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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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## Summary

STUDY AIM: The surge of admissions due to severe COVID-19 increased the patients-to-critical care staffing ratio within the ICUs. We investigated whether the daily level of staffing was associated with an increased risk of ICU mortality (primary endpoint), length of stay (LOS), mechanical ventilation and the evolution of disease (secondary endpoints).

METHODS: We employed a retrospective multicentre analysis of the international Risk Stratification in COVID-19 patients in the ICU (RISC-19-ICU) registry, limited to the period between March 1 and May 31, 2020, and to Switzerland. Hierarchical regression models were used to investigate crude and adjusted effects of the critical care staffing ratio on study endpoints. We adjusted for disease severity and weekly caseload.

RESULTS: Among the 38 participating Swiss ICUs, 17 recorded staffing information. The study population included 437 patients and 2,342 daily assessments of patient-to-critical care staffing 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 (adjusted OR 1.28, 95% CI 0.85–1.93; doubling of ratio) nor the patient-to-physician ratio (adjusted OR 1.07, 95% CI 0.87–1.32; doubling of ratio) were associated with ICU mortality. We found no association of daily critical care staffing on the secondary endpoints in adjusted models.

CONCLUSION: We found no association of reduced availability of critical care staffing resources in Swiss ICUs with overall ICU length of stay nor mortality. Whether long-term outcome of critically ill patients with COVID-19 have been affected remains to be studied.

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## 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, and in some cases overwhelming the critical care facilities entirely [1–3]. Patients admitted to the ICU with severe coronavirus disease 2019 (COVID-19) not only required increased resources but sometimes had to be cared for outside of the regular ICU structure [4–6]. Additional non-specialised critical care staff had to be recruited quickly to cope with the increased burden [7].

There were major differences in the numbers of patients infected with SARS-CoV-2 between regions in Switzerland during the first pandemic wave (March 1 to May 31, 2020) [8]. Southern and Western parts of Switzerland experienced higher SARS-CoV-2 incidence than Central and Eastern parts, which resulted in huge differences in ICU occupancy rates [9, 10]. With the increasing demand in ICU beds, the standard of the Swiss Society of Intensive Care Medicine regarding personnel resources, including required training and critical care staffing per bed, could not always be fully satisfied [11].

Before the SARS-CoV-2 pandemic, some studies suggested a relationship between critical care staffing and mortality in critically ill patients [12–14]. An increase of patient-to-critical care staffing ratio was associated with worse patient outcomes such as transmission of infections, postoperative complications, including pulmonary failure and reintubation, and increased mortality [15–18]. Few reports evaluated the impact of critical care staffing on ICU mortality during a pandemic [19]. The goal of the present study was to investigate whether the differences in resource allocation for critical care staffing 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 17, 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-CoV-2 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]. Informed consent for publication was approved by the Ethics committee (KEK 2020-00322, KEK 2020-00375). Collaborating centres have complied with all local legal and ethical requirements. 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, 20]. 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 has been restricted to the period from March 1, 2020 to May 31, 2020, and to participating ICUs across Switzerland. Due to resource limitations, it was not possible to prospectively obtain comprehensive data on critical care staffing beyond this time window. Data on critical care staffing from March 1 to March 17, 2020 was collected retrospectively.

**ABBREVIATIONS**

| | |
|---|---|
| **APACHE II** | Acute Physiology and Chronic Health Evaluation II |
| **CRP** | C-reactive protein |
| **GCP** | Guidelines on Good Clinical Practice; Directive |
| **IQR** | Interquartile ranges |
| **LOS** | Length of stay |
| **MD** | Mean difference |
| **OR** | Odds ratios |
| **RR** | Rate ratios |
| **RISC-19-ICU** | Risk Stratification in COVID-19 patients in the Intensive Care Unit |
| **SOFA** | Sequential Organ Failure Assessment |
| **SAPS II** | Simplified Acute Physiology Score II |

### Patient data collection

A standardised core dataset was prospectively collected during the ongoing COVID-19 pandemic for all critically ill COVID-19 patients admitted to the collaborating centres [1, 20]. 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

Critical care staffing, in terms of 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, critical care 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).

### Confounders

All analyses include the month of ICU admission (March vs April/May) to adjust for time effects. Due to the limited number of deaths in May, we combined the months April and May for analyses. We *a priori* selected the disease severity scores Acute Physiology and Chronic Health Evaluation II (APACHE II) and SOFA as confounding variables. Both scores reflect relevant domains of disease severity in a composite score. Additionally, we identified weekly caseload as a relevant confounder which might be associated with the outcomes of interest and critical care staffing. All confounding variables are static and measured at admission date.

### Data transformation

Calculation of the disease severity scores 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: $\Delta = X^*\{\max(Y_3,Y_5) - \min(Y_0,Y_1)\} + (1\text{–}X)^*\{\min(Y_3,Y_5) - \max(Y_0,Y_1)\}$ where $Y_d$ is the measured SOFA, respectively CRP, at day $d$Î$\{0,1,3,5\}$, $X = 1$ 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. Calendar day of ICU admission was used as a restricted cubic spline with 3 knots chosen at the 10th, 50th and 90th percentiles [21]. We used a likelihood ratio test (LRT) 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 and the presence of mechanical ventilation, while we used a hierarchical Poisson regression model for LOS, a hierarchical Gaussian regression model for ΔSOFA/ΔCRP and a hierarchical logistic regression model [22].We report crude and adjusted odds ratios (OR), rate ratios (RR) or mean differences (MD) with 95% confidence intervals. All hierarchical regression models accounted for the fact that admissions are nested within hospitals, that is, for each hospital a random intercept was estimated.

