1 Introduction

Without effective treatment, the current responses to the coronavirus disease (COVID-19) pandemic involve aggressive suppression measures causing massive socio-economic disruptions. Seroprevalence studies have found that most people in epicentres of the outbreak have remained uninfected [1-4]. Vaccination against SARS-CoV-2, which causes COVID-19, is the most desired solution to end the pandemic [5]. Multiple candidate vaccines are being developed, and some have already been authorized and deployed for mass immunization [6].

The success of any vaccination program depends on its acceptance and uptake in the population. Vaccine hesitancy, defined as delays or refusal to accept vaccination [7], has been declared as one of the ten leading threats to global health by the World Health Organization (WHO) since 2019 [8]. Given an estimated basic reproductive number of 2.2 to 5.7 [9], about 55% to 82% of the population need to be immunized to halt SARS-CoV-2 transmission, assuming the vaccine has 100% efficacy in preventing infection. SARS-CoV-2 vaccine hesitancy could substantially limit herd immunity. Online population-representative surveys conducted in the early phase of the pandemic (March to April 2020) have found varying prevalence of SARS-CoV-2 vaccine hesitancy when it becomes available: from 14% in Australia [10] to 26% in France [11] and 42% in the US [12], with some sociodemographic variations.

Hong Kong is a densely populated city with over 7.5 million people and an international transport and trading hub in southern China. Having been hit by the severe acute respiratory syndrome (SARS) epidemic in 2003 with over 300 deaths [13], the general public has shown a high level of vigilance for COVID-19 with almost universal (>95%) voluntary mask-wearing [14]. However, during the 2009 swine flu (H1N1) pandemic, the Hong Kong population showed low acceptability (<45%)[15] and uptake of the pandemic H1N1 vaccine

[16]. The vaccine acceptance among healthcare workers, who play a vital role in building the public's confidence in the vaccine, was also low in Hong Kong (<48%) [17]. We examined the intention to vaccinate against SARS-CoV-2 and the associated factors in a representative sample of Chinese adults in Hong Kong.

2 Methods

2.1 Study design and participants

We did a landline telephone and mobile cross-sectional survey using a structured questionnaire during 9 to 23 April 2020, about 2 to 4 weeks after the peak of the second wave of COVID-19 outbreak in Hong Kong, with 1035 cases and four deaths by the end of the data collection period. Since the beginning of the first wave in January 23, the Hong Kong Government has implemented border restrictions, quarantine and isolation, contact tracing, and social distancing but no enforced lockdown [14]. The methods and other findings from the survey have been reported elsewhere [18].

Participants were Hong Kong residents aged 18 years or above who could communicate in Chinese. We randomly sampled participants by random digit dialling using landline telephone and from a population-representative panel of over 100,000 mobile phone users managed by a reputable survey company in Hong Kong (mobile phone ownership rate in Hong Kong=97.1%) [20]. For the landline telephone survey, a random list of landline telephone numbers was generated based on the official's numbering plan for telecommunication services. Upon successful contact with an eligible household, a resident whose next birthday was closest to the interview date was invited to participate. Trained interviewers administered the landline survey by using a computer-assisted telephone interviewing system. Cognitive interviewing with ten subjects was done to refine the questionnaires. A random fifth of the landline interview record was counterchecked to ensure quality. For the mobile survey, invitations by mobile text messages were sent to a random list of panellists stratified by sex and age, with no second-stage sampling. Those who agreed to participate received a private link to a web-based computer-assisted interviewing system and self-administered the questionnaire. The Institutional Review Board of the University of Hong Kong/ Hospital Authority Hong Kong West Cluster (UW 20-238) approved the study. All participants provided informed consent before participation.

2.2 Measures

The main outcome measure was intention to receive SARS-CoV-2 vaccine; we asked participants "If a vaccine against SARS-CoV-2 becomes available, would you take it?". Similar to other studies [10, 12], we used a 3-point response options of "yes", "no", and "undecided". Those who responded "no" or "undecided", which indicated vaccine hesitancy, were further asked the reason for not taking the vaccine, with response options of "do not trust the effectiveness of vaccination" (not effective), "not necessary", "no time to get vaccinated" (no time), and "worry about the side effects of the vaccine" (side effect). The participants could select more than one option.

