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Transmission Possibility of COVID-19 via Surgical Smoke Generated by the Use of Laparoscopic Approaches: A Subject of Debate During the Pandemic

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Abstract

Background: The smoke created by energy-based devices during surgery may have the potential to transmit viral components to operating room staff. The COVID-19 pandemic has changed staff safety regulations. However, it is not clearly understood whether it can be transmitted via surgical smoke. Laparoscopic approaches have become the standard surgical procedure in many cases, but some of previous investigations have advised to pretermit these approaches due to high risk of COVID-19 transmission.
Materials and Methods: We reviewed the English literature that were indexed in the PubMed, Google Scholar, and Scopus databases by using key words including Virus, viral transmission, surgical smoke, surgical plum, laparoscopy, and COVID-19 both solely and in two-word combination. A total of 87 articles were found relevant, and after reviewing the abstract, 33 articles were shortlisted and summarized.
Results: Previous studies have focused on different surgical instruments that generate smoke, methods to collect and analyze the smoke and to understand the implications of its exposure after an analysis. A total of 9 out of 11 studies on the potential transmission of human papilloma virus through surgical smoke found evidence in favor of transmission. There were studies on the possible transmission of HIV, hepatitis B virus, and Sabin poliomyelitis vaccine virus 2.
Conclusion: We do not believe that laparoscopic procedures may have extra risk for COVID-19 transmission compared with the open procedures, but it is always advised that the operating room staff adhere to the safety instructions during the COVID-19 pandemic.

Keywords: COVID-19 pandemic, surgical smoke, laparoscopic surgery, viral transmission

Introduction

The COVID-19 pandemic has become a main concern of medical facilities all around the world, but as Marie Curie once said, ''Nothing in life is to be feared, it is only to be understood.'' Thus, there should be a systematic approach to dealing with every aspect of this pandemic. As surgeons, we should contribute to, first, understanding the potential harms of performing surgery on the COVID-19 patients for the operation room staff during this period and, second, making every effort to minimize them. In this regard, reviewing previous literature on viral disease transmission to the caregivers during surgery is crucial.

Current guidelines about COVID-19 transmission during open and laparoscopic interventions are inconclusive to some extent, but the main point is to take every precaution recommended and to not scuttle through surgery whenever needed.

The presence of infectious microorganisms in surgical smoke has been investigated in previous studies. These studies had diverse methodologies, subject characteristics, and were different in conclusion in terms of confirming viral contamination among the operating room staff.

Methods

We reviewed the literature written in English by using key words including virus, viral transmission, surgical smoke, surgical plum, laparoscopy, and COVID-19 both solely and

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in two-word combination. The articles indexed in the PubMed, Google Scholar and Scopus databases were searched. A total of 87 articles were found relevant, and after reviewing the abstract, 33 articles that were related to the study topic were completely reviewed and summarized by the 2 authors of the study.

Results

Most of the primary studies on evaluating the role of surgical smoke in transmission of infection were dedicated to human papilloma virus (HPV). These articles stated diverse results ranging from HPV not found in the plume to demonstrating that the HPV contamination was possible for the operation room staff.

The first insight into the occupational hazard of contamination with viral content via surgical vapor was published in 1988 when Garden et al.[1] established the presence of HPV DNA both in intra-lesion biopsy specimens and in vapor specimens collected in a bubble chamber after CO_2 laser treatment of plantar verrucae. Southern blot analysis revealed the presence of intact viral DNA in both specimens. These authors subsequently proved the infectivity of the laser plume of bovine papillomavirus by inducing cutaneous fibropapillomas by inoculation into the skin of calves.[2] The bovine papillomavirus DNAs were present in all of the laser plume specimens and, surprisingly, tumors were developed in all of the three healthy animals at sites of inoculation. Andre et al.[3] biopsied genital condylomata lesions of 3 patients and analyzed generated plums from laser ablation of these patients for the existence of virus DNA. They found DNA of HPV-6 in biopsy and plums of 2 cases, but the third case was found negative for HPV DNA in both tissue and plume specimens.

Ferenczy et al.[4] utilized the filter hybridization technique to confirm the presence of HPV DNA in patients with previously proven condyloma acuminata who underwent CO_2 laser treatment. HPV DNA was detected in smoke samples (65/110) (60%), but swabs obtained from the ears, eyelids, and nasopharynx of the surgeons, who wore standard surgical masks, were clear.

