Reflections on the Current State of Infusion Therapy

Matthew B. Weinger and Andrew Kline

This article reviews the current state of intravenous (IV) infusion technology and delineates aspects that would benefit from improved design and development. It provides context for the current landscape of infusion technology by briefly describing the history of infusion therapy and highlighting key events and innovations that have shaped modern infusion. Building on previous reports that focused on medication errors and patient safety, the current work concentrates on the limitations of existing technology and related workflows that constrain clinical efficiency and overall value. Future innovations that could advance infusion system safety, efficacy, usability, efficiency, and overall value to clinicians and the healthcare system also are discussed. Of note, this article focuses on volumetric infusion pumps used in clinical settings.

Beyond reducing medication errors, an important potential benefit of optimal design of infusion technology is the prospect of considerable cost savings. Each preventable adverse drug event (ADE) has been reported to cost nearly $9,000. Through built-in designs and adherence to the “five rights of medication administration,” smart pumps can help decrease the incidence of ADEs. Indeed, not only is avoidable patient harm wrong, it also has proven to be expensive. Moreover, care process inefficiencies add increased costs to a healthcare system that is already far too costly for the quality of care offered.

A Brief History of Infusion Therapy

IV infusion therapy has a long and remarkable history. The first recorded attempt to give an infusion was in 1492, when physicians tried to transfuse Pope Innocent VIII via vein-to-vein anastomosis from three young boys—both the Pope and his donors died. The first working infusion device was created in 1658 by Sir Christopher Wren who attached a quill to a pig’s bladder to instill a mixture of alcohol and morphine into the veins of sick dogs.

Learning of Wren’s success, Richard Lower, a London cardiologist, infused a man named Arthur Coga with sheep blood to calm him, inciting a “benign form of insanity.” Dr. Lower used primitive versions of the same elements of modern-day syringes, needles, and catheters. As experimentation continued, the proliferation of adverse events led both the British Royal Society and the Vatican to ban transfusions in the late 1660s, and infusion science was put on hold for more than a century.

In 1795, the American physician Philip Syng Physick once again advocated for human-to-human blood transfusions. However, it was not until the 1820s that James Blundell, an English physician and obstetrician, performed the first documented successful transfusion. Blundell also developed two mechanical infusion devices: the gravitator, which used gravity to deliver fluids in a regulated stream, and the impellor, which infused fluids under pressure. These devices sound eerily similar to current technologies.

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Infusion science accelerated in the 1830s during London’s cholera epidemic. Dr. William O’Shaughnessy reported in *The Lancet* in 1832 that cholera victims lost a high concentration of their saline and alkali. In response, Dr. Thomas Latta performed the first nonblood IV infusions of sodium chloride and bicarbonate and was able to save eight of the 25 victims he treated. In the mid- to late 1800s, numerous clinicians initiated and advocated for IV medication administration. The most common IV medications were narcotic substances, including opium and cocaine.

IV medication administration, as well as fluid and transfusion therapy, became part of routine military medicine during the Second World War. The first civilian infusion service may have occurred in 1940 at Massachusetts General Hospital (MGH), where one nurse served as the infusion “operator.” Clinicians returning to civilian practice helped to proliferate modern IV therapy. While mechanical peristaltic pumps (e.g., for cardiopulmonary bypass and dialysis applications) were introduced earlier, and the first ambulatory pump was marketed in the late 1950s, the first modern electromechanical infusion pumps became commercially available in the 1960s. An important early innovation was the use of an electronic drip detector that allowed feedback control to a microprocessor to improve flow accuracy. As the market matured, competitors introduced further innovations, including the first “volumetric” infusion pump, whereby the volume being pumped was directly measured and recorded (within constraints to be discussed later); “air-in-line” and downstream (distal) occlusion alarms; and the use of a proprietary disposable.

So-called “smart” pumps were first conceived by Dr. Nathaniel Sims and his team at MGH in 1992, then implemented in 1997. The first permutation of the team’s fully operational smart pump showed the promise of interoperability by connecting the pump to a computer library of infusion medications. Their most important innovation was the incorporation of a hospital-proctored drug library into the pump’s software, thereby allowing the user to select specific drugs, concentrations, doses, and rates. The MGH pump also included an early version of dose error reduction software (DERS) that alerted the user to potential problems with their on-pump programming. Mike Cohen and Tim Vanderveen were the first to describe the smart pump in a 2002 issue of the Institute for Safe Medication Practices newsletter. In 2010, Sims noted that “since infusion pumps are used in so many settings in almost every hospital bed, many changes will no doubt be forthcoming in the next few months or years.” Smart pumps can now be found in most major hospitals worldwide and have undoubtedly prevented many serious infusion errors. However, as currently implemented, they only prevent a portion of all infusion-related harm, leaving many unresolved safety and quality issues with IV therapy.

