Venous drainage is key for CPB

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Introduction

The importance of venous drainage is often underestimated during cardiopulmonary bypass where high blood flows are required continuously. As a matter of fact, the pump flow that can be achieved in cardiopulmonary bypass is almost entirely inflow dependent. At typical flow rates for adult patients of 4 l/min, even a venous reservoir level of 2.5 litres provides sufficient volume to maintain flow for just about 30 seconds (= 2 litres) if venous drainage is interrupted for some reason (eg venous line collapse, air leak etc). Thirty seconds are indeed not much time to identify and solve all sorts of possible problems. However, for a reservoir level of 500 ml at the time of venous drainage shut-down, the remaining time for action is close to zero, and, hopefully, the pump is stopped automatically. It is well known that for the arrested heart, the available time to solve such problems and to get the pump restarted is counted in minutes and is, of course, temperature dependent.

Remote cannulation

Compared to routine procedures with central cannulation as outlined above, inadequate venous drainage is more often a problem with remote venous, eg femoral cannulation, as it is preferred for small access surgery, redo procedures and other complex operations. To some degree, the limits of venous drainage with remote cannulation can be overcome by augmentation using either a centrifugal pump or vacuum assistance. However, there are anatomical, physiological and physical limits to the augmentation of venous return with these techniques as well as safety factors to be considered.

Anatomical limitations for augmentation of venous drainage

In adults, the typical diameter of the inferior vena cava is more than 20 mm and the flow to be handled at rest by the inferior vena cava is about two-thirds of the cardiac output or target flow. In contrast, the diameter of an access vein in the groin measures about 8 mm and allows for a 24 Fr percutaneous cannula, which in turn has to handle the entire pump flow, typically around 4 l/min at normothermia for target flow of 2.4 l/min/m².

Physiological limitations for augmentation of venous drainage

The superior and inferior vena cava as well as the right atrium have naturally a soft wall and this allows them to adapt in size to the blood volume to be held and transported. This design implies that positive intravenous pressure is necessary to prevent the venous system from collapsing. Hence, the more pronounced negative pressures created by the augmentation of venous return with centrifugal pumps or vacuum are not always helpful and can shut down venous drainage completely. That phenomenon is also the reason why percutaneous cannulae used for remote cannulation in cardiopulmonary bypass have to be long enough to reach the right atrium, where more blood is available for drainage. However, the soft tissues of the right atrium can also get sucked into the orifices of the cannula and this again compromises venous drainage. It has also to be mentioned here that the formed elements of the blood (eg red cells) resist compression quite well, but rapid decompression or strong negative pressures are not tolerated and result in haemolysis. This phenomenon and the risk of cavitation are further reasons why the negative pressure generated for augmentation of venous return should be limited to 50 mmHg.

Physical limitations for augmentation of venous drainage

It is a fact that there is no pump in the world that can suck water from more than about 10 m below its position, because the maximum vacuum that can be generated by the strongest pumps is at best close to the barometric pressure or approximately 760 mmHg (torr). Furthermore, the resistance in a rectilinear tube or a long percutaneous cannula and its tubing increases with its length, up to a point where flow can no longer be improved whatever the pump performance. In contrast, the flow increases with the diameter of a tube by the power of four. Hence, a venous cannula that has twice the diameter will allow sixteen times more flow.

Smart cannula designs

Self-expanding venous cannulae (smart canula®, Smartcanula LLC, Lausanne, Switzerland) as shown in figure 1 have been designed to overcome the limitations outlined above. As a result of the smart cannulation principle – "collapsed insertion and expansion in situ" – a cannula with a large diameter can be brought into the inferior vena cava, the right atrium and the superior vena cava even if the access vessel is relatively small, as in the groin. Traditional percutaneous cannulae are rectilinear, and therefore the access vessel diameter determines the cannula diameter over its entire length. Figure 2 shows this situation, where a traditional percutaneous cannula was inserted through the femoral vein. As a result, the cannula diameter is relatively small at the level of the right atrium and the entire blood flow has to be pulled through this narrow lumen in order to reach the pump-oxygenator. Typically a 24 Fr cannula is used and if we calculate the surface of Continued on next page
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the cross section even with zero wall thickness the area available for flow is only about 50 mm².

In contrast, a smart cannula® inserted through the same common femoral access vessel measures 16 Fr at time of insertion and opens up to 36 Fr once after shape change (figure 3). Up to 50% more flow can be reached by gravity drainage alone. However, this excellent result is not only due to the increased cannula diameter over a large proportion of its length, but also to the fact that the grid structure allows for direct drainage of renal flow, for example, into the cannula lumen without having to travel first to the right atrium and then over the entire length of the narrow lumen of a traditional rectilinear percutaneous cannula.

Figure 3 shows also the recommended position of the smart cannula® tip within the superior vena cava, thus allowing for keeping the entire caval axis, i.e., the superior vena cava, the right atrium, the inferior vena cava and one iliac vein open for venous drainage, a technique we call “temporary caval stenting”.

Current and future developments

The smart cannula principle can also be applied to paediatric venous cannulae where 15/24 Fr and 12/20 Fr designs are now available. On the arterial side, the self-expanding mechanism is helpful for cannulation of spastic arteries where it can be very difficult to insert traditional cannulae of adequate size.

The concept of temporary stenting of the venous blood path can also be extended further to meet challenging clinical situations. It is well known that volume loss is a major problem during ECMO procedures for failing/fibrillating hearts where an important proportion of the circulating blood volume can get pooled in a dilating left ventricle, left atrium and pulmonary vasculature. Figure 4 demonstrates the technique of trans-pulmonary decompression of the left ventricle which has been successfully used in the experimental setting for recovery of the blood volume and consequent normalization of the pump flow.

New versions of the Smartcannula are being developed for use in ECMO procedures.

References


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