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MAJOR ARTICLE

Factors Associated With SARS-CoV-2 Attack Rates in Aged Care—A Meta-analysis

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Background. The coronavirus disease 2019 (COVID-19) pandemic has resulted in significant morbidity and mortality in aged-care facilities worldwide. The attention of infection control in aged care needs to shift towards the built environment, especially in relation to using the existing space to allow social distancing and isolation. Physical infrastructure of aged care facilities has been shown to present challenges to the implementation of isolation procedures. To explore the relationship of the physical layout of aged care facilities with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) attack rates among residents, a meta-analysis was conducted.

Methods. Using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocol (PRISMA-P), studies were identified from 5 databases using a registered search strategy with PROSPERO. Meta-analysis for pooled attack rates of SARS-CoV-2 in residents and staff was conducted, with subgroup analysis for physical layout variables such as total number of beds, single rooms, number of floors, number of buildings in the facility, and staff per 100 beds.

Results. We included 41 articles across 11 countries, reporting on 90 657 residents and 6521 staff in 757 facilities. The overall pooled attack rate was 42.0% among residents (95% CI, 38.0%–47.0%) and 21.7% in staff (95% CI, 15.0%–28.4%). Attack rates in residents were significantly higher in single-site facilities with standalone buildings than facilities with smaller, detached buildings. Staff-to-bed ratio significantly explains some of the heterogeneity of the attack rate between studies.

Conclusions. The design of aged care facilities should be smaller in size, with adequate space for social distancing.

Keywords. aged care; built environment; COVID-19 infection; physical layout.

Globally, aged care facilities (ACFs) have been recognized as high-risk settings for severe outcomes from coronavirus disease 2019 (COVID-19) [1]. Once severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has been introduced into a facility, it has the potential to have high transmission rates, which have been associated with a range of factors including crowding, sharing of bathroom facilities, and gathering in common areas, which result in prolonged close physical contact between aged care staff and other residents [2]. Aerosol transmission in indoor settings is a recognized problem and can be mitigated by building design and ventilation [3]. Residents can present with atypical symptoms, and those with cognitive impairment such as dementia may be less able to communicate their symptoms, leading to a delayed diagnosis [4]. Elderly residents are more likely to develop severe illness or die due to age, medical comorbidities, and frailty [5, 6]. Data from various countries demonstrate that between 24% and 84% of all deaths from COVID-19 have been residents of ACFs [7].

Evidence of the role of built environment on spread of SARS-CoV-2 is limited in aged care. However, it is widely accepted that contacts in closer proximity are at higher risk of infection [6]. There is a gap in infection control in aged care around the built environment, especially in relation to using the existing space to allow social distancing and isolation [8]. The main aim of this study was to explore the relationship of physical layout features of ACFs with SARS-CoV-2 infection rates among residents.

METHODS

Search Strategy and Inclusion/Exclusion Criteria

The protocol for this meta-analysis was registered with PROSPERO (CRD42020220594) and followed the steps outlined in Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [9]. A systematic search of the databases PubMed (MEDLINE), Embase, Web of Science, Scopus, and ProQuest was conducted spanning the period of 2020–2021.

Keywords used for searches of medical subject headings were grouped according to the condition: "COVID-19" or

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"COVID19" or "COVID-2019" or "coronavirus" or "SARS-CoV-2" or "SARS-CoV-19"; and setting: "aged care facility" or "long term care facility" or "skilled nursing facility" or "nursing home" or "residential care facility." Initial screening of articles based on the title and abstract was done to remove duplicates. The reference lists of relevant articles were also reviewed to identify studies for inclusion and to cluster articles reporting on the same outbreak. Studies that were published only in English and contained primary data were considered for inclusion in the meta-analysis, and were evaluated independently and by full text by 2 study investigators (M.K. and A.Q.) according to predetermined inclusion criteria (Table 1). In cases of disagreement, consensus was reached through discussion. The initial searches and full text screening were conducted from 23 February 2021 and 18 March 2021. The search was last updated on 31 October 2021 by MK and AQ.

