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Major Article

An assessment of outpatient clinic room ventilation systems and possible relationship to disease transmission

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Background: With healthcare shifting to the outpatient setting, this study examined whether outpatient clinics operating in business occupancy settings were conducting procedures in rooms with ventilation rates above, at, or below thresholds defined in the American National Standards Institute/American Society of Heating, Refrigerating and Air-Conditioning Engineers/American Society for Health Care Engineering Standard 170 for Ventilation in Health Care Facilities and whether lower ventilation rates and building characteristics increase the risk of disease transmission.

Methods: Ventilation rates were measured in 105 outpatient clinic rooms categorized by services rendered. Building characteristics were evaluated as determinants of ventilation rates, and risk of disease transmission was estimated using the Gammaitoni-Nucci model.

Results: When compared to Standard 170, 10% of clinic rooms assessed did not meet the minimum requirement for general exam rooms, 39% did not meet the requirement for treatment rooms, 83% did not meet the requirement for aerosol-generating procedures, and 88% did not meet the requirement for procedure rooms or minor surgical procedures.

Conclusions: Lower than standard air changes per hour were observed and could lead to an increased risk of spread of diseases when conducting advanced procedures and evaluating persons of interest for emerging infectious diseases. These findings are pertinent during the SARS-CoV-2 pandemic, as working guidelines are established for the healthcare community.

BACKGROUND

Outpatient healthcare clinics are physically located in various settings such as hospital outpatient departments, ambulatory surgery centers, free-standing urgent care or emergency departments, retail clinics, and physician offices.[1] Outpatient clinics are providing an increased range of services, from general exams to minor surgical procedures.[2] In turn, these services may carry with them an associated set of infectious disease exposure risks. Humans can generate airborne transmission of microorganisms by talking, breathing, sneezing or coughing, or through procedures such as colonoscopies, tracheal intubation, suction during intubation, delivery of oxygen, bronchoscopy, and noninvasive ventilation,[3] or during suctioning of body fluids, endotracheal aspiration, nebulizer treatment, and collection of sputum.[4]

The Facility Guidelines Institute establishes guidelines for the planning, design and construction of hospitals, outpatient facilities, and residential healthcare and support facilities for the development of safe health and residential care-built environments.[5] The American National Standards Institute (ANSI), the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the American Society for Health Care Engineering (ASHE)'s joint Standard 170 for Ventilation in Health Care Facilities incorporates the Facility Guidelines Institute definitions and set the minimum requirements intended for adoption by code-enforcing agencies[6] as defined in Table 1. The International Building Code and National Fire Protection Association are the primary construction codes and classify building types based on the occupants' ability to evacuate the building in emergencies rather than the activities performed within the building. Because the outpatient clinics generally have less than 5 patients incapable of self-preservation in an emergency, the clinics are

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Table 1
ANSI/ASHRAE/ASHE standard 170 for ventilation in health care facilities

Function of space	Minimum total air changes per hour (ACH)	Pressure relationship to adjacent areas
General examination room*	4	No requirement
Treatment room†	6	No requirement
Procedure room‡	15	Positive
Bronchoscopy, sputum collection, and pentamidine administration	12	Negative

ACH, air changes per hour; *ANSI*, American National Standards Institute; *ASHE*, American Society for Health Care Engineering; *ASHRAE*, American Society of Heating, Refrigerating and Air-Conditioning Engineers.
*room used for clinical exam and vitals.
†exam room used for additional function (treatment or procedure).
‡not restricted environment but sterile instruments or field used.

typically classified as business (Group B) occupancy. As health care specific building codes would not normally pertain to business occupancy, it is unclear if the health care ventilation standards are integrated into outpatient clinic design or lease agreements in these types of buildings. With more medical procedures transitioning to the outpatient setting, experts are concerned that clinic designs should include ventilation standards based on the provided outpatient services,[7] the challenges in implementing the ventilation standards due to shared patient care areas and administrative spaces,[8] and the need for building occupancy code changes.[9] Several studies have shown an association with low ventilation and disease transmission in outpatient clinics[10-14] and in hospital settings.[15-18] This study examined whether outpatient clinics operating in a business occupancy setting were conducting procedures in rooms with ventilation rates above, at, or below thresholds defined in the ANSI/ASHRAE/ASHE Standard 170 for Ventilation in Health Care Facilities and whether lower ventilation rates and building characteristics increase the risk of transmission of infectious disease.

