An evaluation of methods of increasing the flow rate of i.v. fluid administration

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Summary
I have evaluated in vitro methods of increasing the flow rate of clear fluids through an i.v. cannula at room temperature. These included, alone and in combination: increasing the height of a gravity-fed system; increasing the i.v. cannula diameter, manual compression of the lower drip chamber and the use of pressure bags. Flow rate was measured using a uroflowmeter, which was found to be reliable and reproducible. The most effective methods of increasing flow were the use of a 14-gauge cannula rather than a 16-gauge cannula, which resulted in a 50 % increase, and the use of a 300-mm Hg pressure bag with automatic adjustable pressure regulator, which doubled the flow rate. The combination of these two tripled the overall flow to nearly 600 ml min⁻¹. Manual compression of the drip chamber, despite producing peak pressures of more than 100 cm H2O, was an inefficient method of improving flow compared with an external pressure bag. (Br. J. Anaesth. 1995; 75: 361–365)

Key words
Fluids, i.v. Fluids, therapy. Infusions, i.v. Infusions, rate.

The need to replace rapidly blood and other fluids lost during anaesthesia and surgery has led to the development of highly efficient systems for warming and delivering i.v. fluids. Some of these such as the Rapid Infusion System [1] (Hemometrics Corporation, MA, USA) and the Level 1 blood warmer series [2] (Penco Medical Ltd, London, UK) are capable of delivering up to 1000 ml min⁻¹ of fluid at temperatures approaching 37 °C, but are expensive, both in terms of the hardware and the disposables required. In centres without these facilities and on occasions where sudden unexpected blood loss has occurred, there is still the requirement for simple methods of rapidly increasing the flow rate through an i.v. infusion cannula.

Our simple method of increasing flow is to elevate the infusion bag, thus increasing the “pressure head” between the fluid in the infusion bag and the patient. The maximum pressure head attainable is restricted by the length of the fluid administration set and is usually less than 150 cm. This may not be sufficient for adequate flow, even with the largest i.v. cannula if the cannula is kinked [3] or there is significant venous resistance [4, 5].

There are two alternatives to simple elevation of the infusion bag; first, manual intermittent compression of the lower drip chamber of the giving set using the ball valve to occlude the distal outlet of the upper drip chamber. Personal observation suggests that this method is used by many anaesthetists when rapid increases in i.v. infusion rate are required. Second, the infusion bag may be placed within an external pressure sleeve and then an air bag inflated within this sleeve, raising the pressure to 200–300 mm Hg. There are inherent problems with this because of a gradual decrease in pressure within the pressure bag as fluid empties from the bag [6]. There are several different types of pressure bag, the most efficient being a rigid box of the Norfolk and Norwich pattern [7]. Automatic adjustable pressure regulators similar to those used as automatic tourniquets in orthopaedic and plastic surgery have been used to overcome the problem of the pressure decreasing as the fluid empties from the bag [8–11]. Finally, a pressure bag may be combined with intermittent manual compression of the lower drip chamber. This study was designed to assess the effectiveness of these methods in increasing the flow rate of crystalloid and colloid administration through an i.v. cannula.

Methods
The basic equipment consisted of a sterile blood administration set C2071 (Baxter Healthcare Ltd, Norfolk, UK) together with a 16-gauge (id = 1.25 mm) or 14-gauge (id = 1.65 mm) Jelco i.v. cannula (Criticon Ltd, Berkshire, UK). Two different i.v. fluids were used: 500-ml bags of 0.9 % sodium chloride i.v. infusion BP in a Viaflex container B1323 (Baxter Healthcare Ltd) and 500-ml bags of Gelofusine plasma substitute in an Ecoflex polyethylene container (B. Braun Medical Ltd, Aylesbury, UK).

The flow rate of fluid from the cannula was measured by the Urodyn 1000 uroflowmeter (Dantec Electronics Ltd, Bristol, UK). This is an automated device used to measure urine flow rate in patients
with, for example, bladder outflow obstruction. It consists of a collecting funnel at the base of which is a metal disc kept rotating at speed by a Servo motor (fig. 1). The amount of electrical energy required to keep the disc speed constant when fluid lands on the disc is proportional to the amount of fluid landing on the disc per second, in other words, to the flow rate of the fluid. A graphical representation is generated together with the duration, maximum flow, mean flow and total volume of fluid which has been infused.

