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Intraocular pressure variation during colorectal laparoscopic surgery: standard pneumoperitoneum leads to reversible elevation in intraocular pressure

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Abstract
Background
The potential effects of laparoscopic surgery on intra- and postoperative intraocular pressure (IOP) are not completely understood. Although prior studies have reported that pneumoperitoneum may increase IOP, it is not clear whether this increase is related to the effects of pneumoperitoneum or to the patient's position, such as the Trendelenburg position. This study aimed to evaluate the potential fluctuations of IOP during colorectal laparoscopic surgery in two groups of patients: those with and those without Trendelenburg positioning.
Methods
For this prospective study 45- to 85-year-old patients undergoing laparoscopic colorectal surgery were enrolled after a thorough ophthalmologic assessment. The study protocol included measurement of IOP at eight different time points (before, during, and after surgery) using a contact tonometer in both eyes.
Results
The study enrolled 29 patients: 17 (58.6 %) with Trendelenburg position placement during surgery and 12 (41.4 %) without Trendelenburg positioning. The two groups did not differ in terms of gender, age, body mass index (BMI), American Society of Anesthesiology (ASA) class, or operative time. In all the patients, pneumoperitoneum induction led to a mild rise in IOP, averaging 4.1 mmHg. The patients with Trendelenburg positioning showed a greater increase than the patients without it (5.05 vs 4.23 mmHg at 45 min; $p = 0.179$), but IOP evaluation 48 h after surgery showed no substantial differences between the two groups. Among the 29 patients, 17 (58.6 %) showed an increase in IOP of 5 mmHg or more during surgery. A greater percentage of the patients who underwent Trendelenburg positioning showed an IOP increase of 5 mmHg or more (76.5 vs 33.3 %; $p = 0.020$). At the multivariate analysis, no potential predictors of increased IOP during surgery was identified.
Conclusions
Standard pneumoperitoneum (≤14 mmHg) led to mild and reversible IOP increases. A trend was observed toward a greater IOP increase in patients with Trendelenburg positioning. Thus, the patient's position during surgery may represent a stronger risk factor for IOP increase than pneumoperitoneum-related intraabdominal pressure.
Keywords
Colorectal surgery Glaucoma Intraocular pressure Laparoscopy Pneumoperitoneum Trendelenburg

Elevated intraocular pressure (IOP) is a major risk factor for glaucoma. To date, IOP lowering is the only treatment methods shown to prevent ongoing optic nerve damage. It is known that IOP shows both short-term fluctuations and long-term variations within subjects and can be affected by several drugs [*1–3*].

A persistently increased IOP may cause progressive damage to the optic nerve. The timing and severity of this damage is influenced by genetic vulnerability of the nerve fibers and depends on several factors such as age, ethnic group, family history of glaucoma, medical conditions, and drug use (e.g., prolonged steroid therapies). Transient elevation of IOP after ocular surgery also is known to cause glaucoma progression, particularly in patients with advanced glaucoma [*4*].

The laparoscopic approach has gained wide popularity in general surgery, including colorectal procedures for both benign and malignant diseases [*5*], due to the well-known advantages in postoperative recovery [*6*]. Prior studies have demonstrated that induction of pneumoperitoneum may increase the IOP up to 10 mmHg during laparoscopic procedures [*7–9*]. Nevertheless, it is not clear whether the observed increase in IOP during laparoscopic abdominal surgery is related to the effects of pneumoperitoneum, to the patient's position such as the Trendelenburg position during surgery, or to both. Furthermore, it is not known whether the elevation in IOP observed during surgery persists during the postoperative period.

This study therefore aimed to evaluate the potential fluctuations of IOP during colorectal laparoscopic surgery with 12- to 14-mmHg carbon dioxide (CO_2) pneumoperitoneum in two groups of patients classified as with or without Trendelenburg positioning up to 30° during the surgical procedure. Because currently available techniques do not enable continuous measurement of IOP [*10*], the IOP measurements in the current study were taken at several different time points before, during, and 48 h after surgery using the ICARE Pro Tonometer (Icare Finland Oy, Helsinki, Finland), an easy-to-use device that provides reliable measurements independently of the patient's posture [*11*].

Materials and methods

Study design and population

This prospective clinically based study was carried out in the Digestive, Colorectal, and Oncological Surgery Unit at the University of Torino. The inclusion criteria specified an age of 45–85 years, a body mass index (BMI) of 35 kg/m^2 or less, an American Society of Anesthesiologists (ASA) classification of 1–3, and a surgical indication of laparoscopic colorectal procedure. The exclusion criteria ruled out an established diagnosis of glaucoma with topical therapy, a documented increase in IOP, and recent (≤6 months) eye infections.