We adapted items on knowledge and perception of SARS-CoV-2 infection from the COVID-19 Rapid Qualitative Assessment Tool developed by the WHO [20]. Participants reported their (1) knowledge of the major mode of transmission (droplets from infected people, direct contacts with infected people, and touching contaminated objects/ surfaces)[21]; (2) perceived danger of COVID-19 with responses options of "very dangerous (i.e., life-threatening)", "dangerous (i.e., require hospitalization)", "somewhat dangerous (i.e., require home care)", and "not dangerous (i.e., can perform activities of daily living)"; and (3) perceived risk of contracting SARS-CoV-2 in the coming 6 months (from 0 "not likely at all" to 10 "very likely").

Data on sociodemographic (sex, age, education), self-reported chronic diseases diagnosed by a physician, smoking (never/ former/ current smokers) and alcohol drinking were also collected. Alcohol drinking was categorized into non-drinkers (never or former drinkers), occasional drinkers, and regular drinkers (at least monthly).

2.3 Statistical analysis

We combined data from the landline and mobile surveys and weighted the prevalence estimates by the sex, age, and education distributions of the general adult population by using census data from the Census and Statistics Department of the Hong Kong Government [22]. Given the ordinal responses of intention to vaccinate against SARS-CoV-2 (yes=0, undecided=1, no =2), we used partial proportional odds models to calculate the proportional odds ratio (OR) with 95% confidence interval (CI) of intention to vaccinate against SARS-CoV-2 for sociodemographic factors, chronic disease, smoking, and alcohol drinking. A higher OR indicates greater SARS-CoV-2 hesitancy. Compared with ordered logistic regression, the partial proportional odds model is less restrictive and can relax the parallel lines constraints for explanatory variables that violate the proportional odds assumption [23]. For such variables, the partial proportional odds model will compute the OR of "undecided or no" *vs* "yes" and the OR of "no" *vs* "undecided or yes" separately. This approach is also more efficient than multinomial ("no" *vs* "yes" and "undecided" *vs* yes) or binary ("no or undecided" *vs* "yes") logistic regression by preserving the information conveyed by the ordinal nature of the outcome variable.

We hypothesized that inadequate knowledge in SARS-CoV-2 transmission and lower perceived danger of COVID-19 were associated with greater SARS-CoV-2 vaccine hesitancy. The partial proportional odds models were also used to examine the association of knowledge and perceptions of SARS-CoV-2 with vaccine hesitancy, adjusting for sociodemographic and other factors. With a small number of cases, the response options of ‘somewhat dangerous” and “not dangerous” were combined for perceived danger of COVID-19. Based on the median score of perceived risk of contracting SARS-CoV-2, we divided the participants into three groups of similar numbers of participants by lower (0–2), average (3–4) and higher (5–10) perceived risk.

All analyses were conducted in Stata/MP version 15.1. We used complete case analyses because there was no missing value in all variables. A 2-sided $P<0.050$ indicates statistical significance.

3 Results

The response rate was 61.3% (500 of 816) for the landline telephone survey and 61.7% (1001 of 1623) for the mobile self-administered survey. Of the 1501 participants, 53.6% (n=672) were females, 48.5% (n=748) aged 50 years or older, and 15.0% (n=187) had chronic disease (mostly hypertension [n=84] and diabetes [n=74]).

Overall, 45.3% (95% CI: 42.3–48.4%) of the participants intended to vaccinate against SARS-CoV-2 when it becomes available, 29.2% (26.5–32.1%) were undecided, and 25.5% (22.9–28.2%) had no intention. Table 1 shows that the prevalence of SARS-CoV-2 hesitancy (undecided or no intention) significantly differed across participants of different age ($P<0.001$), chronic diseases ($P<0.001$), smoking ($P=0.003$), and alcohol drinking ($P<0.001$) status.

The most common reason for SARS-CoV-2 vaccine hesitancy was “side effects” (56.6%; 469 of 810), followed by “not effective” (31.8%; 243 of 810), “not necessary” (31.7%; 260 of 810), and “no time” (11.3%; 99 of 810). Figure 1 shows that the most common reason for hesitancy was “side effect” (70.3%; 310 of 429) in undecided participants and “not necessary” (47.2%; 178 of 381) in those with no intention.

