Intravenous fluid resuscitation: was Poiseuille right?

Andrew D Reddick, Julie Ronald, William G Morrison

Ninewells Hospital, Dundee, UK

Correspondence to
Andrew D Reddick, Emergency Department, Ninewells Hospital, Dundee DD1 9SY, UK;
andrew.reddick@nhs.net

Accepted 10 February 2010
Published Online First
26 June 2010

ABSTRACT

Aim To compare the flow rates of readily available intravenous infusion devices and to compare the effect of the addition of pressure or a needle-free intravenous connector device.

Methods Several intravenous devices with different characteristics had their flow rates determined under a standard set of conditions. The flow rates were then measured with the addition of a pressure bag to the system and then with a needle-free intravenous connector device. The flow rates and change in flow rates were then analysed.

Results The results showed a general agreement with Poiseuille's law. The needle-free connector slowed the rate of flow by up to 41.4% with the greatest effect on short, wide-bore devices. The addition of pressure had a greater effect on longer devices.

Conclusions Short, wide cannulae should be used when rapid fluid resuscitation is required. Needle-free devices should not be used when rapid fluid resuscitation is needed.

INTRODUCTION

Poiseuille's law states that flow of liquid in a tube is directly proportional to the radius to the power 4 and inversely proportional to the length. This means that in theory a short, wide-bore cannula is preferable to a longer, narrower venous catheter in a situation where large volumes of fluid need to be infused rapidly. Poiseuille's law also tells us that rate of flow is also directly related to pressure.

There has been little work published on the practical application and comparison of these principles and teaching and clinical practices, such as in advanced trauma life support,[1] are based on theory rather than experimental comparisons. Study data published in 2006 did however show that by reducing the length of 14, 16 and 18 gauge cannulae to the length of a 22 gauge cannula flow rates could be increased by up to 18% and the time taken to infuse a litre of saline reduced by up to 15%.[2]

In recent years the use of needle-free intravenous access systems has increased with the intention of decreasing needlestick injury, avoidance of touch contamination of intravenous equipment and decreasing blood and fluid spillage. While these are desirable, the insertion of these devices appears to act as a 'flow restrictor' and significantly reduce the rate at which fluids can be administered. Previous work on the use of antireflux valves has shown that maximum flow rate of fluid through a 16 gauge cannula can be reduced by up to 38% under gravity but little effect was noted on flow rate when using a 20G cannula.[3]

The aim of this study is to compare the flow rates of readily available intravenous access devices with differing physical characteristics and to compare the effects of the addition of a pressure bag or a needle-free intravenous access connector on the different cannulae.

METHODS

A variety of sizes of intravenous fluid administration devices were employed in the study. These were a selection of different devices available in our emergency department (ED), table 1. The distal 16G port and the proximal 18G port of the 15 cm triple lumen central venous catheter were used. The distance measured from the injection hub to the exit port on the catheter was considered to be the length of the device.

A 1-litre bag of 0.9% saline was connected to each cannula in turn by a standard giving set. The combined weight of the cannula, giving set and bag of saline was recorded before the bag was hung from an intravenous stand which was set at a height of 130 cm above a sink. A height of 130 cm was chosen as an approximation of the height above the resuscitation trolleys that our intravenous stands are set at in our resuscitation room. The cannula was taped to the sink in order to prevent any movement. The giving set valve was fully opened and the fluid was allowed to run for 10 min or until the point where it stopped running into the top chamber of the giving set. The apparatus was then weighed and the difference in the weight before and after was recorded. The volume of normal saline that had run through the infusion set was then calculated.

The experiment was repeated with the addition of a Vygon 'Bionector' needle-free intravenous access device to each cannula. A further run through of the experiment was performed without the Bionector but with the addition of a standard intravenous pressure bag, which was inflated to a pressure of 300 mm Hg prior to the fluid being released. The percentage change in flow rate for each cannula with the addition of a Bionector or pressure was then calculated.

RESULTS

The flow rates and changes to the flow rates with the addition of pressure or a Bionector are summarised in table 2.

DISCUSSION

The results show, not surprisingly, a general agreement with Poiseuille's law. The width and length of a cannula had a predictable effect on the rate of flow of saline. The comparable rates between a 22G 25 mm cannula and an 18G central line port and a 20G 33 mm cannula with a 16G central line port produced an interesting and unexpected result in that the central line did not outperform these small cannulae. This probably says more about our

Table 1 Intravenous devices

Catheter	Description	Size
Braun* vasofix safety cannula	Standard over the needle cannula	22G 25 mm
Braun vasofix safety cannula	Standard over the needle cannula	20G 33 mm
Braun vasofix safety cannula	Standard over the needle cannula	18G 45 mm
Braun vasofix safety cannula	Standard over the needle cannula	16G 50 mm
Braun vasofix safety cannula	Standard over the needle cannula	14G 50 mm
Hospira† 'Abbocath-T'	Over the needle rapid access catheter	14G 140 mm
Vygon‡ 'Leadercath'	Single lumen Seldinger technique central venous catheter	14G 150 mm
15cm triple lumen central venous catheter	Triple lumen Seldinger technique central venous catheter	16G 34 cm distal port
15cm triple lumen central venous line	Triple lumen Seldinger technique central venous catheter	18G 35 cm proximal port

*Braun Medical, Sheffield, UK.
†Hospira UK, Royal Leamington Spa, UK.
‡Vygon UK, Cirencester, UK.

