Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Review Article

Special Article - The impact of 2019 novel coronavirus on heart injury: A Systematic review and Meta-analysis

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ABSTRACT

Background: Evidence about COVID-19 on cardiac injury is inconsistent.
Objectives: We aimed to summarize available data on severity differences in acute cardiac injury and acute cardiac injury with mortality during the COVID-19 outbreak.
Methods: We performed a systematic literature search across Pubmed, Embase and pre-print from December 1, 2019 to March 27, 2020, to identify all observational studies that reported cardiac specific biomarkers (troponin, creatine kinase–MB fraction, myoglobin, or NT-proBNP) during COVID-19 infection. We extracted data on patient demographics, infection severity, comorbidity history, and biomarkers during COVID-19 infection. Where possible, data were pooled for meta-analysis with standard (SMD) or weighted (WMD) mean difference and corresponding 95% confidence intervals (CI).
Results: We included 4189 confirmed COVID-19 infected patients from 28 studies. More severe COVID-19 infection is associated with higher mean troponin (SMD 0.53, 95% CI 0.30 to 0.75, $p < 0.001$), with a similar trend for creatine kinase–MB, myoglobin, and NT-proBNP. Acute cardiac injury was more frequent in those with severe, compared to milder, disease (risk ratio 5.99, 3.04 to 11.80; $p < 0.001$). Meta regression suggested that cardiac injury biomarker differences of severity are related to history of hypertension ($p = 0.030$). Also COVID19-related cardiac injury is associated with higher mortality (summary risk ratio 3.85, 2.13 to 6.96; $p < 0.001$). hsTnI and NT-proBNP levels increased during the course of hospitalization only in non-survivors.
Conclusion: The severity of COVID-19 is associated with acute cardiac injury, and acute cardiac injury is associated with death. Cardiac injury biomarkers mainly increase in non-survivors. This highlights the need to effectively monitor heart health to prevent myocarditis in patients infected with COVID-19.

Contents

Abbreviations and acronyms: ACE2, angiotensin converting enzyme 2; CI, confidence intervals; CK-MB, creatine kinase–MB; COVID-19, coronavirus disease 2019; hsTnI, hypersensitive troponin I; NT-proBNP, N-terminal pro–B-type natriuretic peptide; RR, risk ratio; SARS-CoV, severe acute respiratory syndrome coronavirus; SMD, standard mean difference; WMD, weighted mean difference.

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Introduction

Up to Mar 29, 2020, there were 665,361 (82,342 in China and 583,019 outside of China) confirmed cases of novel coronavirus (COVID-2019) infection reported worldwide, causing 30,864 deaths (http://www.nhc.gov.cn). The target of COVID-2019, angiotensin converting enzyme 2(ACE2), is expressed in the heart, esophagus, kidney, bladder and ileum as well as the alveoli.[1] Severe Acute Respiratory Syndrome coronavirus (SARS-CoV) has many similarities to COVID-2019 and has been shown in an animal model to mediate myocardial inflammation and damage through down-regulation of myocardial ACE2. Direct effects of SARS-CoV on the myocardium may have been responsible for adverse cardiac outcomes in patients with SARS[2] and the myocardium may be directly affected by COVID-2019.[1] Recently, two case reports from China[3] and Italy[4] have found that COVID-2019 could cause fulminant myocarditis, even without symptoms and signs of interstitial pneumonia. But whether acute cardiac injury is common and whether it is associated with death is still unclear. We thus undertook a systemic search of the literature for evidence of cardiac injury among individuals infected with COVID-2019.

Methods

Search strategy and selection criteria

The systematic review is reported following the Meta-analysis Of Observational Studies in Epidemiology (MOOSE) guidelines.[5] No language restrictions were imposed on the search. We searched the electronic databases Pubmed, and Embase from Dec 12,019 to Mar 272,020 using the keywords "coronavirus", "pneumonia", "nCoV", "HCoV", "SARS-CoV-2", "COVID*", "NCP*", alone and in combinations as well as medRxiv (https://www.medrxiv.org), SSRN (https://www.ssrn.com) and the reference lists of all studies identified. Eligible studies were those that reported cardiac specific biomarkers (troponin, creatine kinase–MB fraction, myoglobin, or NT-proBNP) or acute cardiac injury. Any studies reporting cardiac specific biomarkers or acute cardiac injury according to severity of COVID-19, or mortality according to cardiac injury, were included. Studies of the same hospital with period within range of other studies, or with data that could not be reliably extracted were excluded.

