Removal of Hazardous Surgical Smoke Using a Built-in-Filter Trocar: A Study in Laparoscopic Rectal Resection

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Removal of Hazardous Surgical Smoke Using a Built-in-Filter Trocar: A Study in Laparoscopic Rectal Resection

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Background: Surgical smoke containing potentially carcinogenic and harmful materials is an inevitable consequence of surgical energy devices, and constitutes a substantial occupational hazard in the operating room. This study aimed to evaluate the efficacy of a built-in-filter trocar in eliminating hazardous surgical smoke during laparoscopic and robotic rectal surgery.

Methods: Ten patients who underwent rectal cancer resection were enrolled. Five patients underwent surgery utilizing a nonfiltered trocar, and the remaining 5 utilized a built-in-filter trocar. Gas samples were aspirated from the peritoneal cavity over 30 minutes of electrocauterization and collected in a Tedlar bag. Concentrations of surgical smoke were measured using ultraperformance liquid chromatography and gas chromatography.

Results: Eleven hazardous chemical compounds (benzene, toluene, ethylbenzene, xylene, styrene, formaldehyde, acetaldehyde, propionaldehyde, butyraldehyde, isovaleraldehyde, and valeraldehyde) were identified in the surgical smoke. With the built-in-filter trocar, removal rates of 69% for benzene ($P=0.028$), 72% for toluene ($P=0.009$), 67% for butyraldehyde ($P=0.047$), 46% for ethylbenzene ($P=0.092$), 44% for xylene ($P=0.086$), 35% for styrene ($P=0.106$), 39% for formaldehyde ($P=0.346$), and 33% for propionaldehyde ($P=0.316$) were achieved.

Conclusions: This study confirmed the presence of harmful materials in surgical smoke. Evacuation of surgical smoke through a disposable built-in-filter trocar is a simple and effective way in reducing volatile organic compounds concentrations.

Key Words: smoke, laparoscopy, micropore filter, trocar

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As complex and time-consuming laparoscopic procedures such as radical gastrectomies, colectomies, and hepatectomies become more common, a concomitant increase in the prolonged use of monopolar cautery, ultrasonically activating scissors, and high-powered bipolar devices are utilized. The smoke generated by the use of these instruments is known to contain harmful substances. This has prompted researchers to examine the health effects of surgical smoke on surgeons and other medical staff in the operating room.[1,2] Thus far, Thus far, studies have identified volatile organic compounds (VOC), nitriles, phenols, and fatty acids as the main chemical compounds in surgical smoke.[2–10]

Various interventions have been designed to eliminate smoke generated during open conventional or laparoscopic procedures.[2,3,11–15] Among the devices currently in use are local exhaust ventilation (LEV) systems and individual smoke evacuation units. Unfortunately, LEV is rarely seen in clinical practice because of a high cost, complicated set-up, and issues related to noise, ease of use, and the distraction factor of having such interventions in operating rooms.

This present study aims to examine the efficacy of a built-in-filter trocar during laparoscopic rectal cancer resection in eliminating hazardous chemicals.

MATERIALS AND METHODS

Pilot Study

A pilot study was first undertaken involving 2 laparoscopic uterine myomectomy patients to verify that the filter functions appropriately. Surgical smoke was collected on 2 separate occasions using a conventional and a disposable built-in-filter trocar (TROPIAN; Tropian Tech., Gunpo, Korea). Each smoke sample was sent to The Korean Testing and Research Institute for comparison analysis.[16] The analysis indicated a 96% removal in benzene, 100% removal in 1,2-dichloroethane, 93% removal in toluene, 75% removal in ethylbenzene, 92% removal in styrene, 95% removal in acetaldehyde, and 100% removal in propionaldehyde (Table 1).

Patients

Ten patients with rectal cancer were selected from Korea University Anam Hospital between June 2014 and

TABLE 1. Gas Analysis in the Pilot Study

Volatile Organic Compounds	Nonfiltered Sample (ppm)	Filtered Sample (ppm)	Removal Rate (%)
Benzene	0.098	0.004	96
1,2-Dichloroethane	0.039	0.000	100
Toluene	0.082	0.006	93
Ethylbenzene	0.020	0.005	75
Styrene	0.013	0.001	92
Acetaldehyde	1.230	0.060	95
Propionaldehyde	0.040	0.000	100

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August 2014. The sample size was determined on the basis of the results obtained from the pilot study, for which each group with >4 patients could achieve a power greater than 80%. The patients were alternatively assigned into 2 groups; the control group undergoing surgery with a conventional trocar (n = 5), and the experimental group undergoing surgery with using a 5-mm TROPIAN trocar (n = 5). All 10 patients underwent successful laparoscopic or robotic rectal surgery. The study was approved by the Institutional Review Board of Korea University Anam Hospital (AN140315-003), upon obtaining written consent from the patients or their legal guardians, following a thorough explanation of the study objectives and methods.

