Experiences of Renal Replacement Therapy Delivery in Swedish Intensive Care Units during the COVID-19 Pandemic

Daniel Hertzberg\textsuperscript{a} Mårten Renberg\textsuperscript{a} Jesper Nyman\textsuperscript{a} Max Bell\textsuperscript{a, b} Claire Rimes Stigare\textsuperscript{a}

\textsuperscript{a}Department of Perioperative Medicine and Intensive Care, Karolinska University Hospital, Stockholm, Sweden; \textsuperscript{b}Department of Physiology and Pharmacology, Karolinska Institutet, Stockholm, Sweden

Keywords
Critical care · Renal replacement therapy · Coronavirus disease-19 · Health resources

Abstract
Background: The COVID-19 pandemic led to a rapidly increased demand for intensive care unit (ICU) and renal replacement therapy (RRT) worldwide. RRT delivery was threatened by a lack of specially trained staff and equipment. We investigated how the first wave of COVID-19 affected RRT delivery in Swedish ICUs. Methods: An Internet-based questionnaire was sent to ICU lead physicians which included quantitative and qualitative questions regarding RRT demand, equipment availability, and use of continuous renal replacement therapy (CRRT), intermittent haemodialysis (IHD), and peritoneal dialysis (PD) during spring 2020. Results: Twenty-five ICUs responded and these treated 64\% of COVID-19 ICU patients in Sweden. ICU capacity increased by 292\% (IQR 171–347\%). Median peak capacity was reached during the 18th week of the year. RRT use increased overall by 133\% and in Stockholm by 188\%. 36\% of units seques- tered CRRT machines. IHD was used in 68\% and PD in 12\% of ICUs. RRT fluid and filter shortages were experienced by 45\% and 33\% of wards, respectively; consequently, prescription alterations were made by 24\% of ICUs. Calcium solution shortages were reported in 12\% of units that led to citrate protocol changes. Staffing shortages resulted in RRT sometimes being delivered by non-RRT-trained staff, safety incidents relating to this occurred, although no patient harm was reported. Conclusion: During the first wave of the COVID-19 pandemic, RRT demand increased extensively causing staff and equipment shortages, altered CRRT protocols, and increased use of IHD and PD. The impact on patient outcomes should be assessed to effectively plan for further surge capacity RRT demand.

Introduction

In critically ill patients with coronavirus disease-19 (COVID-19), acute kidney injury is common and 20–30\% of patients require renal replacement therapy (RRT) \cite{1–6}. As the pandemic swept across the world in spring 2020, intensive care units (ICUs) had to rapidly increase their bed capacity and in parallel increase provision of RRT, including continuous renal replacement therapy (CRRT), intermittent haemodialysis (IHD), and peritoneal dialysis (PD). In Sweden, delivery of CRRT recorded...
in the Swedish intensive care register increased by 150% between 1 March and 30 June 2020 compared to the same period in the previous 2 years (1,432 in 2020, and 987 and 913 in 2018 and 2019) [7]. Supplies of RRT materials such as renal replacement fluids and filter availability were threatened during the pandemic with a surge in demand throughout Europe for dialysis products. Manufacturers faced the challenge of increasing production while simultaneously struggling with staffing problems, factory closures, and distribution difficulties due to closed borders. Indeed, the global dialysis devices and equipment market declined by 1.2 million dollars in 2020 [8]. Alternative methods of RRT which could reduce staff workload or transfer tasks to non-ICU nurses were used, such as IHD and PD. PD was proposed within the intensive care community as a potential means of providing RRT to patients in the event that CRRT and IHD resource capacity was exceeded [9].

