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Flow Accuracy of IV Smart Pumps Outside of Patient Rooms During COVID-19

Jeannine W.C. Blake, MS, RN
Karen K. Giuliano, PhD, RN

In late 2019 the novel coronavirus disease 2019 (COVID-19) emerged in China, causing severe respiratory illness with persistent person-to-person transmission.¹⁻³ The first diagnosed case in the United States was reported in late January, sparking an initial US public health response that included restricted travel, traveler screening, and required quarantine.¹ Because of the growing number of cases, the World Health Organization (WHO) declared a global health emergency on January 30, 2020; on March 11, 2020, the WHO issued a pandemic declaration.^{4,5} With the disease showing a high transmission rate, atypical symptoms, high rates of mortality, and documented transmission from patient to health care worker, fear grew as countries hurried to prepare.³

When a previously unknown pathogen causes an epidemic rate of infection, the success of national health systems relies on reserves of health care supplies and their appropriate allocation.⁴ Effective distribution, training, and use of personal protective equipment (PPE) is key to preventing spread between patients and health care workers.⁴ In the setting of COVID-19, PPE that was once taken for granted as a disposable commodity quickly became a treasured resource to maintain the personal health and safety of health care workers.⁴

Patients who contract COVID-19 experience a wide spectrum of symptom severity that requires care ranging from at-home symptom management to inpatient intensive care.⁶ The COVID-19 pandemic introduced a need to increase hospital intensive care capacity rapidly in order to be able to provide adequate care for the patients presenting with this disease.² Although SARS-CoV-2, the virus that causes COVID-19, is primarily transmitted via droplets, aerosol-generating procedures can cause the virus to remain in the air for up to 3 hours and be infective through simple inhalation.^{7,8} Aerosol-generating procedures performed on patients positive for COVID-19 present an elevated infection risk for health care workers.^{5,8} Most studies suggest that aerosol-generating procedures include preintubation ventilation, intubation, tracheostomy, open-airway suctioning, cardiopulmonary resuscitation, and noninvasive ventilation.⁸

Jeannine W.C. Blake is Intensive Care Nurse, Rhode Island Hospital, Providence, Rhode Island, and PhD Candidate, College of Nursing and Institute for Applied Life Sciences, University of Massachusetts Amherst, 651 N Pleasant St, Amherst, MA 01003 (jcondon@umass.edu).

Karen K. Giuliano is Associate Professor (Joint), College of Nursing and Institute for Applied Life Sciences, University of Massachusetts Amherst, Amherst, Massachusetts.

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In order to provide the complex care required by critically ill patients infected with the highly contagious SARS-CoV-2, frontline clinicians have had to implement practice changes to address patient care needs while simultaneously conserving PPE and reducing personal exposure risk. One of the resultant practice changes was to move medical devices, most commonly intravenous (IV) infusion pumps, away from the bedside and into the anterooms or hallways outside of patient rooms. This article aims to provide nurses with the information needed to support clinical decision-making during IV infusion therapy when IV infusion devices are located away from the patient bedside.

Background

Adversity drives people to change habits, adjust protocols, and innovate. In the case of COVID-19, the scarcity of PPE pushed health care workers to conserve and make do with what was available. As a result, health care workers were quickly required to balance unimaginable clinical demands for the sickest patients while also preserving personal safety.

In intensive care units (ICUs), where the most-critical patients go for care, aerosol-generating procedures are required frequently and, in some cases, continuously. To mitigate the risk of exposure and effectively manage the use and conservation of PPE, the doors to patient rooms must be kept closed, and nurses and other clinicians must limit contact frequency and time in COVID-19 isolation rooms. With the doors closed and PPE required to enter, nurses are unable to enter into patient rooms quickly or easily to manage the multiple lines and infusions required to care for critically ill patients. For very sick patients, even a brief pause in a life-sustaining infusion from an occlusion, air in the line, or the completion of a medication bag can have dire consequences. Because infusion pumps cannot be controlled without direct device interaction, the use of longer-than-usual extension tubing allows for placement and operation of the pumps outside of patient rooms. This practice has been rapidly adopted for care of critically ill patients with COVID-19 and is permitted by the US Federal Drug Administration (FDA) for the duration of this public health emergency under Emergency Use Authorization.⁹ One goal of this FDA policy

is to “help foster technologies that maintain a safer physical distance between the health care provider and patient affected by COVID-19.”⁹ A modification that the FDA determines would not create undue risk is “remote monitoring and/or manual control of infusion pumps to manage the care of a patient without physically entering a patient’s room.”⁹