Data Extraction

Among the studies that reported the number of infected residents in an aged care facility and total number of residents, the extracted data included baseline characteristics of the facility: facility type, total number of residents, age range of residents, and total number of staff; and outbreak characteristics: description of origin of outbreak, estimated duration of outbreak, attack rate in residents and staff, and case fatality rate in residents. The design features of the facilities, including total number of beds, occupancy, staff-to-bed ratio, presence of shared rooms, number of floors, number of connected units in the facility, and number of buildings in the facility, were also extracted as potential risk factors for the spread of SARS-CoV-2 in facilities. Data were initially entered into Microsoft Excel in a "Comma Separated Values" file format. The characteristics of studies, outbreak information, and physical layout information are included in Supplementary Tables 2, 3, and 4, respectively.

Table 1. Inclusion and Exclusion Criteria

Inclusion	Exclusion
Peer-reviewed articles, commentaries, and case reports that contain primary data and are published in English	Editorials, commentaries with no primary data Guidelines, recommendations, and position papers
Aged care facility/nursing home/long-term care facility setting	Modeling studies
Current or retrospectively reporting on outbreak of COVID-19 in humans Includes facility-level information: total number of residents, total number of staff, infection rates and facility-level/built environment details, ≥1 of the following: bed capacity, occupancy, layout, number of floors, number of connections internally and externally to other buildings, ventilation system, etc.	Full text not available online

Abbreviation: COVID-19, coronavirus disease 2019.

Quality Assessment

Two independent reviewers (M.K. and A.Q.) followed the Joanna Briggs Institute critical appraisal guidelines to determine whether each question received a "yes," "no," or "unclear" answer [10–12]. Studies were considered to be high quality if 80%–100% of the responses to the critical appraisal questions were "yes" and of moderate quality if 50%–79% of the responses were "yes." Only studies that were appraised as high or moderate quality were included in this review. This review appraised cohort, case–control, and cross-sectional studies. Cohort studies were required to have at least 6 "yes" answers to be included in the review. Case–control studies only needed 5 "yes" answers. Cross-sectional studies were included if ≥4 questions were answered as "yes." The numbers of "yes" answers required for high, moderate, and low quality for each study type are detailed in Supplementary Table 1. Any significant disagreement between the readers was resolved through discussion. Interobserver agreement was assessed. Subgroup analysis and meta-regression based on study quality were also conducted (details below).

Data Analysis

The meta-analysis was done using R (version 3.6.3) in R Studio using the "metafor" package and the Stata 17 "metaprop_one" command [13]. This Stata command fits an intercept-only random-effects logistic regression model to obtain a pooled estimate [14].

The outcome of interest in the studies was analyzed by a meta-analysis of proportions [15]. The pooled attack rate of SARS-CoV-2 in residents and staff was calculated. The random-effects model was adopted over the fixed-effect model due to the presence of heterogeneity resulting from variations of effects from individual studies confirmed by I^2 >0% according to the following formula:

$$I^2 = \left(\frac{Q - df}{Q}\right) \times 100\%.$$

Tests for heterogeneity were performed for all the proportions based on I^2 statistics, and P values from Q statistics were used to assess between-study variability and degree of freedom (df). For all computations, statistical significance was set at $P < .05$. Forest plots were generated.

Subgroup analysis and meta-regression using the layout variables and study quality criteria were done using the random-effects model described above. Studies with missing variable information were omitted in the subgroup analysis. The variables that were explored further in the subgroup analysis were occupancy (>80% occupancy vs <80% occupancy), total number of beds (<150 beds vs >150 beds), total number of single rooms, presence of shared rooms, number of floors (≤2 floors vs >2 floors), staff per 100 beds (staff per

100 beds >119 vs <119), number of buildings in the facility, and lockdown policy before or after the first confirmed case of COVID-19.

RESULTS

A total of 41 articles met the inclusion criteria (Supplementary Data), comprising 10 216 COVID-19-positive residents and 1183 COVID-19-positive staff from 757 facilities in 11 countries. Most of the studies were prospectively conducted (n = 17) in sites after identification of outbreaks or a first case of COVID-19 in the facility, with an average follow-up period of about 30 days (95% CI, 19.5–33). Among the studies with information on the first case of outbreaks, 14 studies described outbreaks where the index case was an aged care staff member, while in 12 studies the first positive case was a resident.

