Effect of changes in syringe driver height on flow: a small quantitative study

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ABSTRACT

Objective: To quantify flow irregularities in drug delivery caused by vertical displacement of syringe pumps.

Methods: A bench experiment was performed to quantify the effect of height on pumps used in our intensive care and theatre settings. A standard syringe pump and line set loaded with a dye solution was run through a graduated length of tubing, and the effect of changing pump height quantified by measuring progress down the tubing over time.

Results: A 30 cm elevation produced significant drug delivery boluses — up to seven times the programmed rate at 2 mL/h. Delivery rate increased in inverse proportion to the programmed rate, as did the time taken to return to the programmed rate. Lowering the pump 30 cm resulted in no-flow times of up to 180 seconds at a flow rate of 2 mL/h — again inversely proportional to programmed rate.

Conclusions: Vertical displacement of a common syringe pump by 30 cm produced significant bolus and cessation phenomena. These findings confirm the observations of previous authors and also demonstrate significant flow irregularities with smaller vertical displacements than previously tested. Further testing with other brands of pumps is required before a solution to this clinically important problem may be approached.

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Syringe pumps are commonly used in intensive care and theatre settings to deliver a wide range of potent drugs to patients whose condition is inherently unstable. Haemodynamic instability frequently accompanies changes in patient position during transport or even routine care. However, there is little discussion in the literature about the potential for vertical displacement of syringe pumps to cause bolus and flow cessation effects. Although of great clinical significance, these effects are not widely known.

We tested these phenomena by a simple bench experiment which measured the effect on drug delivery of raising and lowering a commonly used syringe pump.

Methods

A syringe pump loaded with a 50 mL syringe of methylene blue dye solution was attached to a standard triple-lumen central line via a standard tubing set. To simulate physiological central venous pressure (CVP), the tip of the central line was immersed and secured in a jug of water to a depth that produced a CVP reading via the distal lumen of 5 cmH_2O.

The gross effects of vertical displacement of the pump were confirmed using two specimens each of two different brands of syringe pump. The effects were demonstrated to be equivalent when the pump was displaced relative to the central venous line apparatus and vice versa. All quantitative data were derived from a single pump specimen, displaced relative to a stable central line and recording apparatus. Air was carefully excluded from the syringe, and syringe size and tubing were standardised.

About 100 cm of the tubing was secured against a tape measure, and the dye front was advanced onto the scale, with a small air space to produce a sharp interface for readings. The volume of the measurement tubing was ascertained, allowing the volume of any bolus delivered on elevating the pump to be calculated. After a zero point was established, a known volume of fluid was injected into the line, and the volume of each unit length was determined after multiple tests.

In the first step of the experiment, steady-state flow was confirmed, before measurements at different programmed delivery rates. The measurement line was primed, and the pump started and purged to establish flow. After approximately 60 seconds, progress of the dye front on the scale was recorded over five consecutive 10-second intervals. This both demonstrated that steady state was achieved, and allowed correlation of the programmed rate with the delivered rate.

After confirmation of steady-state flow, the pump was either rapidly raised 30 cm or lowered 30 cm from baseline, over a period of 1 second or less. The subsequent delivered rate was then determined by measurements at 10-second intervals until steady state was reattained. Measurements were performed three times for each apparatus configuration, and results were averaged.

On pump elevation, the bolus volume delivered and the time to return of steady-state flow were determined at programmed pump delivery rates of 2, 5, 10 and 20 mL/h. The equivalent bolus dose of a 3 mg/50 mL inotrope solution was calculated from the bolus volume delivered. On pump lowering, the time without flow and the time to return of steady-state flow were determined at pump delivery rates of 2, 5 and 10 mL/h.

The possibility that the small amount of air at the dye–air interface contributed to compliance and variation of the system was investigated by measuring the size of the air column at different rates and elevations. This failed to show any measurable compression.

Results

Steady-state flow rates at different programmed pump delivery rates are shown in Table 1. At a programmed rate of 2 mL/h, the calculated delivery rate was 1.57 mL/h, substantially lower than the programmed rate. Faster rates were delivered more accurately.

The effect of raising the syringe pump by 30 cm after documenting 20 seconds of steady-state flow is shown in Table 2 and Figure 1. The proportional increase in delivered rate with pump elevation was highest at low programmed flow rates, with a sevenfold increase at a programmed rate of 2 mL/h, and a twofold increase at a programmed rate of 20 mL/h. The time taken to return to steady state was shorter for higher flow rates — 20 seconds at 20 mL/h, but at least twice as long at lower rates. The bolus volumes delivered when the pump was raised are shown in Table 3 and Figure 2. Volumes ranged from 71 to 161 μL, equivalent to 4.3 to 9.7 μg of inotrope for a solution with concentration 3 mg/50 mL.

