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Original Article

The association between international and domestic air traffic and the coronavirus (COVID-19) outbreak

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Abstract *Background:* The World Health Organization (WHO) has declared the current outbreak of the novel coronavirus (COVID-19) a global pandemic. Many countries are facing increasing numbers of COVID-19 cases, which are, in their origin mostly attributed to regular international flight connections with China. This study aims to investigate this relation by analyzing available data on air traffic volume and the spread of COVID-19 cases.
Methods: and findings: We analyzed available data on current domestic and international passenger volume and flight routes and compared these to the distribution of domestic and international COVID-19 cases.
Results: Our data indicate a strong linear correlation between domestic COVID-19 cases and passenger volume for regions within China ($r^2 = 0.92$, $p = 0.19$) and a significant correlation between international COVID-19 cases and passenger volume ($r^2 = 0.98$, $p < 0.01$).
Conclusions: The number of flight routes as well as total passenger volume are highly relevant

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risk factors for the spread of current COVID-19. Multiple regions within Asia, as well as some in North America and Europe are at serious risk of constant exposure to COVID-19 from China and other highly infected countries. Risk for COVID-19 exposure remains relatively low in South America and Africa. If adequate measures are taken, including on-site disease detection and temporary passenger quarantine, limited but not terminated air traffic can be a feasible option to prevent a long-term crisis. Reasonable risk calculations and case evaluations per passenger volume are crucial aspects which must be considered when reducing international flights.

Introduction

The current coronavirus (COVID-19) outbreak with its epicenter in Wuhan has been declared a global pandemic by the World health organization (WHO). Despite the unwavering international interest on this public health crisis, information on biology and transmission of this virus are limited and final mortality rates are subject to only rough estimation.[1–3] Interestingly, there are varying approaches in different countries on how to best avoid further COVID-19 exposure from outside. While new data is acquired amid these discussions, some countries have restricted travel to regions with high amounts of COVID-19 cases. So far, a wide range of distinct operational procedures and measures have been implemented with respect to air traffic. While some countries have completely shut down border crossings and restricted flights in affected areas,[4] others have implemented fever measurements and 2-week long self-quarantine for travelers to contain further spread of COVID-19 cases. Since the extent of COVID-19 cases vary enormously between different countries, ranging from very high numbers to none or only a few cases, making decisions on if and how to restrict air traffic from heavily affected countries remains challenging. The united effort of all countries to decrease the speed of COVID-19 spread and reduce undetected cases from traveling into their respective countries[5] further adds to this challenge.

This study has, for the first time, evaluated data on international air traffic and COVID-19 cases worldwide, analyzed potential distribution patterns and assessed to what degree air traffic contributed to the global COVID-19 exposure.

Materials & methods

Air traffic data

Acquiring exact data on Chinese air traffic is challenging. Currently, the Civil Aviation Administration of China (CAAC) has partially restricted access to information on passenger volume, destinations and locations. At the same time, only a few studies have focused on international connection of the Chinese aviation market.[6,7] Restricted access to current data therefore requires analysis of available data and studies on the Chinese aviation market and other countries.

China domestic air traffic and passenger throughput

According to the CAAC, China is divided into 4 economic regions: East China, Northeast China, Central China and West China. The passenger throughput data from 2013 to 2018 for each economic region were sourced from the publicly available annual civil aviation industry databases of the CAAC. The CAAC databases do not include domestic Chinese air traffic in 2019; therefore, domestic air traffic in 2019 within China was not included in the analysis.

Total annual domestic passenger numbers

The total number of annual domestic Chinese passengers from 2013 to 2018 were sourced from the publicly available annual civil aviation industry databases of CAAC.

