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Research Article

COVID-19 outbreaks in residential care homes in Hong Kong and effectiveness of vaccine against severe outcomes

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ABSTRACT

Background: COVID-19 outbreaks in residential care homes for the elderly (RCHEs) and for persons with disability (RCHDs) have caused significant morbidity and mortality during 5th epidemic in Hong Kong. This article reviewed COVID-19 outbreaks situation and estimated the effectiveness of receiving at least two-dose of COVID-19 vaccine in preventing severe outcomes.

Methods: To estimate attack rates and vaccination coverage, documentation on COVID-19 infection and their vaccination records of residential care homes (RCH) residents reported between December 31, 2021 and May 31, 2022 were reviewed, and infected cases were follow-up for 4 weeks for severe outcomes or death. Correlation between vaccination coverage against attack rate by types of homes was examined. Infected RCH residents with available information were included in the analysis of vaccine effectiveness against severe outcomes and death.

Results: COVID-19 vaccination coverage was low in RCHDs (median 0.46, IQR: 0.24–0.76) and very low in RCHEs (median 0.08, IQR: 0.00–0.19). Higher attack rates were recorded among RCHE residents (median 0.84, IQR: 0.64–0.93) and higher case fatality rate (CFR: 28.1%) than in RCHDs (median 0.58, IQR: 0.31–0.84; CFR: 3.9%). The attack rate decreased when vaccination coverage increased for both RCHEs ($\rho = -0.131$, $p < 0.001$) and RCHDs ($\rho = -0.333$, $p < 0.001$). Comparing with infected residents who were unvaccinated/vaccinated with one-dose, receiving at least two-dose was estimated to be effective in reducing severe outcomes in 31% and 36% of infected RCHE and RCHD residents respectively; with greater reduction in mortality among RCHD than RCHE residents (54% and 38%, respectively). Vaccine effectiveness of two-dose of BNT162b2 against severe outcomes and death are higher than that of CoronaVac.

Conclusions: Increasing COVID-19 vaccination could have significant impact on reducing the risk of COVID-19 outbreaks in RCHs. At least two-dose of COVID-19 vaccine is still effective in reducing severe outcomes and death among infected residents in RCHs during Omicron epidemic.

1. Introduction

With the emergence of highly transmissible SARS-CoV-2 variants, many countries experienced resurgence of coronavirus disease 2019 (COVID-19) in December 2021 [1]. Hong Kong survived through the first 2 years without community-wide outbreaks by adopting stringent border control measures and sustained non-pharmaceutical interventions including territory-wide mask wearing and social distancing [2,3]. The COVID-19 vaccination campaign was launched since February 26, 2021 and local disease activity maintained at “zero” from April to December 2021 after the 4th wave [4]. However, the 5th wave started since December 31, 2021 with widespread transmission amid the emergence of Omicron variant swiping all over the world. Locally, Omicron variant (>80%) has overtaken Delta to be the main variant since the last week in year 2021, despite over 64% of the local population having been vaccinated with two-dose of COVID-19 vaccine as of 31 December 2021 [5]. Following the recognition of positive rapid antigen tests (RAT) as confirmed cases on top of PCR-based testing from February 26, 2022, the number of daily recorded cases reached the peak in early March with more than 70,000 cases per day, reflect-

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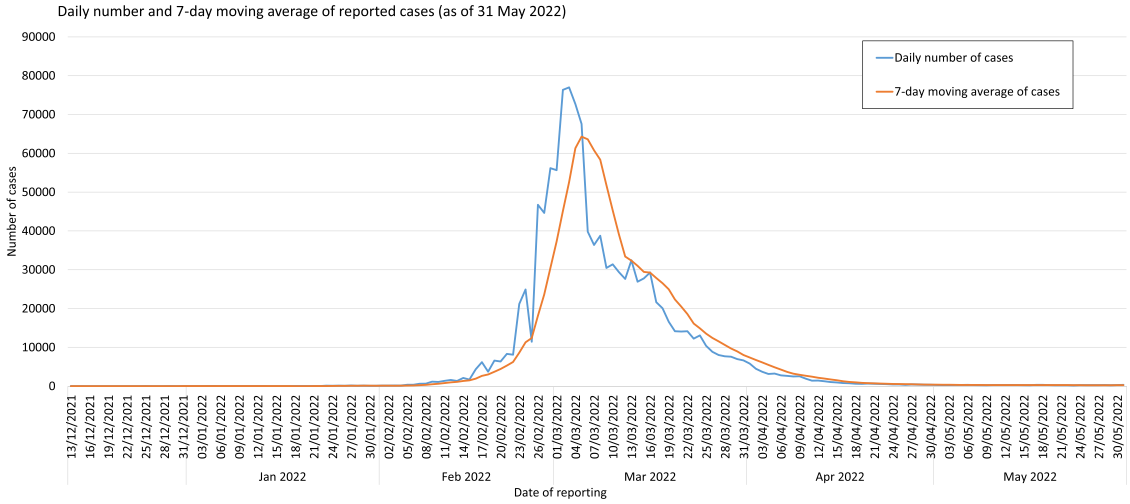

Fig. 1. Daily number of cases and 7-day moving average since 5th wave in Hong Kong (as of May 31, 2022).

ing widespread transmission in the community (Fig. 1) [6,7].

Elderly and persons living in long-term care facilities are particularly vulnerable population of infection because of ageing, underlying chronic diseases and institutional environment [8]. A systematic review found that COVID-19 outbreaks in aged care facilities often have devastating consequences with single-facility attack rates of 45% and case fatality rates of 23% [9]. Problems with infections may be more difficult to diagnose because of their subtle presentations, delays in diagnosis, and treatment allow transmission to occur within the facility [10]. COVID-19 outbreaks in long-term care facilities have caused significant morbidity and mortality in many countries [11,12].

In Hong Kong, epidemic situation of the 5th wave was much more severe than previous 4 waves, and the situation was particularly serious in the residential care home (RCH) setting. Public hospitals were overwhelmed and many cases could not be admitted [13]. Due to high infection risk in the community, the Government announced on February 25, 2022 that people tested positive by RAT should be considered as positive cases in order to avoid delay in diagnosis by nucleic acid test, and infected people could stay at home if they were not admitted [14]. Many RCH residents tested positive by RAT were isolated in the RCH, while some were isolated in the community isolation facilities. Generally, residents in residential care homes for the elderly (RCHEs) were older and may live with more chronic diseases than those in residential care homes of the disability (RCHDs). Most RCHs are run by private operators (65%), while subvented RCHs (35%) are run by non-governmental organization under subvention by the Government. All RCHs should observe the licensing requirement under the Social Welfare Department (SWD) [15,16].

