USE OF A HEAT EXCHANGER TO CONTROL THE TEMPERATURE OF CRYOPROTECTANT ENTERING THE BODY

BACKGROUND

The Cryonics UK (CUK) call-out manual includes a procedure for cooling the cryoprotectant before it enters the body via the carotid artery during perfusion. The arrangement is shown below. However, there has been some concern about the effectiveness of this method, and whether it could warm the cryoprotectant in certain circumstances rather than cooling it. This is reflected in warnings in the call-out manual. As a consequence, the use of a heat exchanger and associated cooling fluid has generally been omitted in call-out situations.

To check these concerns, tests were carried out in April 2019, just prior to the 6/7 April CUK training meeting. Testing was intended to give an indication of the effectiveness of the method and to provide sufficient information to allow improved methods to be adopted. It was not intended to provide data on exact rates of cooling for different conditions.

TESTING CARRIED OUT

The test conditions used were:

- Water was used to simulate 10% and 30% VM1 perfusate. Part of the time it was used at ambient temperature (about 8°C) and at other times it was cooled with ice (to about 4 to 5°C) to simulate perfusate stored in a refrigerator.
- The cooling fluid used in the heat exchanger circuit was ethylene glycol antifreeze as used for car engines.
- Ice and freezer blocks, from a freezer at about -18°C, were used (separately) to cool the cooling fluid.
- The rate of flow of "cryoprotectant" (i.e. the water used in the tests to simulate cryoprotectant) was adjusted to be similar to the rates expected during a typical perfusion. Adjustment was based on visual inspection of outflows and a flow indicator. From observed level changes in the fluid reservoirs, a "moderate" flow, used to simulate initial rates expected in most cases, was about 60mL/min. A "slow" rate of around 10L/min was also used to simulate cases where there is poor patient uptake.

EXISTING EQUIPMENT SET-UP

The heat exchanger set-up was assembled and run using the submersible pump arrangement given in the CUK manual and shown in Figures 1 and 2. In addition, temperature probes were introduced to check the temperature of the "cryoprotectant" before and after passing through the heat exchanger and of the antifreeze coolant .

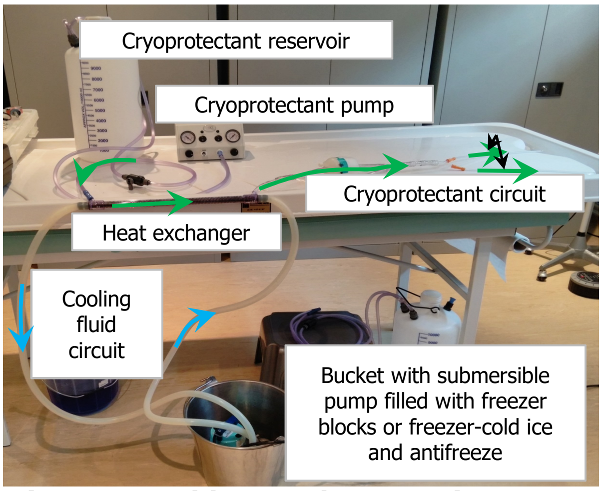

Figure 1 Old procedure: equipment

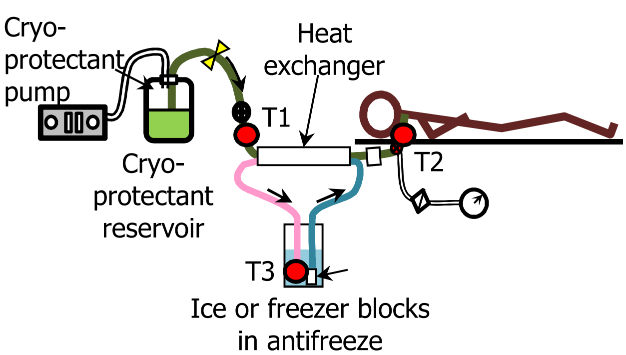

Figure 2 Old procedure: schematic

Temperature readings at points T1 and T2 showed that, for both freezer blocks and ice cubes, the "cryoprotectant" was heating up by about 2°C as it passed through the heat exchanger. The antifreeze in the bucket was also found to be heating up, despite flowing through the cold freezer blocks or ice cubes.

The problem was traced to the submersible pump which is quite powerful, at 750W, all of which is transferred to the coolant solution as heat as it passes through the pump. This more than negates the cooling effect of the ice cubes or freezer blocks, and results in the antifreeze being over to 20°C as it leaves the pump and enters the heat exchanger. This validates the concerns that the procedure would be counter-productive, and earlier reluctance to use it. Any arrangement must have a pump whose motor is outside the coolant circuit and that is cooled externally of the coolant circuit.

NEW ARRANGEMENT

The problem of the submersible pump was solved by using a roller pump that had previously been used to deliver cryoprotectant during perfusion of patients (now replaced by a pressure system). This is a much more complicated and costly piece of equipment than is really needed but was used since CUK has two of these pumps that are no longer used.

The circuit is essentially the same as that shown in Figure 2 but unlike the submersible pump, the roller pump requires the coolant circuit to be mainly free of air with the coolant reservoir above the level of the pump. The change of that part of the circuit is shown in Figure 3, and the equipment is shown in Figure 4.