The pooled attack rate for SARS-CoV-2 in ACFs was 42.0% (95% CI, 38.0%–47.0%) in residents (Figure 1) and 21.7% (95% CI, 15.0%–28.4%) in staff. The score for heterogeneity across studies was highly significant for both resident studies (Q = 12306.4078; d = 37; $P < .0001$) (Figure 2) and staff (Q = 1327.6350; d = 22; $P < .0001$) (Figure 3).

The median number of beds and occupancy rate among the facilities included in the analysis were 150 (95% CI, 126–194) and 86.5% (95% CI, 7.3%–96.8%), respectively. Facility size ranged from 100 beds to 356 beds across the 41 studies. The median number of staff per 100 beds was 119 (95% CI, 107–160), ranging from 34 to 429 staff per 100 beds. Only 2 studies specified that facilities did not have any shared rooms, while 12 studies reported shared rooms with varying occupancies from double occupancy to a maximum of 12 beds in a unit. Of the 9 studies that specified the number of floors in a facility, 4 had ≤2 floors. Eight facilities were standalone single buildings, while 4 facilities included multiple buildings on the same site.

A subgroup analysis showed the attack rates of SARS-CoV-2 in residents by occupancy, total number of beds, single rooms, presence of shared rooms, number of floors, staff per 100 beds, number of buildings in the facility, and the lockdown policy before or after the first confirmed case of COVID-19. In the subgroup analyses, the attack rate was significantly higher

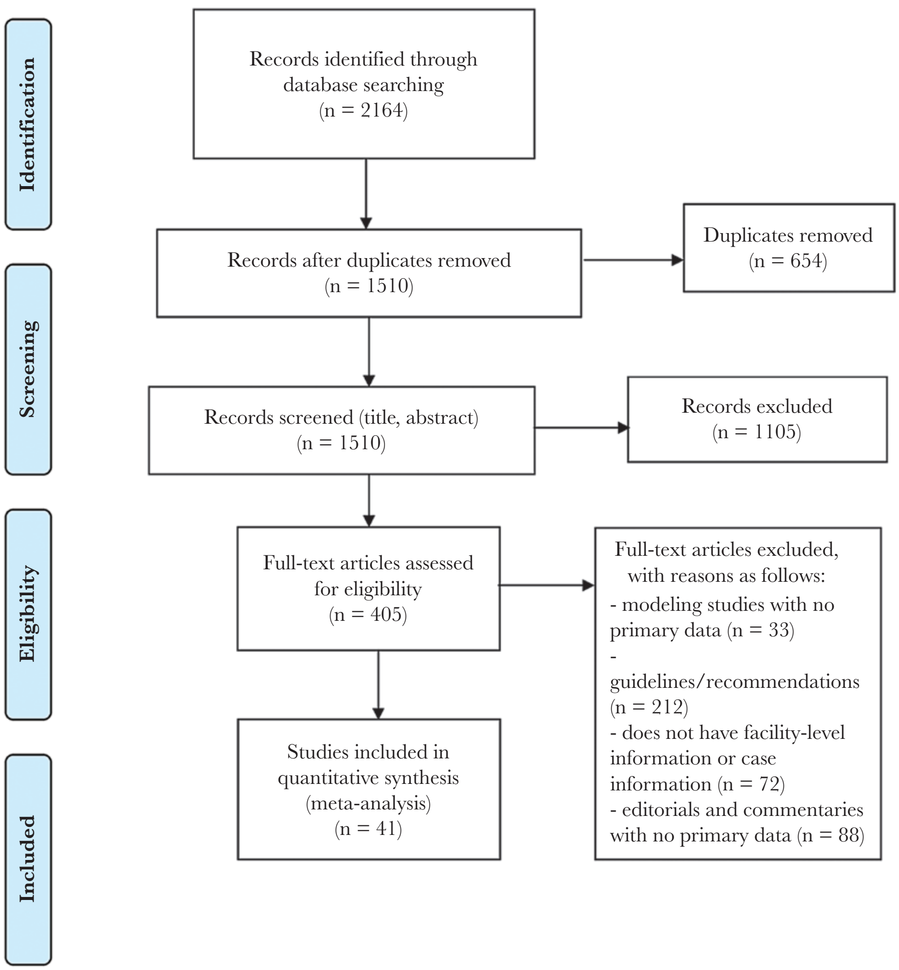
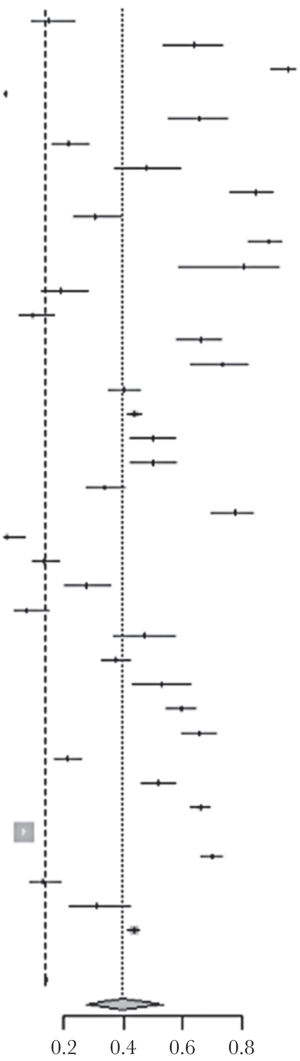