The complex care of critically ill patients often requires the simultaneous administration of multiple IV medications using large-volume IV smart pumps (IVSPs). Under normal circumstances, most IVSPs are located at the bedside only a few feet from the patient, where the nurse can see the patient and the pump when administering and adjusting medications. Frequent nursing intervention is necessary to manage concurrent IV medication administration, including infusion titrations, bolus/loading of medication doses, and intermittent medication dosing. Nursing intervention is also necessary to ensure that the correct volume of each individual infusion is completely delivered through the lengthy extension tubing. Managing IVSPs outside the rooms of patients with COVID-19 may also entail infusing multiple compatible medications together to reduce the use of extension tubing and the potential need to attend to frequent nuisance alarms or other tasks necessary to ensure continuous flow. Even when IVSPs are located at the bedside, IV infusion is associated with high rates of adverse drug events and medication errors, many of which can be life threatening.¹⁰ Remote IV infusion also makes it more difficult to verify patient identity during dual nurse medication checks. Operation of the IVSP in these circumstances is intricate, requires high levels of cognitive attention, and can be error prone.^{10,11} Nurses must recognize the potential for error associated with IV infusion under normal circumstances and keep in mind the added risk when moving the IVSPs farther from the patient, especially when both cannot be seen concurrently.

Moving IVSPs outside of patient rooms requires modifications to allow the IV tubing to reach the patient; the Figure includes images of real-world use and modifications. Various methods for increasing the length of IV tubing are now being used so patients can continue to receive their medications even while the IVSPs are placed outside the room at distances of 15 feet or more. Placing the pumps outside the rooms improves nursing workflow

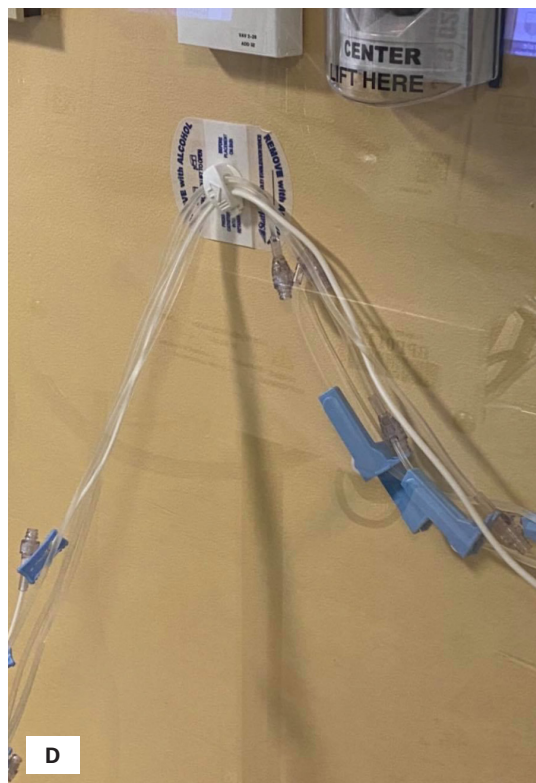
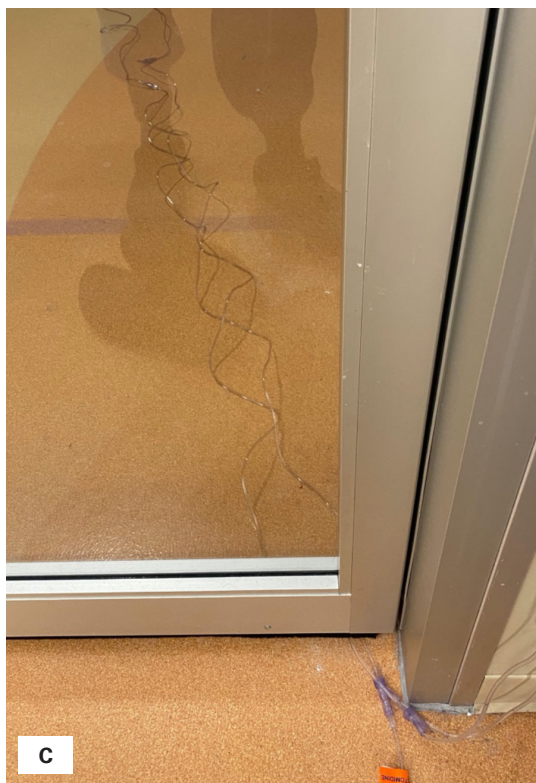


