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Building a hemodiafiltration system from readily available components for continuous renal replacement therapy under disasters and pandemics: preparing for an acute kidney injury surge during COVID-19.

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REVIEW

Building a hemodiafiltration system from readily available components for continuous renal replacement therapy under disasters and pandemics: preparing for an acute kidney injury surge during COVID-19

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Purpose of review
The novel corona virus (SARS-CoV2) has been demonstrated to cause acute kidney injury due to direct cellular toxicity as well as due to a variety of autoimmune glomerular diseases. The concept of a surge of infected patients resulting in an overwhelming number of critical patients has been a central concern in healthcare planning during the COVID-19 era.

Recent findings
One crucial question remains as to how to manage patients with end stage renal disease and acute kidney injury in case of a massive surge of critically ill infected patients. Some publications address practical and ingenious solutions for just such a surge of need for renal replacement therapy. We present a plan for using a blood pump, readily available dialysis filter, and a prefilter and postfilter replacement fluid set up. This is in conjunction with multiple intravenous pumps to develop a simple hemofiltration apparatus.

Summary
The current set up may be a readily available option for use in critical situations where the need for renal replacement therapy outstrips the capacity of traditional hemodialysis services in a hospital or region.

Keywords
acute kidney injury, anticoagulation, blood pump, continuous veno-venous hemofiltration, COVID-19, hemodiafiltration, hemofiltration

INTRODUCTION

The novel Wuhan coronavirus (SARS-CoV2) and the disease resulting from it (COVID-19) first discovered in China in 2019 has resulted in nearly 25 million infections to date (late August 2020), and more than 750 000 fatalities world-wide [1]. Given the interconnected supply chains, this epidemic has also affected global trade, commerce, and health care in an unprecedented way [2]. The provision of modern medical care requires a high degree of industrialization, digitalization, training, and is resource intensive [3▪]. This means that the current – or a similar – pandemic has the potential to shut down critical supply chains disrupting medications and solutions needed for day-to-day medical care [4▪▪]. The highly infectious nature of COVID-19, leaves the possibility of large waves of infected patients that would overwhelm healthcare capacity [5]. This would potentially mean patients who could have been rescued may not have access to life saving care as has been noted during the COVID-19 outbreak in Italy [6▪▪].

The more complex and ill the patient population is, the more difficult their care during a time of

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KEY POINTS

- COVID-19 is likely to induce critical healthcare shortages in ICU beds and dialysis care.
- Simple hemofiltration set ups can serve as a useful back up in event of severe hemodialysis service shortage and especially continuous renal replacement therapy shortages in ICU during a COVID surge.
- The current set up can be powered via outlet or via battery. It can include heparin anticoagulation, and can include prefilter fluid only, or in more permissive situations pre and postfilter fluid.

potentially devastating supply chain failures [7]. This is again compounded by the speed of outbreaks and the possibility of massive numbers of patients overwhelming the capability of healthcare systems to provide critical intensive care services (ICU) [7]. While the need for ICU care is closely monitored, the need for renal replacement therapy (RRT) has not been monitored as of yet as a critical service that may be in short supply during a COVID-19 'surge' [8].

COVID-19 has been noted to cause acute tubular necrosis in the majority of acute kidney injury (AKI) cases that frequently develop in infected patients [9]. There is a significant minority of patients who develop rhabdomyolysis developing pigment-induced AKI [9]. An interesting group of patients also develop thrombotic microangiopathy and other glomerulopathies after COVID-19 infection [10▪▪]. In addition to shock and third spacing, and rhabdomyolysis, it appears that COVID-19 is a potent inducer of autoimmune phenomenon due to innate (complement) and adaptive immune dysfunction [11]. This can occur during the acute phase, or afterward as seen in the case of pediatric patients who develop multisystem inflammatory syndrome in children associated with COVID-19 [12]. In adults there is concern that many patients will develop chronic pulmonary fibrosis after viral infection [13].

