Review Article

Occupational adverse effects and protective factors in bronchoscopy

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Abstract: The application of bronchoscopy has resolved a series of diagnostic and treatment challenges in pulmonary diseases. However, the occupational adverse effects experienced by healthcare workers in interventional pulmonology should receive increasing attention. Various aspects of adverse effects in bronchoscopy are often neglected, and healthcare workers frequently ignore guidelines for personal protection against factors such as radiation, smoke, pathogenic microbiological aerosols, cryogenic gas, etc. Thus, there is an urgent need to conduct additional research to establish standards for occupational adverse effects and protective measures related to bronchoscopy.

Keywords: Bronchoscopy; occupational exposure; protective factors; health personnel

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Introduction

The widespread application of bronchoscopy has resolved a series of diagnostic and treatment challenges in pulmonary diseases, including tracheal and bronchial stenosis as well as unexplained hemoptysis caused by malignant tumors. However, the occupational exposure and hazards experienced by healthcare workers during bronchoscopy have been increasingly realized. The present review analyzes various aspects of adverse effects experienced by healthcare workers in bronchoscopy and discusses effective prevention measures.

Occupational radiation exposure

Certain flexible bronchoscopy procedures may be aided by X-ray imaging techniques during bronchoscopy, including transbronchial (transpulmonary) biopsy, collection of cytology brush specimens from peripheral lung tissues, transbronchial needle aspiration of peripheral lung tissues, localization of radiopaque foreign bodies, airway stent placement, and postoperative exclusion of pneumothorax (1). In addition, during computed tomography (CT)-guided percutaneous lung biopsy, CT-guided radioactive particle implantation, and high-dose rate endobronchial brachytherapy, healthcare workers are inevitably exposed to ionizing radiation such as X-rays and the β- and γ-rays produced by radioactive particles like ^{125}I. The long-term use of radiation-related interventions increases the risk of occupational radiation exposure. The dose of occupational radiation received by healthcare workers in interventional pulmonology is usually insufficiently high to cause acute adverse reactions. Therefore, the hazards of chronic adverse reactions are often neglected, and healthcare workers frequently ignore recommendations for personal protection.

Biological effects of occupational radiation exposure

Occupational radiation exposure includes chronic low-dose radiation, and its biological effects can be divided into non-stochastic and stochastic effects. Non-stochastic effects include erythema, skin peeling, myelosuppression, organ atrophy, cataracts, and infertility. The severity of non-stochastic effects varies with changes in the radiation dose, and a dose threshold exists. The 2007 "Recommendations of the International Commission on Radiological Protection" (ICRP) proposed that occupational radiation exposure should be limited to ≤20 mSv/year (2). The stochastic effects include carcinogenic and genetic effects, and the probability of occurrence (but not the severity) is related to the dose level. Zielinski *et al.* (3) conducted a long-term follow-up study of 67,562 medical workers who had been exposed to chronic low-dose ionizing radiation between 1951 and 1987. They observed 1,309 cases of cancer. The mean annual exposure among cancer patients between 1951 and 1970 was 1.14 mSv/year, and between 1971 and 1987, it was 0.36 mSv/year. The incidence of thyroid cancer was significantly elevated, and the incidence of liver cancer was significantly elevated among females, which implies that low-dose ionizing radiation increases the incidence of cancer.

Radiation exposure and protection under X-ray guidance

Peripheral transbronchial biopsy is a primary method used to biopsy peripheral lung tissues for the diagnosis of lung cancer. X-ray imaging techniques can be used to aid certain flexible bronchoscopy procedures. For example, the application of X-ray-guided localization in the biopsy of peripheral lung lesions can significantly enhance the rate of positive diagnosis. However, it also exposes healthcare workers to X-rays. Steinfort *et al.* (4) calculated the radiation dose received by patients and healthcare workers during 45 ultrasound bronchoscopies with fluoroscopic guidance. Their results showed that for each session of ultrasound bronchoscopy with fluoroscopic guidance (median fluoroscopic screening time: 96±55 s), the patient received a median radiation dose of 0.49±0.37 mSv. The effective radiation dose received through protective garments was attenuated to 0.4 µSv for the operator and 0.2 µSv for the assistant. Katsurada *et al.* (5) calculated the radiation dose received by healthcare workers over 132 cases of endobronchial ultrasonography with a guide sheath under X-ray guidance (EBUS-GS). The results showed that in a procedure with a median radiation time of 7.6 min, the operator received a median radiation dose of 12 µSv. Changes in the patient's body mass index and the location of the R-EBUS probe resulted in a relative increase in the radiation dose received by healthcare workers. The study data indicated that, although healthcare workers are only exposed to small doses of radiation during bronchoscopy procedures under X-ray guidance, radiation safety precautions should not be neglected.

