RESULTS OF FLOW TESTS CARRIED OUT ON CANNULAS AND TUBING

TESTS CARRIED OUT 2022

SYNOPSIS

During perfusion, perfusion pressure needs to be accurately monitored to ensure that the pressure is neither too high, risking damage to the brain, nor too low, risking incomplete perfusion. However, wherever it is measured, there will be a drop in head across the cannulas to the carotid arteries and any other tubing or equipment between the monitoring point and the patient, resulting in measured pressures being higher than that actually delivered to the patient.

Although this problem is recognised by cryonics practitioners, no published data on the extent of the errors that may arise could be found. To determine whether such errors are significant, simple testing was carried out for cannulas and tubing of the type used during Cryonics UK's standard perfusion methods.

It is concluded that, at the flows normally used during perfusion, errors in pressure measurement due to loss of pressure across the cannulas used by Cryonics UK are generally small, and may be ignored. Essentially, where good flow is obtained, the perfusion process will be largely controlled by the rate of flow, and any pressure loss across the cannulas is not a concern, whilst when flows are poor, there will be negligible pressure loss across the cannulas.

Pressure loss across the standard 6.4mm (¼") delivery tubing will be small but combined losses due to narrower tubing, a filter, flow meter or heat exchanger, depending on the equipment used. For this reason, the perfusate (cryoprotectant) pressure should be checked just before the perfusate enters the cannulas, as shown in Figures 1 and 2, as given in the Cryonics UK call-out manual.

BACKGROUND

PERFUSION PRESSURES AND FLOW RATES

There has been much discussion over the years about the best pressures to use for perfusion. Until recently, a sustained pressure of about 140mm Hg (mercury) was considered to be a suitable maximum with a possible slight increase for brief periods. More recently, there has been a trend to recommend lower pressures, typically 80-100mm Hg. Cryonics UK currently uses 80-100mm Hg, with the option to increase this to 120mm Hg if flow becomes too slow. This compares with the maximum desirable systolic pressure in a living person of 140mm Hg, above which they are considered to be suffering from hypertension, although many people do, in fact, have much higher systolic blood pressure without suffering noticeable brain damage.

Recommendations[1] also include reducing pressure if necessary to avoid excessively high flows to give the perfusate time to fully perfuse tissue. For the final stages, a maximum rate of 1 litre of perfusate in 30 minutes is recommended, but flows could be higher, perhaps twice this. These rates correspond to about 35mL/minute and 70mL/minute, respectively.

MEASUREMENT OF PERFUSION PRESSURE

Perfusion pressure is important because excessive pressure could cause brain damage and too low a pressure could result in poor perfusion. Because of the importance of maintaining the correct perfusion pressure, it is normally monitored in several ways:

- by pressure gauge in the perfusate tubing just before the cannulas to the carotid arteries – see Figures 1 and 2;
- by pressure gauge in the pump, for the CUK pressure pump system – see Figure 1; and
- by measuring the height of the perfusate above the patient, for the Alcor gravity feed system – see Figure 2.

