Extending tubing to place intravenous smart pumps outside of patient rooms during COVID-19: an innovation that increases medication dead volume and risk to patients

Jeannine W C Blake 1, Karen K Giuliano,1 Robert D Butterfield,2 Tim Vanderveen,3 Nathaniel M Sims4

ABSTRACT
The COVID-19 pandemic has stretched hospitals to capacity with highly contagious patients. Acute care hospitals around the world have needed to develop ways to conserve dwindling supplies of personal protective equipment (PPE) while front-line clinicians struggle to reduce risk of exposure. By placing intravenous smart pumps (IVSP) outside patient rooms, nurses can more quickly attend to alarms, rate adjustments and bag changes with reduced personal risk and without the delay of donning necessary PPE to enter the room. The lengthy tubing required to place IVSP outside of patient rooms comes with important clinical implications which increase the risk to patient safety for the already error-prone intravenous medication administration process. This article focuses on the implications of increasing medication dead volume as intravenous tubing lengths increase. The use of extended intravenous tubing will lead to higher medication volumes held in the tubing which comes with significant safety implications related to unintended alterations in drug delivery. Safe intravenous medication administration is a collaborative responsibility across the team of nurses, pharmacists and ordering providers. This article discusses the importance and safety implications for each role when dead volume is increased due to IVSP placement outside of patient rooms during the COVID-19 pandemic.

INTRODUCTION
The COVID-19 pandemic brought many new challenges to acute care settings as healthcare workers (HCW) have been confronted with high rates of transmission, and high morbidity and mortality.1 As the...
need for hospitalisation increased to capacity with highly contagious patients with COVID-19, healthcare facilities around the world were faced with the need to reduce front-line clinician exposure in the face of limited supplies of personal protective equipment (PPE). This critical situation called for expansive and unprecedented innovation to treat the patients, expand critical care capacity and simultaneously protect the workforce. The need for patients with COVID-19 to be mechanically ventilated for extended periods resulted in high analgesia and sedation requirements. Coupled with concurrent vasoactive infusions, this resulted in many patients requiring multiple continuous infusions requiring titration and near-continuous management.

Intravenous smart pumps (IVSP) are one of the most commonly used medical devices in critical care, particularly for the treatment of patients with COVID-19. Non-therapeutic disruptions in medication infusions caused by frequent air-in-line alarms, occlusions or empty medication containers can lead to serious consequences for critically ill patients. The practice of placing the IVSP outside patient rooms allows nurses to more quickly attend to alarms, initiate rate adjustments and change bags without the delay of donning the PPE necessary to enter the room. A 29 March 2020 social media message from the Chief of Medicine at Massachusetts General Hospital specifically referred to locating a patient’s many infusion devices in the hallway outside the patient’s room and was widely disseminated as a significant innovation in COVID-19 care (figure 1).

COVID-19 INFUSION TECHNOLOGY INNOVATIONS
The use of lengthy extension tubing to remotely locate IVSP outside of the patient intensive care unit (ICU) room has also been referred to as remote intravenous medication administration. Although this practice has been used previously to allow for intravenous medication delivery during MRI examinations, it is now being used during COVID-19, most extensively in critical care. Multiple infusions and aerosol-generating procedures such as intubation and endotracheal suctioning common in critical care further increase concern for transmission to HCWs. The practice of placing IVSP in hallways and anterooms can reduce clinician COVID-19 exposure risk while still allowing for frequent intravenous medication adjustments. Ideally, the implementation of this practice would have been preceded by evidence-based policy and clear standardisation. Given the extreme pressure of the pandemic this was not possible but timely statements and suggestions have been disseminated to guide care facilities when establishing guidelines. In addition, recent data support that this practice can significantly decrease in COVID-19 exposure based on a reduction of the number of nurse entries into the patient’s room following the relocation of intravenous pumps from inside to outside of the room.