The uroflowmeter may be recalibrated for fluids with different densities and viscosities [personal communication, Dantec Electronics Ltd, Bristol, UK]. (The relative densities of the two fluids tested are: Gelofusine = 1017 mg ml⁻¹, 0.9 % saline = 1004 mg ml⁻¹ [personal communication, B. Braun Medical Ltd].) Direct calibration of the uroflowmeter was performed before each experiment by pouring a measured 400 ml of the fluid under test into the flow transducer at an even flow rate. If the measured volume differed from the actual volume by >1 %, calibration was performed again. Each technique of increasing the flow rate was repeated four times.

The pressure head of fluid was taken as the vertical distance between the lowest part of the infusion fluid bag and the tip of the i.v. cannula (fig. 1). This was to avoid the problem of the pressure head changing as the infusion bag empties. The cannula was clamped horizontally in a burette stand such that fluid emerging from the tip fell into the collecting funnel of the uroflowmeter. Giving sets were changed between each set of four tests and were prefilled before each test such that a full bag of fluid was emptied each time.

Manual compression of the lower drip chamber was performed as efficiently as possible by the author each time. The frequency of compression was determined by the speed of refill of the lower drip chamber after release, but was approximately 20–25 per min.

The pressure at the outlet of the system was measured using a National Semiconductors 1603D pressure transducer. Arterial pressure transducer tubing was used to connect this transducer to a 22-gauge needle inserted into the rubber injection port of the blood administration set. The needle tip was at the same height as the transducer. A small pilot study indicated that this 22-gauge needle had no effect on the flow rate through the cannula. Calibration of the pressure transducer up to 300 mm Hg was performed before use with a mercury sphygmomanometer. All experiments were performed at room temperature on the test day (20 °C).

EXPERIMENT 1—PRESSURIZATION TECHNIQUES

Six different methods of increasing the rate of administration of 0.9 % sodium chloride through a 16-gauge cannula were compared: (1) gravity-fed, 100-cm pressure head; (2) gravity-fed, 150-cm pressure head; (3) manual compression of the lower drip chamber, 100-cm pressure head; (4) compression within a flexible pressure bag (Infusable Disposable Pressure Infusor, Vital Signs Inc., Totowa, NJ, USA), inflated manually to 300 mm Hg at the start; (5) compression within a rigid pressure bag (Norfolk and Norwich Medical Equipment, Norwich, UK) with constant 300 mm Hg of pressure provided by an automatic adjustable tourniquet device (VBM Automatic Tourniquet 2X500/E, Medizintechnik GmbH, West Germany), monitored with an aneroid pressure gauge; and (6) as (5) in addition to manual compression of the lower drip chamber.

EXPERIMENT 2—CANNULA SIZE

The flow rates of 0.9 % sodium chloride were measured through 14- and 16-gauge Jelco i.v. cannulae under four different conditions: (1) gravity-fed, 100-cm pressure head; (2) manual compression of the lower drip chamber, 100-cm pressure head; (3) compression within a rigid pressure bag kept at a constant 300 mm Hg of pressure; and (4) as (3) in addition to manual compression of the lower drip chamber.

EXPERIMENT 3—COLLOID VS CRYSTALLOID

To assess the differences between different infusion fluids, the rates of emptying of 500-ml bags of Gelofusine and 0.9 % saline were measured under two different conditions: (1) gravity-fed, 100-cm pressure head; and (2) compression within a rigid
pressure bag kept at a constant pressure of 300 mm Hg with the automatic adjustable tourniquet device.

