Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Table 1 Filtering face piece class 3 (FFP3) respirator fit test results.

			Sex		
			Female	Male	Total
Test result	Pass	Count (%)	665 (81.8)	213 (90.3)	878 (83.7)
	Fail	Count (%)	148 (18.2)	23 (9.7)	171 (16.3)
Total		Count	813	236	1049

Although the majority of healthcare staff in the UK are female,[1] they work within structurally biased healthcare systems and are provided with respiratory PPE designed for males.[4,5] Although males are generally at higher risk of death from COVID-19 than females,[1] it is concerning that young female healthcare staff are reported to have double the COVID-19-related mortality rate compared with age-matched females in the general population.[1] It is possible that staff from minority ethnic groups, with higher mortality and morbidity risks from COVID-19,[6] are also at higher risk of failing fit tests because of different facial geometry.[1,7]

Our study was limited by a lack of routinely recorded data on the sex of those undergoing fit testing. Inferring sex may introduce information bias, in particular for transgender healthcare staff. This highlights the urgent need for healthcare institutions to record sex and ethnicity disaggregated demographic data during fit testing to minimise discrimination against women and minority groups. Based on our findings, our institution has improved its data collection and now routinely records gender, sex assigned at birth (if different from gender), and ethnicity data for all respirator fit tests so that we can study the impact of these demographics on respirator fit.

The lessons to be learned from the COVID-19 pandemic are not simply about maintaining adequate stocks of PPE, but also about tackling systemic discrimination in order to protect staff, who may feel pressured to work with poorly fitting, inadequate, PPE.[6] This responsibility lies with healthcare institutions and public bodies who can exert their purchasing power to influence the manufacturers of PPE. All people working in healthcare have the right to adequate PPE, and to work in an environment free from systemic discrimination.

Authors' contributions

Conception of the article: AC, AA
Data collection: AA, PC, AC
Statistical analysis: EdS, AA
Drafting of manuscript: AA, PC, EdS, MK, AC
All authors reviewed and revised drafts of the manuscript and approved the final version

Declarations of interest

The authors declare that they have no conflicts of interest.

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Influence of room ventilation settings on aerosol clearance and distribution

Nicolaas H. Sperna Weiland[1,*], Roberto A. A. L. Traversari[2], Jante S. Sinnige[1], Frank van Someren Gréve[3], Anne Timmermans[4], Ingrid J. B. Spijkerman[3], Wessel Ganzevoort[4] and Markus W. Hollmann[1]

[1]Department of Anaesthesiology, Amsterdam UMC, Amsterdam, The Netherlands, [2]The Netherlands Organisation for Applied Scientific Research TNO, Delft, The Netherlands, [3]Department of Medical Microbiology, Amsterdam UMC, Amsterdam, The Netherlands and [4]Department of Gynaecology, Amsterdam UMC, Amsterdam, The Netherlands

*Corresponding author. E-mail: n.h.spernaweiland@amsterdamumc.nl

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Editor—During the severe acute respiratory syndrome coronavirus-1 epidemic, healthcare workers involved in aerosol-generating procedures, such as tracheal intubation or bronchoalveolar lavage, were at increased risk of becoming infected.[1] For the current coronavirus disease 2019 pandemic caused by severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), several international guideline committees have recommended that these procedures be performed in airborne isolation rooms.[2–4] These rooms typically have a negative pressure relative to the adjacent hallway and a relatively high air exchange rate. However, because they are limited in most hospitals, it is inevitable that, in the context of a pandemic, aerosol-generating procedures in SARS-CoV-2-infected patients take place in other hospital environments, such as operating theatres or general ward rooms.

Ventilation system properties differ in various hospital settings, and this could influence aerosol behaviour, potentially compromising healthcare worker safety. For instance, ventilation systems in operating theatres are not designed for airborne isolation, but to protect the surgical field from contamination using a positive-pressure system. In ward rooms, air exchange rates are much lower than in an airborne isolation room or operating theatre. To our knowledge, no previous study has compared the relative influence of room pressure and air exchange rate on aerosol behaviour in different hospital settings. We aimed to quantify this to identify potential risks associated with different working environments. The results could guide specific recommendations that may help in choosing optimal working environments to protect healthcare workers performing aerosol-generating procedures.

We performed a simulated aerosol-generating procedure on six different single-patient hospital rooms (Supplementary data A1–A5) with varying air exchange rates (1–91 change [s] h^{-1}) and pressure gradient towards the adjacent hallway (P_{room}–$P_{hallway}$; measured with a needle micromanometer [AccuBalance® 8380; TSI, Shoreview, MN, USA]). One of the rooms with a low air exchange rate was equipped with an air purification unit (City Touch™; Camfil, Stockholm, Sweden) recirculating 600 m^3 h^{-1} through an efficiency particulate air filter with a 99.5% particle removal efficiency to improve air exchange rate.

Aerosols were dispersed from a test fluid (Durasyn® 164/Emery; INEOS, London, UK) using a nebuliser (ATM 226; Topas GmbH, Dresden, Germany) positioned at the head end of the bed (1 m above ground level). Two particle counters (SOLAIR 3100; Lighthouse, Boven-Leeuwen, the Netherlands), sampling air 1.5 m above ground level, were placed in the periphery of the room and in the hallway next to the closed door. All equipment was remotely operated to avoid room disturbance; doors remained closed during the entire measurement sequence. The study protocol measurements consisted of a 15 min baseline and 15 min of particle dispersal followed by a washout time recording of 60 min.

