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PHYSIOLOGICAL AND TECHNICAL NOTES

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Pressure-guided positioning of bicaval dual-lumen catheters for venovenous extracorporeal gas exchange

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Abstract *Purpose:* Bicaval dual-lumen catheters allow for single-site cannulation venovenous extracorporeal gas exchange and facilitate early mobilization of patients. Using these catheters blood is drained from the superior and inferior venae cavae, pumped through a respiratory membrane, and returned into the right atrium. The insertion of these catheters is challenging as their correct positioning is fundamental to reduce recirculation and avoid severe complications. We describe here a new technique for the positioning of bicaval dual-lumen catheters. *Materials and methods:* The right internal jugular vein was percutaneously cannulated in nine sheep. The distance between skin and tricuspid valve was measured from the point of pressure change in the waveform of a Swan–Ganz catheter being retracted from the right ventricle into the right atrium. The atrium-tricuspid valve-ventricle axis was determined by observing the fluctuations of the tip of the Swan–Ganz entering the ventricle during fluoroscopy. A bicaval dual-lumen catheter was placed on the basis of these evaluations and connected to an extracorporeal respiratory support system. *Results:* The position of the catheter was verified at necropsy approximately 18 h after insertion. In all cases the catheter was correctly placed, with the central port situated in front of the tricuspid valve. *Conclusions:* The described technique may help to position bicaval dual-lumen catheters for venovenous extracorporeal gas exchange without the use of transesophageal echocardiography or contrast media during fluoroscopy.

Keywords Extracorporeal membrane oxygenation · Catheterization · Acute respiratory distress syndrome

Introduction

Bicaval dual-lumen catheters are increasingly used to perform extracorporeal gas exchange for the treatment of respiratory failure [1, 2]. When using these catheters, blood is drained from the superior and inferior venae cavae through two dedicated ports and is pumped through a respiratory membrane. The blood is then returned to the patient through a separate lumen with its port situated in the right atrium and oriented toward the tricuspid valve (see Fig. 1). Compared to the usual dual-site cannulation (femoro-jugular or femoro-femoral), dual-lumen catheters allow for single-site cannulation, usually performed through the right internal jugular vein. This has the major

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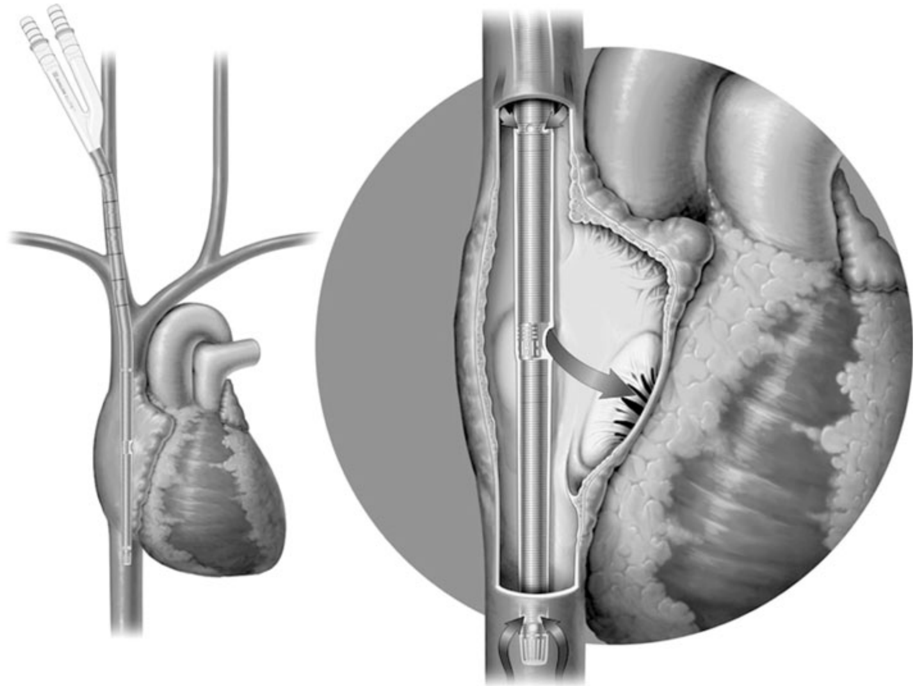

Fig. 1 Representation of a bicaval dual-lumen catheter. Bicaval dual-lumen catheters are usually placed through the right internal jugular vein and advanced into the inferior vena cava. Venous blood is drained from the superior and inferior venae cavae and pumped through a respiratory membrane. The oxygenated and carbon dioxide-cleared blood is thereafter returned to the patient through a dedicated lumen with its port in the right atrium directed toward the tricuspid valve. Image used with permission of Avalon Laboratories, available at http://www.avalonlabs.com/images/image1.jpg

advantage of freeing up the femoral veins thus allowing for passive and active physical therapy [3]. Other putative advantages are a reduced risk of catheter-related infection and insertion site bleeding and reduction in recirculation [4]. Recirculation, which is strictly linked to catheter positioning [5], occurs when oxygenated and carbon dioxide-cleared blood exiting the respiratory membrane through the infusion port is shunted back into the circuit through the drainage ports [6].

