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Is laparoscopic surgery risk for surgical teams during the coronavirus disease pandemic? An *in vitro* study with a laser and high-speed camera

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Abstract. – OBJECTIVE: Laparoscopic surgery has been suggested to pose a risk of infection to the surgical team due to aerosol and gas leakage during the coronavirus (COVID-19) pandemic. However, there have been no studies on the risk of gas and aerosol leakage in laparoscopic surgery. We aimed to answer the question "Is the aerosol and gas leakage in laparoscopy is hazardous in terms of coronavirus infection?" with this study.

MATERIALS AND METHODS: In this study, gas and aerosol leaks were documented by simulating the entry and exit maneuvers from a trocar during laparoscopic surgery using a high-speed camera, fog, and laser in a model representing the abdomen.

RESULTS: The maximum gas and aerosol leakage were found during wet gauze extraction from the 10 mm trocar, and its velocity reached 7.5 m/s. The fastest aerosol leakage rate was observed when a 5 mm grasper was extracted from the 5 mm trocar. The results of the subsequent trials were consistent with these values.

CONCLUSIONS: Higher leakage speeds were observed than the velocity of the exhaled air in a resting person. The surgical crew members, who work very close to the trocars and each other, are at serious risk of infection with COVID-19 which can spread as fast as exhalation speed through trocars. Since there is an evident risk of infection for the surgical crew from laparoscopic surgery of a patient whose intraabdominal fluids are infected with COVID-19, patients must be evaluated elaborately for COVID-19 preoperatively and infected patients should undergo surgery conventionally.

Key Words:
Laparoscopic surgery, Pandemic, COVID-19, SARS-CoV-2, Experimental study, *In vitro* study.

Introduction

In the coronavirus pandemic, the commonly performed laparoscopic surgery has been speculated to pose a risk of infection to the surgical team[1]. In a UK (United Kingdom) study[2], 56% (133/237) patients having an acute appendicitis operation had an open procedure. This is at significant odds with UK practice prior to the pandemic, where only a small number of patients had open procedures (0.4%). This is likely due to guidance issues that suggested laparoscopic surgery should be avoided due to concerns about aerosol-generating procedures[2]. Carbon dioxide (CO_2) gas with a pressure of 14 mmHg is used to enlarge the surgical site. Considering that a minimum of 2 m of social distancing is advised during this pandemic, the surgical crew members, who work very close to the trocars and each other, are at serious risk of infection with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which can spread as fast as exhalation airspeed through trocars. When laparoscopic instruments enter and exit the abdomen via trocars, high-speed gas leakage can occur from the edges of the sealing ring of the trocars[3]. The gas evacuated from the discharge tab can be rendered harmless by draining it into the hospital vacuum system or underwater drainage system using a hose attached to the faucet[4]. However, a system that can prevent high-velocity gas leakages during the entrance and exit of surgical instruments via trocars is not available.

Moreover, accumulated smoke due to cauterization is sometimes evacuated via the stopcock valve to clear the visual field. During this step, high-speed gas leakage occurs again from the abdomen toward the operational theater. Along with high-speed leakage, blood, peritoneal fluid, and saline used for irrigation can spread to the environment in aerosol form. However, the speed and range of this spread and the possibility of a hazard threat to the surgical team remain unknown.

In the past, blood-borne viruses, such as the

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hepatitis B virus, HIV, and HPV have been found in surgical smoke during laparoscopy via aerosolization[5]. However, the only evidence of viral transmission to medical staff documented in the literature was post-laser ablation of HPV-positive vaginal warts. On the other hand, laparoscopy is thought to be safer than open surgery since it involves less contact with infectious blood. However, because of the differing transmission routes of infection, the conclusion cannot be extended to SARS-CoV-2. In addition, the viruses that have been examined so far are not respiratory viruses. As a result, with SARS-CoV-2, the danger of aerosol exposure must also be considered. If the virus is present in these particles (with a diameter of 5 m), it can be inhaled and induce infection[6].

To the best of our knowledge, there have been no quantitative studies on these topics. We designed a study to document leakage during laparoscopic surgery to understand these issues better.