METHODS

In this study, 105 clinic rooms were evaluated from 22 outpatient clinics of varying specialties associated with a medical practice group within a major US metropolitan area. Room ventilation was measured using a balometer (Alnor Balometer Capture Hood, TSI Incorporated, Shoreview, MN) to measure the cubic feet per minute at the air supply for each room. The following equation was used to calculate total air changes per hour (ACH = cubic feet per minute x [60/room volume ft^3]).[19] Indoor carbon dioxide (CO_2) in parts per million (ppm) was measured with an indoor air quality monitor (Q-TRAK Model 7575, TSI Incorporated, Shoreview, MN). Airflow direction was observed using a smoke tube (Dräger Air Current Tubes CH25301). Rate of air mixing was determined by generating a puff of smoke at the worker height breathing zone in the center of the clinic room and observing the time (in seconds) it took for the puff of smoke to disperse.

Each clinic room was assigned to a mutually exclusive building category. “Medical office building” was defined as the medical or dental clinic being the only occupants located within the building. “Shopping center” meant that the clinic was attached to nonmedical commercial buildings. “Stand-alone clinic” was defined as the clinic building not being attached to any other buildings. Building age, number of floors, and total clinic square footage was obtained from the building lease management office, websites or clinic lease agreements.

The Gammaitoni-Nucci model was used to estimate the risk of disease transmission based on measured ventilation rates. The average adult human respiration rate is 0.48 m^3/h; 12.7 quanta/h for *Mycobacterium tuberculosis*, 100 quanta/h for influenza, and 570 quanta/h for measles.[20,21]

Statistical analysis

We performed comparisons of ACH among room, procedure and building types using the Kruskal-Wallis test and Mixed-effects models, while using distribution plots to illustrate the variation in ACH graphically. The relationships between ACH and CO_2 and air mixing were determined using linear regression. The relationship between directional airflow and room type was determined using Fisher's Exact test. All graphs and statistical analyses were produced using STATA Statistical Software Version 16.0 (StataCorp, College Station, TX).

RESULTS

Air changes per hour

Among the 105 clinic rooms assessed, approximately half were identified as treatment rooms as the clinics provide a wide variety of services. Exam rooms were only used for general medical exams. Procedure rooms were labeled and identified, whereas treatment rooms were exam rooms where additional treatments or procedures were provided. Aerosol-generating procedures (AGP) included suctioning body fluids and air passageways, nebulizing medications, and sputum induction. Minor surgical procedures included skin biopsy and other dermatological procedures such as skin tag and wart removal, incision and drainage, loop electrosurgical excision procedure, fine needle aspiration, intrauterine device and Nexplanon insertion, colposcopy, and vein ablation. The median ACH was highest in procedure rooms, and thus minor surgical areas. Treatment rooms, which corresponds to rooms in which aerosol-generating procedures occurred, had approximately the same median ACH as exam rooms (Table 2). There was no statistically significant difference in ACH between room types (Kruskal-Wallis test $P = .89$) or procedure types (Kruskal-Wallis test $P = .73$).

Overall, 10% of the clinic rooms assessed did not meet the minimum ANSI/ASHRAE Standard 170 of 4 ACH for general exam rooms. This finding was not limited to a specific room or procedure type; 16% of exam, 9% of treatment and 8% of procedure rooms, 9% of rooms used for aerosol-generating procedures, and 6% of rooms used for minor surgeries did not meet the 4 ACH standard. Only 67% of treatment rooms met the minimum ANSI/ASHRAE Standard 170 of 6 ACH for treatment rooms. Only 9% of procedure rooms met the ANSI/ASHRAE Standard 170 of 15 ACH for procedure rooms. In rooms where aerosol-generating procedures occurred, only 15% met the ANSI/ASHRAE Standard 170 of 12 ACH for bronchoscopy, sputum collection, pentamidine administration and isolation (AII) rooms. Only 12% of

Table 2
Clinic rooms (n = 105)

	n	Median ACH	25th percentile	75th percentile
Room types				
Exam	25	6.8	4.7	11.6
Treatment	57	6.9	4.9	10.2
Procedure	23	7.6	4.4	11.3
Procedure types				
Aerosol-generating	63	7.0	5.1	9.9
Minor surgical	17	5.6	4.3	12.4
Building type				
Medical office building	45	7.6	5.0	11.5
Shopping center	30	5.9	4.3	7.9
Stand-alone	30	6.8	5.1	14.4

ACH, air changes per hour.