There are numerous concerns related to elongated tubing, including physical safety and tripping hazards for clinicians. Potential patient safety issues include increased infection risk, line dislodgement and challenges associated with ensuring the five rights of medication administration. In addition to these concerns, the extended tubing needed for remote intravenous medication administration has important clinical implications related to IVSP performance which is the main focus of this article. In particular, the retained medication volume inside the extended tubing requires additional consideration for the administration of intravenous medications to prevent error and ensure medication delivery as intended.
FRONT-LINE PERSPECTIVE
Critically ill patients with COVID-19 require a tremendous amount of dedicated care from bedside care providers. Acute respiratory distress syndrome (ARDS), pulmonary fibrosis and shock have become common secondary diagnoses for patients presenting with severe cases of COVID-19. In my own experience as a critical care nurse who spent months providing direct care in dedicated COVID-19 ICUs, I (first author) can say that I felt scared every shift that I spent at work.

One of the sickest patients with COVID-19 I cared for was a young woman who suffered from severe shock, ARDS, pulmonary hypertension, right heart failure and acute kidney failure. At the time I worked in a hospital that did not permit use of IVSP outside of patient rooms, and now equipped with a working knowledge of the implications of this practice, I can understand how the decision about whether or not to allow this practice is a difficult one. However, as a front-line clinician providing care, I also appreciate the improved workflow facilitated by this practice. I spent the majority of each 12-hour shift at my patient’s bedside managing three vasopressor medications, two sedatives and one paralytic agent in addition to multiple intermittent doses of around-the-clock intravenous antibiotics and electrolyte replacements. I entered and existed her room numerous times and spent many hours at her bedside, all the while wondering if the negative pressure room and N95 mask that I was wearing (the one that had been cleaned and now reused) were really going to protect me after all this time spent with a patient who required a continuous aerosolising pulmonary intervention. In those moments, I wished to escape to the safety of the hallway to do even a fraction of my work from its security.

INTRAVENOUS TUBING VOLUME
Tubing volume is determined by the inner diameter and length of the tubing; a higher tubing volume will contain more medication. This leads to significant safety implications as it increases the risk for unintended changes in drug delivery. Each member of the medication administration team must be aware of the implications of increased tubing volume and take care to adjust practices appropriately.

Single drug volume
Single drug volume refers to the fluid volume within the length of tubing from the pump channel to the distal tubing connection (figure 2). As IVSP tubing is extended, the single drug volume increases, creating potential patient safety issues which must be considered.

Common volume
Common volume, also referred to as dead volume or shared volume, is the volume of fluid in a length of tubing through which multiple infusions are running (figure 2). The volume contained by a line connector or manifold is also considered part of the common volume, plus any other fluid paths between the manifold and the bloodstream, including the venous access catheter volume.

ADDITIONAL SYSTEM CONSIDERATIONS
Even under ordinary circumstances, IVSP medication administration is error prone, particularly when using multiple infusions which often include medications that have rapid onset and narrow therapeutic threshold, such as vasoactive drugs. An important consideration is the potential for increasing outlet pressure, which is the resistance to forward flow, with the use of remote IVSP. The addition of long and small-bore extension tubing will reduce flow rate, especially with the configuration shown in figure 2A, which will be challenging to detect because the intended flow rate will still be displayed on the IVSP. A critical example is the case of a continuous infusion of a critical anticoagulant such as heparin in which low flow would mean undetected subtherapeutic thresholds when outlet pressure increases. Elongated tubing also increases the opportunity for adsorption to the tubing itself for medications such as insulin, thus decreasing the amount of delivered medication compared with the intended dose. Higher volumes are required for priming long intravenous tubing, increasing the risk of air in line or disconnections due to the increased number of connection points along the tubing length. Longer lines also pose increased risk of partial or complete occlusions when passing beneath doorways and around bedside equipment. All of these issues must be considered and mitigated.

REMOTE INTRAVENOUS MEDICATION ADMINISTRATION SYSTEM SET-UP
Consider the clinical implications of the following three IVSP configurations.