Number of domestic passengers by economic region in 2018 and COVID-19

As the 2018 number of domestic passengers for each economic region in China is not publicly available, we

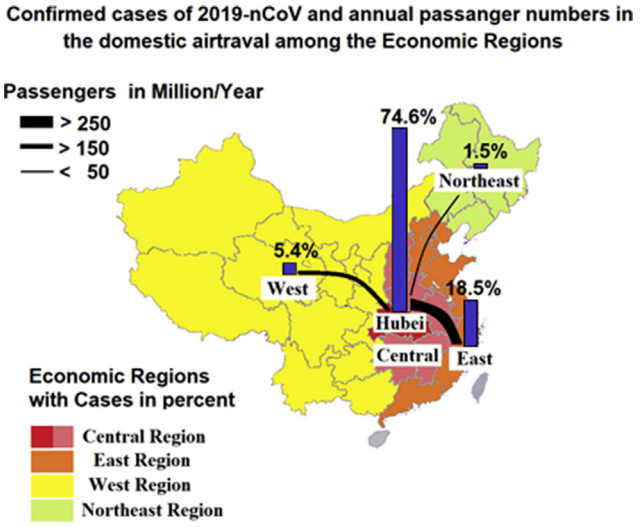

Figure 1. Confirmed COVID-19 cases in the four economic regions of China and their respective passenger numbers for domestic air traffic.

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estimated this data from the 2018 passenger throughput and total numbers of annual domestic passengers (see Fig. 1). We determined that the total number of passenger throughput was significantly correlated to the total amount of annual domestic passenger from 2013 to 2018 ($r = 0.99$, $r^2 = 0.99$, $p < 0.01$). We further demonstrated that the number of passenger throughput in each economic region in China was significantly correlated to the total annual domestic passenger from 2013 to 2018 (East China: $r = 0.99$, $r^2 = 0.99$, $p < 0.01$; Northeast China: $r = 0.99$, $r^2 = 0.99$, $p < 0.01$; Central China: $r = 0.99$, $r^2 = 0.99$, $p < 0.01$; West China: $r = 0.99$, $r^2 = 0.99$, $p < 0.01$). We calculated the ratio of passenger throughput in each economic region as the quotient of the number of passenger throughput in each economic region divided by the total number of passenger throughput in 2018. The number of domestic passengers in each economic region in China in 2018 was derived as the product of the ratio of passenger throughput in each economic region divided by the total number of domestic passengers in China in 2018.

China international air traffic and routes

Analysis was based on the publicly available data for Chinese international air traffic from the Official Aviation Guide (OAG) and the number of confirmed COVID-19 cases reported by the WHO. The number of Chinese international routes from 2011 to 2016 were sourced from publicly available reports by OAG. Since Chinese international air traffic data from 2017 to 2019 was not publicly available, we instead used international air traffic data from 2011 to 2016.

Total annual international passenger numbers

The total number of annual international passengers in China from 2011 to 2016 were sourced from publicly available annual civil aviation industry databases of the CAAC.

Number of international passengers by international region

Since international passenger numbers for each region in China in 2016 were not made publicly available, we estimated this data from the number of international routes from and to China and the total amount of annual international passengers in China in 2016.

We determined that the total number of international routes in China was highly correlated to the total annual international passengers from 2011 to 2016 ($r = 0.94$, $r^2 = 0.89$, $p < 0.01$). In addition, the number of international routes from China to each world region significantly correlated to the total number of annual international passengers from 2011 to 2016 (Asia: $r = 0.88$, $r^2 = 0.79$, $p < 0.05$; Europe: $r = 0.98$, $r^2 = 0.96$, $p < 0.01$; North America: $r = 0.98$, $r^2 = 0.96$, $p < 0.01$; Southwest Pacific: $r = 0.98$, $r^2 = 0.96$, $p < 0.01$; Africa: $r = 0.93$, $r^2 = 0.87$, $p < 0.01$; South America: $r = 0.92$, $r^2 = 0.85$, $p < 0.01$). We calculated the ratio of international routes from China to each world region in 2016. The number of international passengers from China to each international region in 2016 was derived as the product of the ratio of international routes.

Confirmed COVID-19 cases

The total number confirmed cases of COVID-19 for regions in China and internationally were sourced from the COVID-19 situation reports made publicly available by the WHO. Analysis included data until up February 5th, 2020.

