10 clinical tips for advancing patient safety when using syringe pump systems for microinfusion intravenous drug therapy

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INVITED COMMENTARY

10 clinical tips for advancing patient safety when using syringe pump systems for microinfusion intravenous drug therapy

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Introduction

Syringe infusion pumps are widely used for continuous and precise intravenous (i.v.) administration of highly concentrated drugs at low flow rates such as 0.1–10 ml h^{-1} (microinfusion).[1] Microinfusion, in contrast to macroinfusion (7–50 ml h^{-1}), is used in critical care medicine and anaesthesia to prevent fluid overload, particularly in neonates and infants and also in patients receiving multiple infusions.

Significant challenges with i.v. drug infusion therapy are medication errors, infection and drug incompatibilities, but flow-rate variabilities in particular have been highlighted as a persistent problem when using syringe pump systems for microinfusion.[2] The use of syringe infusion pumps at low flow rates for i.v. administration of highly concentrated, short-acting physiologically potent drugs can put patients at risk of serious clinical consequences. Key challenges include delayed drug delivery (caused by, for example, syringe infusion pump start-up, infusion line dead spaces), inaccurate drug delivery (resulting from, for example, use of nonvalidated syringes), irregular drug delivery (such as free flow, during/after syringe infusion pump changeover, or caused by vertical displacement of the infusion pump), inadvertent infusion line occlusion (with undetected interruption of i.v. drug delivery and risk of release drug bolus administration) and dosing errors (due to flow rate variability in multiinfusion syringe pump set-ups).[3]

Despite continuous development in technology and improvement in education over the past years, there remains considerable patient risk due to both a lack of awareness on the part of healthcare professionals, and to the intrinsic physical shortcomings and inappropriate use of these systems. The physical principles that result in problems with syringe infusion pumps are subject to several recommendations that can be found in the scientific literature, and to prevent potentially serious effects it is critical that healthcare providers understand in their daily practice, how the physical effects related to the infusion hardware and the fluid dynamics of a syringe infusion pump system can influence their patients' safety.[4]

This work aims to present key clinical tips that are comprehensive and collated from an expert group to improve patient safety when using syringe infusion pump systems for i.v. drug therapy.

Clinical tip 1: Train all users on their specific infusion pump system

Continuing education is needed to prevent adverse events related to shortcomings of i.v. drug infusion systems. It is crucial to raise awareness and to teach prevention of problems and countermeasures to overcome them, including hands-on training and prediction tools to visualise the effects of changing infusion pump settings on multiinfusion dosing.[5]

Recommendation: Create and maintain a raised awareness of the potential risks to the patient receiving syringe infusion pump i.v. drug therapy through a programme of continuous training and education.

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Clinical tip 2: Establish and maintain proper protocol management for i.v. drug infusions

Standardisation of procedures for the delivery of i.v. drug therapy by syringe infusion pump systems has been shown to result in a significant reduction in risks for patients.[6]

Recommendations: (1) Establish and maintain proper protocols for the management of syringe pump start-up, syringe infusion pump handling during patient transfer, syringe changeover, prevention and management of infusion line occlusion, and composing lower-risk multi-infusion set-ups. (2) When determining the concentration and flow rate of the drug infusion to be delivered, use standardised drug solution and lists for flow rate selection. To prevent dosing errors, no bedside calculations should be done.

Clinical tip 3: Use infusion syringes that have been validated by the syringe pump manufacturer

Different brands of syringe of equal volume can have different internal and external dimensions. Tables for syringe brand and volumes are available on syringe drivers, but such availability allows users to select an incorrect syringe brand, with potential for inaccurate drug delivery. The use of nonvalidated syringes may produce errors of between 10% under-delivery and 24% over-delivery. Up to 22% over-delivery has been recorded when a validated syringe was used but incorrectly chosen from the syringe driver menu. Availability of more than one brand of syringe within a department/hospital increases the risk of adverse drug delivery events.[7]

Recommendations: (1) It is recommended that manufacturers demonstrate infusion pump–syringe compatibility, and that only infusion syringe brands that have been validated by the syringe pump manufacturer should be used. (2) A simple syringe library of the pump may decrease selection errors.

Clinical tip 4: Use the smallest appropriate sized Luer lock syringe

Small syringes are less compliant (volume shift per pressure change, due to elasticity and compressibility of components) and run with a higher plunger speed rate compared to larger syringes. The use of smaller syringes has been shown to result in significantly less start-up delay, significantly shorter time to reach target flow rate, lower drug delivery interruption resulting from syringe changeover and vertical displacement, less time to infusion pump alarm and release of a smaller bolus in the event of infusion line occlusion.[8–13]

Recommendation: Use the smallest appropriate sized Luer lock syringe where possible, especially whenever highly concentrated i.v. drugs are administered at flow rates of $<1\,ml\,h^{-1}$.

Clinical tip 5: Keep the compliance and resistance of the infusion pump system as low as possible

The magnitude of the combination of resistance and compliance of all components of syringe infusion pump systems, as well as gaps between syringe and pump housing, and syringe plunger and pump driver, result in considerable start-up delays, dosing errors during syringe changeover, flow irregularities during vertical displacement, delays in occlusion alarm times and risk of bolus release, all of which put the patient at clinical risk.[14]

Recommendations: (1) Use low-compliant syringe infusion pump set-ups and well fitting syringe – syringe-pump assemblies ensuring that the syringe is firmly secured in the syringe pump with minimal mechanical gaps whenever highly concentrated i.v. drugs at low flow rates are administered. (2) Avoid infusion components that increase resistance of the infusion pathway.

