The effect of airflow on HAIs risk in hospital: a review

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Abstract. HAIs (Healthcare Associated Infections) are infections that are acquired when a person (host) receives health services that result in increased cost, extended Length Of Stay, and even death. This paper review a way to reduced the risk of airborne HAIs transmission based on a number of journals on management that regulates incoming and outgoing air to eliminate or reduce the number of infectious agents in indoor air to reduce the incidence of HAIs through indoor air management in health care. Ensuring that indoor air quality is good with sufficient ACH and low AOA, so that it is safe for patients, staff, and others who are at the health care location.

1 Introduction

Infection is a condition in which a host is exposed to an infectious agent, where the infectious agent invades and multiplies within the host [1]. The occurrence of infection can happen anywhere when there is a possibility of contact between the infectious agent and the host, and it can also occur during healthcare treatment in a hospital, thus becoming a Healthcare Associated Infection (HAIs) [2][3]. HAIs are undesirable events that have the potential to incur additional costs due to added diagnoses or prolonged length of stay, or even death, so efforts are made to prevent them from occurring, even though their presence is difficult to eliminate and the incidence rate remains quite high both globally and in Indonesia [4][5][6].

The occurrence of HAIs happens during the patient care process where the incubation period does not occur when the patient has entered the care period and does not happen when they first enter the hospital [7][8][9][10][11]. Even in certain areas, it has become a location for the transmission of specific diseases that are currently a concern in those areas, such as tuberculosis [12].

HAIs are still one of the health problems in various countries around the world (WHO, 2016) with a global proportion of 9% of all inpatient patients [13]. HAIs have a direct impact as an economic burden on the country (APEC, 2013) with morbidity and mortality still high

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worldwide throughout 2016. There were 37,000 deaths recorded in Europe and 99,000 deaths in the United States due to HAIs. 4%–56% of all causes of death in neonates, with an incidence rate of 75% in Southeast Asia and Sub-Saharan Africa [14][15].

The same events also occurred in Latin America, Asia, and Africa. In 2016, the World Health Organization (WHO) reported that the incidence rate of HAIs reached 19.1%. In Europe, 4.5 million patients experience HAIs each year, and in the United States, there are 1.7 million HAIs annually. The Centers for Disease Control and Prevention (CDC) from 50 countries also shows a high incidence rate of HAIs in several areas, such as in the intensive care unit (45%) and in the Neonatal Intensive Care Unit (NICU) (8%), and in the Intensive Care Unit (ICU) (41%) (CDC, 2012). Meanwhile, the incidence rate of HAIs occurring in Indonesia is 15.74%, which is worse compared to developed countries that range from 4.8-15.5% [16]

According to the Indonesian Minister of Health, people in the hospital environment, such as patients, health workers, and attendants/visitors are at high risk of being infected by infectious agents [17]. So far, hospitals have become a place for interaction between healthy and sick individuals, so they have the potential to cause environmental pollution and health problems [18][19].

HAIs that often occur in hospitals can mostly be classified into groups of HAIs caused by infusions, urinary tract infections due to catheters, surgical site infections, and respiratory infections [7][20]. HAIs can be transmitted in ways that correspond to the infectious nature of the microorganisms involved. The infectious agents responsible for HAIs can include bacteria, viruses, parasites, or pathogenic fungi, among others. The transmission or spread of these infectious agents is influenced by the virulence of the infectious agent in invading the host, combined with the opportunities available for such invasion to occur. In general, an infection can be transmitted through direct contact or droplet transmission [21][22]. It can even occur indirectly, namely through a vector or vehicle, and in this case, the free air serves as a significant vehicle for the transmission of infectious agents that can be transmitted through the air from an individual carrying the infectious agent to the target individual of infection, where the infectious agents carried in aerosols can remain in indoor air for a considerable period of time until there is host-pathogen agent contact that results in the emergence of HAIs [22]. The transmission of infectious agents causing HAIs is more likely to occur during a surge in the number of patients, especially during a pandemic, particularly in low end class wards during visiting hours, even though regulations have been implemented stating that the room area should be 80-110m2 per bed [23]. This paper reviews efforts to reduce the risk of HAIs by controlling environmental factors in hospitals.

