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Original Research Article

Evaluation of the chemical, cytological and bacteriological compositions of surgical smoke and evaluation of purification of smoke by ultraviolet light and various filters in laparoscopic surgeries

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ABSTRACT

Background: The present study aimed to assess the cytological, bacterial and chemical composition of laparoscopic surgical smoke and the evaluation of purification of surgical smoke by smoke purifying device containing ultraviolet (UV) light and various filters.
Methods: Sixty patients undergoing laparoscopic abdominal surgery lasting >45 min were included in this randomized controlled study. The patients were divided into two groups: group A-smoke passing through smoke purifying device and group B-smoke without passing through smoke purifying device. Sample for cytological, bacteriological and chemical analysis were collected from both the groups. The primary outcome measures were to find the cytological, bacteriological and chemical composition of surgical smoke. The secondary outcome measure was evaluation of purification of surgical smoke by smoke purifying device containing ultraviolet light and various filters. Intergroup comparison of categorical and continuous variables was done using the Chi square test/Fisher's exact test and unpaired t test respectively.
Results: The present study shows the group A wherein smoke evacuating device containing various filters were used has no bacterial growth as well as no cells seen on cytological evaluation as compared to the group B wherein 21/30 (70.0%) cases had few lymphocytes and 3/30 (10.0%) cases had coagulase-negative *Staphylococci* wherein smoke evacuation device was not used. However, the chemical composition was comparable in both the groups.
Conclusions: The smoke evacuation and filtration device, filtrates and clears the smoke of cells and bacteria as it passes through it.

Keywords: Surgical smoke, Laparoscopic surgery, Purification of smoke, Filters

INTRODUCTION

The surgical smoke released into the operation theatre environment may pose harm to the operation theatre personnel. Surgical smoke has the disadvantages ranging from hindrance of vision of the surgeon, malodor to harmful effects due to its composition. Various studies for evaluation of the composition of surgical smoke and whether they are harmful to the operation theatre personnel, has been going on since many years. Chemical composition of surgical smoke has been documented in many studies.[1] *Papillomavirus* has been found in wart vapour from a carbon dioxide laser and electrocoagulation.[2] Another study has found human immunodeficiency virus, its proviral DNA in laser smoke.[3] An experimental study found viable mouse melanoma cells after coagulation with a carbon dioxide laser.[4] Viable tumour cells have also been found in the

plume from a neodymium laser.[5] Smoke particles collected during mammoplasties have been demonstrated to be mutagenic to the TA98 strain of salmonella bacteria, thus the presence of mutagenic chemicals in surgical smoke was proven.[6] Little is known in the literature regarding the contents of surgical smoke in laparoscopic surgery.[7]

The bacteriological activity has been proved with *Neisseria*, coagulase negative *Staphylococcus*, *Corynebacterium* and viruses like human papilloma virus (HPV) has been isolated from surgical smoke.[8,9] Thus bacteria, viruses, cancer cells and various chemicals have been isolated from surgical smoke till date. There is paucity of data available in the published literature on the assessment of chemical, bacteriological and cytological composition and hazards of surgical smoke and the utility of smoke purifying devices in India. The present study aimed to assess the cytological, bacterial and chemical composition of laparoscopic surgical smoke and the evaluation of purification of surgical smoke by smoke purifying device containing ultraviolet light and various filters.

METHODS

This randomized controlled study was conducted between April 2021 and June 2022 in the major operation theatres, Poona Hospital and Research Centre, Pune, India. After approval from the Institutional Ethics Committee (letter no. RECH/ECBHR/2020-21/0035), a written informed consent was obtained from all the patients prior to enrolment explaining the risks and benefits of the procedure. Patients undergoing laparoscopic abdominal surgery lasting >45 min were included. Patients of diagnostic laparoscopy and converted to open surgery were excluded.

Out of 62 patients assessed for eligibility, after exclusion 60 patients were randomly divided into two groups with the help of www.randomizer.org; group A-smoke passing through smoke purifying device and group B- smoke without passing through smoke purifying device (Figure 1). The program was known as research randomizer. The program produced two sets of random numbers out of the range of numbers provided by taking user input on having uniqueness of the numbers to be generated. For the present study, the program produced two sets of unique numbers per set. The sheet of the random numbers was ready before the study was started.