Correct positioning of bicaval dual-lumen catheters is therefore a major challenge. The current standard of care for catheter placement is to use fluoroscopy and/or transesophageal echocardiography [1, 7]. Indeed, once the jugular vein has been cannulated, it is essential to advance the guidewire into the inferior vena cava and check its position during progressive dilation in order to avoid looping or displacement of the guidewire [8], as well as potentially severe complications during catheter insertion like ventricular rupture [9]. Moreover, as the three ports of the dual-lumen catheters are not visualized via conventional fluoroscopy, it is usually necessary to use either contrast media [10] or transesophageal/transthoracic echocardiography [1, 7, 11] to assure that the outlet port is in the right atrium. Finally, it is very important to tightly secure the cannula to the skin in order to prevent longitudinal displacement and/or axial rotation. In summary, correct positioning of the catheter is fundamental to reduce recirculation and therefore to optimize the efficiency of extracorporeal respiratory support.

We report here a simple technique for the placement of bicaval dual-lumen catheters that we developed in sheep.

Materials and methods

This study was approved by the US Army Institute of Surgical Research Animal Care and Use Committee and was conducted in compliance with the Animal Welfare Act, the Implementing Animal Welfare Regulations, and in accordance with the principles of the Guide for the Care and Use of Laboratory Animals.

Cannulation and positioning technique

Nine healthy sheep (47 ± 4 kg) were anesthetized, endotracheally intubated, and mechanically ventilated. The neck was sheared and, with the sheep in the supine position, the right internal jugular vein was punctured with an 18-gauge needle under ultrasound guidance. An 8.5-Fr sheath introducer (Arrow International, Reading, PA) was placed via Seldinger technique and a 7.5-Fr Swan–Ganz catheter (Edwards Lifesciences, Irvine, CA) was introduced. The external part of the catheter was connected to a pressure transducer in order to measure the pressure at the distal port of the Swan–Ganz. The balloon was thereafter inflated and the catheter was cautiously

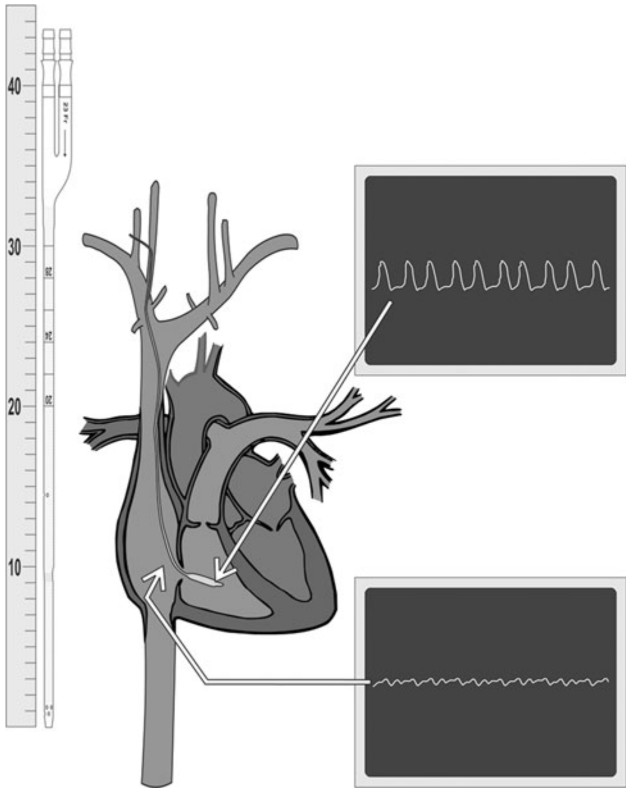

Fig. 2 Schematic representation of the technique. A Swan–Ganz catheter is introduced into the venous system through the right internal jugular vein and advanced into the right ventricle. The atrium-tricuspid valve-ventricle axis is evaluated by observing the fluctuations of tip of the Swan–Ganz entering the ventricle during fluoroscopy. Once the typical ventricular pressure profile is observed (*upper screen*), the catheter is slowly retracted. The catheter is considered to be in the right atrium in front of the tricuspid valve, as soon as the displayed pressure profile changes to atrial (*lower screen*). The Swan–Ganz catheter is thereafter retracted and the introduced distance (skin to tricuspid valve) is measured (the ruler on the left shows distance in cm). As the distance between central and distal port of the used bicaval dual-lumen catheters is known (9.5 cm), this length is added to the distance previously measured and the correct depth of catheter introduction is computed accordingly. The bicaval dual-lumen catheter is placed on the basis of these evaluations