Materials and Methods

We used a size 8.5 glove to simulate the abdomen undergoing laparoscopic surgery. The glove was tied from the elbow level to ensure no leakage. Thereafter, we cut the first, second, and fifth fingertips of the glove and placed two 10 mm and one 5 mm trocars through the fingers. The fingers were tied with a 2/0 silk suture to prevent leakage. We stabilized the glove by placing the elbow and the two uncut fingers on the table. The glove was insufflated to a pressure of 14 mmHg with smoke made from SAFEX brand fog solution by SAFEX F2010 plus brand fog generator. During the shooting, we used a DANTEC Dynamics brand particle image velocimetry (PIV) system to create a green laser (2 × 30 mJ [double cavity] and 1000 Hz) and laser sheet optics to illuminate the smoke and aerosol particles. Light scattered off the aerosol particles within the two-dimensional laser plane was collected using a high-speed scientific complementary metal-oxide-semiconductor (sCMOS) camera (Phantom brand) located perpendicular to the laser sheet (Figure 1). Images were recorded at 528 frames per second (fps). Image recording and data analysis were performed for a 5 mm laparoscopic dissector and grasper through a 5 mm trocar, 5 mm dissector, grasper, 10 mm endoclip adaptor, and wet gauze through a 10 mm trocar.

Velocity vectors were calculated by applying the cross-correlation algorithm to images. The gas discharge spread angles and spread ranges were estimated based on the velocity vectors.

Results

Based on the high-speed camera footage, the fastest gas leakage occurred when the 5 mm grasper came in and out through the 5 mm trocar. We also calculated the propagation velocity of gas leakage parallel to the long axis of the 5 mm trocar (2.3 m/s) (Figure 2). The aerosol spread was not observed in these tests. On the other hand, aerosol spread occurred when wet gauze was retrieved from the 10 mm trocar. We calculated its velocity as 7.5 m/s (Figure 3). The leakage speeds of all surgical instruments entering and exiting through the 5 and 10 mm trocars are given in Table I.

The main and fastest stream direction of leaked gases was forward from the trocar entrance to the long axis of the trocar. Some air spread with rapid turbulence was observed shortly after exiting the trocar (Figure 4).

Discussion

Although laparoscopic surgery provides many benefits for patients postoperatively[7,8], it may be harmful to the surgical crew in the pandemic context. Regardless of the COVID-19 test results of the patients, the surgical crew was at risk of being infected because false-negative results are common[9]. The risk of infection of the surgical crew will increase if the virus is present in the abdominal organs and fluids. The virus is present

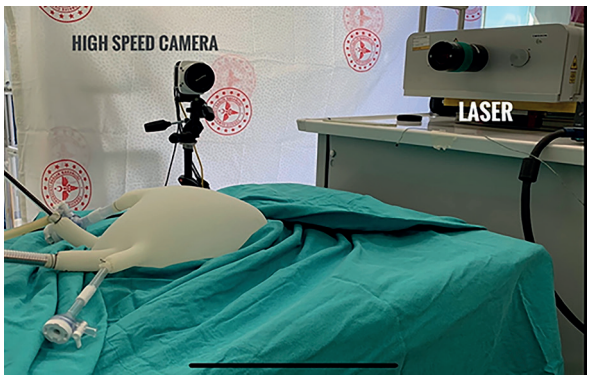

Figure 1. Experimental set-up.

