Journal of Namibian Studies, 31 S2 (2022): 310-332 ISSN: 2197-5523 (online)

Aerosol Generating Procedures And Associated Control/Mitigation Measures: A Comprehensive Review

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Abstract:

Aerosol generating procedures (AGPs) have come under increased scrutiny due to their potential to spread infectious diseases, particularly in the context of the COVID-19 pandemic. AGPs are medical procedures that can produce airborne particles, posing risks to healthcare workers and patients. This article provides a comprehensive review of AGPs and the associated control and mitigation measures.

The types of AGPs, including respiratory procedures, surgical procedures, and cardiopulmonary resuscitation, are discussed, along with the mechanisms of aerosol generation. The risk of infectious disease transmission during AGPs is explored, with evidence from various studies highlighting the potential for the spread of respiratory viruses, bacteria, and other pathogens. To minimize the risks associated with AGPs, a multi-faceted approach involving engineering controls, administrative controls, and personal protective equipment (PPE) is necessary. Engineering controls, such as negative pressure rooms and high-efficiency particulate air (HEPA) filtration, aim to reduce the spread of aerosols. Administrative controls, including patient screening, isolation precautions, and staff training, focus on minimizing exposure and modifying work practices. PPE, such as respirators, eye protection, and gowns, acts as a barrier to prevent inhalation and contact with infectious particles. However, challenges exist in implementing these control measures effectively, including PPE shortages, staff compliance, and infrastructure limitations. Ongoing research is crucial to better understand the characteristics of aerosols generated during AGPs and to develop innovative control strategies. This article emphasizes the importance of a collaborative approach among healthcare organizations, policymakers, and researchers to prioritize the safety of healthcare workers and patients during AGPs and to ensure the effective implementation of evidence-based control measures.

Introduction:

Aerosol generating procedures (AGPs) have gained significant attention in recent years, particularly in the context of healthcare settings and infectious disease transmission [1]. AGPs are medical procedures that can produce airborne particles, or aerosols, which have the potential to spread infectious agents and pose risks to healthcare workers and patients [2,3]. With the emergence of highly infectious respiratory diseases, such as COVID-19, the importance of understanding AGPs and implementing effective control and mitigation measures has become increasingly evident [4,5].

AGPs encompass a wide range of procedures, including intubation, extubation, bronchoscopy, non-invasive ventilation, and cardiopulmonary resuscitation, among others [6,7]. These procedures can generate aerosols containing infectious particles that can remain suspended in the air for prolonged periods and travel considerable distances, increasing the risk of transmission [8]. The potential for aerosol generation varies depending on the specific procedure, the patient's condition, and the equipment used [9].

The risk of infectious disease transmission associated with AGPs has been well-documented in various healthcare settings [10]. Studies have shown that healthcare workers involved in AGPs are at a higher risk of contracting respiratory infections compared to those not involved in such procedures [11,12]. The transmission of infectious agents via aerosols has been implicated in outbreaks of diseases such as severe acute respiratory syndrome (SARS), influenza, and more recently, COVID-19 [13,14].

Given the potential risks associated with AGPs, it is crucial to implement effective control and mitigation measures to protect healthcare workers and prevent the spread of infectious diseases [15]. These measures encompass a range of strategies, including engineering controls, administrative controls, and personal protective equipment (PPE) [16]. Engineering controls focus on reducing the generation and dispersion of aerosols through methods such as negative pressure rooms, high-efficiency particulate air (HEPA) filtration, and aerosol containment devices [17,18]. Administrative controls involve policies and procedures aimed at minimizing exposure, such as patient screening, isolation precautions, and staff training [19].

PPE is a critical component of protecting healthcare workers during AGPs [20]. Respiratory protection, such as N95 respirators or powered air-purifying respirators (PAPRs), is essential to prevent the inhalation of infectious aerosols [21]. Other PPE includes gowns, gloves, eye protection, and face shields, which provide barriers against contact with contaminated surfaces and bodily fluids [22].

Despite the availability of control and mitigation measures, challenges remain in effectively implementing them in healthcare settings [23]. Issues such as PPE shortages, inadequate staff training, and non-compliance with infection control protocols have been identified as barriers to optimal protection during AGPs [24,25]. Additionally, the rapid evolution of infectious diseases, such as the emergence of new variants, highlights the need for ongoing research and adaptation of control measures [26].

