Aerosolization risk during endoscopic transnasal surgery: a prospective qualitative and quantitative microscopic analysis of particles spreading in the operating room

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OBJECTIVE  The coronavirus disease 2019 (COVID-19) pandemic represents the greatest public health emergency of this century. The primary mode of viral transmission is droplet transmission through direct contact with large droplets generated during breathing, talking, coughing, and sneezing. However, the virus can also demonstrate airborne transmission through smaller droplets (< 5 μm in diameter) generated during various medical procedures, collectively termed aerosol-generating procedures. The aim of this study was to analyze droplet contamination of healthcare workers and splatter patterns in the operating theater that resulted from endoscopic transnasal procedures in noninfected patients.

METHODS  A prospective nonrandomized microscopic evaluation of contaminants generated during 10 endoscopic transnasal procedures performed from May 14 to June 11, 2020, in the same operating theater was carried out. A dilution of monosodium fluorescein, repeatedly instilled through nasal irrigation, was used as a marker of contaminants generated during surgical procedures. Contaminants were collected on detectors worn by healthcare workers and placed in standard points in the operating theater. Analysis of number, dimensions, and characteristics of contaminants was carried out with fluorescence microscopy.

RESULTS  A total of 70 samples collected from 10 surgical procedures were analyzed. Liquid droplets and solid-tissue fragments were identified as contaminants on all detectors analyzed. All healthcare workers appeared to have been exposed to a significant number of contaminants. A significant degree of contamination was observed in every site of the operating room. The mean (range) diameter of liquid droplets was 4.1 (1.0–26.6) μm and that of solid fragments was 23.6 (3.5–263.3) μm.

CONCLUSIONS  Endoscopic endonasal surgery is associated with the generation of large amounts of contaminants, some of which measure less than 5 μm. All healthcare workers in the surgical room are exposed to a significant and similar risk of contamination; therefore, adequate personal protective equipment should be employed when performing endoscopic endonasal surgical procedures.

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to a patient’s airway and use instrumentation to manipulate respiratory mucosal surfaces, where the patient’s upper respiratory secretions are present with a high viral load. In particular, clinical examination of and diagnostic or surgical invasive procedures for the upper aerodigestive tract expose healthcare workers to direct transmission of SARS-CoV-2 via inhalation or ocular instillation of contaminated droplets, as well as to indirect transmission via contact with contaminated hands or surfaces.

The primary mode of viral transmission is droplet transmission, which refers to the spread of infection through direct contact with large droplets generated during breathing, talking, coughing, and sneezing. These particles travel for short distances and remain airborne briefly before settling due to gravity.

However, increasing scientific evidence confirms that the virus can also have airborne transmission. This refers to the potential risk of viral spread through smaller droplets generated during various medical procedures, collectively termed aerosol-generating procedures (AGPs). AGPs generate droplets less than 5 μm in diameter, called droplet nuclei, that are too small to settle due to gravity and thus remain floating in the air and carried around by air currents. In this way, various pathogens such as SARS-CoV-2 can travel for long distances and remain in the air for hours, with only a slight reduction in infectivity. Droplets < 5 μm are not effectively filtered by surgical masks and can be inhaled directly into pulmonary alveoli.

Endoscopic evaluation of the upper Airways is a potential irritative stimulation capable of producing aerosols as a result of sneezing and coughing. During endoscopic endonasal surgery, the risk of aerosol generation and particle size depend on the instrumentation used. These surgical procedures may be classified as thermal and cold procedures. In particular, thermal procedures, such as those that use electrocautery, laser, and ultrasonic scalpel, coagulate and vaporize tissues and thereby generate very small droplets. Nonpowered cold endonasal procedures show a lower risk of aerosol production. Conversely, powered instruments, such as endonasal shavers and especially drills, create tissue disruption and high airflow, leading to significant contamination of healthcare workers and the environment.