Figure 1. PRISMA flow diagram for study selection process.



Study	Events	Total	Proportion	95% CI	Weight (Fixed)	Weight (Random)
Abe 2020	14	93	0.15	(0.09; 0.24)	0.2%	2.6%
Arons 2020	57	89	0.64	(0.54; 0.73)	0.3%	2.7%
Atalla 2021	111	116	0.96	(0.90; 0.98)	0.1%	2.5%
Belmin 2020	5	1250	0.00	(0.00; 0.01)	0.1%	2.5%
Bernadou 2020	58	88	0.66	(0.55; 0.75)	0.3%	2.7%
Bigelow 2020	37	170	0.22	(0.16; 0.29)	0.4%	2.7%
Blain 2020	38	79	0.48	(0.37; 0.59)	0.3%	2.7%
Bouza 2020	82	97	0.85	(0.76; 0.90)	0.2%	2.6%
Buntinx 2020	40	130	0.31	(0 23; 0.39)	0.4%	2.7%
Collison 2020	107	120	0.89	(0.82; 0.94)	0.2%	2.6%
de Man 2020	17	21	0.81	(0.59; 0.93)	0.0%	2.4%
Dora 2020	19	99	0.19	(0.13; 0.28)	0.2%	2.6%
Eckardt 2020	10	105	0.10	(0.05; 0.17)	0.1%	2.6%
Garcia-de Castro 2020	99	150	0.66	(0.58; 0.73)	0.5%	2.7%
Goldberg 2020	58	79	0.73	(0.63; 0.82)	0.2%	2.6%
Graham 2020	126	313	0.40	(0.35; 0.46)	1.0%	2.7%
Kennelly 2020	764	1741	0.44	(0.42; 0.46)	5.9%	2.7%
Krone 2021	80	160	0.50	(0.42; 0.58)	0.6%	2.7%
Louie 2020	78	156	0.50	(0 42; 0.58)	0.5%	2.7%
Mas-Romero 2020	67	198	0.34	(0.28; 0.41)	0.6%	2.7%
McMichael 2020, McMichael 2020, Morris 2020	101	130	0.78	(0.70; 0.84)	0.3%	2.7%
Miller 2020	1	96	0.01	(0.00; 0.07)	0.0%	2.0%
Montoya 2020	29	215	0.13	(0.10; 0.19)	0.3%	2.7%
Patel 2020	35	127	0.28	(0 20; 0.36)	0.4%	2.7%
Roxby 2020, Roxby 2020	6	83	0.07	(0.03; 0.15)	0.1%	2.5%
Sacco 2020	41	87	0.47	(0.37; 0.58)	0.3%	2.7%
Shi 2020	146	389	0.38	(0.33; 0.42)	1.3%	2.7%
Shrader 2020	52	98	0.53	(0.43; 0.63)	0.3%	2.7%
Tarteret 2021	224	375	0.60	(0.55; 0.65)	1.2%	2.7%
Taylor 2020	171	260	0.66	(0.60; 0.71)	0.8%	2.7%
Voeten 2021	63	300	0.21	(0.17; 0.26)	0.7%	2.7%
Beran 2020	158	301	0.52	(0.46; 0.57)	1.0%	2.7%
Brouns 2020	480	727	0.66	(0.63; 0.69)	2.3%	2.7%
Brown 2020	5218	78 607	0.07	(0.06; 0.07)	67.4%	2.7%
Feaster & Goh 2020	408	582	0.70	(0.66; 0.74)	1.7%	2.7%
Kimball 2020	23	176	0.13	(0.09; 0.19)	0.3%	2.7%
Psevdos 2020	25	80	0.31	(0.22; 0.42)	0.2%	2.6%
Sanchez 2020	1207	2773	0.44	(0.42; 0.45)	9.4%	2.7%
		90 660				
Random-effects model			**0.40**	**(0.28; 0.54)**	--	**100.0%**