Apparatus of Trocar and Gas Collection

The commercially available TROPIAN trocar is equipped with a built-in-filter located immediately before the exhaust valve (Fig. 1). Once the valve is opened, the surgical smoke is filtered as it freely passes through the built-in-chamber. Following this, the filtered smoke is evacuated to the environment (Fig. 2). The original design of the TROPIAN trocar does not permit the collection of filtered gas from its filtering chamber. For the purpose of this study, the filter component obtained from the product company was placed in between a conventional laparoscopic port and a 10 L gas-collecting Tedlar bag (Figs. 3, 4).

For the control group, the smoke sample was collected directly from the working port without passing through the filter. The filter is made of 2 separated layers of processed and refined charcoal. Each layer has 1200 m^2/g of surface area to absorb a large amount of smoke. The space between the 2 charcoal layers is occupied by innumerable 1 to 50 μm micropores designed to trap liquid and aerosolized substances (Fig. 5). Samples were collected until the 10 L Tedlar bag was full, approximately for 30 minutes.

FIGURE 1. Photograph of the 5 mm TROPIAN built-in-filter trocar. The body has a built-in-chamber containing filters (arrow head), and the filtered smoke is evacuated once the exhaust valve (arrow) is opened.

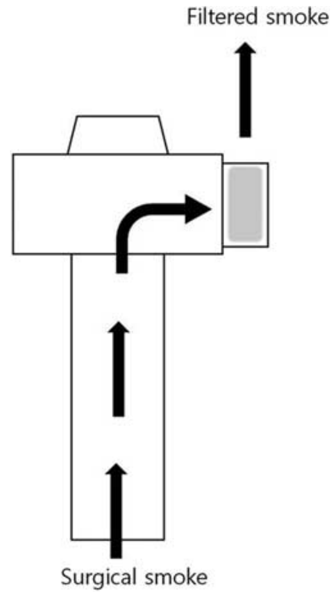

FIGURE 2. Schematic diagram of the built-in-filter trocar. The arrows indicate the flow of surgical smoke.

Energy Devices

The energy devices used for surgery were electrocautery and an ultrasonically activating scalpel. Electrocautery device settings for cut mode and cautery were set at 25W each. The ultrasonic device (Harmonic Generator 300; Ethicon Endo-Surgery Inc., Cincinnati, OH) was standard

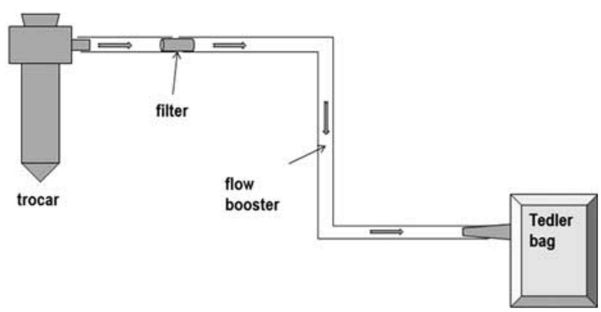

FIGURE 3. Schematic diagram of the smoke collecting system.

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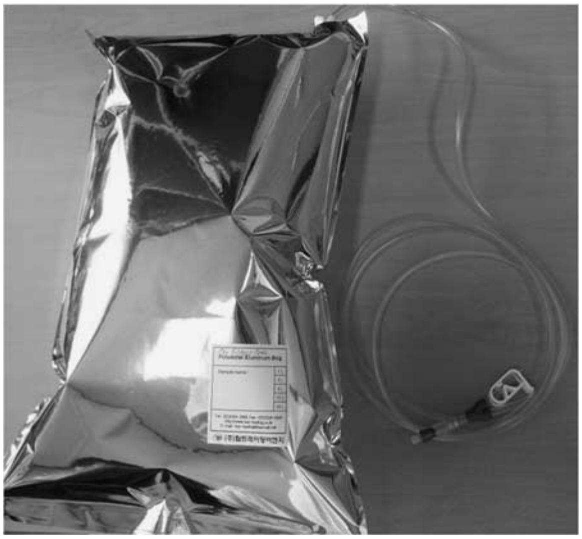

FIGURE 4. Photograph of the Tedlar bag.

for all dissections. Operative gas samples were collected during the rectal dissection phase, as this phase has the highest usage of electocautery and ultrasonic scalpel.

