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Assessing the impact of respiratory infections and weather conditions on donor attendance and blood inventory in Hong Kong

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Abstract

Background—Maintaining a stable, safe and sufficient blood supply is crucial to the healthcare system. Every year, seasonal influenza epidemics lead to substantial hospitalizations and pose intense pressure on blood transfusion service worldwide, especially in an aging population of Hong Kong which often see bi-annual influenza outbreaks. However, limited quantitative studies have been performed to assess the impacts of influenza and other respiratory infections on blood supply.

Methods—We estimated the impacts of respiratory infections on donor attendance and blood inventory, considering the confounding effects of weather conditions. The method only required influenza-like illness data from the existing sentinel surveillance network, local weather data, donor attendance records from blood transfusion service, and blood inventory levels from local healthcare system.

Results—We estimated the number of donor attendance dropped by 6–10% when the number of consultations with influenza-like illnesses (ILIs) reported by sentinel general outpatient clinics exceeded 5 per 1,000 consultations, which is a moderate activity level and has been observed frequently in Hong Kong. Blood inventory decreased with increased ILI consultation rates reported by sentinel general outpatient clinics. Adverse weather conditions had negative impacts on both donor attendance and blood inventory.

Conclusion—Epidemics of influenza and other respiratory infections coupled with adverse weather conditions affected blood supply in Hong Kong. The pressure on blood transfusion service to maintain a stable and sufficient blood supply during influenza seasons should not be overlooked, especially in an aging population of Hong Kong.

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Joseph T. Wu, Eric H. Y. Lau, Cheuk-Kwong Lee, Ching-Wa Lau and Kathy Leung designed the experiments. Ching-Wa Lau, Cheuk-Kwong Lee and Kathy Leung collected data. Kathy Leung, Eric H. Y. Lau and Joseph T. Wu analysed the data. Kathy Leung, Cheuk-Kwong Lee, Eric H. Y. Lau, Ching-Wa Lau and Joseph T. Wu interpreted the results and wrote the manuscript.

Keywords

Blood donation; donor; blood inventory; influenza; respiratory infection; temperature; adverse weather

Introduction

Every year, influenza season in winter poses challenges for blood transfusion service worldwide to deliver stable and adequate supply of blood products [1–3]. Blood donors are less willing to donate under harsh winter weather conditions or are deferred to donate due to influenza-like illnesses [4], while blood use might surge with increases in hospitalizations due to more injuries and infections, especially in the aging population of many developed countries and regions [5]. Maintaining a stable, safe and sufficient blood supply has been therefore difficult in recent years facing the widespread of influenza epidemics that are more severe than usual, such as in Australia during 2015–2017 and in UK and US in 2018. In Hong Kong, two influenza seasons are usually observed in winter and summer, and emergency appeals for blood donations are often triggered by low inventory levels three to six times every year (Table S1).

Careful planning and management of blood supply is essential during influenza epidemics and pandemics [5, 6]. In Hong Kong, blood supply relies solely on voluntary donations from less than 3% of the population received by Hong Kong Red Cross Blood Transfusion Service (BTS), which is managed by Hong Kong Hospital Authority (HA) [7]. Unlike many populations, Hong Kong continues to see a steady increase in blood use over the past decade with a fast aging population [8]. Based on the population projection by Census and Statistics Department [9], we estimated that the blood use would increase by 66% by 2040, compared with that of 2017 (Figure S1). The increase would be mainly driven by the elderly aged over 80, who used 35% of blood in 2017 but would be using 48% of blood in 2040. Hong Kong is now experiencing blood shortages more often even outside winter influenza seasons and is more susceptible to the adverse impacts of severe influenza epidemics. Considering the impacts of influenza epidemics is thus very important for better planning and management of blood donations in Hong Kong.