All the patients signed a study-specific informed consent form. The study protocol received the approval of the Hospital Ethical Committee (Protocol no. 0026385).

Data collection

For each patient enrolled in the study, the following demographic and clinical data were collected: gender, age, BMI, smoking habits, arterial blood pressure, cardiovascular diseases, type 2 diabetes, and chronic therapies. Furthermore, an eye specialist (A.G.) conducted a thorough assessment of each patient to evaluate the presence of exudates or retinal hemorrhage, glaucoma, hypermetropia, myopia, astigmatism, and other eye diseases.

Measurement of IOP was performed for both eyes at eight time points, as follows: time 0 (at patient awakening 6–1 h before surgery), time 1 (5 min after induction of anesthesia), time 2 (5 min after induction of pneumoperitoneum), time 3 (5 min after placement of the patient in Trendelenburg position), time 4 (20 min after placement of the patient in Trendelenburg position), time 5 (45 min after placement of the patient in Trendelenburg position), time 6 (5 min after abdominal desufflation), time 7 (5 min before patient extubation), and time 8 (48 h after surgery).

The baseline IOP value was measured 6–1 h before surgery with the patients in horizontal position. Two measures were performed for all the patients, and the baseline IOP was defined as the mean value of these.

The tonometer used to measure IOP was the Icare Pro Tonometer, an easy-to-use instrument characterized by a range of measurements from 5 to 50 mmHg and a display accuracy of 0.1 mmHg [*11*, *12*]. For each assessment, the Icare Pro Tonometer registers three measures, giving the average value as the final result.

The IOP measure was assessed without any topical anesthesia instillation, with the instrument held perpendicular to the cornea a distance of 3–5 mm from the latter with patient in horizontal position.

At each IOP measurement, arterial blood pressure, heart rate, peak airway pressure, end-tidal carbon dioxide ($etCO_2$), etsevoflurane, intravenous (IV) fluid volume, and blood loss also were recorded.

To define increased IOP, we chose a pressure increase of 5 mmHg or more compared with the preoperative value. This cutoff value was chosen because the circadian fluctuations are considered normal up to 4 mmHg [*13*].

Surgical technique

All procedures were performed by a single experienced surgeon (M.M.). Our surgical techniques have been described elsewhere [*14*]. Briefly, pneumoperitoneum was created with a Veress needle at an intraabdominal pressure of 12–14 mmHg. Four or five trocars were used. For left hemicolectomy and rectal anterior resection, a high vascular ligation, a complete left colon mobilization, and a proximal rectum transection were completed laparoscopically. A suprapubic minilaparotomy then was performed to extract the specimen, resect the proximal margin, and introduce the stapler anvil. Finally, pneumoperitoneum was reestablished, and a stapled mechanical anastomosis was fashioned laparoscopically.

Right hemicolectomies were completed by performing a laparoscopic high vascular ligation, a complete mobilization, and mesenteric dissection of the distal ileum, cecum, ascending colon, hepatic flexure, and proximal transverse colon. A transverse minilaparotomy then was performed in the right hypochondrium to extract the specimen, transect the ileum and the transverse colon, and fashion a manual ileocolic anastomosis. Finally, the pneumoperitoneum was reestablished to verify the anastomosis and close the mesenteric defect by a laparoscopic running suture.

Throughout surgery, intraperitoneal pressure was maintained at a level of 12–14 mmHg. When the Trendelenburg position was required, a fixed 30° angle was used.

Anesthesia protocol

The anesthesia protocol was standardized for the drugs used during the procedure. After baseline IOP measurement in both eyes, the patients received midazolam 2 mg for premedication. An automatic monitor (Monitor for Anaesthesia S/5 TM DATEX-OHMEDA, GE Healthcare Finland Oy, Helsinki, Finland) was used for standard monitoring including electrocardiography (ECG, 3 leads), heart rate, pulse oximetry, noninvasive blood pressure, invasive blood pressure in ASA 3 patients, neuromuscular transmission, entropy, and temperature.