Configuration 1
As described by Shah et al from Mt Sinai, the physical manifold, often a ‘gang of 4-way stopcocks’, is located outside the patient room, as depicted in figure 2A. In this published example, connection to the patient was made with two lengths of non-compliant, kink-resistant, transducer extension tubing. Unfortunately, this configuration creates about 20 mL of added common volume, which comes with elevated risk to patient safety, especially when one of the infusion rates is a critical titrated medication. This is because a change in the rate of any infusion included in the high common volume will impact the flow rate of all other common volume infusions, regardless of the programmed flow rate on the IVSP. This configuration has been observed in various clinical settings by the authors. However, it is the least desirable configuration...
for flow rate accuracy as compared with the other configuration options described below.

**Configuration 2**

Figure 2B shows the use of tubing extension sets, originally developed for patients having MRI studies, connected to a manifold or low-volume multiline connector close to the patient’s venous access. This option significantly reduces the potential risks associated with remote IVSP use because the common volume is the same as in routine clinical practice.27

**Configuration 3**

IVSPs with fully remote-controlled capability, originally developed for MRI studies, provide a potential option for the delivery of intravenous medications for isolated patients.28 However, MRI-safe pumps are costly, would require extensive end user training and
would add an additional user interface to the already complex tasks of intravenous medication administration, and any manipulation of the drug container or tubing would still require room entry by the caregiver. On 13 May 2020, the US Food and Drug Administration issued request for emergency use authorisation (EUA) submittals from manufacturers for infusion pumps with remote monitoring or remote manual control. However, this EUA was revoked on 21 September 2020, and it is unknown at this time whether any pumps with the remote monitoring or control capability were ever approved or introduced. At this time, there is no validation for the safety implications of adopting these MRI-safe pumps outside the MRI setting and this would have to be established before this option could be recommended for practice. Given the currently available equipment, configuration 2 is considered the most ideal set-up at this time when placing IVSP outside of patient rooms.

**NURSING IMPLICATIONS**

Nurses are the final checkpoint before a medication reaches a patient and have primary responsibility for the system set-up. Nurses monitor for physiological effects of medications and are often the first to identify when an intended effect has failed to be achieved. Given the multiple factors to consider with remote intravenous medication administration, education and understanding is essential for front-line nurses to ensure the safest and most accurate intravenous medication administration. Given the current pressure on front-line nurses, additional time spent on education may pose a challenge and additional burden. Inadequate training will amplify the risks associated with placing IVSP outside patient rooms and this must be weighed when a care facility is choosing to permit this practice. Along with education, new practice standards and protocols would need to be developed.

**Intravenous medication rate changes**

Ideally, medications should infuse independently through intravenous tubing without joining any other infusion prior to entering the patient’s bloodstream. This is ideal regardless of the tubing length or medication rate because fluids are incompressible within the single drug volume and therefore a rate adjustment programmed in the IVSP will be accompanied by an immediate adjustment at the patient’s bloodstream. This situation may be impractical in critical care because of the need for multiple life-critical infusions. Therefore, consider the following when multiple medications must be infused through a single venous access location.

- Small-volume multiline connectors should be attached close to the patient’s venous access to minimise the common volume. Reducing the common volume in this way will help decrease the risk of unintended, and potentially dangerous, drug delivery alterations if a rate change occurs for any one medication or fluid flowing through the common volume.

- If a small-volume multiline connector is not available, a nurse may use a typical manifold or ‘gang’ of four-way stopcocks to attach multiple infusions to one venous access location; a disadvantage is that these often have a large common volume of 2–4 mL or more. Another option is to attach additional medications to a tubing using available Y-site connectors. However, this practice should be avoided whenever possible regardless of IVSP location relative to the patient as it leads to significantly higher common volumes and higher risk of drug delivery alterations, especially with critical titratable medications.

- With all methods, it is of utmost importance to join infusions as close to the patient bloodstream as possible.