However, there is limited literature quantifying the impact of epidemics of influenza and other respiratory infections on blood supply [10]. Several literature articles predict that influenza epidemics have a substantial negative impact without providing detailed quantitative analyses [11, 12], or only in mathematical models because of the lack of empirical data [13]. To fill this research gap, we assess and quantify the impacts of influenza and other respiratory infections on donor attendance and blood inventory, by analyzing local data available from April 2014 to June 2017, to provide more evidence to BTS in the Hong Kong context.

Materials and methods

Data

We retrospectively obtained data from five sources between 15 April 2014 (since daily blood inventory data from HA were available to BTS) and 30 June 2017 (Figure 1):

1. Data of donor attendance and blood inventory

In Hong Kong, all public hospitals are managed by HA to provide more than 70% of inpatient services [14]. Data about actual blood use are not available for analysis, so we obtained the daily number of blood product units (i.e. red blood cells and whole blood) in stock/inventory by HA blood bank (Figure S2). We collected the daily number of blood donor attendance and blood donors successfully donated from BTS.

2. Surveillance data on influenza activity

To measure influenza activity in Hong Kong, we obtained surveillance data on weekly rates of influenza-like illnesses (ILI) reported by sentinel private general practitioners (GPs) and general outpatient clinics (GOPCs) from Centre for Health Protection (CHP). We also obtained laboratory data on weekly rates of influenza detections among samples submitted to the Public Health Laboratory Services Branch (PHLSB) and laboratory data on weekly hospitalization rates in public hospitals with principal diagnosis of influenza from CHP (Figure 1 and Figure S5). We used linear interpolation to calculate daily estimates from the weekly statistics.

3. Surveillance data on the activity of other respiratory infections

Similar to influenza, the PHLSB also reports laboratory results of other respiratory specimens submitted by the ILI surveillance network and local hospitals, including parainfluenza viruses, adenovirus, respiratory syncytial virus, rhino virus and enteroviruses. We gathered the total number of ILI samples tested positive for all the respiratory viruses available other than influenza.

4. Weather data

Adverse weather conditions have been shown to affect donor attendance [15]. Detailed monthly reports about Hong Kong weather are available on the website of Hong Kong Observatory (<http://www.hko.gov.hk/>). We obtained daily mean temperature, total rainfall and adverse weather warnings in effect every day, such as cold weather warning, frost warning, rainstorm warning and typhoon cyclone warning etc.

5. Dates of public holidays

Dates of public holidays in Hong Kong are available on the GovHK website of Hong Kong (<https://www.gov.hk/en/about/abouthk/holiday/>).

Statistical analysis

We calculated Pearson's correlation coefficients between pairs of daily number of donor attendance, donors donated successfully and donor deferrals (Figure S3). We found that daily number of donor attendance were highly correlated with both donors donated successfully ($\rho = 0.99$) and deferrals ($\rho = 0.88$), and therefore we only included donor attendance in the subsequent analyses.

We only included daily number of blood product units in inventory by HA blood bank in the analysis, because the daily number of blood products that BTS issued to HA blood bank was highly correlated to the daily number of blood products that HA blood bank issued to HA hospitals (Figure S4). However, blood products are issued daily by the BTS to HA blood bank to replenish inventory, and therefore the daily blood use at HA hospitals may not be estimated accurately (information from our communication with BTS and HA).

We fitted two Poisson regression models for donor attendance and blood inventory respectively to establish their potential association with the activity of influenza and other respiratory infections. We included one of the below indicators for the activity of influenza and other respiratory infections each time in the regression model as these indicators were highly correlated with each other (Figure S6):

1. GP ILI
2. GP ILI attributable to influenza + GP ILI attributable to other respiratory infections
3. GOPC ILI
4. GOPC ILI attributable to influenza + GOPC ILI attributable to other respiratory infections
5. Flu hospitalization + GP ILI attributable to other respiratory infections
6. Flu hospitalization + GOPC ILI attributable to other respiratory infections