Sawchuk et al.[5] compared the presence of HPV DNA in the vapor obtained from CO_2 laser electrocoagulation for the treatment of human plantar warts via bioassay. Five out of eight vapor specimens of laser and four out of seven specimens of electrocoagulation-derived vapor were found positive for HPV DNA. Interestingly, the DNA load was greater in the laser smoke. In an *in vitro* examination, laser and electrocoagulation plum-derived materials of bovine warts were proven to contain HPV viruses with more capability of infection due to viral load in the laser specimen.

There is a report of developing laryngeal papillomatosis in a surgeon after nd:YAG laser treatment of anogenital condylomata due to HPV by Hallmo and Naess.[6] Researchers used an *in situ* DNA hybridization method and showed that similar HPV types 6 and 11 were present both in the surgeon and in the patient. Abramson et al.[3] tested 7 patients with laryngeal papilloma and analyzed plums of laser therapy of these cases for the presence of HPV DNA. They concluded that the related plums were positive only if the suction tube tip had been in direct contact with the lesion.

Sood et al.[7] conducted a study on 49 patients with proven cervical intraepithelial neoplasia who were undergoing loop electrosurgical excision procedures (LEEP). In this study, 39 out of 49 of surgical plume samples were found positive for HPV, mostly with HPV subtypes 16 and 18. This study confirmed that the plume of smoke generated by LEEP had HPV DNA. Further, Ilmarinen et al.[8] retrieved samples from the urethral warts ($n=5$), laryngeal papilloma ($n=5$), and the surgical gloves ($n=20$) used by the staff, which were all found positive for HPV. The results showed that all samples obtained from the surgical gloves were positive for HPV after performing urethral wart procedures, and 1 out of the 5 surgeons and 3 out of the 5 nurses were tested HPV positive after the treatment of laryngeal papilloma. Interestingly, all HPV genotypes were the same as the HPV of corresponding patient tissue specimens.

In a self-reported survey, Gloster and Roenigk[9] compared the incidence of HPV warts between surgeons who utilized CO_2 laser with two large populations as control. There was no significant difference ($P=.569$) in the general incidence of warts between surgeons (5.4%) and patients with warts in the control population from 1988 to 1992 (4.9%). On the other hand, the incidence of site-specific warts in the plantar area ($P=.004$), nasopharyngeal area ($P=.001$), and genital and perianal area ($P=.004$) was different between the study group and patients with warts treated at the Mayo Clinic from 1988 to 1992, which demonstrated a higher risk in nasopharyngeal warts for surgeons and a lower risk in the other forms for this group.

Weyandt et al.[10] collected Petri dishes placed at distances of 1 and 2 m from the treatment field and obtained swabs from the glasses and nasolabial folds of the operating physician. They assessed the generation of aerosols containing HPV DNA during the treatment of genital warts with multilayer argon plasma coagulation and with CO_2 laser ablation. They did not find HPV types of genital warts in any of the Petri dishes and swabs. They concluded that even though HPV DNA might be transmitted via surgical plume, the risk of developing clinically active infection in exposed personnel is low.[11]

Neumann et al. tested the resected cones of LEEPs and the surgical plume resulting from LEEPs of high-grade squamous intraepithelial lesions of the cervix and compared the HPV subtypes. It was found that the LEEP plumes contained high-risk HPV similar to HPV subtypes found in the resected cones.[12]

Terrifying results have been found in gynecologists who had long-term exposure to surgical smoke originating from different treatment methodologies of HPV. Although the possibility of disease transmission has been proposed, actual documented cases of pathogen transmission with a proven causal relation are rare. So far, 4 cases have been proven. A 44-year-old gynecological laser surgeon developed laryngeal papillomatosis and was infected with HPV types 6 and 11 after treating patients with anogenital condylomata known to have the same viral types.[6] A 28-year-old gynecological operating room nurse who was repeatedly involved in electrosurgical and laser treatment of anogenital condylomas developed a recurrent and histologically proven laryngeal papillomatosis. A 53-year-old male gynecologist who had performed laser ablations and LEEPs on >3000 dysplastic cervical and vulvar lesions over 20 years of practice

presented with HPV 16 positive tonsillar squamous cell carcinoma. A 62-year-old male gynecologist with a 30-year history of laser ablation and LEEP subsequently developed an HPV 16 positive base of tongue cancer.[13] All of these 4 cases had no respiratory diseases and were otherwise healthy or having very few other risk factors for the development of oropharyngeal cancer or HPV infection. The expert opinion on the probability of correlation between the occupational exposure and the subsequent disease was positive in all cases.[14] Considering all this, protective measures should be instituted for all health care personnel, particularly for those who are in close contact with surgical plums.[15] Table 1 summarizes studies conducted on evaluating the transmission of HPV via surgical smoke.

