evidence for earlier studies that showed how smoking affects COHb levels during laparoscopic procedures. Our research also shows that variables, including anesthetic type, patient position, and FGF, have no appreciable impact on COHb levels. These results provide a more thorough understanding of the complex dynamics of COHb levels during robotic surgery.

CO is produced endogenously but is also a common environmental pollutant; both sources contribute to the amount of COHb in the blood. COHb, which normally comprises less than 1-2% of the

Table 1. Demographic data

Age, years, mean ± SD	58.8±13.2
Gender, n (%)	
Male	26 (63.4)
Female	15 (36.6)
ASA, n (%)	
I	4 (9.7)
II	28 (68.2)
III	9 (21.9)
BMI, kg/m^2, mean ± SD	29.1±7.4
Surgery type, n (%)	
Prostate	21 (51.2)
Rectum	17 (41.5)
Sleeve gastrectomy	3 (7.3)
Anesthesia type, n (%)	
Desflurane	15 (36.6)
Sevoflurane	14 (34.1)
TIVA	12 (29.3)
Position, n (%)	
Trendelenburg	32 (78.0)
Lithotomy	5 (12.2)
Supine	4 (9.8)
Smoking status, n (%)	
No smoking	14 (34.9)
Active smoker	11 (25.6)
Ex-smoker	13 (32.6)
Passive smoker	3 (7.0)
Fresh gas flow, n (%)	
1 liter	16 (39.0)
2 liters	24 (58.5)
3 liters	1 (2.4)
Surgery time, minutes, mean ± SD	261.6±81.4
Insufliation pressures, mmHg, mean ± SD	14.3±1.5
Ppeak, mmHg, mean ± SD	28.4±4.6

ASA: American Society of Anesthesiology, BMI: Body mass index, Ppeak: Peak airway pressure, SD: Standard deviation.

Table 2. End-tidal carbon dioxide, partial pressure of carbon dioxide, and carboxyhemoglobin levels at time points

	Baseline	1st hour	Post-pneumoperitoneum	PACU
$ETCO_2$ (mmHg); median (IQR)	34 (31.5-36.5)	36 (33.0-38.0)	37.0 (34.25-40.75)	N/A
$PaCO_2$ (mmHg); median (IQR)	37.4 (34.0-40.9)	40.4 (37.7-43.9)	43.60 (39.2-48.4)	41.7 (38.4-44.6)
COHb (%); mean ± SD	2.5±0.5	2.5±0.4	2.4±0.4	2.3±0.4

PACU: Postanesthesia care unit, $ETCO_2$: End-tidal carbon dioxide, $PaCO_2$: Partial pressure of carbon dioxide, COHb: Carboxyhemoglobin, IQR: Interquartile range, SD: Standard deviation.

Table 3. Smoking status and carboxyhemoglobin levels at different time points

	Active smoker; median (IQR)	Passive smoker; median (IQR)	Ex-smoker; median (IQR)	No smoking; median (IQR)	p
Baseline COHb	2.9 (2.6-3.6)	2.2 (2.1-2.2)	2.3 (1.8-2.6)	2.5 (2.3-2.6)	0.003
1st hour COHb	2.8 (2.5-3.5)	2.2 (2.1-2.3)	2.3 (2.2-2.4)	2.4 (2.4-2.5)	0.006
COHb	2.6 (2.5-3.3)	2.1 (1.9-2.1)	2.2 (2.0-2.4)	2.3 (2.2-2.5)	0.009
PACU COHb	2.5 (2.2-2.9)	2.1 (2.0-2.1)	2.3 (2.2-2.6)	2.1 (2.1-2.4)	0.08
DeltaCOHb	-0.6 (-0.7-0.3)	-0.1 (-0.1-0.05)	-0.05(-0.2-0.7)	-0.2 (-0.4-0.2)	0.001

COHb: Carboxyhemoglobin, PACU: Postanesthesia care unit, DeltaCOHb: Difference in PACU COHb levels from baseline measurements, IQR: Interquartile range.

total hemoglobin, is the product of the reaction between CO and hemoglobin. COHb concentration can be used to estimate the amount of CO produced. Less than 2% of COHb is commonly considered normal in non-smokers, although values of 5-10% may suggest mild-moderate CO exposure, and levels of 25-35% are thought to be potentially life-threatening (7).

The peritoneal cavity is insufflated with gas, often CO_2, to provide exposure during laparoscopic surgery. Coagulation of tissue by electrocautery in the hypoxic environment of the abdominal cavity inflated with CO_2 during laparoscopic procedures has been hypothesized to produce CO (7).