Sweden has a total of 83 ICUs in 55 hospitals within primary, secondary, and tertiary centres, and 7 are university hospitals. There are under normal circumstances 522 ICU beds for the Swedish population of 10.38 million people and thus 5.0 ICU beds per 100,000 people [10, 11]. ICU accessibility per capita is among the lowest in Europe; Germany has the highest capacity with 35 ICU beds per 100,000 of the population [11]. Swedish ICU bed capacity increased to a peak of 753 at the height of the pandemic, on 24 April 2020, according to the Swedish Intensive Care Register [7]. COVID-19 patients were treated in 82 units during the spring of 2020 although not all units routinely administer RRT [12]. In our own unit, we experienced difficulties in swiftly increasing RRT capacity to meet demand and in attempting to maintain treatment quality during this surge. We wanted to investigate how ICUs in Sweden prepared for and delivered RRT treatment during the height of the first wave of the COVID-19 pandemic. We conducted a survey using an Internet-based questionnaire to investigate what changes to treatment protocols were made, which problems arose, and what was learnt from this experience. This information is vital in the planning and provision of RRT during the ongoing pandemic in order to optimize treatment and outcome for our patients.

Method

Study Design

This is an observational study conducted as an electronic questionnaire using the Research Electronic Data Capture system hosted at Karolinska Institutet [13]. The questionnaire was emailed to the lead clinicians at all of Sweden’s ICUs in September 2020. It was answered by lead physicians or clinicians responsible for dialysis provision. A month was given to reply to the survey. The questionnaire consisted of quantitative questions including ICU bed and RRT capacity before and during the period 1 March to 30 June 2020. We enquired about use of CRRT, IHD, PD, and availability of dialysis machines, fluids, filters, and adjuvant equipment before and during the pandemic. Qualitative questions were also included in the survey, and respondents could detail problems and solutions to issues that arose with RRT provision during the spring of 2020. In some cases, respondents were directly contacted after the survey in order to clarify a response or acquire additional information.

The primary outcome studied was increase in RRT capacity of ICUs during spring 2020. The second outcome was use of alternative renal replacement therapies (IHD, PD).

We present the results quantitatively with medians and IQRs for continuous data, frequencies and percentages are given for categorical data as well as minimum and maximum values. We have excluded one unit from the quantitative analysis of CRRT delivery because this unit did not deliver CRRT before or during the pandemic but did administer IHD. We additionally detail qualitative information provided by respondents in the corresponding sections. Some data are presented on a regional level but are anonymized regarding individual units.

Results

The survey received responses from 25 ICUs (33%) including units in 6 of Sweden’s 7 university hospitals. The responding critical care units treated 64% (2,977 patients) of all COVID-19 patients (4,655) admitted to Swedish ICUs during the study period [14]. One responding unit delivered only IHD and not CRRT. The questionnaire was fully completed by most respondents with missing answers equally 0.6%.

ICU Bed Capacity

Prior to the pandemic, median critical care unit bed capacity was 7 (IQR 6–9). Capacity increased during the height of the epidemic to a median of 19 beds (IQR 10–25), an increase of 292% (IQR 171–347%). The time at which ICUs reached their peak number of admissions varied and ranged between the 14th and the 26th week of the year, with the median being week 18 (IQR 16–19), which is the week beginning 27 April 2020. Peak admission numbers were reported in Stockholm hospitals during weeks 15 and 16. Hospitals in Gothenburg and the Skåne region reported maximum admission numbers a median of 3 weeks later. Hospitals in northern, southeast, and central Sweden had peak capacity later between weeks 20 and 26.
Continuous Renal Replacement Therapy

Before COVID-19, the number of CRRT apparatus available to ICUs \((n = 24)\) was median 3 (IQR 2–5, range 0–7). During the pandemic, the maximum number of apparatus in use at any one time on each unit was increased by 133% to a median of 4 (IQR 2–5, range 1–12) but with 1 ICU using an additional 12 machines, a 400% increase from normal use. The Stockholm region reported the greatest increase of CRRT use with a mean increase of 188%. 36% of ICUs needed to sequestre CRRT machines, and the median number of apparatus loaned was 3 (IQR 2–3.25) (range 1–6). Respondents reported that extra dialysis machines were most commonly borrowed from other ICU wards in the same or neighbouring hospitals (including paediatric and cardiothoracic ICUs). Machines were also loaned from manufacturers. In order to meet RRT demand, 2 wards reported giving short durations of RRT (12–24 h) and then alternating machines between patients.

