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Critical care staffing ratio and outcome of COVID-19 patients requiring intensive care unit admission during the first pandemic wave: a retrospective analysis across Switzerland from the RISC-19-ICU observational cohort

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Research

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Abstract

Background

The modifications to the standard intensive care unit (ICU) organization that had to be urgently implemented worldwide to overcome the surge of ICU admissions due to patients with a severe coronavirus disease 2019 (COVID-19) have resulted in increased workload and patients-to-nurse ratio. The aim of this study was to investigate whether level of critical care staffing could be associated with an increased risk of ICU mortality (primary endpoint), length of stay, mechanical ventilation and the evolution of disease (secondary study endpoints) in critically ill patients with COVID-19.

Methods

Retrospective multicenter analysis of the international Risk Stratification in COVID-19 patients in the Intensive Care Unit (RISC-19-ICU) registry that prospectively enrolls patients developing critical illness due to COVID-19 in several countries worldwide. The analysis was limited to the period between March 1st, 2020 and May 31st, 2020, to ICUs in Switzerland that have collected additional data on nurse and physician staffing. Hierarchical regression models were used to investigate crude and adjusted effects of critical care staffing ratio on study endpoints. We adjusted for diseases severity and weekly caseload.

Results

Among the 38 Swiss participating ICUs, 17 recorded critical care staffing information. The study population included 437 patients and 2342 daily assessments of patient-to-nurse/physician ratio. Median of daily patient-to-nurse ratio started at 1.0 ([IQR] 0.5–1.5; calendar week 9) and peaked at 2.4 (IQR 0.4-2.0; calendar week 16), while the median of daily patient-to-physician ratio started at 4.0 (IQR 2.1-5.0; calendar week 9) and peaked at 6.8 (IQR 6.3–7.3; calendar week 19). Neither the patient-to-nurse ratio [adjusted Odds Ratio (OR) 1.28, 95% confidence interval (CI) 0.85–1.94; doubling of ratio] nor the patient-to-physician ratio [adjusted OR 1.08, 95% CI 0.87–1.32; doubling of ratio] was associated with ICU mortality. We found no association of critical care staffing on the investigated secondary study endpoints in adjusted models.

COnclusion

The Swiss health care system successfully overcame the first wave of the COVID-19 pandemic with regards to the unprecedented demand for ICU treatments. The reduced availability of critical care staffing resources per critically ill patient in Swiss ICUs did not translate in an overall increased risk of mortality.

Introduction

The rapid spread of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) during the first epidemic wave dramatically stressed healthcare systems in many countries across Europe. In particular, intensive care units (ICUs) were pushed to their limits in terms of critical care staffing resources and bed capacity [1], with some of them being even overwhelmed [2–5]. Patients admitted to the ICU with a severe coronavirus disease 2019 (COVID-19) not only require increased resources [6, 7] but sometimes had to be cared for outside of the regular ICU structure [8–10]. Additional non specialized critical care staff had to be recruited quickly to cope with the increased burden [11, 12].

There were major differences in the numbers of patients infected with SARS-CoV2 between regions in Switzerland during the first pandemic wave (March 1st and May 31st 2020) [13]. Southern and Western parts of Switzerland experienced higher SARS-CoV-2 incidence than Centre and Eastern parts, which translated in huge differences in ICU occupancy rates. [14, 15]. With the increasing demand in ICU beds, the standard of the Swiss Society of Intensive Care Medicine regarding personal resource, including required training and staffing per bed [16], could not always be fully satisfied [17].

Before the SARS-CoV-2 pandemic, some studies suggested a relationship between critical care staffing and critically ill patients mortality [18–20]. An increase of either patient-to-nurse ratio or patient-to-physician ratio was associated with worse patient outcomes such as transmission of infections, postoperative complications, including pulmonary failure and reintubation, and increased mortality [21–26]. Only few reports evaluated the impact of critical care staffing on ICU mortality during a pandemic [27]. The goal of the present study was to investigate whether the differences in critical care staffing resource allocation as well as caseload observed across Swiss ICUs during the first epidemic wave might have affected COVID-19 patient outcomes.

Methods

Study Design

On March 17th, 2020 the prospective observational Risk Stratification in COVID-19 patients in the ICU (RISC-19-ICU) registry was launched to capture COVID-19 features and track characteristics and outcome of patients with SARS-CoV2 infections admitted to ICUs. The registry (ClinicalTrials.gov Identifier: NCT04357275) has been endorsed by the Swiss Society of Intensive Care Medicine (https://www.sgi-ssmi.ch) and was exempt from the need for additional ethics approval and patient informed consent by the ethics committee of the University of Zurich (KEK 2020 − 00322) [1]. The study complies with the Declaration of Helsinki; the Guidelines on Good Clinical Practice (GCP-Directive) issued by the European Medicines Agency as well as the Swiss law and Swiss regulatory authority requirements. The registry has been designed in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for observational studies [28]. Eligibility criteria have been described elsewhere [1, 29, 30]. The current retrospective analysis on the RISC-19-ICU registry (KEK 2020 − 00375) incorporated an extended dataset consisting of daily patient-to-nurse and patient-to-physician ratios. The analysis is restricted to the period from March 1st 2020 to May 31st 2020, and to participating ICUs across Switzerland.

Patient Data Collection

A standardized core dataset [1, 29, 30] was prospectively collected during the ongoing COVID-19 pandemic for all critically ill COVID-19 patients admitted to the collaborating centres. Data collection was performed through an anonymized electronic case report form managed by the REDCap electronic data capture tool hosted on a secure server by the Swiss Society of Intensive Care Medicine. Data were collected on the day of ICU admission, and on days one, two, three, five and seven, including patient characteristics, treatment modalities and organ support therapies, the use of mechanical ventilation, vital parameters, arterial blood gas analyses, and laboratory values such as inflammatory, coagulation, renal, liver and cardiac parameters.

Critical Care Staffing Data

Patient-to-nurse ratio and patient-to-physician ratio per day were prospectively recorded for patients included in the registry as part of the extended dataset. In those participating centres where resource information had not been collected prospectively, staffing and patient assignment data retrieved from the personnel deployment planning (PEP®, staff planning tool, Dübendorf, Switzerland) and local patient assignment tools was matched with the treated patients. Critical care nursing staff consisted of registered nurses and critical care nurses (registered nurses with a postgraduate in critical care nursing).