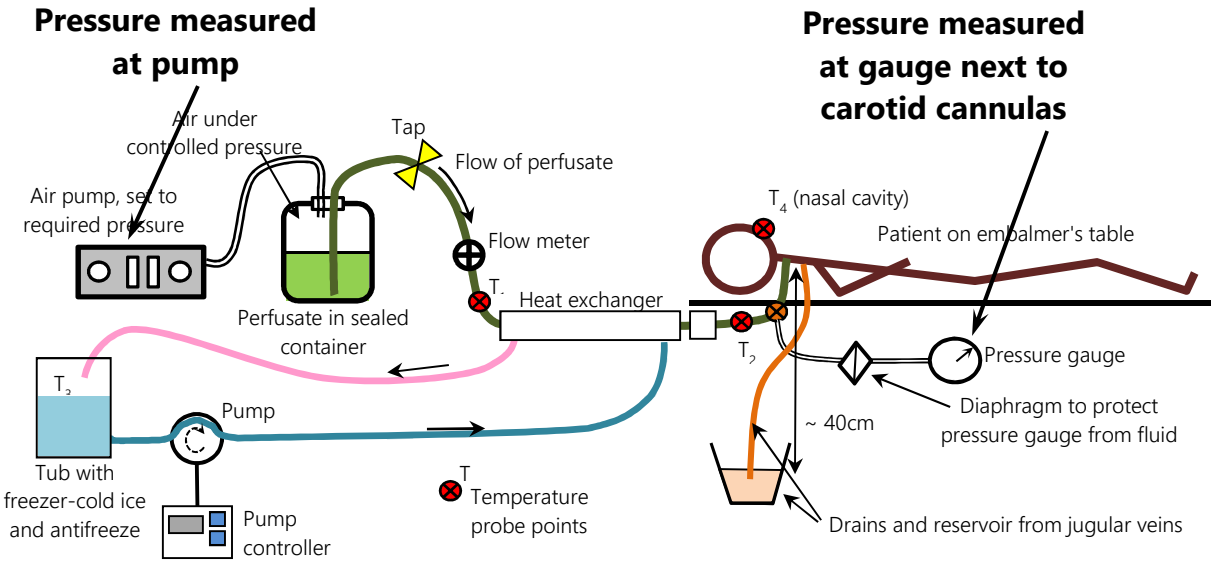

Figure 1 – Perfusion using a pressure pump system

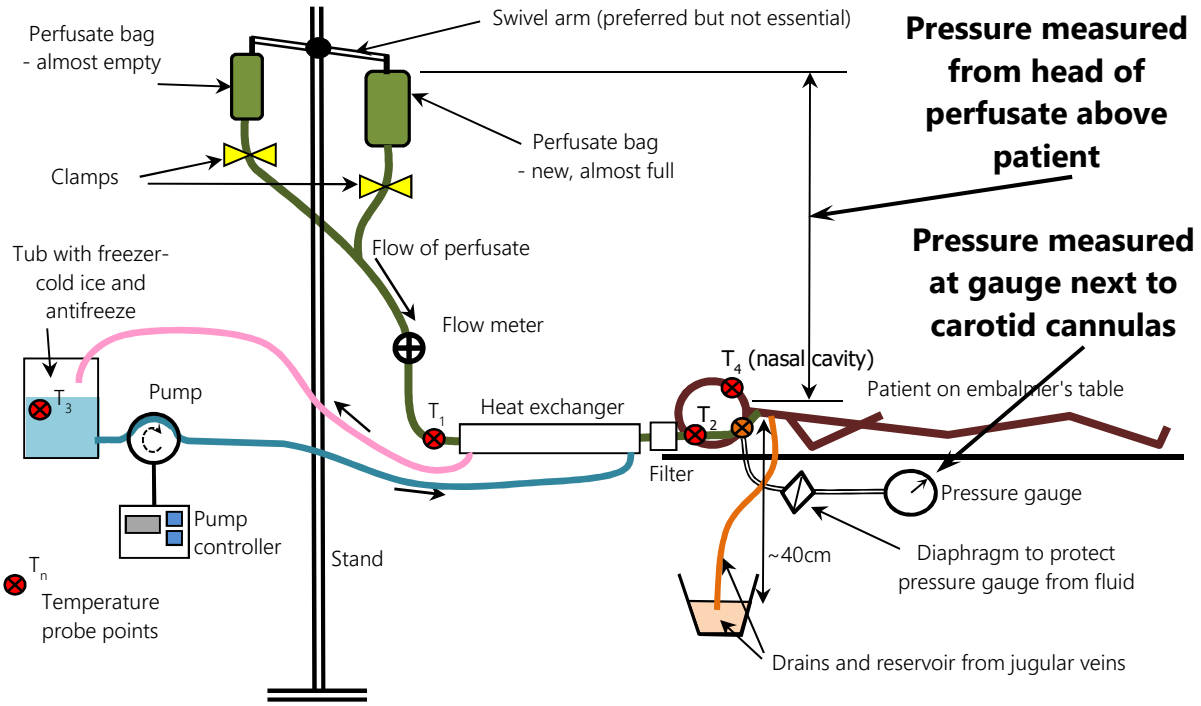

Figure 2 – Perfusion using a gravity flow system

As fluid flows through the cannulas, there will be head loss due to friction, and it has been commented[2] that this could mean that the actual delivered pressure to the patient is less than that measured in the gauge just before the carotid cannulas. If pressure is measured at the pump or calculated pressure from head of perfusate, further errors will occur due to friction in the tubing and equipment such as a filter, flow meter or heat exchanger.

TESTS AND RESULTS

To determine whether this is an issue and, if so, whether corrections should be used to allow for pressure loss in the system, a series of simple tests was carried out, to measure flow against pressure head for various pressure heads and cannula sizes. A test of the tubing, without a cannula, was also included to determine pressure loss in the tubing. The arrangement is shown diagrammatically in Figure 3. The cannulas and tubing used, which were all soft plastic, are shown in Figure 4. Their relevant dimensions are given in Table 1.