Figure: Images taken during the coronavirus disease 2019 pandemic. (A) A Baxter Sigma pump running outside of a patient room; (B) A stack of B. Braun Space Series pumps being used outside of a patient room; (C) Tubing being run under a door and across the floor to reach the patient; (D) An innovative way to use a catheter securement device to hold intravenous lines off of the floor.

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when managing patients with COVID-19 in isolation, allows for easier interaction with the IVSP, and helps reduce risk of exposure for the nurses. Although this practice can be effective in helping to manage competing patient care demands, it is important for nurses to understand the safety implications in order to ensure that medications are still being delivered as expected.

Flow Rate Accuracy: Peristaltic Versus Cassette-Based Technology

BD Alaris, Baxter Sigma, B. Braun Space Series, and ICU Medical Plum Series are the 4 most commonly used IVSPs in US acute care. The BD Alaris, Baxter Sigma, and B. Braun IVSPs use peristaltic pump technology to infuse fluid, whereas the ICU Medical Plum Series pumps use cassette-based volumetric technology. The Ivenix IVSP, which is not yet in clinical use but has recently received FDA approval, also uses cassette-based volumetric technology. A peristaltic pump uses rollers to propel fluid forward by pinching down on the length of tubing.^{12,13} Cassette-based pumps contain a flow regulator and a set of valves to administer fluids properly.^{13,14} Refer to the Table for additional definitions and technology features.

With peristaltic IVSPs, flow rate accuracy of the pumping segment is impacted by variations in system resistance in the form of intake and outlet pressures.¹⁴ When intake pressure decreases and/or outlet pressure increases during IV medication administration, decreases in both flow rate and flow rate accuracy will occur.¹⁴ Most troubling is that the IVSP will continue to display the intended flow rate, making these errors extremely difficult to detect. When volumetric delivery is provided by cassette-based systems (eg, ICU Medical Plum Series or Ivenix IVSPs) the IV infusion is delivered at the programmed rate regardless of system resistance.¹⁴

In addition to changes in system resistance, increasing the tubing length between the IVSP and patient presents additional challenges that must be considered. There is a significant increase in tubing dead volume, increased priming requirements, and elevated risk for air in line and medication adhering to the tubing because of increased tubing surface area. All of these factors can lead to portions of medication doses being left

nonadministered or underinfused, which presents various safety concerns for the patient. Overinfusion may also be a concern in the setting of large amounts of medication left in the dead volume and then subsequently flushed into the patient at a higher-than-intended flow rate. A discussion of clinical implications, ways to mitigate effects, and dosing considerations is provided in the Table.

Conclusion

New practice norms will no doubt continue to develop to address the complex care requirements for patients with COVID-19. The remote use of IVSPs addresses many salient clinical and workflow issues. As the primary users of IVSPs, nurses must be aware of the impact of this practice on the accuracy of IV medication administration and the increased potential for error. The most important aspects of IV medication administration should be patient safety, delivery of medication dosing as intended, and achievement of the desired therapeutic effect and/or measurable patient outcome. Improved understanding of the impact of remote IVSP system set-up can help the health care team make more informed decisions for individual patients and situations. With education and continued vigilance regarding the implications these changes can have, nurses can take steps to decrease risk of flow inaccuracy and other complications to support the safest and most accurate remote IVSP medication administration practices.