**Secondary medications**

System set-up of intermittent medications administered as secondary infusions is important to ensure safe and accurate delivery under ordinary circumstances, and even more so if using a remote IVSP configuration. The extended tubing required to place IVSP outside of patient rooms increases single drug volume and retained residual medication. This is especially important for administration of anti-infective medications to ensure that the entire dose is delivered as intended. Intermittent medication infusions should be followed with adequate flush volumes in order to ensure undelivered medication does not remain in the tubing. It is also important to programme the flush at the same rate as the preceding infusion to avoid delivery of the residual medication at a rate that is either too fast or too slow. Special consideration must be made when the patient is at risk for fluid over-load and this may necessitate intermittent infusions be delivered from inside the patient room in order to lessen required flush volumes.

**Medication concentration changes**

When changing medication concentrations, nurses must consider the single drug and common volumes which still contain the prior medication concentration. When IVSP are located outside of patient rooms configured according to figure 2B, this single drug volume will be quite large. When connecting a new medication container (of a different drug or the same drug in a different concentration) to the existing tubing, the volume of residual medication must be purged out of the single drug volume tubing prior to restarting the infusion. Alternatively, the IVSP tubing set can be replaced entirely.

**Choice of extension tubing**

It is important to consider the type of extension tubing. The advantages of small-bore tubing include lower priming volume, higher rigidity to resist kinking or compression when passing through doorways and potentially higher sensitivity to downstream occlusions. Disadvantages include increased outlet pressure which leads to
a decrease in the IVSP flow accuracy and an undetectable deviation in actual flow rate when compared with the programmed rate. The Emergency Care Research Institute (ECRI) publication contains a link to a calculator where the length and priming volume of a tube can be entered, which provides clinical guidance on potential reductions in IVSP flow accuracy.

**PHARMACISTS**
The expertise of the pharmacist is vitally important to optimise safe medication administration practices with extended IVSP tubing.

**Medication concentration**
When medication concentration increases, the flow rate required for delivery of the same dose of medication will decrease. This carries a higher risk for unplanned drug delivery alterations, especially when common volumes are larger than normal.

**Medication container volume**
Optimal container volumes are important to consider for decreasing medication waste while ensuring the quantity is sufficient based on the medication flow rate and to avoid unnecessary infusion interruption caused by frequent container changes. The increased volume required to prime an extended tubing system should be considered during the medication dispensing process. This may require a larger container for initial system priming, while smaller volume containers will suffice for replenishment.

**Table 1** Summary of most pertinent safety issues and mitigating strategies

<table>
<thead>
<tr>
<th>Safety Concern</th>
<th>Considerations/Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV medication rate changes</td>
<td>can have unexpected effects if there is common volume involved with the infusion.</td>
</tr>
<tr>
<td>Improper secondary medication administration</td>
<td>through extended tubing can lead to high residual volume left either unadministered or flushed in at an unsafe rate.</td>
</tr>
<tr>
<td>The single drug volume must be purged of the prior medication before restarting the infusion</td>
<td>this could be done by changing the tubing entirely or re-priming with the new medication or concentration.</td>
</tr>
<tr>
<td>Carefully consider the type of extension tubing being used.</td>
<td></td>
</tr>
<tr>
<td>Take the following into consideration given the specific patient situation: Small bore tubing = lower priming volume but potentially higher sensitivity to downstream occlusion and more potential for inaccurate flow. Higher rigidity tubing = More resistant to kinking or compression but higher sensitivity to downstream occlusion and more potential for inaccurate flow.</td>
<td></td>
</tr>
</tbody>
</table>

**Nursing**

<table>
<thead>
<tr>
<th>Safety Concern</th>
<th>Considerations/Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improper secondary medication administration</td>
<td>through extended tubing can lead to high residual volume left either unadministered or flushed in at an unsafe rate.</td>
</tr>
<tr>
<td>Ensure all secondary medication administrations are followed by an adequate flush volume to clear the entire single drug volume at the same rate used for the medication administration.</td>
<td>Keep in mind this volume may contribute to fluid overload for at-risk patients which may necessitate intermittent infusions be delivered inside the patient room.</td>
</tr>
<tr>
<td>When changing medication concentration for an already running medication the adjusted rate for the new concentration will affect what volume remains in the single drug volume.</td>
<td></td>
</tr>
<tr>
<td>The single drug volume must be purged of the prior medication before restarting the infusion.</td>
<td>this could be done by changing the tubing entirely or re-priming with the new medication or concentration.</td>
</tr>
</tbody>
</table>