For this reason, numerous authors have suggested minimizing the use of thermal and powered instruments for endoscopic sinus and skull base surgery during the COVID-19 pandemic, as well as to postpone surgical procedures whenever possible. However, current knowledge about this topic is still limited. The majority of studies in the scientific literature are based on cadaver-simulated series in the laboratory, and different experimental models are unable to detect the smallest droplets capable of transmitting SARS-CoV-2.

The goal of the present study was to conduct a qualitative and quantitative microscopic analysis of droplet contamination patterns in the operating theater that developed during endoscopic endonasal surgery, with a specific contamination analysis of each healthcare worker involved in the procedures.

Methods
Study Setting

We performed this prospective nonrandomized single-blind study from May 14 to June 11, 2020. Sample collection was always performed in the same operating theater of the Division of Otolaryngology, University Hospital of Varese, Italy. Microscopic analysis was performed at the Department of Pathology, University Hospital of Varese, Italy. Informed consent was obtained from all patients involved in the study, and policies were approved by the local board of ethics.

All procedures were performed with standard settings and endonasal surgical instrumentation. Both cold knife and motorized instruments were used (DrillCut-X II shaver and INTRA drill handpiece powered by high-performance EC micro motor II equipped with diamond burs [Karl Storz]), as well as bipolar forceps (Integra MicroFrance) and a diode laser (Dornier MedTech). All patients included were tested 48 hours before surgery with a nasopharyngeal swab to exclude SARS-CoV-2 infection, according to regional health regulations, and were admitted to the operating theater only if the test result was negative. All surgical procedures were performed in a positive pressure (3–4 Pa) operating room.

Sample Collection

Standard surgical face masks (Mölnlycke Health Care) were used as detectors. Staff members wore an N95 or N99 mask under the standard surgical mask that was used as detector, as well as safety goggles. Face shields were not worn because these could have reduced the exposure of the detectors to environmental contaminants. The surgical masks that were analyzed as detectors were worn by the first surgeon, scrub nurse, anesthesiologist, and circulating nurse. Moreover, additional surgical masks were placed at fixed distances from the patient’s nostrils to serve as environmental detectors, as follows: 1) at the surgical lamp (100 cm); 2) infusion pump (180 cm); and 3) operating room wall opposite to the patient’s head (370 cm) (Fig. 1).

A solution of 1 ml of 20% monosodium fluorescein and 200 ml of saline water, mixed in a ratio of 1:1004, was used as a marker of biological contamination. Bilateral nasal irrigation with 20 ml fluorescein solution was performed at the beginning of every surgical procedure and repeated every 15 minutes until the end of the operation. The amounts of fluorescein solution used as a marker and saline water used for irrigation to clean the surgical field were registered for every operation. The duration of the endoscopic procedure was also registered.

Some precautions were adopted to reduce any contamination unrelated to the surgical procedures under examination. First, the environmental detectors were in place during only the endoscopic endonasal surgical procedure; in the case of combined procedures, the endoscopic and external approaches were performed at different times, without any overlap between procedures. All detectors were placed after tracheal intubation had been performed and were then removed before tracheal extubation; this was done to avoid droplet transmission from the orophar-
ynx and trachea. Moreover, during the endoscopic surgical procedures, the suction systems were wrapped in plastic bags and kept closed to prevent the escape of any gas that may have influenced the results. Finally, the detectors were always manipulated with sterile surgical gloves, and care was taken to avoid touching the area of measurement. After removal from its site at the end of the procedure, each detector was placed in an airtight plastic bag for transportation of biohazard materials.