We performed model selection based on Akaike information criterion (AIC) to select an appropriate indicator for the activity of influenza and other respiratory infections for each regression model. We also included weather conditions, weekdays and holidays in the models as they are known to be associated with blood donor behaviours in BTS and blood use pattern in HA hospitals. Under extremely adverse weather when typhoon cyclone warning No. 8 (or above) is in effect, BTS service would be suspended. The service of BTS is resumed within two hours upon the signal is cancelled. Therefore, we discounted the coefficients of typhoon cyclone warning No. 8 (or above) by the proportion of service hours suspended (the normal service hours of most BTS donation centres are 11:00–19:00). For example, if BTS donation centres closed four hours out of the eight operating hours, we multiplied the coefficient for typhoon cyclone warning No. 8 by 0.5. Backward variable selection based on AIC (using “stepAIC” function in R) was applied to select a set of explanatory variables from the candidate variables (Table S2).

With the selected set of explanatory variables, we then estimated their impacts on donor attendance or blood inventory in a modified regression model. We fitted generalized additive

models (GAMs) to account for potential non-linearity between the continuous explanatory variables (e.g. temperature and indicators for the activities of flu and other respiratory diseases) and the outcome variable with cubic regression splines. The basis dimension was set as 5. The model fitting was performed using “gam” function from the “mgcv” package in R [16]. There were no missing data in the explanatory and outcome variables included in the regression model. No data points were regarded as outliers.

In addition, we assessed if donation deferral rate was associated with the activity of influenza and other respiratory diseases, by calculating the Pearson’s correlation coefficients between daily deferral rates and GOPC ILI rates. We investigated whether the effects of adverse weather on donation attendance were diluted by donors anticipating or compensating reduced attendance during the 15-day window of each adverse weather signal that was found significantly associated with blood supply and demand in the fitted model, i.e. from one week before to one week after the adverse weather signal. We compared the observed donor attendance or blood units in stock with model prediction, and a notable decrease or increase would be identified if the actual daily number of donor attendance or blood units in stock did not fall within the range of 95% CI of the model prediction.

Results

BTS maintains normal service during Sunday and public holidays nearly all year round unless special arrangement is made for several donation centres on particular public holidays such as Chinese Lunar New Year. However, we estimated that donor attendance dropped substantially by about 20% on Sunday and public holidays (Table 1), which is in accordance with the reduced organization of mobile blood collection service. Adverse weather conditions affected blood donor attendance (Figure 2): the number of attendance started to drop when daily mean temperature was below 15°C, which accounted for about 10% of time in a year; donor attendance reduced by 10–15% when the mean temperature was below 10°C; donor attendance dropped by 8–20% on the days when red or black rainstorm were in effect, which usually happen 4–10 times during rainy season every year; when typhoon cyclone warning No. 8 or above was in effect (official suspension of class and work) at any time between 6:00 to 20:00, the number of attendance dropped by 64%, which usually happen 1–6 times during rainy season every year.

As for activity of influenza and other respiratory diseases, we found the number of donor attendance dropped by 6% when GOPC ILI consultation rate exceeded 5 per 1,000 consultations (Figure 2), which is a moderate activity level and has been observed frequently in every influenza season (Figure S5). No significant association was identified between donation deferral rate and the activity of influenza and other respiratory diseases: the Pearson’s correlation coefficient was $\rho = 0.08$ and $\rho = 0.13$ between donation deferral rate and GOPC ILI rate attributable to influenza and other respiratory infections respectively. It is probably because Hong Kong donors are well informed about the common deferral reasons regarding history of ILI and influenza vaccination. In a separate influenza serological survey conducted in donation centres, more than 80% of donors understood that they should not donate if they had ILI symptoms in the past two weeks or received flu vaccination in the past four weeks.