Table 3
Percentage of clinic rooms meeting the ANSI 170 standard by room and procedure type

	Air changes per hour					
	n	>4	4-6	6-12	12-15	<15
Room type						
Exam	25	16%	32%	32%	8%	12%
Treatment	57	9%	24%	51%	2%	14%
Procedure	23	8%	35%	39%	9%	9%
Procedure type						
Aerosol-generating	63	9%	21%	55%	2%	13%
Minor surgical	17	6%	53%	17%	12%	12%
All rooms	105	10%	29%	44%	5%	12%

ANSI, American National Standards Institute.

rooms where minor surgeries occurred met the ANSI/ASHRAE Standard 170 of 15 ACH for procedure rooms. Even if these procedures could be considered "treatment," only 41% of the rooms met the 6 ACH standards for treatment rooms. Shaded areas in Table 3 illustrate where the minimum standard was not met.

Other indications of ACH

All clinic rooms were within acceptable carbon dioxide values to indicate typical occupied indoor spaces with good air exchange (350-1,000 ppm), except for 2 exam rooms which were slightly above 1,000 ppm. A statistically significant relationship was observed between ACH and CO_2 (P= .02). For each 1-unit increase in CO_2, ACH increases by 0.008 units.

Good air mixing (smoke dispersal within 10 seconds) was observed in 10% of clinic rooms. Fair air mixing (smoke dispersal between 11 and 20 seconds) was observed in 28% of clinic rooms. Poor air mixing (smoke dispersal greater than 20 seconds) was observed in 62% of the clinic rooms. This trend is similar across room types. A statistically significant relationship was observed between ACH and Air Mixing (P< .001). For each 1 second increase in air mixing time, ACH decreased by 0.40 units.

Supply vent air moved towards the door in 68% of clinic rooms and towards the patient in 20% of clinic rooms. In 78% of clinic rooms, directional airflow at the door was into the room, with the remaining percentage having airflow out of the room. Air flowed from the patient towards the door in 46% of clinic rooms and 32% of clinic rooms indicate no direction, indicating no movement away from the patient/provider. This test imitated the generation of an aerosol from the patient. No significant association was determined between any directional airflow (from supply, at door and at patient) and the 3 room types (Fisher's exact test P = .42, P = .21, and P = .77, respectively).

Building characteristics

Exam, treatment and procedure rooms were equivalently allocated in medical office buildings but disproportionately favored treatment rooms in shopping center and stand-alone buildings. There was no statistically significant difference in median ACH and the 3 building types (Kruskal-Wallis test P = .06) or in the individual ACH between building types (mixed effects model, shopping center P = .14, stand-alone P =.68 compared to medical office building) (Table 2). Stand-alone buildings were the newest built (mean age 20 years) and medical office buildings were the oldest buildings (mean age 39 years). There was no statistically significant difference in median building age and the 3 building types (Kruskal-Wallis test P = .08) or in individual ACH between building age (mixed-effects model, P = .80). There was no statistically significant difference in individual ACH based on number of floors within the building (mixed-effects model, P = .20). There was no statistically significant difference in clinic square footage and the 3 building types (Kruskal-Wallis test P = .25) or in individual ACH between clinic square footage (mixed-effects model, P = .46) There was no statistically significant relationship observed from linear regressions between ACH and building age, floors or clinic square feet.

Gammaitoni-Nucci model for infectious disease transmission

In rooms with a minimum of 4 ACH, the transmission of tuberculosis to susceptible persons in the room for 15 minutes would be 32%, increasing to 78% at 1 hour. When increased to 6 ACH, the transmission rate for tuberculosis to susceptible persons decreases to 22% in a 15-minute exposure time, increasing to 64% at 1 hour. If rooms with 12 ACH are used to provide clinical services to tuberculosis patients, the transmission rate is 12% for 15-minute exposure time, increasing to 41% at 1 hour.