Sample Analysis

All samples were analyzed immediately on the same day of surgery to avoid false-negative results due to fluorescein deterioration over time. To avoid environmental contamination, the detectors were processed inside a biological safety cabinet (class II A laminar flow hood). A sample of 1.5 cm² was obtained from each detector, and only the superficial layer of the medical face mask was analyzed. Samples were placed on glass slides and covered with coverslip. Microscopic evaluation was performed with an Olympus BX63 microscope equipped with a Semrock SpGr-B fluorescent filter (497-nm excitation wavelength and 538-nm emission wavelength), X-Cite Series 120Q UV illuminator, FLIR Grasshopper3 51S5C camera, and BioView Duet automated imaging and analysis system. All samples were scored by an experienced medical laboratory technician using a 20× oil immersion objective lens. A 1-cm² area of every detector was analyzed, corresponding to 68 fields of view, using a 20× objective lens. At the time of analysis, the technician was blind to all data regarding the surgical procedure (i.e., single-blind analysis).

We initially tested a panel of negative control samples from uncontaminated detectors by using a microscope equipped with a fluorescent filter, and uniform basal fluorescence was detected for 500–600 msec of exposure time. Afterward, a panel of positive control samples was sprayed with various dilutions of fluorescein solution (1:1004, 1:2004, 1:10,004, and 1:100,004). The positive control samples were analyzed with a microscope equipped with a fluorescent filter, but the exposure time was shorter (350–450 msec) in order to detect only the fluorescence of the fluorescein solution and to suppress the detector’s basal fluorescence (Fig. 2). It was always possible to detect fluorescent droplets, even at the lowest dilution of 1:100,004. To avoid false-positive results, the exposure time was set to 350–450 msec. The proper fluorescein dilution to be used during surgery was established at 1:1004; this provided a sufficient fluorescein concentration even if a high volume of saline solution was used to clean the surgical field.

The contaminants identified on the detectors from the operating theater were differentiated on the basis of appearance. Liquid droplets appeared as round or fusiform spots, with uniform high brightness and a defined regular outline. Organic fragments showed high uneven brightness, variable shapes, and irregular contours and surfaces. Fabric filaments were identified as very long strands more than 400 μm in length, with increased basal fluorescence and very bright fluorescent spots. Samples were stained with toluidine blue, and morphological analysis was performed with bright-field microscopy to confirm their origins (Fig. 3). The observed contaminants were photographed and measured, and the major and minor dimen-

![FIG. 1. Map (A) and intraoperative photograph (B) of the operating room. The first surgeon (a), assistant surgeon (b), scrub nurse (c), anesthesiologist (d), room nurse (e), surgical lamp (f), infusion pump (g), operating room wall (h), main screen (i), assistant's screen (j), anesthesia workstation (k), operating room main door (l), and suction grid (m) are shown. Figure is available in color online only.](image)

![FIG. 2. Fluorescence microscopy images of control samples. A: Negative control image showing the diffuse basal fluorescence of a mask’s fibers at an exposure time of 500–600 msec. B: Positive control image after instillation of 1:100,004 fluorescein solution, showing evidence of droplets at the exposure time of 350–450 msec used to attenuate the basal fluorescence of the mask’s fibers. Figure is available in color online only.](image)
sions of each contaminant were determined with BioView Duet software.

**Measurements and Statistical Analysis**

The contamination index (CI) was defined as the number of contaminants per square centimeter on each detector. The CI values of all detectors present during a single procedure were considered together, and the sum was divided by the duration of the procedure (minutes) to evaluate the relationship between time and degree of exposure to contaminants. The CI values of the surgical team’s detectors and that of the environmental detectors were analyzed to estimate the degree of contamination of the surgical staff and operating room. The dimensions of the contaminants were evaluated to identify differences between members of the surgical team and differences due to distance from the operative field.

All data were analyzed using appropriate software (Prism8, GraphPad Software). The unpaired 2-tailed t-test was performed to investigate whether use of a drill influenced the rate of contamination. One-way analysis of variance with Bonferroni multiple comparison test was used to analyze the degree of contamination related to members of the surgical team and distance from the source of contamination; this test was also used to analyze the degree of contamination exclusively by contaminants less than 5 μm that was related to distance from the surgical field. In this study, p < 0.05 was considered statistically significant.