Anesthesia was induced with sufentanil 0.5 gamma/kg, propofol 2 mg/kg, and rocuronium 0.6 mg/kg. After tracheal intubation, sufentanil 0.3–0.5 gamma/kg/h and sevoflurane in a 40/60 oxygen/air mixture were used to achieve an entropy index of 40–50 as well as a blood pressure and heart rate within 20 % of their pre-induction values. Additional doses of rocuronium (0.12 mg/kg) were administered to maintain one twitch response on a train of four. The lungs were ventilated using an S/5 AVANCE-OHMEDA (GE Healthcare Finland Oy, Helsinki, Finland) anesthesia workstation by setting the breaths per minute and the tidal volume to maintain $etCO_2$ at 30–40 mmHg. Inspired and expired gas and ventilatory variables were monitored. Lactated ringer's solution was administered at 4 ml/kg/h. At the end of the procedure, reversal of neuromuscular blockage was achieved using Sugammadex to avoid the use of atropine-intrastigmine.

Statistical analysis

The current study was considered a "pilot study." Thus, no a priori sample size calculation was performed.
Descriptive analyses were performed using frequencies, percentages, and frequency tables for categorical variables. For the bivariate analysis, chi-square tests were performed to evaluate differences for categorical variables. A binary logistic regression model was used to identify possible factors associated with IOP increase at different times during and after surgery.
In accordance with the Hosmer and Lemeshow [*15*] procedure, only covariates with a p value lower than 0.25 at univariate analysis were introduced into the models. The results are expressed as adjusted odds ratios (ORs) with 95 % confidence intervals (CIs), and the model's goodness of fit was assessed by the Hosmer–Lemeshow test. A two-tailed p value of 0.05 was considered significant for all analyses, which were carried out using Stata, version 10.1 (Stata Corp., College Station, TX, USA, 2007).

Results

The study enrolled 29 patients (14 men and 15 women). The mean preoperative age was 65.5 ± 11.8 years (range, 50–85 years), and the mean BMI was 25.6 ± 3.8 kg/m^2 (range, 18.8–35.1 kg/m^2). The ASA classification was 1 for 6 patients (20.7 %), 2 for 18 patients (62.1 %), and 3 for 5 patients (17.2 %).
All the patients underwent laparoscopic colorectal surgery. The surgical procedure was right hemicolectomy in 11 cases, transverse colon resection in 2 cases, left hemicolectomy in 8 cases, anterior resection of the rectum in 6 cases, and abdominoperineal excision in 2 cases.
The study sample was divided into two groups: one with Trendelenburg position placement during the surgical procedure (17 cases, 58.6 %) and one without Trendelenburg positioning (12 cases, 41.4 %). The main characteristics of the two groups are shown in Table 1. The two groups of patients showed no statistically significant differences in gender, age, BMI, ASA score, or operative time (Table 1).
Table 1
Patient characteristics of the two groups classified according to use of the Trendelenburg position or not during surgery

	Trendelenburg group	**Non-Trendelenburg group**	**p value**
	n (%)	**n (%)**	
No. of patients	17 (58.6)	12 (41.4)	
Gender			0.876
Male	8 (47.1)	6 (50.0)	
Female	9 (52.9)	6 (50.0)	
Age (years)			0.541
≤50	1 (5.9)	0 (0.0)	
51–60	5 (29.4)	1 (8.3)	
61–70	5 (29.4)	6 (50.0)	

	Trendelenburg group	Non-Trendelenburg group	p value
	n (%)	n (%)	
71–80	5 (29.4)	4 (33.4)	
≥81	1 (5.9)	1 (8.3)	
BMI (kg/m^2)			0.297
≤18.50	0 (0.0)	0 (0.0)	
18.51–25.00	6 (35.3)	7 (58.3)	
25.01–30.00	9 (52.9)	5 (41.7)	
≥30.01	2 (11.8)	0 (0.0)	
ASA score			0.064
1	6 (35.3)	0 (0.0)	
2	9 (52.9)	9 (75.0)	
3	2 (11.8)	3 (25.0)	
Operative time (min)			0.761
≤90	4 (23.5)	2 (16.7)	
91–180	9 (52.9)	8 (66.6)	
≥181	4 (23.5)	2 (16.7)	

Data are expressed as number and percentages.

BMI body mass index, ASA american society of anesthesiologists classification

Whereas induction of anesthesia determined an IOP decrease, pneumoperitoneum induction led in all patients to a mild rise in IOP averaging 4.1 ± 2.9 mmHg (range, 0.0–11.2 mmHg) (Table 2; Fig. 1). Nevertheless, the patients with Trendelenburg positioning showed an IOP trend after pneumoperitoneum induction slightly different from that of the patients without Trendelenburg positioning, with the former showing a greater increase. Thus, 45 min after placement of the patient in Trendelenburg position, the mean IOP increase was 5.05 versus 4.23 mmHg at the same time point in the patients without Trendelenburg positioning ($p = 0.179$) (Table 2; Fig. 1).