Heterogeneity: $I^2 = 100\%$, $\tau^2 = 2.9142$, $P = 0$

Figure 2. Pooled attack rate for residents.

in standalone single building facilities (50%; 95% CI, 35.0%–64.0%; $P < .001$) compared with the estimate in facilities with multiple buildings (26%; 95% CI, 10.0%–42.0%; $P < .001$) (Figure 4).

There was no other significant difference observed between subgroups. The attack rate in facilities with <150 beds (52%; 95% CI, 28%–95%) was higher than in facilities with >150 beds (38%; 95% CI, 15%–58%). Facilities with >80% occupancy (42%; 95% CI, 23%–61%) had a higher attack rate compared with those with <80% occupancy (31%; 95% CI, 13%–62%). Facilities that had shared or multiple-occupancy rooms had a pooled attack rate of 33% (95% CI, 15%–51%) among residents. Facilities that had ≤2 floors had a higher attack rate compared with those with >2 floors by 10.0%. The attack rate in facilities with staff per 100 beds being <119 was higher by 14.0% compared with those with more staff (staff per 100 beds ≥119). There was very little difference between facilities that had a lockdown policy enforced before and after the first identified case (1.0%).

Six studies out of 41 addressed ventilation and aerosol transmission but to differing degrees. Two studies had a description of the ventilation system, with an emphasis on not recirculating used air [16, 17]. One study specified performing medication reviews to discontinue aerosol-generating procedures [18]. Three studies investigated and mentioned modifications to ventilation system. De Man and colleagues [19] included a carbon dioxide–controlled energy-efficient system, while Eckardt and colleagues [20] specified that facility engineers and infection control personnel carried out inspections to identify air efficiency and heating, ventilation, and air conditioning (HVAC) optimization, according to the position statement of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), with no further details given on adjustments implemented. Miller and colleagues [21] described the design and

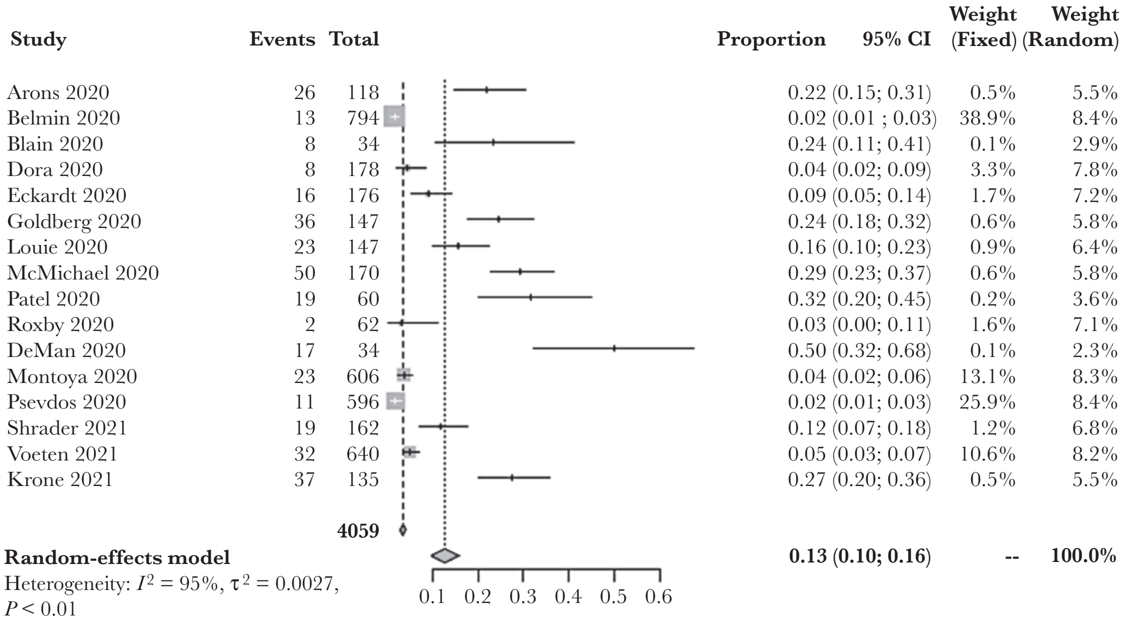


Figure 3. Pooled attack rate for staff.