Table 2 Flow rates of devices

Intravenous catheter	Rate of flow with gravity (ml/min)	Rate of flow with pressure (ml/min)	Rate of flow with Bionector (ml/min)	Percentage increase with pressure	Percentage decrease with Bionector
14G 50 mm cannula	236.1	384.2	138.3	62.7%	−41.4%
14G 14 cm Abbocath	197	366	131.3	85.8%	−33.4%
16G 50 mm cannula	154.7	334.4	109.6	116.2%	−29.2%
14G 15 cm Leadercath	117.3	211.1	101.1	80%	−13.8%
18G 45 mm cannula	98.1	153.1	80.3	56%	−18.1%
16G distal port triple lumen central line	69.4	116.1	67.4	67.3%	−2.88%
20G 33 mm cannula	64.4	105.1	58.5	63.2%	−9.17%
22G 25 mm cannula	35.7	71.4	34.7	100%	−2.80%
18G proximal port triple lumen central line	29.7	79.3	28.7	167%	−3.37%

expectations of a central line rather than any claims made the by manufacturers as the documented flow rates on the packaging of the 16G line and 20G cannula were similar as were the 18G line and the 22G cannula.

The addition of pressure appears to have had a greater effect on longer cannulae. The 14G Leadercath and 14G Abbocath both have a greater increase in rate of flow with the addition of pressure than the shorter 14G cannula. The greatest increase in flow with pressure is with the 18G central line port. The increase in rate of 116% seen with the 16G cannula is unexplained.

Vygon's quoted flow rate for a Bionector is 170 ml/min but the addition of a Bionector to a cannula slowed the rate to well below this level, the fastest flow rate with a Bionector being 138.3 ml/min for a 14G 50 mm cannula. The addition of a Bionector, predictably, had less effect on the slower cannulae than on the faster ones and there may be a lesser effect on those whose rate is influenced more by length than by diameter. This again would be in keeping with the principles of Poiseuille as the addition of a Bionector extends the length of a central line by a smaller percentage than it does a small cannula.

The difference in flow rates between the Leadercath and Abbocath is quite marked given that they are both 14G and there is only a 10 mm difference in their lengths. From the available information the significant difference between the two catheters is that the Leadercath is made from polyurethane while the Abbocath is made from fluorinated ethylene propylene (FEP), a Teflon substance. The lower coefficient of friction of FEP may account for the difference between the two devices.

There are some obvious limitations to this study. Each combination of apparatus was only tested once. This gives a greater chance of experimental error than if the experiments were conducted multiple times.

With the 'faster' cannulae the fluid ran through in less than 10 min and, especially in the pressure bag experiments, the flow as the bag became emptier would have changed. This would have likely given a slower flow rate than if a much shorter time was used, therefore the difference between the fastest and slowest catheters would have been more pronounced.

All the devices used had flow rates quoted by the manufacturers and there is an industry standard procedure for determining flow rate. The purpose of this study was not to test this flow rate but to compare the devices under the same conditions and to look at what happened when they had additional factors added to the infusion circuit.

CONCLUSIONS

In situations where rapid fluid resuscitation is needed fluid delivery by a peripheral cannula of size 18G or greater is preferable to infusion by central line. If a central line is the only obtainable access then the addition of a pressure bag makes a greater difference to rate of flow than it would with a peripheral cannula.

An over the needle FEP large-bore cannula inserted into a large vein is likely to give a greater flow rate than a Seldinger type polyurethane catheter and would be preferable if all other factors are equal.

A needle-free intravenous access connector should not be used when rapid fluid resuscitation is required as it slows the rate of flow by up to 40% with peripheral cannulae.

Competing interests None.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1. **American College of Surgeons Committee on Trauma.** *Advanced trauma life support program for doctors*, 8th edn. Chicago, Illinois, USA: American College of Surgeons, 2009.
2. **Jayanthi NVG,** Dabke HV. The effect of IV cannula length on the rate of infusion. *Injury* 2006;**37**:41—5.
3. **Hall JM,** Roberts FL. An investigation into the reduction in flow rate of intravenous fluids by antireflux valves. *Anaesthesia* 2005;**60**:797—800.