Data collection and extraction

TH and JL scrutinized the titles and abstracts of the 2961 reports identified and excluded clearly irrelevant studies. Two authors (TH and JL) then did independent review of the full reports for the remaining 553 studies and extracted data independently from the 28 with relevant information (eFig. 1 in Supplementary material). Any disagreements were resolved by a third author (YC). When estimates were only presented graphically, we used the software g3data (version 1.51, www.frantz.fi/software/g3data.php) to extract estimates.

Data analysis

For analysis of cardiac injury biomarkers, first standard mean differences (SMD) were calculated for all biomarkers using mean (SD) values and group size, and pooled using random effects models. Then, separate meta-analysis was carried out, with SMD using for troponin (troponin I and T, or high sensitivity troponin I and T), and weighted mean differences (WMD) for other biomarkers. Summary relative risks (RRs) with 95% CIs were estimated for the association between acute cardiac injury and death. The degree of heterogeneity was assessed using the I^2-index. An I^2 statistic was considered to reflect low likelihood (0%–25%), moderate likelihood (26%–75%), and high likelihood (76%–100%) of differences beyond chance, as was a p value, from a Q test of heterogeneity, of less than or equal to 0.05.[6] If the results were homogeneous ($I^2 < 50\%$ and $p > 0.05$), fixed effects models were utilized, whereas if these results were heterogeneous ($I^2 \geq 50\%$ or $p \leq 0.05$), then random effect models were used. If only median and interquartile range (Q25, Q75) were reported, then we assumed the median was equal to the mean and that the standard deviation (SD) was (Q75-Q25)/2. We also conducted meta-regression to assess whether severity differences in cardiac injury biomarkers were modified by patient characteristics: age, sex, smoking, diabetes, hypertension, history of cardiovascular diseases, coronary heart disease, cerebrovascular diseases, chronic obstructive pulmonary diseases, chronic kidney disease, and severity definitions of COVID-19. In this meta-regression analysis cardiac injury biomarkers are selected with priority troponin>CK-MB > myogloblin>NT-proBNP for each study, for example if one study reported troponin and CK-MB, we used troponin as the outcome and used the standard mean difference model to combine the results. Evidence of publication bias was examined using Egger's regression test for funnel asymmetry, in addition to visual inspection of the funnel plots. Combined means of hsTroponin I and NT-proBNP were calculated as the sum, over studies, of the mean value of the biomarker and n is the number of participants. Data were summarised using inverse variance weighted meta-analysis and a 2-sided p value of less than or equal to 0.05 was deemed significant. Statistical analysis was performed with Stata, version 15.1.

Results

Literature search and study characteristics

There were 28 reports of 4189 patients included in 22 studies that provided data describing effects on myocardial injury.[7–29] Nine reported the association of acute cardiac injury with death[13,17,20,21,24,28,30–32] and 4 reported dynamic changes of cardiac biomarkers during hospitalization[20,32–34]. Three included duplicate information from the

same participants[35–37] and were not excluded. Among the included studies reporting effect of infection severity on cardiac injury, two studies compared values between those admitted to intensive care unit (ICU) and those not,[8,12] another 10 compared values between non-survivors with survivors, and the remainder (10 studies) compared severe versus non-severe cases. Fourteen studies reported data from patients in Wuhan, where the epidemic first emerged. Those with more severe disease were somewhat older, fewer women than men, and had higher prevalence of coexisting disorders (Table 1).

