Integrating Real Time Data to Improve Outcomes in Acute Kidney Injury

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\textbf{Introduction}

The desire to have automated data capture, whereby data are collected for processing and analysis without human involvement, has been around for decades. With recent technical and computational improvements, the promise of improved efficiency and quality through the capture, cataloging and analysis of high-dimensional data streams, automatic data capture has permeated myriad fields, including finance, manufacturing and marketing. Only recently, however, has the awareness and appreciation of this data source come to the wider medical community \cite{1}.

As a quantitative field, nephrology relies primarily on discrete, quantitative data and associated calculations for decision-making. In particular, renal replacement therapy (RRT) requires a battery of variables to facilitate delivered dose estimation. The treatment generates significant amounts of data, including pressure readings at various time points and locations in the circuit, changes in clear-

\textbf{Key Words}

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\textbf{Abstract}

Critically ill patients with acute kidney injury requiring renal replacement therapy have a poor prognosis. Despite well-known factors, which contribute to outcomes, including dose delivery, patients frequently miss the target dose and volume removal. One major barrier to effective care of these patients is the traditional dissociation of dialysis device data from other clinical information systems, notably the electronic health record (EHR). This lack of integration and the resulting manual documentation leads to errors and biases in documentation and missed opportunities to intervene in a timely fashion. This review summarizes the technological advancements facilitating direct connection of dialysis devices to EHRs. This connection facilitates automated data capture of many variables – including delivered dose, ultrafiltration rate and pressure measurements – which in turn can be leveraged for data mining, quality improvement and real-time targeted therapy adjustments. These interventions hold the promise to significantly improve outcomes for this patient population.

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ance and ultrafiltration rates. More recent technologies [2] have allowed for real-time measurement of delivered dialysis dose [3–5], estimates of access health [6] and the presence of recirculation [7]. In conjunction with ongoing hemodynamic monitoring, these features provide an opportunity to intervene and improve outcomes for patients requiring RRT [8].

Dialysis data, much of it continuously generated, has traditionally been captured intermittently and poorly, resulting in opportunities for selection bias and transcription error. As a result, the utility of these variables to inform quality/outcomes improvement is severely limited at this time. The imperative to improve outcomes for acute kidney injury (AKI) through real-time adjustments to patient care underlines the need for accurate and timely capture and analysis of RRT data, such as dose delivery [9]. Some of the early technological barriers — including interoperability standards, storage and processing capacity and networking infrastructure — have been eliminated [10], and the promise of connected devices and continuous data streams can now be realized to improve patient care for RRT-requiring AKI.

**Connected Devices in Healthcare**

Recognizing the cognitive burden of complex patients on doctors and nurses, early efforts in medical informatics focused on leveraging computers to ‘ease these demands by automatically acquiring, storing and displaying patient data’ [11]. The medical information bus (MIB) — an IEEE interoperability standard — was the first attempt at connecting bedside devices to a database, electronic health record (EHR) system and clinical decision support [12] and demonstrate the potential of real-time automatic data capture. More recently, the American Medical Informatics Association published the guiding principles of data capture: ‘automation of data capture and documentation should be optimized whenever appropriate, allowing human beings to focus on gathering and entering data that cannot be effectively collected by automated tools’ [13].

Some, automated data capture systems are in existence, particularly in intensive care units and operating rooms, where identifying rapid shifts in clinical conditions are complicated by the number of devices/variables and where the potential benefits are vast [14, 15]. Each device operates independently failing to account for other data sources [1]. Merging all the patients’ data facilitates the ability to use real-time data for clinical care quality improvement and efficiencies of care. Data capture mechanisms for patients with renal disease and those requiring RRT in particular have been limited at best and largely designed to replicate manual flow sheets, thus failing to take advantage of the high volume and continuous nature of the data elements.

**Benefits and Challenges of Automated Data Capture**

Automatic data capture is associated with fewer errors in vital sign measurement, more timely documentation and lower charting burden for nursing, and it also raises the potential for clinical decision support using more accurate and timely data [16, 17]. Indeed, decision support rules that rely on manual data can result in erroneous recommendations due to inaccurate or delayed data, leading to potential adverse events and eventual mistrust of the recommendations [17]. Mechanical ventilation studies have found that when respiratory therapists perform manual charting, values tend to be propagated forward for some time even after settings were, leading to incorrect values during significant portions of patient care [17]. Manual documentation is also subject to selection bias, recall bias and rounding bias, which leads to misleading data [12, 16].

Identification of causal relationships is possible only with accurate and timely capture of data that includes alignment of time stamps and data elements, a virtual impossibility with manual charting [1]. Subtle nuances in heart rate variability, which may predict in-hospital cardiac arrest [18], can only be recognized through efficient and automated data capture, and mortality predictions in critically ill patients are improved with the use of continuously measured hemodynamic variables [19]. Automatic data capture provides the capacity of a more complete and accurate picture of a patient’s current state and trajectory.