Smoke Analysis

All the samples were analyzed at the same institute where the pilot study was conducted, using the same methodology. In brief, aldehyde analysis was performed by the ultraperformance liquid chromotograpy (UPLC; ACQUITY UPLC H-Class, Waters). The UPLC apparatus utilized a spectrophotometric detector (tunable ultraviolet detector; 360 nm) and BEH phenyl column (1.7 μm in particle size) under a measurement temperature of 35°C. The initial water/acetonitrile solvent ratio was 75:25, followed by 40:60 at 17 minutes, then 70:30 at 19 minutes, whereas a constant velocity of 0.4 mL/min was maintained. VOC was further assessed. An automatic thermal desorber (TurboMatrix650 ATD, PerkinElmer) was used to concentrate samples. Initial condensation was performed at 300°C, then the second at −30°C to 300°C, each of which was kept at the following conditions: purge time 1 minute, desorb time 10 minutes, and trap-hold time 1 minute. The outlet split ratio was maintained at 10:1. The condensed samples were then analyzed using a gas chromatography mass spectrometry (GC/MS; 7890B/5977A, Agilent).

Statistical Analysis

For intergroup analysis of each chemical compound, a Mann-Whitney *U* test was performed. The average value was calculated for each chemical compound, followed by calculation of removal rates with the following formula; removal rate = (regular trocar average–filtered trocar average)/regular trocar average. The results were deemed statistically significant at a *P*-value < 0.05. Statistical tests were performed with SPSS for Windows version 18.0 (SPSS, Chicago).

RESULTS

An equal number of patients were assigned into the control and experimental group. In the control group, 2 patients underwent robotic ultralow anterior resection, 2 patients underwent laparoscopic low anterior resection, and 1 patient underwent robotic abdominoperineal resection. In the experimental group, 3 patients underwent robotic ultralow anterior resection, and 2 patients underwent laparoscopic low anterior resection. Demographic and preoperative clinical characteristics in both groups are shown in Table 2. Variables for age, gender, body mass index, and operative time did not reveal any significant differences between these 2 groups.

Smoke analysis revealed 11 VOCs. Mean concentrations of VOCs were compared. Results are depicted in Table 3. The levels of benzene ($P = 0.028$), toluene ($P = 0.009$), and butyraldehyde ($P = 0.047$) differed significantly between the 2 groups, with removal rates > 60% with the built-in-filter trocar. No significant difference was noted with respect to other chemical compounds although the built-in-filter trocar tends to reduce smoke concentration. Trace amounts of isovaleraldehyde and valeraldehyde were detected; however, the removal rates for these compounds could not be calculated.

DISCUSSION

To our knowledge, the present study is thought to be the first clinical study to examine the efficacy of the built-in-filter trocar in removing hazardous chemicals produced during prolonged laparoscopic procedures such as laparoscopic rectal surgery.

It is well known that a number of toxic chemical and cellular compounds are produced during thermolysis.[13,14,17–22] During a laparoscopic procedure in particular, cauterization takes place in the peritoneal cavity where the concentration of oxygen is low because of a surgically-created carbon dioxide pneumoperitoneum. Thus, a large amount of toxic gas is produced.[14,17] When the smoke is evacuated or leaked

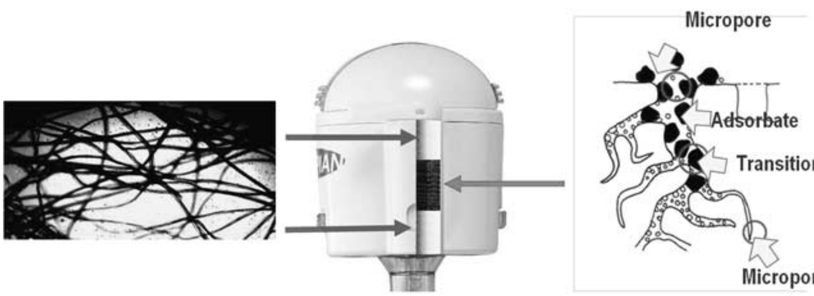

FIGURE 5. The filter is made of 2 layers of processed and refined charcoal (left arrow). Each layer has 1200 m^2/g surface to absorb a large amount of smoke. The space between the 2 charcoal layers (right arrow) is occupied by innumerable 1 to 50 μm micropores designed to trap liquid and aerosolized substances.

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TABLE 2. Patient Demographics and Characteristics Between the Conventional and the Built-in-Filter Groups

Variable	Conventional Trocar (n = 5)	Built-in-filter Trocar (n = 5)	*P*
Age (y)	50.8 ± 4.3	56.4 ± 11.3	0.141
Gender (female/male)	1/4	2/3	0.513
Body mass index (kg/m^2)	23.1 ± 3.3	24.5 ± 2.5	0.251
Operative time (min)	253 ± 91.0	182 ± 33.3	0.251

Values are represented as mean ± SD, or number of patients, as indicated.

through trocar, medical personnel in the operating room are also exposed to the accumulated toxic compounds.