The association of severity with cardiac injury

Overall, cardiac injury biomarkers were higher in severe compared to less severe cases (SMD 0.69, 95% confidence interval [CI] 0.48 to 0.89, $p < 0.001$) (Fig. 1). Mean troponin was higher in severe, compared to less severe cases (SMD 0.53, 95% CI 0.30 to 0.75, $p < 0.001$) as was mean creatine kinase–MB (WMD 1.16, 95% CI 0.73 to 1.59 U/L, $p < 0.001$) and NT-proBNP (WMD 430.2, 95% CI 109.6 to 750.8; $p = 0.009$) but not myoglobin (WMD 75.4, 95% CI -0.67 to 151.4 ng/mL; $p = 0.052$) (eFigs. 2, 3 and 4). Acute cardiac injury, defined as a troponin above upper limit, except in three studies which combined with ECG or echocardiographic abnormalities,[8,12,20] was more frequent in those with severe, compared to mild, disease (summary risk ratio 5.99, 3.04 to 11.80; $p < 0.001$) (eFig. 5). A higher incidence of arrhythmia in severe cases was also reported in one study (44.4% vs. 6.9%, $p < 0.001$).[8]

Meta regression demonstrated that standard mean differences in cardiac injury biomarkers between more and less severe cases in a study were positively associated with the prevalence of hypertension (Fig. 2) but not increasing age, male sex, smoking, other comorbidities and severity definitions of COVID-19 (Table 2).

The association of COVID-19 related cardiac injury with death

Death was more frequent in those with acute cardiac injury compared to those without (summary risk ratio 3.85, 2.13 to 6.96; $p < 0.001$) (Fig. 3). Death was also more frequent in those with more severe COVID-19 compared to those with less severe (summary risk ratio 13.90, 7.32 to 26.40; $p < 0.001$) (Fig. 4).

Dynamic changes of troponin and NT-proBNP during hospitalization

Three studies, in each case, showed dynamic escalation of hsTnI[20,33,34] and NT-proBNP[32–34] levels for survivors and non-survivors. Both pooled hsTnI and NT-proBNP levels increased significantly during the course of hospitalization in those who ultimately died, but no such dynamic changes of hsTnI levels were evident in survivors, NT-proBNP in survivors was only available in one small study[32] (Fig. 5).

Discussion

In this systematic review and meta-analysis, we found that there is an increased risk of acute cardiac injury associated with more severe COVID-2019 infection and this acute cardiac injury is associated with death. Patients with a history of hypertension seem to suffer more from cardiac damage.

Our results are in line with a previous meta-analysis of COVID-19 on cardiac troponin I, which found troponin I significantly increased in COVID-19 patients with severe disease compared to those with milder infection.[38] Increases in troponin I, CK-MB and NT-proBNP are indicators of possible cardiac damage during COVID infection, and three published case reports have found fulminant myocarditis[3,4] and cardiac tamponade[39] after COVID infection. Assessments of the dynamic change in hsTnI and NT-proBNP show that cardiac injury biomarkers rise above normal by the midpoint of hospitalization and spike immediately before death, which seems to be most seen in severe cases. This pattern of elevation suggests that cardiac damage may already exist before multiple organ dysfunction syndrome.

In a large report containing 44,672 confirmed cases from China, approximately 81% of COVID-19 infections were mild cases which did not require hospitalization, with case-fatality rates of 49% in critical cases and 0% in mild ones.[40] In our analysis more severe infection with

Table 1
Characteristics of included studies comparing more severe and less severe cases.