**Cost of Drug Errors**

The Society for Actuaries suggested that the financial cost of medical errors was nearly $1 trillion per year when including both the direct and the indirect (e.g., morbidity, decreased patient quality of life) costs. Considering the impact of the Institute of Medicine’s likely conservative 2001 estimate of nearly 100,000 medical error–related deaths annually, researchers and policy experts have called these errors “America’s most important public health issue.” What might seem like a small error can snowball, producing exponential effects on patients and their cost of treatment. Without a systemwide focus on quality of care, the moral and financial burden of avoidable injury and death will continue to plague healthcare systems worldwide. Technology has a role in reducing injury and cost, but only if it is designed and implemented correctly. Ample opportunities exist for infusion technology to improve substantially the overall value of healthcare processes.

**Drug Library Creation and Maintenance**

A key finding of a recent survey was that hospitals using smart pumps typically adopted this technology due to “inventory age and failure” rather than as part of an overarching “safety strategy.” Moreover, these hospitals were unable to integrate their new pumps with other medication management
technologies (i.e., computerized provider order entry, bar-coded medication administration), thereby limiting the ability of their pumps to fully address the “five rights.” As one indication of the limitations of DERS, only about one-half of the hospitals surveyed implemented hard limits on their pumps. Further, a major reason for DERS noncompliance was incomplete or outdated hospital drug libraries.

For smart pumps to attain their safety improvement potential, drug libraries must be maintained and trusted by the staff. Many installed infusion pumps still do not have wireless functionality; these pumps need to have their libraries uploaded manually—a time-consuming (and therefore expensive) burden on the organization’s healthcare technology management staff. In most hospitals, pharmacists typically are responsible for the ongoing management of the drug libraries. Given hospital pharmacists’ current workload and the rapidly changing landscape of available pharmaceuticals, it can be extremely challenging to keep drug libraries up-to-date. To the extent that newly available medication safety information has not been implemented in a drug library, preventable harm may reach the patient. Another risk of an out-of-date drug library is that clinician users will not find a desired drug in the library and then bypass the DERS safety features through “basic” unlabeled milliliter per hour infusions.

**Workflow Issues**

Much of inpatient nurses’ time is consumed by “low-value” tasks (bundled into what is often called “indirect patient care tasks”).12 Infusion pumps are a major contributor to these care process inefficiencies. According to modern quality improvement practices such as Lean or Six Sigma, tasks that do not generate real value for the organization or the customer (i.e., the patients) should be minimized if not eliminated. In the case of infusion therapy, lower-value time-consuming nursing tasks may include searching for available pumps, priming tubing (including air elimination), manual pump programming, responding to false or unnecessary pump alarms, and managing tubing spaghetti (i.e., tangled plumbing) and secondary infusions.2,13 Redesigned infusion technologies must consider and address these inefficiencies. Given the high cost of nursing care in most facilities, efforts to reduce these low-value tasks will improve nurses’ job satisfaction and yield substantial cost savings for the organization. Below, we discuss specific opportunities for improvements in infusion therapy design and workflow.

**Pump and Tubing Management for Multiple Infusions**

When administering multiple infusions to a single patient, pump and tubing management is currently a frustrating, time-consuming, and error-prone task.14 As a worst-case example, imagine a cardiac surgery patient (either in the operating room [OR] during surgery or the intensive care unit [ICU] immediately afterwards) who is on a dozen or more infusions of vasopressors, inotropes, sedatives, analgesics, muscle relaxants, antibiotics, procoagulants, anticholinergics, electrolyte replacements, and blood products, each with its own pharmaceutical constraints (e.g., drug-drug interactions and incompatibilities, flow rate limits). These infusions, as well as carrier and volume replacement fluids, are infusing through multiple peripheral and central lines. You can see how difficult it can be for the clinician to maintain an accurate mental model of what drugs are administering into what catheters. Current infusion systems do little to support this critical management task. The clinician is constantly fighting with (and sometimes tripping over) equipment and tubing. Errors are common and adverse consequences have been well documented.15,16