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REFERENCES

1. Patel A, Jernigan DB; 2019-nCoV CDC Response Team. Initial public health response and interim clinical guidance for the 2019 novel coronavirus outbreak—United States, December 31, 2019–February 4, 2020. *MMWR Morb Mortal Wkly Rep.* 2020;69(5):140-146.
2. Manca D, Caldiroli D, Storti E. A simplified math approach to predict ICU beds and mortality rate for hospital emergency planning under Covid-19 pandemic. *Comput Chem Eng.* 2020;140:106945. doi:10.1016/j.compchemeng.2020.106945
3. Wang D, Hu B, Hu C, et al. Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus-infected pneumonia in Wuhan, China. *JAMA.* 2020;323(11):1061-1069.
4. Sureka B, Sinha A, Tak V, et al. Customized personal protective equipment (PPE): solution to conservation and management of supplies during the coronavirus disease

Table: Factors Affecting Medication Infusion Accuracy, Delivery, and Safety When Pumps Are Placed Outside of Patient Rooms During the COVID-19 Pandemic

Intake Pressure	
Concept Defined	Intake pressure is the pressure generated above the pump. ¹⁴
Concept Operationalized	Intake pressure is achieved by hanging the IV infusion bags above the IVSP at or above the manufacturer recommended head-height differentials (BD Alaris, 20 in [51 cm] ¹⁵ ; Baxter Sigma, 24 in [61 cm] ¹⁶). Head-height differential refers to the difference between the top of the fluid level in the primary and secondary fluid containers relative to each other, the IVSP, and the patient. ¹⁴ Thus, the pump must also be at the recommended height above the level of the patient’s vascular access.
Cause of Change	Intake pressure will decrease as the amount of fluid in the IV bag decreases, if the head-height differentials are inadequate, or if a line filter becomes clogged. ^{11,14}
Clinical Importance	When intake pressure is too low, flow accuracy is affected so the rate received by the patient will be lower than the programmed rate displayed on the IVSP. ¹⁴
COVID-19 Clinical Implications	In order to ensure that patients are receiving the expected medication dosing and to support flow rate accuracy, the IVSP system and infusion bags should be at the proper heights relative to the patient and to one another. These specifications vary based on type of IVSP system being used; details can be found in individual manufacturer guidelines. Nurse educators, quality professionals, and safety experts should include education on this topic as part of annual competency training programs. Although this knowledge is important for all patients receiving IV medications, it is especially relevant when the pump and the patient may not be visible at the same time.

Outlet Pressure	
Concept Defined	Outlet pressure is the pressure/resistance below the IVSP that the IVSP must overcome to infuse fluid into the patient. ¹⁴
Concept Operationalized	IVSP manufacturers test flow rate accuracy using an outlet pressure of zero; therefore, any increase in outlet pressure can significantly reduce flow rate accuracy. ¹⁴ This effect is even more pronounced with the silicone pumping segment used by the BD Alaris pump because of the silicone elasticity. ¹⁴
Cause of Change	Partial tubing obstruction, high flow rates, increased fluid viscosity, small-bore tubing and catheters, long catheters, needle-free connectors, and the use of manifolds can all lead to increased outlet pressure. ¹⁴
Clinical Importance	As outlet pressure increases, flow accuracy and forward flow decreases, resulting in flow rates that are lower than the programmed rate displayed on the IVSP. ¹⁴
COVID-19 Clinical Implications	<p>Overall: Increasing the length of IV tubing between the IVSP and the patient will result in varying increases in outlet pressure, leading to unknown and undetectable reductions in forward flow and flow rate accuracy. Additionally, when extended IV tubing is draped or placed on the floor between the pump and patient, the IVSP will also have to work against increased gravitational pressure to infuse through the lines and up into the patient.</p> <p>Titratable medications: There may be a need to dose vasoactive, paralytic, and sedative medications with a focus on clinical presentation versus standard protocols. Additionally, when pumps and patient are not visible at the same time, nurses must be vigilant about how decisions are made regarding titration of these high-alert medications.</p> <p>NOTE: Collaboration with the pharmacy is necessary if hard and soft pump limits are being consistently reached with continued subtherapeutic effects.</p> <p>Secondary medications: Increased outlet pressures can cause reductions in secondary infusions. Nurses will have to be particularly vigilant and use increased visual inspection to ensure vital medications such as electrolytes and antibiotics are fully infused in a timely manner.</p> <p style="text-align: right;"><i>Continued</i></p>