Author	No.	Period	Age (yr)		Female		Concomitant chronic diseases							
							Diabetes		Hypertension		Cardiovascular		Cerebral	
Wuhan														
Huang et al[8]	41	2019/12/16–2020/01/02	49	49	15	32	8	25	15	14	23	11		
Wang et al[12]	138	2020/01/01–2020/01/28	66	51	39	48	22	6	58	22	25	11	17	1
Zhou et al[14]	34	2020/02/05–2020/02/13	67	63	38	54								
Yang et al[13]	52	2019/12/24–2020/01/26	65	52	34	30	22	10			9	10		
He et al[17]	54	2020/02/3–2020/02/24	70	66.5	38.5	35.7					19.2	10.7		
Peng et al[19]	112	2020/1/20–2020/2/15	57.5	62	43.75	54.17	25	19.79	62.5	85.42	62.5	54.17		
Zhou et al[20]	191	2019/12/29–2020/01/31	69	52	30	41	31	14	48	23	24	1		
Fu et al[21]	200	2020/1/1–2020/1/30			52.9	50	76.5	66.9	64.7	47.5				
Ruan et al[23]	150	NA	67	50	28	35	18	16	43	28	19	0	10	6
Han et al[26]	47	2020/2/1–2020/2/18	65.08	64.74	29.16	60.87	16.67	13.04	41.67	34.78	16.67	4.35		
Chen et al[24]	274	2020/1/13–2020/02/12	68	51	27	45	21	14	48	24	14	4	4	0
Chen et al[25]	150	2020/1/1–2020/02/29	68.5	57.1	25	47.7	20.8	11.9	58.3	27.8	25	2.4		
Zhang et al[28]	48	2019/12/25–2020/02/15	78.65	66.16	29.4	32.3	29.4	16.1	70.6	64.5	23.5	29	35.3	16.1
Hu et al[29]	323	2020/1/8–2020/02/20	70	58	41.3	50.4	30.2	10.8	42.9	30			3.2	1.9
Outside Wuhan														
Ji et al[9]	49	2020/01/20–2020/02/16	57	38	33	38								
Cai et al[7]	298	2020/01/11–2020/02/09	64	40	57	46								
Lu et al[11]	265	up to 2020/02/7					27	6	46	17	18	4	5	0.4
Hui et al[15]	41	2020/01/21–2020/02/03			0	57								
Wang et al[16]	242	2020/01/17–2020/02/20	57	41	45.9	52.5	10.8	5.4	37.8	10.7	13.5	2	5.4	2
Wan et al[18]	135	2020/01/23–2020/02/8	56	44	47.5	45.3	22.5	3.1	10	9.4	15	1		
Gong et al[22]	189	2020/1/20–2020/3/2	63.5	45	42.9	55.3								
Ma et al[27]	84	2020/1/21–2020/03/2	58	46.5	40	43.8	35	4.7	20	12.5	10	4.7	10	3.1

Data are mean or %. Under each item, the first column is for more severe group, the second column is for less severe group.

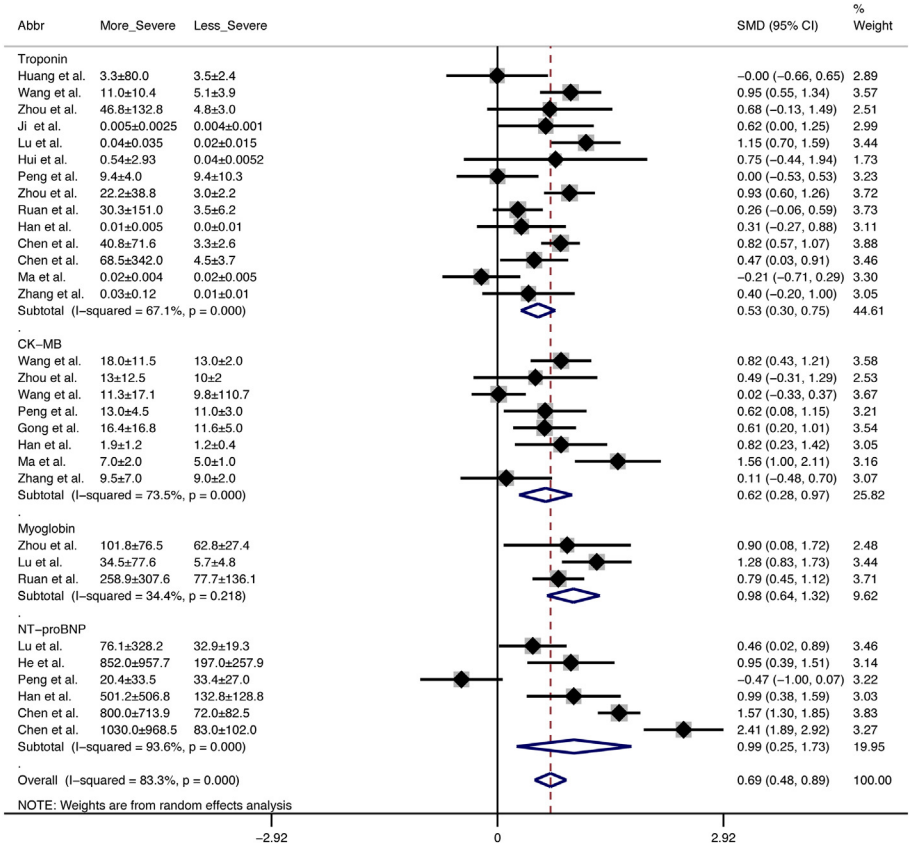

Fig. 1. Forest plots of cardiac biomarkers change between more severe and less cases of COVID-19. SMD, standard mean difference.