We *a priori* used the following confounding variables: month of ICU admission (March vs April/May), APACHE II and SOFA severity scores, as well as weekly caseload either time adjusted (adjusting for only month of ICU admission) or fully adjusted (adjusting for all mentioned variables). 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. We used complete case analysis because of a fraction of missing patients and daily assessments smaller than 3% [21]. We analysed the data using the statistical software R Version 3.6.3.

## Results

### Characteristics of the study population

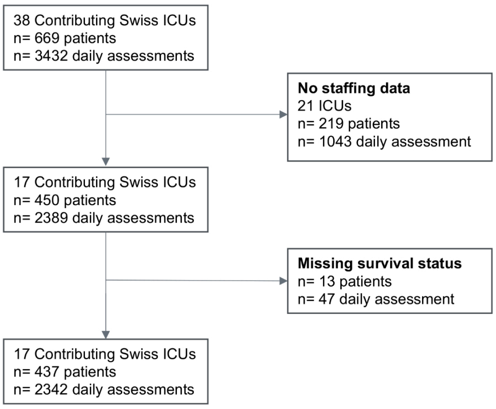
During the first COVID-19 pandemic wave occurring between March 1 and May 31, 2020 in Switzerland, 38 Swiss ICUs collected data from 669 patients representing a total of 3,432 daily assessments (figure 1). Among them, 17 ICUs recorded critical care staffing information and 450 patients with 2,389 daily assessments were eligible for analysis. After the exclusion of 13 (2.9%) patients with missing survival status and their 47 (2.0%) daily assessments, the study population included 17 ICUs, 437 patients and 2,342 daily assessments (figure 1).

Demographics and comorbidities of critically ill patients included in the study are presented in Supplemental 1 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.

ICU mortality reached 20.1% (88 out of 437). Survivors had a median LOS of 13 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

**Figure 1:** Study Flow Chart. During the first epidemic wave. ICU = Intensive Care Unit, n = number



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 Swiss ICUs that did not report critical care staffing had a similar age, gender and ICU mortality distribution [mean age 64.0 (SD 12.8), 74.4% men, 20.0% 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 receive a continuous renal replacement therapy (6.2%), as compared to the study population (supplemental table 2).

### Patient-to-critical care staffing ratio

The daily number of critically ill patients hospitalised in the contributing ICUs mirrored the pandemic wave observed in Switzerland over the study period (March 1 – May 31, 2020, supplemental table 3). 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 2.0–2.4; calendar week 16) (supplemental table 3), 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) (supplemental table 3). Figure 2 shows the modelled calendar day effect on the critical care staffing using restricted cubic splines. Calendar day was non-linearly associated with the patient-to-nurse ratio ($p = 0.007$ from LRT) and with the patient-to-physician ratio ($p = 0.003$ from LRT).

### Effect of patient-to-critical care staffing ratio on study outcomes

A doubling of the daily patient-to-nurse ratio did not influence ICU mortality ($\text{OR}_{\text{time adjusted}}$ 1.33, 95% CI 0.90–1.96; $\text{OR}_{\text{fully adjusted}}$ 1.28, 95% CI 0.85–1.93) (fig. 3A), nor any of the secondary study outcomes: LOS [$\text{RR}_{\text{time adjusted}}$ 1.01, 95% CI (0.96–1.05); $\text{RR}_{\text{fully adjusted}}$ 0.98, 95% CI (0.94–1.03)] (fig. 3B), likelihood of being mechanically ventilated ($\text{OR}_{\text{time adjusted}}$ 0.97, 95% CI 0.60–1.58; $\text{OR}_{\text{fully adjusted}}$ 0.78, 95% CI 0.42–1.44), and $\Delta$CRP ($\text{MD}_{\text{time adjusted}}$ –8.2, 95% CI –33.8–17.5, $\text{MD}_{\text{fully adjusted}}$ –3.3, 95% CI –29.4–22.9) (fig. 3C, fig. 4). Disease evolution as measured by $\Delta$SOFA showed an association with ICU mortality in crude models ($\text{MD}_{\text{time adjusted}}$ –0.91, 95% CI –1.75– –0.06) but not in adjusted models ($\text{MD}_{\text{fully adjusted}}$ –0.20, 95% CI –1.00–0.61). For patient-to-physician ratio, similar results were obtained (fig. 5 and 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 [9, 12–15, 18, 23]. 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 [11]. 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 the daily patient-to-critical care staffing ratio mirroring the increase in the number of patients. This increase remained modest compared to patient-to-critical care staffing ratio that have commonly been reported worldwide before the pandemic, particularly from the USA [15, 23]. This highlights how much flexibility the low pre-pandemic patient-to-critical care staffing ratio gave to Swiss ICUs and might explain why the overall outcome of critically ill patients with COVID-19 hospitalised among Swiss ICUs was not affected by change in patient-to-critical care staffing ratio. It might also reflect that Swiss ICUs had time to prepare themselves for the first wave that first hit in Italy.

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 patient-to-critical care staffing ratio on the quality of critical care, but most, if not all of them, had been performed outside pandemic conditions [4, 19, 24–26]. Usually, studies compared patient outcomes across ICU centres that are run with different critical care staffing ratios [27]. The current setting of a pandemic gave us the opportunity to evaluate the effect of critical care staffing changes over time in each participating centre independently.