presented the outcomes of establishing a negative pressure isolation space in 1 ward of the ACF. Modifications were described as not resource-intensive and rapidly established. Pressure data show that the isolation space maintained an average (SD) hourly value of –2.3 (0.12) Pa pressure differential between it and the external hallway connected to the rest of the facility. No transmission of SARS-CoV-2 between residents isolated to the space occurred, nor did any transmission to the staff or other residents occur. The isolation space was shown to be successfully implemented during the outbreak.

Subgroup analysis based on study quality is displayed in Figure 5. The moderate-quality studies (n = 12) had a pooled attack rate of 57.7% (95% CI, 44.3%–70.6%) in the residents compared with a lower pooled attack rate of 36.2% (95% CI, 24.0%–49.4%) among the high-quality studies (n = 29). The difference was statistically significant (P = .025). There was good interobserver agreement on the total quality scores between the 2 reviewers (intraclass correlation coefficient [ICC], 0.947; 95% CI, 0.984–0.972). The outputs from meta-regression with study quality are shown in Table 2. The SARS-CoV-2 attack rate

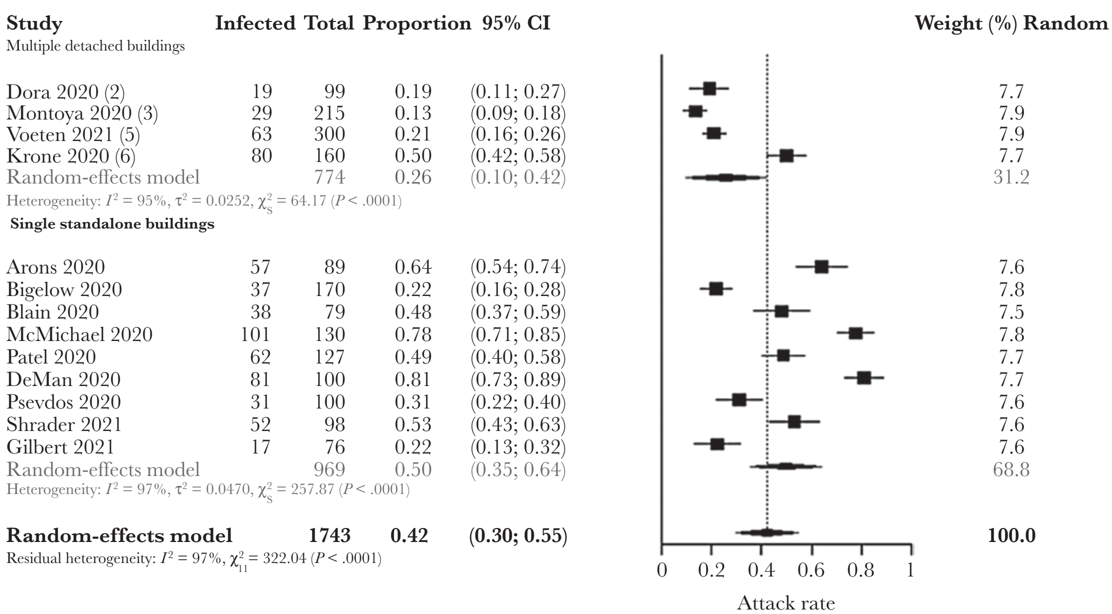


Figure 4. Subgroup analysis comparing single standalone buildings with facilities with multiple buildings.