COVID-19 is associated with 14 times higher mortality risk compared to mild infection, and acute cardiac injury mostly indicated by abnormal cardiac biomarker levels, is associated with 4 times higher mortality risk. In one of the included studies abnormal troponin I was associated with an 80 times higher risk of in-hospital death, although the sample size was small.[20] It is possible that direct cardiac damage or cardiac shock partially explain death.

Based on these results, we are in support of previous suggestions that longitudinal measurement of cardiac damage biomarkers is needed during hospitalization stay for SARS-CoV-2 infection, which may help to identify a subset of patients with cardiac injury, and thereby predict the progression of COVID-19 towards an unfavorable outcome.[38] Moreover, studies shall also be planned to determine whether or not cardiac supportive measures, such as echocardiographic testing and heart failure treatments such as mechanical ventilation, inotropic agents, and vasopressors, are beneficial in patients with significant elevation of cardiac injury biomarkers.

Limitations

Our meta-analysis has several potential limitations. Firstly, there was obvious heterogeneity among studies regarding definitions of

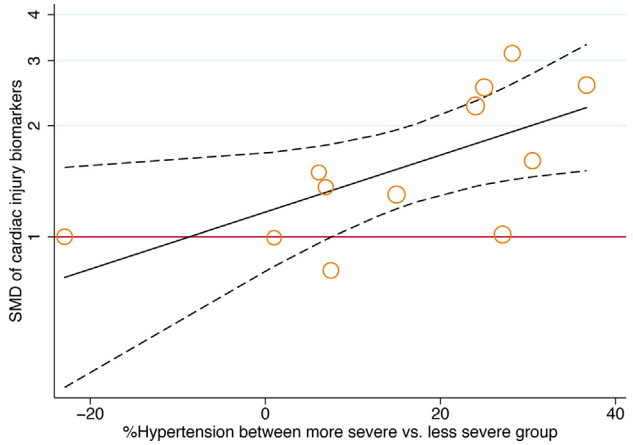

Fig. 2. Meta-regression of standard mean difference for difference of hypertension history on cardiac injury biomarker (more severe vs. less severe, $p = 0.030$).

Table 2
Meta-regression results for baseline characteristics difference on cardiac injury biomarkers of more severe vs. less severe of COVID19.

Between severity	No. study	Coef (exp)	95% CI		*p* Value
Age (per year older)	16	1.02	0.99	1.05	0.220
Female	15	1.00	0.97	1.03	0.979
Smoking	5	1.05	0.97	1.14	0.160
Diabetes	12	1.01	0.99	1.04	0.324
Hypertension	12	1.02	1.00	1.03	**0.030**
Cardiovascular disease[a]	13	1.02	0.98	1.06	0.337
Coronary heart disease	7	1.01	0.97	1.06	0.460
Cerebrovascular disease	7	1.01	0.93	1.11	0.748
COPD	8	1.14	1.00	1.29	0.052
Chronic kidney disease	6	0.99	0.94	1.04	0.562
Severity definitions	16	1.36	0.88	2.12	0.154

Coef = regression coefficients; CIs = confidence intervals. Severity definitions indicate groups are devided by surviors/non-surviors or severe/less severe. Cardiac injury biomarkers are selected in sequence of troponin>CK-MB > myogloblin>NT-proBNP, which indicate that if one study report troponin and CK-MB, we will use troponin as the outcome and use standard mean difference model to pool the data.

[a] Seven of which report data on coronary heart disease were also included.