In addition to the HPV, the presence of other viruses in surgical smoke has also been investigated. Baggish et al.[16] applied CO_2 laser in HIV-infected tissue culture and showed the strong presence of HIV proviral DNA in the collection tubing via polymerase chain reaction. However, the culture of vaporous debris from the tubing yielded p24 antigen only for up to 14 days, suggesting that viral viability was compromised after 2 weeks. On the other hand, Johnson and Robinson[17] demonstrated viable HIV in aerosols generated by oscillating bone saws but not in plumes of electro-cautery, which may be indicative of the role of the smoke temperature created in each method. Although they claimed that HIV remained viable for 14 days in surgical smoke, its infectivity potential to humans is uncertain.[18]

Further, Taravella et al.[19] investigated an excimer laser plum for an infectious polio virus and found a viable virus in infected oral fibroblasts. On the other hand, Kwak et al.[20] collected surgical smoke from 11 patients undergoing laparoscopic or robotic surgery and used an amplification technique for hepatitis B virus (HBV) DNA sequencing and found the presence of HBV in 10 out of the 11 samples of surgical smoke. Table 2 summarizes studies conducted on evaluating the transmission of other viral infections via surgical smoke.

Discussion

The concern about the presence of live elements in the surgical smoke and the subsequent transmission risk to the surgical staff was expressed in several articles published in the 1980s.[21] These live particles are viruses, bacteria, fungus, and viable body cells (greater concern is about viable tumor cells).[22] The COVID-19 pandemic has revived these concerns about the possibility of the existence and transmission of the COVID-19 virus to surgical staff during using coagulation devices. Up to now, there has been no report of finding the COVID-19 virus in the surgical smoke, and if it has been found, its infectivity potential is unknown. Most of the previous studies were focused on HPV or bovine papilloma virus and a very small number of them were focused on viruses such as HIV, HBV, and polio. The overall conclusion of these studies is the possibility of the presence of a potential but not clearly measured virus transmission hazard of smoke inhalation during the surgery of the patients with related diseases, a hypothesis that may be considered for COVID-19.

Also, previous studies have found virus DNA in surgical smokes, but it should be noted that this finding does not establish the infectivity potential of the virus. According to some experts, the whole intact virion has the potential for spreading infection, not just DNA, and in some instances, the whole virion may be weakened or destroyed by sealing devices, rendering them incapable of spreading infection.[17,23] There are no specific data about the COVID-19 virus and this hypothesis may or may not be applicable for this new virus.

There are various subtypes of sealing and cutting devices that produce plums and smoke with different specifications. Ultrasonic devices produce aerosols with a greater capacity of carrying viable particles, whereas bipolar and monopolar cautery and laser burn the tissue and produce smoke with less capacity of holding viable elements due to the thermal effect.[24,25]

There are different and sometimes opposite ideas about the potential of infectivity of plums generated in laparoscopic procedures during the COVID-19 pandemic. The concerns related to laparoscopic procedure hazards have encouraged some organizations to publish guidelines to define limitations and precautions to be practiced while performing these types of surgeries, whereas other organizations believe that laparoscopy is the preferred approach for patients with COVID-19.[26–28] The concerns about the higher infectivity potential of minimally invasive procedures are as follows:

1. High-pressure CO_2 environment produces more aerosols.
2. Aerosols are released in the operating room through port site leak points and trocars with pressure.
3. Some laparoscopic devices such as harmonic scalpel produce larger aerosols and more infectious particles.

Other concerns such as the release of viral particles during tissue ligation or cutting procedures, especially when virus particles are present in the alimentary canal and blood of the subjects being operated on,[29–31] are common between open and laparoscopic surgeries.