Two types of COVID-19 vaccines, targeting the ancestral strain of SARS-CoV-2 virus, are provided free of charge in Hong Kong, including the CoronaVac (inactivated vaccine) and BNT162b2 (mRNA vaccine) [17]. All eligible persons in Hong Kong could choose to receive any type of vaccine in the Community Vaccination Centers or at private medical practitioners. The Outreach Vaccination Arrangement for RCHs under the COVID-19 Vaccination Programme started since April 13, 2021 and residents could choose to receive their preferred type of vaccine voluntarily [18].

We summarized the epidemic situation of COVID-19 in RCHEs and RCHDs, vaccination status and effectiveness of at least two-dose of COVID-19 vaccine in preventing severe outcomes. We also compared the COVID-19 outbreaks in different types of RCH locally.

2. Materials and methods

COVID-19 is statutorily notifiable in Hong Kong and all cases that have been tested positive will be notified to the Centre for Health Protection (CHP), which is the public health authority responsible for epidemiological investigation of COVID-19 cases and surveillance of local situation. The CHP has collaborated with SWD to monitor the COVID-19 outbreaks in RCHs and provided advice on prevention and control measures. All residents resided in RCHs in the first 5 months of 2022 and information on their diagnosis of COVID-19 in the same period was reviewed from the central registry recorded by the CHP. The study period between December 31, 2021 and May 31, 2022 covered infected RCH residents in the 5th epidemic wave in Hong Kong.

Primary outcomes included COVID-19 infection, severe COVID-19 disease and death. Documentation of COVID-19 infection was reviewed from December 31, 2021 to May 31, 2022, while cases were further follow-up for 4 weeks until June 28, 2022 to see if they would develop severe disease or death. The infected residents were considered having severe outcomes if they had seri-

ous/critical condition as defined by their attending doctors, while death within 28 days of tested positive is the adopted surveillance criteria for COVID-19 related mortality locally. For surveillance purpose, COVID-19 deaths includes all cases who died within 28 days of being tested positive, which is also adopted by the United Kingdom [19] and New Zealand [20] on reporting COVID-19 deaths. Only people who are tested positive will be regarded as COVID-19 cases in Hong Kong, this surveillance approach allows simple and timely collection of death data for effective monitoring of recent trend. Outcomes were matched with RCH residents. The number of infected residents with COVID-19 in each RCH during the study period was used to estimate the attack rate among residents. The onset dates or first positive specimen collection dates (if onset dates not available or in asymptomatic patients) were used to construct the epidemic curves.

COVID-19 vaccination status of all infected residents was retrieved from the central database of vaccinations kept by the CHP. The COVID-19 vaccination rates with at least two-dose were correlated with attack rates among the RCHs. For individual analysis to estimate the vaccine effectiveness, residents who had received at least two-dose of COVID-19 vaccine 2 weeks before infection were considered completed the vaccination (at least two-dose group). Otherwise, those residents not fulfill the above would be included in the unvaccinated/vaccinated with one-dose group (control group). Among the "at least two-dose group", vaccinated residents were further classified into those who received at least two-dose of either "CoronaVac" or "BNT162b2". For institution-based analysis, in order to estimate the vaccination coverage of the whole institution before outbreaks, residents having received at least two-dose of COVID vaccine 2 weeks before the first infected case in the outbreaks of the involving RCH were considered completed vaccination. Re-infected residents in the 5th wave were excluded from the calculation since previous infection may confer protection independent from vaccination. Characteristics of infected residents including demographics, symptoms, chronic illnesses and severity were described. The effect of at least two-dose of COVID-19 vaccine against severe outcomes and death were calculated in infected residents.

On institutional level, we examined the correlation between vaccination coverage and type of RCH against attack rate separately. We prepared a scatterplot of vaccination coverage against attack rate and a quantile - quantile plot (Q-Q plot) for checking the normality of the data. We compared 2 groups for respective types of institution (private and subvented) by boxplot and reviewed the distribution of data. To investigate the association between attack rate and vaccination coverage, Spearman rank correlation test were used.

On individual level, Pearson's χ^2 test was employed to evaluate the differences in sex, presence of signs and symptoms, chronic illness prevalence, and vaccination status of the study population. Variables with zero observed counts were excluded from the χ^2 analysis. Modified Poisson regression model was fitted to explore the effect of age, sex, chronic illnesses, and vaccination status on severe outcomes and death among RCHE and RCHD residents [21]. Each variable under examination was adjusted with other variables in this study. Results were expressed in the form of adjusted relative risk (aRR) along with corresponding 95% confidence interval (95% CI). A two-sided α of less than 0.05 (p-value <0.05) was considered statistically significant. The effectiveness of at least two-dose COVID-19 vaccination against severe outcomes and death was estimated as 1-aRR. Analyses were performed using the "glm2", "sandwich", and "lmtest" packages in R software environment (version 4.2.1) [22].

3. Results

3.1. Institutional level analysis

Among the 1103 RCHs in Hong Kong from December 31, 2021 to May 31, 2022, there were 804 RCHEs and 299 RCHDs with over 62,000 and 17,000 residents, respectively. The median age of RCHE residents was 86 (IQR 77–91) years old and RCHD residents was 50 (IQR 38–60) years old. There were more female than male residents (F:M = 1:0.7) in RCHEs while vice versa was observed in RCHDs (F:M = 1:1.3).

The daily number of cases in RCHs rose rapidly in February and reached the peak in March with more than 1000 cases per day (Fig. 2), similar to the rising trend in the community. As of May 31, 2022, over 45,000 COVID-19 cases were reported in RCHE and over 10,000 cases were reported in RCHD.

There were 804 RCHEs (165 subvented [20.5%] and 639 private [79.5%]) and 299 RCHDs (222 subvented [74.2%] and 77 private [25.8%]) during the study period. For RCHEs, the median attack rate was 0.84 (IQR: 0.64–0.93), which was higher than that of RCHDs (0.58, IQR: 0.31–0.84). The median vaccination coverage of at least two-dose was 0.08 (IQR: 0.00–0.19) in RCHEs, which was lower than that of RCHDs (0.46, IQR: 0.24–0.76).