Electrocoagulation and harmonic scalpel devices were used in all the procedures. Sample for cytological, bacteriological and chemical analysis were collected from both the groups. During the procedure the pneumoperitoneum was allowed to leak out through the gas vent of a 5 mm trocar. One end of a sterile suction tubing was connected to trocar and another end attached to the smoke purifying device (group A). The smoke purifying device had an exit portal from which purified smoke sample could be collected. The smoke purifying device used was a smoke evacuator machine AONES SERIES 6 PRO filter (components: three stage filter-primary filter, makes life of main filter longer (high efficiency particulate air (HEPA)+ultra-low penetration air (ULPA)+Carbon particles), independent carbon filter-for removing humidity and odour, UVC chamber with two UVCs for killing bacteria, final filter (HEPA+ULPA) and fluid trap: 1000 ml). Another set of smoke samples were collected without passing the smoke through smoke purifying device (group B).

The smoke released during laparoscopy that passed through the smoke purifying device and without the use of smoke purifying device was allowed to pass through normal saline filled under water seal bags for cytological evaluation. The liquid recovered was left for sedimentation for 2 hours, then centrifuged to concentrate the cells and the cytospins slides were prepared for routine Giemsa staining. Bacterial culture plates of blood agar were exposed to smoke through the purifier and without the purifier under all aseptic precautions. Culture plates were incubated and further isolated and tested. Surgical smoke with and without passing through smoke purifying device for chemical analysis was collected into Tedlar bag of 500 ml capacity. Chemical analysis was done using gas chromatography and mass spectrometry (GCMS) by means of following parameter for chemicals like formaldehyde, acetone and other chemicals as were previously found in literature as contents of surgical smoke. Column used: GsTek GSBP-5Ms (ID×L 0.32 mm×30 m, film thickness 0.25 um). Solvent: dichloromethane (DCM). Method: 40°C hold for 5 min, 40 °C-180 °C with ramping rate of 5 °C/min, 180-280 °C with ramping rate of 20° C /min. Carrier gas: helium (1.5 ml/min flow rate) injection: splitless mode 2 ul injection volume.

The primary outcome measures were to find the cytological, bacteriological and chemical composition of surgical smoke. The secondary outcome measure was evaluation of purification of surgical smoke by smoke purifying device containing ultraviolet light and various filters. On the basis of a previously published study,[8] a sample size of 30 patients was calculated for each group by a formula,

$$N^{10}=\frac{\{2p_{av}\,(1-p_{av})(Z_{\alpha}+Z_{\beta})^{2}\}}{\Delta^{2}},$$

where,

N is the number of subjects in each group, Δ is the difference between two proportions and pav is the anticipated average proportion.

We have taken Z_{α} a standard normal variate at 1% type 1 error ($p<0.01$)=2.58, and Z_{β} a standard normal deviate of 80 % at type II error=0.84 to reject the null hypothesis.

