The application of extracorporeal life support (ECLS) to older children and adults with severe respiratory failure is steadily increasing. The traditional approach utilized to obtain vascular access for ECLS in these patients is operative cutdown, which can be time consuming and prone to bleeding complications. Percutaneous vascular access may be less time consuming and less prone to bleeding complications.Gattinoni et al,1 Pesenti et al,2,3 and Jardin et al4 have used percutaneous access with success. In this review, we report our experience of using percutaneous vascular access to cannulate adult patients for venovenous ECLS.

Anticoagulation: The cannulas were heparinized with a mean of 800 units heparin/mL of heparinized saline. Heparinized saline was used to flush the cannulas every 6 to 8 hours to maintain heparin levels of 100 to 150 units/mL. In all, there were 15 unsuccessful percutaneous cannulation attempts. In six cases, the cannula site was used for multiple venovenous ECLS cannulations. In one case in a patient with severe uremia, the cannula site was used for multiple venoarterial ECLS cannulations. In all cases, the cannula site was followed with the cannula in situ for up to 8 days. The cannula was removed when it was no longer required for ECLS.

Interventions: The cannulation of the internal jugular and femoral veins (FVs) using the Seldinger technique for venovenous ECLS.

Measurements and results: Between May 1992 and November 1997, we performed percutaneous cannulation for venovenous ECLS in 94 adult patients with respiratory failure. The mean (± SD) age was 36.1 ± 12.7 years old (range, 17 to 65 years). The mean (± SD) weight was 80.7 ± 22.3 kg (range, 36 to 156 kg). The right internal jugular vein (RIJV) was used for venous drainage access in all but four cases. The right FV (n = 56), the left FV (n = 3), or the RIJV (n = 4) was utilized for venous reinfusion. The maximum blood flow (± SD) during ECLS was 57.6 ± 17.5 mL/kg/min (range, 22.4 to 127.8 mL/kg/min), with a postmembrane outlet pressure (± SD) of 146 ± 43 mm Hg (range, 56 to 258 mm Hg) at the maximum flow rate. There were 11 unsuccessful percutaneous cannulation attempts. In three patients (3%), the complications consisted of arterial injury requiring operative cutdown and repair. In six patients (6%), cannula-site bleeding required pursestring suture reinforcement of the cannula site. One patient died from the perforation of the superior vena cava during cannulation.

Conclusions: Based on these data, we conclude that percutaneous cannulation may be utilized to provide venovenous ECLS in adults.

Key words: catheterization, venous; extracorporeal membrane oxygenation, adult; respiratory insufficiency

Abbreviations: AF = atriofemoral; ECLS = extracorporeal life support; FA = femoroarterial; FV = femoral vein; PAC = pulmonary artery catheter; RIJV = right internal jugular vein; SVC = superior vena cava

From May 1992 to November 1997 at the University of Michigan Medical Center, 94 adult patients >17 years old with severe respiratory failure were placed on venovenous ECLS utilizing a percutaneous vascular access technique. Our ECLS management technique in the setting of adult respiratory failure has been previously described.5,6 Percutaneous vascular access was obtained using a modified Seldinger technique. Both the right neck and either inguinal region were aseptically prepped and draped. The skin was infiltrated with a local anesthetic, and an 18-g needle was advanced into the venous lumen. This was replaced by a flexible, 0.038-inch stainless-steel guidewire. The skin was then incised, and the percutaneous tract was serially dilated to accept an arterial cardiopulmonary bypass cannula (Bio-Medics; Eden Prairie, MN). These cannulas feature a thin-walled, wire-wound polyurethane design that minimizes resistance and improves flow capability. We used an “arterial” cannula in both veins because it is shorter (37 cm) than the venous cannula (50 cm), and because it creates less resistance. The cannulas were appropriately positioned in the mid-right atrium and common iliac vein. In general, the optimal position was the point where the cannulas were advanced to their full tapered length. A heparinized saline solution (1 U heparin/mL in normal saline) was then used to flush the cannulas. Once both of

Materials and Methods

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the canulae were in place, the patient was systemically anticoagulated. The canulae were affixed to the skin with several sutures of No. 0 silk. The canulae were then de-bubbled and connected to the extracorporeal bypass circuit.