Study Outcomes

Primary endpoint was ICU mortality. Secondary endpoints were ICU length of stay (LOS), mechanical ventilation and evolution of disease as assessed by Sequential Organ Failure Assessment (SOFA) score and C-reactive protein (CRP) levels over time during the ICU stay (see below for the calculation formula).

Data Transformation

Calculation of the disease severity scores Acute Physiology and Chronic Health Evaluation II (APACHE II), Simplified Acute Physiology Score II (SAPS II) and SOFA scores was performed using an openly available code library associated with the registry [31].

Maximum differences (Δ) in SOFA and in CRP between days 0 or 1, and 3 or 5, were calculated as follows: $\Delta = X^*\{\max(Y_3,Y_5) - \min(Y_0,Y_1)\} + (1-X)^*\{\min(Y_3,Y_5) - \max(Y_0,Y_1)\}$ where Y_d is the measured SOFA, respectively CRP, at day $d \in \{0,1,3,5\}$, $X = 1$ if $[(Y_3 + Y_5)/2-(Y_0 + Y_1)/2] > 0$, and $X = 0$ otherwise.

Statistical Analysis

We described the study population by counts (n), percentages (%), mean, median, standard deviation (SD) and interquartile range (IQR). Our main variable of interest was the critical care staffing ratio (daily patient-to-nurse and daily patient-to-physician ratio). For each admission, we calculated the median of the daily 'patient-to-critical-care-staffing' ratio over the ICU stay.

We used a hierarchical Gaussian regression model to investigate whether the calendar day of ICU admission is associated with the logarithm of 'patient-to-critical-care-staffing' ratio, while accounting for the fact that admissions are nested within hospitals. Calendar day of ICU admission was used as a restricted cubic spline with 3 knots chosen at the 10th, 50th and 90th percentiles [32]. We used a likelihood ratio test to test the non-linear effect of calendar day association on the patient to critical care staffing ratio.

We used multivariable hierarchical regression models to investigate the effect of 'patient-to-critical-care-staffing' ratio on primary and secondary outcomes. We used a hierarchical logistic regression model to investigate the effect of 'patient-to-critical-care-staffing' ratio on ICU mortality, while we used a hierarchical Poisson regression model for LOS [33], a hierarchical Gaussian regression model for ΔSOFA/ΔCRP and a hierarchical logistic regression model to investigate whether a doubling of the 'patient-to-critical-care-staffing' is associated with the presence of mechanical ventilation. We report crude and adjusted odds ratios (OR), rate ratios (RR) or mean differences (MD) with 95% confidence intervals (CIs). We *a priori* defined the following confounding variables: APACHE II and SOFA severity scores, as well as weekly caseload. The 'patient-to-critical-care-staffing' ratio and the weekly caseload was modelled as a linear continuous logarithm-transformed (with respect to basis 2) variable, i.e. the effect on study outcomes is expressed in the doubling of the patient to critical care staffing ratio or the weekly caseload.

Results

Characteristics of the Study Population

During the first COVID-19 pandemic wave occurring between March 1st, 2020 and May 31st 2020 in Switzerland (Supplemental 2 Fig. 1), 38 Swiss ICUs collected data from 669 patients representing a total of 3432 daily assessments (Fig. 1). Among them, 17 ICUs recorded critical care staffing information. After the exclusion of 13 patients with missing survival status, the study population included 17 ICUs, 437 patients and 2342 daily assessments (Fig. 1).

Demographics and comorbidities of critically ill patients included in the study are presented in Table 1. Mean age was 62.6 years (SD 12.3 years) and about three fourths were male. Patients were severely ill with relatively high severity [mean SAPS-II 57.8 (SD 17.3), mean APACHE II 21.2 (SD 6.8), and multiple organ dysfunction scores [mean SOFA score 11.4 (SD 4.5)] at the time of admission. Most (84.9%) were on mechanical ventilation, and more than half (55.4%) were put in prone position sometimes during their ICU stay. Continuous renal replacement therapy was administered in 13.0% of the critically ill patients.

Table 1
Patient characteristics and outcomes, by surviving status.

	Survivors	Non-survivors	Overall
	(N = 349)	(N = 88)	(N = 437)
Gender			
Male	81 (76.8%)	25 (71.6%)	106 (75.7%)
Female	268 (23.2%)	63 (28.4%)	331 (24.3%)
Age			
Mean (SD)	61.0 (12.4)	68.8 (9.63)	62.6 (12.3)
SAPS II			
Mean (SD)	55.9 (17.5)	65.5 (14.1)	57.8 (17.3)
APACHE II			
Mean (SD)	20.5 (6.86)	24.1 (5.86)	21.2 (6.82)
SOFA			
Mean (SD)	11.0 (4.40)	13.0 (4.66)	11.4 (4.52)
Median patient to nurse ratio over ICU stay			
Mean (SD)	1.79 (0.783)	1.91 (0.674)	1.81 (0.765)
Missing	80 (22.9%)	27 (30.7%)	107 (24.5%)
Median patient to physician ratio over ICU stay			
Mean (SD)	4.02 (3.15)	4.17 (2.98)	4.05 (3.11)
Missing	80 (22.9%)	27 (30.7%)	107 (24.5%)
Length of stay in ICU (in days)			
Median (IQR)	13.0 [6.0, 22.0]	10.5 [6.0, 22.2]	13.0 [6.0, 22.0]
Missing	0 (0%)	2 (2.3%)	2 (0.5%)
Smoking history			
Non smoker	207 (59.3%)	46 (52.3%)	253 (57.9%)
Past history	90 (25.8%)	24 (27.3%)	114 (26.1%)

Notes: SAPS II = Simplified Acute Physiology Score II, APACHE II = Acute Physiology and Chronic Health Evaluation II, SOFA = Sequential Organ Failure Assessment, ICU = Intensive Care Unit, N = Number, SD = Standard Deviation