Table 2 shows the results from the partial proportional odds models, in which all independent variables except chronic disease status and alcohol drinking met the proportional odds assumption (Wald test P>0.050). Therefore, the models did not impose constraints for parallel lines for chronic disease status and alcohol drinking. Multivariable analyses found that female sex, older age, having a chronic disease, and social and regular drinkers (*vs* non-drinkers) were associated with lower odds of SARS-CoV-2 vaccine hesitancy. Bivariate analyses found that higher education was associated with vaccine hesitancy, but the associations became null after adjusting for other factors. Compared with never smokers, the odd of vaccine hesitancy was significantly higher in current smokers. The results were similar when binary logistic regression ("undecided or no intention" vs "intended to vaccinate") were used (Table S-1 in the Supplementary information).

Of the 1501 participants, 87.8% (n=1324) correctly stated "droplets from infected people" as a major mode of transmission. The corresponding prevalence were 75.9% (n=1157) for "direct contact with infected people" and 52.0% (n=755) for "touching contaminated objects/ surfaces". Only 44.7% (n=669) were able to correctly state all three major modes of transmission. For perceived danger of COVID-19, 45.3% (n=638) considered COVID-19 "very dangerous, 46.5% (n=737) "dangerous", and 8.3% (n=126) "somewhat/ not dangerous". The participants tended to rate the risk of getting infected in the coming 6 months on the low side (median [IQR] = 3 [2–5] on a scale of 0 to 10), and hence 34.1% (n=531), 28.7% (n=431) and 37.2% (n=539) participants were classified as having lower (0–2), average (3–4) and higher (5–10) perceived risk, respectively.

Table 3 shows that inadequate knowledge of the major modes of SARS-CoV-2 transmission and lower perceived danger of COVID-19 were associated with greater SARS-CoV-2 vaccine hesitancy. The results were similar with or without adjusting for sociodemographic, smoking and alcohol drinking, and other variables on knowledge or perception of COVID-19.

The results from binary logistic regression were also similar (Table S-1 in the Supplementary information).

4 Discussion

In this population-based survey in Hong Kong, less than half (45.3%) of the participants intended to vaccinate against SARS-CoV-2 when it becomes available. Although results from different surveys may not be directly comparable, our vaccine hesitancy rate (54.7%) appeared to be higher than those reported in other population-based surveys in Australia, France and the US (14%–42%) conducted during a similar period (March to April 2020) [10-12]. The much smaller COVID-19 outbreak in Hong Kong while we collected the data than outbreaks in most other places may partly explain the discrepancy. It is also possible that the practice of almost universal mask-wearing, which is effective in curbing transmission [24], might have reduced the perceived need of vaccination in some Hong Kong people. Given previous findings in Hong Kong that only a fraction of those intended to vaccinate against pandemic H1N1 took the vaccine [16], the actual vaccination against SARS-CoV-2 would likely be lower and unlikely to reach the minimal herd immunity threshold of 55% (assuming a basic reproductive number of 2.2)[9]. Importantly, many participants were "undecided" (29.2%), and interventions that can address their common drivers of hesitancy such as safety concerns (70.3%) could help motivate them to accept the vaccine.

Our sociodemographic variations in SARS-CoV-2 vaccine hesitancy showed some differences in the direction of associations from those in other surveys conducted during a similar period [10-12]. We found that females were more likely than males to accept the vaccine, which may help improve immunization rate in children since mothers are often the decision-makers of child vaccination [25]. The surveys in French and US adults, however, found that more females than males were hesitant about taking the vaccine [11-12]. Our older participants and those with chronic diseases, who are more susceptible to severe COVID-19 complications and deaths [26], were less hesitant about receiving the vaccine. The surveys in the US and Australia but not France also observed a lower vaccine hesitancy in older adults [10-12]. Of note, SARS-CoV-2 vaccination might be contraindicated in people of extreme age and those with certain medical conditions, and increasing vaccine acceptance among the vast majority of younger and healthy people are needed to protect the most vulnerable groups by herd immunity. We also found more vaccine hesitancy in the higher educated, while the opposite was observed in France, the US and Australia [10-12]. These corroborate previous findings that the determinants of vaccine hesitancy likely differ across places [7]. While further cross-cultural studies are warranted to understand the discrepancies, these findings collectively suggest that sociodemographic information, which is readily obtainable, are useful in identifying subpopulations with low vaccine acceptance for targeted interventions. Still, local surveys need to be done first.