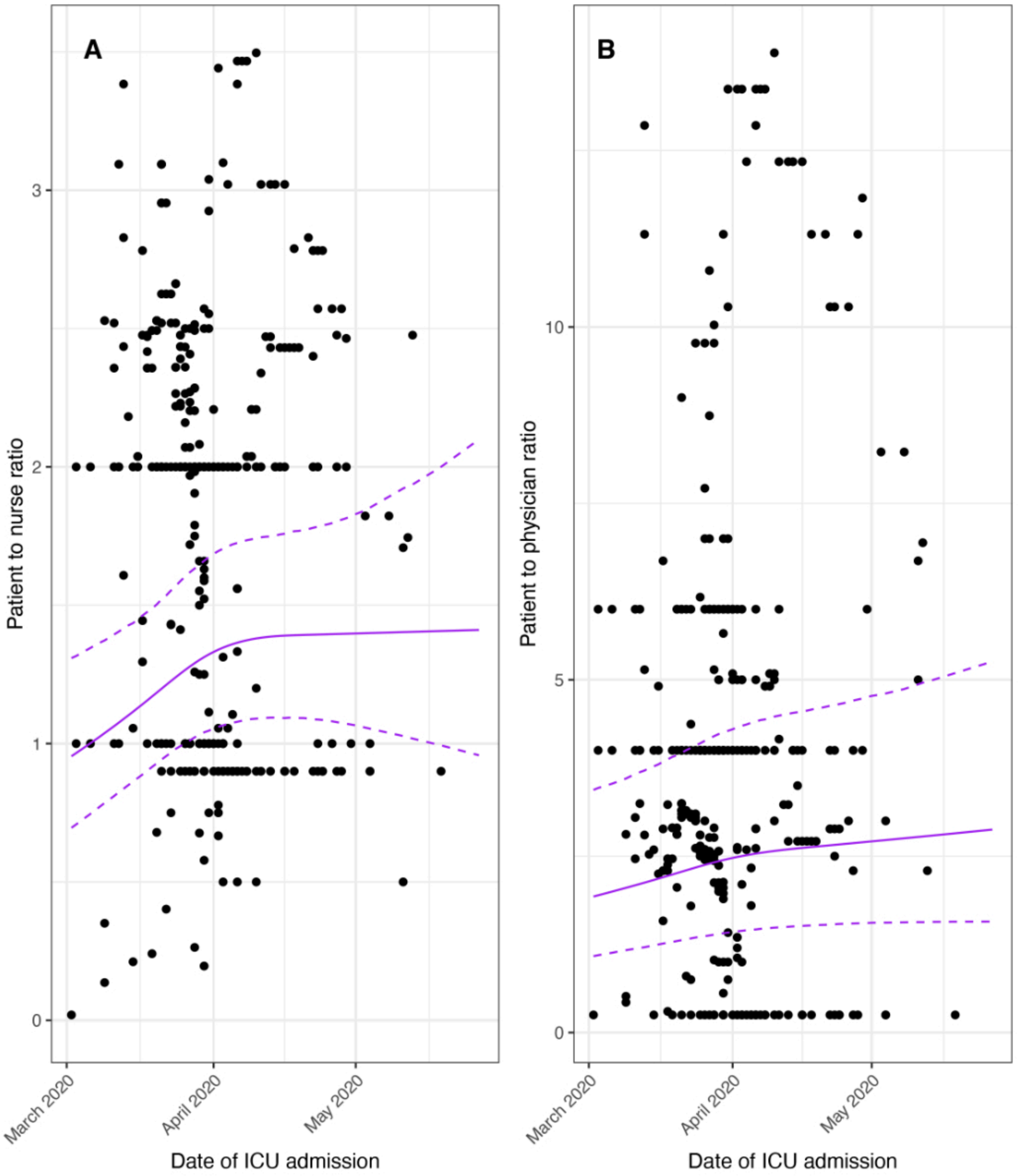
Organisational characteristics have been recently shown to affect the outcome of critically ill patients during the COVID-19 pandemic: in a study from Belgium, Taccone et al. reported that ICU overflow and the proportion of supplementary beds specially created during the pandemic to care for critically ill patients with COVID-19 were associated with increased in-hospital mortality [28]. 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 [29]. None of these studies investigated patient-to-critical care staffing 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 [30]. Also, Hugonnet et al. previously reported that a high nurse-to-patient ratio was associated with a decreased risk for late-onset ventilator-associated pneumonia [31]. Unfortunately, the RISC-19-ICU registry does not collect data to report this outcome.

The increase in critical care staffing during the pandemic could only be reached by hiring healthcare 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. Information on the variation of skill-mix across shifts is unfortunately not recorded in our data set. We could have speculated that the reduction in specialised care could have contributed to a worse outcome for the most severely ill patients [32, 33], which our study, however, did not confirm. Yet, the supervising task for the ICU specialists might have been dramatically higher. This might explain why healthcare workers from Swiss ICUs have increasingly been reporting anxiety, depression, and peri-traumatic distress as well as low well-being [34].

Our study has several strengths that make our observations potentially generalisable. 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-critical care staffing 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, but 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, after which most centres systematically introduced dexamethasone. This may have altered mortality, especially in critically ill patients with high disease severity [35]. 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 [36]. Fourth, 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 centres that did not record critical care staffing information had a less severe diseases status. Fifth, since information on critical care staffing was collected at an aggregated level (i.e., generally for each ICU) and not at an individual level (i.e, for each individual patient), our inferential conclusions on individual outcomes might be affected by a cross-level bias [37], despite the use

**Figure 2:** Patient-to-critical care staffing ratio. ICU = Intensive Care Unit



of hierarchical approaches that include cross-level structure in their analyses [38, 39]. Finally, due to resource limitations, we were not able to collect patient-to-critical care staffing data beyond the study time period.