**Pharmacists**

<table>
<thead>
<tr>
<th>Safety Concern</th>
<th>Considerations/Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carefully consider changes in medication concentration.</td>
<td></td>
</tr>
<tr>
<td>Higher concentration medications are generally administered at lower flow rates, increasing the risk for unplanned alterations in drug delivery, especially when common volumes are large.</td>
<td></td>
</tr>
<tr>
<td>Medication container volumes must be considered for increased priming volumes, decreasing waste and also avoiding unnecessary infusion interruption due to frequent container changes.</td>
<td></td>
</tr>
<tr>
<td>Consider a larger container for initial setup if larger priming volumes are required while smaller volumes may be sufficient for subsequent container replacements depending on the continuous rates.</td>
<td></td>
</tr>
<tr>
<td>Ensure secondary infusion flushes are appropriate.</td>
<td></td>
</tr>
<tr>
<td>Orders for flush volumes should be sufficient for flushing the entire length of tubing being used for secondary medication infusions, rates for these flushes should also be ordered or suggested based on the rate for the secondary medication being infused.</td>
<td></td>
</tr>
<tr>
<td>Carefully consider the implications of delayed drug library updates.</td>
<td></td>
</tr>
<tr>
<td>When updates are needed, especially relevant to remove IVSP use, ensure installation across entire IVSP fleet is completed as quickly as possible.</td>
<td></td>
</tr>
</tbody>
</table>

**Ordering Providers**

<table>
<thead>
<tr>
<th>Safety Concern</th>
<th>Considerations/Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flush for secondary medications.</td>
<td></td>
</tr>
<tr>
<td>Ensure an adequate flush at an appropriate flow rate is ordered to follow secondary infusions especially when an order is required per facility policy.</td>
<td></td>
</tr>
<tr>
<td>Adequate and appropriate venous access device use.</td>
<td></td>
</tr>
<tr>
<td>Collaborate regularly with nurses to ensure adequate venous access is available to decrease the number of medications flowing together through a common volume.</td>
<td></td>
</tr>
</tbody>
</table>

**Summary of most pertinent safety issues and mitigating strategies**

- **Safety Concern:** IV medication rate changes can have unexpected effects if there is common volume involved with the infusion.
- **Considerations/Strategy:** When possible, medications should each flow independently through IV tubing without joining any other infusion prior to entering the blood stream. This may be impractical in critical care in which case the next best option is to use small-volume multi-line connectors that are attached as close to the patient’s venous access as possible.
- **Safety Concern:** Improper secondary medication administration through extended tubing can lead to high residual volume left either unadministered or flushed in at an unsafe rate.
- **Considerations/Strategy:** Ensure all secondary medication administrations are followed by an adequate flush volume to clear the entire single drug volume at the same rate used for the medication administration. Keep in mind this volume may contribute to fluid overload for at-risk patients which may necessitate intermittent infusions be delivered inside the patient room.
- **Safety Concern:** When changing medication concentration for an already running medication the adjusted rate for the new concentration will affect what volume remains in the single drug volume.
- **Considerations/Strategy:** The single drug volume must be purged of the prior medication before restarting the infusion, this could be done by changing the tubing entirely or re-priming with the new medication or concentration.
- **Safety Concern:** Carefully consider the type of extension tubing being used.
- **Considerations/Strategy:** Take the following into consideration given the specific patient situation: Small bore tubing = lower priming volume but potentially higher sensitivity to downstream occlusion and more potential for inaccurate flow. Higher rigidity tubing = More resistant to kinking or compression but higher sensitivity to downstream occlusion and more potential for inaccurate flow.
Secondary medication flush
Pharmacists should ensure that a flush for secondary infusions is included with intermittent medication orders. Ideally, this would be part of an order set with flush volume and rate suggestions based on the specific system set-up.