Venous access was the method of choice for the support of patients with isolated respiratory failure. The direct surgical cutdown and exposure of the vessels was occasionally performed in cases of emergent or arterial cannulation. A femorojugular bypass was used preferentially over a femorofemoral bypass for several reasons. First, jugular access to the right atrium allowed for the use of a short, low-resistance drainage cannula. Second, it has been suggested that the spherical configuration of the right atrium allows for better drainage of venous blood, compared to the tubular configuration of the femoral vein (FV). A high flow yields greater oxygen delivery until the point where the recirculation of oxygenated venous blood from the reinfusion cannula back into the drainage cannula limits a further increase. A femorofemoral bypass may reduce the amount of recirculation, but it has been thought that a jugulojugular bypass for several reasons. First, jugular access to the right atrium was occasionally performed in cases of emergent or arterial cannulation. The choice of catheter was made based on the anticipated flow rate needed for venovenous bypass, estimated to be 70 to 100 mL/kg/min. Many cannulae are available, and each has a specific pressure/flow relationship. Significantly different flow characteristics may be present for the same size cannula (usually referenced by the outer diameter) made by different manufacturers. The "M-number" is an experimentally derived resistive factor that describes this pressure/flow relationship, and it allows for the estimation of flow for any specific cannula given a defined pressure change across the circuit.8,9 Having the knowledge of this number before or during cannulation is helpful in selecting the appropriate cannula.

Once ECLS was initiated, in order to prevent hemorrhage or hematoma formation in these systemically heparinized patients, the central venous and arterial monitoring catheters were neither placed nor removed. We used continuous venous oximetry pulmonary arterial catheters (PACs) in all patients. If a preexisting right internal jugular PAC was present, the introducer sheath was left in place and used as the guidewire access for placing the internal jugular ECLS cannula. A new PAC was placed elsewhere before the bypass was initiated. A PAC in other positions was utilized for the entire ECLS run.

Occasionally, in the patients who developed cardiac failure, cannulation was converted to provide venoarterial bypass. There were no strict criteria for conversion. The patients with hypotension, hypoxemia (SaO2 of < 80%), or hypoperfusion that did not respond to therapy were considered for conversion. The development of cardiac failure as a sequela of multiple organ failure was usually an indication of a nonsurvivable injury. However, the patients who had acute, reversible cardiac failure were converted to a venoarterial bypass, with the hope that temporary cardiac support would allow adequate oxygen delivery until the native cardiac function recovered. We preferred to use a short cannula in the right common carotid artery when arterial access was necessary. To accomplish this, an operating team was assembled in the ICU, and the right side of the neck was aseptically prepped and draped. An oblique incision parallel to the sternocleidomastoid muscle was made medial to the jugular venous cannula using electrocautery, and the common carotid artery was exposed and controlled proximally and distally. A short (9-cm tip), single end-hole arterial cannula (Bio-Medicus) was selected, and the artery was ligated distally to prevent embolization distal to the cannula. The artery was then clamped proximally, an arteriotomy was created, and the cannula was placed into the vessel. It was secured in the vessel by two ligatures of 2–0 silk. The cannula was then connected to the reinfusion line of the ECLS circuit, and the femoral venous line was clamped and either flushed with heparinized saline or connected to the drainage limb of the circuit.

RESULTS

One hundred eighty-eight percutaneous cannulation attempts were performed in 94 patients. In seven cases, we were unable to access the vein with a needle: six in the internal jugular vein and one in the FV. A direct cutdown on the vessel was required for cannulation in these instances. In three cases, the femoral artery was injured during the percutaneous cannulation, and a cutdown was required for the repair of the artery and the subsequent venous cannulation. In one case, the jugular vein was lacerated and required a cutdown to achieve venous cannulation. One patient died from the perforation of the superior vena cava (SVC) during an attempt to cannulate the right internal jugular vein (RIJV). Therefore, of the 188 percutaneous venous cannulation attempts, 176 attempts (94%) were successful. The cannulas were placed percutaneously for venous drainage in the RIJV (n = 84) and the right FV (n = 4). Venous reinfusion cannulas were placed in the left FV (n = 3), the right FV (n = 86), or the RIJV (n = 4). The sizes of the cannulas placed ranged from 19 to 23F (see Table 1). The maximum blood flow (± SD) initially achieved from the extracorporeal circuit was 57.6 ± 17.5 mL/kg/min (range, 22.4 to 127.8 mL/kg/min). The postmembrane outlet pressure (± SD) at that maximum blood flow was 146 ± 43 mm Hg (range, 56 to 258 mm Hg).