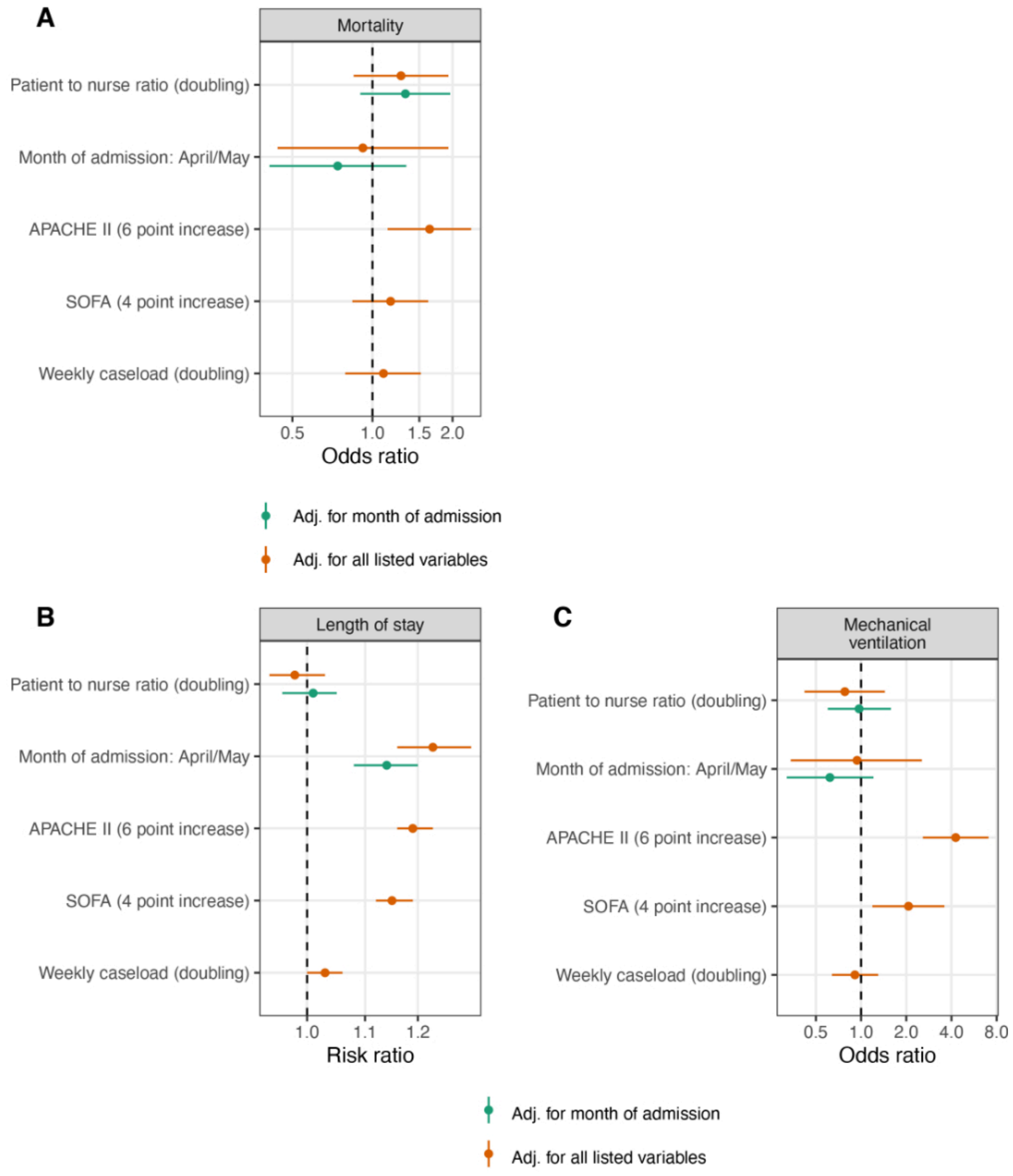
## Conclusion

Providing a sufficient number of highly trained personnel as standard within ICUs is a too often overlooked aspect when it comes to pandemic preparedness. Our study demonstrates that the pre-pandemic low patient-to-critical care staffing ratio that are being enforced by the Swiss Society for Intensive Care Medicine helped the Swiss healthcare system to successfully overcome the first wave of the COVID-19 pandemic. We found no association between reduced critical care staffing resources per patient and overall length of stay or mortality in Swiss ICUs. Future studies should address the effect of reduced availability of critical care staff on long-term outcomes (e.g. post-traumatic stress disorders) of critically ill patients with COVID-19 and the mid-term consequences of the augmented workload on healthcare workers' health.

## Availability of data and materials

Any intensive care unit or other centre 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 centre after approval of the study protocol by the registry board. Repro-

**Figure 3:** Patient-to-nurse ratio and study outcomes. APACHE II = Acute Physiology and Chronic Health Evaluation II, SOFA = Sequential Organ Failure Assessment



ducibility of the results in the present study was ensured by providing code for registry-specific data transformation and statistical analysis for collaborative development on the GitHub and Zenodo repositories. The registry protocol and data dictionary are publicly accessible at https://www.risc-19-icu.net.

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**Figure 4:** Patient-to-nurse ratio and delta SOFA, delta CRP. APACHE II = Acute Physiology and Chronic Health Evaluation II, SOFA = Sequential Organ Failure Assessment, CRP = C-reactive protein