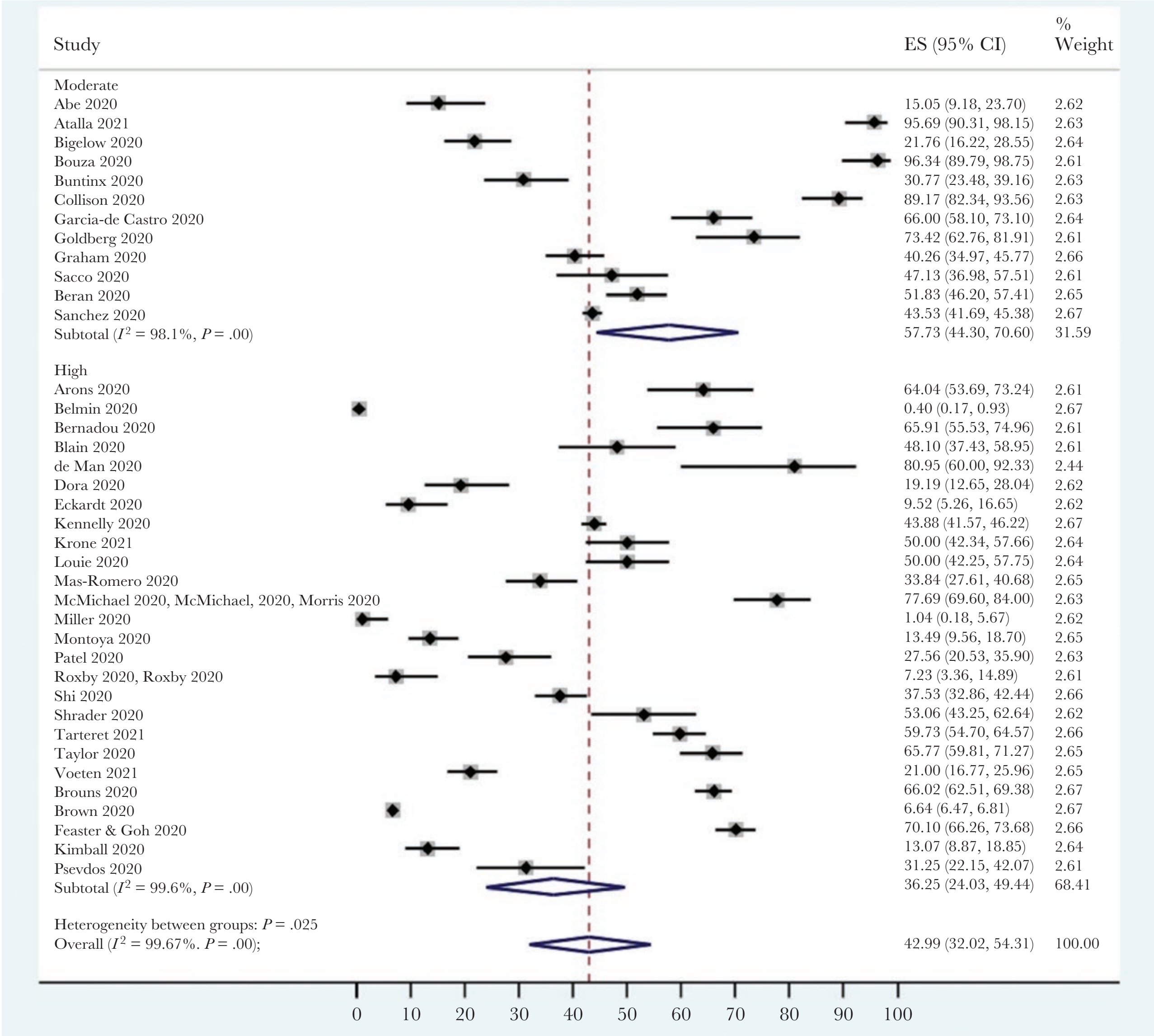


Figure 5. Subgroup analysis by quality.

among residents in moderate-quality studies was 3.38 (95% CI, 1.13–10.08) times higher (P = .029) than in high-quality studies.

DISCUSSION

We confirm a high attack rate of SARS-CoV-2 in aged care residents and high risk of outbreaks in this setting. This study informs the role of the built environment in planning and designing single standalone facilities with all residents housed within 1 building of ACFs vs facilities that house residents across multiple separate detached buildings. Other factors associated with attack rate were staff per 100 beds and total number of beds, indicative of facility size.