We were the first to examine the associations of smoking and alcohol drinking with SARS-CoV-2 vaccine hesitancy. Despite growing evidence suggesting that smoking is linked to COVID-19 severity and deaths [27], our smokers were more hesitant than non-smokers. We have reported elsewhere that unproven claims that smoking may protect against COVID-19 have been widely circulated in social media platforms [18]. This might have partly contributed to a lower perceived need for vaccination in some smokers exposed to such misinformation. Apart from advice to quit smoking, smokers should be warned about their greater likelihood of worse COVID-19 outcomes to increase vaccine uptake. On the contrary, our alcohol drinkers were less hesitant than non-drinkers about getting the vaccine. During the second wave of COVID-19 outbreak in Hong Kong, the largest cluster of local outbreak involved over a hundred customers and staff members from four bars [28], which also resulted in enforced closures of all premises that mainly sell alcoholic beverages during the entire data collection period. Although speculative, such a large outbreak and the high risk of bar-goers might explain their greater intention to be vaccinated. Our results, if replicated by further studies, could apply to other places where outbreaks from clusters of bar-goers have been reported.

Our findings on the reasons for not taking the vaccine and knowledge and perceptions of COVID-19 suggested SARS-CoV-2 vaccine hesitancy follows the Confidence, Complacency and Convenience ("3Cs") model of vaccine hesitancy [7]. Nearly half of the participants were hesitant because of safety concerns, and about one-third believed it would not be effective, suggesting the lack of confidence in the vaccine. Given the rapid, fast-tracked development of the vaccine, ensuring its rigorous testing with transparent reporting of its effectiveness and side effects and the approval process is not jeopardized by ulterior motives are paramount to build the public's confidence. Misinformation or conspiracy theories against SARS-CoV-2 vaccine propagated by anti-vaccine activists would undermine vaccine confidence and need to be curbed [29].

About one-third of participants with SARS-CoV-2 vaccine hesitancy considered the vaccine unnecessary. This belief, coupled with the association of lower perceived danger of COVID-19 with greater hesitancy, indicated vaccine complacency. A recent study has also found a higher rate of SARS-CoV-2 vaccine acceptance in US adults with greater perceived severity of COVID-19 [30]. Public health messaging to raise public awareness of the notable fatality rate and potential long-term sequela of COVID-19 (e.g., fatigue and dyspnoea [31]) are needed, especially in Hong Kong and elsewhere that had less severe disease burden. Despite the high level of vigilance for COVID-19 [14], only 44.7% of the participants correctly stated the three major modes of SARS-CoV-2 transmission. We found that inadequate knowledge of the mode of the transmission was independently associated with SARS-CoV-2 vaccine hesitancy. These results should be useful for promoting vaccine uptake in future vaccination campaigns.

Our study had several limitations. First, causality could not be inferred because of the cross-sectional design. Second, similar to most studies on vaccine hesitancy, our measures were self-reported. Third, we included a few options when assessing the reasons for vaccine hesitancy, which could not capture other potential drivers of hesitancy such as political orientations [11] and vaccine-related attributes [32]. Studies that use more options, discrete choice experiments or qualitative method could provide more in-depth understandings of SARS-CoV-2 vaccine hesitancy. Fourth, although we adjusted for several sociodemographic and other factors, the associations of knowledge and perception of SARS-CoV-2 infection with vaccine hesitancy might be explained by unmeasured or residual confounding factors. Fifth, despite a satisfactory response rate of over 60%, non-response bias could not be excluded. To improve representativeness, we weighted the data by sex, age and education of the general population. The estimates computed by using weighted and unweighted data were also very similar. Finally, our study only provided a snapshot of the pattern of SARS-CoV-2 vaccine hesitancy in Hong Kong, which may evolve with time and the development of the pandemic and vaccines. After 3 weeks of zero local case by late June, Hong Kong was hit by the third and then fourth wave of COVID-19 outbreak, which were more severe than the first two waves, raising the number of confirmed case to over 10000 and death tolls to 168 by the first anniversary of the outbreak (www.coronavirus.gov.hk). It is possible that successive waves of outbreaks and the greater disease burden would increase the public's perceived value of SARS-CoV-2 vaccine, thereby changing vaccine hesitancy. Continuous monitoring is needed to inform timely public health measures to improve vaccine acceptance and uptake.