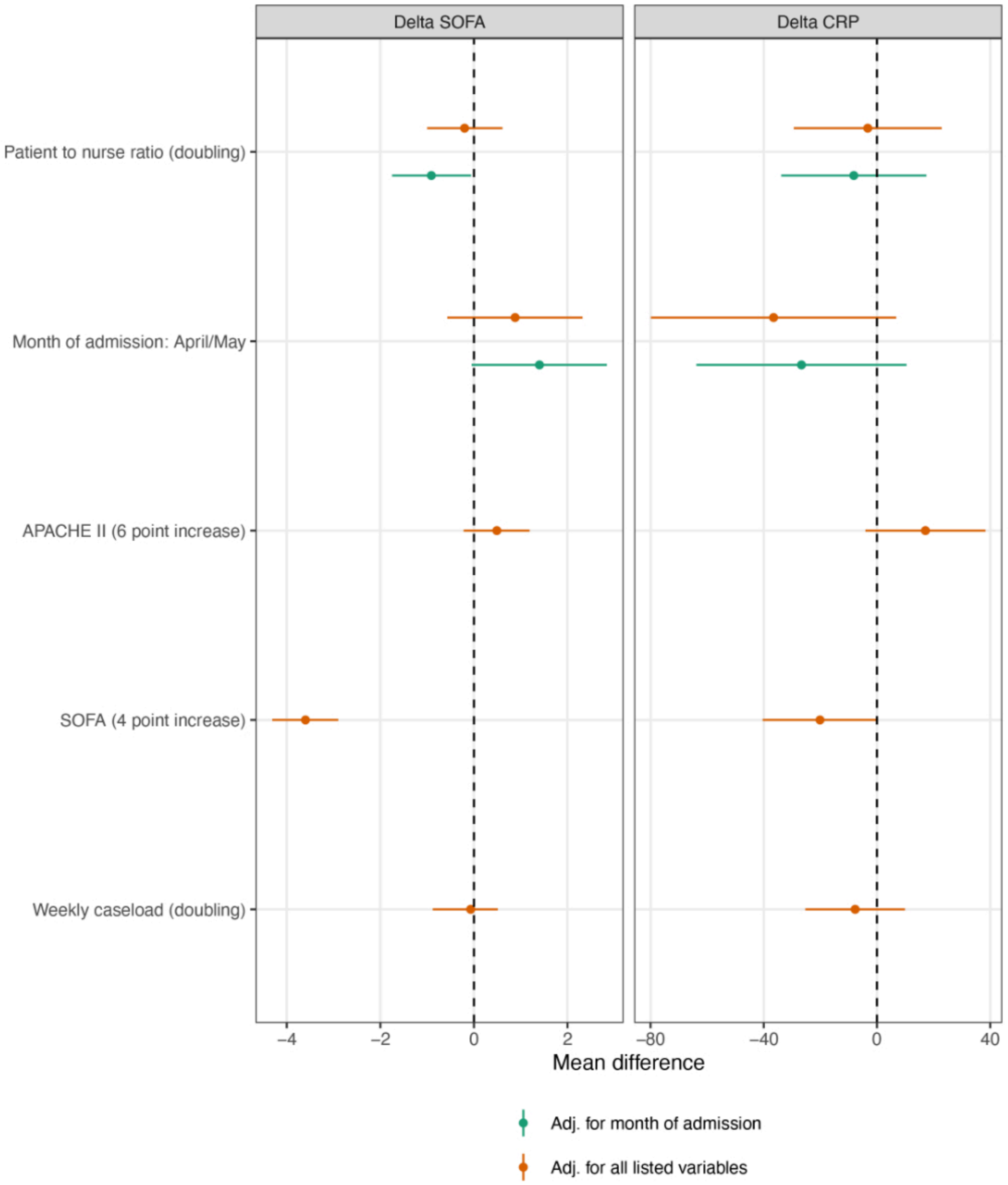

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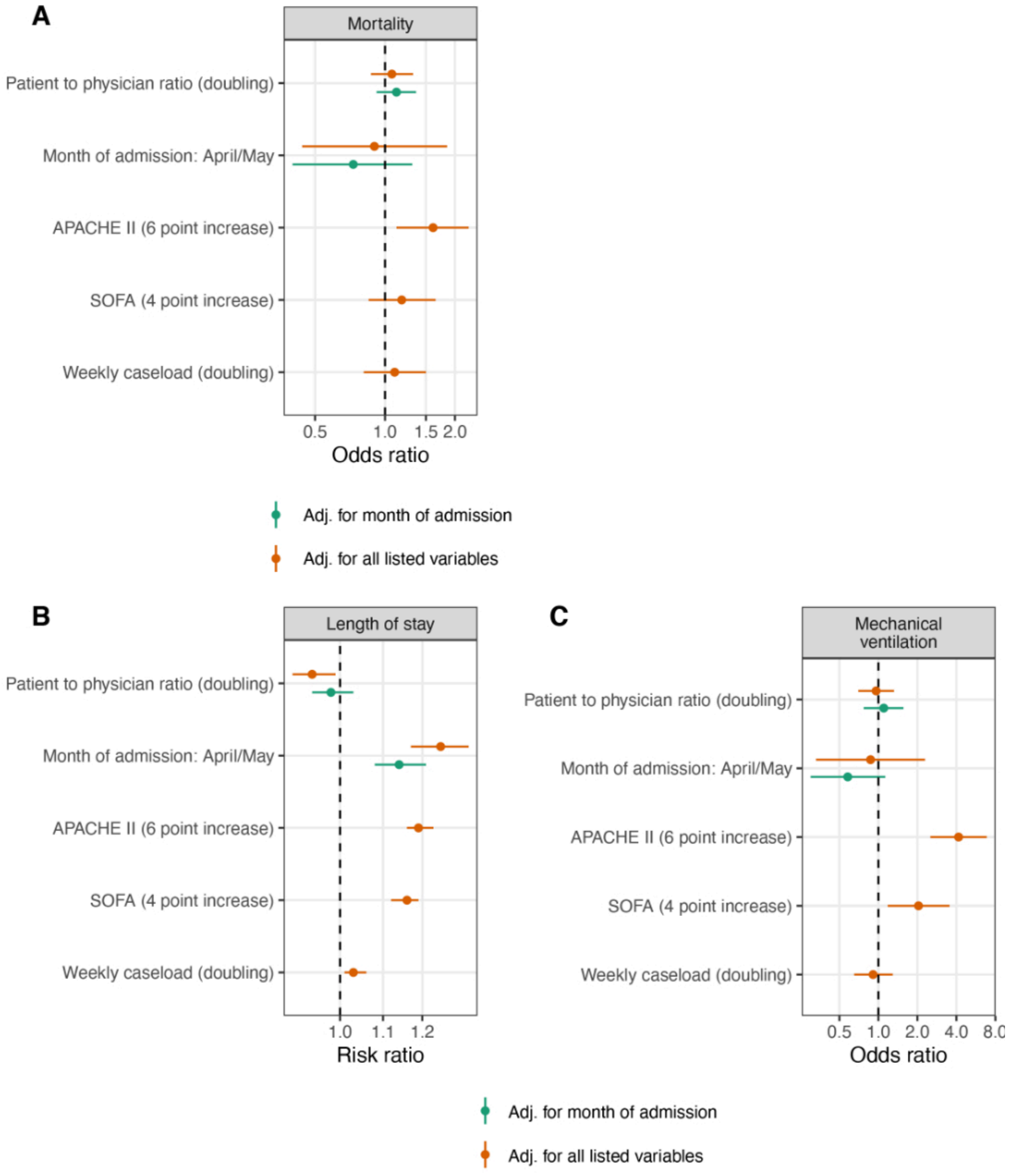
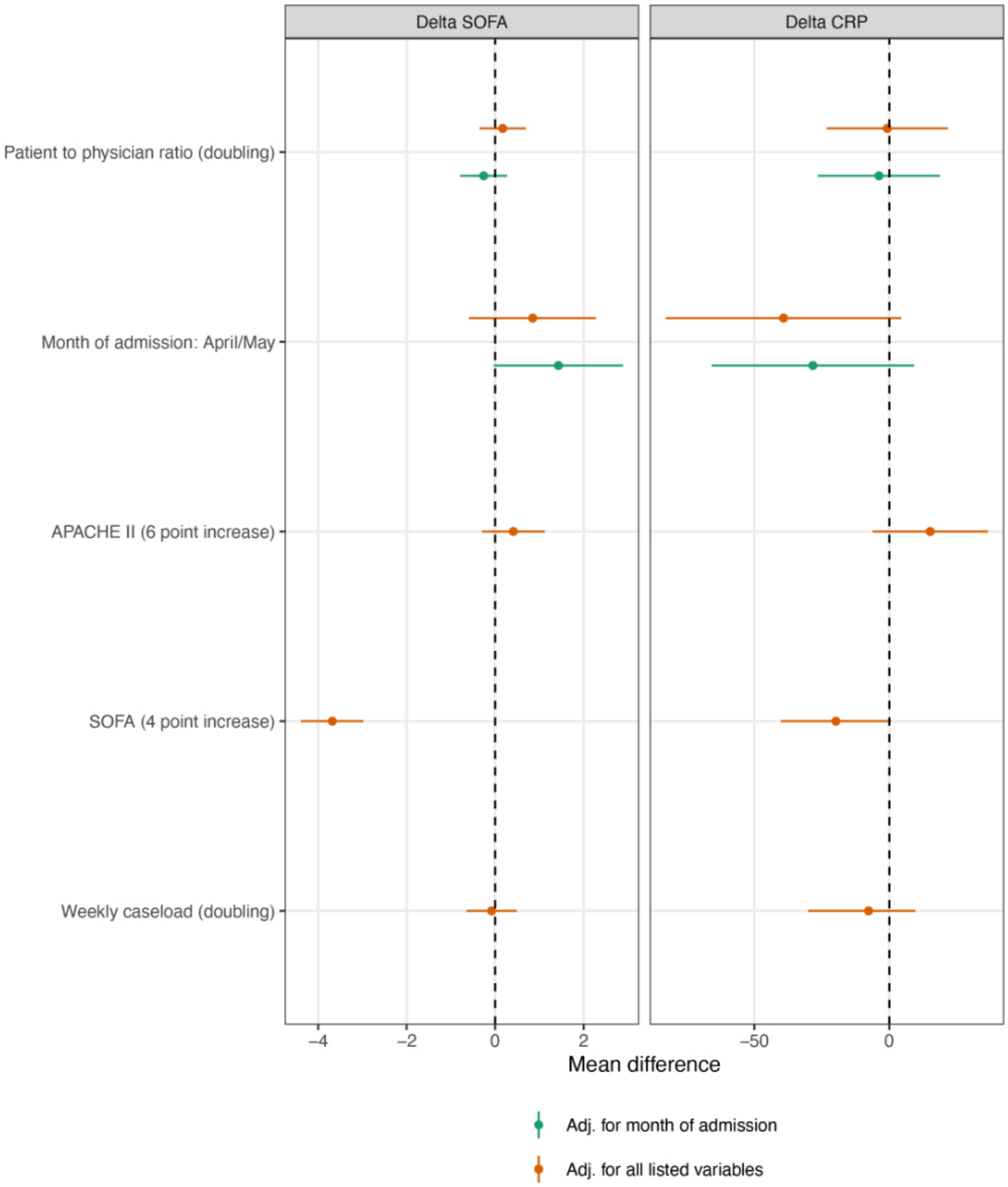
**Figure 5:** Patient-to-physician ratio and study outcomes. APACHE II = Acute Physiology and Chronic Health Evaluation II, SOFA = Sequential Organ Failure Assessment