	Survivors	Non-survivors	Overall
Current smoker	25 (7.2%)	7 (8.0%)	32 (7.3%)
Missing	27 (7.7%)	11 (12.5%)	38 (8.7%)
Body mass index (kg/m2)			
Mean (SD)	29.1 (5.24)	29.0 (6.32)	29.1 (5.45)
Median [Min, Max]	28.0 [15.6, 50.8]	27.4 [19.3, 58.4]	27.8 [15.6, 58.4]
Missing	6 (1.7%)	11 (12.5%)	17 (3.9%)
Steroids used			
No	304 (87.1%)	68 (77.3%)	372 (85.1%)
Yes	45 (12.9%)	20 (22.7%)	65 (14.9%)
Experimental therapy used			
No	184 (52.7%)	48 (54.5%)	232 (53.1%)
Yes	165 (47.3%)	40 (45.5%)	205 (46.9%)
Mechanical ventilation			
No	60 (17.2%)	6 (6.8%)	66 (15.1%)
Yes	289 (82.8%)	82 (93.2%)	371 (84.9%)
Prone positioning			
No	168 (48.1%)	27 (30.7%)	195 (44.6%)
Yes	181 (51.9%)	61 (69.3%)	242 (55.4%)
ECMO			
No	336 (96.3%)	78 (88.6%)	414 (94.7%)
Yes	13 (3.7%)	10 (11.4%)	23 (5.3%)
Continuous Renal Replacement Therapy or Hemodialysis of any form			
No	308 (88.3%)	72 (81.8%)	380 (87.0%)
Yes	41 (11.7%)	16 (18.2%)	57 (13.0%)
Chronic arterial hypertension			

Notes: SAPS II = Simplified Acute Physiology Score II, APACHE II = Acute Physiology and Chronic Health Evaluation II, SOFA = Sequential Organ Failure Assessment, ICU = Intensive Care Unit, N = Number, SD = Standard Deviation

	Survivors	Non-survivors	Overall
Not present	180 (51.6%)	38 (43.2%)	218 (49.9%)
Present	169 (48.4%)	50 (56.8%)	219 (50.1%)
Ischemic heart disease			
Not present	301 (86.2%)	69 (78.4%)	370 (84.7%)
Present	48 (13.8%)	19 (21.6%)	67 (15.3%)
Other heart disease			
Not present	310 (88.8%)	75 (85.2%)	385 (88.1%)
Present	39 (11.2%)	13 (14.8%)	52 (11.9%)
Diabetes mellitus			
Not present	262 (75.1%)	60 (68.2%)	322 (73.7%)
Present	87 (24.9%)	28 (31.8%)	115 (26.3%)
Chronic pulmonary disease			
Not present	295 (84.5%)	73 (83.0%)	368 (84.2%)
Present	54 (15.5%)	15 (17.0%)	69 (15.8%)
Immunosuppression			
Not present	294 (84.2%)	68 (77.3%)	362 (82.8%)
Present	55 (15.8%)	20 (22.7%)	75 (17.2%)
Notes: SAPS II = Simplified Acute Physiology Score II, APACHE II = Acute Physiology and Chronic Health Evaluation II, SOFA = Sequential Organ Failure Assessment, ICU = Intensive Care Unit, N = Number, SD = Standard Deviation			

ICU mortality reached 20.1% (88 out of 437). Survivors had a median LOS of 13.0 days (IQR 6.0–22.0 days) whereas non survivors had a median LOS of 10.5 days (IQR 6.0-22.2).

The mean ΔSOFA 0.1 (SD 6.5) and the mean ΔCRP was 6.8 (SD 159) mg/L, which suggests that no clinically meaningful evolution of inflammation or organ failure occurred during the first 5 days in the ICU.

Characteristics of the patients with known discharge status from those 19 ICUs that did not report staffing had a similar age, gender and ICU mortality distribution [mean age 64.0 (SD 12.8), 74.4% men, 20.% ICU deaths), but a less severe disease status [mean SAPS II 44.6 (SD 18.4), mean APACHE II 16.5 (SD 6.9), mean SOFA 9.2 (SD 4.2)], and were less likely to be mechanically ventilated (62.6%) or to received a continuous renal replacement therapy (6.2%), as compared to the study population (Supplemental 1 Table 2).

'Patient-to-Critical-Care-Staffing' Ratio

The daily number of critically ill patients hospitalized in the contributing ICUs mirrored the pandemic wave observed in Switzerland over the study period (March 1st - May 31st, 2020, Supplemental 2 Fig. 1). This number increased from 3 (calendar week 9) to 134 (calendar week 13) and decreased thereafter to 1 (calendar week 22). The median of the daily patient-to-nurse ratio started at 1.0 (IQR 0.5–1.5; calendar week 9) and peaked at 2.4 (IQR 0.4-2.0; calendar week 16) (Fig. 2A), while the median of the daily patient-to-physician ratio started at 4.0 (IQR 2.1-5.0; calendar week 9) and peaked at 6.8 (IQR 6.3–7.3; calendar week 19) (Fig. 2B).

Effect of Patient-to-Critical-Care-Staffing Ratio on Study Outcomes.

A doubling of the daily patient-to-nurse ratio did neither influence ICU mortality (OR_{crude} 1.35, 95% CI 0.91-2.00; $OR_{adjusted}$ 1.28, 95% CI 0.85–1.94) (Fig. 3A), nor any of the secondary study outcomes [LOS (RR_{crude} 1.01, 95% CI (0.97–1.06); $RR_{adjusted}$ 1.00, 95% CI (0.96–1.04) (Fig. 3B), likelihood of being mechanically ventilated (OR_{crude} 0.92, 95% CI 0.57–1.50; $OR_{adjusted}$ 0.78, 95% CI 0.42–1.43) and ΔCRP (MD_{crude} -8.4, 95% CI -34.0-17.1, $MD_{adjusted}$ -5.8, 95% CI -31.6-20.0). (Fig. 3C, Fig. 4). Disease evolution as measured by ΔSOFA showed an association with ICU mortality in crude models (MD_{crude} -0.97, 95% CI -1.81- -0.12) but not in adjusted models ($MD_{adjusted}$ -0.23, 95% CI -0.99-0.54). For patient-to-physician ratio, similar results were obtained (Fig. 5A, B, C, Fig. 6).

Discussion

It has been hypothesised that reduced critical care staffing and increased workload might have influenced mortality and outcomes in critically ill patients with COVID-19 [14, 18–21, 26, 34]. According to the guidelines of the Swiss Society of Intensive Care Medicine, a critically ill patient requiring controlled mechanical ventilation as well as prone positioning should be cared for by at least three ICU-certified nurses per day [16]. This high quality standard often could not be fulfilled during the first pandemic wave in the participating Swiss ICUs.