On the other hand, it should be noted that the use of sealing devices is common in both laparoscopic and open procedures, but the management of surgical smokes is easier and more practical during laparoscopic approaches than open surgery. During laparoscopic procedures, we can place the suction tip near the surgery field, evacuate smoke under a controlled situation, and use a smoke filtering system to trap infectious particles, none of which is feasible in the open procedures.

Based on the mentioned information and in the lack of concrete evidence, we do not believe that laparoscopic procedures may have extra risk compared with the open procedures, but it is always preferred to adhere to the safety instructions to be followed during these surgeries.

(1) Laparoscopic surgeries on the known patients with COVID-19 should be limited to the emergency situations (as open procedures).
(2) All of the operating room staff should have personal protection equipment in compliance with the governmental and hospital guidelines.
(3) While using coagulation devices, a suction tube should be placed near the surgical field and attached to a standard filtering system that is capable of trapping viruses.

TABLE 1. SUMMARY OF STUDIES ABOUT HUMAN PAPILLOMA VIRUS INCLUDED IN THE REVIEW

First author	*Year*	*Virus*	*Smoke sample collection site*	*Instrument used*	*Subject*	*Result*
Garden et al.[21]	1988	BPV	Bubble chamber in line with vacuum system	CO_2 laser (power density: 380 W/cm^2)	Seven patients with plantar or mosaic verrucae	Viral DNA was detected in two out of seven vapor collections
Andre et al.[3]	1990	HPV-6	Bubble chamber in line with vacuum system	CO_2 laser (power density: 3200 W/cm^2)	Three patients with large condylomata	HPV-6 DNA was detected in the two specimens
Ferenczy et al.[4]	1990	HPV of different types	Different methods	CO_2 laser	Dacron swabs from 110 patients with genital infection	HPV DNA found in 65 swabs
					Five prefilter canisters	HPV DNA found in one canister
					Four fume vacuum tubes	All was negative
					Nasopharynx, eyelids, and ears of the laser surgeon	All was negative
Sawchuk et al.[5]	1990	HPV 1/2	Vacuum device maintained 2 cm above the wart surface	CO_2 laser (power density: 1270 W/cm^2)	Eight people with plantar warts. Half of the lesion treated with laser and half with electrocoagulation	HPV DNA was detected in five of eight laser-derived vapor
				Electrocoagulation		HPV DNA was detected in four of seven electrocoagulation-derived vapor
Hallmo and Naess[6]	1991	HPV	Built-in suction of the laser device	Nd:YAG laser (maximum power of 100 W)	A 44 year-old laser surgeon with absolute negative risk factor for laryngeal papilloma other than treating patients with condyloma cuminata	DNA from HPV types 6 and 11 was identified
Sood et al.[7]	1994	HPV	Stackhouse smoke-evacuation system	LEEP	49 women with either histologic or cytologic evidence of CIN II or CIN III	18 HPV-positive filters came from the 39 patients with HPV-positive tissue samples. DNA sequencing was performed on 8 samples, and in all cases the HPV subtype was identical in the tissue and in the filter.
Calero and Brusis[14]	2003	HPV	Built-in suction of the laser device	Electrosurgical and laser surgical excisions of anogenital condylomas	A 28 year-old gynecological operating room nurse	Recurrent and histologically proven laryngeal papillomatosis

(*continued*)

Table 1. (Continued)