Grabs, Grabs (Christian Bürkle, MD); Medical ICU, Cantonal Hospital St.Gallen, St. Gallen (Gian-Reto Kleger, MD); Service d'Anesthesiologie, EHNV, Yverdon-les-Bains (Marilene Franchitti Laurent, MD; Jean-Christophe Laurent, MD); Abteilung für Anaesthesiologie und Intensivmedizin, Hirslanden Klinik Im Park, Zürich (Tomislav Gaspert, MD; Marija Jovic, MD); Intensivmedizin & Intermediate Care, Kantonsspital Olten, Olten (Michael Studhalter, MD); Institut für Anaesthesiologie und Intensivmedizin, Klinik Hirslanden, Zurich (Christoph Haberthuer, MD; Roger F. Lussman, MD); Anaesthesie Intensivmedizin Schmerzmedizin, Spital Schwyz, Schwyz (Daniela Selz, MD; Didier Naon, MD); Dipartimento Area Critica, Clinica Luganese Moncucco, Lugano (Andrea Glotta, MD; Samuele Ceruti, MD); Institut für Anaesthesiologie Intensivmedizin & Rettungsmedizin, See-Spital Horgen & Kilchberg, Horgen (Julien Marrel, MD; Mirko Brenni, MD); Klinik für Operative Intensivmedizin, Kantonsspital Aarau, Aarau (Rolf Ensner, MD; Marc Michot, MD); Intensivstation, Kantonsspital Schaffhausen, Schaffhausen (Nadine Gehring, MD); Intensivstation, Spital Simmental-Thun-Saanenland AG, Thun (Antje Heise, MD); Klinik für Anaesthesie Intensivmedizin Operationszentrum und Schmerzmedizin, Kantonsspital Muensterlingen, Muensterlingen (Tobias Huebner, MD; Thomas A. Neff, MD); Division of Intensive Care, University Hospitals of Geneva, Geneva (Sara Cereghetti, MD; Filippo Boroli, MD; Jerome Pugin, MD, PhD).

**Figure 6:** Patient-to-physician ratio and delta SOFA, delta CRP. APACHE II = Acute Physiology and Chronic Health Evaluation II, SOFA = Sequential Organ Failure Assessment



### 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. AM and MPH had full access to the study data and take full responsibility for the accuracy of the data analysis. All authors read and approved the final manuscript.

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### Conflict of interest

MPH, PDWG and RAS declared having received unrestricted grants from CytoSorbents Europe GmbH (Berlin, Germany) and Union Bancaire Privée (Zurich, Switzerland) to maintain the RISC-ICU registry. All other authors declared no conflict of interest related to the present work.

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# Supplementary material

**Table S1:**
Patient characteristics and outcomes, by surviving status.

| | | **Survivor** | **Non-survivor** | **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) |
| | Median [Min, Max] | 62.0 [24.0, 92.0] | 70.0 [31.0, 86.0] | 64.0 [24.0, 92.0] |
| SAPS II | Mean (SD) | 55.9 (17.5) | 65.5 (14.1) | 57.8 (17.3) |
| | Median [Min, Max] | 61.0 [15.0, 90.0] | 69.0 [24.0, 88.0] | 64.0 [15.0, 90.0] |
| APACHE II | Mean (SD) | 20.5 (6.86) | 24.1 (5.86) | 21.2 (6.82) |
| | Median [Min, Max] | 22.0 [3.00, 38.0] | 24.5 [5.00, 35.0] | 23.0 [3.00, 38.0] |
| SOFA | Mean (SD) | 11.0 (4.40) | 13.0 (4.66) | 11.4 (4.52) |
| | Median [Min, Max] | 11.0 [0, 20.0] | 13.5 [0, 21.0] | 11.0 [0, 21.0] |
| Median patient-to-nurse ratio over ICU stay | Mean (SD) | 1.79 (0.783) | 1.91 (0.674) | 1.81 (0.765) |
| | Median [Min, Max] | 2.00 [0.0194, 3.50] | 2.00 [0.667, 3.47] | 2.00 [0.0194, 3.50] |
| | 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) |
| | Median [Min, Max] | 3.15 [0.250, 13.9] | 4.00 [0.250, 13.4] | 3.19 [0.250, 13.9] |
| | Missing | 80 (22.9%) | 27 (30.7%) | 107 (24.5%) |
| Length of stay in ICU (in days) | Mean (SD) | 17.7 (24.5) | 17.7 (29.9) | 17.7 (25.6) |
| | Median [Min, Max] | 13.0 [0, 273] | 10.5 [0, 268] | 13.0 [0, 273] |
| | 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%) |
| | 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 haemodialysis 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 | 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%) |
| Month of ICU admission | March | 204 (58.5%) | 56 (63.6%) | 260 (59.5%) |
| | April/May | 145 (41.5%) | 32 (36.4%) | 177 (40.5%) |

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

**Table S2:**
Characteristics of patients with known discharge status from 19 hospitals not recording critical care staffing*.