We observed a significant increase of both the daily patient-to-nurse and the daily patient-to-physician ratio mirroring the increase in the number of patients. This increase remained modest compared to patient-to-nurse ratio that have commonly been reported worldwide before the pandemic [21, 35], particularly from the USA [34]. Importantly, it did not significantly affect the measured overall outcome of critically ill patients with COVID-19 [36].

Our study is to the best of our knowledge among the first to evaluate the impact of critical care staffing on the outcomes of critically ill patients during a pandemic. There have been reports highlighting the importance of the nurse-to-patient ratio on the quality of critical care [37–39], but most, if not all of them, had been performed outside pandemic conditions [6, 27, 40]. Usually, studies compared patient outcomes across ICU centres that are run with different staffing ratio [41, 42]. The current particular setting of a pandemic gave us the opportunity to evaluate in addition the effect of critical care staffing changes over time in each single participating centre independently.

Organizational characteristics have been recently shown to affect the outcome of critically ill patients during the COVID-19 pandemic: in a recent study from Belgium, Taccone et al. reported that ICU overflow and the proportion of supplementary beds specially created during the pandemic to care for critically ill patients with COVID-19 were associated with increased in-hospital mortality [43]. Similarly, the US Department of Veteran Affairs Hospital found that strains on critical care capacity – captured by surrogate markers such as the ratio of ICU COVID-19 occupancy to the maximum ICU bed number - were significantly associated with increased COVID-19 ICU mortality [44]. None of these studies investigated patient-to-nurse ratio. However, previous studies reported that better critical care staffing levels as well as higher quality of training of ICU personnel reduced the duration of mechanical ventilation [45]. Also, Hugonnet et al. previously reported an increased risk of late-onset ventilator associated pneumonia by lower patient-to-nurse ratio [46]. Unfortunately, the RISC-19-ICU registry does not collect data to report this outcome.

The increase for nurses and physicians during the pandemic could only be reached by hiring health-care workers without ICU-specific expertise. Thus, the increase in the daily patient-to-nurse and patient-to-physician ratio was linked to a relative decrease in ICU-trained staff. We could have speculated that the reduced specialized care could have contributed to a worse outcome for the most severely ill patients, which our study did however not confirm. Yet, the supervising task for the ICU specialists was dramatically higher. This might explain why healthcare workers from Swiss ICUs have increasingly been reporting anxiety, depression, peri-traumatic distress as well as low well-being [36].

Our study has several strengths that make our observations potentially generalizable. First, the participating centres cover a large spectrum of the existing ICU models of organization: we were able to recruit small low-intensity medical and surgical primary ICUs as well as several large high-intensity interdisciplinary tertiary centres. Second, although all participating ICUs were not equally affected – Eastern Switzerland being much less affected than Western and Southern Switzerland - we could find a consistent effect of patient-to-nurse and patients-to-physician ratio on ICU mortality and duration of mechanical ventilation across all ICUs after adjustment for heterogeneity based on caseload.

Our study also suffers from some limitations. The primary endpoint was ICU mortality, as the RISC-19-ICU registry does not collect data on hospital mortality. Second, the data was collected before the publication of the Recovery trial results [47], after which most centres systematically introduced dexamethasone. This may have altered mortality, especially in critically ill patients with high disease severity. Third, not all centres used experimental therapies and we could not exclude a potential bias, as some of these treatments, e.g. chloroquine, have been associated with an increased risk of mortality [48]. Finally, not all Swiss participating ICUs have been collecting data on critical care staffing which might have introduced a selection bias. We found that patients from centers which did not record critical care staffing information had a less severe diseases status.

Conclusion

Our study demonstrates that the Swiss health care system successfully overcame the first wave of the COVID-19 pandemic with regards to the unprecedented demand for ICU treatment. The reduced availability of critically care staffing resources per critically ill patient in Swiss ICUs did neither affect overall ICU LOS nor mortality. Future studies should address the effect of reduced availability of critical care staff on critically ill patients most severely affected by their disease and the mid-term consequences of the augmented workload on healthcare workers health.

Abbreviations

Acute Physiology and Chronic Health Evaluation II = APACHE II

Confidence interval = CI

Coronavirus disease 2019 = COVID-19

C-reactive protein = CRP

Guidelines on Good Clinical Practice = GCP = Directive

Intensive care units = ICUs

Intensive care unit = ICU

Interquartile ranges = IQR

Length of stay = LOS

Mean difference = MD

Odds ratios = OR

Rate ratios = RR

Risk Stratification in COVID-19 patients in the Intensive Care Unit = RISC-19-ICU

Sequential Organ Failure Assessment = SOFA

Simplified Acute Physiology Score II = SAPS II

Declarations

Ethics approval and consent to participate

The registry (ClinicalTrials.gov Identifier: NCT04357275) has been endorsed by the Swiss Society of Intensive Care Medicine (https://www.sgi-ssmi.ch) and was exempt from the need for additional ethics approval and patient informed consent by the ethics committee of the University of Zurich (KEK 2020-00322). The current retrospective analysis on the RISC-19-ICU registry (KEK 2020-00375) incorporated an extended dataset consisting of daily patient-to-nurse and patient-to-physician ratios. All centres have complied with all local legal and ethical requirements.

Consent for publication

Informed consent for publication was approved by the Ethics committee (KEK 2020-00322, KEK 2020-00375). All collaborating centers have complied with all local legal and ethical requirements.

Availability of data and materials

Any intensive care unit or other center treating critically ill COVID-19 patients is invited to join the RISC-19-ICU registry at https://www.risc-19-icu.net. While the registry protocol prevents the deposition of the full registry dataset in a third-party repository, analyses on the full dataset may be requested by any collaborating center after approval of the study protocol by the registry board. Reproducibility of the results in the present study was ensured by providing code for registry-specific data transformation and statistical analysis for col- laborative development on the GitHub and Zenodo repositories. The registry protocol and data dictionary is publicly accessible at https://www.risc-19-icu. net.

Competing interests

The authors declare that they have no competing interests regarding the present study.