Transmission of influenza to susceptible persons in the room is 95% in rooms with a minimum of 4 ACH, 86% in rooms with 6 ACH, but reduces to 65% in rooms with 12 ACH for a 15-minute exposure time. Transmission increases to at or near 100% after an hour. Transmission of measles only slightly reduces from 100% with 15 AHC (Fig 1).

DISCUSSION

Overall, the results indicate that the evaluated outpatient clinics did not fully meet healthcare ventilation standards as listed in the Standard 170 for Ventilation in Health Care Facilities. Additional ventilation measurements and observations of air movement in these clinic rooms proved to be indicators of air changes per hour. Building characteristics were evaluated and were not found to be determinants of ventilation rates. Lastly, based on estimated infectious disease transmission risk, outpatient clinics may have an increased risk of transmission of infectious diseases due to the lack of ventilation.

Air measurements

This study confirmed that the included outpatient clinic settings are not designed to supply ventilation rates based on the types of procedures or services provided in specific rooms, even though the procedures being performed in these settings are increasingly complex and represent a potentially higher risk of infection. There was no difference in ACH by room type or procedures type. CO_2 measurements and air mixing rates can be used as indicators of ACH. No directional airflow observations were associated with a particular room type.

This study found a portion of outpatient clinic rooms failed to meet the ANSI/ASHRAE 170 minimum standards for ventilation in healthcare. Lower ACH in outpatient clinic rooms conducting more advanced procedures can lead to an increased risk of spread of infectious diseases. We echo the concern that ventilation standards are not being met and should be integrated into clinic design and reaffirms that there are challenges in compliance with ventilation standards in nonhospital settings.

Building characteristics

Building characteristics, types, age, number of floors, and clinic square footage were not associated with ACH. However, clinic rooms in stand-alone buildings had higher ACH than rooms in shopping centers or medical office buildings. Stand-alone buildings were newer than the other building types and similar to shopping center buildings with fewer floors than medical office buildings.