**Results**

A total of 70 samples (7 from each surgical procedure) were collected during 10 endoscopic endonasal surgical procedures performed for various pathologies; different endoscopic instruments were used depending on the type of pathology treated. Data concerning the surgical procedures are summarized in Table 1.

Analysis of contamination of masks worn by the members of the surgical team showed that the first surgeon was the most exposed, with a mean CI of 21 (14.5 droplets and 6.5 solid fragments), followed by the anesthesiologist (mean CI 20.6; 9.5 droplets and 11.1 solid fragments), circulating nurse (mean CI 17.2; 10.1 droplets and 7.1 solid fragments), and scrub nurse (mean CI 14.8; 9.5 droplets and 5.3 solid fragments). When we analyzed the environmental detectors, we determined a mean CI of 19.7 for the surgical lamp, 18.2 for the infusion lamp, and 18.2 for the operating room wall (Fig. 4).

The global CI of procedures performed with drills was 176.5; when drills were not used, the value was 152. Considering only liquid droplets, the cumulative CI was 104.8 for procedures with drills versus 93.5 for procedures without drills; considering only solid fragments, the values were 74.7 and 58.5, respectively. The mean (range) diameter of liquid droplets was 4.1 (1.0–26.6) μm, whereas that of solid fragments was 23.6 (3.5–263.3) μm.

Contaminants smaller than 5 μm were found on every detector analyzed, except those present during 3 surgical procedures. In 2 procedures, contaminants < 5 μm were found on all detectors except the one on the infusion pump; in 1 procedure, contaminants < 5 μm were found only on the detector of the first surgeon. The dimensions of the two types of contaminants (liquid droplets and solid fragments) found on the masks of the surgical team members and on the environmental detectors are summarized in Fig. 5.

We observed no statistically significant differences in the CI values of the procedures performed with and without drills. This was found when we analyzed liquid droplets (mean ± SD CI 104.8 ± 11.71 for procedures with...
Table 1. Surgical endoscopic transnasal procedures

<table>
<thead>
<tr>
<th>Pt No.</th>
<th>Pathology Type of Surgery</th>
<th>Duration (mins)</th>
<th>Instrumentation</th>
<th>Fluorescein Solution (ml)</th>
<th>Saline Solution (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>JNA Endoscopic excision</td>
<td>170</td>
<td>Bipolar forceps, shaver, drill, &amp; laser</td>
<td>220</td>
<td>1050</td>
</tr>
<tr>
<td>2</td>
<td>Nasopharyngeal neoformation Marsupialization</td>
<td>40</td>
<td>Shaver</td>
<td>40</td>
<td>800</td>
</tr>
<tr>
<td>3</td>
<td>Maxillary ameloblastoma Endoscopic excision</td>
<td>110</td>
<td>Bipolar forceps, shaver, &amp; drill</td>
<td>140</td>
<td>700</td>
</tr>
<tr>
<td>4</td>
<td>Frontal empyema Marsupialization &amp; ESS revision</td>
<td>110</td>
<td>Bipolar forceps, shaver, &amp; drill</td>
<td>140</td>
<td>1000</td>
</tr>
<tr>
<td>5</td>
<td>Ethmoidomaxillary ameloblastoma Endoscope-assisted radical maxillectomy</td>
<td>130</td>
<td>Bipolar forceps, shaver, drill, &amp; laser</td>
<td>160</td>
<td>3600</td>
</tr>
<tr>
<td>6</td>
<td>Cavernous sinus neoformation Biopsy &amp; ESS</td>
<td>120</td>
<td>Bipolar forceps, shaver, &amp; drill</td>
<td>160</td>
<td>900</td>
</tr>
<tr>
<td>7</td>
<td>Frontal sinus SCC on IP Craniendoscopic resection</td>
<td>90</td>
<td>Bipolar forceps, shaver, drill, &amp; laser</td>
<td>120</td>
<td>1500</td>
</tr>
<tr>
<td>8</td>
<td>Ethmoidal neoformation Endoscopic excision</td>
<td>120</td>
<td>Bipolar forceps &amp; shaver</td>
<td>160</td>
<td>800</td>
</tr>
<tr>
<td>9</td>
<td>CRS w/ orbital cellulis Bilateral FESS</td>
<td>120</td>
<td>Bipolar forceps &amp; shaver</td>
<td>160</td>
<td>900</td>
</tr>
<tr>
<td>10</td>
<td>Ethmoidal &amp; maxillary empyema Rt-sided FESS &amp; Lt-sided middle antrostomy</td>
<td>90</td>
<td>Bipolar forceps &amp; shaver</td>
<td>160</td>
<td>1500</td>
</tr>
</tbody>
</table>