**EXPERIMENT 4—TYPE OF FLUID CONTAINER**

Gelofusine is marketed in a semi-rigid polyethylene container (Ecolac). As the container empties during infusion of the fluid, the semi-rigid walls of the container tend to resist collapse. To assess if this exerted a negative effect on the maximal rate of emptying of the container, Gelofusine was decanted into an empty 500-ml 0.9 % saline Viaflex bag and the rate at which this emptied was compared with that from the standard container. This was performed under two different conditions: (1) gravity-fed, 100-cm pressure head; and (2) compression within a rigid pressure bag kept at a constant pressure of 300 mm Hg pressure with the automatic adjustable tourniquet device.

Statistical analysis was performed using the Arcus Pro-Stat statistical computer software program DOS version 3 (Medical Computing Ltd, Aughton, West Lanes, UK). Statistical analysis was by one-way analysis of variance (ANOVA) comparing mean flow rates from each experiment. Individual comparisons between mean flow rates from different experiments were performed by modified t testing with Bonferroni correction.

**Results**

**EXPERIMENT 1—PRESSURIZATION TECHNIQUES**

The mean flow rates from all conditions in experiment 1 were significantly different from each other (ANOVA, $F = 1525.506, P < 0.0001$). The residual sd for within-group comparison of flow rate was only 0.09 ml s$^{-1}$, demonstrating the reliability and reproducibility of the uroflowmeter in measuring fluid flow rates. The most efficient method of increasing the rate of flow was the use of a rigid pressure bag with a constant pressure of 300 mm Hg produced by the automatic adjustable pressure regulator. This resulted in an approximate doubling in flow rate. Manual compression of the lower drip chamber of the fluid administration set using the ball valve to occlude the outlet of the upper chamber was only marginally better than the gravity-fed infusion alone or the external 300-mm Hg pressure bag alone. The pressures recorded at the proximal (patient) end of the fluid administration set were much less than the pressures being applied at the infusion bag. The greatest pressures (more than 100 cm H$_2$O) were recorded when manual compression of the lower drip chamber was used with a 16-gauge cannula (table 1).

**EXPERIMENT 2—CANNULA SIZE**

The use of a 14- rather than a 16-gauge improved flow by approximately 50 % for all the different conditions tested ($P < 0.0001$). Manual compression of the lower drip chamber made no difference to the mean flow rate through the 14-gauge i.v. cannula, either under gravity-fed infusion or with a pressure bag pressurized to 300 mm Hg (table 2).

**EXPERIMENT 3—CRYSTALLOID VS COLLOID**

Predictably, the increased density and viscosity of Gelofusine resulted in lower flow rates than 0.9 % saline under a gravity-fed infusion ($P < 0.0001$), although the difference was clinically small when pressurized to 300 mm Hg ($P = 0.0017$) (table 3).