Table 2

Mean intraocular pressure (IOP) values and the number of patients showing an increased IOP according to use of the Trendelenburg position or not during surgery

		Time 0	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	Time 7	Time 8
Mean IOP values (mmHg)										
Trendelenburg	Right eye	18.16	13.68	18.39	18.88	19.23	18.67	15.09	13.74	17.12
	Left eye	19.34	14.02	18.06	18.96	17.85	19.01	14.72	14.55	17.60
Non-Trendelenburg	Right eye	17.45	12.57	14.88	14.88	14.50	13.69	13.45	13.22	16.98
	Left eye	17.93	12.85	14.40	14.00	15.46	14.00	14.06	13.31	19.45
Patients with increased IOP (n = 17)										
Trendelenburg (n = 13)	Right eye		0	8				2	1	1

		Time 0	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	Time 7	Time 8
	Left eye		0	6				3	2	0
Non-Trendelenburg (n = 4)	Right eye		0	2				3	1	0
	Left eye		0	2				3	2	1

Time 0 (preoperatively), time 1 (5 min after induction of anesthesia), time 2 (5 min after induction of pneumoperitoneum), time 3 (5 min after placement of patient in Trendelenburg position), time 4 (20 min after placement of patient in Trendelenburg position), time 5 (45 min after placement of patient in the Trendelenburg position), time 6 (5 min after abdominal desufflation), time 7 (5 min before patient extubation), time 8 (48 h after surgery). Increased IOP was defined as a rise in pressure of ≥5 mmHg or more compared with the preoperative value

IOP Intraocular pressure

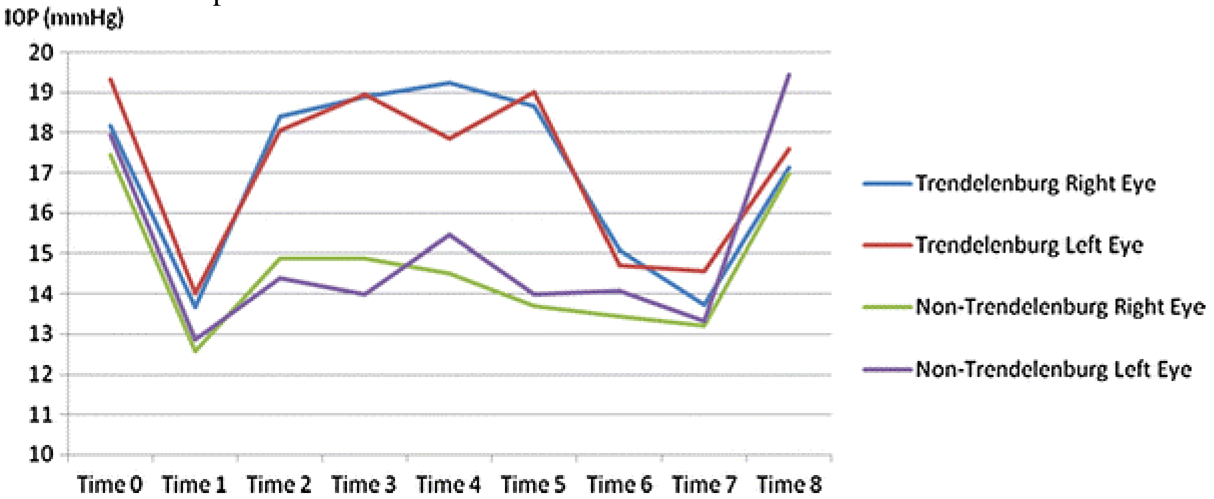

Fig. 1

Mean intraocular pressure trends according to the use of Trendelenburg position or not during surgery: time 0 (preoperatively), time 1 (5 min after induction of anesthesia), time 2 (5 min after induction of pneumoperitoneum), time 3 (5 min after placement of the patient in Trendelenburg position), time 4 (20 min after placement of the patient in Trendelenburg position), time 5 (45 min after placement of the patient in Trendelenburg position), time 6 (5 min after abdominal desufflation), time 7 (5 min before patient extubation), time 8 (48 h after surgery)

The mean IOP in the two groups showed similar values at the preoperative assessment (time 0) and a similar reduction after anesthesia induction (time 1). On the other hand, after pneumoperitoneum induction and during the surgical procedure (time 2–5), the Trendelenburg group showed a greater IOP increase in both eyes (Fig. 1). Abdomen desufflation and extubation of the patient led to a realignment of IOP in both groups, and the evaluation 48 h after surgery showed no substantial differences between the Trendelenburg and non-Trendelenburg groups (Fig. 1).