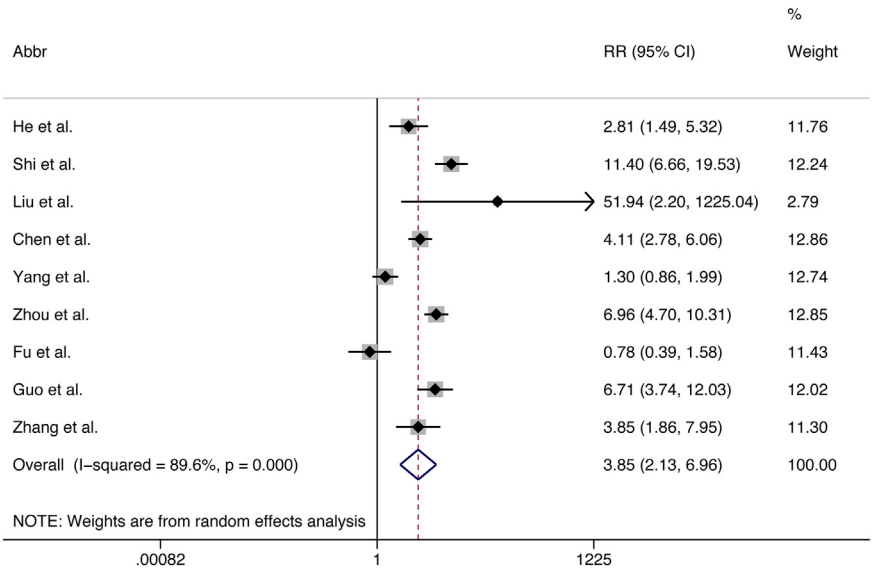

Fig. 3. Forest plots showing risk ratio (RR) for death according to acute cardiac injury (yes vs. no).

severity of COVID-19, acute cardiac injury and biomarkers to detect cardiac injury although no significant publication bias were observed (eFig. 6). Secondly, this meta-analysis was conducted for studies that failed to describe all relevant characteristics of individual patients and it was hard to adjust for potentially confounding factors such as age, gender and use of treatments, such as renin angiotensin aldosterone system inhibitors. Finally, all included studies were retrospective and there are risk of bias in the data collected.

Conclusions

The severity of COVID-19 is associated with acute cardiac injury, and the latter is associated with death. Patients with a history of hypertension seem to suffer more from this kind cardiac damage. Future studies are needed identify whether cardiac supportive measures and heart failure treatments are beneficial in severe patients infected with COVID-19.

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Author contributions

YC and BN designed the study. JL and TH identified and acquired reports of trials and extracted data. JL and TH performed all data analyses, checked for statistical inconsistency, and interpreted data. MW, CA, and

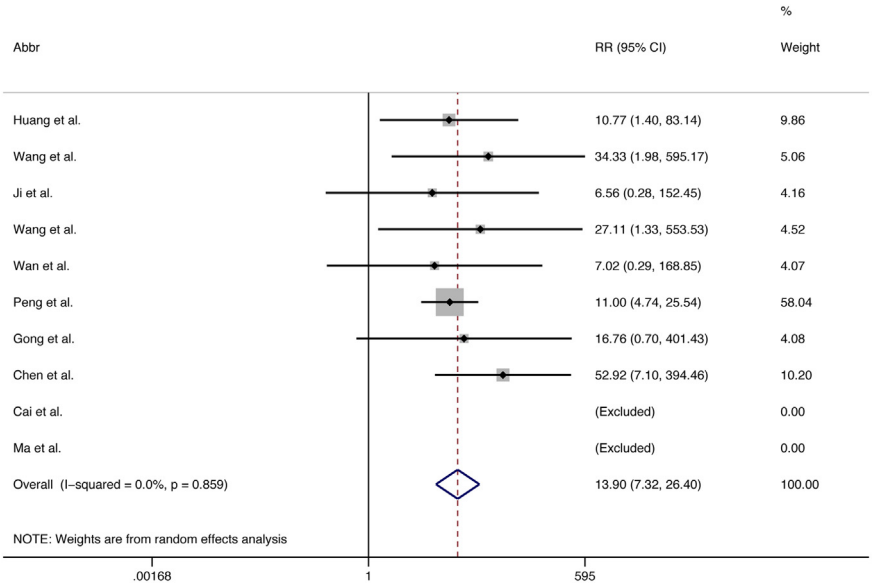

Fig. 4. Forest plots showing risk ratio (RR) for death according to severity of COVID-19 (more severe vs. less).