CT and CT fluoroscopy-guided percutaneous lung biopsy are currently the most commonly used imaging-guided methods of percutaneous lung biopsy. Compared to traditional CT guidance, CT fluoroscopy provides real-time guidance, which reduces the procedure time and the number of punctures. It also decreases the duration of the patient's exposure to X-rays and enables access to smaller lesions and to lesions in suboptimal locations. However, it increases the radiation exposure of the operator. Buls *et al.* (6) recorded the radiation dose received by patients and healthcare workers during 82 procedures performed under CT fluoroscopy guidance. Among 46 patients who underwent a biopsy, the median entrance skin dose was 380 mSv; for 18 cases of breast tissue biopsy, the median entrance skin dose of the healthcare workers was 0.174 mSv. All healthcare workers wore protective lead garments providing protection of 0.50-mm lead equivalents at the front and 0.25 lead equivalents at the sides and back.

Radiation-related protective measures during bronchoscopy procedures under X-ray guidance should follow the principles of protection for general occupational radiation exposure. These principles are as follows: (I) as time protection, the operator should master the interventional surgical procedures to reduce the duration of radiation exposure; (II) as distance protection, the operator should maintain a certain distance from the patient and should place the X-ray image intensifier as close to the patient as possible. Personnel should also maintain an appropriate distance, standing a far from the operating table as possible; (III) as personal protection, X-ray protective equipment, such as lead clothing, glasses, and collars with a 0.50-mm lead equivalence, should be worn (6); (IV) healthcare workers should receive training related to radiation protection, and protection awareness should be increased; (V) bronchoscopy procedures and CT rooms should be carefully managed, and the relevant medical devices should be maintained (1).

Radiation exposure and protection from radioactive particles

Chemotherapy is a crucial treatment method for most lung cancer patients who cannot be treated surgically. Radioactive particle implantation also has several advantages: it is minimally invasive, offers accurate target irradiation, and does not increase lung tissue damage. Implantation methods include CT-guided radioactive particle implantation and high dose rate endobronchial brachytherapy. Currently, ^{125}I and ^{192}Ir are the most commonly used radioactive particles. ^{125}I releases γ-rays, and ^{192}Ir releases β- and γ-rays. Zhuo *et al.* (7) performed CT-guided ^{125}I implantation in 20 patients with malignant tumors and monitored the radiation dose. The ^{125}I source intensity was 2.2×10^7–3.3×10^7 Bq, and an average of 19.65 particles were implanted per patient. The radiation dose was measured immediately after and 2, 4, and 6 months after surgery, and those values were compared to the natural background radiation dose. The results showed that the radiation dose decreased rapidly with increasing distance; at a distance of 50 cm, the detected dose was similar to the natural background radiation dose (10.2–10.8 μSv/h). The mean radiation dose detected immediately after surgery was 60.38±31.92 μSv/h at the body surface and 10.64±0.51 μSv/h at 50 cm; the mean radiation dose detected at the body surface after 6 months was 12.31±4.05 μSv/h. Hence, the radiation dose attenuated with time, and the dose detected at the body surface after 6 months was close to the natural background dose.