Intermittent Haemodialysis

IHD was administered during the pandemic on 68% of ICUs, and the median number of IHDs in use at any one time was 1 (IQR 1–2) range 0–3. Machines were sometimes used in more than one patient per day. The prescription for IHD was made most often by nephrologists (70%) but in 30% of cases by intensivists. IHD was delivered mainly (84%) by renal medicine consultants and staff, although in 10.5%, it was given by ICU staff.

Peritoneal Dialysis

PD was used regularly on only one of the ICUs surveyed prior to the spring of 2020. During the pandemic, it was used on 3 wards (12%) where it was given to a median of 1 patient at any given time (IQR 1–1.5). These wards reported mixed results with one of the units reporting satisfaction with its use. In 1 ICU, its use was limited to one patient with PD prior to admission but difficulties reaching fluid balance goals were reported.

RRT Fluids

RRT fluid availability to 50% \((n = 12)\) of the ICU wards was reportedly unaffected, 16% \((n = 4)\) experienced a lack of dialysis fluid, and a further 29% \((n = 7)\) were forced to change prescriptions in order to maintain treatment to all patients that required it. In 21% \((n = 5)\) of the ICUs, this involved reducing the delivered dose of CRRT and other units changed the type of fluid used. This included changing from citrate anticoagulation to heparin and changing dialysate or replacement fluids to formulas with different electrolyte configurations or concentrations than the first-choice preparations. No serious incidences of electrolyte imbalance were reported to the survey.

Dialysis Filters

Dialysis filter supply was unaffected in 67% of units \((n = 16)\), a quarter of wards \((n = 6)\) experienced a lack of filters, and a further 8.3% \((n = 2)\) changed to filters that were not their first choice due to lack or threatened lack of availability. Two ICUs extended filter use time to exceed the manufacturers’ recommendations due to a shortage of filters. Although not a direct question in the survey, 4 wards anecdotally reported experiencing hypercoagulability and filter clotting, which led to citrate dose being increased and/or additional use of heparin anticoagulation in these units.

Other RRT-Related Medications

Shortages of other RRT-related products were experienced by 38% of ICU wards \((n = 9)\). 13% \((n = 3)\) altered routines to accommodate this lack of supply. These medications included amino acid supplementation and calcium for intravenous infusion. Calcium solutions shortages were experienced by 3 ICUs, which forced users to substitute their solutions with a compound containing a different concentration of calcium during citrate anticoagulation and to reprogramme RRT machines. As a consequence, 2 units reported incidents of both hypercalcaemia and hypocalcaemia although none of the patients suffered permanent harm.

Staffing

ICU nurse shortages were acute. Four ICUs (17%) described that staff other than those who normally administer CRRT were involved in RRT delivery. In one case, theatre nurses were trained to operate dialysis machines. Two other ICUs describe a number of incidents with incorrect fluid bags being administered or fluid bag compartment contents not being mixed prior to use. These problems were attributed to workload pressure and to staff not used to RRT being involved in its delivery.

Planning and Alterations to Routines

The time available to plan for expansion of RRT services after the admission of the first cases of patients with COVID-19 to Swedish ICUs (6 March 2020) varied between regions, and this was partly reflecting in the data regarding when peak COVID admissions occurred [15]. ICUs report that planning strategies for RRT delivery included preparing guidelines for dose reduction in case of
supply failure, planning to begin or increase use of IHD machines, purchasing CRRT apparatus, and establishing RRT training programmes. One ICU that does not normally deliver RRT began preparing to give treatment during the pandemic. In several cases, change to routines or use of extra machines was never actually necessary.

Other alterations involved connecting RRT directly to the ECMO circuit in a cardiothoracic unit in which this was not routine praxis. Infrastructure changes were reported; in one example, new plumbing was installed in order to provide water for RRT, which was delivered in new ward spaces. 