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Table: Continued

Dead Volume	
Concept Defined	The volume of carrier fluid an infusion must traverse starting from the point of entry into the IV tubing set before entering the blood stream ¹⁷ ; the Massachusetts General Hospital Drug Infusion Safety group ¹⁸ offers videographic materials for managing dead volume.
Clinical Importance	The length of tubing contributing to the dead volume will greatly affect the efficacy and dosing of the medication being infused. The effects seen on initiation of a new infusion will depend heavily on the dead volume, the rate at which the carrier fluid is infusing, and drug concentration. ¹⁷ Once the drug is fully mixed with the carrier fluid in the dead volume, it is now also available for inadvertent bolus if an upstream flush were to be delivered; depending on the amount of dead volume and the medication type, this could have potentially devastating physiologic effects. ¹⁷ Another consideration is in the setting of very low carrier flow rates and intermittent infusions. Once the infusion completes, any medication that remains in the tubing is not fully delivered to the patient and may lead to underinfusion and inaccurate dosing.
COVID-19 Clinical Implications	<p>Dead volume is dependent on tubing configuration of multiple infusions through a single IV access location.¹⁷ Extending IV tubing to allow for pumps to remain outside of patient rooms means potential for increased dead volume if infusions are connected to the carrier fluid farther from the patient and nurses are less able to immediately assess the therapeutic effects of the medication being infused.</p> <p>High-alert medications: Nurses should be appropriately trained on the effects of dead volume for all patient care but especially when tubing is extended so pumps can be placed outside of rooms. There must be an understanding of how infusion point of entry will affect dead volume as well as understanding of the implications of an upstream flush.</p> <p>Secondary medications: Nurses will need to pay special attention to the set-up and location of entry in the system to ensure a secondary medication is being fully delivered. In many cases, this will require additional flush volumes to be programmed into the pump. These flushes should be at the same infusion rate as the secondary medication flow rate.</p> <p>Depending on the length of extension tubing, it is conceivable for 20 mL or more of medication to remain in the IV tubing, which represents at least 40% of the dose for a 50-mL bag. For antibiotics, the most commonly administered secondary medications, a flush can ensure complete delivery, but the scheduled administration time will be delayed. For electrolyte replacements, the second most commonly delivered secondary medication, it is imperative to assure that the flush is not set too fast, as an unintended bolus of electrolytes such as potassium can cause life-threatening complications.</p>
IV-Line Surface Area	
COVID-19 Clinical Implications	The use of additional IV-line extension sets increases the likelihood of adherence to plastic surfaces of the tubing for some medications, such as insulin. ¹⁹ To the extent possible, the use of dedicated lines for these types of medications, along with increased monitoring of therapeutic effects, may help address variations in medication delivery.
IV-Line Priming	
COVID-19 Clinical Implications	<p>When using extension tubing, increased priming volume is required to eliminate air from the administration set before use. To decrease the risk of air being drawn into the line, nurses will need to confirm this volume on the basis of the individual line configurations and then take these configurations into account when programming the volume to be infused.</p> <p>NOTE: This process leads to significantly more waste than under normal conditions, which can be problematic in situations of vital medication shortages.</p>
Air in Line	
COVID-19 Clinical Implications	When extension sets are added, each additional connection increases the risk of air being drawn into the line during infusion. ¹⁴ Achieving the required tubing extensions using the fewest number of connections possible and more frequent checking of line connections will help to ensure that connections remain properly tightened and secure. Unfortunately, if air does get in the line, the process required to remove the air will be more cumbersome because of the increased tubing length.