We estimated the mean number of blood product units in inventory by HA was 4,262 (95% CI: 4,257–4,266). There was a negative association between daily mean temperature and the number of blood product units in stock. Compared with daily mean temperature 30°C, blood stock dropped by about 20% when the mean temperature was below 15°C. The decrease of blood inventory was associated with increased GOPC ILI consultation rates (Figure 2). We estimated blood product inventory on average increased by 10% on Saturday. BTS routinely issue more blood products to HA on Saturdays, though the number varies and is subject to the inventory of both BTS and HA. HA hospitals usually also reduce arrangement of routine practices over the weekends, e.g. the non-urgent transfusions and surgeries (we do not have access to the detailed data but obtained this information from communication between BTS and HA).

We found no adverse weather signals were associated with blood inventory levels, but “black rainstorm”, “typhoon cyclone No. 8 warning (or above)” and “frost warning” were associated with substantial decrease in daily number of donor attendance (Table 1). We further investigated whether donor attendance increased one week before and one week after the adverse weather signal to compensate the loss in donations (see Methods). For all typhoon cyclone No. 8 warnings in effect during daytime, we only identified a substantial increase in donor attendance on 14 June 2017 after the typhoon cyclone No.8 warning on 12 June 2017, which however corresponded to the World Blood Donor Day. The increase in blood donors was most likely due to BTS’ campaign on that day [17]. For frost warnings, we only identified a substantial increase in donor attendance on 19–22 January 2016 before the frost warning on 23–26 January 2016, which was in line with BTS’ emergency appeal for blood donations anticipating the coldest weather experienced by Hong Kong over the past 60 years (Table S1) [18, 19]. No substantial increase or decrease on other days were identified (Figure 3).

Discussion

In this study, we found that blood supply in Hong Kong are affected by circulation of influenza and other respiratory infections, coupled with the effects of adverse weather conditions and low temperature during winter influenza seasons. Given the difficulties to routinely maintain a stable and sufficient blood supply in Hong Kong, our results highlight the importance of closely monitoring the fluctuations in blood supply and demand, especially in winter seasons. We estimated that donor attendance decreased by ~10% when mean temperature dropped below 10 °C, which often coincided with the peak of influenza circulation that further reduced > 5% donor attendance in winter seasons, posing intense pressure on BTS. Although the service pressure on public hospitals has been extensively discussed during the past several influenza seasons in Hong Kong [20–23], the pressure on BTS has not yet received sufficient attention. As part of the public healthcare system of Hong Kong, the pressure on BTS during influenza seasons should not be overlooked.

Our study provides a quantitative statistical method to assess the effects of influenza and other respiratory infections on blood supply with empirical surveillance data that are currently available. This method can be readily incorporated to the present monitoring, planning and management of the Hong Kong Red Cross Blood Transfusion Service (BTS).

Currently, appeals for blood donation is triggered by HA's low blood inventory levels. However, no matter how promptly the public respond to the appeal, it would take some time to replenish the blood inventory. With our method, appeals for blood donation could be triggered more timely than current practice, if reduction in donor attendance and blood inventory can be anticipated in short-run forecast combining data from different sources, e.g. anticipated sudden drop in temperature during influenza seasons or long public holidays. At the moment, we had only access to the aggregate statistics of blood products issued to hospitals or in inventory but not the actual blood use, not to mention detailed blood usage by disease categories or hospital departments. Therefore, we could not perform an in-depth analysis to investigate how low temperature and circulation of respiratory infections had driven the blood use, or identify the major comorbidities increasing the blood use. More investigations should be done to better inform blood use during outbreaks of respiratory infections, if real-time data from electronic blood tracking system were accessible.

Our study has several limitations. First, only the numbers of blood products in inventory by HA were used as indicators for blood use. Ideally, the number of blood products actually used by HA hospitals would be the best proxy, but they were not available for analyses yet. The blood products issued by HA inventory to HA hospitals may not reflect the actual blood use. Some blood products might have been issued but were never used due to expiry. Changes in clinical practice might have been made in response to reduced blood supply or constraints of manpower during flu seasons, e.g. non-urgent transfusions or surgeries might be postponed. Second, we included all available blood data from HA during 15 Apr 2014 and 30 Jun 2017 ever since they were available to BTS. However, the data only covered a few influenza seasons. More accurate estimation would be obtained if blood data with longer time span were available. Third, we fit GAM models with fixed basis dimensions. The estimation would be more accurate if more data were available to allow more flexible function forms to describe the effects of continuous variables. Fourth, there are only limited quantitative studies on the associations between influenza seasons and blood supply. We could not compare our results with situations in other countries and regions and assess whether our findings are potentially confounded by other factors, such as population demographics, structure of local healthcare systems and practice of blood transfusion service. Nonetheless, our results imply that monitoring of blood supply during flu epidemics is still important to other health systems with similar population structure, if the elderly are the main driver for blood use currently or in the near future [7].