Of the 29 patients, 17 (58.6 %) showed an IOP increase of 5 mmHg or more during surgery compared with the preoperative value. These 17 patients were compared according to the use of the Trendelenburg position or not during surgery (Table 2). Once again, a greater percentage of the patients who underwent Trendelenburg positioning during surgery showed an IOP increase of 5 mmHg or more (76.5 vs 33.3 %; p = 0.020).

In the subgroup of patients with an IOP increase of 5 mmHg or more, the IOP evaluation 48 h after surgery showed an increase of 5 mmHg or more compared with the preoperative value in only two patients (6.9 %): one in the Trendelenburg group (right eye only) and one in the non-Trendelenburg group (left eye only; p = 0.147) (Table 2).

We conducted a multivariate analysis aimed at identifying potential predictors of increased IOP during surgery (Table 3). Once again, increased IOP was defined as an increase of 5 mmHg or more compared with the preoperative evaluation. The following were analyzed as independent variables: Trendelenburg position, age group, BMI group, ASA score, and operative time.

Table 3

Potential predictors of an increase in intraocular pressure (IOP)

Variables	**Adjusted OR**	**p value**
IOP increase after induction of pneumoperitoneum—right eye		
Trendelenburg position	7.54	0.161
Age group	0.04	0.045[a]
BMI group	1.41	0.724
ASA score	5.18	0.267
Operative time	0.30	0.337
IOP increase after induction of pneumoperitoneum—left eye		
Trendelenburg position	2.44	0.440
Age group	1.88	0.340
BMI group	2.35	0.342
ASA score	0.73	0.754
Operative time	0.51	0.425
IOP increase after abdominal desufflation—right eye		
Trendelenburg position	0.26	0.375
Age group	0.29	0.285
BMI group	0.78	0.841
ASA score	2.48	0.497
Operative time	9.36	0.070
IOP increase after abdominal desufflation—left eye		
Trendelenburg position	1.19	0.910
Age group	0.97	0.962
BMI group	0.48	0.553
ASA score	0.77	0.832
Operative time	1.32	0.814
IOP increase before patient extubation—right eye		
Trendelenburg position	0.51	0.815
Age group	0.43	0.346
BMI group	1.24	0.929
ASA score	1.72	0.809
Operative time	0.71	0.878
IOP increase before patient extubation—left eye		
Trendelenburg position	1.94	0.766
Age group	0.63	0.631

Variables	Adjusted OR	p value
BMI group	0.18	0.390
ASA score	0.17	0.268
Operative time	10.19	0.151

Increased intraocular pressure was defined as a rise in pressure of ≥5 mmHg or more compared with the preoperative value

[a] $p < 0.05$

OR odds ratio, BMI body mass index, IOP Intraocular pressure, ASA american society of anesthesiologists classification

In the multivariate analysis, the only significant variable was the age group, which seemed to be protective against a rise in IOP after pneumoperitoneum induction (right eye: age class adjusted OR, 0.04; p = 0.045). Nevertheless, this result should be considered with caution given the small number of patients. No other variable was statistically significant (Table 3).

Discussion

To date, the potential effects of pneumoperitoneum during laparoscopic surgery on intra- and postoperative IOP are not completely understood. Available literature data suggest that pneumoperitoneum may increase IOP up to 10 mmHg [*7–9*]. It is well-known that IOP variations greater than 10 mmHg may damage the optic nerve and cause progressive visual loss [*1*, *2*, *16*, *17*]. The increase in IOP causes damage to the optic nerve in a cumulative degree based both on how long IOP is increased and on the intrinsic, genetically related vulnerability of the optic nerve. For instance, subjects with limited outflow facility in the trabecular meshwork may experience a greater rise in IOP, and this could prove clinically relevant for people with glaucoma.