We present and adapt here a solution that has been adopted by health systems in the United States and abroad. A simple system that can be used during times of critical shortage to provide a convection-based hemofiltration system as an alternative to conventional dialysis [14]. This can be set to provide a continuous RRT alternative that may prove lifesaving [14]. As the evidence becomes clearer that COVID-19 is likely to remain a seasonal or endemic issue for some time to come, it is imperative that a plan is developed to protect the most vulnerable and complex of our patients. This is also important to develop in COVID-19 patients given the disease's penchant for inducing severe renal failure due to various causes [11].

THE RATIONALE

The original design of this apparatus was derived under the severe deprivation and disorder engendered by the tragic multilateral Syrian civil war [14]. The United Nations sponsored physicians working in Syrian hospitals with scant supplies, found the number of available hemodialysis and peritoneal dialysis machines to be in short supply [14]. They published a case series of three patients treated with improvised hemofiltration devices after various critical illnesses and combat injuries [14]. Further, in the critical care setting, intermittent hemodialysis may not be tolerated and acute peritoneal dialysis may not be rapidly effective [14]. As such, a modality mimicking continuous veno-venous hemodialysis/hemofiltration (CVVHD, CVVH) was desirable [14].

THE APPARATUS

The apparatus consists of two intravenous pumps, one serving as a heparin drip, and the other serving to regulate the flow of prefilter replacement fluid to prevent clotting and provide hydrostatic driving force for hemofiltration [14]. A blood pump and a filter work in tandem to pump the 'arterial port's' blood mixed with replacement fluid across a standard hemodialysis filter [14]. In such a way the replacement fluid pump drives hemofiltration and the presence of a high flow of predialysis replacement fluid prevents clot formation [14]. This occurs by diluting the blood before it enters the dialysis filter [15], clotting is also inhibited by heparinization of blood.

Finally, we propose a postfilter replacement fluid can be added. Postfilter fluid replacement would allow for improved hemofiltration, and more options for solute to control calcium and potassium levels. The replacement fluids can be standard commercial admixtures or can be Isotonic saline, 1/2 normal saline, or bicarbonate based solutions with additives titrated to the patient's current blood values. Ultrafiltration while difficult to control with just prefilter fluid replacement, can more successfully be controlled if a postfilter fluid replacement option is available.

Power supply is another issue, and the authors of the Syrian KI articles (authors anonymized), discussed the need for alternative sources of power [14]. Alternating current power can be used to power the intravenous pumps and the blood pump when available. If the supply chain disruption results in power grid disruption, the use of commercial batteries like care batteries powering such an apparatus becomes a viable option [14]. Please refer to Fig. 1