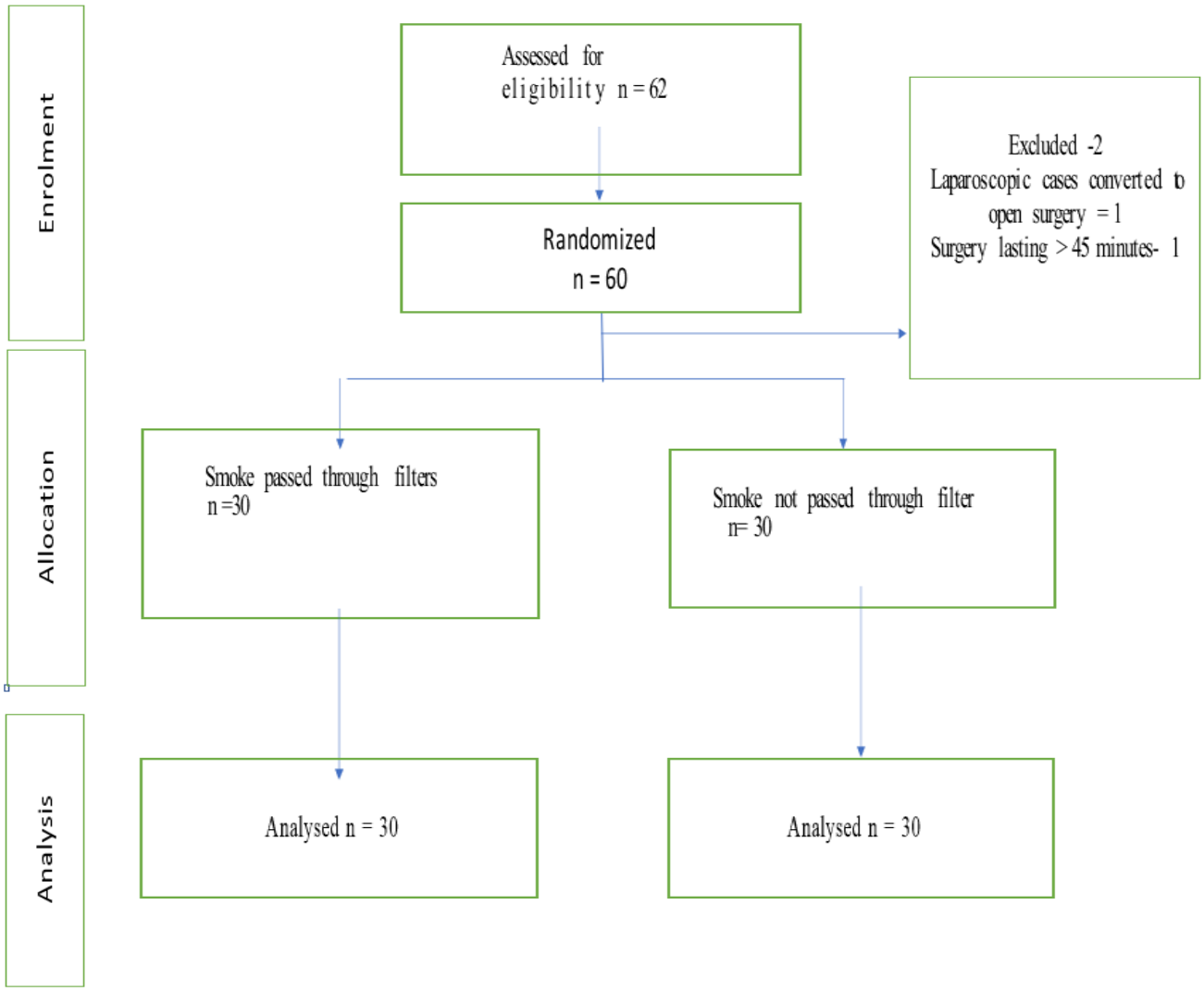

Figure 1: CONSORT template.

Statistical analysis

Data collected were entered in Excel 2007 and analysis of data was done using Statistical Package for Social Sciences for Windows, version 24.0 from IBM Corporation, Armonk, NY, USA. The data on categorical variables are shown as n (% of cases) and the data on continuous variables are presented as mean and standard deviation (SD). The inter-group comparison of distribution of categorical variables was tested using the Chi square test or Fisher's exact probability test. The means of continuous variables were tested using unpaired t test. The confidence limit for significance was fixed at 95% level with a $p<0.05$.

RESULTS

The present randomized controlled study was conducted to assess the cytological, bacterial and chemical composition of laparoscopic surgical smoke and the utility of smoke purifying device containing ultraviolet light and various filters. Of 62 patients assessed for eligibility, 2 were excluded because conversion to open surgery (1) and surgery lasting less than expected duration of 45 minutes (1). Sixty patients were randomized of 30 patients each into group A (smoke released was evacuated using smoke purifying device) and group B (smoke released was not passed through smoke purifying device) (Figure 1).

The mean age, gender and type of surgery were comparable between the two groups (Table 1). The chemical and bacteriological composition was comparable between the two groups, whereas the percentage of patients in whom lymphocytes were found in the smoke was significantly higher in group B as compared to group A (Table 2).

Table 1: Comparison of baseline characteristics.

Baseline characteristics	Group A	Group B	P value
	N (%)	N (%)	
Mean age±SD in years	46.6±10.7	42.9±12.7	0.235*
Gender			
Male	14 (46.7)	14 (46.7)	0.999 **
Female	16 (53.3)	16 (53.3)	
Type of surgery			
Laparoscopic hernia	9 (30.0)	8 (26.7)	0.514***
Laparoscopic cholecystectomy	9 (30.0)	9 (30.0)	
Laparoscopic appendectomy	8 (26.7)	7 (23.3)	
Laparoscopic ovarian cyst excision	0 (0.0)	3 (10.0)	
Laparoscopic total hysterectomy	4 (13.3)	3 (10.0)	

*Unpaired t test was used; **Chi square test was used; ***Fisher's exact test was used; SD-standard deviation.