IVSP drug library considerations
The updating of drug libraries for a hospital IVSP fleet is a fundamentally important aspect of intravenous medication administration safety. IVSP library update dissemination is not instantaneous; indeed, only about 80% of hospital IVSP have been found to be updated within 10 days of a new wireless update release. These delays are likely to be greater when, due to COVID-19, a higher proportion of IVSP are continuously in use, and rarely power cycled, or when rental IVSP are used to supplement a hospital's fleet. When a previous version of a drug library and dose error reduction system remain installed on an IVSP, errors can occur due to obsolete dose limit settings, drug concentration updates, missed alerts and false alerts. As updates are released which are relevant to remote intravenous medication infusion, it is important that the updates be installed in all IVSP as quickly as possible and monitored using a verification process.

ORDERING PROVIDERS
It is essential for ordering providers to be knowledgeable with regard to the impact system set-up has on intravenous medication delivery. The implications of single drug volume and common volume should be considered and discussed with nurses and pharmacists when considering dose changes, flush requirements and decisions about venous access.

Dose adjustment considerations
When a critically ill patient requires multiple titrated medications through a common volume, dose rate changes must be carefully considered. If a hydrating fluid or carrier is infusing concurrently with other medications, decreasing and especially abruptly discontinuing that infusion could have a significant physiological effect for other medications that share the common volume. Consider gradually tapering the hydrating or carrier fluid rather than turning it off so the subsequent impact on the delivery of other medications can adjust more gradually, thus decreasing the safety risk for the patient. When critical medications are infusing, the high risk associated with abrupt discontinuation of carrier fluid likely justifies any added complexity of tapering the carrier fluid.

Flush ordering for intermittent medications
As previously described, it is important for appropriate flush doses to be ordered for intermittent medications run as secondary infusions. Many facilities consider this flush dose to be a prescribed medication and prohibit its use without an order.

Venous access devices
To decrease the number of medications infused together through a common volume, providers should collaborate with the nurse to ensure adequate venous access. This may mean inserting a triple lumen catheter rather than a double lumen or providing additional points of access when appropriate. Prioritising these added lines of central access for patients requiring vasoactive medications, or incompatible infusions such as total parenteral nutrition is essential.

Table 1 offers a summary of pertinent safety concerns and the associated strategies for mitigating risks for all practitioner groups.

CONCLUSION
Ensuring safe patient care is always a collaborative responsibility of the entire team and medication administration during the COVID-19 pandemic is no exception. As the intravenous tubing system is extended outside the patient room, the complexity and cognitive demands of intravenous medication administration are increased, and mindfulness about the characteristics of novel configurations is essential for nursing, pharmacy and ordering providers.

While the practice of remote IVSP medication administration has quickly come into widespread use during COVID-19, the potential utility may extend well beyond. In the short term, it could be used with any patient with infectious disease to improve the speed in which care can be provided and reduce staff exposure.

Contributors JWCB conceptualised the manuscript, wrote draft 1 of the manuscript and figures and table and coordinated all other author feedback and revision. KKG contributed significantly to drafting all aspects of the manuscript including content development and editing. RDB, TV and NMS contributed significantly to important intellectual content and revision of the manuscript in its entirety.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests As a consultant in medical product development, KKG has performed consulting services for numerous medical device companies. RDB has been employed by an infusion pump manufacturer and is currently a paid consultant for several infusion pump manufacturers. TV has consulted for several infusion pump manufacturers.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement No data are available.

This article is made freely available for use in accordance with BMJ’s website terms and conditions for the duration of the covid-19 pandemic or until otherwise determined by BMJ. You may use, download and print the article for any lawful, non-
commercial purpose (including text and data mining) provided that all copyright notices and trade marks are retained.

**ORCID iD**
Jeannine W C Blake  http://orcid.org/0000-0001-6717-9496

**REFERENCES**
7. Daily innovation in the @MGHMedicine MICU to maximize #COVID19 patient care while preserving PPE. IV alarms are easier to manage when they are outside of the room. In: @katrinaarmstrong, ed 2020.

386