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Authors' contributions

MMJ, AM, YAQ, MPH and SMJ conceived and designed this study. PDWG, MTE, SK, RAS, UP, SC, FB, JM, AAS, HK, PS, AD, IF, AH and JCL acquired the data. AM and MPH performed data validation, statistical analysis and visualisation. MMJ, MTE, SMJ, MPH and YAQ interpreted the data. YAQ and SMJ drafted the manuscript. MMJ, AM, MPH, PDWG, MTE, SK, RAS, UP, SC, FB, JM, AAS, HK, PS, AD, IF, AH and JCL critically revised the manuscript. MPH had full access to the study data and takes full responsibility for the accuracy of the data analysis. All authors read and approved the final manuscript.

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Figures

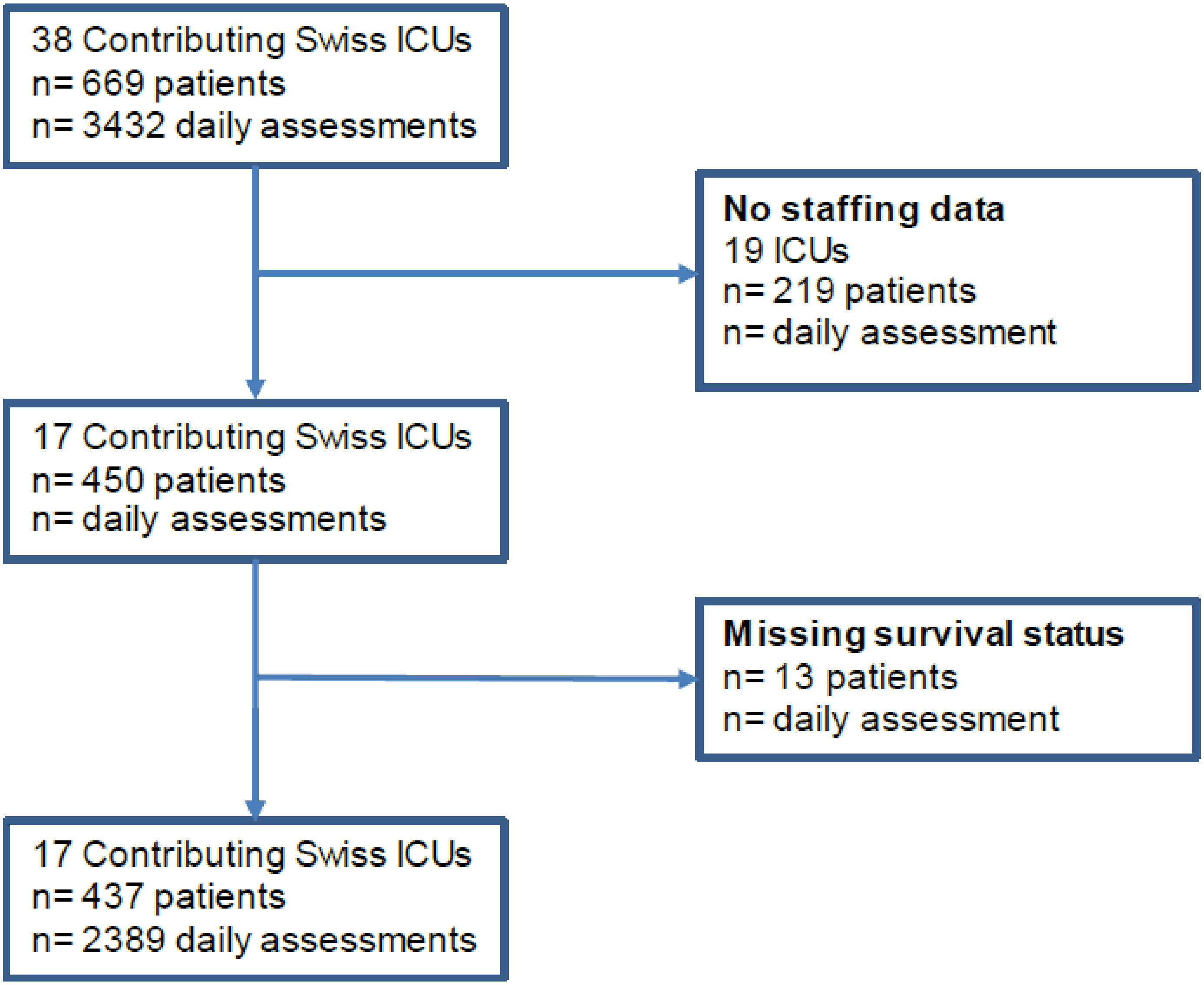

Figure 1

Study Flow Chart. Between during the first epidemic wave Notes: ICU = Intensive Care Unit, n = number