The effect of lowering the syringe pump 30 cm after documenting steady-state flow is shown in Table 4, Table 5 and Figure 3. At all rates tested, flow rate dropped to zero when the pump was lowered. The time before flow resumed was greatest at a programmed rate of 2 mL/h at 50 seconds, and the time to return to steady-state delivery ranged from 180 seconds at a programmed rate of 2 mL/h to 90 seconds at 10 mL/h.

Findings on the second brand of pump tested were not quantified, but were similar to those reported.

As a control, horizontal displacement of the pump or manipulation of the tubing did not produce any measurable effect on flow rates.

Table 1. Steady-state flow rates at different programmed delivery rates

Measurement		Programmed delivery rate (mL/h) 2	5	10	20
Relative progress in 10 s (cm)*					
1		0.5	1.5	2.8	6.0
2		0.5	1.4	3.1	5.8
3		0.4	1.6	2.9	6.3
4		0.5	1.5	2.8	5.9
5		0.4	1.4	3.2	5.6
Progress (mm/s):	Average	0.46	1.48	2.96	5.92
	Range	0.4–0.5	1.4–1.6	2.8–3.2	5.6–6.3
Calculated delivery rate (mL/h)		1.57	5.01	10.11	20.23

* Relative progress of dye front.

Table 2. Effect of raising pump 30 cm (at time, 20 seconds) on delivery rate

Measurements at different programmed delivery rates		Time (s) 10	20	30	40	50	60	70	80
2 mL/h									
Progress (mm/s):*	Range	0.5–0.6	0.5-0.6	3.4–4.2	1.4–1.6	0.9–1.0	0.6–0.8	0.6–0.7	0.5–0.7
	Average	0.53	0.57	3.70	1.50	0.97	0.70	0.63	0.57
Calculated delivery rate (mL/h)		1.82	1.94	12.64	5.12	3.30	2.39	2.16	1.94
5 mL/h									
Progress (mm/s):*	Range	1.3–1.5	1.2–1.6	4.6–4.9	2.7–2.9	1.9–2.2	1.5–1.7	1.4–1.6	1.3–1.5
	Average	1.40	1.37	4.77	2.83	2.03	1.63	1.50	1.40
Calculated delivery rate (mL/h)		4.78	4.67	16.28	9.68	6.95	5.58	5.12	4.78
10 mL/h									
Progress (mm/s):*	Range	2.9–3.3	2.6–3.0	7.2–7.2	3.9–4.3	3.1–4.2	2.8–3.0	2.8–2.9	2.8–3.0
	Average	3.03	2.83	7.20	4.17	3.50	2.93	2.83	2.90
Calculated delivery rate (mL/h)		10.36	9.68	24.60	14.24	11.96	10.02	9.68	9.91
20 mL/h									
Progress (mm/s):*	Range	5.3–6.0	5.3–5.8	10.4–11.6	5.6–6.1	5.4–5.9	5.2–6.0	5.2–5.9	5.5–5.7
	Average	5.57	5.57	11.20	5.77	5.63	5.70	5.67	5.60
Calculated delivery rate (mL/h)		19.02	19.02	38.26	19.70	19.25	19.47	19.36	19.13

* Progress of dye front. Values are the range and average of three separate readings.

Figure 1. Effect of raising pump 30 cm (at time, 20 seconds) on delivery rate

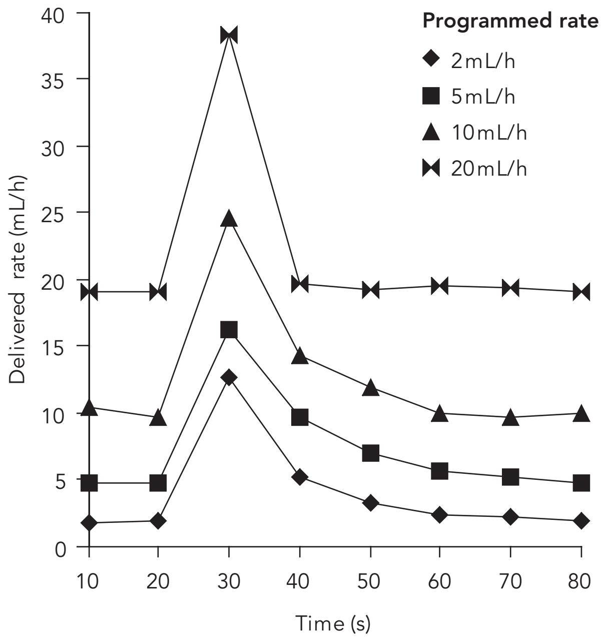


Table 3. Effect of raising pump on bolus volume and equivalent dose of inotrope delivered

Programmed rate (mL/h)	Bolus volume (μL)	Equivalent dose of inotrope (μg)*
2	71.18	4.3
5	121.16	7.3
10	141.08	8.5
20	161.01	9.7

* For an inotrope solution with concentration of 3 mg/50 mL.