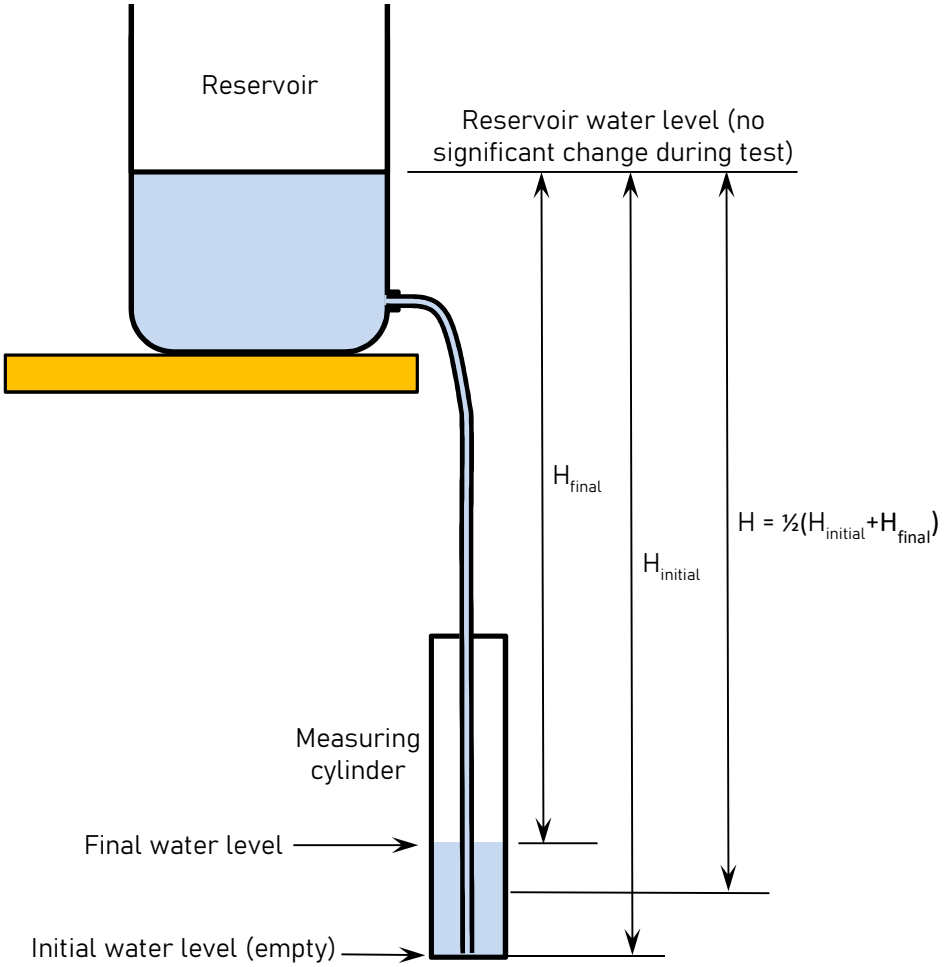

Figure 3 – Arrangement used to measure flow in a cannula/tubing system for various values of pressure (i.e. pressure loss)

Cannula A represents the typical sized cannula that is used for insertion into the carotid arteries for perfusion. The smaller cannulas might be used in smaller vessels if, for instance, perfusion were carried out in a child, or through the vertebral arteries; a procedure that has some advantages but is difficult to perform.

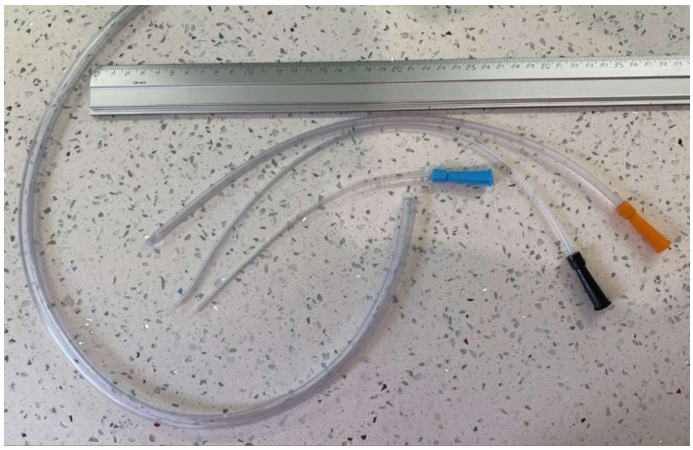

Figure 4 – Cannulas A (orange) and C (blue) and 6mm tubing used in tests

CANNULA AND TUBING DIMENSIONS

Cannula A (orange)
length 350mm diameter 3.2mm

Cannula B (black)
length 350mm diameter 2.0mm

Cannula C (blue)
length 188mm diameter 1.6mm

Tubing
length 1900mm diameter 6.4mm (¼")

Table 1 – Dimensions of cannulas and tubing used in tests

Initially, flow was measured for the three cannulas used, attached to a length of tubing. This enabled pressure to be plotted against flow for each tubing/cannula system. Next, the test was repeated for the tubing without a cannula.