The early use of MIB has given way to general medical interoperability standards, including the HL7 protocol, which allows for devices to connect to clinical information systems with patient matching [1, 10]. With the increasing implementation of EHRs as a central source for patient data, in conjunction with vendor systems facilitating data capture and integration, vital sign measurements, ventilators and infusion pumps can already be connected to the EHR [20]. Further connection of devices, including dialysis machines is likely, despite the middleware, hardware, software and technical expertise-related barriers to implementation. This is being ac-
accelerated by the fact that computer systems and servers have become relatively inexpensive and able to handle the large data volume generated [10, 20]. This makes accuracy and analytics the major challenge.

Of particular concern are measurement inaccuracies arising from poor signal quality – during patient movement or handling, for example – which may lead to inappropriate decision support or alerts. Development and implementation of information technology and best engineering practices help in mitigating these concerns [1]. Indeed, machine learning algorithms that integrate multiple data types/sources can help lower false alarm rates [21].

Despite the contention that for high dimensional data such as vital sign measurements, clinicians provide effective smoothing by selecting appropriate measurements for inclusion in the record [22], this has not been shown and usually results in the loss of clinically relevant data, time trends, predictive capability and ability to perform data analytics and quality improvement [20, 23, 24]. The fear that automated systems may fail to provide accurate measurements is similarly unfounded [25].

**Leveraging Data Capture in Dialysis to Improve Patient Care**

Compared to vital signs and mechanical ventilators, the connectivity of dialysis devices has lagged, particularly due to a lack of standardization of terminology for various parameters across devices. Given the high number of available measures and the acuity of AKI patients, there is a clear need for automated data capture from RRT devices, especially since manual collection is error-prone, prevents coordination with other clinical variables and precludes improving clinical outcomes using automated data driven clinical decision-making [26].

In the early days of hemodialysis, there was recognition that device data connected to other operational systems has significant value for patient safety and quality of care but implementation has since lagged [27]. Dialysis machines, while able to capture some data, are rarely configured to stream and incorporate data with other information, thus hampering research in adequacy measures, real-time volume management and hemodynamic predictions.

For AKI patients receiving RRT, the prescribed dose is frequently lower than recommended [28, 29], but even when the prescription is appropriate, the delivered dose is often lower still [30], particularly in critically ill patients [31]. An ongoing loss of filter capacity coupled with frequent downtime and constant hemodynamic variations in critically ill patients [29, 30, 32], leads to highly variable intra-patient Kt measurements, similar to that in stable, chronic hemodialysis [33]. The current methodology of using effluent volumes to estimate dialysis dose in AKI is inaccurate [28, 30], but the lack of real-time and accurate data has limited the development of more reliable and timely estimates [34].

Fluid balance estimation for patients on RRT remains an ongoing challenge. Patients achieve target balance within 500 ml on fewer than half of therapy days, and manual charting of ultrafiltration volumes contains inaccuracies on 60% of therapy days [35]. Accurate and me-
ticulous volume and fluid management is crucial in AKI, as hypervolemia is associated with increased mortality [36, 37]. The use of blood volume monitoring systems have been associated with improved ultrafiltration [38, 39] without worsening hypotensive episodes [38–40]. Matching this with cardiac output may provide further improvements [41]. Current device technology is sufficiently advanced as to capture treatment conductivity, urea kinetics, blood volume changes, thermal balance and access recirculation, among other variables [2, 42, 43], yet they are not integrated – despite the potential to result in improved outcomes [7, 44–47]. Currently available techniques for adequacy assessment include conductivity-based methods, urea sensors and spectrophotometric methods [3, 4]. These methods can eliminate the need for blood sampling, ensure accuracy and consistency of delivered dose, detect access recirculation and enable quality assurance [48]. Ionic dialysance, for example, can accurately and constantly detect changes in clearance [5] and problems with recirculation [7] without intermittent blood sampling. When connected to EHRs, this continuous clearance monitoring can lead to real-time decision support thus facilitating the adjustment of dialysis prescriptions and timely interventions [7, 44]. Similarly, ultraviolet absorbance in dialysate can help monitor dose delivery, allowing for timely prescription adjustments [3, 49].

Automated collection of granular temporal data facilitates data mining, rule-making and discovery and detection of important events that effect dose and outcome [50]. Distinct temporal patterns and changes in captured variables, including pressure measurements, can further be combined and exploited to understand unique subtle-patterns that may have significant impact [6]. They may help improve dose delivery, filter life, catheter and access positioning and adjustment, medication dosing and volume management, which in synergy may improve outcomes in AKI (fig. 1).

**Conclusion**

The care of critically ill patients with AKI requiring RRT is complex and involves the monitoring of many parameters. Connecting dialysis devices to the EHR comes with challenges, but these are being eased through implementation and investigation in other healthcare domains. Linking dialysis devices to the EHR with real-time data streams can lead to accurate and complete data capture, data mining, real-time analytics, predictive models and quality improvement. It can facilitate discovery of novel parameters that impact clinical outcomes in this complex, high-risk, critically ill population. While these technologies provider the promise of improved patient care and outcomes, their implementation will need careful study to confirm that promise and ensure the absence of negative unintended consequences.

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**References**


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