Discussion

This study is unique in demonstrating bolus and cessation effects produced by vertical displacement of a syringe pump by only 30 cm, a significantly smaller displacement than previously tested.[1-6] The study confirms the findings of other authors. Igarashi et al[2] demonstrated increased internal line pressure and flow with elevation of a syringe pump, and Kern et al[3] showed significant no-flow times after lowering three different models of syringe pump. Weiss et al[5] and Klem et al[7] found flow irregularities to be greater at low flow rates. The bolus volumes delivered when the pump was raised (Table 3 and Figure 2) were consistent with those previously demonstrated by Neff et al.[4]

The results show two surprisingly large effects of changing the syringe driver height by only 30 cm during steady-state infusion. As expected, the magnitude of the bolus effect and the time to return to steady state were greater at lower infusion rates, presumably because the lower luminal pressures generated by lower pump speeds are proportionally smaller than the hydrostatic change produced by altering pump height. An equivalent susceptibility of low flow rates to lowering the pump was observed.

The potential clinical relevance of these findings relate to positioning and transport of inotrope-dependent patients, and appropriate concentrations of highly potent cardiovascular agents. Sitting or reclining a patient in bed may produce vertical displacement of a central line situated in the neck in excess of 30 cm, exposing the patient to bolus or cessation phenomena. Further, manual handling of syringe pumps during transport may place them anywhere between bed height and high overhead (eg, during transfer to or from emergency vehicles or computed tomography tables), producing vertical displacement well in excess of 30 cm.

Our findings support the conclusion that inotrope and vasopressor infusions should be diluted so as to allow higher pump speeds — probably greater than 2–5 mL/h. In addition, vertical displacement of syringe pumps should be minimised during periods of critical haemodynamic instability, as displacement by as little as 30 cm can produce significant irregularities in drug delivery.

To these points may be added the recommendations of other authors regarding flow irregularities in syringe pumps. Weiss et al[5] demonstrated that use of larger syringes and infusion lines with higher compliance could increase irregularities in drug delivery. They also showed[6] that antisiphon valves added to syringe pump circuits worsened flow irregularities. Schultz et al[8] found that entrapment of air in

Figure 2. Bolus volumes delivered after raising pump 30 cm

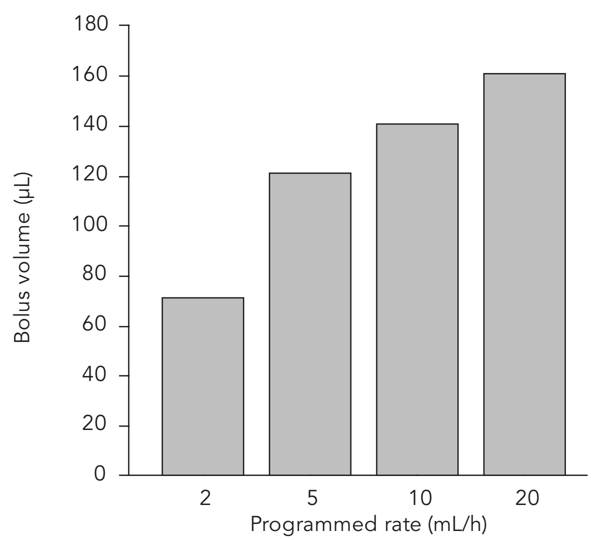
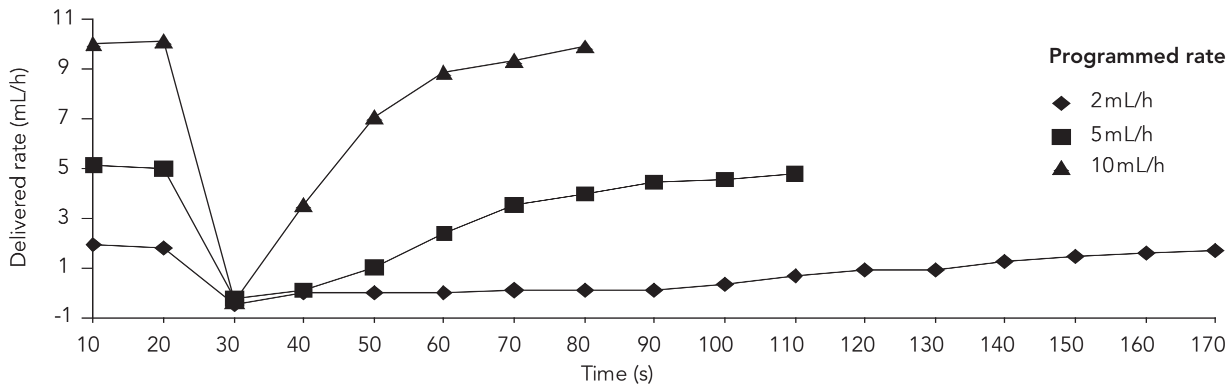