The effective coordination of concurrent therapy is important. Two medications being infused by different pumps may be contraindicated to be infused through the same IV line. The concurrent infusion of two drugs, one acidic and the other alkaline, can produce an insoluble salt that occludes the IV. Alternatively, one drug running through the same line may inactivate the other. Drug-drug incompatibilities can also occur when drugs are infused through different IV sites. For example, the effects of one drug can alter the effects of a second. There are reports of inadvertent double dosing, where one
clinician starts an infusion, fails to notify another clinician (or the electronic health record [EHR] system fails to do so), and then a second clinician gives a second dose of the same drug. A more subtle adverse consequence of numerous infusions in the same patient is fluid overload. In the patient on fluid restriction (e.g., someone with heart failure or brain injury) neither the pharmacist nor the bedside nurse may be aware that the myriad infusions of IV medications accumulate to a total fluid volume that exceeds the desired level of hydration. Thus, when one patient has multiple infusions, the pumps should communicate with each other, thereby enabling appropriate bedside decision support related to drug-drug interactions, drug incompatibilities, and total fluid therapy goals.

For the typical ward patient on just one or two infusions, the total space (or volume) and weight consumed by one or two infusion pumps, tubing, and an IV pole usually are manageable, though the risks of physical harm during transport is well described. However, consider our cardiac surgical patient who now may have as many as 16 pumps at the head of the bed (along with monitors, ventilators, and other supportive technology). The total weight and bulk of pumps, fluid sources, and tubing can present an impediment to easy patient access. Further, current multiple-line infusion pumps have numerous bags of drugs and fluids hanging above them. Use errors are commonly reported related to the difficulties clinicians have trying to figure out which drug/fluid source is associated with which pump or pump channel. Thus, better methods of organizing, handling, and transporting pumps and their associated drug/fluid sources and tubing need to be developed and promulgated. In addition to smaller, lighter, easier-to-use pumps, greater effort must be invested in tubing management systems and to new ways for clinicians to organize fluid/drug sources in different ways.

Secondary Infusions
Most patients only have one IV, and the most common use of that IV is for hydration administered as a milliliter per hour infusion of a crystalloid solution. Even when a patient who is able to take oral fluids (and thus does not need IV fluids) is on a regular IV drug regimen (e.g., intermittent IV antibiotics), it is still common to administer a low rate of IV fluids to maintain vein patency and to flush through the drug doses after they are complete. Thus, nurses often administer secondary or “piggyback” infusions in which the drug dose is attached to an already active IV fluid infusion at a Y-site above the infusion pump inlet. To ensure preferential flow of the secondary infusion, that IV bag must be hung higher than the primary fluid bag. These secondary infusion sets use a backflow (or check) valve to prevent retrograde flow from the primary to the secondary fluid sources. The desired dose of drug from the secondary source is then programmed into the infusion pump.

However, this very common bedside “plumbing” arrangement is prone to medication errors. A 2012 report described how, without proper set up, secondary infusions can be delivered at uncontrolled and often incorrect rates. Disturbingly, these incorrect flow rate errors can be insidious, without detection by the pump or the user. Therefore, secondary infusions should never include continuous high-alert medications. Smart pumps should be designed to eliminate the risks of secondary infusion errors and, further, should reduce the complexity currently associated with administering more than one drug or fluid to a patient through the same IV site.

Flow Continuity
Drugs administered by infusion pumps at a specified rate are generally assumed to infuse continuously at the set rate within the infusion pump standard (specified as ±5% level of flow accuracy). Instead, under some circumstances, current infusion pumps administer fluids at highly discontinuous rates, including long periods of little or no infusion into the patient. Such flow discontinuity occurs most commonly at low infusion rates, especially when there is appreciable fluid volume between the pump and the patient in higher-compliance tubing (e.g., larger bore or softer tubing walls) and the IV access site has higher flow resistance (e.g., small-bore catheters). In such situations, long periods of time (tens of minutes or
longer) can elapse after a flow rate change before the change actually reaches the patient. While a careful analysis of international infusion pump standards (e.g., IEC 60601-2-24:2012) and infusion pump reference manuals is beyond the scope of this article, suffice it to say that 5% accuracy is only guaranteed for specified (albeit typical) conditions. Thus, in low-flow, high-distal resistance applications, a syringe pump may be preferred.