Our study provided the first population-representative estimate of SARS-CoV-2 vaccine hesitancy in Hong Kong, which could be used as a reference point for comparisons by later studies.

Our findings suggest the uptake of vaccination against SARS-CoV-2 in the general population of Hong Kong would unlikely be high after the vaccine is available. The differences in the prevalence of SARS-CoV-2 vaccine hesitancy by sex, age, chronic disease status, current smoking and alcohol drinking suggested the need to understand and address the barriers. Inadequate knowledge of SARS-CoV-2 transmission and lower perceived danger were independently associated with vaccine hesitancy, which provided understandings of the drivers of vaccine hesitancy. SARS-CoV-2 vaccination campaigns need to proactively address the issues above to boost confidence and mitigate vaccine complacency to improve the uptake of the vaccine.

Funding: This study did not receive any funding.

Declaration of Competing Interest: None.

Acknowledgement: We thank the participants for their participation in the survey and Social Policy Research Ltd for implementing the survey.

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Table 1

Prevalence of intention to vaccinate against SARS-CoV-2 by participants' characteristics

	Intention to vaccinate against SARS-CoV-2, Unweighted No. (weighted %)[a]			*P*
Characteristics	Yes	Undecided	No	
Overall	691 (45.3)	429 (29.2)	381 (25.5)	
Sex				0.093
Male	292 (43.0)	190 (28.5)	190 (28.5)	
Female	399 (47.5)	239 (29.9)	191 (22.7)	
Age, years				< 0.001
18–29	81 (35.3)	67 (29.0)	77 (35.7)	
30–39	91 (33.6)	92 (34.2)	89 (32.2)	
40–49	108 (41.2)	80 (31.7)	68 (27.1)	
50–59	127 (44.7)	75 (31.6)	51 (23.7)	
60+	284 (61.7)	115 (23.0)	96 (15.3)	
Education level				0.083
Primary or below	138 (51.7)	64 (30.0)	45 (18.4)	
Secondary	398 (44.7)	236 (27.2)	230 (28.1)	
Tertiary	155 (41.5)	129 (31.6)	106 (26.9)	
Having a chronic disease				< 0.001
No	574 (41.5)	393 (31.3)	347 (27.2)	
Yes	117 (67.0)	36 (17.7)	34 (15.4)	
Smoking				0.006
Never smokers	506 (47.3)	293 (28.7)	255 (24.0)	
Former smokers	79 (46.5)	54 (35.5)	34 (18.0)	
Current smokers	106 (36.9)	82 (27.5)	92 (35.6)	
Alcohol drinking				0.075
Non-drinkers	357 (46.9)	189 (25.6)	233 (27.6)	
Occasional drinkers	205 (43.3)	162 (38.4)	76 (18.3)	
Regular drinkers	129 (43.7)	78 (25.9)	72 (30.4)	

COVID-19=coronavirus disease 2019; SARS-CoV-2=severe acute respiratory syndrome coronavirus 2.

[a] Row percentage; weighted by sex, age, education of the general population of Hong Kong.

Table 2

ORs of SARS-CoV-2 vaccine hesitancy for sociodemographic and other factors in Hong Kong adults calculated by partial proportional odds models[a] (N=1501)