The following protective measures should be in place for healthcare workers performing radioactive particle implantation procedures (7). (I) Rational treatment plans should be formulated according to the principles of standardization and optimization, including particle selection, implantation methods, number of particles, gross activity, and simulation dose and its distribution. (II) Lead clothing including a hat, collar, gloves, glasses, and other radiation protection tools and a lead equivalence of 0.18–0.25 mm should be worn. The surgeon should also wear protective glasses and leaded gloves, and long-handled tweezers should be used to retrieve the radioactive particles. (III) Waste particles should be considered and disposed of in radioactive waste bins. After surgery, a γ-ray detector should be used to carefully determine whether any particles remain on the work surfaces or the ground. (IV) Personal dosimeters to monitor the accepted level of low-energy radiation should be prepared and used appropriately. (V) Surgeons should be proficient in the procedures, as proficiency reduces the contact time with the radioactive source.

The following post-operative precautions are necessary (7). (I) No special protective measures are necessary for general post-operative care. When providing care at close range (<50 cm), patients should be covered with a rubber sheet or wear leaded clothing with a lead equivalence of 0.18–0.25 mm. (II) No special protective measures are necessary after discharge. A distance of 1 m should be maintained from family members, and no protection is needed after 6 months. (III) Regular post-operative follow-ups are needed to detect any displacement of particles. Effective measures should be implemented in patients prone to displacement to prevent the loss of particles.

Smoke

The use of laser ablation, high-frequency electric knives, argon plasma knives, and other thermal ablation technologies under bronchoscopy has been applied to resolve a number of conditions caused by airway obstruction, including breathing difficulties, obstructive pneumonia, and hemoptysis as well as to treat local airway hemostasis and for ablation of benign and malignant tumors. However, the use of such thermal ablation technology results in the incomplete combustion of proteins, fats, and other components of human tissues, which produces visible smoke. Not only does this smoke have a strange odor and obstruct the endoscopic field of view, it also releases toxic chemical compounds into the ambient air (8).

Smoke production and hazards

Laser treatment under bronchoscopy primarily depends on the thermal effects of the laser; light energy is converted to thermal energy and produces a series of tissue changes. It causes the coagulation, vaporization (100 ℃), or carbonization (210 ℃) of the irradiated tissues, thereby achieving ablation of lesions. When the temperature reaches 100 ℃, water within tissue boils and begins to vaporize and produce smoke (9). The high-frequency electric knife uses the thermal effects generated by passing a high-frequency electric current through the tissue, which causes the explosive vaporization of tissues under the electrode. This results in the formation of flat, narrow, non-bleeding incisions a few millimeters deep. Different thermal effects can be generated using the electric knife by controlling the electric current. The argon plasma coagulation uses high-frequency and high-voltage ionization of argon gas into argon ions, which allows continuous conduction of an electric current.

Research has determined that surgical smoke contains 95% steam; the remaining 5% is chemical compounds and tissue debris, which may be hazardous to human health. The smoke produced from laser treatments contains particles with an average diameter of 0.3 μm, whereas electrocautery smoke can contain particles with an average diameter of <0.1 μm (10). It was recently determined that electrocautery and argon plasma coagulation induced the production of a high concentration (>100,000 cm^{-3}) of particles ranging from 10 nm to 1 μm in diameter. These can be directly inhaled by healthcare workers and invade the alveoli, which may be hazardous to human health (11).

Smoke primarily contains toxic and hazardous chemical compounds, invisible particles, viable pathogens and viruses, and viable cancerous cells (12).

Toxic and hazardous chemical compounds

A number of toxic and hazardous chemical compounds have been detected in smoke, including hydrocyanide, benzene, hydrocarbons, carbon oxides, aldehydes, phenols, and fatty acids. Among them, CO and acrylonitrile are the primary toxic and hazardous compounds (13). Despite the relatively low level of exposure, healthcare workers are subjected to long exposure times and long-term repeated inhalation of toxic and hazardous chemical compounds within smoke, which may also have various risks. Overexposure to CO causes headaches, nausea, emesis, and heart arrhythmia, and may further damage cardiovascular function in patients with cardiovascular disease (14). Acrylonitrile is a colorless volatile liquid with a pungent odor. It is highly toxic and can easily be absorbed by the skin and lungs. Animal studies have shown that repeated or long-term exposure to acrylonitrile can cause mucosal inflammation, cancer, and other health problems (13). Exposure to benzene can trigger nausea and headaches, while long-term exposure can result in hematopoietic disorders, which may cause anemia or even lymphomas (10).