The scatterplot of vaccination coverage against attack rate in RCHE and RCHD is shown in Figure 3. No association or only a weak correlation between vaccination coverage and attack rate were found from the plot. We further examined the normality of the data by Q-Q plots (Fig. 4). As the distribution of attack rate and vaccination coverage in both RCHE and RCHD were not normally distributed, we calculated Spearman's rank correlation coefficient to examine the correlation between attack rate and vaccination coverage as a non-parametric measure of

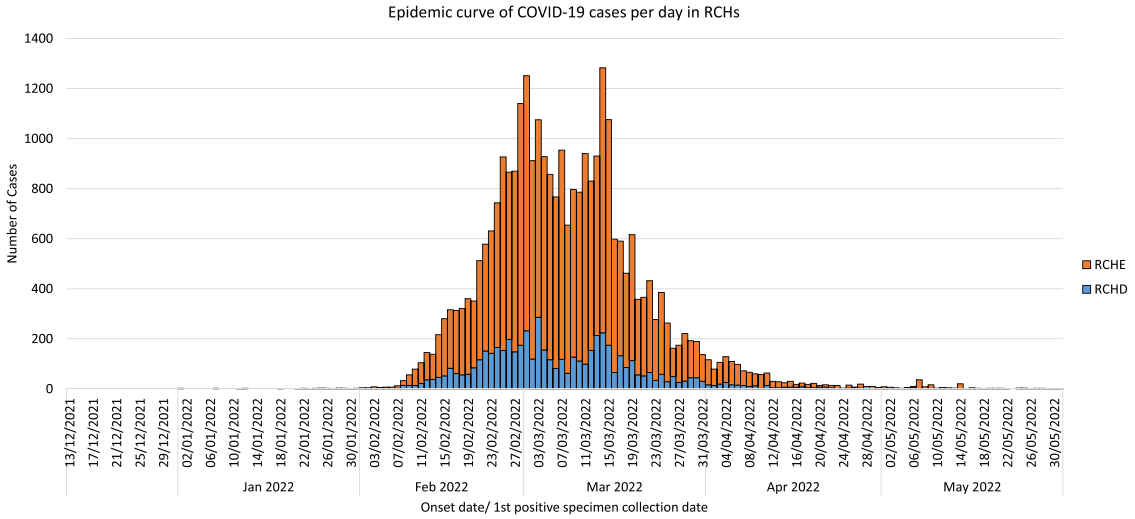

Fig. 2. Epidemic curve among COVID cases per day in residential care homes (as of May 31, 2022).

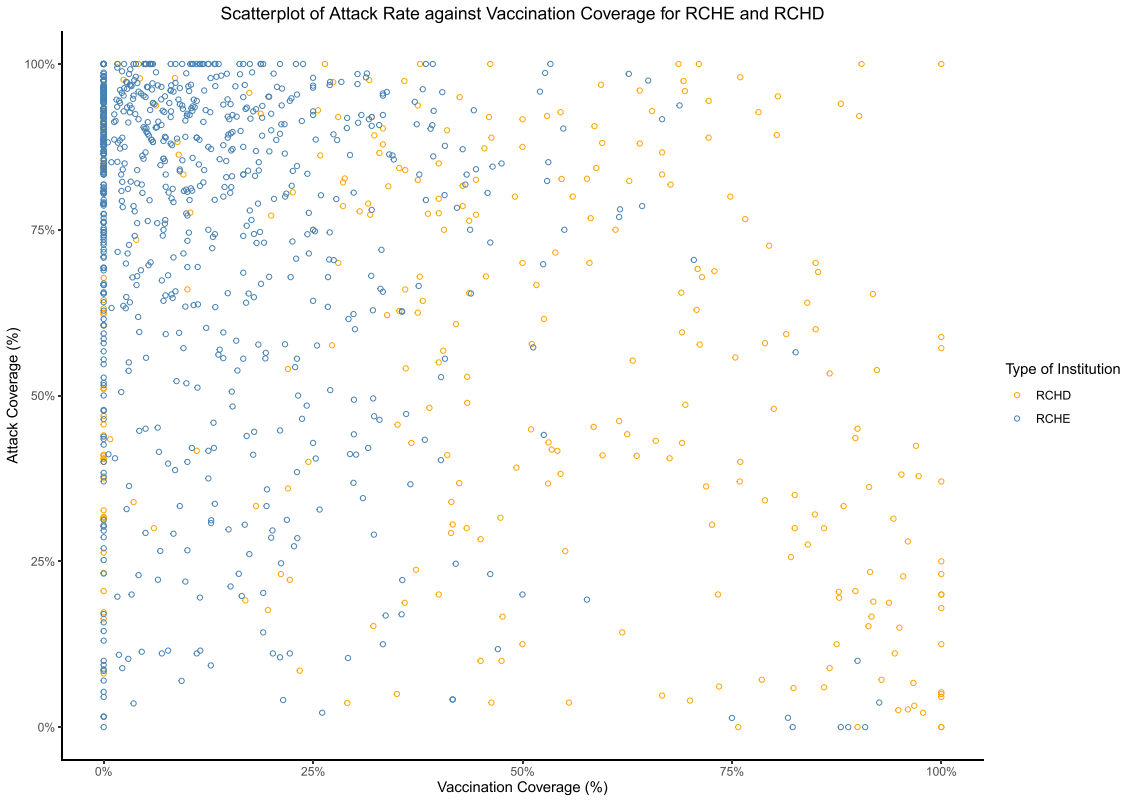

Fig. 3. Scatterplot of attack rate against vaccination coverage for 804 RCHEs and 299 RCHDs; attack rate: proportion of infected residents among each institution; vaccination coverage: proportion of residents with at least two-dose of COVID-19 vaccination among each institution.

strength and direction of association. Weak negative relationships were found between these 2 variables in both RCHE ($\rho = -0.131$, $p < 0.001$) and RCHD ($\rho = -0.333$, $p < 0.001$), suggesting decreased attack rate with increased vaccination coverage.

3.1.1. Private and subvented institution

In comparison with subvented institutions, the median attack rates of both private RCHEs and RCHDs were higher. The median attack rates were 0.88 (IQR: 0.72–0.95) and 0.66 (IQR: 0.44–0.80) in private and subvented RCHEs, respectively, while the median attack rates were 0.77 (IQR: 0.28–0.93) compared to 0.55 (IQR: 0.32–0.81) for private and subvented RCHDs respectively. Regarding vaccination coverage of at least two-dose, the median vaccination coverage in private institution was lower than in subvented. The median vaccination coverages were 0.07 (IQR: 0–0.17) and 0.15 (IQR: 0.01–0.24) for private and