### Table 1

<table>
<thead>
<tr>
<th>Condition</th>
<th>Volume (ml)</th>
<th>Time (s)</th>
<th>Peak flow (ml s$^{-1}$)</th>
<th>Mean flow (ml s$^{-1}$)</th>
<th>Peak pressure (cm H$_2$O)</th>
<th>% of Baseline flow rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity-fed, 100 cm height</td>
<td>549.5 (2.1)</td>
<td>168 (1)</td>
<td>3.55 (0.06)</td>
<td>3.2 (0)</td>
<td>30.5 (0.6)</td>
<td>100</td>
</tr>
<tr>
<td>Gravity-fed, 150 cm height</td>
<td>550.5 (4.2)</td>
<td>135 (0.5)</td>
<td>4.88 (0.05)</td>
<td>4 (0)</td>
<td>35.6 (0.6)</td>
<td>125</td>
</tr>
<tr>
<td>Gravity-fed, 100 cm height + manual compression</td>
<td>551 (4.3)</td>
<td>123 (3.6)</td>
<td>14.95 (0.5)</td>
<td>4.45 (0.06)</td>
<td>106.5 (3.4)</td>
<td>139</td>
</tr>
<tr>
<td>300 mm Hg pressure (manual inflation)</td>
<td>546 (3.7)</td>
<td>96 (2)</td>
<td>7.95 (0.13)</td>
<td>5.48 (0.1)</td>
<td>60.5 (0.6)</td>
<td>178</td>
</tr>
<tr>
<td>300 mm Hg pressure (automatic)</td>
<td>544 (4.6)</td>
<td>77 (2)</td>
<td>8.58 (0.05)</td>
<td>7.03 (0.15)</td>
<td>63 (0.8)</td>
<td>220</td>
</tr>
<tr>
<td>300 mm Hg pressure (automatic) + manual compression</td>
<td>541.3 (3)</td>
<td>74 (1)</td>
<td>15.35 (0.26)</td>
<td>7.33 (0.1)</td>
<td>112 (2.9)</td>
<td>229</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Cannula size</th>
<th>Condition</th>
<th>Mean flow (ml s$^{-1}$)</th>
<th>Peak pressure (cm H$_2$O)</th>
<th>% of Baseline flow rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-gauge</td>
<td>Gravity-fed, 100 cm height</td>
<td>3.2 (0)</td>
<td>30.5 (0.6)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Gravity-fed, 100 cm height + manual compression</td>
<td>4.45 (0.06)</td>
<td>106.5 (3.4)</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>300 mm Hg pressure (auto)</td>
<td>7.03 (0.15)</td>
<td>63 (0.8)</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>300 mm Hg pressure (auto) + manual compression</td>
<td>7.33 (0.1)</td>
<td>112 (2.9)</td>
<td>229</td>
</tr>
<tr>
<td>14-gauge</td>
<td>Gravity-fed, 100 cm height</td>
<td>5.03 (0.05)</td>
<td>24.8 (0.5)</td>
<td>157</td>
</tr>
<tr>
<td></td>
<td>Gravity-fed, 100 cm height + manual compression</td>
<td>5.13 (0.05)</td>
<td>85.3 (3)</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>300 mm Hg pressure (auto)</td>
<td>9.78 (0.26)</td>
<td>56 (1.4)</td>
<td>305</td>
</tr>
<tr>
<td></td>
<td>300 mm Hg pressure (auto) + manual compression</td>
<td>9.38 (0.55)</td>
<td>92.3 (1.3)</td>
<td>267</td>
</tr>
</tbody>
</table>
EXPERIMENT 4—TYPE OF FLUID CONTAINER

When Gelofusine was repackaged in a flexible bag there was a small but significant increase in the mean rate of emptying in the gravity-fed system ($P = 0.0192$). However, this difference was nullified by the effect of 300 mm Hg of constant pressure provided by the automatic adjustable pressure regulator (table 3).

**Table 3** Comparison of different fluids and containers—0.9 % saline and Gelofusine given through a 14-gauge cannula. Gelofusine supplied in a rigid container is compared with Gelofusine in a flexible 0.9 % saline container. Baseline flow rate is taken as the flow rate, gravity-fed with 100-cm pressure head, through a 16-gauge Jelco cannula. Values are mean (st).

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Condition</th>
<th>Mean flow (ml s⁻¹)</th>
<th>Peak pressure (cm H2O)</th>
<th>% of Baseline flow rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9 % Saline</td>
<td>Gravity-fed, 100 cm height</td>
<td>5.03 (0.05)</td>
<td>24.8 (0.5)</td>
<td>157</td>
</tr>
<tr>
<td></td>
<td>300 mm Hg pressure (auto)</td>
<td>9.78 (0.26)</td>
<td>56 (4.4)</td>
<td>305</td>
</tr>
<tr>
<td>Gelofusine—standard rigid container</td>
<td>Gravity-fed, 100 cm height</td>
<td>3.7 (0)</td>
<td>21 (0)</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>300 mm Hg pressure (auto)</td>
<td>9.43 (0.05)</td>
<td>52.3 (0.5)</td>
<td>295</td>
</tr>
<tr>
<td>Gelofusine—flexible container</td>
<td>Gravity-fed, 100 cm height</td>
<td>4.13 (0.13)</td>
<td>22 (0)</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>300 mm Hg pressure (auto)</td>
<td>9.23 (0.5)</td>
<td>57.8 (0.5)</td>
<td>288</td>
</tr>
</tbody>
</table>

Discussion

The rate-limiting factors for flow through an i.v. cannula are internal diameter and length [12], however, the largest readily available cannula in most hospitals in the UK is 14 standard wire gauge (SWG), with an internal diameter of 1.65 mm, and thus the possible increases in flow from altering this factor are limited. The maximum flow obtained of 9.78 ml s⁻¹ for a 14-gauge cannula is equivalent to nearly 600 ml min⁻¹ and has previously been shown to be the maximum flow obtainable from any make of 14-gauge i.v. cannula under 300 mm Hg of pressure [12].