	SARS-CoV-2 vaccine hesitancy			
	Crude OR (95% CI)	*P*	Adjusted OR (95% CI)[b]	*P*
Sex				
Male	1			
Female	0.80 (0.66–0.97)	0.023	0.79 (0.64–0.98)	0.034
Age, years				
18–29	1		1	
30–39	1.02 (0.74–1.42)	0.89	1.02 (0.73–1.42)	0.91
40–49	0.74 (0.53–1.03)	0.071	0.75 (0.53–1.05)	0.095
50–59	0.53 (0.38–0.74)	<0.001	0.55 (0.38–0.78)	0.001
60+	0.42 (0.31–0.57)	<0.001	0.44 (0.31–0.64)	<0.001
Education level				
Primary or below	1		1	
Secondary	1.53 (1.17–2.01)	0.002	1.04 (0.76–1.43)	0.82
Tertiary	1.81 (1.34–2.45)	<0.001	1.01 (0.68–1.50)	0.96
Having a chronic disease				
No	1		1	
Yes[c]	0.50 (0.36–0.67)	<0.001	0.64 (0.46–0.90)	0.010
Yes[d]	0.50 (0.36–0.67)	<0.001	0.90 (0.60–1.35)	0.60
Smoking				
Never smokers	1		1	
Former smokers	0.95 (0.70–1.29)	0.75	1.19 (0.85–1.66)	0.31
Current smokers	1.53 (1.20–1.95)	<0.001	1.82 (1.34–2.47)	<0.001
Alcohol drinking				
Non-drinker	1		1	
Occasional drinkers[c]	0.96 (0.76–1.22)	0.76	0.84 (0.66–1.07)	0.17
Occasional drinkers[d]	0.50 (0.37–0.67)	<0.001	0.42 (0.31–0.57)	<0.001
Regular drinkers	0.92 (0.71–1.18)	0.51	0.62 (0.46–0.85)	0.003

COVID-19=coronavirus disease 2019; SARS-CoV-2=severe acute respiratory syndrome coronavirus 2; OR=odds ratio; CI=confidence interval.

[a] The variables of having a chronic disease and social drinker violated the proportional odds assumption

[b] Adjusted for other variables in the table

[c] OR of "undecided or no" *vs* "yes" responses of intention to vaccinate against SARS-CoV-2.

[d] OR of "no" *vs* "undecided or intend to vaccinate" responses of intention to vaccinate against SARS-CoV-2.

Table 3

Prevalence of intention and ORs of SARS-CoV-2 hesitancy for knowledge and perception of COVID-19 calculated by partial proportional odds models (N=1501)

	Intention to receive vaccination Unweighted No. (Weighted %)[a]			SARS-CoV-2 vaccine hesitancy			
	Yes	Undecided	No	Crude OR (95% CI)	*P*	Adjusted OR (95% CI)[b]	*P*
Knowledge of SARS-CoV-2 transmission							
Correct	339 (47.2)	189 (30.7)	141 (22.2)	1		1	
Partially correct	338 (45.6)	225 (28.4)	206 (26.0)	1.33 (1.09–1.61)	0.004	1.27 (1.04–1.56)	0.021
Incorrect	14 (24.4)	15 (23.9)	34 (51.7)	4.09 (2.48–6.75)	<0.001	2.63 (1.55–4.45)	<0.001
Perceived danger of COVID-19							
Very dangerous	344 (54.4)	175 (28.0)	119 (17.5)	1		1	
Dangerous	318 (40.6)	208 (29.3)	211 (30.1)	1.61 (1.32–1.97)	<0.001	1.62 (1.31–2.00)	<0.001
Somewhat/ not dangerous	29 (22.2)	46 (34.9)	51 (42.9)	3.24 (2.28–4.60)	<0.001	2.47 (1.71–3.58)	<0.001
Perceived risk of contracting SARS-CoV-2							
Higher (5–10)	254 (48.3)	143 (28.2)	142 (23.5)	1		1	
Average (3–4)	176 (40.1)	125 (29.4)	130 (30.5)	1.26 (1.00–1.60)	0.052	1.26 (0.99–1.62)	0.064
Lower (0–2)	261 (46.5)	161 (30.1)	109 (23.4)	0.85 (0.68–1.07)	0.16	0.92 (0.72–1.16)	0.47

COVID-19=coronavirus disease 2019; SARS-CoV-2=severe acute respiratory syndrome coronavirus 2; OR=odds ratio; CI=confidence interval.

[a] Row percentage; weighted by sex, age, and education of the general population of Hong Kong.

[b] Adjusted for sex, age, education level, chronic disease, smoking and alcohol drinking status, and other variables in the table.