Invisible particles

Invisible particles may be fine or coarse. The primary chemical components of fine particles are sodium, potassium, magnesium, calcium, and iron. Coarse particles are incompletely combusted human tissue fragments, and the main chemical components are carbon and oxygen. Invisible particles can travel long distances in the air, with smaller particles travel up to 100 cm. They are also easily inhaled by healthcare workers and patients and may damage the respiratory system, leading to alveolar congestion, interstitial pneumonia, asthma, bronchitis, and chronic pneumonia (13,15).

Viable pathogens and viruses

Microbiological cultures of samples of smoke generated from laser surgery have revealed the presence of coagulase-negative staphylococci, *Neisseria*, and *Corynebacterium*. Virus particles also have been detected in smoke produced from laser treatment of papillomas. Human immunodeficiency virus (HIV) fragments were detected in the smoke produced from affected patients (15). However, there is currently insufficient evidence for the transmission of pathogens to healthcare workers via surgical smoke (14).

Viable cancerous cells

Electric knife and laser surgery can result in the dissemination of complete cells and blood through surgical smoke. However, the viability of cells in surgical smoke is still controversial. A number of studies have reported the discovery of cancer cells in surgical smoke. Fletcher *et al.* (16) found a small number of viable melanoma cells within surgical smoke, and viable cells were present in cell cultures at 5–7 days. Regardless of viability, cancerous cells carry cancerous genes and are disseminated via surgical smoke. Further investigation of the implantation and transfer of vaporized tumor cells is necessary (12).

Protective measures for surgical smoke

Smoke extraction device

There should be sufficient and reasonable use of smoke extraction devices, including reasonable device placement and control of the evacuation speed. The US National Institute for Occupational Safety and Health (NIOSH) recommends the use of surgical smoke evacuators with high-efficiency filtration systems with an evacuation speed of at least 31–46 m/s during surgical procedures. The NIOSH also recommends that smoke capturing devices should be placed within 5 cm of the surgical field during the production of surgical smoke (17). A special smoke evacuator should be used during laser irradiation, and the tip of the smoke evacuator should be placed within 5 cm of the laser irradiation area (17). Electrosurgical knives with smoke capturing devices or evacuators have recently been put into use. In China, smoke extraction devices are still not used in all bronchoscopy rooms, and the relevant protective measures are insufficient. Most smoke generated during procedures is aspirated using negative-pressure suction devices. There are currently no studies of the protective measures used in bronchoscopy rooms, but comparisons can be made to surgical smoke extraction devices. It is also necessary to establish standard specifications for surgical smoke protection in bronchoscopy rooms.

Personal protection

High filtration surgical masks, protection goggles, gloves, and isolation gowns should be worn. Surgical masks are only able to block particles larger than 5 μm and often do not provide sufficient smoke filtration protection. A high filtration mask should be fitted closely to the face of the healthcare worker and should seal tightly around the nose and mouth. The mask should be worn properly at all times (18).

Hazards from laser electromagnetic radiation

Unlike ordinary light, a laser device produces a light beam that is coherent, monochromatic, unidirectional, and minimally divergent. The retina is the tissue most vulnerable to laser injury caused by focusing light radiation, and even small amounts of energy produced by relatively low-power laser devices can significantly damage the retina (19).

As mentioned above, laser technology has become a key method in bronchoscopic treatments. In addition to the generation of hazardous smoke, lasers are a type of electromagnetic radiation that may lead to beam hazards.

Hazards of medical lasers experienced by healthcare workers

There are many types of medical lasers; those used for the treatment of airway lesions include neodymium-doped yttrium aluminum garnet (Nd:YAG) lasers, CO_2 lasers, and holmium lasers. Among them, the Nd:YAG laser possesses strong ablative abilities and can be used for cutting, burning, vaporizing, and deep coagulation. It is currently the most commonly used laser technology in respiratory medicine. Based on the risks to the operator, laser safety can be divided into four classes. The classification of the laser is based on the length of the maximum permissible emission (MPE) compared to the human aversion response. The MPE determines how long an unprotected eye can be exposed to a laser beam before injury occurs.