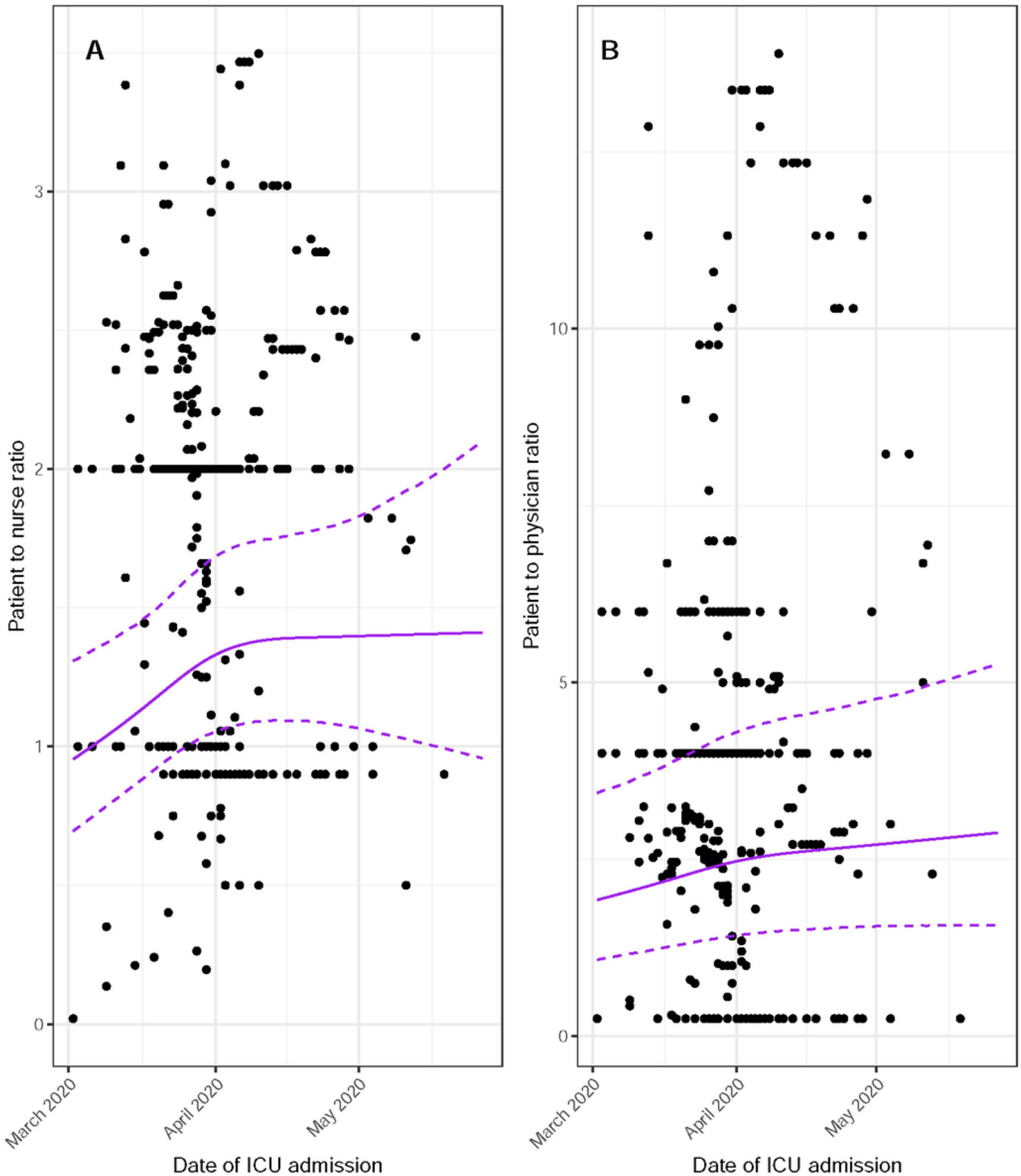

Figure 2

A, B. Patient-to-Critical-Care-Staffing’ Ratio Notes: ICU = Intensive Care Unit

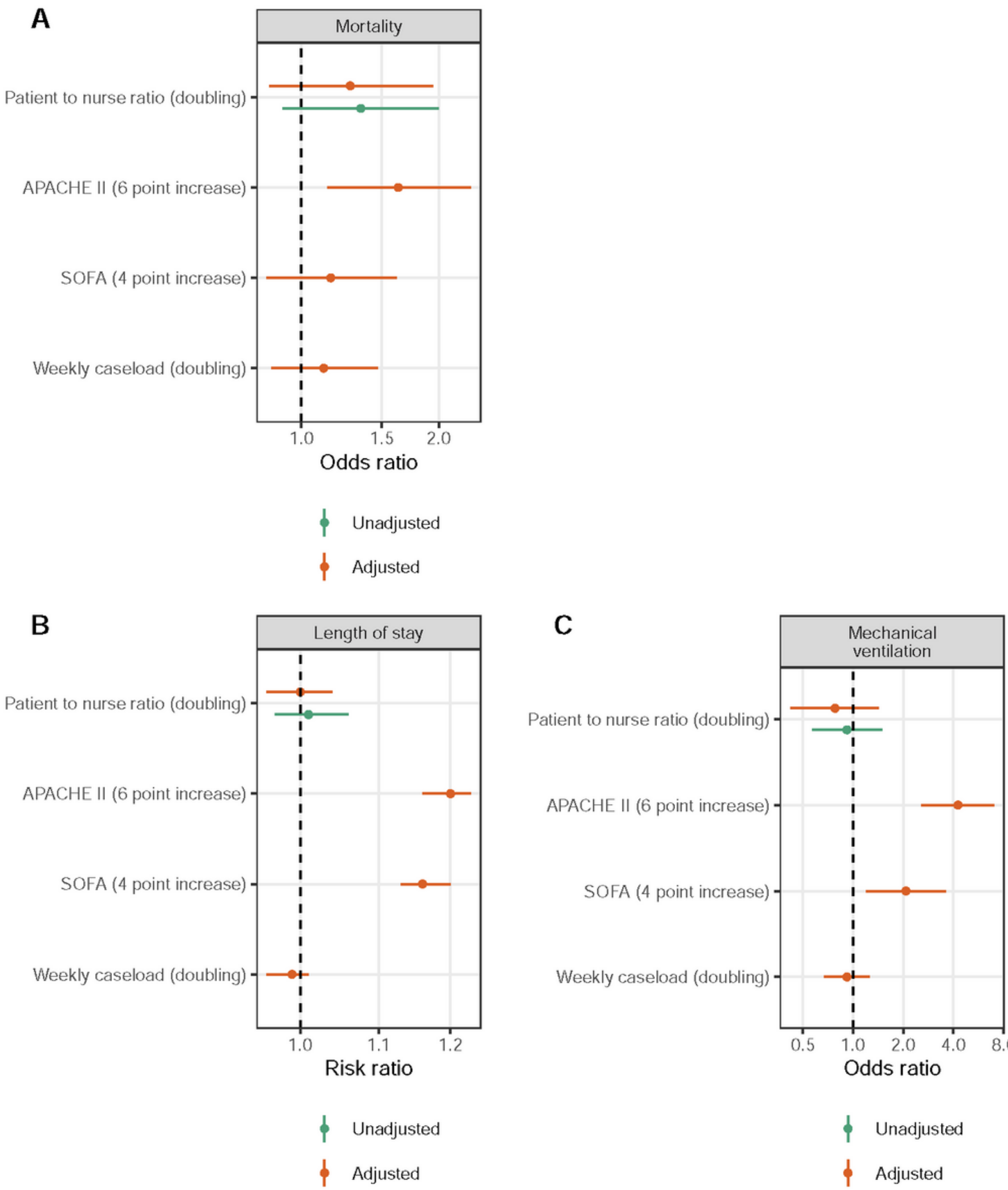

Figure 3

A, B, C. Patient-to-nurse ratio and Study Outcomes Notes: APACHE II = Acute Physiology and Chronic Health Evaluation II, SOFA = Sequential Organ Failure Assessment