Discussion

The COVID-19 pandemic led to a rapid increase in number of patients requiring intensive care and in parallel an increase in demand for RRT. CRRT use increased overall by a third but varied between regions and in Stockholm increased by 188%. IHD was used in two-thirds of wards. Threatened and actual shortages of RRT expendables, fluids, and filters led to alterations in RRT dose prescriptions, fluid, and filter choices as well as to prolonged filter use. Filter clotting problems were reported. A shortage of specialist ICU nurses trained in dialysis delivery led to non-specialist staff being involved in administration of RRT. A number of potentially dangerous incidents related to changes in RRT use were reported by units during this time.

The COVID-19 pandemic has resulted in a surge in demand for critical care and RRT worldwide, and the logistical and practical problems experienced are common to many health-care providers; however, our study is unique in reporting these experiences in detail from a large group of ICUs. Hick described 3 levels of care provision during surge capacity events such as disasters and pandemics. These are conventional, contingency, and crisis care defined by the availability of staff, spaces, and supplies [16]. Contingency care while not consistent with conventional practice should maintain or have minimal impact on patient care. Crisis care however can only aim to provide sufficient care [17, 18]. The goal of disaster preparedness is to maintain conventional or contingency care for as long as possible [19]. Provision of RRT in Sweden seems in most cases to have met criteria for conventional care although in some instances where dose revision and machine rotation were necessary, care levels were reduced to the level of contingency care. Results from a study from our own unit demonstrated survival (57% at 3 months) and renal recovery, defined as return to within 1.5 times baseline creatinine (occurring in 73.8%) among COVID-19 RRT patients to be relatively high compared to data from other countries and would suggest that care levels were maintained at an adequate level [20].

A number of critical care groups and health-care providers have produced guidelines regarding planning and administration of ICU resources and RRT during surge capacity situations. These should be used to guide formulation of local recommendations [3, 19, 21–23]. Of the three aspects of care provision identified by Hicks, availability of highly trained staff to provide RRT is often identified as the most difficult to consistently maintain and may have the greatest impact on patient safety and RRT quality [24].

Limitations and Strength of the Study

This study was conducted as a survey with voluntary participation, and replies were received from 33% of ICUs, covering 66% of all COVID-19 admissions during the study time. The results reported may not reflect the experiences of the non-participating units. The survey was conducted retrospectively 3 months after the period being studied and relies on the correct recollection of information. Recall bias may have been introduced. It is possible that units underreported adverse incidences related to RRT therapy and we do not claim to have exhaustively reported these.

The study’s strengths are that it covers the RRT experiences from units treating the majority of patients (nearly 3,000) in Swedish ICUs and it covers all of the Stockholm region. It is unique in giving insight into the practicalities of RRT administration during an unprecedented period in ICU history.

Study Implications

The study highlights logistical and practical difficulties associated with trying to meet a sudden increase in demand of RRT, a highly technically advanced treatment. The findings regarding shortages of RRT equipment and consumables should be used by supply chain managers, pharmacists, and manufacturers to plan for continued care during the ongoing COVID outbreak. Local guidelines should be available and reviewed to clearly specify how dose and modality changes, as well as fluid choices, should be made in the event of fluid shortages to minimize impact on patient safety and outcome. Strict procedures regarding reprogramming of machines and calcium citrate protocols should be made in the event of future calcium shortages. Strategies regarding rotation of RRT.
machines may be necessary to provide a minimum level of RRT to as many patients as necessary in the event of surge capacity according to crisis management principles. Cooperation and liaison with nephrological services should be optimized to maximize use of IHD treatments and post-RRT care.

The study highlights the importance of the flexible use of different renal replacement modalities during a crisis and the importance of collaboration with nephrological services. The survey showed that IHD was administered to a majority of patients at some point during their ICU stay, and in a study of COVID-19 ICU patients at Stockholm’s Karolinska hospital, 40% of ICU survivors received at least one IHD treatment after ICU discharge [20].

PD was not widely used in the Swedish units, which responded to our survey, but this modality has for some time been gaining interest as an alternative means of administering low-maintenance RRT particularly in low- and middle-income countries. This interest has increased among all health-care providers during the pandemic [25].