Medical lasers are Class 3B or Class 4 lasers (18), and Class 4 lasers have sufficient power to cause instantaneous eye or skin injury in humans. The diffuse reflection of such lasers is also very harmful to the eyes and skin (18).

Most of the reported laser eye accidents involve at least some carelessness, such as not wearing eye protection, and could have been avoided by following standard laser safety practices. In addition to looking directly at the laser source, reflection of the beam by a mirror or nearby object occasionally causes such accidents. The victim usually experiences a sudden and severe disturbance of vision in one eye preceded by a visible flash of bright colored light and an audible pop without pain. The subsequent clinical course can be characterized by marked improvement during a period of a few days to weeks, mainly due to clearing of hemorrhage and subsidence of inflammation at the site of injury (19). Shum *et al.* (20) reported the case of a 31-year-old beauty parlor aesthetician who was operating an Nd:YAG cosmetic laser machine of 1,064 nm wavelength with the probe held in the opposite direction when on firing, the laser shot fired into her left eye. The patient heard a "pop" sound and immediately saw floaters and experienced blurring of vision. Optical coherence tomography taken over the injured area during a 6-week follow-up showed thickened retina and preretinal hyper-reflectivities. Humphrey's visual field showed a dense scotoma emanating from the blind spot. Eventually, scarring occurred at the lesion site, and the patient's vision recovered.

In bronchoscopy rooms, the primary hazard of medical lasers is ocular injury caused by reflected laser beams. The wavelength of Nd:YAG lasers is 1.06 μm, and a power of <40 W is commonly used, which causes retinal and choroid damage in humans. Virtually all reported laser injuries have involved the retina and were caused by relatively low-power, pulsed Nd:YAG lasers.

Protective measures (21)

Eye protection

When performing bronchoscopy with medical lasers, patients and healthcare workers should wear goggles to protect the eyes from specific laser wavelengths. The goggles can be made of plastic or glass and should include protective side shields.

Skin protection

The skin injuries inflicted by lasers tend to be milder than the ocular injuries and can usually be treated. However, skin exposure to lasers should be avoided. The end of the laser handle may cause burns during procedures and should be placed on a wet cloth or mat after use.

Environmental safety

(I) Due to the reflected energy of lasers, medical devices with reflective surfaces should be avoided in the bronchoscopy room, and reflective surfaces should not be exposed in the surgical field. (II) During laser operation, a "Laser in Use" warning sign should be placed outside the bronchoscopy room, and non-essential personnel should be prohibited from entering. (III) The bronchoscopy room should be equipped with fire extinguishers, and good fire safety education should be provided.

Precautions for laser use

(I) Strong vibrations should be avoided when moving lasers to prevent damage to the laser. (II) The aiming beam should be precise, accurately calibrated, and always ready for use. (III) Liquids should not be present in the surrounding areas to reduce the risk of electrical accidents. (IV) Only trained doctors and nurses should operate the laser. (V) Lasers should be managed and maintained by specialists, and laser use should be registered. (VI) During laser use, the switch should be placed in the "ready" mode, and it should be switched to the "standby" mode when not in use. The foot switch should be suitably positioned to prevent accidents. In case of accidents, such as accidental laser emission or fires, the "emergency" button should be pressed immediately to switch off the machine. (VII) During laser use, the flow rate of oxygen, N_2O, and other combustible gasses should be stopped or reduced to very low levels to minimize the risks of fires and explosions. Laser use should be avoided in procedures involving the placement of highly flammable implants in the airway, such as silicone objects (endotracheal tubes, stent grafts, silicone stents). This may easily lead to airway injury, especially at oxygen concentrations above 40% or due to high-power laser output.

Enhanced training for healthcare workers

Surgeons and manufacturer technicians should be invited to the bronchoscopy room to conduct classes and demonstrations. This will familiarize healthcare workers in the bronchoscopy room with the basic steps and procedures of laser ablation therapy. Healthcare workers should master the performance of Nd:YAG lasers, all related safety precautions, as well as the methods, disinfection procedures, and maintenance measures necessary to extend instrument life, which will ensure its smooth operation and improve the quality of medical care.