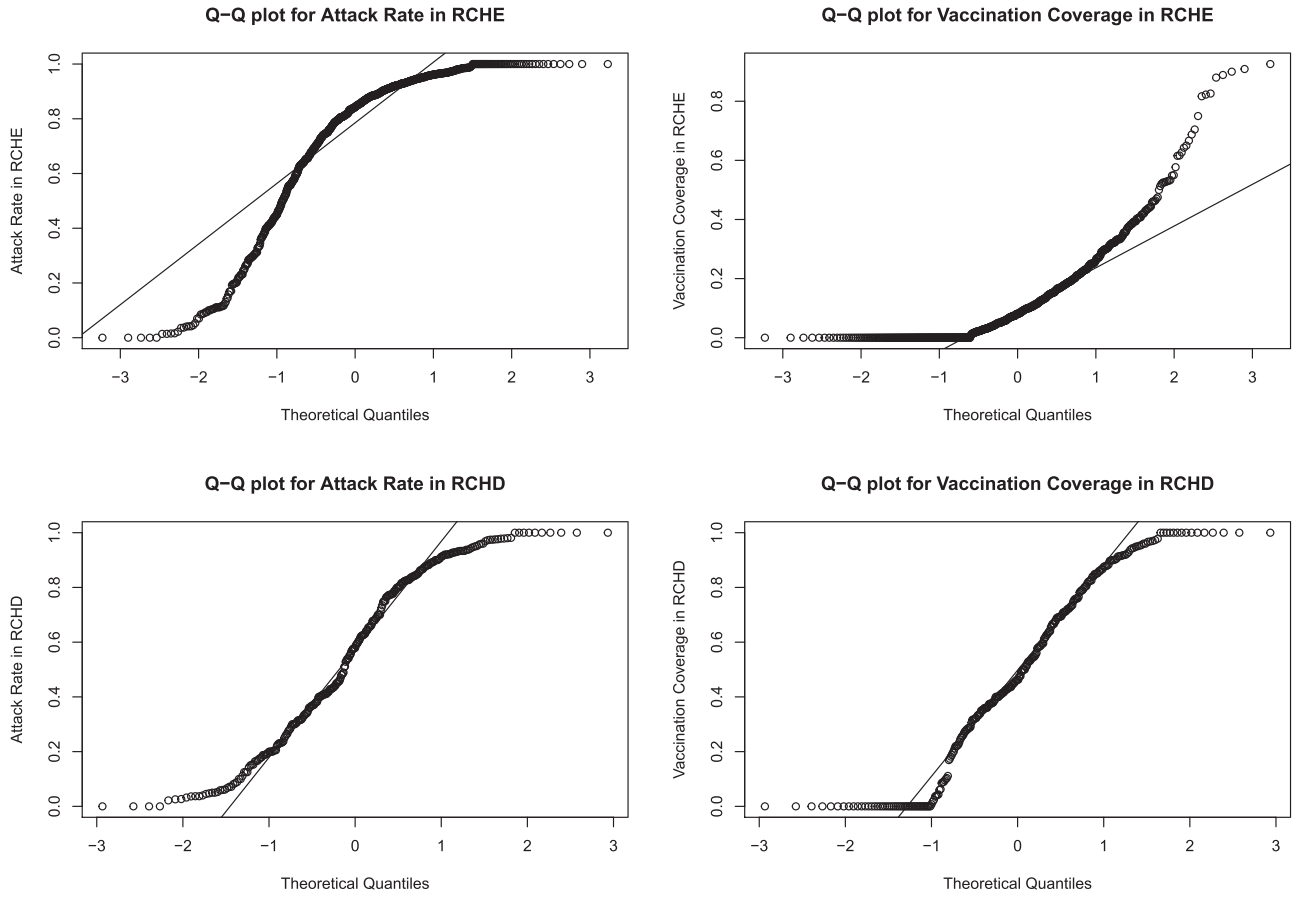

Fig. 4. Q-Q plots of attack rate and vaccination coverage of RCHE and RCHD respectively for checking normality.

subvented RCHE, 0.43 (IQR: 0.22–0.77) and 0.48 (IQR: 0.26–0.76) for private and subvented RCHD respectively (Fig. 5).

3.2. Individual level analysis

A total of 13,977 infected RCHE residents and 1636 infected RCHD residents with available information were included in the analysis. Infected residents in RCHEs were older, with higher proportion of females and chronic illness than those in RCHDs. Also, RCHEs had higher mortality (CFR: 28.1%) than RCHDs (CFR: 3.9%). These 2 different groups of population were analyzed separately for the effect of COVID-19 vaccine against severe outcomes and death (Table 1).

For RCHEs, 11878 and 2099 cases were included in the "unvaccinated/vaccinated with one-dose (control group)" and "at least two-dose", respectively. Among the 2099 "at least two-dose" cases, 1900 cases received CoronaVac and 199 cases received BNT162b2 (Table 2). After contracted with COVID-19, more individuals had fever (31.4%), pneumonia (5.7%) and shortness of breath (SOB) (22.9%) in the control group, as compared with both of the two-dose groups (fever: 25.9%/26.1%; pneumonia: 3.8%/4.0%; SOB: 15.4%/13.6% for CoronaVac and BNT162b2 respectively). The proportion of individuals being asymptomatic was higher in both of the two-dose groups (CoronaVac: 17.0%; BNT162b2: 24.1%) than the control group (16.9%).

For RCHDs, 992 and 644 cases were included in the "unvaccinated/vaccinated with one-dose (control group)" and "at least two-dose" respectively. Among the 644 "at least two-dose" cases, 507 cases received CoronaVac and 137 cases received BNT162b2 (Table 3). More individuals had fever (37.3%), pneumonia (2.2%) and SOB (8.5%) in the control group, as compared with both of the two-dose groups (fever: 32.0%/27.7%; pneumonia: 1.2%/0.0%; SOB: 5.1%/0.7% for CoronaVac and BNT162b2, respectively).

For RCHE cases (Table 4), the adjusted risk of having severe outcomes was 0.69 (95% CI: 0.64–0.74) times lower and the risk of death was 0.62 (95% CI: 0.56–0.68) times lower among patients with at least two-dose (any type) as compared with the controls. For type of vaccine, the adjusted risk of severe outcomes among residents with at least two-dose of BNT162b2 (aRR: 0.48, 95% CI: 0.36–0.65) was lower than residents with CoronaVac (aRR: 0.71, 95% CI: 0.66–0.77). Also, the adjusted risk of death among residents with at least two-dose of BNT162b2 (aRR: 0.41, 95% CI: 0.28–0.61) was lower than residents with CoronaVac (aRR: 0.64, 95% CI: 0.58–0.71).