In the peritoneal cavity during laparoscopic cholecystectomy, Beebe et al. (4) found CO at a median concentration of 345 ppm 5 min after the use of electrocautery and at a concentration of 475 ppm at the conclusion of the procedure, both of which were higher than the 35 ppm upper limit for an hour of exposure set by the Environmental Protection Agency (7). Despite the increase in CO, there was no evidence that these patients had significant CO absorption, as the COHg values were the same before, during, and on the day after surgery. While a comparable number of patients in our retrospective analysis experienced little to no change in COHb levels, in the majority of cases, COHb concentrations decreased compared with baseline. Soro et al. (8) assumed that laparoscopic surgery does not result in appreciable increases in COHb levels, even under closed-system anesthesia and without pulmonary CO elimination. This is most likely due to the low peritoneal absorption of CO. They concluded that adult patients who received pneumoperitoneum gas renewals regularly and electrocautery for normal durations did not experience CO intoxication. No patient displayed any evidence or clinical indications for CO poisoning according to Baum et al. (9). Furthermore, Strauss et al. (10) showed that during the first 6 h of closed-system anesthesia, COHb barely increased by 0.4% on average.

Exogenous CO is present in cigarette smoke and is absorbed by the lungs to produce COHb. The accuracy of both self-reporting and inhalation by passive smokers can be investigated using measurable COHb levels. COHb levels and self-reported smoking have a statistically significant relationship (11). Thus, the association between COHb changes and perioperative problems in smokers, non-smokers, and passive smokers was identified. We demonstrated a correlation between smoking status and COHb levels, which differed from that reported by Park et al. (12). Furthermore, compared with baseline levels, our study revealed an interesting finding of decreased PACU COHb levels among active smokers. We attributed this reduction to the use of high concentrations of inspired oxygen (FIO_2) from room air together with the provision of adequate and efficient mechanical ventilation during the prolonged duration of robotic surgery. These results highlight the critical need for adequate ventilation and the impact of increasing FIO_2 on reducing COHb levels in active smokers during robotic procedures.

Numerous studies and case reports have shown that CO production in the anesthetic circuit caused by dried absorbents leads to elevated COHb levels and clinical symptoms of CO toxicity (13-16). When volatile anesthetic drugs are degraded by conventional CO_2 absorbents without sufficient moisture, CO is produced within the anesthesia breathing circuit (13,17). Different inhalation anesthetics generate CO at varying rates, and CO exposure under anesthesia is indirectly correlated with FGF in the respiratory circuit (2,14,18). In contrast to the predicted associations, we found no association between COHb level, anesthetic type, and FGF. Park et al. (12) evaluated hemodynamic and respiratory parameters, COHb, and postoperative hepatic and renal function in patients who underwent prolonged laparoscopic procedures to compare the effects of minimal flow with those of high flow desflurane anesthesia. The COHb values in the minimal-flow group were significantly higher than those in the high-flow group. However, there was no difference in the COHb concentration from the baseline concentration in the minimal-flow group. They also found that none of the patients in either group had COHb concentrations greater than 1.5%. The researchers concluded that both minimal-flow and high-flow desflurane anesthesia are equally safe and effective during prolonged laparoscopic surgery (12).

The findings of this study revealed that deltaCOHb had a similar propensity to increase with increasing BMI and age. This suggests that older and overweight individuals have an increased risk of developing elevated COHb levels following surgery. Nevertheless, it should be noted that this risk decreases when surgery lasts longer and patients receive more thorough ventilation. In other words, even in older and heavier patients, a lower risk of increased postoperative COHb levels is associated with longer surgical times and more successful ventilation methods.

Study Limitations

The limitations of our study include the inability to monitor changes in COHb levels with continuous measurements and the lack of follow-up on postoperative respiratory complications. Patient data were obtained through the hospital information system and anesthesia monitoring forms. These factors contribute to the constraints of our study.

CONCLUSION

In summary, our findings indicate that longer operation times, variations in anesthetic agents, and controlled FGF do not increase the likelihood of elevated COHb levels. This implies that laparoscopic surgery does not significantly increase the risk of heightened COHb levels, provided patients receive sufficient hyperventilation with oxygen concentrations between 40% and 80% and continuous efforts are made to effectively remove intra-abdominal smoke. Furthermore, the outcomes suggest that a range of anesthetic medications and reduced FGF can be safely used in robotic surgery, regardless of patient position or procedure duration. These findings underscore the importance of effective smoke extraction systems and appropriate ventilation strategies for reducing the occurrence of CO-related complications during laparoscopic surgery.

Ethics

Ethics Committee Approval: The records of patients aged 18 years who underwent elective robotic surgery in the robotic operating room of the Gazi University Faculty of Medicine between December 2021 and December 2022 were retrospectively evaluated following the approval of the Gazi University Local Ethics Committee (approval number: 2023-259, date: 21.02.2023).

Informed Consent: Retrospective study.

Author Contributions

Concept: S.E., Design: S.E., Supervision: G.İ., Resources: G.İ., Materials: Ö.E., Data Collection or Processing: Ö.E., Analysis or Interpretation: Ü.Ö.T., Literature Search: Ü.Ö.T., Writing: S.E., Critical Review: G.İ.

Conflict of Interest: No conflict of interest is declared by the authors.

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