With the introduction of COVID-19 vaccines and priority being given to high-risk groups such as residents dwelling in aged care, the attack rates are expected to reduce; however, the immunogenicity of COVID-19 vaccines is lower in frail, elderly people, and influenza outbreaks in ACFs with high vaccination rates are common [22, 23]. The intensity of outbreaks here makes it important to consider the role of the built environment, including ventilation, which was addressed in 14.6% of studies (n = 6) at varying levels of detail, in addition to standard public health measures.

Table 2. Results of Meta-regression Analysis of Attack Rates in Residents on Study Quality of the Included Studies

	Moderator	Odds Ratio (95% CI)	SE	*P* Value
Study quality	Intercept	0.46 (0.25–0.86)	0.14	.014
	Moderate	3.38 (1.13–10.09)	1.89	.029

In our study, single-site facilities have a higher attack rate than sites with multiple units that are detached. Isolating residents infected with COVID-19 in traditional dormitory-style institutional-based care with multiple floors, multiple-occupancy rooms, and narrow corridors is difficult with limited space for single rooms [24, 25]. There has been a gradual shift from older designs of ACFs to a smaller and home-based cottage style of care.

In the meta-regression, facility size had a significant association with attack rate among residents in developed countries. Larger facility size and urban location were significantly ($P < .001$) related to the increased probability of having a COVID-19 case [24]. Although occupancy, related to facility size, had no significant association in our study, higher occupancy rates have been identified as independent risk factors for SARS-CoV-2 infection in other studies [26]. In recent years, countries such as Australia, Canada, and the United States have lowered nursing home occupancy, moving toward more single rooms and person-centered homes offering long-term care services to individuals [25].

Although the pooled attack rate of SARS-CoV-2 among aged care staff was relatively lower than in residents in this study (21.7%), these individuals should remain a priority in targeted interventions including masks and vaccines. Hashan and colleagues reported that 46% of outbreaks were introduced into the facility by staff [2]. In the meta-regression, our study found that staff per 100 beds is associated with the attack rates in residents. Those who work as casual aged care staff tend to work in >1 facility, resulting in the movement of aged care staff across multiple facilities [27]. Staff who are a largely composed of a vulnerable group of migrants, usually lacking health benefits are less likely to be vaccinated [23].

The physical infrastructure of an ACF presents challenges to the implementation of isolation and social distancing procedure [24]. Sufficient space is required for social distancing; however, shared rooms with multiple occupancy are still prevalent in many facilities around the world [6]. Ventilation is also critical but is not addressed in reported aged care outbreaks. Studies have demonstrated that a larger facility size and being built according to older design standards were associated with a greater frequency of COVID-19 cases [5]. Modifying the built environment could be feasible and have fewer barriers than interventions that involve individual consent. Implications on infection control with regards to physical layout characteristics in aged care need to be explored more rigorously in scientific studies.

There are some limitations to this meta-analysis. As the COVID-19 pandemic is still ongoing, most of the studies provide a snapshot of the attack rates of SARS-CoV-2 in aged care facilities at a certain point in time. The follow-up period in observational studies may not coincide with the actual end of the outbreak, and there is no information as to whether another outbreak was in the same facility after the study period ended. Given that is it is possible for facilities to have multiple outbreaks, it is possible that a longer follow-up period could have resulted in more outbreaks or cases being reported in the included facilities [28]. In the studies included, there was a range in testing rates among residents and staff. For this reason, underreporting of attack rates could be possible. Not everyone in the facilities were tested, an the attack rates in some studies were reported as a proportion of positive cases over those who were tested, which is widely accepted as the closest estimate to the attack rate [29]. There were instances where studies reported that staff or residents refused to be tested as well [30]. Most studies did at least provided the number of beds in the facilities involved in outbreaks. However, it was challenging to obtain a complete set of information on physical layout characteristics and detailed floorplans. This could be due to safety reasons, competition among care providers, and/or the need to maintain the confidentiality and privacy of residents and staff.

CONCLUSIONS

The findings of this study suggest that facilities that have residents and staff in closer proximity to each other due to smaller facility size have higher attack rates of COVID-19 especially among residents. Consequently, infection control policies should address factors such as total number of beds and staff-to-100 bed ratios and consider appropriate modifications to institution-like single-building facilities with multiple-occupancy rooms.

Supplementary Data

Supplementary materials are available at *Open Forum Infectious Diseases* online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

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Patient consent. This study does not include factors necessitating patient consent.

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