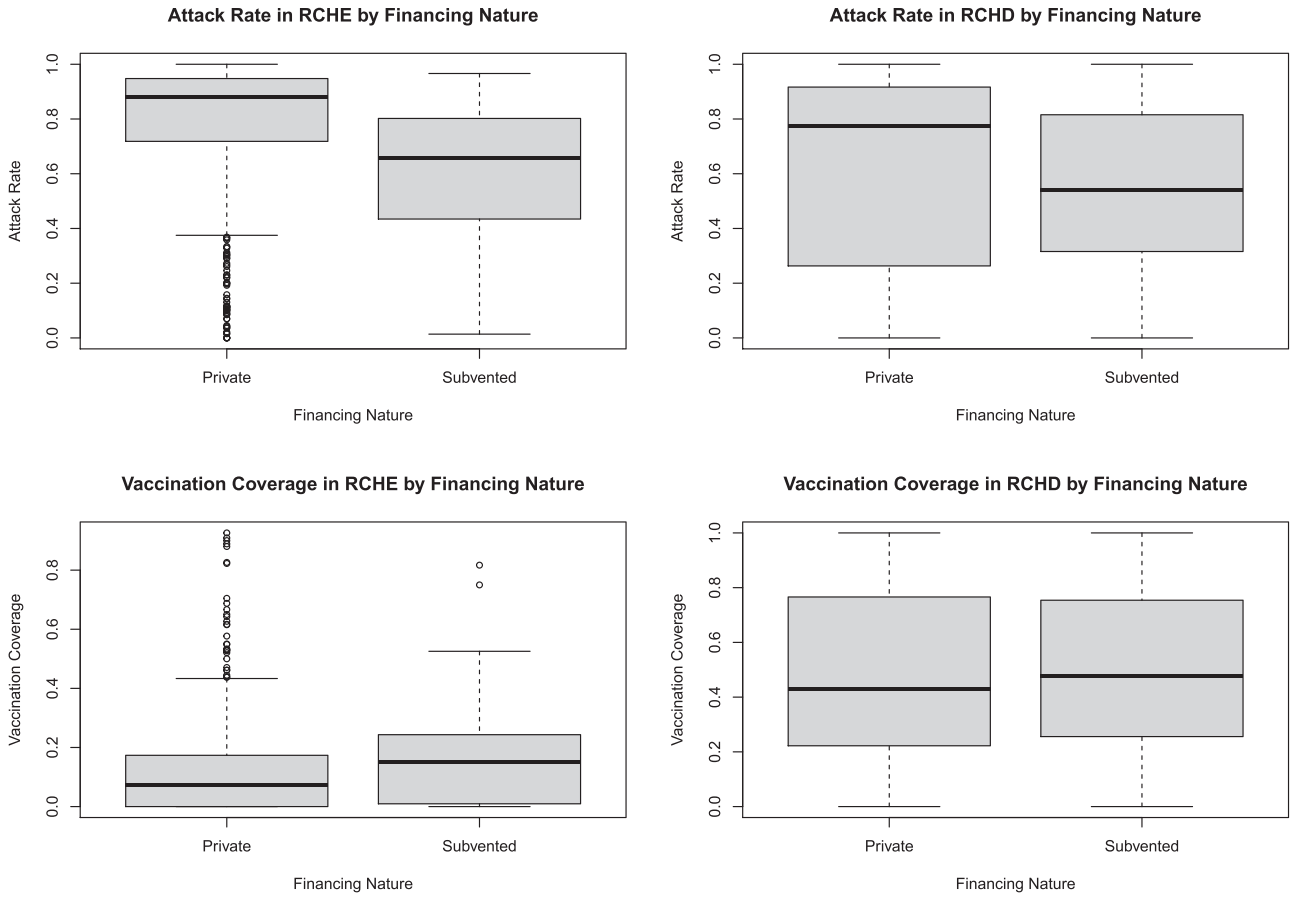

Fig. 5. Boxplots showing median and inter-quartile range (IQR) of attack rate and vaccination coverage of RCHEs and RCHDs by financing nature (private vs subvented).

Vaccine effectiveness (VE) of at least two-dose (any type) against severe outcomes and death was 31% (95% CI: 26%–36%) and 38% (95% CI: 32%–44%), respectively, compared with unvaccinated/vaccinated with one-dose. For type of vaccine, VE of at least two-dose of BNT162b2 against severe outcomes and death (52% and 59%, respectively) were higher than that of CoronaVac (29% and 36%, respectively).

For RCHD cases (Table 5), patients vaccinated with at least two-dose (any type) had 0.64 (95% CI: 0.45–0.91) times lower risk of having severe outcomes and 0.46 (95% CI: 0.23–0.91) times lower risk of death, as compared with the controls. For type of vaccine, the adjusted risk of severe outcomes among residents with at least two-dose of BNT162b2 was 0.21 (95% CI: 0.05–0.84) times lower as compared with the control, while vaccination with at

Table 1
Residents infected with COVID-19 in RCHEs and RCHDs with available information.

	RCHE cases (n = 13977)		RCHD cases (n = 1636)	
Age				
Median age (IQR)	87	(79–92)	55	(42–64)
Sex				
Female	7291	(52.2%)	666	(40.7%)
Male	6686	(47.8%)	970	(59.3%)
Chronic illness				
No	12633	(90.4%)	1553	(94.9%)
With 1 disease	995	(7.1%)	78	(4.8%)
With >1 diseases	349	(2.5%)	5	(0.3%)
COVID-19 vaccination				
Unvaccinated/one-dose	11,878	(85.0%)	992	(60.6%)
At least two-dose (overall)	2099	(15.0%)	644	(39.4%)
• CoronaVac	*1900*	*(13.6%)*	*507*	*(31.0%)*
• BNT162b2	*199*	*(1.4%)*	*137*	*(8.4%)*
Clinical				
Asymptomatic	2379	(17.0%)	250	(15.3%)
Severe outcomes (including death)	5201	(37.2%)	151	(9.2%)
Death (CFR)	3921	(28.1%)	63	(3.9%)

Table 2
Residents infected with COVID-19 in RCHEs by vaccination status.

	Unvaccinated or Vaccinated with one-dose (n = 11878)		Vaccinated with at least two-dose (n = 2099)			
			CoronaVac (n = 1900)		*BNT162b2* (n = 199)	
Age						
Median age (IQR)	87	(80-92)	86	(78-91)	79	(70-88)
Sex						
Female	6154	(51.8%)	1057	(55.6%)	80	(40.2%)
Male	5724	(48.2%)	843	(44.4%)	119	(59.8%)
Chronic illness						
Chronic cardiac disease	506	(4.3%)	53	(2.8%)	17	(8.5%)
Chronic pulmonary disease	180	(1.5%)	20	(1.1%)	2	(1.0%)
Chronic renal disease	224	(1.9%)	20	(1.1%)	6	(3.0%)
Chronic liver disease	44	(0.4%)	5	(0.3%)	2	(1.0%)
Diabetes mellitus	530	(4.5%)	77	(4.1%)	9	(4.5%)
Immunodeficiencies	44	(0.4%)	15	(0.8%)	3	(1.5%)
Signs and symptoms						
Fever>=38 ˚C	3727	(31.4%)	493	(25.9%)	52	(26.1%)
Cough	2524	(21.2%)	317	(16.7%)	37	(18.6%)
Pneumonia	675	(5.7%)	73	(3.8%)	8	(4.0%)
Sore throat	263	(2.2%)	44	(2.3%)	7	(3.5%)
Shortness of breath	2716	(22.9%)	292	(15.4%)	27	(13.6%)
Runny nose	98	(0.8%)	10	(0.5%)	3	(1.5%)
Diarrhea	74	(0.6%)	8	(0.4%)	1	(0.5%)
Vomiting	304	(2.6%)	43	(2.3%)	5	(2.5%)
Fatigue	205	(1.7%)	26	(1.4%)	4	(2.0%)
Loss of taste/smell	4	(0.0%)	0	(0.0%)	0	(0.0%)
Asymptomatic	2008	(16.9%)	323	(17.0%)	48	(24.1%)

Table 3
Residents infected with COVID-19 in RCHDs by vaccination status.