CRS = chronic rhinosinusitis; ESS = endoscopic sinus surgery; FESS = functional endoscopic sinus surgery; IP = inverted papilloma; JNA = juvenile nasopharyngeal angiofibroma; Pt = patient; SCC = squamouscellular carcinoma.

Discussion

The spread of SARS-CoV-2 has taught the healthcare community the importance of containing diffusion of infection and defending healthcare workers from infective agents. Their protection is obviously important for both the operators themselves as well as for the entire society.

The main modality of SARS-CoV-2 transmission is through the inhalation of droplets or contact with contaminated surfaces. However, increasing scientific evidence confirms that the virus can also have airborne transmission. This refers to the potential risk of viral spread through small droplets (less than 5 μm) generated during AGPs. These particles can travel long distances and remain in the air for many hours owing to their small dimensions, and they represent an important vehicle for the spread of SARS-CoV-2 and other infective agents.

In clinical otolaryngology, the diagnostic and therapeutic procedures performed on the upper aerodigestive tract are associated with significant production of droplets and aerosol due to the presence of saliva and mucous secretions. Knowing that these procedures generate droplets and aerosols is paramount to keeping healthcare providers and patients safe from potential infective agents that may be present. However, the rates of contamination risk associated with specific AGPs have not been elucidated. Several studies have been published that attempted...
to quantify aerosolization generated during sinonasal surgical procedures and to identify devices and modalities capable of containing the spread of droplets. However, there are many limitations of the published models, which did not evaluate the smallest airborne particles generated by AGPs and did not detect environmental contamination distant from the source. Both Sharma et al.\textsuperscript{18} and Workman et al.\textsuperscript{13} used nasal instillation of fluorescein to investigate droplet and splatter patterns resulting from common endoscopic endonasal procedures performed on cadaver head specimens. They concluded that endoscopic endonasal procedures generate a small number of droplets, except when high-speed drills are used. However, only particles visible to the human eye (larger than 20 $\mu$m)\textsuperscript{13} and deposited at short distances (less than 183 cm in the Sharma et al.\textsuperscript{18} study and less than 80 cm in the Workman et al. study\textsuperscript{13}) from the specimens were measured.\textsuperscript{13,18} In a subsequent article, Workman et al.\textsuperscript{19} attempted to quantify airborne aerosol production after endonasal instrumentation under cadaveric surgical conditions. They used an optical particle sizer that was able to detect particles less than 10 $\mu$m in size and positioned 15 cm from the specimen.\textsuperscript{19} However, in this study, droplets larger than 10 $\mu$m in size were not evaluated, and the nature of the contaminating particles, including volume, density, aerodynamic characteristics, range of contamination, and splatter pattern, was not analyzed. Moreover, a semiquantitative comparison between various otolaryngology procedures was performed by Guderian et al.,\textsuperscript{20} who described an in vitro microscopic analysis of particles and aerosols generated with the use of cold and powered instruments from hard and soft fresh porcine specimens in a test chamber. They showed that lasers generate a considerable amount of aerosol, whereas drilling was associated with a remarkable generation of solid particles. The largest amount of particles was released during electrocoagulation, whereas no contaminants were detected after use of cold instrumentation.\textsuperscript{20}