We found cooperation and liaison with nephrology departments was key to reducing the workload of ICU nurses and effectively utilizing resources to offer RRT to the greatest number of patients. Increased collaboration between ICU and nephrology services is likely to be vitally important not only in future crises but also under normal circumstances for many health-care settings where a chronic lack of ICU nurses may become a reality.

The impact of the changes to conventional care imposed by the pandemic in all aspects of ICU treatment, and in particular in RRT on patient outcome could not be explored in our survey but must be investigated and assessed. Further revision to surge capacity RRT protocols may be necessary in light of such findings.

**Conclusion**

The COVID-19 pandemic led to an increase in RRT demand in Swedish ICUs. Units reported shortages of trained staff, dialysis fluids, filters, and machines as well as of adjuvant treatments such as calcium solutions. RRT protocols were altered, and the use of IHD and in a few cases PD increased. The impact of these changes on patient outcomes should be assessed. Information acquired in this survey should be used to effectively plan for RRT demand during the ongoing COVID-19 pandemic and future crises.

**Acknowledgments**

The authors would like to thank all the intensive care physicians who took their time to respond to the survey and to the Swedish Intensive care Society (Svenska Intensivvårdssällskapet) who distributed the survey.

**Statement of Ethics**

The study complied with the Declaration of Helsinki and was approved by the Swedish Ethical Review Authority (Diary number 2020-02859). The data obtained contain no information on individual patients, and individual ICUs are not identified.

**Conflict of Interest Statement**

The authors declare no competing interests.

**Funding Sources**

This study was funded by grants from Stockholm county council.

**Author Contributions**

Daniel Hertzberg, Mårten Renberg, and Max Bell performed data curation and wrote, reviewed, and edited the manuscript. Jesper Nyman wrote, reviewed, and edited the manuscript. Claire Rimes Stigare conceptualised the study, performed data curation, wrote and edited the manuscript.

**Data Availability Statement**

All data generated or analysed during this study are included in this article. Further enquiries can be directed to the corresponding author.

**References**

1. Rudnick MR, Hilburg R. Acute kidney injury in COVID-19: another challenge for nephrology. *Am J Nephrol*. 2020;51:761–3.
2. Zahid U, Ramachandran P, Spitaliewitz S, Alasadi I, Chakarbori A, Azhar M, et al. Acute kidney injury in COVID-19 patients: an inner city hospital experience and policy implications. *Am J Nephrol*. 2020;51:786–96.
3. Nadim MK, Forni LG, Mehta RL, Connor MJ, Liu KD, Ostermann M, et al. COVID-19-associated acute kidney injury: consensus report of the 25th Acute Disease Quality Initiative (ADQI) Workgroup. *Nat Rev Nephrol*. 2020;16:747.
References

4 Gupta S, Coca SG, Chan L, Melamed ML, Brenner SK, Hayek SS, et al. AKI treated with renal replacement therapy in critically ill patients with COVID-19. JASN. 2021;32(1):161–76.

5 Cummings MJ, Baldwin MR, Abrams D, Jacobson SD, Meyer BJ, Balough EM, et al. Epidemiology, clinical course, and outcomes of critically ill adults with COVID-19 in New York City: a prospective cohort study. Lancet. 2020;395:1763.

6 Intensive Care National Audit Research Centre. ICNARC report on COVID-19 in critical care Case Mix Programme Database. Available from: www.icnarc.org.

7 Swedish Intensive Care Register. Data portal. Swedish Intensive Care register. 2021. Available from: httpportal.icuregswe.orgutdata-utbrott/covid-19/.

8 The Business Research Company. Dialysis Devices and Equipment Global Market Report 2020–30: Covid 19 Impact and Recovery. 2020. wwwreportlinker.comDialysis-Devices-And-Equipment-Global-Market-Report--Covid--Impact-and-Recovery.htm.

9 Shankaranarayan D, Neupane SP, Varma E, Shimonov D, Gerardine S, Bhasin A, et al. Peritoneal dialysis for acute kidney injury during the COVID-19 pandemic in New York City. Kidney Int Rep. 2020;5:1532–4.