	Unvaccinated or Vaccinated with one-dose (n = 992)		Vaccinated with at least two-dose (n = 644)			
			CoronaVac (n = 507)		*BNT162b2* (n = 137)	
Age						
Median age (IQR)	57	(43-66)	53	(42-63)	44	(33-56)
Sex						
Female	420	(42.3%)	199	(39.3%)	47	(34.3%)
Male	572	(57.7%)	308	(60.7%)	90	(65.7%)
Chronic illness						
Chronic cardiac disease	15	(1.5%)	2	(0.4%)	1	(0.7%)
Chronic pulmonary disease	6	(0.6%)	3	(0.6%)	0	(0.0%)
Chronic renal disease	3	(0.3%)	1	(0.2%)	0	(0.0%)
Chronic liver disease	6	(0.6%)	1	(0.2%)	0	(0.0%)
Diabetes mellitus	23	(2.3%)	14	(2.8%)	1	(0.7%)
Immunodeficiencies	10	(1.0%)	3	(0.6%)	0	(0.0%)
Signs and symptoms						
Fever>=38˚C	370	(37.3%)	162	(32.0%)	38	(27.7%)
Cough	177	(17.8%)	93	(18.3%)	37	(27.0%)
Pneumonia	22	(2.2%)	6	(1.2%)	0	(0.0%)
Sore throat	34	(3.4%)	18	(3.6%)	17	(12.4%)
Shortness of breath	84	(8.5%)	26	(5.1%)	1	(0.7%)
Runny nose	21	(2.1%)	16	(3.2%)	12	(8.8%)
Diarrhea	9	(0.9%)	1	(0.2%)	0	(0.0%)
Vomiting	29	(2.9%)	12	(2.4%)	1	(0.7%)
Fatigue	17	(1.7%)	8	(1.6%)	6	(4.4%)
Loss of taste/smell	0	(0.0%)	0	(0.0%)	0	(0.0%)
Asymptomatic	152	(15.3%)	82	(16.2%)	16	(11.7%)

least two-dose of CoronaVac was showed to have lower risk of death (aRR: 0.48, 95% CI: 0.24–0.96) as compared with the control.

VE of at least two-dose (any type) against severe outcomes and death was 36% (95% CI: 9%–55%) and 54% (95% CI: 9%–77%) respectively, compared with unvaccinated/vaccinated with one-dose. For type of vaccine, VE of at least two-dose of BNT162b2 against severe outcomes was 79% (95% CI: 16%–95%). However, only one death was recorded among RCHD residents who received BNT162b2, the result of its VE against death was not significant. VE of at least two-dose of CoronaVac against severe outcomes was not significant, while its VE against death was 52% (95% CI: 4%–76%).

Table 4
Adjusted relative risk (aRR) against severe outcomes and death, and effectiveness of at least two-dose of COVID-19 vaccines among RCHE cases.

	Level	aRR	95% CI	*p*-value
Severe outcomes				
Age (per year)		1.02	1.01–1.02	<0.0001
Sex	Female	**Ref**		
	Male	1.33	1.27–1.39	<0.0001
No. of chronic illness	None	**Ref**		
	1	1.08	1.00–1.17	0.0630
	>1	1.28	1.15–1.43	<0.0001
Vaccination	Unvaccinated/one-dose	**Ref**		
	At least two-dose:			
	• BNT162b2	0.48	0.36–0.65	<0.0001
	• CoronaVac	0.71	0.66–0.77	<0.0001
Death				
Age (per year)		1.02	1.02–1.03	<0.0001
Sex	Female	**Ref**		
	Male	1.44	1.37–1.52	<0.0001
No. of chronic illness	None	**Ref**		
	1	1.09	0.99–1.20	0.0865
	>1	1.34	1.18–1.53	<0.0001
Vaccination	Unvaccinated/one-dose	**Ref**		
	At least two-dose:			
	• BNT162b2	0.41	0.28–0.61	<0.0001
	• CoronaVac	0.64	0.58–0.71	<0.0001
Vaccine effectiveness of at least two-dose [1 - aRR (95% CI)]				
Severe outcomes	At least two-dose:			
	• BNT162b2	52%	(35–64)	
	• CoronaVac	29%	(23–34)	
Death	At least two-dose:			
	• BNT162b2	59%	(39–72)	
	• CoronaVac	36%	(29–42)	

Table 5
Adjusted relative risk (aRR) against severe outcomes and death, and effectiveness of at least two-dose of COVID-19 vaccines among RCHD cases.

	Level	aRR	95% CI	*p*-value
Severe outcomes				
Age (per year)		1.04	1.03–1.04	<0.0001
Sex	Female	**Ref**		
	Male	1.25	0.92–1.70	0.1526
No. of chronic illness	None	**Ref**		
	1	1.67	1.04–2.69	0.0327
	>1	2.00	1.01–3.95	0.0461
Vaccination	Unvaccinated/one-dose	**Ref**		
	At least two-dose:			
	• BNT162b2	0.21	0.05–0.84	0.0280
	• CoronaVac	0.72	0.50–1.03	0.0715
Death				
Age (per year)		1.06	1.05–1.07	<0.0001
Sex	Female	**Ref**		
	Male	1.15	0.69–1.89	0.5943
No. of chronic illness	None	**Ref**		
	1	1.27	0.52–3.11	0.5960
	>1	3.03	1.57–5.87	0.0010
Vaccination	Unvaccinated/one-dose	**Ref**		
	At least two-dose:			
	• BNT162b2[a]	0.33	0.05–2.45	0.2799
	• CoronaVac	0.48	0.24–0.96	0.0393
Vaccine effectiveness of at least two-dose [1 - aRR (95% CI)]				
Severe outcomes	At least two-dose:			
	• BNT162b2	79%	(16–95)	
	• CoronaVac	28%	(0–50)	
Death	At least two-dose:			
	• BNT162b2[a]	67%	(0–95)	
	• CoronaVac	52%	(4–76)	

[a] Only one death was recorded among RCHD residents who received at least two-dose of BNT162b2.