Pathogenic microbiological aerosols

Formation and hazards of pathogenic microbiological aerosols

Aerosols are solid or liquid particles suspended in a gaseous medium. Aerosols in which the particles are microorganisms are referred to as microbiological aerosols, and aerosols in which the microorganisms are pathogenic are referred to as pathogenic microbiological aerosols, which commonly include bacterial, viral, and fungal aerosols (22). Pathogens can be transmitted via aerosols from human to human and from the environment to humans. Most infectious respiratory diseases caused by bacteria and viruses are spread through contact with infected patients or the inhalation of aerosol droplets contaminated by patients.

The viability of microorganisms within microbiological aerosols is highly variable and affected by many factors, including temperature, humidity, and time. The interactive effects of multiple conditions can cause a continuous decline in the viability of microorganisms within microbiological aerosols. The air is not a suitable temporary habitat for the microorganisms within the aerosols, and they will not be transmitted over long distances. However, once a certain concentration and diameter are reached and suitable airflow conditions are in place for delivery to susceptible groups, the risk of infection increases greatly for healthcare workers who have close contact with the patient (23).

Studies outside of China have reported that the transmission of highly infectious diseases from patients to healthcare workers is uncommon. However, several cases of *Streptococcus pyogenes*, *Neisseria meningitides*, *Haemophilus influenzae*, and *Acinetobacter baumannii* transmission to healthcare workers through occupational exposure have been reported (24). Furthermore, healthcare workers account for approximately 20% of cases of acquired severe acute respiratory syndrome worldwide. Due to the exposure to certain airborne pathogens, many medical procedures also increase the risk of occupational exposure to infection of healthcare workers (25,26).

Marchand *et al.* (25) collected air samples during bronchoscopic procedures from two bronchoscopy rooms in two hospitals. The sampling range was within a 1.5-m radius of the patient's mouth and the surgeon's breathing zone. The results showed that during the waiting and preparation stages for a bronchoscopy, the culturable bacterial concentrations of air samples were higher than the background concentrations collected at the end of the procedure. All samples included at least one *Staphylococcus* species. Although most of the culturable bacteria were normal non-pathogenic species of *Streptococcus*, *Neisseria*, and *Corynebacterium*, certain opportunistic pathogens were also found, including *Streptococcus pneumoniae*. The study did not detect any *Mycobacterium* or influenza viruses.

The transmission of tuberculosis (TB) from TB patients to healthcare workers during bronchoscopy is a recognized occupational risk (27). Calculations by Catanzaro (28) showed that more than 200 units per hour of aerosolized infectious mycobacteria are released during intubation and bronchoscopy. Intubation under bronchoscopy simulates the patient's cough reflex, which produces particles of various sizes that can remain viable for hours in the air. Large particles shrink due to evaporation and become small particles, which can remain airborne for longer periods of time. These particles are composed of saliva, mucus, and microbes; most are 0.1–10 μm in size and can be inhaled into the lungs. If the pathogen-laden particles are inhaled and deposited into the respiratory tract, they may cause a respiratory infection (25).

In addition, surgeons who do not wear protective goggles may be at risk of HIV infection when performing bronchoscopy on patients with acquired immunodeficiency syndrome, as HIV may be transmitted via the conjunctiva. There are currently no studies reporting the transmission of HIV infection to healthcare workers during bronchoscopy procedures. However, the risk of infection is believed to be higher in healthcare workers performing bronchoscopy in patients with an unknown HIV status.

Protection from pathogenic microbiological aerosols in the bronchoscopy room

Management of infection sources

All patients should undergo comprehensive evaluation prior to bronchoscopy. The Japan Society for Respiratory Endoscopy recommends that all patients who undergo respiratory endoscopy should first be tested for hepatitis B virus, hepatitis C virus, HIV, and syphilis using interferon-gamma release assays (IGRAs) to prevent droplet transmission to healthcare workers (29,30). Patients with suspected TB should undergo a tuberculin test, IGRAs, and T cell-based TB infection tests; patients diagnosed with active TB should be referred to designated TB medical institutions for treatment (31,32).

Prophylactic immunization

All healthcare workers should be vaccinated for *Mycobacterium tuberculosis*, and timely testing of their immune status should be performed. Healthcare workers who have long-term contact with TB patients should be regularly tested with IGRAs to screen for latent TB infection and to assess the risk of TB infection (33).