Downstream plumbing can have a tremendous influence on flow continuity. Downstream occlusion alarms signal that an increase in downstream pressure has reached a threshold and, after the occlusion is released, the infusion can resume. However, release of the occlusion may result in a postocclusion bolus to the patient due to the pent-up pressure. This is particularly relevant in neonates, in whom the smallest bolus can have clinical significance. Next-generation infusion technology must reduce flow rate fluctuations where possible and, more importantly, make the actual dynamic flow profile more transparent to the user.

**Dead Space**
A drug will only start having an effect when it enters the patient’s bloodstream, yet pumps record a drug as being given after it leaves the pump. An appreciable delay can occur between when a drug leaves the pump and when it enters the patient’s vascular system. This delay will vary for every infusion, with the most critical factors being the nature (e.g., compliance) and amount of tubing (i.e., fluid volume) between the pump and the patient, the type (i.e., size, length) of IV catheter used, and the programmed flow rate. The volume of fluid between the pump infusion mechanism and the IV catheter hub is known as the “dead space” or “dead volume.” For a continuous unchanging infusion, the delayed effect due to dead space is only relevant upon the initiation of the infusion. However, every time a dosage change occurs, the effects of the change will be subject to the same delay.

Studies show that due to dead space and pump start-up performance, it can take between 0 and 40 minutes for correct flow-rate continuity to be achieved.\(^{18}\) Paradoxically, because large-bore central venous lines have more dead space, infusions through them can have greater delays before physiological effects are seen. A delayed onset of effect can lead clinicians to increase the infusion to an excessive rate due to perceived inadequate dosage. Thus, “clinicians wishing to optimize therapy of complicated patients … may fail to recognize [the long time for a drug to reach its target at the desired concentration] and inadvertently set drug delivery rates to harmful levels by overly rapid adjustments of infusion pump settings.”\(^{19}\) The higher initial rate and time required to attain a new steady state may be especially pronounced in pediatric (and especially neonatal) patients.\(^{20}\)

Infusion pump technology could mitigate the effects of dead space to attain prompter and safer transitions between infusions. Because patients often receive multiple infusions, especially in critical care areas, it will be important for future designs to account for “dead space” and for clinicians to remain mindful of rate disparities and limitations.

**Battery Power and Pump Management**
Patients rarely stay in the same place for very long. Even very ill patients can require transportation to imaging tests or procedures. In fact, based on better outcomes in recent studies,\(^ {21}\) critically ill patients are now being routinely ambulated. Picture a patient with multiple life-threatening conditions receiving multiple infusions via pumps, on a mechanical ventilator, etc., walking (with assistance) the halls of the ICU (an increasingly standard practice!). The increasing emphasis on patient ambulation argues for next-generation pumps to be smaller, lighter, and more portable. Further, during transport, electromechanical technology must be on battery power. Although hospital-based pumps have battery power (typically allowing at least four and up to eight hours off AC main power with a full battery), unlike dedicated ambulatory pumps, extended battery life has not been a design priority.

**Locating Missing Pumps**
It has been reported that as many as one in five infusion pumps in a hospital are “lost” at any one time, thereby requiring hospitals to
have far more pumps than are clinically required. These “lost” pumps are typically found abandoned in remote parts of the facility (a corner in recreation therapy) or hidden (e.g., hoarded), for example, in a closet on a unit for “just-in-case” use. Some hospitals have begun to use a location management technology such as active radio frequency identification (RFID) to keep better track of their pump inventory. Because current pumps do not typically have appropriate built-in technology, this feature becomes an expensive add on. Next-generation pumps should include “location-aware” technology. This would facilitate asset tracking, as well as improve adherence to the “five rights” by facilitating the ability to associate specific pumps with specific patients.

Health Information Technology Integration

The American healthcare system, like those in other developed nations, has begun to aggressively embrace health information technology (HIT) as a panacea for improving value (i.e., benefit/cost ratio), safety, efficiency, and even patient satisfaction. In fact, the scientific evidence supporting the widespread belief in this “technology elixir” is limited, and examples of false starts and abject failures are numerous. Nonetheless, HIT is here to stay and does provide opportunities to improve the safety and efficiency of infusion management. In this section, we discuss the potential for automated pump programming and administration documentation, as well as opportunities for more patient-tailored therapy.