Table 2: Comparison chemical, bacteriological and cytological composition between the two groups.

Composition	Group A	Group B	P value
	N (%)	N (%)	
Chemical composition			
CO_2	30 (100.0)	30 (100.0)	0.999
Other	0 (0.)	0 (0.0)	
Bacteriological composition			
Coagulase-negative *Staphylococci*	0 (0.0)	3 (10.0)	0.237
Nil	30 (100.0)	27 (90.0)	
Cytological composition			
Few lymphocytes	0 (0.0)	21 (70.0)	0.001
No cells	30 (100.0)	9 (30.0)	

Fisher's exact test was used.

DISCUSSION

Surgical smoke is a part of the environment during operative and invasive procedures. As harmonic energy sources and electrosurgery have become a routine practice, surgical, nursing and other staff are at increased risk for health concerns associated with exposure to surgical smoke peri-operatively. Since the mid-1970s, the body of evidence documenting the hazardous components of surgical smoke has continued to grow. Despite the evidence and recommendations of a various organizations, there are no uniform requirements mandating surgical smoke evacuation. The present study was conducted to assess the bacterial, cytological and chemical composition of surgical smoke produced during laparoscopic procedures and utility of purification by smoke purifying devices.

In the present study, in all the cases in both the groups CO_2 was found that was used to create pneumoperitoneum. Other chemicals were not found in the smoke of both the groups by GCMS test. A review article by Barret et al reported that possible hazards of surgical smoke and aerosols were potentially dangerous to both operation room (OR) personnel and patients. The potential risks to OR personnel include pulmonary irritation and inflammation, transmission of infection, and genotoxicity. The potential dangers to patients occur primarily during laparoscopic procedures in which surgical smoke is concentrated in the peritoneal cavity. These potential dangers include CO toxicity, port-site metastases from cancer spread through aerosolized cells, and toxicity to the peritoneal compartment and its contents.[1] Beebe et al reported that at the end of the surgery the median CO concentration was 475 ppm.[7] Dobrogowski et al stated that a complete qualitative and quantitative analysis of the air samples showed a number of chemical substances present, such as aldehydes, benzene, toluene, ethylbenzene, xylene, ozone, dioxins and others.[11] Hensmean et al reported that 21 chemicals, some highly toxic, had been identified in the electrosurgical smoke produced in a closed environment. These consist of hydrocarbons, nitriles, fatty acids, and phenols. The study concluded that electrosurgical smoke produced in a closed environment contains several toxic chemicals. The study further stated that effects of these on cell viability, macrophage, and endothelial cell activation were not known but measures to reduce smoke and evacuate it during endoscopic surgery were advisable.[12] Krones et al stated that surgical plume of all instruments comprehends toxic components including e.g., acrylamide, acetaldehyde, formaldehyde, and

benzene, which were toxic, and partly cancerogenic compounds. The study further stated that the concentrations estimated for daily routine are probably below relevant health risk, but the exposition to surgical smog should be minimised at any time using offtake devices.[13] Mootz et al reported that hydrogen cyanide (3-51 parts per million), acetylene (2-8 parts per million), and 1, 3-butadiene (0.15-0.69 parts per million) were identified in the plume.[14] Sagar et al reported that electrocautery smoke was found to contain significant levels of benzene, ethyl benzene, styrene, carbon disulphide and toluene. The study further stated that detectable quantities of at least one of these chemicals was found in each of the patients studied.[15]

In the present study, of 30 cases in group A, none had coagulase-negative *Staphylococci aureus*. Of 30 cases studied in group B, 3 (10.0%) had growth of coagulase-negative *Staphylococci*. Our findings are comparable to Capizzi et al study of 1998 wherein thirteen consecutive patients underwent CO_2 laser resurfacing of 13 bacterial cultures, 5 resulted in growth of coagulase-negative *Staphylococcus*. Of these five positive specimens, one also had growth of *Corynebacterium* and one had growth of *Neisseria* proving the danger of transmission of bacteria through the inhalation of surgical smoke.[8] Schultz et al studied using an experimental model of porcine tissue embedded with *Serratia marcescens* to determine the extent of viable bacteria present in surgical plume. The results showed that only blended current electrosurgery, not laser plume or coagulation electrosurgery, contained viable bacteria. Further, the study revealed that placing a suction device near the electrosurgical site reduced the number of aerosolized viable bacteria.[16] Our findings were similar to Schultz et al studies in view of absence of any bacteria or cells in smoke samples obtained after passing through smoke purifying devices.[16] Schultz et al opined that effective smoke capture does prevent bacteria in smoke from being aerosolized.[16] It also significantly reduces contamination of a simulated surgical wound by as much as 50% to 60% in contrast to control.