Outcome measures and statistical analysis

We evaluated the relationship between domestic air traffic, measured by the passenger throughput and the number of domestic passengers, and the number of confirmed COVID-19 cases in each economic region within China. Outside of China, we evaluated the relationship between international air traffic, measured by the number of international routes, the number of international passengers, the number of foreign cities with international air travel with China, and the number of confirmed COVID-19 cases in each international region. Lastly, we evaluated the relationship between air traffic and the number of confirmed COVID-19 cases in both domestic economic regions of China and international regions of the world. All continuous measurements are presented as mean $\pm$ standard error of the mean. An unpaired student's t-test was used to determine the statistical significance in the number of confirmed COVID-19 cases in China for each economic region and for international regions. All correlation analysis was evaluated using linear regression. P-values <0.05 were considered statistically significant. GraphPad Prism (GraphPad Software 8.0.1) was used for all analyses.

Results

Passenger volume and travel routes

In the past two decades, domestic and international flights have increased in China, which is also reflected by the increasing passenger volume. According to data from the CAAC, the entire Chinese aviation industry transported 611.74 million passengers in 2018, an increase of 10.5% over the previous year. 548.06 million of these passengers were carried on domestic routes. 55.45 million passengers were carried on international routes, an increase of 7.4% compared to 2016. The latest available data on the international passenger number are from 2018 and estimated at 63 million. While air traffic is the predominant form of international passenger traffic with China, it has a lower share on domestic routes than other forms of transport e.g. car, bus and train. The rail system alone carried 2.357 billion passengers in 2014.

Domestic air traffic and COVID-19 cases

According to the data from the CAAC in 2018, air traffic in China is mostly attributable to the eastern part of the country with 53.2% in the east, 29.4% in the west, 6.3% in the northeast and 11.1% in the central region. Although the

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number of domestic flight passengers exceeds international flight passengers, trains and cars are the predominant form of travel in Chinese provinces and regions. Domestic COVID-19 cases outside of the central region exceed international COVID-19 cases by far. Analyses of domestic flights show an inhomogeneous passenger distribution within China (Fig. 1). Analysis of the total number of COVID-19 cases of regions shows a correlation with the current passenger volume (Fig. 2).

International air traffic

Cases worldwide and corresponding air traffic level

The global distribution of COVID-19 cases occurs particularly in Asia, where also most of the flight routes are destined to. This is followed by Europe and North America with comparable route numbers (Fig. 3). While in North America, the flight destinations are concentrated on fewer countries (USA and Canada) and fewer international airports, the number of countries and destinations affected in Europe is much higher. The direct comparison of international passengers and COVID-19 cases shows a significant correlation with a clear trend on Asian countries which have the most flight routes with China (Fig. 4). Accordingly, Europe, North America and the Southwest Pacific have lower numbers, while in Africa and South America, with a negligible percentage of flight routes, there are no initial cases. A statistical analysis of international cases shows a statistically significant pattern between the high-volume air traffic region Asia and the low-traffic region Europe (Fig. 4). No such significant correlation is found in the United States, where the case numbers remain relatively low, and in the Southwest Pacific, where only Australia is affected.

Correlation of domestic and international air traffic, passengers and COVID-19 cases

On the domestic front, data analysis reveals that when comparing the passenger traffic in China by region and total case numbers, a correlation can be assumed ($r^2 = 0.92$ and $p < 0.19$) (doted line, Fig. 5). The COVID-19 cases are much higher per passenger number than on the international scale. Although these numbers are relatively lower per passenger, this correlation is highly significant ($r^2 = 0.98$ with a $p < 0.01$ (Fig. 5)).

Discussion

With the current COVID-19 crisis being a global pandemic, some aspects are especially worrisome: A large percentage of affected patients appear to be simultaneously asymptomatic and infectious,[8] a potential key aspect which may have significantly increased transmission rates. In addition, compared to the Ebola virus, which mainly occurred in rural and sparsely populated areas, COVID-19 has developed in the country with the highest global population density. Thus, air traffic has been a main vector for the global spread of COVID-19. While our data is incomplete due to only limited availability of information, our findings suggest a direct correlation between passenger numbers between mainland China and international destinations and diagnosed COVID-19 cases outside of China. The big differences in COVID-19 cases numbers per passenger in China vs. internationally are most likely related to extensive domestic transportation by train and car whereas international COVID-19 spread is practically solely attributable to air traffic and passenger numbers. International traffic with China mainly depends on the air traffic network, since mainland China is geographically relatively isolated from other world centers, even within Asia. Our analyzed data further indicate that international cases cannot be viewed as individual events. The number of international cases is directly correlated to the number of air traffic routes and passenger volume, which is a troublesome finding.