2 Airborne disease

Transmission of infectious agents with the help of air vehicles or what is known as airborne disease occurs due to the mechanism of contact of infectious agents from the air that enters through the movement of room air from individuals carrying infectious agents to target individuals for infection and enters through the respiratory tract during inspiration or enters through surgical wounds. This incident is difficult to prevent considering that respiration and surgical procedures in hospitals are absolute necessities. The result is that HAIs occur, and airborne disease is quite difficult to prevent considering that the air in the hospital room has been contaminated with infectious agents so that HAIs transmission is very possible, especially since HAIs through the air are ⅓ of the total number of HAIs [24][25].

On the other hand, in a hospital there are many interactions between patients, medical personnel, non-medical personnel, attendants, delivery people, traders and visitors or other personnel, making the interaction between individuals in the hospital even greater, making HAIs more likely to occur. In general, a classical model of infectious disease is the result of interactions between infectious agents, host factors and the environment [26][27].

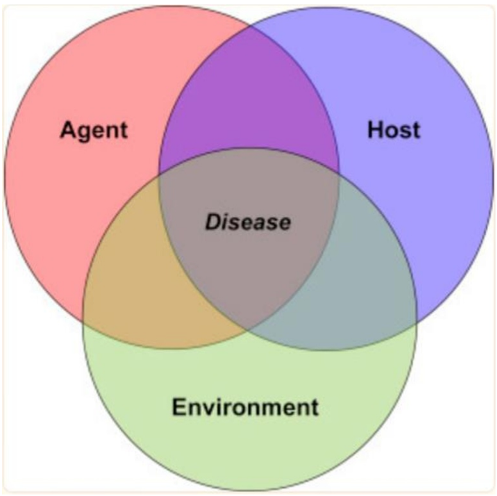

Fig. 1. Agent-host-environment interactions [26]

There are 3 main factors that cause HAIs, namely 1. Environmental conditions; 2. Patient conditions and susceptibility; 3. Lack of knowledge and awareness of health service providers and medical workers [14][28]. From this understanding, it can be seen that there are environmental factors that can be the key to transmitting infections, so if you want to control HAIs transmission, you must control the environmental factors related to it. To deal with airborne disease, NIOSH (National Institute for Occupational Safety and Health) even prioritizes environmental aspects over other aspects [29]

3 Infectious agents in room

Fundamentally different from bacteria that can live outside the host, a virus can only survive if it is inside the host. When outside the host, viruses and bacteria can survive for several hours to days, even bacteria can survive longer because bacteria can live outside the host. The longer outside the host for some types of viruses will reduce their virulence and eventually die. So effective transmission occurs when social contact occurs in the same room with air conditions that do not flow or rotate smoothly to be replaced by new air, because before dying in the open air or before successfully infecting a new host, a virus in the room will be able to survive floating in the room's aerosol for several hours [30]. High temperatures can kill viruses and this technique is used to sterilize medical equipment combined with other techniques such as the use of chemicals, filters to the use of radiation including ultraviolet (UV). UVA with a wavelength of 315-400nm and UVB with a wavelength of 280-315nm can effectively kill viruses, but UVC with a wavelength of 200-280nm is the one that is very potent in killing viruses [31]

In practice, the opportunity to eliminate viruses easily and quickly from inside the treatment room is by moving the virus from inside the room to outside so that the virus dies naturally exposed to UV sunlight or by utilizing artificial UV when the room is not in operation, especially at night. The use of high temperatures and chemicals cannot always be applied considering the damage that occurs as a result, so the use of airflow to eliminate or reduce the concentration of infectious agents is a fairly good choice.

4 Age of air: an environmental factor to be controlled

There is a strong relationship between ventilation, air flow control and transmission of infectious agents, so negative pressure is applied to isolation rooms in the hope of preventing transmission [32]. What mainly influences airborne transmission (apart from immune factors) is the distance from the source of the infectious agent to the host, interaction, air flow (speed and distance), air quality, density of the infectious agent in the air and age of air (AOA). All of these can pose a risk of transmission that can be reduced by keeping the air flow stable and always renewed by maintaining the balance of inlet and outlet air flow so that the indoor air remains relatively new or the lower AOA by the mixing/dilution and replacement mechanisms. The faster of the air changes make the lower density of the infectious agents in the room [33][34].

Air flow is also greatly influenced by both of the temperature gap and the pressure gap. [35] The air flow is directly proportional to the pressure gap that occurs, the higher of the pressure gap, the faster the airflow and be replaced with new air and vice versa, the smaller of the pressure gap will cause a delay in air exchange. The same way with the temperature gap, more temperature gap cause more air mixing and replacement as the smaller temperature gap will cause a delay in air mixing. Air mixing itself means dilution or reduction of the infectious agents concentration in room and air replacement a shorter AOA. The straighter and shorter inlet to outlet distance, make more efficient of the air exchange and lowering the AOA.