This article aims to provide a comprehensive review of AGPs and the associated control and mitigation measures. It will explore the various types of AGPs, the mechanisms of aerosol generation, and the evidence supporting the risk of infectious disease transmission. Furthermore, it will discuss the different strategies and technologies available for controlling and mitigating the risks associated with AGPs, including engineering controls, administrative controls, and PPE. The challenges and considerations in implementing these measures will also be addressed, along with future directions for research and practice.

Types of Aerosol Generating Procedures:

AGPs encompass a wide range of medical procedures that have the potential to generate aerosols containing infectious particles [27]. These procedures can be classified into different categories based on the mechanism of aerosol generation and the level of risk associated with them [28]. Understanding the types of AGPs is crucial for developing targeted control and mitigation strategies.

Respiratory Procedures:

Respiratory procedures are among the most commonly recognized AGPs. These procedures involve the manipulation of the airway or respiratory tract, which can lead to the generation of aerosols [29]. Examples of respiratory AGPs include:

1. Intubation and Extubation: Intubation involves the insertion of an endotracheal tube into the patient's airway, while extubation is the removal of the tube [30]. These procedures can generate aerosols due to the manipulation of the airway and the potential for coughing or gagging [31].

2. Bronchoscopy: Bronchoscopy is a procedure that involves the insertion of a flexible tube with a camera into the patient's airways to visualize the lungs and collect samples [32]. The procedure can generate aerosols through the manipulation of the airways and the use of suction [33].

3. Non-Invasive Ventilation (NIV): NIV refers to the delivery of ventilatory support through a mask or other interface without the need for intubation [34]. Aerosol

generation can occur due to the high gas flow and potential leakage around the mask [35].

4. Tracheostomy: Tracheostomy involves creating an opening in the neck to insert a tube directly into the trachea [36]. The procedure can generate aerosols during the insertion and removal of the tube, as well as during suctioning [37].

5. Nebulizer Treatment: Nebulizers are devices that convert liquid medication into a fine mist for inhalation [38]. The use of nebulizers can generate aerosols containing medication and potentially infectious particles [39].

Surgical Procedures:

Certain surgical procedures can also generate aerosols, particularly those involving high-speed devices or procedures in the respiratory tract [40]. Examples include:

1. Dental Procedures: Dental procedures, such as drilling, scaling, and root planing, can generate aerosols containing saliva, blood, and other oral fluids [41]. These aerosols can potentially carry infectious agents [42].

2. Orthopedic Procedures: Orthopedic procedures involving high-speed cutting tools, such as saws and drills, can generate aerosols containing bone particles and other debris [43]. While the risk of infectious transmission may be lower compared to respiratory procedures, appropriate precautions are still necessary [44].

3. Laparoscopic Surgery: Laparoscopic surgery involves the use of insufflation gas to create space in the abdominal cavity [45]. The release of this gas during the procedure can generate aerosols, although the risk of infectious transmission is considered low [46].

Cardiopulmonary Resuscitation (CPR):

CPR is a life-saving procedure that involves chest compressions and rescue breaths to maintain circulation and oxygenation in a patient with cardiac arrest [47]. The performance of CPR can generate aerosols through the compression of the chest and the delivery of rescue breaths [48]. The risk of infectious transmission during CPR has been a concern, particularly in the context of highly infectious diseases [49].

Mechanisms of Aerosol Generation:

Understanding the mechanisms of aerosol generation during AGPs is essential for developing effective control and mitigation strategies. Aerosols are generated through various physical processes, including [50]:

1. Mechanical Disruption: Mechanical disruption occurs when a procedure physically disturbs a surface or liquid, resulting in the release of aerosols [51]. This can happen during procedures such as intubation, extubation, or dental drilling [52].

2. Air Turbulence: Air turbulence can generate aerosols by dispersing particles from surfaces or liquids [53]. Procedures that involve high-flow oxygen or gas, such as non-invasive ventilation or nebulizer treatment, can create turbulent airflow and generate aerosols [54].

3. Cavitation: Cavitation refers to the formation and collapse of vapor cavities in a liquid due to rapid changes in pressure [55]. This process can generate aerosols when the cavities collapse near the surface of a liquid, such as during dental scaling or surgical procedures [56].

4. Evaporation: Evaporation of liquids can lead to the formation of aerosols as the liquid droplets transition to a gaseous state [57]. This mechanism may be relevant in procedures involving the use of liquids or bodily fluids [58].

Risk of Infectious Disease Transmission:

The risk of infectious disease transmission associated with AGPs has been a significant concern in healthcare settings. Numerous studies have investigated the transmission of various infectious agents during AGPs, providing evidence of the potential risks [59].