We must emphasize that this rational focuses on the initial stages of COVID-19 spread. Population size, custom controls as well as the increasingly implemented control measures may affect the scale and behavior of further virus spread. Additionally, it is quite likely that domestic flight routes in China have also been frequented by international travelers who may have also combined domestic air-travel with other transportation modalities e.g. cruises, trains and others. These aspects may have also impacted the data.

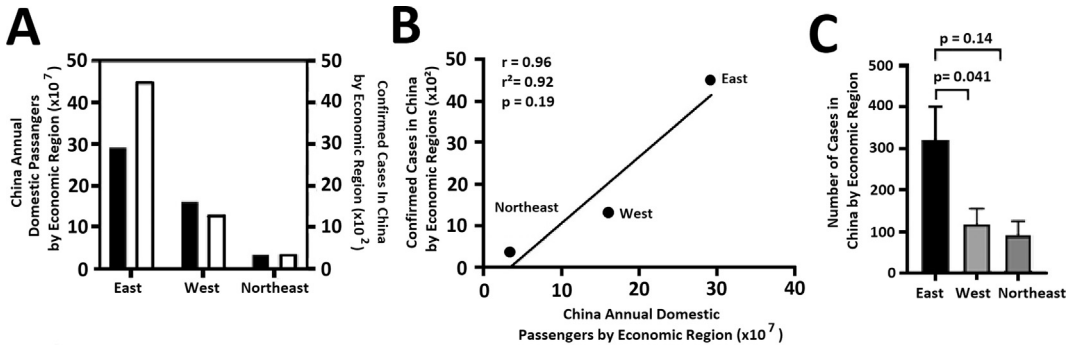

Figure 2. Distribution (A) and correlation (B) of domestic passenger numbers and cases in each economic region: east, northeast, and west. (C) Medium number of cases and mean of the error for affected provinces in each region and statistical analysis between their respective cases.

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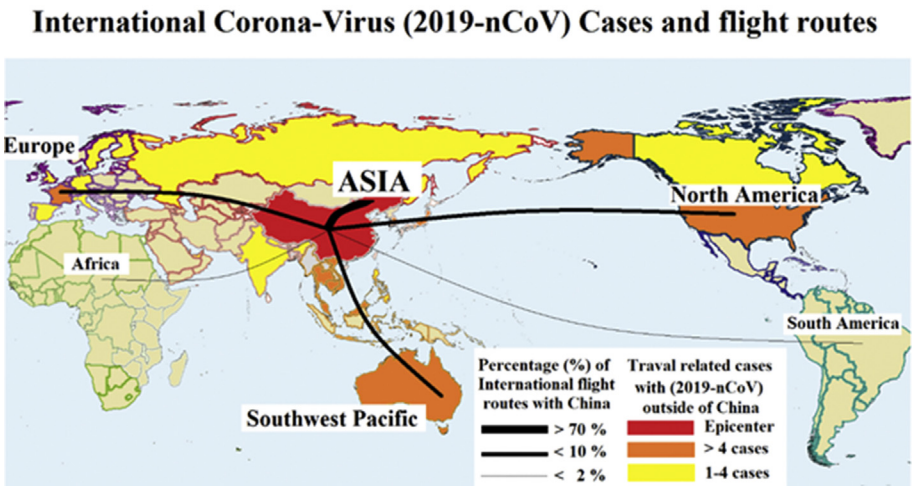

Figure 3. Depiction of COVID-19 spread and international flight routes with China.