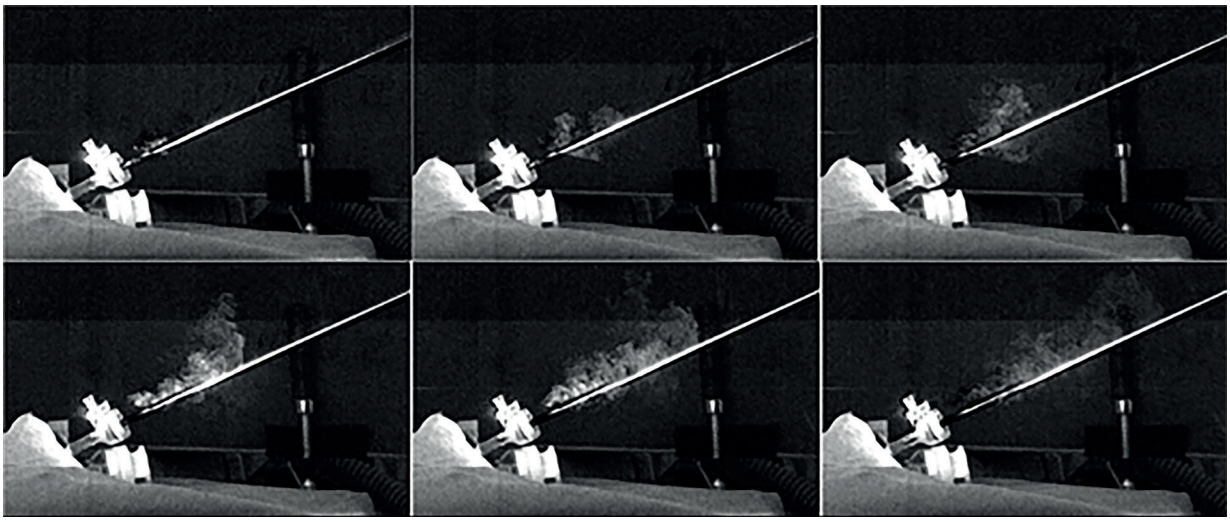

Figure 2. Gas leakage during 5 mm grasper exits through 5 mm trocar.

in the abdominal cavity in COVID-19 infected patients[10]. Although new researches show that swab and RNA replication samples were taken from abdominal fluids with COVID-19 infected patients can be resulted negative, two recent[11,12] 2021 publications also recommend strict precautions about minimally invasive surgery during the pandemic. This situation may cause additional risks in laparoscopic interventions because the possibility of aerosol formation during laparoscopic surgery is higher.

In a systematic review, written by Boghdady et al[1], they recommend if possible and safe, conservative management is the primary alternative during the pandemic, but if laparoscopy is strongly indicated can be used with precautions and

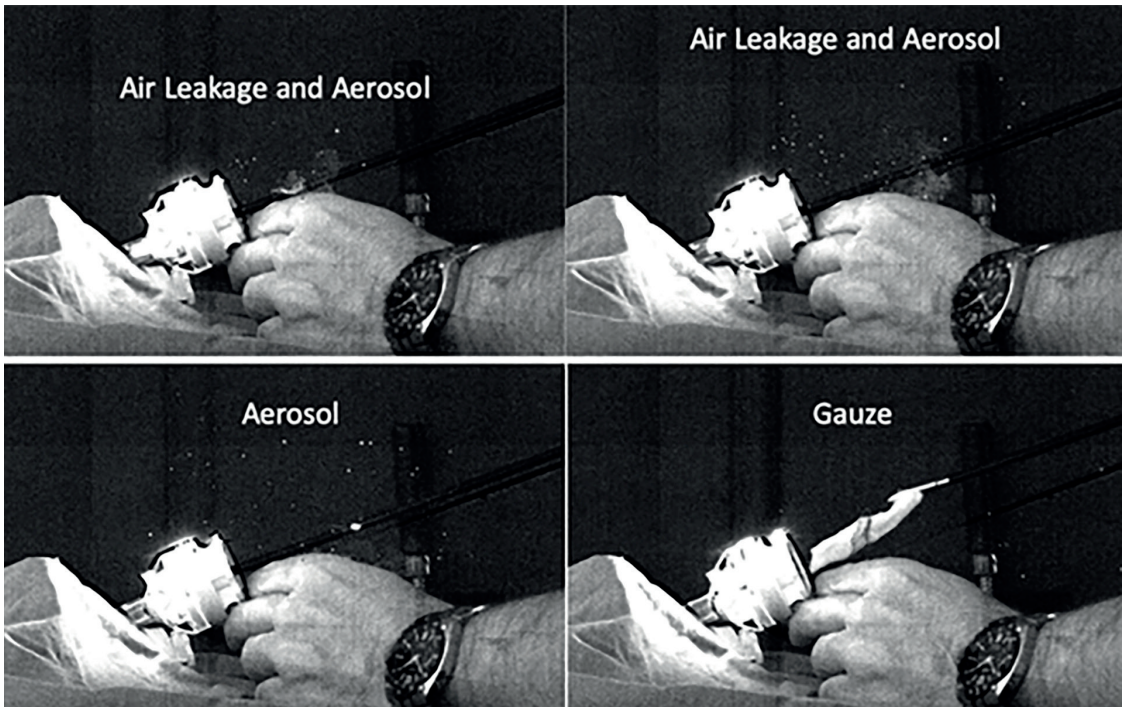

Figure 3. Gas and aerosol leakage during wet gauze exits through 10 mm trocar.

Table I. Propagation velocity of surgical instruments exit through 5- and 10-mm trocars.

Surgical Instruments	5 mm trocar		10 mm trocarl			
	5 mm Dissector	5 mm Grasper	5 mm Dissector	5 mm Grasper	10 mm Clip	Wet Gauze
Propagation velocity (m/s)	1.8	2.3	1.3	1.5	0.8	7.5

precautions should be respected to protect health care workers from possible aerosolized virus contamination.