As awareness regarding the hazards of surgical smoke grows, various efforts have been made to evacuate the smoke during laparoscopic surgery.[14,15,21] Individual smoke evacuation units are known to be the most effective of all currently available systems. In the LEV system, centralized smoke evacuation systems trap surgical smoke via a centrally located suction hose and transfer it to a location where filtration is performed. They offers the advantage of powerful smoke removal than portable system.[13] Portable smoke evacuation systems are currently the most adaptable choice in the operating room. These systems rely primarily on a filter that is responsible for directly filtering contaminants; either charcoal-based or ultralow particulate air (ULPA) filters.[13] Because LEV systems must be placed relatively close to the source of surgical smoke to ensure effective removal, such systems pose the inconvenience of needing to move dynamically with the operating field.[3]

Many studies have suggested that a filter should be installed on the valve of the surgical cannula in an effort to protect medical staff and patients from such risks.[2,13,14,17,21] This was demonstrated in our study, where we examined the efficacy of a built-in-filter trocar in eliminating hazardous chemical smoke during laparoscopic rectal surgery. The trocar used in this study was designed to remove toxic compounds in surgical smoke simply using a built-in-filter. Analysis of the surgical smoke confirmed that benzene, toluene, and butyraldehyde were largely absent from the smoke samples collected in the experimental group, indicating that the toxic compounds in surgical smoke can be filtered using a trocar equipped with a built-in-filter. This trocar does not result in decreasing the pneumoperitoneum pressure when the exhaust valve of the built-in-chamber is opened. In addition, the market price of this trocar is very comparable to that of conventional trocars. Moreover, the use of this apparatus eliminates the need for an additional external device or system. This reduces the cost and noncost burdens associated with regular maintenance and cleaning of hoses and tubes, and eliminates the need for a complicated set-up each time surgery is performed.

In the main experiment, benzene, toluene, ethylbenzene, xylene, styrene, formaldehyde, acetaldehyde, propionaldehyde, butyraldehyde, isovaleraldehyde, and valeraldehyde were detected, although xylene, styrene, formaldehyde, butyraldehyde, isovaleraldehyde, and valeraldehyde were not detected in the pilot study even though the same technique was utilized; conversely, 1,2-dichloroethane was not detected in the main study. The large obvious difference was also observed in the removal rate of each substance between the pilot and the main studies. On the basis of existing research, such discrepancies are likely to stem from differences in the thermolytic reaction time related to a different nature of surgeries between studies. Much longer operating time with much more vigorous use of energy devices in the main study can be another explanation.

In this experiment, cellular materials, bacteria and viruses which have been also found in surgical smoke[12,17,18,20,21] were not tested. This is obviously 1 limitation of the study. Those substances should be accessed through other separate studies. In fact, the authors' research group has been continuously interested in the surgical smoke hazard issue and recently reported the very first detection of hepatitis B virus in surgical smoke.[23]

CONCLUSIONS

This study confirmed the presence of harmful materials in surgical smoke. Evacuation of surgical smoke through a built-in-filter trocar is a simple and cost-effective way of reducing hazardous hydrocarbon concentrations. As this study was carried out on a relatively small scale, larger scale prospective trials are needed to substantiate our findings. Furthermore, it is hoped that with the awareness of the hazards of surgical smoke to medical personnel, there will be continued interest and research aimed towards effectively addressing this matter.

TABLE 3. Concentrations Levels of Volatile Organic Compounds Released and Removal Rate

	Concentration (ppm)			
Volatile Organic Compounds	Conventional Trocar (n = 5)	Built-in-filter trocar (n = 5)	*P*	Removal Rate (%)
Toulene	0.028 ± 0.009	0.008 ± 0.006	0.009	72
Benzene	0.068 ± 0.03	0.020 ± 0.015	0.028	69
Butyraldehyde	0.009 ± 0.004	0.004 ± 0.002	0.047	60
Ethylbenzene	0.005 ± 0.003	0.003 ± 0.004	0.092	46
Xylene	0.005 ± 0.003	0.003 ± 0.004	0.086	44
Formaldehyde	0.22 ± 0.17	0.13 ± 0.12	0.346	39
Styrene	0.003 ± 0.004	0.002 ± 0.004	0.106	35
Propionaldehyde	0.02 ± 0.01	0.01 ± 0.008	0.316	33
Acetaldehyde	0.39 ± 0.24	0.39 ± 0.23	0.834	-
Isovaleraldehyde	0.000 ± 0.000	0.000 ± 0.000	1.000	-
Valeraldehyde	0.000 ± 0.000	0.000 ± 0.000	0.134	-

Values are represented as mean ± SD, or percentage, as indicated.

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