In conclusion, we showed that circulation of respiratory infections coupled with adverse weather conditions had negative impact on blood supply in Hong Kong. It is important to closely monitor the fluctuations, especially during winter and influenza seasons, to react more promptly to blood shortage alerts. The intense pressure on blood transfusion service to maintain a stable and sufficient blood supply during outbreaks of influenza and other respiratory infections should not be overlooked, especially in the aging population of Hong Kong with a susceptible public healthcare system.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1. Outcome and explanatory variables in the regression model.

(A) Daily number of donor attendance with markers indicating Typhoon No. 8 warnings, Frost warnings and the first day of Chinese Lunar New Year. (B) Daily number of blood products issued to HA hospitals. (C) Daily number of blood products in stock/inventory by HA blood bank with markers indicating the dates when BTS appealed for more blood donations. (D) Daily ILI consultation rates attributable to influenza per 1,000 consultations reported by GOPCs (linear interpolation from weekly rates). (E) Daily ILI consultation rates attributable to other respiratory infections per 1,000 consultations reported by GOPCs. (F) Daily mean temperature ($^{\circ}\text{C}$). (G) Daily total rainfall (mm).

A. Blood donor attendance **B. Blood product units in stock**

Figure 2. Impacts of temperature and GOPC ILI consultation rates on donor attendance and blood inventory estimated in the GAM model (with cubic regression splines and basis dimensions of 5).

(A) The effects of daily mean temperature and GOPC ILI consultation rates on donor attendance. (B) The effects of daily mean temperature and GOPC ILI consultation rates on blood product units in stock/inventory by HA. Heat plot at the bottom of each subplot showed the frequency of data points. Darker colour indicated higher frequency.

Figure 3. The number of donor attendance before and after typhoon cyclone No. 8 warning on 12 June 2017 and frost warning on 23–26 January 2016.

(A) Number of donor attendance on 5–19 June 2017. The World Blood Donor Day was on 14 June 2017 and BTS had blood donation campaign on that day. (B) Number of donor attendance between 16 January and 2 February 2016. BTS appealed publicly to call for more blood donations on 19 January 2016 in preparation for the upcoming cold weather.

Table 1.

The association of categorical variables with blood supply estimated in the GAM model

Donor attendance		
Variable	Relative donor attendance	95% CI
Saturday	0.99	0.98–1.00
Sunday	0.79	0.78–0.80
Public holiday	0.82	0.81–0.83
Summer holidays	0.96	0.96–0.97
Rain	0.99	0.99–1.00
Amber rainstorm	0.96	0.95–0.97
Red rainstorm	0.92	0.92–0.94
Black rainstorm	0.80	0.77–0.83
Typhoon cyclone No. 8 or above in effect during 6:00–20:00	0.36	0.35–0.38
Blood stock/inventory		
Variable	Relative blood stock/inventory	95% CI
Saturday	1.12	1.12–1.13
Sunday	0.99	0.98–1.00
Public holiday	0.97	0.96–0.97
Summer holidays	1.02	1.02–1.03
Rain	0.99	0.99–1.00
Amber rainstorm	0.99	0.99–1.00
Red rainstorm	1.02	1.01–1.03
Black rainstorm	1.09	1.07–1.10
Typhoon cyclone No. 8 or above in effect during 6:00–20:00	1.06	1.05–1.08