Clinical tip 6: Minimise the number of infusion pumps connected to the same venous catheter lumen

Multiinfusion is associated with significant flow rate variability, infusion line dead spaces and related dosing errors. The magnitude of the dosing error depends on the connection and disconnection of syringe pump assemblies and their set flow rates, dimensional dead spaces (manifold design, port selection, extension lines and central venous catheters) and the physical properties of the infusion components used.[15–17]

Recommendations: (1) When using multiinfusion syringe pump set-ups, minimise the number of infusion pumps assemblies per catheter lumen. (2) Connect infusion line extensions as near as possible to the central venous catheter and (3) attach the medications with shortest half-lives proximally (closest) to the patient so as to keep dimensional dead space low. (4) Separate potent drugs from less potent drugs. (5) Use multilumen central venous catheters if possible, and/or use carrier infusion if appropriate. Apart from carrier infusions, (6) avoid combinations of high- and low-flow rate medications on the same lumen. (7) Consider specially designed multiline extension sets.

Clinical tip 7: Avoid vertical displacement of an infusion pump during drug delivery

Vertical displacement of syringe pumps may cause irregular drug delivery due to hydrostatic pressure changes in the infusion line syringe pump assembly, with siphoning or emptying of drug solution into or from the infusion system. The extent of irregularity will depend on mechanical gaps and the internal compliance of infusion lines, syringes and syringe pumps and also on the height of displacement.[11,18]

Recommendations: (1) Ensure that the vertical positioning of syringe infusion pumps is not changed relative to the patient (2) and that infusion lines are not allowed to form loops, especially when using drugs with short half-lives. (3) Consider technical innovations combining the change of the patient and pump height such as attaching syringe pump stacks to incubators or beds. (4) If the height of the patient bed has to be adapted, perform changes systematically and slowly. (5) Carefully manage syringe infusion pump handling during patient transfer.

Clinical tip 8: Avoid very low flow rates

Very low flow rates (<0.5 ml h^{-1}) result in dramatically increased start-up delays and increased drug delivery interruption following syringe changeover and vertical displacement of the syringe infusion pump. Time to infusion pump alarm in the event of an infusion line occlusion may be considerably delayed.[10,11,13,19]

Recommendation: Avoid very low flow rates whenever highly concentrated i.v. drugs at low flow rates are administered.

Clinical tip 9: Use the most sensitive occlusion alarm pressure reasonably possible

Detecting the occlusion of an infusion catheter is an important problem with syringe pumps using the pressure monitoring system of the pump. Delays of more than 75 min before triggering the occlusion alarm and occlusion release boluses of >1 ml have been reported. Main factors affecting occlusion alarm time and post occlusion bolus are flow rate, syringe size and also the sensitivity of the occlusion pressure alarm.[9,12]

Recommendations: (1) Adjust and maintain the pump's occlusion alarm pressure to the most reasonably possible sensitivity to make it easier to identify any blockage of the infusion line, while preventing false alarms. (2) Use in-line pressure monitoring or infusion pumps with monitoring capabilities (where available). (3) When setting up in-line pressure monitoring, ensure that the threshold is set once steady state has been achieved. (4) Activate the pump's bolus retraction mode or release pressurized occlusion bolus to atmospheric pressure before opening the blocked infusion line. (5) Include specific guidance on occlusion alarm settings in infusion protocols.

Clinical tip 10: Minimise pump start-up delays and flow irregularities during pump changeover

Delayed drug delivery observed during syringe infusion pump start-up is mainly the result of mechanical gaps between the mounted syringe and the pump, the compliance and resistance of the syringe–syringe pump assembly, and also pressure differences between the central venous catheter and the newly connected syringe pump assembly. These can lead to anterograde or retrograde infusion volumes with additional flow variability. Mechanical gaps can be removed by a standardised priming procedure performed prior to connecting the infusion line to the patient. FASTSTART functionality (provided by some infusion pumps) is mainly used when a purging bolus is not possible. Although in general providing benefit when used for continuous infusion of i.v. fluids and other medications, check valves and antisiphon valves can considerably increase start-up delays until the opening pressure of the valve is reached. This is especially relevant during syringe changeover when infusing highly concentrated, i.v. short-acting critical drugs.[10,14,19,20]

Microinfusions are run continuously and fresh infusions are required on a regular basis. Recent clinical research has demonstrated that, independent of the changeover strategy used, at least 25% of critical haemodynamic events occurred around changeover when administering norepinephrine to critically ill adult patients.[21] Beside start-up delays, dead volume effects and pressure differences between the i.v. catheter and the newly connected syringe pump also seem to be responsible for the observed under or over infusion.[17,22] In addition, needle-free connectors have been demonstrated to cause significant volume shifts when manipulating infusion lines.[23]

Recommendations: (1) To speed up syringe pump start-up, ensure that the syringe is firmly secured in the syringe pump. (2) Be aware of the effect of compliance and resistance. (3) Administer a free, purging bolus before connection of the tubing to the i.v. catheter, or use FASTSTART functionality. (4) Be aware of the effect of the use of check and antisiphon valves on the start-up delays, and if so, preferably use valves with low opening pressures. (5) When neutral needle-free connectors are used in the infusion line, clinicians should be aware of their performance regarding bolus, back flow and opening pressure. (6) Ensure your protocols include infusion pump changeover elements, such as minimising pressure differences between the catheter and the newly connected syringe pump, keeping the syringe pump compliance low, using bolus purging before connecting or using FASTSTART functionality.

In conclusion, vigilance, strict protocols and optimally designed and assembled equipment are needed for advancing patient safety using syringe infusion pump systems for i.v. drug therapy, all of which are supported by adherence to this set of clear, practical recommendations.

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