Table 4. Effect of lowering pump 30 cm (at time, 20 seconds) on delivery rate over 10–80 seconds

Measurements at different programmed delivery rates	Time (s) 10	20	30	40	50	60	70	80
2 mL/h								
Progress (mm/s):* Range	0.5–0.6	0.4–0.6	–0.1 to –0.2	0.0–0.0	0.0–0.0	0.0–0.0	0.0–0.1	0.0–0.1
Average	0.57	0.53	–0.13	0.00	0.00	0.00	0.03	0.03
Calculated delivery rate (mL/h)	1.94	1.82	–0.46	0.00	0.00	0.00	0.11	0.11
5 mL/h								
Progress (mm/s):* Range	1.4–1.5	1.4–1.5	–0.3 to 0.1	0.0–0.1	0.2–0.4	0.6–0.8	1.0–1.1	1.1–1.2
Average	1.50	1.47	–0.07	0.03	0.30	0.70	1.03	1.17
Calculated delivery rate (mL/h)	5.12	5.01	–0.23	0.11	1.02	2.39	3.53	3.99
10 mL/h								
Progress (mm/s):* Range	2.8–3.0	2.9–3.0	–0.1 to –0.1	0.9–1.1	2.0–2.2	2.5–2.8	2.7–2.8	2.7–3.0
Average	2.93	2.97	–0.10	1.03	2.07	2.60	2.73	2.90
Calculated delivery rate (mL/h)	10.02	10.14	–0.34	3.53	7.06	8.88	9.34	9.91

* Progress of dye front. Values are the range and average of three separate readings.

Figure 3. Effect of lowering pump 30 cm (at time, 20 seconds) on delivery rate



the delivery syringe increased the susceptibility of flow rate to vertical displacement.

Our results also suggest inaccurate delivery of programmed flow at lower rates (Table 1).

We propose that hydrostatic pressure changes affecting internal line pressure and flow are the mechanism of bolus and cessation phenomena. Movement of the syringe plunger within the tolerance of the pump clasp and the contribution of different mechanical systems may further contribute.

In our experiment, the effect of CVP was fixed. It is possible that the effect of pump displacement varies with different CVP values. Further, diverse mechanical systems used in different pumps may vary in their susceptibility to the effects described here.

Neff et al[9] reported substantial delays, of the order of 60 minutes, for some pumps to achieve steady-state flow when the line was not initially pressurised. Their study used paediatric flow rates of only 1 mL/h, and demonstrated a greatly reduced delay if the line was pressurised first, as in our study. A delay in reaching steady state due to line pressurisation was thus avoided in our study.

Further research is required to investigate other pumps and mechanisms, and to enhance the statistical significance of our findings with larger data sets.

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Table 5. Effect of lowering pump 30 cm (at time, 20 seconds) on delivery rate over 90–170 seconds

Measurements at different programmed delivery rates	Time (s)								
	90	100	110	120	130	140	150	160	170
2 mL/h									
Progress (mm/s):* Range	0.0–0.1	0.0–021	0.0–0.3	0.1–0.4	0.2–0.4	0.2–0.5	0.4–0.5	0.4–0.5	0.5–0.5
Average	0.03	0.10	0.20	0.27	0.27	0.37	0.43	0.47	0.50
Calculated delivery rate (mL/h)	0.11	0.34	0.68	0.91	0.91	1.25	1.48	1.59	1.71
5 mL/h									
Progress (mm/s):* Range	1.2–1.4	1.3–1.4	1.4–1.4	nt	nt	nt	nt	nt	nt
Average	1.30	1.33	1.40	nt	nt	nt	nt	nt	nt
Calculated delivery rate (mL/h)	4.44	4.56	4.78	nt	nt	nt	nt	nt	nt

* Progress of dye front. Values are the range and average of three separate readings. nt = not tested..

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