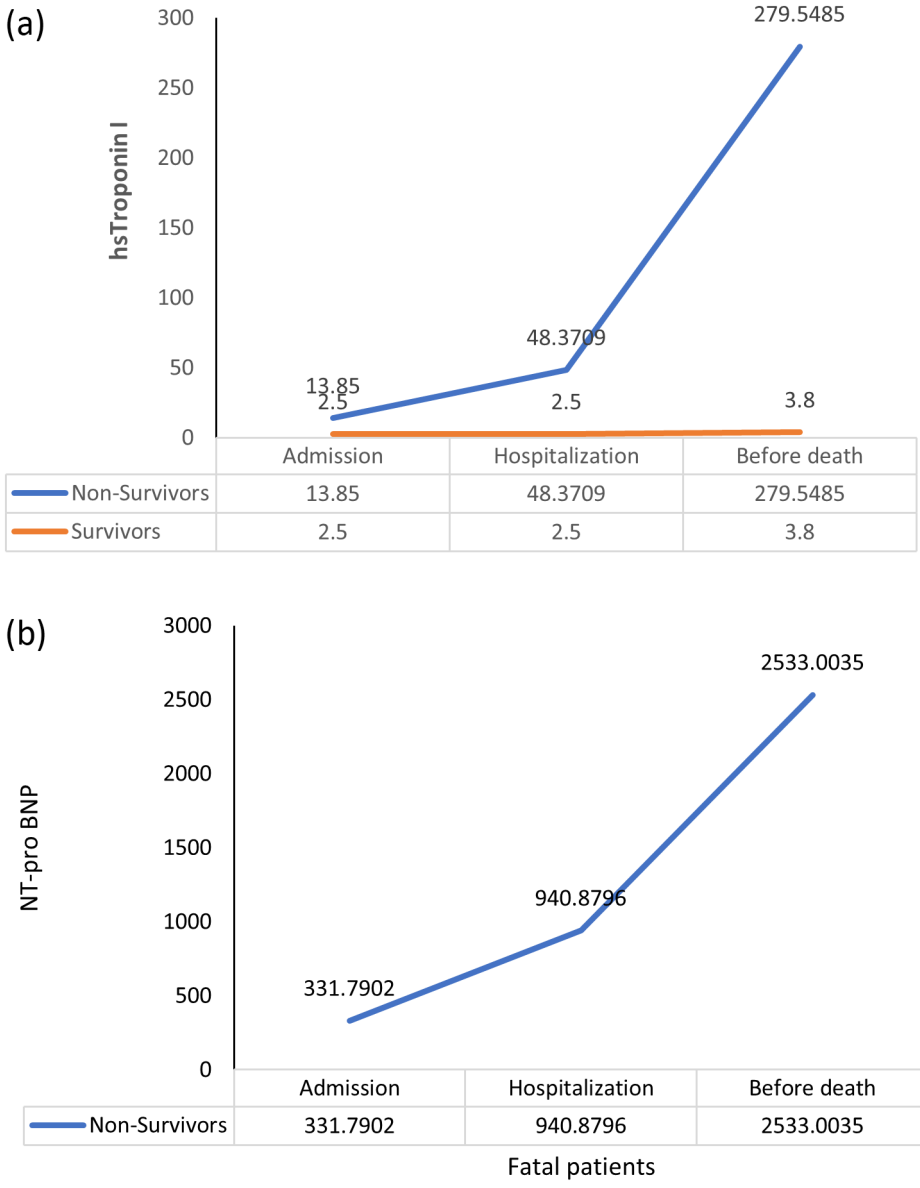

Fig. 5. Combined time series change of hs-Troponin I (a) and NT-proBNP (b).

CY contributed to data interpretation. LJ drafted the letter and all other authors critically reviewed the letter. All authors approved the final version of manuscript. YC is the guarantor of this work.

Declaration of competing interest

BN is supported by an Australian National Health and Medical Research Council Principal Research Fellowship; holds a research grant for this study from Janssen; and has held research grants for other largescale cardiovascular outcome trials from Roche, Servier, and Merck Schering Plough; and his institution has received consultancy, honoraria, or travel support for contributions he has made to advisory boards or the continuing medical education programmes of Abbott, Janssen, Novartis, Pfizer, Roche, and Servier. MW is a consultant for Amgen, Inc., and Kirin. CA holds a NHMRC Senior Principal Research Fellowship and has received fees from Boehringer Ingelheim and Amgen for participating in advisory panels, from Takeda China and Boehringer Ingelheim for speaking at seminars, and a research grant from Takeda China paid to his institution. The other authors have no disclosures.

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