In laparoscopic surgery, especially with wet gauze, air and aerosol leaks propagate into the surgical theater, reaching a speed of 7.5 m/s.

The highest leakage occurred during the entry and exit of surgical equipment with a 5 mm grasper and 5 mm trocar. Prior to the experiments, we hypothesized that most leakages occurred when a 5 mm grasper passed through a 10 mm trocar. However, we re-evaluated the subject and applied the principles of fluid dynamics. In conclusion, the gas speed was higher when it passed through a path with a smaller diameter, given constant mass and pressure[13]. Higher leakage speeds result in more significant aerosol and viral particle spread.

Most leakages occurred with the graspers due to their anatomy. The jaws of the dissector fully fit each other when in the closed position without any space between them. On the other hand, the grasper is utilized for clutching, not slipping, so it is like a toothed jaw with some gaps between the jaws. Due to these anatomical differences, when the dissector passes through the trocars, there is less leakage. However, when the grasper enters or exits, there is more leakage due to the gaps between the jaws that sealing rings cannot prevent.

Leakage currents mainly occur forward and parallel to the trocar axis, and turbulent flows occur just in front of the trocar outlet. This phenomenon is explained by flow dynamics. Turbulence is caused when high-pressure high-speed gas passes through a constriction towards an expanded area[13]. For this reason, the spread can be omnidirectional, but it mainly proceeds in the forward direction.

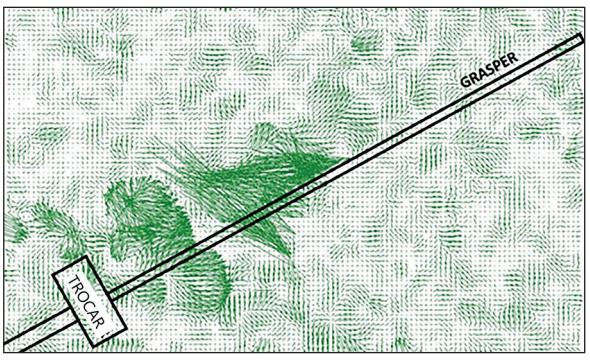

Figure 4. Vectorial view of gas leakage.

We did not observe aerosol formation or leakage during the insertion of dry gauze into the setup, but there was gas leakage. In the wet gauze trials, there was an excessive amount of aerosol formation and leakage, and the calculated velocity of the aerosols was 7.5 m/s. In the situation of a contaminated abdomen, this step would pose the most significant risk of infection.

Studies showed that exhaled air velocity varied from 2.2 m/s to 9.9 m/s in normal healthy persons[14]. The surgical crew members, who work close to trocars, are at risk of being infected by a virus that can spread as fast as exhalation airspeed through trocars. The social distancing of at least 2 meters apart should be strictly observed during this pandemic[15].

The most significant limitation of this research is that it is an *in vitro* study. Another limitation is infectivity and virulence of COVID-19 in abdominal fluids cannot be shown with this study.

Conclusions

The surgical crew members performing laparoscopic surgery in a patient whose intra-abdominal fluids are infected with SARS-CoV-2 may be at risk of infection. Therefore, patients must be carefully evaluated for SARS-CoV-2 infection preoperatively, and in our opinion, the infected patients should undergo conventional surgery or should wait for the ending of the contagious period of the disease. Laparoscopic surgical instruments should be modified to minimize air leakage while passing through the trocar valves. Laparoscopic suction devices are preferred over gauze for surgical site cleansing. Surgical materials, such as wet gauzes should be removed from the abdomen after desulfation because they can also cause aerosol propagation.

Precautions that we recommend about minimally invasive surgery during the pandemic are listed below:

– All patients who plan to undergo an operation should be tested for SARS-CoV-2;
– All surgical crew should abide by the rules about personnel protective equipment regulations according to the guidelines;
– Laparoscopic surgical instruments should be modified to minimize air leakage;
– Gauze usage during laparoscopic surgery should be kept at a minimum level;
– Suction devices should be preferred to gauzes;
– A closed aspiration system should be used for the desulfation of the gases.

Further studies should be conducted on patients infected with SARS-CoV-2 to determine the abdominal viral load and evaluate our study's results to elucidate the contamination risk explicitly.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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Authors' Contribution

All of the authors have contributed equally to both the experimental part and writing process.

Institution Review Board

This article does not contain any studies with human participants or animals performed by any of the authors, so no institutional review board approval is required.

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