The length of i.v. cannulae of similar diameter varies only slightly between manufacturers, so this is not a major factor [13]. The length of the giving set tubing is also relatively fixed, unless there is a blood-warming coil in the system. If this is the case, then the potential disadvantage of the increased length of tubing may be offset by a reduction in viscosity because of the increased temperature of the fluid and by the use of pressure infusions.

Many anaesthetists use manual compression of the lower drip chamber as a method of suddenly increasing the flow rate through an i.v. cannula. This set of experiments has shown that this is an inefficient method and inferior to the application of an external pressure bag.

The reason behind the failure of this technique is undoubtedly because of the mechanism of refilling of the lower drip chamber. When released after manual compression, the lower chamber refills initially by reflux of fluid (producing transient negative flow back up the giving set tubing) before filling from above. It is possible that by inserting a one-way valve into the system and constructing the lower drip chamber of more rigid material, the speed of refilling of the lower drip chamber could be improved. The British Standard on fluid administration sets [14] permits such a modification, which is currently under investigation.

The use of an automatic adjustable pressure regulator more than doubles the flow rate over a gravity-fed infusion and is superior to the use of manually inflated pressure bags, which require attention to maintain pressure as the infusion bag empties of fluid. This agrees with the results of a previous study of flow rates [15], although the method of measurement of flow rate in that study had an accuracy of only ± 10 %. Although well described in the literature [8–11], and a relatively cheap and simple method of increasing fluid flow compared with purpose-built fluid administration systems, automatic adjustable pressure regulators appear not to be in common usage. One such system, easily constructed, incorporates a “suction manifold” to remove air rapidly from the pressure bag when the infusion bag is empty, thus facilitating rapid changeover of infusion bags [10].

There appears to be no reason why colloids such as Gelofusine and Haemaccel (Hoechst UK Ltd, Middlesex, UK) are marketed in semi-rigid polyethylene containers whereas all crystalloids and the colloid Hespain (Du Pont Pharmaceuticals, Letchworth, UK), are in flexible Viaflex or Steriflex plastic containers. The use of flexible plastic containers for packaging colloids would confer a small but significant advantage in terms of an increase in maximum flow rate compared with semi-rigid polyethylene containers. Previous reference has been made to the disadvantages of the semi-rigid polyethylene containers [16, 17]. Air inlet valves, which may increase the rate of emptying from plastic semi-rigid containers were not studied in these experiments as their use may prevent subsequent use of pressure bags. They have been recently reviewed [18] and their disadvantages, including potential contamination and “soaking” of the filter, have been highlighted.

While there are clearly manpower benefits to be gained from using pressurization techniques not requiring direct supervision, there are also potential risks. There is a risk of air embolism from any device which pressurizes an i.v. infusion. This risk is reduced if there is a member of staff directly involved in the pressurization technique. A blood administration set itself offers some protection to air embolism.

This study has not attempted to evaluate the contribution of venous resistance to flow rates. This
has been extensively investigated in several recent studies [3, 4, 19, 20] and has been found to be an important determinant of flow. However, this venous resistance to flow is a constant factor for a given vein in a given patient at a particular time. The use of two moderate-sized cannulae has been found to provide better overall flow rates than one large cannula in patients with small veins [5].

Blood was not used as the fluid in any of these experiments because of the expense and the difficulties of obtaining sufficient quantities of immediately time-expired bank blood. One must therefore be cautious about applying these techniques to blood transfusion. In addition, it is theoretically possible for red blood cells to be damaged by their high-velocity passage through a narrow aperture.

Acknowledgements

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References