1. Respiratory Viruses: Respiratory viruses, such as influenza, SARS, and COVID-19, have been shown to be transmitted through aerosols generated during AGPs [60,61]. Healthcare workers involved in AGPs have been found to have a higher risk of infection compared to those not involved in such procedures [62,63].

2. Bacterial Infections: AGPs can also contribute to the transmission of bacterial infections, such as tuberculosis [64]. Procedures involving the respiratory tract, such as bronchoscopy or intubation, have been associated with an increased risk of tuberculosis transmission to healthcare workers [65,66].

3. Bloodborne Pathogens: While the risk of bloodborne pathogen transmission during AGPs is generally considered lower compared to respiratory pathogens, it cannot be completely excluded [67]. Procedures that involve exposure to blood or bodily fluids, such as dental procedures or surgical interventions, may pose a risk of transmission of pathogens like hepatitis B virus (HBV) or human immunodeficiency virus (HIV) [68,69].

The risk of transmission during AGPs is influenced by several factors, including the infectivity of the pathogen, the duration and intensity of exposure, the proximity to the source of aerosols, and the effectiveness of control measures in place [70]. Healthcare workers in close proximity to the patient during AGPs, such as anesthesiologists or dental professionals, may be at a higher risk of exposure [71,72].

Control and Mitigation Measures:

To minimize the risk of infectious disease transmission associated with AGPs, a comprehensive approach involving multiple control and mitigation measures is necessary [73]. These measures can be categorized into engineering controls, administrative controls, and personal protective equipment (PPE) [74].

Engineering Controls:

Engineering controls focus on reducing the generation and dispersion of aerosols at the source [75]. These controls involve physical barriers, ventilation systems, and aerosol containment devices [76]. Examples of engineering controls include:

1. Negative Pressure Rooms: Negative pressure rooms are designed to maintain a lower air pressure inside the room compared to the surrounding areas, preventing the escape of aerosols [77]. These rooms are equipped with specialized ventilation systems that filter and exhaust the air, reducing the risk of transmission [78].

2. High-Efficiency Particulate Air (HEPA) Filtration: HEPA filters are designed to capture particles as small as 0.3

microns with a high level of efficiency [79]. The use of HEPA filters in ventilation systems can help remove infectious aerosols from the air, reducing the risk of transmission [80].

3. Aerosol Containment Devices: Aerosol containment devices, such as intubation boxes or aerosol shields, are designed to create a physical barrier between the healthcare worker and the source of aerosols [81]. These devices can help minimize the dispersion of aerosols during procedures like intubation or dental treatment [82].

Administrative Controls:

Administrative controls involve policies, procedures, and protocols aimed at minimizing exposure to infectious aerosols [83]. These controls focus on modifying work practices and managing patient care activities to reduce the risk of transmission [84]. Examples of administrative controls include:

1. Patient Screening and Triaging: Implementing screening protocols to identify patients with suspected or confirmed infectious diseases can help prioritize and allocate appropriate resources for AGPs [85]. Triaging patients based on their risk level can guide the selection of appropriate control measures and PPE [86].

2. Isolation Precautions: Establishing isolation precautions for patients undergoing AGPs can help minimize the spread of infectious aerosols [87]. This may involve placing patients in single rooms, implementing airborne precautions, and restricting non-essential personnel from the area [88].

3. Staff Training and Education: Providing comprehensive training and education to healthcare workers on the risks associated with AGPs and the proper use of control measures is crucial [89]. Regular training sessions, competency assessments, and simulation exercises can help ensure that healthcare workers are prepared to safely perform AGPs [90].

4. Minimizing AGPs: Evaluating the necessity of AGPs and considering alternative procedures or techniques that generate fewer aerosols can help reduce the overall risk of transmission [91]. This may involve using closed

suctioning systems, avoiding unnecessary bronchoscopies, or utilizing non-invasive ventilation when appropriate [92].

Personal Protective Equipment (PPE):

PPE is a critical component of protecting healthcare workers during AGPs [93]. PPE acts as a barrier to prevent the inhalation of infectious aerosols and contact with contaminated surfaces or bodily fluids [94]. The selection and use of appropriate PPE should be based on the specific AGP being performed and the level of risk associated with it [95].

1. Respiratory Protection: Respiratory protection, such as N95 respirators or powered air-purifying respirators (PAPRs), is essential during AGPs to prevent the inhalation of infectious aerosols [96]. N95 respirators filter out at least 95% of airborne particles when properly fitted and used [97]. PAPRs provide an even higher level of protection by delivering filtered air through a hood or helmet [98].