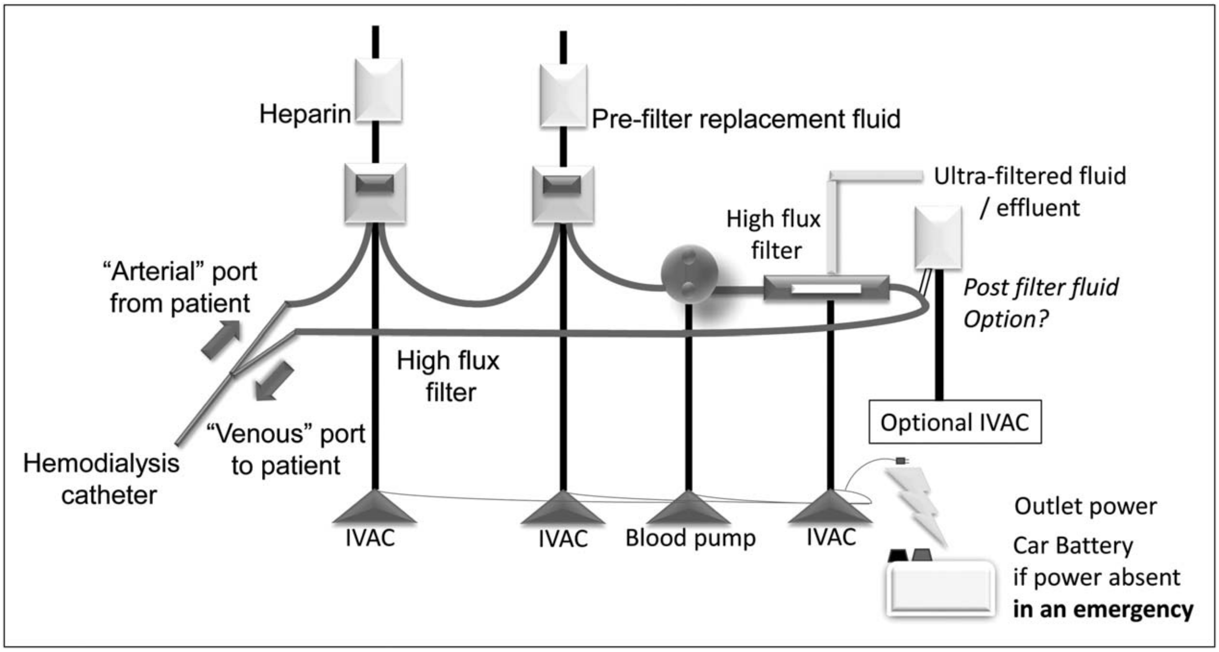

FIGURE 1. Improvised hemofiltration system. IVAC, intravenous automation control pump.

for suggested hemofiltration apparatus with design modifications suggested.

DISCUSSION

The challenge of the COVID-19 era, is that of a highly industrialized and technologically developed society, having to make do with less technology and resources than what has traditionally been allocated [2]. As the COVID-19 epidemic continues to ebb and flow, it is clear that social distancing, supply chain disruptions, and periodic epidemiologic flares of infections will continue to vex our healthcare system [2]. The healthcare systems of the United States and the western world are the most highly developed in the world; however, a healthcare system pushed beyond its capacity and its expectations of flawless care can quickly collapse [4▪▪,16].

While COVID-19 care has improved with prone positioning [17], remdesivir [18–21], and even more with dexamethasone [22], there remains much to be learned at this point as care has not yet evolved for all patients across the illness spectrum [23▪]. The question of hydroxychloroquine use for prophylaxis and treatment remains a controversial and politically sensitive topic [24].

Immune modulation for those with cytokine storm presentations, and acute respiratory distress syndrome has not yet yielded a consensus [25]. Indeed, the very mechanism of COVID-19 pathogenesis suggests a potent component of auto immunity and endothelial dysfunction as a major mediator of short-term and long-term morbidity and mortality [25]. New organ dysfunction is even being discovered after COVID-19 infection in the neurological system.

The pioneering work of many prominent nephrologists is beginning to show varied but consistent patterns of renal dysfunction due to COVID-19 [9,10▪▪,11]. The initial challenge of stabilizing critical COVID-19 patients with CVVHD/CVVH is crucial to preventing unnecessary loss of life. More difficult discussions lay ahead about allocation of resources, health equity, and the ethics of determining who has access to life saving care in a time of severe shortages [6▪▪]. Public policy and prudent planning has yet to effectively curtail COVID-19 in most industrialized countries, with the position of the United States being the most grave of the western world [1,2,5].

The solution proposed is a simple inelegant way to provide some level of RRT in a time of crisis [14]. The ability to customize the CVVH setup will obviously be more readily available in a less severe shortage involving only a lack of dialysis machines. In more severe shortages, power grid disruptions, or wartimes situations support for such a system will be less robust [6▪▪]. It will remain tenable as a modality to offer RRT, as opposed to traditional intermittent hemodialysis and peritoneal dialysis, which require extensive supply chains [6▪▪].

CONCLUSION

It has become apparent that the Achilles heel of the modern western society is its complexity and interdependence. In the coming years it seems that a system's self-reliance and ingenuity will be the traits that allow selective healthcare ecosystems to provide advanced care. There is a real risk that sustaining all but the most basic of medical care could collapse in a surge. We present and applaud an ingenious solution arrived at by a group of concerned physicians fighting the scourge of illness in a hellish environment so severe, that even COVID-19 has yet to match the horrors that inspired this simple apparatus. We add on a way to customize filtration with a postfilter fluid pump addition that could allow for more precise RRT that could be offered as long as the basic needed supplies remain available. Flexibility and local ingenuity must be cultivated among healthcare systems to provide local solutions in an era of organizational disarray.

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Conflicts of interest

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