However, all previous studies\textsuperscript{13,18,19} were carried out in experimental settings and used human cadaver head specimens or animal tissues. This may have hampered the lack of blood and mucus secretion in the surgical field and therefore may have altered the propensity for aerosol production during endoscopic endonasal procedures; in addition, in preclinical models, it is not possible to evaluate the degree of contamination of the operating theater and surgical staff. To overcome these limitations, Murr et al.\textsuperscript{16,17} analyzed the in vivo risk of aerosolization in the office and operating room by using an optical particle sizer. In the outpatient setting, they showed a significant increase

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig5.png}
\caption{Mean sizes of contaminants related to surgical staff members (A) and environmental detectors (B) at increasing distance from the surgical field. Both graphs show the amounts of liquid droplets and solid fragments. For each type of contaminant, size appeared to be relatively constant and was not influenced by distance from the surgical field. Figure is available in color online only.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig6.png}
\caption{Comparison of mean CI values due to the generation of droplets (A) and solid fragments (B) during surgical procedures that did or did not use a drill. Mean (longest horizontal line) and standard deviation (whiskers) are shown.}
\end{figure}
in measured particle concentration during endoscopic endonasal debridement with cold instrumentation and suction, whereas diagnostic nasal endoscopy was not associated with aerosol generation. In addition to these findings, increased aerosol concentration due to use of powered instruments (debrider and drill) was detected at only the position of the operating surgeon, with no evidence of any increase in the concentrations of measured particles around the positions of any other surgical staff member (anesthesiologist and circulating nurse). However, use of the optical particle sizer to detect contaminants is associated with several limitations. In particular, only airborne particles between 0.3 μm and 10 μm can be detected, the specific composition of the contaminants cannot be identified, and non–patient-generated particulates such as dust are also detected. Therefore, at present, an in vivo microscopic and morphological analysis of contaminants, including evaluation of the range of spread and quantification of the degree of contamination of the surgical staff and operating room environment, is lacking.

In this prospective nonrandomized study that used optical microscopy, particles as large as 1 μm were detected and qualitative analysis of the contaminants was performed. In particular, contaminants were composed of not only liquid droplets but also solid particles. The latter included organic fragments such as mucosa, cartilage, and bone that resulted from tissue disruption during surgery and tissue fibers, which were probably derived from gauze used to clean the instruments. Moreover, it is important to note that the mean droplet size was 4.16 μm and numerous solid particles less than 5 μm in size were also detected. According to previous studies, small contaminants (less than 5 μm) may remain in the air for many hours, reaching long distances and penetrating through standard surgical face masks.

In the present study, quantification of degree of contamination of the surgical staff and environment was also performed with measurement of contaminants in the operating theater during surgery. In particular, the first surgeon had the most exposure to contaminants, probably due to being the closest to the source of aerosolization (i.e., the patient's nostrils). Surgical staff had fairly constant positions during endoscopic endonasal surgical procedures. The anesthesiologist, who was positioned toward the feet of the patient at a distance of at least 2 m from the patient's nose, was partially shielded by the automatic ventilator; therefore, it is surprising that the anesthesiologist was the second most contaminated staff member after the first surgeon. This finding may be explained by the anesthesiologist's position along the direction of the airstreams generated by the laminar airflow system of the operating theater. On the other hand, it is difficult to explain why the room nurse was the third in terms of degree of contamination, because they constantly change position inside the room during surgery and often leave the operating room to get requested surgical materials available outside the room. The scrub nurse had the lowest degree of contamination, and this can probably be explained by their position being partially shielded by the first surgeon. However, globally, the degree of contamination of each healthcare worker involved in endoscopic endonasal surgery was considerable and comparable, because no statistically significant differences were found between different staff members. This suggests that all members of the surgical team are at high risk for contamination.