2. Eye Protection: Eye protection, such as goggles or face shields, is necessary to prevent the entry of infectious aerosols through the mucous membranes of the eyes [99]. Face shields provide additional protection by covering the entire face and preventing contact with contaminated surfaces [100].

3. Gowns and Gloves: Gowns and gloves serve as barriers to prevent contact with contaminated surfaces and bodily fluids [101]. Fluid-resistant gowns and gloves should be used during AGPs to minimize the risk of exposure [102].

4. Donning and Doffing Procedures: Proper donning (putting on) and doffing (taking off) procedures for PPE are critical to ensure maximum protection and prevent self-contamination [103]. Healthcare workers should be trained on the correct sequence and techniques for donning and doffing PPE specific to AGPs [104].

Challenges and Considerations:

Despite the availability of control and mitigation measures, implementing them effectively in healthcare settings can be challenging [105]. Several factors can impact the successful implementation and adherence to these measures [106].

1. PPE Shortages: During outbreaks or pandemics, the demand for PPE can outstrip the supply, leading to shortages [107]. Limited availability of appropriate PPE can compromise the safety of healthcare workers and hinder the implementation of control measures [108].
2. Staff Training and Compliance: Ensuring that all healthcare workers receive adequate training on the use of control measures and PPE can be challenging, especially in resource-limited settings [109]. Non-compliance with infection control protocols, improper donning and doffing techniques, and inconsistent use of PPE can undermine the effectiveness of control measures [110].
3. Facility Infrastructure: Implementing engineering controls, such as negative pressure rooms or HEPA filtration systems, may require significant infrastructure modifications and financial investments [111]. Healthcare facilities with limited resources may face challenges in implementing these controls effectively [112].
4. Evolving Evidence and Guidelines: The evidence surrounding AGPs and the associated risks of transmission is continually evolving, particularly in the context of emerging infectious diseases [113]. Keeping up with the latest research findings and updating guidelines and protocols accordingly can be challenging for healthcare organizations [114].

Future Directions:

Ongoing research and innovation are crucial to enhance the understanding of AGPs and improve the effectiveness of control and mitigation measures [115]. Some key areas for future research and development include:

1. Aerosol Characterization: Further research is needed to characterize the properties of aerosols generated during different AGPs, including particle size distribution, concentration, and infectivity [116]. This knowledge can inform the development of targeted control measures and risk assessment strategies [117].
2. PPE Design and Innovation: Advances in PPE design and materials can improve the comfort, fit, and protection level for healthcare workers [118].

Innovations such as powered air-purifying respirators with integrated face shields or self-decontaminating fabrics can enhance the safety and usability of PPE [119].

3. Aerosol Containment Technologies: The development of novel aerosol containment devices and technologies can help minimize the dispersion of infectious aerosols during AGPs [120]. Examples include portable negative pressure systems, aerosol suction devices, and air disinfection technologies [121].

4. Simulation and Training: Incorporating simulation-based training and virtual reality technologies can enhance the training and competency assessment of healthcare workers in performing AGPs safely [122]. Realistic simulations can provide opportunities for hands-on practice and improve preparedness for real-world scenarios [123].

5. Infection Control Guidelines: Regularly updating and disseminating evidence-based infection control guidelines specific to AGPs is essential to ensure that healthcare organizations have access to the latest recommendations [124]. Collaborative efforts among professional societies, public health agencies, and healthcare institutions can facilitate the development and implementation of standardized guidelines [125].

Conclusion:

AGPs pose significant risks for the transmission of infectious diseases in healthcare settings. The potential for aerosol generation and the associated risks of infection transmission highlight the importance of implementing comprehensive control and mitigation measures. A multi-faceted approach involving engineering controls, administrative controls, and appropriate PPE is necessary to protect healthcare workers and prevent the spread of infectious agents.

However, challenges exist in effectively implementing these measures, including PPE shortages, staff training and compliance issues, and resource constraints. Ongoing research and innovation are essential to address these challenges and improve the understanding of AGPs and the effectiveness of control measures.

Healthcare organizations, policymakers, and researchers must collaborate to prioritize the safety of healthcare workers and patients during AGPs. Investing in research, infrastructure, and training programs is crucial to enhance preparedness and response capabilities for infectious disease outbreaks and ensure the consistent application of evidence-based control measures.

As the healthcare landscape continues to evolve and new infectious threats emerge, it is imperative to remain vigilant and proactive in addressing the risks associated with AGPs. By staying informed about the latest research findings, adopting best practices, and fostering a culture of safety, healthcare organizations can better protect their workforce and provide high-quality care to patients.

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