In the present study, of 30 cases in group A, lymphocytes were not found on cytological examination. Of 30 cases studied in group B, 21 (70.0%) specimens few lymphocytes were found on cytological examination (p=0.001). The absence of cells in the group A where smoke evacuators were used proves the usefulness of smoke evacuators though the harm caused by the inhalation of few lymphocytes are not studied. The avoidance of any contaminant in the theatre air would always be recommendable. Our findings are similar to study conducted by Champault et al where six of the nine samples (66.7%) yielded cell.[17] The four cytospins that were used for immunohistochemistry demonstrated cells of mesothelial origin. Ikramuddin et al reported that out of 35 patients, in two patients, aerosolized mesothelial cells were identified.[18] Sutinen et al reported that benign and malignant breast tissue can be identified with automatic tissue analysis system.[19]

Gioutsos et al concluded that carcinogenic, mutagenic and reprotoxic volatile organic compounds in surgical smoke can be efficiently reduced by mobile smoke evacuation system, providing improved protection for medical personnel. Devices specifically designed for smoke evacuation are more efficient than standard suction tools. Smoke evacuation devices are an economical and efficient alternative or complementary system to an operating theatre equipped with laminar airflow system. Their daily usage can drastically reduce the exposition to volatile organic compounds (VOCs).[20] Mowbrey et al in their review article opined that the potentially carcinogenic components of surgical smoke were sufficiently small to be respirable. Infective and malignant cells were found in the smoke plume, but the full risk of this to the theater staff is unproven.[21]

Even though surgical smoke is not an immediate health hazard, OR personnel should be aware of the potential long-term health risks associated with exposure. Also, direct physical injury and carcinogenesis of surgical smoke contents previously detected have been well demonstrated in-vitro and animal models, it is difficult to describe the long-term effects on humans due to the inherent time lag and the inability to prove causality.[22] The calculated risk of hazards as a result of exposure to surgical smoke during surgeries like laparoscopic cholecystectomy must be negligible. Yet it should be kept in mind that repeated exposure to a cocktail of these substances increases the possibility of developing adverse effects. Therefore, it is necessary to remove surgical smoke from the OR in order to protect medical personnel.

The pneumoperitoneum creates a different situation to that encountered in open surgery, because the smoke is kept moist, pressurized and concentrated. As magnification of video screen allows, the smoke appears to contain some large particles, visible to the naked eye. As opposed to open surgeries where smoke diffuses slowly in the theatre atmosphere, the fumes produced during laparoscopic surgery are vented out in a concentrated jet by virtue of the positive pressure in the abdominal cavity. Smoke evacuation is feasible and potentially useful way to reduce the surgical smoke. Smoke evacuator is able to capture the smoke generated at the surgical site and remove it to an area away from the surgical team where it can be filtered. This has shown to be one of the most effective in limiting exposure to the noxious odour and potential health hazards of electrosurgical smoke. Inhalation of these by the OR personnel or even the patient is known to be hazardous. Though various surgical smoke purifying devices have emerged and modified down the years, purification of surgical smoke is not routinely practised which may be due to high cost of maintenance or lack of awareness of potential dangers of surgical smoke, and thereby developing an attitude of negligence.

Limitations

The present study was single centre conducted on limited patient population of 60 patients, hence these results cannot be extrapolated to large population. Some laparoscopic surgeries involved very little coagulation and smoke formation due to ease of surgery because of less adhesion and various other factors, hence composition of smoke may differ accordingly. The solvents for chemical analysis used may not be compatible for the chemical components, hence the chemical components might not have been detected. Multi-centric studies with large sample size should be undertaken to substantiate the research findings described in this paper.

CONCLUSION

The present study shows the group A wherein smoke evacuating device containing various filters were used has no bacterial growth as well as no cells seen on cytological evaluation as compared to the group B wherein 21/30 (70.0%) cases had few lymphocytes and 3/30 (10.0%) cases had coagulase-negative staphylococci wherein smoke evacuation device was not used. However, the chemical composition was comparable in both the groups. This data shows the smoke evacuation and filtration device, filtrates and clears the smoke of cells and bacteria as it passes through it.

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