A curve was fitted to each set of data using polynomial (parabolic) functions. This enabled pressure (i.e. pressure loss) for each tubing/cannula system to be obtained for any flow rate. This, in turn, allowed the head loss in the cannula itself to be determined, by deducting the head loss in the tubing for any given flow from the total head loss in the tubing/cannula system.

The results obtained are shown in Table 2. Figure 5 presents the results graphically for the typical range of flows likely to be encountered during perfusion.

Flow rate – mL/min	Head loss across cannulas and along tubing – mm Hg							
	Water				70% VM1 perfusate			
	Cannula A	Cannula B	Cannula C	Tubing, per m	Cannula A	Cannula B	Cannula C	Tubing, per m
10	0	1	2	0.0	0	3	7	0.3
20	0	3	4	0.1	1	6	16	0.5
35	1	5	7	0.1	1	12	32	1.0
50	1	8	11	0.2	2	17	52	1.4
70	2	11	16	0.3	2	26	84	2.0
100	2	17	25	0.5	4	39	144	2.9
200	6	38	62	1.2	8	98	448	6.5
300	9	63	110	2.2	13	175	910	10.7
400	14	93	169	3.5	19	270	1530	15.6
500	19	128	240	5.1	26	385	2310	21.1
600	24	167	323	7.0	34	518	3248	27.2
800	38	258	522	11.6	51	842	5602	41.3
1000	54	367	767	17.4	72	1240	8590	57.9