4. Discussion

Attack rates and case fatality rates are useful indicators that reflect the impact of outbreaks among RCH residents [23]. The higher the attack rate causes greater challenge in terms of disturbance of daily routine and substantial workload. Primary outcomes are severe disease and death because of their greater public health importance. COVID-19 outbreaks in RCHEs had higher attack rates with higher mortality but lower vaccination coverage than that in RCHDs; private homes had higher attack rates and lower vaccination coverage than in subvented homes. Results showed that outbreaks situation was more severe and vaccination coverage was worse in RCHEs than in RCHDs, which was further exacerbated by the financing status that both conditions in private RCHs were inferior to subvented RCHs. We have further examined the correlation between vaccination coverage against attack rate by types of home separately. The results were statistically significant, suggesting attack rate decreased when vaccination coverage increased for both RCHEs ($\rho = -0.131$, $p < 0.001$) and RCHDs ($\rho = -0.333$, $p < 0.001$), although the association is weak and cannot support a causal inference. Similar findings could be observed in other places. A study in England showed that outbreak severity decreased as long-term care facilities vaccination coverage increased, with 80.6% reduction in the attack rates and 45.9% reduction in outbreak duration when comparing outbreaks in the pre-vaccination period with outbreaks in the postvaccination period [24].

On individual level, higher proportion of infected residents who were unvaccinated/vaccinated with one-dose had more severe symptoms including SOB and pneumonia than those with at least two-dose in both RCHEs and RCHDs. For RCHE residents, increasing age, male, and multiple chronic illnesses were significant risk factors for severe outcomes and death, while having at least two-dose (any type) was protective with 31% reduction in risk of severe outcomes and 38% reduction in risk of death. Furthermore, RCHE residents who received at least two-dose of BNT162b2 had a lower risk of severe outcomes and deaths (with VE against severe outcomes and death: 52% and 59%, respectively) than those with CoronaVac (with VE against severe outcomes and death: 29% and 36%, respectively). For RCHD residents, increasing age, and multiple chronic illnesses were significant risk factors for severe outcomes and death, while having at least two-dose was protective with 36% reduction in risk of severe outcomes and 54% reduction in risk of death. However, only RCHD residents having at least two-dose of BNT162b2 showed a significant 79% reduction in risk of severe outcomes, while only RCHD residents with at least two-dose of CoronaVac showed a significant 52% reduction in risk of death. Since only one death was recorded among RCHD residents who received BNT162b2, the non-

significant result of its VE against death may be related to rare event in this group.

In this large observation study using territorial-wide infection and vaccination data in indigenous RCHs, we confirmed at least two-dose of COVID-19 vaccines is effective in reducing COVID-19 related severe outcomes and death. Compared with infected residents who were unvaccinated/vaccinated with one-dose only, receiving at least two-dose (any type) was estimated to be 31% and 36% effective in reducing severe outcomes among infected RCHE and RCHD residents, respectively; while higher reduction in mortality among infected RCHD than RCHE residents (54% vs 38%, respectively). In RCHEs, VE of at least two-dose of BNT162b2 against severe outcomes and death are higher than that of CoronaVac. In RCHDs, VE of at least two-dose of BNT162b2 against severe outcomes is higher than that of CoronaVac.

According to the literature, high-coverage vaccination is an effective intervention to prevent SARS-CoV-2 transmission and death among long-term care facilities residents. COVID-19 outbreak in a long-term care home in Canada, vaccine effectiveness against severe infection was 52.5% in residents [25]. In the United States, early COVID-19 vaccinated nursing homes had fewer hospitalizations and/or deaths among infected residents [26]. More than 70% of long-term care facilities population in Spain were fully vaccinated, 74% of COVID-19 deaths among residents were prevented when compared with prevaccination period [27]. However, these studies were performed before the emergence of the highly transmissible Omicron variant and did not specify different types of RCH.

Our study has several limitations. For the correlation between attack rates and vaccination rates, we did not include RCH staff since information about all full-time and part-time staff was not available. They either had completed two-dose vaccination or subject to frequent compulsory testing at their own expense if not completed two-dose [28]. Secondly, the testing frequency for COVID-19 could be different between RCHs that might not allow unbiased estimation of infection. Third, the location and size of institutions may influence attack rates as the RCH may be located in a district with higher incidence of SARS-CoV-2 infection and affected by large resident capacity [29]. Lastly, the outbreak characteristics may also be associated with any changes in broader policy such as non-pharmaceutical interventions and changing territory-wide incidence rates.

Concerning vaccine effectiveness of at least two-dose of vaccine against severe outcomes, unmeasured confounding might exist as in any observational studies. But this concern is minimized since important confounders for severe outcomes were adjusted in our analysis. Second, any severe outcomes after June 28, 2022 were not included, as severe outcomes including death developed more than 4 weeks after infection were unlikely to be related to COVID-19. Lastly, the potential of waning vaccine-induced immunity and recent emergence of highly transmissible Omicron variant may have unknown degree of impact on the vaccine effectiveness.

5. Conclusions

Before the 5th wave, the coverage of RCH residents with at least two-dose of COVID-19 vaccination was low in RCHDs and very low in RCHEs. During the 5th wave, majority of RCHs were badly attacked by the Omicron variant, particularly higher median attack rates (0.84) and mortality (CFR: 28.1%) in RCHEs than RCHDs (median attack rates: 0.58; CFR: 3.9%). Our results suggested that increasing COVID-19 vaccination could have a significant impact on reducing the risk of COVID-19 outbreaks in RCHs.

Our study also estimated the vaccine effectiveness in preventing severe outcomes and death from COVID-19, with stratification on RCHEs and RCHDs, aiming to providing more scientific evidence to inform the promotion of vaccination programme in institutional settings. We found that COVID-19 vaccination with at least two-dose is still effective in reducing COVID-19 related severe outcomes (31% and 36% lower risk of severe outcomes among infected RCHE and RCHD residents respectively) and death (38% and 54% lower risk of death among infected RCHE and RCHD residents, respectively) amid the COVID-19 epidemics mainly caused by Omicron variant. For the type of vaccine, BNT162b2 conferred higher protection against severe outcomes and death than CoronaVac. Concerns about the potential of waning vaccine-induced immunity and emergence of new COVID-19 variants highlight the need to enhance the vaccination coverage in RCHs and continue to monitor vaccine effectiveness.

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Author contributions

MH Joanna LEUNG: Conceptualization and design, Data Curation, Analysis, Investigation, Methodology, Validation, Writing – Original Draft Preparation, Writing – Review & Editing; KH KUNG: Conceptualization and design, Methodology, Supervision, Writing – Review & Editing; Ian SK YAU: Data Curation, Analysis, Investigation, Methodology, Validation, Writing – Original Draft Preparation, Writing–Review & Editing; YY FUNG and KN MOHAMMAD: Data Curation, Analysis, Investigation,

Methodology, Software, Validation, Writing – Original Draft Preparation, Writing – Review & Editing; CC Andrew LAU, KW Albert AU and SK CHUANG: Methodology, Supervision, Writing – Review & Editing, Final Approval.

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Declaration of competing interest

The authors declare no competing interests.

Data availability statement

Due to data privacy regulations and the sources of data involved multiple departments that are subject to third party restrictions, the raw data on both individual level and institutional level of this study cannot be shared.

Ethics statement

NA.