Abbreviations: COVID-19, coronavirus disease 2019; IV, Intravenous; IVSP, intravenous smart pump.

- 2019 (COVID-19) pandemic. *J Fam Med Primary Care*. 2020;9(5):2180.
5. Couper K, Taylor-Phillips S, Grove A, et al. COVID-19 in cardiac arrest and infection risk to rescuers: a systematic review. *Resuscitation*. 2020;151:59-66.
 6. Fauci A, Lane HC. Covid-19 - Navigating the uncharted. *N Engl J Med*. 2020;382(13):1268-1269.
 7. Howard BE. High-risk aerosol-generating procedures in COVID-19: respiratory protective equipment considerations. *Otolaryngol Head Neck Surg*. 2020:194599820927335.
 8. Harding H, Broom A, Broom J. Aerosol generating procedures and infective risk to healthcare workers: SARS-CoV-2—the limits of the evidence. *J Hosp Infect*. 2020;105(4):717-725. doi:10.1016/j.jhin.2020.05.037
 9. US Department of Health and Human Services. Enforcement policy for infusion pumps and accessories during the coronavirus disease 2019 (COVID-19) public health emergency. 2020. Accessed April 28, 2020. <https://www.fda.gov/media/136701/download>
 10. Giuliano KK. Intravenous smart pumps: usability issues, intravenous medication administration error, and patient safety. *Crit Care Nurs Clin North Am*. 2018;30(2):215-224. doi:10.1016/j.cnc.2018.02.004
 11. Institute for Safe Medication Practices. Smart pumps in practice: survey results reveal widespread use, but optimization is challenging. Published April 5, 2018. Accessed July 2, 2019. <https://www.ismp.org/resources/smart-pumps-practice-survey-results-reveal-widespread-use-optimization-challenging>
 12. US Food and Drug Administration. Infusion pumps. 2018. Accessed June 26, 2020. <https://www.fda.gov/medical-devices/general-hospital-devices-and-supplies/infusion-pumps>
 13. Hedlund N, Sarangpur S, Kayler S, O'Brien K, Beer I. Primary intravenous set consumption across 3 branded infusion pumps. *J Infus Nurs*. 2017;40(4):206-214. doi:10.1097/NAN.0000000000000229
 14. Butterfield R, Sims N. Go with the flow: insights into complex infusion delivery systems. AAMI Foundation's National Coalition to Promote the Safe Use of Complex Healthcare Technology. <http://www.aami.org/Patient-Safety/content.aspx?ItemNumber=5596&navItemNumber=4615>
 15. User manual: Alaris System with Guardrails. CareFusion; 2019. Accessed May 3, 2020. <https://www.bd.com/en-us/offerings/capabilities/infusion-therapy/infusion-system-software/guardrails-suite-mx-software>
 16. PCA II pump operator's manual model 2L3104. Baxter Healthcare; 1993. Accessed May 3, 2020. <http://www.ardusmedical.com/manuals/BAXTER-PCA-II-PUMP.pdf>
 17. Ma H, Lovich MA, Peterfreund RA. Quantitative analysis of continuous intravenous infusions in pediatric anesthesia: safety implications of dead volume, flow rates, and fluid delivery. *Paediatr Anaesth*. 2011;21(1):78-86.
 18. Massachusetts General Hospital. Part 2: managing dead volume. Published 2017. Accessed June 2, 2020. http://druginfusionsafety.massgeneral.org/deadvolume_part2
 19. Thompson CD, Vital-Carona J, Faustino EV. The effect of tubing dwell time on insulin adsorption during intravenous insulin infusions. *Diabetes Technol Ther*. 2012;14(10):912-916.