Most likely, laminar airflow from the ceiling above the surgical table, which is directed toward the operating room corners where suction grids are placed, may influence the distribution of contaminants. Although this aspect does not seem to change the impact of contamination on healthcare workers, further studies should analyze this aspect of contamination.

The analysis of environmental detectors showed that the degree of contamination decreased with increasing distance from the aerosolization source, without differences between liquid droplets and solid particles. However, the correlation between degree of contamination and distance from the patient was not statistically significant, suggesting that the risk of contamination is similar at any distance from the patient and at any position in the operating room. The size of the contaminant does not seem to be associated with distance and/or pattern of contamination, for both liquid droplets and solid particles. Surprisingly, no correlation was observed between
surgical time and degree of contamination, but the latter seems to be more dependent on the instrumentation used during the surgical procedure. In particular, it has been shown that high-speed drills generate the largest number of contaminants, with a predominance of solid particles. In contrast to current studies in the literature, in our study the concomitant use of suction did not prevent spread of particles in the operating room. Notably, in our experience, all endoscopic surgical instruments including shavers produce aerosols and spread droplets, as demonstrated by the significant degree of contamination detected even in surgical procedures that did not use a drill.

The patients described in the present study were treated according to the same general principles of endoscopic transnasal surgery commonly used in neurosurgical settings to approach the skull base. The same instruments (drills, shavers, laser, etc.) and nasal irrigation with saline solution were used. Therefore, on the basis of our results, we conclude that the same high risk of contamination is applicable to endoscopic transnasal endoscopic procedures.

In summary, this was the first prospective study conducted during surgery to use an easy and reproducible parameter, defined as CI, to quantify risk of contamination for healthcare workers in the operating room; in addition, the particles generated during endoscopic endonasal surgery were characterized in terms of size and composition with microscopic analysis. However, there are several limitations to this study that have to be mentioned. First, the study was conducted on a limited number of patients. Second, the surgical procedures differed in terms of duration, endoscopic instrumentation used, and surgical staff (i.e., different endoscopic surgeons with different levels and areas of expertise). This heterogeneity might have affected the number of contaminants generated during surgery. Third, the airstreams generated by the laminar airflow system of the operating theater and the airflows produced by the movements of the healthcare workers inside the room, as well as by the opening and closing of the operating room door, may have affected the range of contamination and splatter patterns of the particles observed. Finally, the present study was not carried out with the intention to detect the presence of SARS-CoV-2 within these particles. In our view, the reported observations may be valid for other infective agents.

Conclusions

This was the first prospective study to provide quantification of the degree of contamination of surgical staff and environment, as well as microscopic qualitative analysis of particles generated during endoscopic endonasal surgery. A significant number of contaminants (liquid droplets, bone or mucosal fragments, and tissue fibers) less than 5 μm was found in the operating room. These contaminants were able to remain in the air for many hours, reach long distances, and possibly penetrate through standard surgical face masks. High degree of contamination was observed for all healthcare workers and at any distance from the patient, suggesting that the risk of contamination is high for endoscopic endonasal surgery and comparable among all surgical staff members. No correlation was observed between duration of surgery and degree of contamination. It has been demonstrated that use of a high-speed drill generates a large number of contaminants, regardless of simultaneous use of suction, which was not enough to avoid the spread of particles. On the basis of these preliminary findings, we recommend all surgical staff always wear at least an N95 mask and protective goggles or face shields. Environmental protection systems, such as negative pressure and laminar airflow systems in the operating room, are unable to protect medical and nursing staff from risk of contamination during endoscopic endonasal surgery. Future studies are needed to increase knowledge about aerosol-generating endoscopic endonasal procedures and to identify proper prevention measures and effective personal and environmental protective devices, with the aim of containing aerosol generation and spread during endoscopic endonasal surgical procedures.

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Disclosures
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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