Use of ventilators and high-efficiency air filters

Effective measures such as the use of ventilators are needed to maintain negative pressure in the bronchoscopy room. The use of high-efficiency air filters ensures the continuous discharge of air to the outside environment, which reduces the concentration and survival time of pathogenic microbiological aerosols and lowers the risk of inhalation by healthcare workers.

Physical protection

Healthcare workers should wear masks. Normal gauze masks are unable to block pathogenic microbiological aerosols; hence, antibacterial filtering masks with a tight seal around the nose and mouth are recommended. When administering invasive treatments or care, care should be taken to avoid sharps injuries. Surgeons should be proficient with all procedures. Moreover, timely aspiration of airway secretions and blood produced by the patient should be performed, and safety precautions should be taken.

Ultraviolent air disinfection

Shortwave ultraviolet irradiation (200–275 nm) can efficiently eliminate bacteria in pathogenic aerosols and enable rapid disinfection of indoor air. This prevents cross-contamination in hospitals and protects healthcare workers. Irradiation should be performed before cleaning, and good ventilation should be maintained.

High-level sterilants and disinfectants during respiratory endoscope cleaning

After each respiratory endoscopy, the endoscope must be cleaned and disinfected by endoscope cleaning staff. As flexible bronchoscopes have a complex structure, numerous angles and bends, multiple valves, long and narrow operating channels, and low heat resistance, they are prone to blind spots in cleaning. Hence, thorough disinfection and sterilization are difficult. During the cleaning and disinfection of respiratory endoscopes, in addition to thorough cleaning and disinfection to prevent cross-contamination, emphasis should be placed on the hazards that cleaning and disinfection staff are exposed to due to the volatilization and spraying of the chemical compounds used for cleaning and disinfection. The volatilization and spraying of high-level disinfectants such as ortho-phthalaldehyde, glutaraldehyde, and peracetic acid, as well as sterilants such as glutaraldehyde and peracetic acid used during disinfection, are hazardous to the respiratory system, skin, and conjunctiva of the endoscope cleaning and disinfection staff (34).

Hazards of different disinfectants and sterilants experienced by healthcare workers

The most common high-level disinfectants used in respiratory endoscopy include glutaraldehyde, ortho-phthalaldehyde, and peracetic acid, with glutaraldehyde being used most often.

Glutaraldehyde

Glutaraldehyde can be used for manual and automated cleaning and disinfection as well as for sterilization. It has a relatively high usage rate among disinfectants for respiratory endoscopes. The effective concentration of glutaraldehyde for the disinfection of flexible endoscopes is 2.0–2.5%. The use of glutaraldehyde disinfectants at a mean concentration of 2.0–3.5% results in different levels of irritation and allergic reactions at various skin and mucosal sites, with case reports describing contact dermatitis, conjunctivitis, and occupational asthma. Currently, there have been no reports of deaths or cancer cases, and no *in vivo* or *in vitro* studies suggesting the presence of genetic and reproductive toxicity (35). Vyas *et al.* (36) conducted a survey of 348 current endoscopy nurses and 18 former nurses who left their jobs for health reasons. Among them, 91.4% were primarily exposed to glutaraldehyde. The survey found that the mean force expired volume in 1 second of the former nurses was 93.82% [95% confidence interval (CI): 88.53–99.11%], which was significantly lower than that of the current nurses exposed to glutaraldehyde (104.08%; 95% CI: 102.35–105.73%). This implies that occupational exposure to glutaraldehyde was associated with chronic airway inflammation.

Ortho-phthalaldehyde

Ortho-phthalaldehyde can be used for manual and automated cleaning and disinfection, but not for sterilization. The effective concentration of ortho-phthalaldehyde for the disinfection of flexible endoscopes is 0.3–0.55%. Ortho-phthalaldehyde disinfectants remain stable within a pH range of 3–9 and do not produce harmful volatile compounds. They also do not produce irritating odors and are less irritating to the skin and mucosal membranes than glutaraldehyde (35).