5 Direction and air change

The basic thing about indoor air velocity is about its direction and speed [36]. Several research results show that safe air flow in the treatment room must be high in flow rate [24] The turnover rate above 2ACH (air change per hour) is considered the best parameter to prevent HAIs. Increasing the ventilation rate from 2.5 to 5.5 ACH was only able to increase the removal of 30% of aerosols. Even to reduce the concentration and exposure time of infectious agents in patients and officers, ASHRAE 170 recommends 6-12ACH for infectious isolation rooms. Although a higher air turnover rate is believed to be able to dilute indoor agent contaminants, it has not been able to eliminate the risk of cross-infection in the room air and must still take into account the direction of the indoor air path [24].

Air flow has been shown to reduce the risk of nosocomial infections by removing and diluting the concentration of infectious agents in the air. The purpose of air change is to remove old air containing infectious agents in the room so that it is replaced by new air that is free of infectious agents. The air mixing mechanism will change the concentration of air content in the room so that the concentration of infectious agents decreases, while differences in temperature, wind speed and direction can influence the mixing and replacement of air in a room, if the temperature difference is large enough it will lead to a mixing effect, and if it is not too large it will lead more to an air replacement effect [33]

The event of air mixing and air exchange can be fulfilled naturally or with the help of mechanical air and temperature regulators or better known as HVAC (heating ventilation and air-conditioning) but ideally it is directional and laminar. It's cause the air moves from inlet point to the outlet, the direction of the movement can change with other stimuli on the path. [24][37][38][39].

This is the differences in the design or position of the air inlet and outlet can make differences in the speed and airflow [40]. This is where the importance of window design, number and windows position, and the number size and position of blowers lies because they will affect to the wind direction, wind path, temperature and air humidity, that make more safe from HAIs.

6 Optimization of Indoors With Natural and Mixed Air Flow

Indoors air plays a role of the infectious agents growth and their spread, as the ventilation plays a role in the spread and cross-infection of infectious agents [19]. The humidity, temperature, lighting and airflow involvethe growth of infectious agents [10][41]. Techniques for mixing and changing air can work by naturally, mechanically or in combination. Mechanically airflow can be d+one with a blower or with HVAC which is indeed used for several basic purposes, for temperature comfort, odor control, removing contaminants and protecting against HAIs [42][43][44].

Unlike natural airflow, artificial airflow can be done with a certain design that can guarantee the airflow speed that is adjusted to the surrounding environmental conditions. Although natural airflow has the potential to eliminate infectious agents more than mechanical airflow, but the mechanical airflow, created the negative pressure is possible which is very important in certain conditions. The risk of transmission can be formulated using the following formula [46] :

$$P = \frac{Case}{S} = 1 - e^{-\frac{Iqpt}{Vn}} \tag{1}$$

Note :
P : risk of airborne transmitted diseases
p : pulmonary ventilation rate (m3/h)
n : ACH
q : quanta/h
v : volume (m3)
t : time (h)

Passive airflow ventilation for two heights gap can be estimated using the equation below :

$$Qs = CdA\sqrt{2gHd\frac{Ti - To}{Ti}} \tag{2}$$

Note :
Qs : Buoyancy-driven ventilation airflowrate (m^3/s)
A : cross-sectional area of opening, (m^2) – assumes equal area for inlet and outlet
Cd : Discharge coefficient for opening (typical value is 0,62)
g : gravitational accelaration on earth (9,81 m/s^2)
Hd : Height from midpoint of lower opening to midpoint of upper opening (m)
Ti : Average indoor temperature between the inlet and outlet (K)
To : Outdoor temprature (K)

6 Conclusion

An effective step to reduced the risk of HAIs is to create optimum airflow (sufficient ACH) which will help eliminate or reduce the levels of infectious agents by improving air age so that the air is always new (low AOA) so that the balance of inlet and outlet airflows must be always be maintained in the Hospital. This makes it possible to conduct further research on AOA, especially for rooms with mixed mechanical and natural airflow whose speed and direction are always changing. In addition, it can also be an input for hospital management practitioners to reduce the risk of HAIs in all rooms, both treatmen rooms and support rooms, because infection transmission does not only occur in rooms where there are patiens, but in all rooms in the hospital [47][48][49][50][51].

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