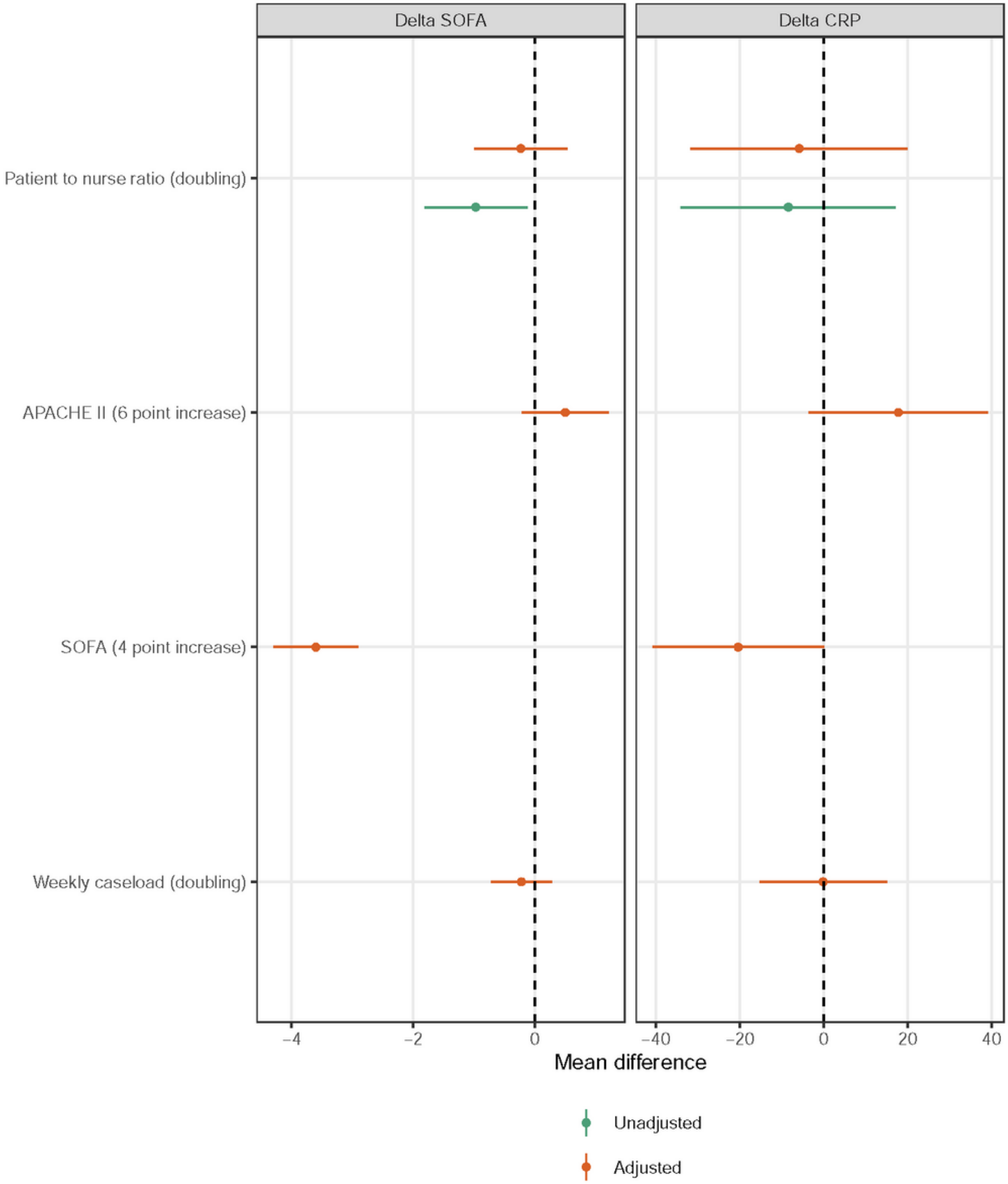

Figure 4

Patient-to-nurse ratio and Delta SOFA, Delta CRP Notes: APACHE II = Acute Physiology and Chronic Health Evaluation II, SOFA = Sequential Organ Failure Assessment, CRP = C-reactive protein