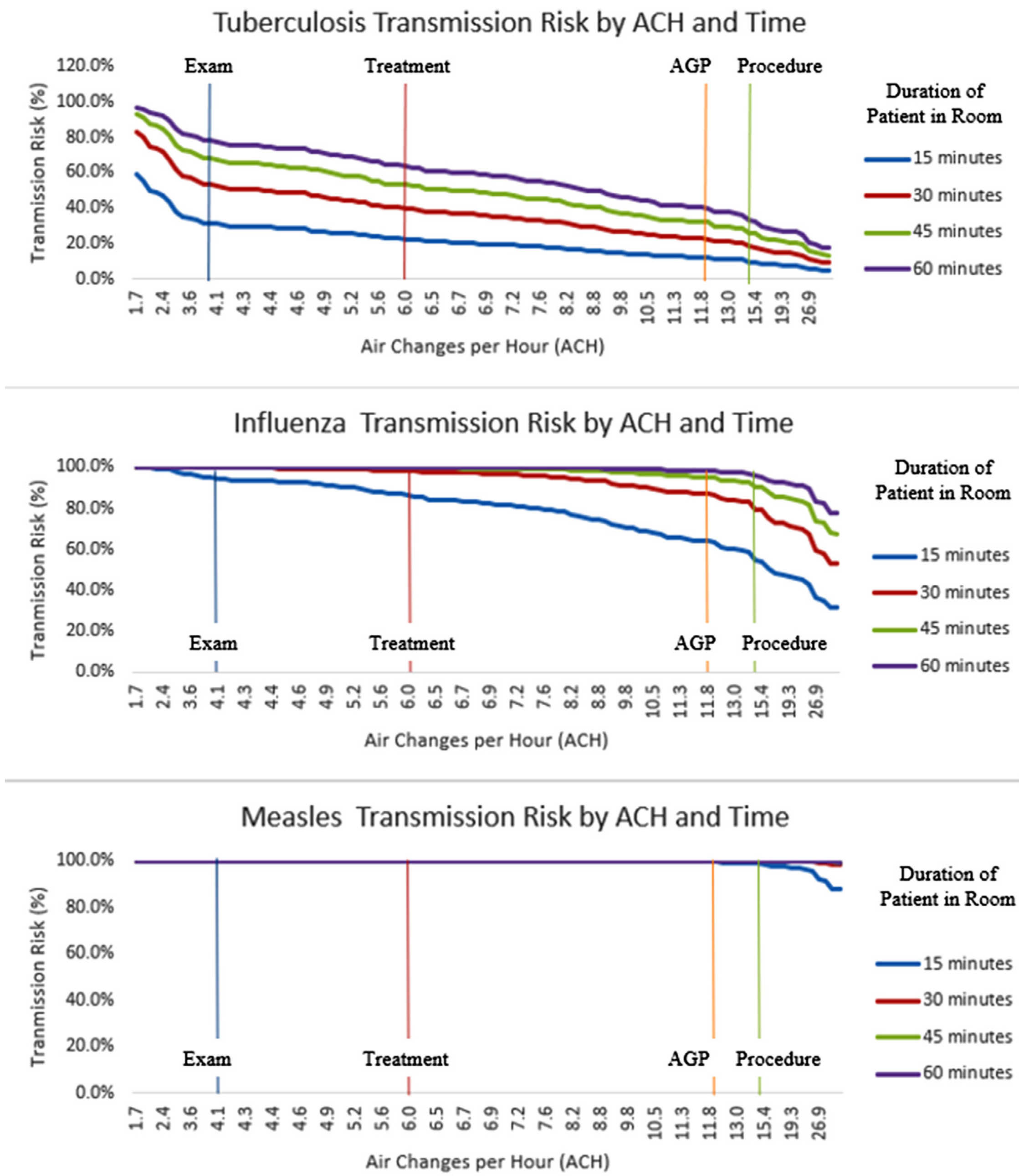

Fig 1. Transmission risk models based on measured ACH and calculated by the Gammaitoni-Nucci model (ANSI healthcare ventilation standards for exam, treatment, aerosol-generating procedures (AGP) and procedure rooms demarked vertically).

Disease transmission risk

The infectious disease transmission models based on the ACH values in this study, created from the Gammatoni-Nucci Model, indicated that outpatient clinic rooms would facilitate transmission rather than protect workers and patients when ACH does not meet the ventilation standard based on procedures performed in the rooms. Increased ventilation and personal protective equipment are the best practices to reduce transmission of infectious diseases in any healthcare setting. An additional concern is the increasing role outpatient clinics play in response to evaluating patients during outbreaks of emerging infectious diseases. These responses commonly recommend that patient evaluations be conducted in a negative pressure isolation room that are required to have 12 ACH. When working in outpatient clinic space with a lower than minimum standard ACH, the ability to safely perform assessments and patient care may inadvertently increase the risk to workers and the potential spread of the disease within the clinic.

LIMITATIONS

Due to the majority of the clinics being in leased space, access to the main ventilation system was not possible. Therefore, the study was designed to measure ventilation within the clinic space without measuring ventilation rates for the entire building. Statistical analysis for building variables may have bias due to repeated observations for building age, floors, and square footage since may clinic rooms were within the same clinic or building. As many clinics share space with multiple specialties throughout the week, multiple procedures are performed in the same rooms, making the rooms challenging to categorize. Due to the nature of outpatient visits, it is difficult to track nosocomial infections and disease spread from exposure in the outpatient clinic which would support the infectious disease transmission risk modeling. The development of an outpatient module for the CDC's National Healthcare Safety Network could be a tool to track infections associated with the outpatient setting.

CONCLUSION

If this study is representative of outpatient clinics in general, it is projected that 10% of all clinic rooms would not meet the minimum requirements for general exam rooms, 40% would not meet the requirements for treatment rooms, and over 80% of rooms where more advanced procedures are performed, such as aerosol-generating procedures and minor surgeries, would not meet the higher standards set by ANSI/ASHRAE. Lower ACH in outpatient clinic rooms where more advanced procedures are conducted could lead to an increased risk of spread of infectious diseases and constrain patient care when evaluating persons of interest for emerging infectious diseases. While lower air change rates were observed in all building types, the observation that newer built and 1-story stand-alone buildings had higher air change rates compared to the other building types may be due to better control of the ventilation system. Factors such as national ventilation standards, intended use, and services provided should be considered when designing and leasing all healthcare settings. These findings are pertinent during the SARS-CoV-2 pandemic as we establish working guidelines for the healthcare community.

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