Peracetic acid

Peracetic acid can be used for manual and automated cleaning and disinfection as well as for sterilization. The commonly used concentrations of peracetic acid are 0.2% and 0.35%. The use of peracetic acid results in irritation of the eyes, skin, and respiratory mucosa (35).

Protection of healthcare workers

To minimize the exposure of workers to disinfectants and disinfectant volatile gases, the automated cleaning and disinfection of bronchoscopes is recommended. When possible, bronchoscopes should also be disinfected in special rooms with automatic ventilation systems or in fume cupboards (34).

Workers should apply good personal protection measures when cleaning and disinfecting and should wear the necessary protective items, such as rubber gloves that fully cover the forearms, protective masks with goggles to prevent conjunctival irritation and protect against splashes, long-sleeved waterproof garments, and masks (or disposable activated carbon masks when possible) to reduce the inhalation of volatilized or sprayed disinfectant droplets. The bronchoscopy room should also be ventilated regularly (34).

All healthcare workers who may be exposed to aldehydes should receive a physical examination prior to initiating work. After completion, the Department of Occupational Health should conduct regular checks of pulmonary function and ask the workers if they have experienced discomfort. Professional and technical workers engaging in bronchoscopy procedures should also receive education related to patient care, infection control, and device cleaning, including the safe use of aldehydes and the potential health hazards during device cleaning.

Common cryogenic gases used in cryotherapy

Endoluminal cryotherapy with bronchoscopy is a transbronchial bronchoscopic intervention that introduces CO_2, N_2O, and other cryogenic gases via a cryoprobe to treat airway stenosis, hemorrhage, and other lesions. The cryogenic source is a component of the cryotherapy device. Commonly used cryogens include CO_2 and N_2O due to their low cost, with CO_2 being most widely used. Cryogens use the low temperatures generated due to continuous heat absorption during vaporization to achieve the effects of cryotherapy. Cryogens absorb heat and are ultimately vaporized into CO_2 and N_2O gases, which can easily diffuse within the operating theater and cause waste gas pollution, resulting in certain hazards to healthcare workers if inhaled.

N_2O is a colorless gas with a sweet odor that is stable at room temperature and has mild anesthetic effects. It is commonly used to induce anesthesia in surgeries. The exposure limit to N_2O as a waste anesthetic gas recommended by NIOSH is 25 ppm (46 mg/m^3) (37). N_2O primarily produces its effects via inhalation. At high concentrations, N_2O causes asphyxiation; at low concentrations, it affects the central nervous system, cardiovascular system, liver, hematopoietic system, and reproductive system (38). An N_2O concentration of 50–67% (500,000–670,000 ppm) is used to induce anesthesia. Studies of dentists and assistants have reported that long-term occupational exposure to N_2O can result in limb numbness, difficulty concentrating, abnormal sensations, and impaired balance (38).

Although there are currently no studies related to the measurement and investigation of cryogen waste gases produced during bronchoscopic cryotherapy, it is still necessary to implement protective measures to reduce the occupational exposure to N_2O, such as the installation of waste gas evacuators, use of diluters, and use of personal protection. Currently, bronchoscopy rooms are usually connected to evacuators that dispose of cryogen waste gases, thereby reducing their indoor concentrations. However, the effects on outdoor air pollution and the risks to the outdoor population require further investigation. CO_2, which is less costly and safer, may be used to avoid occupational N_2O exposure.

Conclusions

Interventional diagnostic and treatment techniques for respiratory diseases have become ubiquitous in clinical applications. The rapid development of these techniques and the achievement of good results are accompanied by the increasing issues of occupational exposure and hazards experienced by healthcare workers. This review analyzed the occupational exposure of healthcare workers in interventional pulmonology to radiation exposure, smoke pollution, laser radiation, pathogenic aerosols, disinfectants, and cryogenic gases, and discussed the related protective measures.

In China, the occupational exposure and protection of healthcare workers in interventional pulmonology has been neglected. Although certain expert consensus and guidelines for occupational exposure have been established and related studies have been conducted, there is still a lack of emphasis on this topic. This topic urgently requires the continued collaboration of healthcare workers in interventional pulmonology, with reference to interventional medicine in other disciplines, to conduct additional research to establish standards for occupational exposure, hazards, and protection in interventional pulmonology.

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