10 Statistics Sweden SCB. Population statistics. httpswww.scb.seenfinding-statisticsstatisticss-by-subject-areapopulationpopulationcompositionpopulation-statistics.

11 Bauer J, Brüggmann D, Klingelhofer D, Maier W, Schwetman L, Weiss DJ, et al. Access to intensive care in 14 European countries: a spatial analysis of intensive care need and capacity in the light of COVID-19. Intensive Care Med. 2020;46:2026–34.

12 Ponce D, Balbi AL, Durand JB, Moretta G, Divino-Filho JC. Acute peritoneal dialysis in the treatment of COVID-19-related acute kidney injury. Clin Kidney J. 2020;13:269–73.

13 Harris PA, Taylor R, Thielle R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap): a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform. 2009;42:377–81.

14 Swedish Intensive Care Register. Rapport-erade vårduttäckningar av Coronavirus [Internet]. Available from: https://portal.icuregswe.org/siri/report/corona.inrapp.

15 Folkhälsomyndigheten. COVID-19 Daily statistics. Swedish Public health authority. Available from: https://www.folkhalsomyndigheten.se/smittskydd-beredskap/utbrott/aktuella-utbrott/covid-19/.

16 Hick JL, Koenig KL, Barbisch D, Bey TA. Surge capacity concepts for health care facilities: the CO-S-TR model for initial incident assessment. Disaster Med Public Health Prep. 2008;2 Suppl 1:S31–7.

17 Hick JL, Barbera JA, Kelen GD. Refining surge capacity: conventional, contingency, and crisis capacity. Disaster Med Public Health Prep. 2009;3:S59–67.

18 Hick JL, Einav S, Handling D, Kissoon N, Dichter JR, Devereaux AV, et al. Task Force for Mass Critical Care. Surge capacity principles: care of the critically ill and injured during pandemics and disasters: CHEST consensus statement. Chest. 2014;146:e15–16S.

19 Wurm T, Scholtes K, Kolibay F, Schorscher N, Ertl G, Ernestus RL, et al. Hospital preparedness for mass critical care during SARS-CoV-2 pandemic. Crit Care. 2020;24:386.

20 Eriksson KE, Campoccia-Jalfe F, Rysz S, Rimes-Sügäre C. Continuous renal replacement therapy in intensive care patients with COVID-19: survival and renal recovery. J Crit Care. 2021 Aug;64:125–30.

21 Chua HR, MacLaren G, Choong LH, Chionh CY, Khoo BZE, Yeo SC, et al. Ensuring sustainability of continuous kidney replacement therapy in the face of extraordinary demand: lessons from the COVID-19 pandemic. Am J Kidney Dis. 2020;76:392–400.

22 Government NSW. Renal replacement therapy in the ICU during COVID-19 pandemic. Available from: https://www.health.nsw.gov.au-Infectious-covid-19-communities-of--practice--Pages--guide--renal--replacement--therapy.aspx.

23 Intensive Care Society; The Renal Association; The British Renal Society. Renal replacement therapy for critically unwell adult patients: guidelines for best practice and service resilience during COVID-19 [Internet]. [cited 2021 Jan 20]. Available from: https://renal.org/sites/renal.org/files/Clinical%20Practice%20Guideline_RRT%20for%20Critical%20Unwell%20Adult%20Patients_FINAL.pdf.

24 Kee YK, Kim EJ, Park KS, Han SG, Han IM, Yoon CY, et al. The effect of specialized continuous renal replacement therapy team in acute kidney injury patients treatment. Yonsei Med J. 2015;56:658–65.

25 Nadim MK, Forni LG, Mehta RL, Connor MJ Jr, Liu KD, Ostermann M, et al. COVID-19-associated acute kidney injury: consensus report of the 25th Acute Disease Quality Initiative (ADQI) Workgroup. Nat Rev Nephrol. 2020 Dec;16(12):747–64. Epub 2020 Oct 15. Erratum in: Nat Rev Nephrol. 2020 Nov 2.

DOI: 10.1159/000519261

Blood Purif 2022;51:584–589