Informed consent

NA.

References

[1] World Health Organization. COVID-19 weekly epidemiological update edition 97. 2022. Available at: https://www.who.int/publications/m/item/weekly-epidemiological-update-on-covid-19-22-june-2022 (accessed August 1, 2022).
[2] YWD Chan, S Flasche, TLT Lam, et al., Transmission dynamics, serial interval and epidemiology of COVID-19 diseases in Hong Kong under different control measures, Wellcome Open Res 5 (2020) 91 Available at https://wellcomeopenresearch.org/articles/5-91 .
[3] HY Lam, CCA Lau, CH Wong, et al., A review of epidemiology and public health control measures of COVID-19 variants in Hong Kong, December 2020 to June 2021, IJID Reg 2 (2022) 16–24.
[4] HKSARG Press Releases. COVID-19 vaccination programme officially launched. 2021. Available at: https://www.info.gov.hk/gia/general/202102/26/P2021022600815.htm (accessed August 1, 2022).
[5] HKSARG. Hong Kong vaccination dashboard: vaccine doses administered. 2022. Available at: https://www.covidvaccine.gov.hk/en/dashboard/dailySecondDose (accessed Aug 1, 2022).
[6] HKSARG Press Releases. Government continues adopting risk-based testing strategy. 2022. Available at: https://www.info.gov.hk/gia/general/202202/25/P2022022500816.htm?fontSize=1 (accessed August 1, 2022).
[7] Centre for Health Protection of the Department of Health, HKSAR. Latest situation of COVID-19 (as of 31 May 2022). 2022. Available at: https://www.chp.gov.hk/files/pdf/local_situation_covid19_en_20220531.pdf (accessed August 1, 2022).
[8] World Health Organization. Coronavirus disease (COVID-19). 2021. Available at: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/coronavirus-disease-covid-19 (accessed August 1, 2022).
[9] MR Hashan, N Smoll, C King, et al., Epidemiology and clinical features of COVID-19 outbreaks in aged care facilities: a systematic review and meta-analysis, EClinicalMed 33 (2021) 100771.
[10] RA. Garibaldi, Residential care and the elderly: the burden of infection, J Hosp Infect 43 (Suppl) (1999) S9–18.
[11] C Suetens, P Kinross, P Gallego Berciano, et al., Increasing risk of breakthrough COVID-19 in outbreaks with high attack rates in European long-term care facilities, July to October 2021, Euro Surveill 26 (49) (2021) 2101070.
[12] Centers for Disease Control and Prevention. Nursing home Covid-19 data dashboard. 2022. Available at: https://www.cdc.gov/nhsn/covid19/ltc-report-overview.html (accessed August 1, 2022).
[13] HKSARG Press Releases. Government announces arrangements for persons pending admission to hospitals or isolation facilities. 2022. Available at: https://www.info.gov.hk/gia/general/202202/15/P2022021500524.htm (accessed August 1, 2022).
[14] HKSARG Press Releases. Selecting and using rapid antigen tests. 2022. Available at: https://www.info.gov.hk/gia/general/202202/27/P2022022600796.htm (accessed August 1, 2022).
[15] Social Welfare Department, HKSAR. Licensing scheme for residential care homes for the elderly. 2022. Available at: https://www.swd.gov.hk/en/index/site_pubsvc/page_lr/sub_rche/id_introd/ (accessed August 1, 2022).
[16] Social Welfare Department, HKSAR. Licensing scheme for residential care homes for persons with disabilities. 2022. Available at: https://www.swd.gov.hk/en/index/site_pubsvc/page_lr/sub_rchdtop/id_rchd/ (accessed August 1, 2022).
[17] HKSARG. About the Vaccines. 2022. Available at: https://www.covidvaccine.gov.hk/en/vaccine (accessed August 1, 2022).
[18] HKSARG Press Releases. Outreach vaccination arrangement for RCHs under COVID-19 vaccination programme starts. 2021. Available at: https://www.info.gov.hk/gia/general/202104/13/P2021041300415.htm (accessed August 1, 2022).
[19] UK Health Security Agency. Technical summary. UK Health Security Agency data series on deaths in people with COVID-19. 2022. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1052203/UKHSA-technical-summary-update-February-2022.pdf (accessed November 28, 2022).
[20] New Zealand Ministry of Health. COVID-19: current cases. Available at: https://www.health.govt.nz/covid-19-novel-coronavirus/covid-19-data-and-statistics/covid-19-current-cases (assessed November 28, 2022)
[21] G. Zou, A modified poisson regression approach to prospective studies with binary data, Am J Epidemiol 159 (7) (2004) 702–706.
[22] R Core Team. R: A language and environment for statistical computing Vienna, Austria: R Foundation for Statistical Computing; 2021. Available at: https://www.R-project.org (accessed August 1, 2022).
[23] M Utsumi, K Makimoto, N Quroshi, N. Ashida, Types of infectious outbreaks and their impact in elderly care facilities: a review of the literature, Age Ageing 39 (3) (2010) 299–305.
[24] R Giddings, M Krutikov, T Palmer, et al., Changes in COVID-19 outbreak severity and duration in long-term care facilities following vaccine introduction, England, November 2020 to June 2021, Euro Surveill 26 (46) (2021) 2100995.
[25] C Williams, D Al-Bargash, C Macalintal, et al., Coronavirus disease 2019 (COVID-19) outbreak associated with severe acute respiratory syndrome coronavirus 2 (SARS–CoV-2) P.1 lineage in a long-term care home after implementation of a vaccination program-Ontario, Canada, April-May 2021, Clin Infect Dis 74 (6) (2022) 1085–1088.
[26] V Mor, R Gutman, X Yang, et al., Short-term impact of nursing home SARS-CoV-2 vaccinations on new infections, hospitalizations, and deaths, J Am Geriatr Soc 69 (8) (2021) 2063–2069.
[27] De Salazar PM, Link N, Lamarca K, Santillana M. High coverage COVID-19 mRNA vaccination rapidly controls SARS-CoV-2 transmission in Long-Term Care Facilities. Res Sq [Preprint]. 2021 Apr 12:rs.3.rs-355257. doi:10.21203/rs.3.rs-355257/v1. Update in: Commun Med (Lond). 2021 Jul 16;1:16. PMID: 33880465; PMCID: PMC8057244.
[28] HKSARG Press Releases. 44th round of compulsory testing for staff members of RCHEs, RCHDs and nursing homes to commence shortly. 2021. Available at: https://www.info.gov.hk/gia/general/202112/31/P2021123000362.htm?fontSize=1 (accessed August 1, 2022).
[29] AP Costa, DR Manis, A Jones, et al., Risk factors for outbreaks of SARS-CoV-2 infection at retirement homes in Ontario, Canada: a population-level cohort study, CMAJ 193 (19) (2021) E672–E680.