advanced. When the displayed pressure profile changed, indicating the entrance into the right ventricle, fluoroscopy was used to ensure that no coiling of the Swan–Ganz catheter had occurred. Moreover, by observing via fluoroscopy the fluctuations of the tip of the Swan–Ganz passing from the right atrium to the right ventricle, the orientation of the right atrium-tricuspid valve-ventricle axis was evaluated. To assess the exact distance from skin to tricuspid valve, the balloon was thereafter deflated and the Swan–Ganz catheter slowly retracted. As soon as the pressure profile changed from ventricular to atrial (see Fig. 2), indicating the presence of the tip in the right atrium and in front of the tricuspid valve, the Swan–Ganz was removed and the length of the introduced portion of the catheter measured.

A radio-opaque flexible 0.038″ J-guidewire was then introduced through the sheath and advanced through the superior vena cava and the right atrium into the inferior vena cava. Correct position was confirmed via fluoroscopy. After a bolus of 150 U/kg of heparin the sheath introducer was removed, leaving the guidewire in the venous system. Progressive dilation was performed with a standard dilation kit (12, 16, and 20 Fr). A 23-Fr bicaval dual-lumen catheter (Avalon Elite, Avalon Laboratories, Rancho Dominguez, CA) was then inserted. As the distance from the central outlet port (return port) to the distal drainage tip of the used Avalon is 9.5 cm, this length was added to the distance previously measured. For example, if the distance from skin to tricuspid valve was 20 cm, the catheter was introduced for a total of 29.5 cm. Considering the previously evaluated orientation of the tricuspid valve, the cannula was rotated in order to direct the central return port toward the tricuspid valve. The catheter was then connected to the extracorporeal respiratory support system (Cardiohelp, Maquet Cardiopulmonary AG, Hirrlingen, Germany) by a standard wet-to-wet technique and tightly sutured to the skin of the animals. Sheep were then turned to the prone position, placed in a metabolic cage, and awakened. Extracorporeal gas exchange was performed for 18–20 h in awake, spontaneously breathing sheep at a blood flow of approximately 2 L/min.

Results

The bicaval dual-lumen catheter was inserted uneventfully in all sheep. At necropsy the chest was opened and the position of the catheter was evaluated. The correct position of the catheter was confirmed visually in all cases, i.e., the central outlet port was in front of the tricuspid valve and the proximal and distal ports were respectively positioned in the superior and inferior vena cava.

Discussion

By exploiting the pressure profiles of the venous system, the described approach allows for precise measurement of the distance from skin to tricuspid valve without the use of transesophageal echocardiography or contrast media during fluoroscopy. Knowing the distance from central port to distal tip, the depth to which the catheter has to be advanced can be easily computed. Moreover, the fluoroscopic evaluation of the orientation of the tricuspid valve, by observing the fluctuations of the Swan–Ganz catheter entering the right ventricle, seems to be adequate to suggest the optimal rotation of the cannula.

The use of this technique could be of interest in particular for those patients in which extracorporeal respiratory support is started while awake and spontaneously breathing [12, 13]. Indeed, in this particular subset of patients the use of transesophageal echocardiography to guide catheter placement could be very challenging. Moreover, the use of contrast media during fluoroscopy represents an additional risk for the development of acute kidney injury in critically ill patients [14], which are already characterized by a very high incidence of renal failure [15].

Some limitations of the described technique need, however, to be mentioned. First, severe cardiac abnormalities, in particular severe tricuspid regurgitation, could complicate the interpretation of the ventricle to atrium pressure profile change. Second, the cost of the Swan–Ganz catheter could be of concern. In our study, the Swan–Ganz catheter used for the measurement was thereafter positioned in the pulmonary artery through the left internal jugular vein and used throughout the experiment for hemodynamic monitoring. In case a pulmonary catheter was not indicated for clinical purposes, a viable solution could be the use of another type of radio-opaque balloon-tipped catheter, which would constitute a cheaper alternative to the Swan–Ganz catheter.

Conclusion

The technique described here could guide the positioning of bicaval dual-lumen catheters in order to perform single-site cannulation for venovenous extracorporeal gas exchange without the use of transesophageal echocardiography or contrast media during fluoroscopy.

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