| | | **Survivor** | **Non-survivor** | **Overall** |
|---|---|---|---|---|
| | | **(n = 156)** | **(n = 39)** | **(n = 195)** |
| Gender | Male | 115 (73.7%) | 30 (76.9%) | 145 (74.4%) |
| | Female | 39 (25.0%) | 9 (23.1%) | 48 (24.6%) |
| | Missing | 2 (1.3%) | 0 (0%) | 2 (1.0%) |
| Age | Mean (SD) | 62.4 (13.1) | 70.4 (8.96) | 64.0 (12.8) |
| | Median [Min, Max] | 63.0 [10.0, 87.0] | 72.0 [50.0, 85.0] | 66.0 [10.0, 87.0] |
| SAPS II | Mean (SD) | 42.4 (18.4) | 53.6 (15.8) | 44.6 (18.4) |
| | Median [Min, Max] | 36.0 [11.0, 80.0] | 51.0 [24.0, 81.0] | 38.0 [11.0, 81.0] |
| APACHE II | Mean (SD) | 15.8 (6.83) | 19.0 (6.45) | 16.5 (6.86) |
| | Median [Min, Max] | 13.0 [5.00, 32.0] | 18.0 [9.00, 30.0] | 14.0 [5.00, 32.0] |
| SOFA | Mean (SD) | 9.16 (4.02) | 9.23 (4.91) | 9.17 (4.20) |
| | Median [Min, Max] | 9.00 [0, 21.0] | 9.00 [0, 19.0] | 9.00 [0, 21.0] |
| Length of stay in ICU (in days) | Mean (SD) | 11.7 (12.5) | 13.6 (10.6) | 12.1 (12.1) |
| | Median [Min, Max] | 8.00 [0, 66.0] | 13.0 [0, 50.0] | 9.00 [0, 66.0] |
| Smoking history | Non smoker | 100 (64.1%) | 25 (64.1%) | 125 (64.1%) |
| | Past history | 21 (13.5%) | 9 (23.1%) | 30 (15.4%) |
| | Current smoker | 14 (9.0%) | 1 (2.6%) | 15 (7.7%) |
| | Missing | 21 (13.5%) | 4 (10.3%) | 25 (12.8%) |
| Body mass index (kg/m2) | Mean (SD) | 29.2 (6.19) | 29.2 (5.38) | 29.2 (6.01) |
| | Median [Min, Max] | 27.8 [20.1, 57.1] | 28.1 [20.8, 49.5] | 27.8 [20.1, 57.1] |
| | Missing | 29 (18.6%) | 4 (10.3%) | 33 (16.9%) |
| Steroids used | No | 141 (90.4%) | 22 (56.4%) | 163 (83.6%) |
| | Yes | 15 (9.6%) | 17 (43.6%) | 32 (16.4%) |
| Experimental therapy used | No | 99 (63.5%) | 23 (59.0%) | 122 (62.6%) |
| | Yes | 57 (36.5%) | 16 (41.0%) | 73 (37.4%) |
| Mechanical ventilation | No | 70 (44.9%) | 3 (7.7%) | 73 (37.4%) |
| | Yes | 86 (55.1%) | 36 (92.3%) | 122 (62.6%) |
| Prone positioning | No | 110 (70.5%) | 14 (35.9%) | 124 (63.6%) |
| | Yes | 46 (29.5%) | 25 (64.1%) | 71 (36.4%) |
| ECMO | No | 156 (100%) | 39 (100%) | 195 (100%) |
| | Yes | 0 (0%) | 0 (0%) | 0 (0%) |
| Continuous renal replacement therapy or haemodialysis of any form | No | 148 (94.9%) | 35 (89.7%) | 183 (93.8%) |
| | Yes | 8 (5.1%) | 4 (10.3%) | 12 (6.2%) |
| Chronic arterial hypertension | Not present | 88 (56.4%) | 17 (43.6%) | 105 (53.8%) |
| | Present | 68 (43.6%) | 22 (56.4%) | 90 (46.2%) |
| Ischemic heart disease | Not present | 139 (89.1%) | 27 (69.2%) | 166 (85.1%) |
| | Present | 17 (10.9%) | 12 (30.8%) | 29 (14.9%) |
| Other heart disease | Not present | 127 (81.4%) | 30 (76.9%) | 157 (80.5%) |
| | Present | 29 (18.6%) | 9 (23.1%) | 38 (19.5%) |
| Diabetes mellitus | Not present | 124 (79.5%) | 23 (59.0%) | 147 (75.4%) |
| | Present | 32 (20.5%) | 16 (41.0%) | 48 (24.6%) |
| Chronic pulmonary disease | Not present | 137 (87.8%) | 30 (76.9%) | 167 (85.6%) |
| | Present | 19 (12.2%) | 9 (23.1%) | 28 (14.4%) |
| Immunosuppression | Not present | 148 (94.9%) | 34 (87.2%) | 182 (93.3%) |
| | Present | 8 (5.1%) | 5 (12.8%) | 13 (6.7%) |

*From the 19 hospitals 24 patients out of 219 patients had an unknown discharge status.

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

**Table S3:**
Admission characteristics, by week of ICU admission.

| Week of ICU admission | No. of ICU admissions | No. of non-survivors | Median patient-to-nurse ratio | Q1 patient-to-nurse ratio | Q3 patient-to-nurse ratio | Median patient-to-physician ratio | Q1 patient-to-physician ratio | Q3 patient-to-physician ratio |
|---|---|---|---|---|---|---|---|---|
| 9 | 3 | 1 | 1 | 0.5 | 1.5 | 4 | 2.1 | 5 |
| 10 | 6 | 0 | 1 | 0.4 | 2 | 2.8 | 0.5 | 4 |
| 11 | 31 | 7 | 2 | 1.6 | 2.5 | 3.6 | 2.5 | 5 |
| 12 | 86 | 19 | 2.4 | 2 | 2.6 | 3.1 | 2.8 | 4 |
| 13 | 134 | 29 | 2 | 1 | 2.2 | 4 | 2.4 | 6 |
| 14 | 73 | 14 | 1.1 | 0.9 | 2 | 4 | 1.3 | 5 |
| 15 | 37 | 6 | 2 | 2 | 2.4 | 4.2 | 3.2 | 5.1 |
| 16 | 26 | 7 | 2.4 | 2 | 2.4 | 2.7 | 2.7 | 4 |
| 17 | 24 | 3 | 2 | 0.9 | 2.6 | 2.9 | 0.2 | 4 |
| 18 | 8 | 1 | 1 | 0.9 | 1.9 | 4 | 1.6 | 7.1 |
| 19 | 5 | 0 | 1.7 | 1.4 | 1.8 | 6.8 | 6.3 | 7.3 |
| 20 | 3 | 0 | 1.7 | 1.3 | 2.1 | 1.3 | 0.8 | 1.8 |
| Overall | 437 | 88 | 2 | 1 | 2.4 | 3.2 | 2.4 | 5.1 |