Data were stored digitally and processed offline (MATLAB R2018b; MathWorks Inc., Natick, MA, USA). After triplicate measures on each hospital room, data were synchronised and particle concentration counts were averaged per minute. Because SARS-CoV-2 aerosols appear in two peak concentrations with aerodynamic diameters of 0.25–1.0 and >2.5 μm, we analysed particle size ≥0.5 μm to assess room ventilation efficacy.[5] In all situations, the baseline aerosol concentration was 0–0.6 × 10^6 m^{-3}, which increased to 10–92 × 10^6 and 0.2–10 × 10^6 m^{-3} after aerosol dispersal in the hospital rooms and in the hallway, respectively. Aerosol washout was modelled as the fitted natural exponential decay function (R^2 >0.95 for all situations), as proposed by the US Centers for Disease Control and Prevention (Supplementary data A6).[6]

We classified the six rooms according to their ventilation system properties with air exchange rate (high *vs* low) and pressure gradient towards the hallway (positive *vs* neutral *vs* negative). Results are summarised in Table 1 and in the Supplementary data. There was considerable variation between the rooms with the 99% removal time of aerosols ranging between 7 and 307 min depending on air exchange rate. On the room with the lowest air exchange rate, the addition of an air purification unit improved air exchange rate from 1 to 11 change(s) h^{-1} and 99% removal time of aerosols from 307 to 47 min. Aerosol distribution to the hallway, calculated as the ratio of areas under the curve ($AUC_{hallway}/AUC_{room}$), was associated with pressure hierarchy. We found significant distribution (4–15%) on positive-pressure rooms, detectable distribution (1%) on neutral-pressure rooms, and unmeasurable (0%) on negative-pressure rooms. For each pressure gradient, higher ventilation rates seemed to reduce hallway exposure (Supplementary data A7).

These results highlight the importance of ventilation system settings on aerosol clearance and distribution in various in-hospital settings. In this study, aerosols remained airborne for more than 5 h in a room with low ventilation rate. These rooms should be considered ‘contaminated’ for extended durations after aerosol-generating procedures have been performed in SARS-CoV-2-infected patients, as it has been shown that airborne SARS-CoV-2 remains viable for at least 3 h.[7] Addition of a recirculating air purification unit in these rooms improved aerosol washout dramatically; this could be a simple and inexpensive solution to improve safety for healthcare workers.

Air exchange rate in the operating theatre was very high, and therefore, the time needed to remove 99% of all aerosols was very short. Although this may vary between hospitals,[8] in our setting, aerosol distribution to the hallway could not be neglected for a positive-pressure gradient. Whereas reduced

Table 1 Classification of room pressure gradients, ventilation system settings, and aerosol clearances. Detailed descriptive information on included rooms and their ventilation system settings. Rooms were classified according to their ventilation system properties with air exchange rate (high *vs* low) and pressure gradient towards the hallway (positive *vs* neutral *vs* negative). The main outcome measures for the study were aerosol clearance, expressed as the time necessary to remove 99% of aerosols after a simulated aerosol-generating procedure and relative hallway exposure, expressed as the ratio between hallway and room exposure. Lower 99% contaminant removal times were found on rooms with higher air exchange rates. We found significant aerosol distribution (4–15%) in positive-pressure rooms, detectable distribution (1%) in neutral-pressure rooms, and unmeasurable distribution (0%) in negative-pressure rooms. Higher ventilation rates seemed to reduce hallway exposure. APU, air purification unit; AUC, area under the curve.

	Positive-pressure gradient		No pressure gradient		Negative-pressure gradient	
	Low ventilation rate	High ventilation rate	Low ventilation rate	High ventilation rate	Low ventilation rate	High ventilation rate
Descriptive data						
Included rooms						
Room type	Delivery room	Standard operating theatre	Ward room	Ward room+APU	Airborne isolation room	Negative-pressure operating theatre
Room volume (m^3)	68	129	66	66	37	129
Anteroom (if present; m^3)	15	—	—	—	9	—
Ventilation system settings						
Pressure hierarchy (P_{room}–$P_{hallway}$; Pa)	9	20	0	0	−15	−2
Exchanged air per hour ($m^3\ h^{-1}$)	169	11 287	71	699	286	11 680
Air exchange rate (changes h^{-1})	3	88	1	11	8	91
Aerosol concentration of ≥0.5 μm						
Room						
Baseline ($10^6\ m^{-3}$)	0.2	0	0.6	0.2	0.1	0
Peak ($10^6\ m^{-3}$)	85	13	92	82	63	10
Cumulative exposure (AUC 10^6)	81.3	1.94	142	53.2	35.7	1.23
Hallway						
Baseline ($10^6\ m^{-3}$)	0.3	0.1	0.2	0.2	0.1	0.2
Peak ($10^6\ m^{-3}$)	10	0.4	1.0	0.5	0.2	0.2
Cumulative exposure (AUC 10^6)	12.4	0.08	0.75	0.01	0.04	0.00
Main outcome						
Aerosol clearance and distribution						
99% Contaminant removal time (min)	93	7	307	47	38	7
Hallway exposure, relative to room exposure (%)	15	4	1	0	0	0

hallway exposure was found in neutral- and negative-pressure environments, healthcare workers in the room benefit most from high air exchange rates to reduce the amount of aerosols quickly. It is important to assess the local situation when deciding on the best location for aerosol-generating procedures in SARS-CoV-2-infected patients.

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Declarations of interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bja.2020.10.018.

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