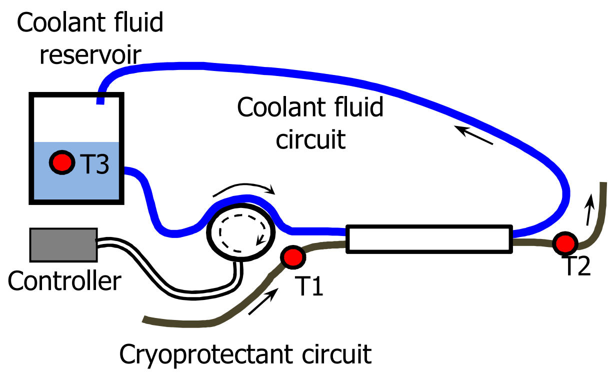

Figure 3   New pump circuit

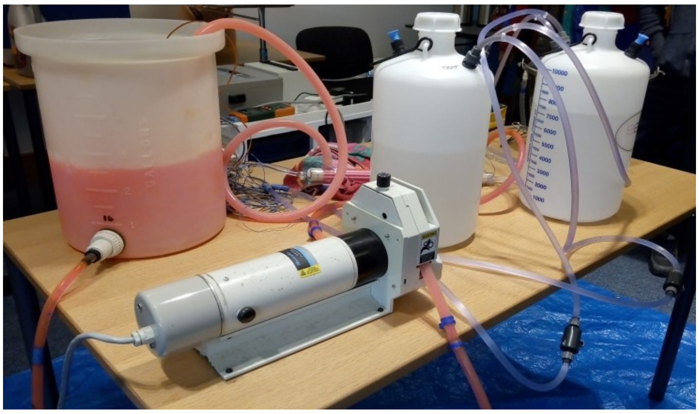

Figure 4   Equipment for new circuit

The main findings of the tests were:

- Freezer blocks gave little cooling of the "cryoprotectant"; typically only 1 to 2°C for "cryoprotectant initially at about 4°C.
- Ice cubes gave about 4°C cooling for "cryoprotectant" at a "moderate" flow rate and initial temperature of 5 to 8°C (all values approximate). Tests at "low" flow showed cooling of 6 to 7°C for an initial temperature of about 8°C. For very low flow, the "cryoprotectant", being actually water in the test, froze in the heat exchanger.
- With ice cubes in the coolant reservoir, the temperature of the antifreeze cooling fluid hovered at about -11 to -10°C throughout most of the testing, rising to about -9°C after 30 minutes of continuous pumping, indicating that the ice cubes were continuing to cool the fluid effectively even after this time.
- Demonstrations of the procedure during the weekend training session, using ice cubes that had been kept in an electric cool box for some hours, gave similar amounts of cooling of the "cryoprotectant" even though the ice cubes were slightly warmer, giving an antifreeze coolant temperature of about -9°C to -8°C.

WHAT HAS BEEN LEARNED

The lessons to be learned from the testing are:

- A submersible pump, especially if it is high power, is unsuitable for use with the heat exchanger because the heat generated by the pump is transferred to the cooling fluid, resulting in the cryoprotectant being warmed, not cooled.
- Freezer blocks, which potentially offer better performance than ice cubes because of their lower melting point, do not perform as well as ice because of their lower surface area and the poor heat transmission through their plastic sides.
- Ice from a freezer at about -18°C will cool the antifreeze coolant to about -11°C during perfusion, allowing cryoprotectant at about 4°C to 8°C to be cooled to be cooled by about 4°C for moderate flows and by about 6°C to 8°C for low flows. This gives sufficient temperature control to ensure that dilute cryoprotectant fluid can be delivered at optimum temperature.
- To ensure good temperature control, the temperature should be monitored at point T2 (just before entering the patient). Monitoring of temperatures at points T1 and T3 is also desirable but not essential. This monitoring can be achieved using CUK's existing temperature probes and data logger which can monitor 4 probes simultaneously, allowing an additional probe to monitor patient temperature in the usual way.
- The method is suitable for cooling cryoprotectant in the earlier stages of perfusion when dilute solutions are used (e.g. Cryonics Institute's 10% and 30% VM1 solutions which are stored in a refrigerator at about 4°C) but is not suitable the concentrated solution used in the later stages of perfusion (e.g. Cryonics Institute's 70% VM1 which is stored in a freezer at about -18°C).

CONSEQUENCES FOR CUK PERFUSION METHODS

- The temperature of cryoprotectant entering the patient should be monitored and, for low concentration cryoprotectant, a decision made as to whether it should be cooled using the heat exchanger. This will depend on its initial temperature.
- If cooling is used, the new method using a roller pump should be used. A submersible pump should not be used.
- For higher concentration cryoprotectant which is normally delivered too cold to be further cooled by this method, insulating covers should be used over the cryoprotectant reservoir bottles to keep it as cool as possible during perfusion. These covers will also be advantageous for lower concentrations.
- These changes in procedure should take place with immediate effect and will be incorporated in the next update of the CUK call-out manual.