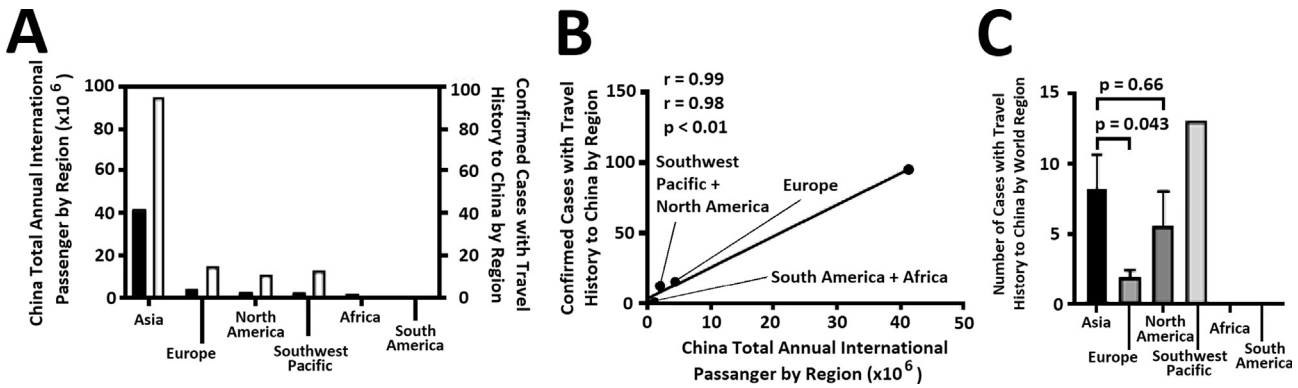

Figure 4. Distribution (A) and correlation (B) of international passenger numbers and global cases: Asia, Europe, North America, Southwest Pacific, Africa and South America. C) Medium number of cases and mean of the error for affected countries in each region as well as their respective case numbers.

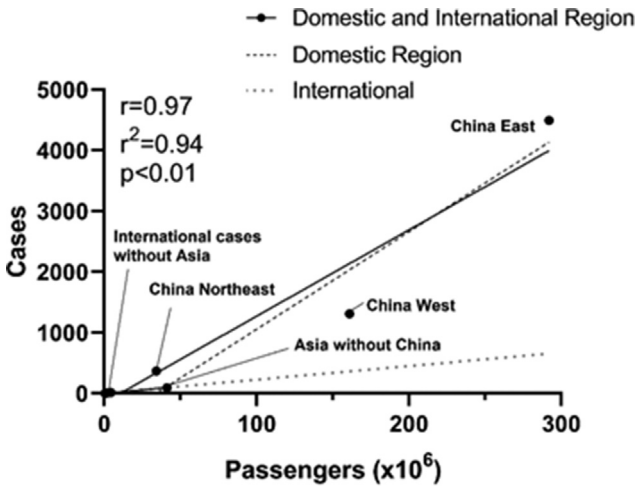

Figure 5. Correlation of COVID-19 cases vs. passengers: only China (domestic region), international region, and both combined (domestic and international regions).

Between January 27th and 30th, we observe major international flight restrictions to China. At the same time, an explosion of case numbers within new epicenters is detected which has given further rise to international virus spread, affecting Italy and Iran in particular. Newly diagnosed COVID-19 cases with potential travel history to China have most likely become negligible — yet incalculable — because of persisting travel restrictions to China and the development of new epicenters with continuous international flight routes. Therefore, continuous flight services from these secondary epicenters have presumably played a major role in COVID-19 spread.

Conclusion

Air travel is a major facilitator in the international distribution of COVID-19 cases whereas domestic COVID-19 spread is contributed to other means of transportation, including trains and buses. Total passenger numbers in mainland China directly correlate to reported COVID-19 cases with travel history to China. International air traffic is breaking down with increasing COVID-19 cases in many countries. While our data supports this development, we must critically reevaluate air traffic restrictions and

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whether their continuous use is effective with respect to increasing global COVID-19 cases.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author contribution

HL: data acquisition, data interpretation, final analysis, drafting of the manuscript, final approval for publication.
VK: data acquisition, analysis and interpretation, drafting of the manuscript, final approval for publication.
PK: data interpretation, drafting of the manuscript, final approval for publication.
AM: data interpretation, drafting of the manuscript, final approval for publication.
HI: data interpretation, drafting of the manuscript, statistical analyses.
MZ: data interpretation, drafting of the manuscript, final approval for publication.
JB: data interpretation, critical revision for important intellectual content, final approval for publication.
TK: data interpretation, conception and design of the work, critical revision for important intellectual content, final approval for publication.

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Declaration of Competing Interest

The authors have no conflicts of interest to disclose.

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