Table 2 – Pressure loss across cannulas and tubing for various flows

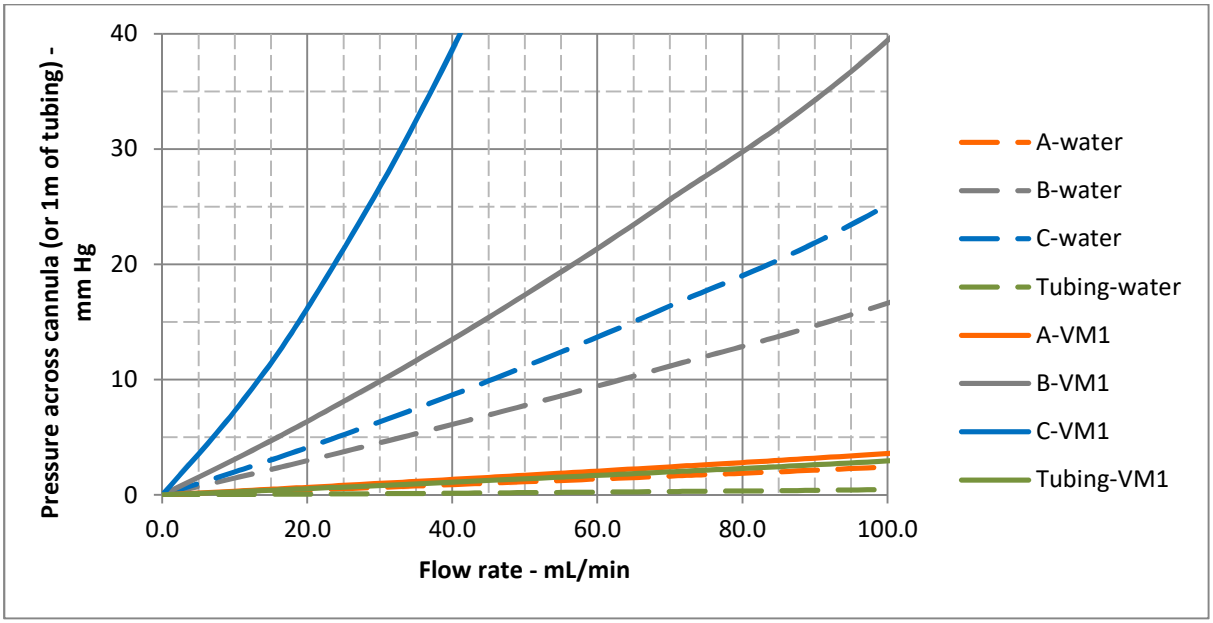

Figure 5 – Pressure loss across cannulas and tubing for various flows

DISCUSSION

HEAD LOSSES AND FLOW RATES – CANNULAS AND TUBING

The head loss values shown in Table 2 and Figure 5 should be viewed in relation to the overall perfusion pressure of 80-100mm Hg, possibly increasing to 120mm Hg for very low flows. A further consideration when assessing the results is the actual flow rates typically used in perfusion. As stated previously, flow rates during perfusion will be less than 70mL/min, reducing to no more than 35mL/min in the final stage. Since perfusate flows through two cannulas, in parallel, actual flows through each cannula will be half these values, so the maximum flow rate through a cannula would be unlikely to exceed about 35mL/min for dilute perfusate and about 20mL/min for the concentrated, final stage perfusate.

Head loss in relation to these considerations is discussed below.

Head loss for water (similar viscosity to saline solution and dilute perfusate)

It can be seen from Table 2 (cells highlighted in blue) that:

- at a maximum anticipated flow through a cannula of 35mL/min, head loss through cannulas A, B and C was 1, 5 and 7mm Hg, respectively – that is, losses were negligible to minor;
- at a maximum anticipated flow through the tubing of 70mL/min, head loss was 0.3mm Hg per metre of tubing – giving a negligible head loss of 0.6mm for a 2m length of tubing;
- thus, the combined head loss through the cannulas and 2m of tubing during normal perfusion procedure would less than 10mm Hg.

Head loss for 70% VM1 perfusate (final stage perfusion, maximum viscosity)

Again, from Table 2 (cells highlighted in fawn):

- at a maximum anticipated flow through a cannula of 20mL/min, head loss through cannulas A, B and C was 1, 6 and 16mm Hg, respectively – that is, losses were again negligible to minor, though noticeably higher in cannula C, the smallest cannula;

- at a maximum anticipated flow through the tubing of 35mL/min, head loss was 1.0mm Hg per metre of tubing – giving a head loss of 2.0mm for a 2m length of tubing;
- thus, the combined head loss through the cannulas and 2m of tubing is less than 10mm Hg for cannulas A and B but was higher for cannula C, at 18mm; and
- at the very low flows, of about 20mL/min through the tubing, 10mL/min through each cannula, which can occur during the later stages of perfusion, combined head loss through the cannulas and tubing would be less than 10mm, even for the smallest cannula.

OTHER SOURCES OF HEAD LOSS

Other items in the tubing/cannula system that may affect pressure loss are: the use of narrower tubing; the heat exchanger; and other obstructions such as a filter or flow meter.

Theoretical calculations, which give good agreement with measured values for the 6.4mm (¼") tubing tested, suggest that reducing the tubing diameter to 4.76mm ($^3/_{16}$") would result in negligible pressure loss for water or 70% VM1 at the anticipated flows. Reducing the tubing further, to 3.18mm ($^1/_8$"), would result in about 10-15mm head loss for water at 70mL/min and a similar amount for VM1 at 35mL/min.

The effects of a filter, flow meter, or heat exchanger will depend on the specific equipment used during a perfusion. The combined effect of all these could be significant especially for final-strength perfusate. This could lead to significant errors in measured perfusate pressure if the pressure is determined by the pressure at the pressure pump (for the pressure system, Figure 1) or by the height of the perfusate reservoir above the patient (for the gravity system, Figure 2). However, if the pressure is measured just before the fluid flows into the cannula, as indicated in the figures, then these errors will be avoided. However, as stated in the Cryonics UK manual, it is imperative to set up the pressure gauge correctly to avoid errors. (Accuracy of the pressure gauge measurements can be checked against the pump or head measurements when there is no flow, when the pressure difference between any two points on the system will be determined only by their difference in height.)

CONCLUSION

For the flow rates normally used during Cryonics UK standard perfusion methods, pressure loss across any of the typical cannulas used by Cryonics UK is small, and no correction will be needed to allow for this. Similarly, for the typical 6.4mm diameter tubing that is normally used, pressure loss along the length of tubing, up to 2m length, will be very small. There could be some significant pressure loss across the delivery tubing, depending on the tubing diameter, and any equipment such as a filter, flow meter or heat exchanger, so that pressure should be checked just before the perfusate enters the cannulas. Details of this are given in the Cryonics UK call-out manual.

REFERENCES

1. Recommendations are based on *Human Cryopreservation Procedures*, Aschwin de Wolf and Charles Platt, 2020.
2. Conversations primarily with Cryonics UK; with Aschwin de Wolf of Advanced Neural Biosciences; Andy Zawacki of Cryonics Institute, and others.

M. Carter July 2022