Automated Programming and Documentation

If the existing HIT already contains the essential patient-specific medication therapy information, why isn’t this information routinely and automatically sent to and available on the appropriate infusion pump (i.e., electronic data input)? Why don’t pumps routinely and automatically send their infusion information to the existing HIT for therapy verification, clinical documentation, and other purposes like decision support (i.e., electronic data output)? These notions are not new, and the impediments are not primarily technological. In fact, some pump vendors are already doing one or both with selected HIT vendors in selected clinical sites. However, appreciable impediments to ubiquitous bidirectional data sharing between pumps and HIT remain, with the same being true for other bedside devices (e.g., physiological monitors). The sidebar titled “Example Case: The Future of Infusion Therapy” describes a clinical scenario that demonstrates the potential value of a fully integrated approach.

Patient-Specific Therapy

To date, infusion pumps have accommodated patient identification as well as weight and height, but these have had to be entered by the bedside provider manually. In addition, other patient-specific attributes influencing therapy effectiveness or safety have not been available at the pump. For example, if an infused drug to which the patient is allergic is inadvertently ordered, administration is the last chance to catch the error and prevent harm. If the pump “knew” a patient’s medication allergies, it could generate an alert during pump programming. Few clinicians are willing to enter patient allergies or other patient-specific data manually on an infusion pump (and manual entry is problematic due to potential data input errors). These factors underscore the value of a robust HIT system that is interconnected to the infusion system software.

Many drug effects are influenced by numerous pharmacokinetic (PK; the relationship between administered dose and blood levels) and pharmacodynamic (PD; the relationship between blood levels and both desired and undesired effects) factors. Patient

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**Example Impediments to Ubiquitous Data Transfer**

<table>
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<tr>
<th>Insufficiently specified and/or adopted national/international standards for data terminology and connectivity</th>
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<tr>
<td>Legacy device and software database architecture and other technological constraints that do not allow or facilitate data exchange</td>
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<tr>
<td>Lack of incentives for health information technology and infusion pump vendors to “play with each other”</td>
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<tr>
<td>Food and Drug Administration constraints and concerns</td>
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<td>Proprietary data formats and/or communication protocols</td>
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<td>Concerns about data integrity and accuracy (when received from an outside source)</td>
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<td>Cybersecurity concerns</td>
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age is perhaps the single most important factor affecting both PK and PD, with reduced dosing generally warranted (all other things being equal) at both extremes of young and old age. An elderly patient may be much more sensitive to both the effects and potential side effects of a drug. Other important PK factors include patient gender, renal, and liver function. Other PD factors include heart, lung, and brain function and the concomitant use of other drugs acting on those major organs. When two drugs acting on the same effect site are coadministered, the result is often more than additive (i.e., synergistic). If age and other PK-PD information was available in the infusion software, then appropriate dosing guidance (e.g., during titration of a potent medication) or alerts/reminders could be appropriately activated and displayed on the pump. Access to information at the time of programming about patient-specific dosing adjustments (i.e., effects on PK and PD) could substantially improve drug efficacy and safety while reducing unwanted side effects.

Electronic Dashboards
Additional HIT integration benefits are beginning to be realized through the development and use of electronic displays of infusion therapy status. These displays, sometimes called dashboards, can be synchronized via wireless with all pumps in a unit. Such dashboards have the capacity to strengthen clinical workflow by highlighting issues and events as they occur and thereby allowing for intermediary action. For example, a dashboard on a tablet computer carried by a ward nurse who is covering eight patients can inform her of an ongoing occlusion alarm in one room or a fluid infusion that has run dry. Similarly, an infusion dashboard at the central nursing station can highlight an air-in-line alarm in one room or a new medication ordered to be administered to another patient. Nurses can thereby monitor multiple active pumps from a single screen, increasing efficiency, and more readily coordinating timely care with other clinicians on their team. Thus, with this technology, a fleet of pumps can be viewable and managed contemporaneously as they are being handled intelligently at the bedside. Such integrated task management technology can also reside as a web app on a cell phone to provide the nurse with a continually updated to-do list. Further, dashboards can help keep track of the pump fleet on a unit, facilitate acquisition of an unused pump, and avoid pump hoarding. With a different dashboard, pharmacists can monitor a unit’s pump fleet to identify when new infusions need to be mixed and delivered to the unit. Similarly, the pharmacist can identify any pumps that have not been

EXAMPLE CASE: THE FUTURE OF INFUSION THERAPY

Nurse Jim Smith receives a text message on his cell phone that an IV gentamycin dose is due on his patient Gilda Jones (who was admitted to the hospital with a pneumonia requiring IV antibiotics). Jim goes to the medication dispensing station and types in Gilda Jones’ name. Because it is due in a few minutes, the gentamycin order is presented at the top of the list of all of Mrs. Jones’ medication orders.