First author	Year	Virus	Smoke sample collection site	Instrument used	Subject	Result
Weyandt et al.[10]	2011	HPV	9-cm diameter petri dishes were placed at 1 and 2 m distance to the treatment field. Also, swabs were obtained from the inside of the tube of the suction hand-piece and from the inside of the suction used during laser treatment. Additional swabs were obtained from the glasses and nasolabial folds of the staff	CO_2 laser Multilayer APC	Lesion of patients with genital warts	All plates were HPV DNA negative. HPV DNA type 6 was found in 3 of the 10 plume strainers. HPV DNA was not found in any of the plates at 1 m distance, but at 2 m distance from the treatment field, 2 of 18 plates were HPV DNA positive. All swabs obtained from glasses were negative One swab pair obtained from nasolabial folds was positive for HPV type 38, and another swab pair from nasolabial folds was positive for beta-HPV DNA unclassified type.
Ilmarinen et al.[8]	2012	HPV	1 cm^2 piece of surgical masks and 1 cm^2 piece of the glove covering the top of the right index finger	CO_2 laser	Five patients with recurrent respiratory papillomatosis. Surgical staff also were sampled from oral mucosa, oral mucosa, and laser plume masks	All oral mucosa specimens and surgical mask samples obtained from the employees tested were negative for HPV. The surgeons' gloves tested HPV positive in 1 of the 5 cases, and those of the surgical nurse in 3 of the 5 cases were positive.
					Five male patients with urethral wart. Surgical staff also were sampled from oral mucosa, oral mucosa, and laser plume masks	All samples obtained from the surgical gloves of the staff tested positive for HPV
Rioux et al.[13]	2013	HPV 16	Procedures were performed in an environment without proper ventilation or mask	Laser ablation and LEEP for more than 3000 dysplastic cervical and vulvar lesions over 20 years	A 53 year-old male gynecologist with no identifiable risk factors for oropharyngeal cancer or HPV with the exception of occupational exposure to HPV-positive laser plumes	Right tonsil showed invasive squamous cell carcinoma of moderate to poor differentiation
		HPV 16	Poor ventilation environment	CO2 laser ablation and LEEP for 15 years each	A 62 year-old gynecologist with no risk factor except for occupational exposure	Base of the tongue revealed a squamous cell carcinoma
Neumann et al.[12]	2018	HPV	Smoke evacuation system without direct contact with the cervix uteri	LEEP	Samples from 24 patients with cytological evidence for HSIL	Surgical plume samples were positive for one sample of HPV 16, one HPV 39, and two HPV 53

APC, argon plasma coagulation; BPV, bovine papilloma virus; CIN, cervical intraepithelial neoplasia; HPV, human papilloma virus; HSIL, high grade squamous intra-epithelial lesion; LEEP, loop electrosurgical excision procedure.

Table 2. Summary of Studies About Nonhuman Papilloma Virus Included in the Review

First author	*Year*	*virus*	*Smoke sample collection site*	*Instrument used*	*Subject*	*Result*
Baggish et al.[16]	1991	HIV	Smoke evacuator hand piece ~1 cm above and beyond the laser beam exit port	CO_2 laser (power density: 500 W/cm^2)	Ten milliliters of HIV-infected cells (10^7 cell/mL) containing one copy of HIV/cell were decanted into a sterile petri dish	PCR analysis of debris from the collecting tube was positive for proviral HIV DNA, but no sustained infection of HIV cultured cells was observed
Johnson and Robinson[17]	1991	HIV-1	Operating room suction canister	Electrocautery in the coagulation or the cutting mode	Mixture of human banked O packed red blood cell, RPMI 40, and 1 cc of culture medium containing 10^5 tissue culture infectious doses of HIV-1	Negative culture result
				High-speed bone cutting router		5 out of 9 culture results were positive
				Oscillating bone saw		1 out of 4 culture results was positive
				Wound irrigation syringe jet		Negative culture result
Taravella et al.[19]	1999	Sabin poliomyelitis vaccine virus 2	Stackhouse laser smoke evacuation unit was held ~1 cm from the surface of the plates containing live virus	VISX Star Excimer Laser System set on a phototherapeutic keratectomy protocol	Human embryonic lung fibroblasts inoculated with stock Sabin poliomyelitis vaccine virus 2	Positive for virus
Kwak et al.[20]	2016	HBV	Swirling Aerosol Collector in connection with a vacuum pump	Routine laparoscopic or robotic surgery electrocoagulation and electrocautery device	11 HBs Ag-positive patients who underwent laparoscopic or robotic surgery for colorectal, gastric, and hepatic resections	HBV was detected in 10 of the 11 samples of surgical smoke

HBV, hepatitis B virus; HIC, human immunodeficiency virus.

(4) The operating room should be equipped with a negative pressure ventilation system.
(5) Use of sealing devices should be limited, and, if possible, ultrasonic devices should be replaced with monopolar or bipolar electrocautery.
(6) Gas leakage from trocars should be minimized by using appropriate trocars and small incisions equal to the trocar diameter.
(7) Pneumoperitoneum pressure and flow should be kept at minimum needed to limit gas and aerosol distribution.[32]
(8) Coagulation instrument power should be kept as low as possible to minimize aerosol production.[32]
(9) In the known patients with COVID-19, Trendelenburg positioning during laparoscopy should be limited to improving patient ventilation.[32]

Data Availability Statement

The data will be available on request to the corresponding author.

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