A recently published review [*18*] highlighted the potential injuries of increased IOP during laparoscopic colorectal surgery based on the evidence of a reported risk for perioperative visual loss after colorectal resection quoted as 1.24 per 10,000 in a large cohort study of more than 5.6 million surgical procedures [*19*]. However, in this review, no studies could be identified directly that quantified the effects of intraoperative positioning on IOP for patients undergoing laparoscopic colorectal surgery.

We conducted a study to evaluate IOP fluctuations during colorectal laparoscopic surgery using pneumoperitoneum induction values of 12–14 mmHg in two groups of patients based on the use of the Trendelenburg position or not during surgery. The study protocol included the measurement of IOP at eight different time points (before, during, and after surgery) using a contact tonometer in both eyes. One strength of the study was represented by the comparability between groups with regard to main potential risk factors for IOP increase such as gender, age, BMI, and operative time (Table 1).

The main finding of the study was that although pneumoperitoneum induction determined a mean IOP increase of 4 mmHg, up to 11 mmHg in some cases, and 58.6 % of the patients showed an IOP increase of 5 mmHg or more, the patients placed in Trendelenburg position during surgery exhibited both a greater IOP increase (mean increase in values 45 min after placement in the Trendelenburg position, 5.05 vs 4.23 mmHg; p = 0.179) and a greater percentage of cases with an IOP increase of 5 mmHg or more (76.5 vs 33.3 %; p = 0.020).

The aforementioned data underscore a trend toward a greater IOP increase for patients placed in Trendelenburg position, thus suggesting that the patient's position during surgery may represent a stronger risk factor for an IOP increase than pneumoperitoneum-related intraabdominal pressure. Nevertheless, this hypothesis was not supported by the multivariate analysis of our results, which showed that Trendelenburg positioning was not a statistically significant risk factor for increased IOP (Table 3). Furthermore, it is important to emphasize that although the Trendelenburg group showed a greater IOP increase in both eyes during surgery, the IOP evaluation 48 h after surgery showed no substantial differences between the Trendelenburg and non-Trendelenburg groups (Fig. 1), thus suggesting that the greater IOP increase did not lead to permanent damage.

Thus, our study showed that laparoscopic surgery with a 12- to 14-mmHg pneumoperitoneum does not represent a risk factor for a potentially harmful IOP increase, but at the same time, it exhibited different trends in mean IOP in the two groups of patients, specifically during the surgical procedure. These fluctuations, more marked for subjects placed in Trendelenburg position during surgery, are worthy of further research and suggest that the monitoring of IOP requires more attention during the Trendelenburg placement of patients.

On the basis of the current study results, we can conclude that standard pneumoperitoneum, up to 14 mmHg, leads to mild and reversible IOP increases. Consequently, routine ophthalmologic examination before surgery may not be warranted for patients undergoing laparoscopic abdominal surgery. Nevertheless, in the presence of preexisting glaucoma, an ophthalmologic consultation may be required to identify subjects at greater risk for potentially harmful IOP increases. Furthermore, when the surgical procedure requires Trendelenburg positioning, this potential risk may be increased. Moreover, the current study analyzed the effects of the 12- to 14-mmHg CO_2 pneumoperitoneum routinely used in colorectal procedures, which leads to a mean IOP increase of 4 mmHg. Although this increase is unlikely to be dangerous for an healthy optic nerve, it might be significantly higher when high pneumoperitoneum insufflation pressures are used, such as in gynecologic and urologic procedures, with potential damage not only in patients with advanced glaucoma but also in normal eyes.

With regard to IOP variation profiles in the two eyes, it is well known that under normal conditions, IOP fluctuations show a symmetric pattern between the right and left eyes [*20*]. Although in the current study, involving IOP measurement in both eyes at each time point, we recorded only minor differences between eyes, it is important to underscore that the two patients with an IOP increase of 5 mmHg or more 48 h after surgery showed this increase in one eye only. Thus, in patients at high risk for IOP increases, preoperative ophthalmologic examination and perioperative IOP measurements should always be performed for both eyes to detect potential differences.

Although the findings of our study confirm the hypothesis that the laparoscopic technique is safe also from an ophthalmologic point of view, further research is needed. The sample size was limited, thus limiting the power of the study. Because the study was designed on a voluntary basis and because we proposed that asymptomatic patients undergoing colorectal surgery be enrolled in the study protocol for research purposes, the study involved a convenience sample, which was the one we were able to reach in a reasonable time. Nevertheless, our preliminary findings should act as a stimulus for further studies involving larger samples and different abdominal surgical procedures with both low and high insufflation pressures.

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