After Jim reviews and selects the gentamycin, the correct unit dose is dispensed in an IV bag that also contains an RFID tag. Jim takes the bag into the patient room and assesses Mrs. Jones. Jim then logs into the IV pump (currently administering maintenance fluid therapy) with his fingerprint after the pump automatically recognizes him from the RFID tag on his hospital name badge. The pump then asks Jim to confirm the patient’s name and medical record number. He does this with a secure custom application on his cell phone, linked by Bluetooth to the pump, that reads the RFID tag on Mrs. Jones wristband and transmits it to the pump. The pump then presents a list of pending orders for Mrs. Jones, where the gentamycin order appears first (because there were no overdue orders and it is the most current). Jim selects the gentamycin order, confirms all of the “five rights” on the screen, connects the distal end of the gentamycin bag’s tubing into the pump’s secondary inlet port, and hits “start infusion.”

The time at which the infusion began and its other attributes are automatically sent to the EHR, as well as to the pharmacy’s computer system. During the infusion, the pump monitors downstream pressure and flow characteristics and uses advanced software algorithms to identify potential changes, such as pending infiltration. Concurrently, Jim can monitor the infusion’s status from an infusion status display on his smart phone. Further, in near real time, the amount of drug infused is sent to Mrs. Jones’ electronic medical record so that her physician can see the progress of the prescribed treatment.
upgraded to the latest version of the institution's drug library. Another dashboard can allow healthcare technology managers to be able to monitor an entire hospital’s pump fleet for maintenance issues (e.g., need for battery replacement) or software upgrades. Much like the smart pump user interface, these dashboards need to provide usable, useful, and actionable information and be more widely available.

**Future Innovations to Improve Infusion Therapy**

Even if all of the above issues were adequately addressed with contemporary technology, major hurdles remain to fully adopting and integrating available technologies. Substantial opportunities exist for future innovations to enhance medication delivery efficiency, effectiveness, safety, and user satisfaction.

**Custom Drug Packaging**

Although many medications are packaged in bags or bottles, thereby allowing direct infusion via an administration set, a surprising number of routinely used parenteral medications must be repackaged into a different container before they can be infused via a pump. Further, in the OR, anesthesia professionals still draw up from vials or bottles and infuse most if not all of their IV medications. To attain desired levels of patient safety, many more medications must be delivered from the original manufacturer or an authorized batch repackager to the point of care in a form that can be immediately used in the pump. Further, the point-of-care medication packaging should include machine-readable (preferably wireless and automatic) drug and concentration identification.

**Environmental Impact**

Infusion technology can adversely influence the patient's care environment; it can be loud, bright, and bulky. There is a high incidence of sleep deprivation in hospitalized patients (especially those in intensive care). These sleep disturbances contribute to slower recovery as well as “ICU delirium,” which has been clearly associated with worse patient outcomes and long-term psychiatric effects.
detection (e.g., mass spectrometry) and sensor (e.g., lab on a chip) technologies are capable of doing this, but the technical challenge remains being able to do so accurately, reliably, and cost effectively in near real time. Again, entrepreneurs are actively attempting to develop such technologies, and we envision success in the not-too-distant future.

Infiltration Prevention and Recognition
Many believe that the “holy grail” of infusion therapy is the elimination of IV infiltrations. Infiltration remains a critical safety and efficacy issue in infusion therapy, not to mention a major contributor to patient and clinician dissatisfaction. Paradoxically, many bedside clinicians mistakenly believe that pump downstream pressure sensors will “detect” infiltration. Numerous entrepreneurs and infusion pump companies have attempted to develop technologies to reliably detect infiltration, thus far without apparent success. The real innovation will be when infusion technology can prevent infiltrations.

Conclusion
Smart pumps have become the norm in hospitals throughout the developed world. Although many advances in their technology and safety have occurred, much of their true potential has not yet been realized. We have attempted to identify areas requiring further improvement. Smart pumps are still universally regarded by clinicians as being clunky, difficult and inconvenient to use, and frequently an impediment to high-quality care. Addressing these issues will require a deliberate and rigorous application of user-centered design approaches that have been refined in the field of human factors over the last half-century. With these investments, infusion pumps can become the exemplar for other medical devices in terms of true partnership with their clinician users to attain the safety, effectiveness, and efficiency required of healthcare delivery in the coming decades.

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References


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