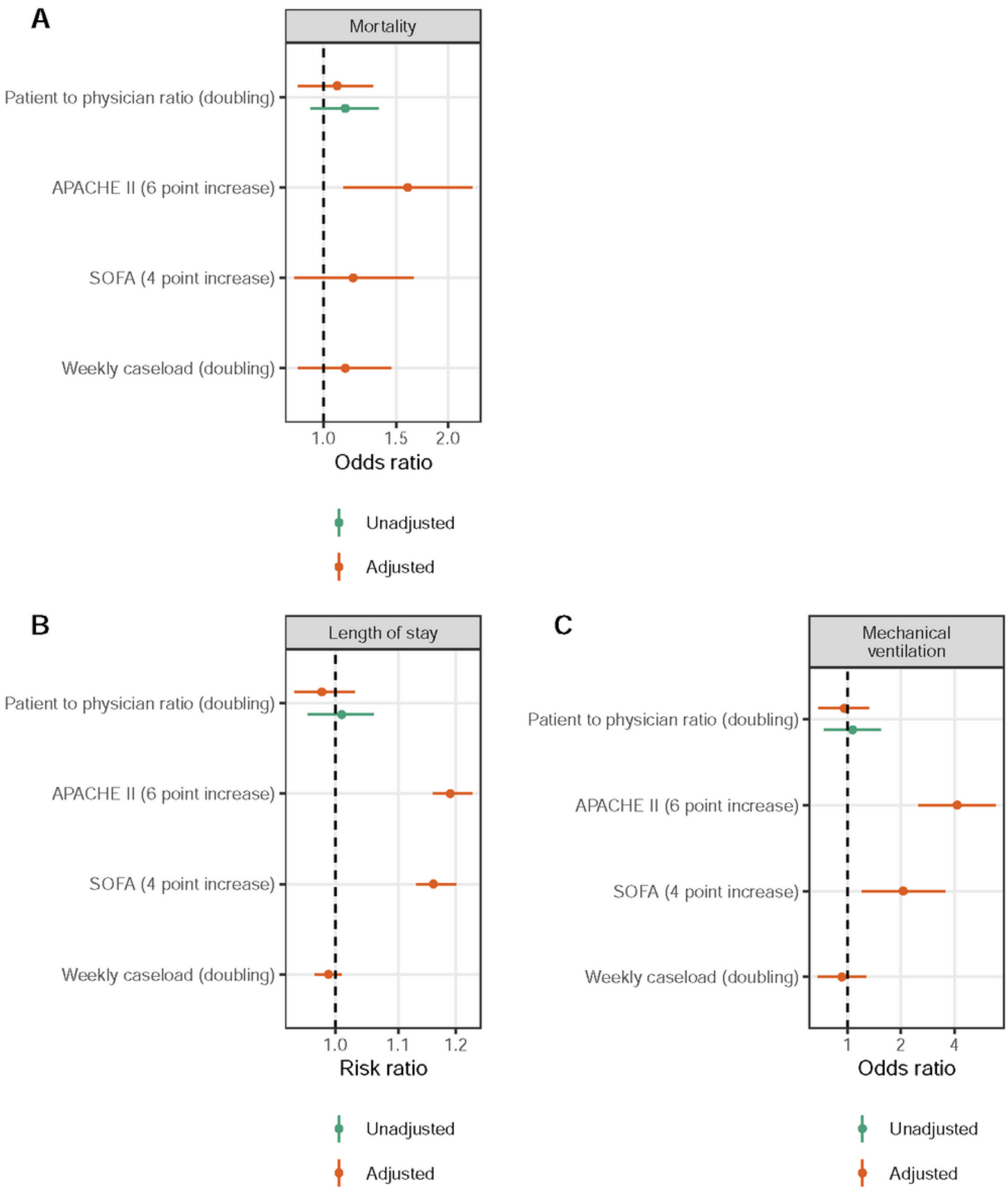

Figure 5

A, B, C. Patient-to-physician ratio and Study Outcomes Notes: APACHE II = Acute Physiology and Chronic Health Evaluation II, SOFA = Sequential Organ Failure Assessment

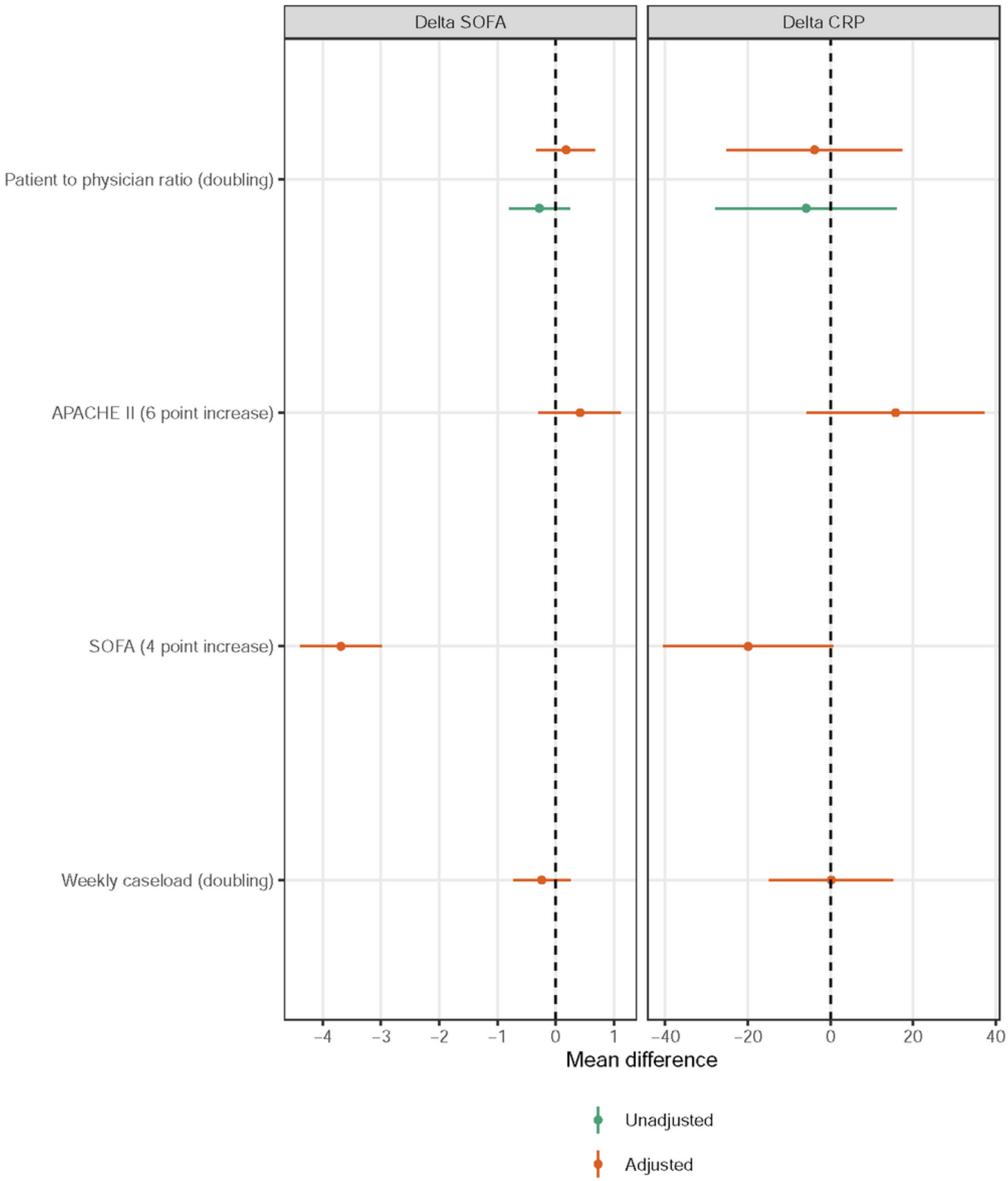

Figure 6

Patient-to-physician ratio and Delta SOFA, Delta CRP Notes: APACHE II = Acute Physiology and Chronic Health Evaluation II, SOFA = Sequential Organ Failure Assessment

Supplementary Files

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