Complications included a femoral arterial injury in three patients (3%). In one case, the femoral artery was injured when the needle and guidewire were passed through the anterior and posterior walls of the femoral artery and into the vein. The cannulation was unsuccessful after the subsequent dilatation of the tract. A cutdown revealed the injury. Dilating the tract of an inadvertent arterial puncture was the cause of the two other arterial injuries. Pulsatile bleeding at the puncture site during sequential
dilation identified these instances. In all cases, the arterial injury was identified before bypass was initiated. A direct cutdown of the vessel and temporary arterial control was achieved, followed by venous cannulation and initiation of bypass. Once stable on bypass, the arterial injury was repaired primarily in all cases. One patient developed ipsilateral foot necrosis, most likely a result of embolization from the arterial injury, that later required a partial amputation. The other two patients had no further sequelae. In one patient, the cannula could not be placed after the dilation of the subcutaneous tract. A cutdown revealed that the jugular vein had a 1.5-cm posterior laceration that was repaired and was followed by proper cannulation. One patient sustained a cardiac arrest after initiation of bypass. Blood was drained from the right FV and was reinfused into the right jugular vein. A right thoracotomy revealed a large hemothorax and an SVC perforated by the jugular cannula. Despite repair and conversion to venoarterial bypass, the patient died.

Bleeding at the cannula site requiring additional surgical intervention or transfusion occurred in six patients (6%). In all of these cases, hemostasis was achieved by placing a pursestring suture in the skin around the cannula puncture site. Three patients (3%) required a conversion to venoarterial bypass because of inadequate gas exchange or cardiac failure while on venovenous support. In these cases, arterial access was accomplished via the cutdown of the right common carotid artery. This required the control of the jugular vein cannulation site with the placement of ligatures around the cannula. An alternative method was to approach the artery medially without the dissection of the vein; under these circumstances, venous control was not required. All three of these patients died of causes unrelated to cannula placement.

Blood product utilization was previously reported for the first 74 adult ECLS patients at the University of Michigan. These patients included patients who were cannulated both percutaneously and by direct cutdown. The mean (median) daily use of blood components while on ECLS were as follows: packed red blood cells 4.6 U (3.2 U), platelet concentrates 15.0 U (13.6 U), fresh-frozen plasma 0.5 U (0.3 U), cryoprecipitate 1.0 U (0.1 U).

**Table 1—Characteristics of Bio-Medicus Cannulas**

<table>
<thead>
<tr>
<th>Cannula Size</th>
<th>Length, cm</th>
<th>M-number</th>
<th>Expected Flow at 100 cm H2O Gradient, L/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>17F</td>
<td>25</td>
<td>3.05</td>
<td>2.4</td>
</tr>
<tr>
<td>19F</td>
<td>25</td>
<td>3.4</td>
<td>1.8</td>
</tr>
<tr>
<td>21F</td>
<td>25</td>
<td>3.15</td>
<td>2.3</td>
</tr>
<tr>
<td>23F</td>
<td>25</td>
<td>2.9</td>
<td>3.5</td>
</tr>
<tr>
<td>25F</td>
<td>25</td>
<td>2.6</td>
<td>6.5</td>
</tr>
<tr>
<td>27F</td>
<td>25</td>
<td>2.05</td>
<td>4.8</td>
</tr>
<tr>
<td>29F</td>
<td>25</td>
<td>2.3</td>
<td>7.0</td>
</tr>
</tbody>
</table>

**Discussion**

Extrathoracic cannulation for partial cardiopulmonary bypass was described in the late 1960’s as a safe method for the stabilization of critically ill cardiac surgery patients during the induction of general anesthesia. This technique generally involved the cutdown and cannulation of the femoral artery and vein under local anesthesia. In the 1970’s, Bartlett et al described a technique of extrathoracic cannulation for venoarterial bypass to support gas exchange in newborn infants with severe respiratory failure. The small caliber of the femoral vessels in this patient population precluded their use, so the RIJV and common carotid artery were the conduits used for access. This method had several advantages over femorofemoral bypass. First, it allowed a high flow with a low resistance by using a short, large-diameter venous cannula with the tip located in the high-capacity right atrium. Second, the arterial return was reinfused into the aortic arch via the right common carotid artery, providing a better perfusion of oxygenated blood to the upper torso, the heart, and the brain than was accomplished using the femoral artery. In addition, the right common carotid artery and internal jugular vein could be ligated with relative impunity, unlike their femoral counterparts.

In 1979, Gattinoni et al first described the use of venovenous partial cardiopulmonary bypass to manage severe respiratory failure in adult patients. This technique involved the extrathoracic cannulation of both the jugular vein and the FV using cutdown. Blood was drained from the common FV (both proximally and distally) and the distal jugular vein, and then was returned to the proximal jugular vein. The disadvantages of this method were the long operative time required for cannulation, a greater risk of bleeding, the restriction of patient mobility, and difficult nursing care. Later, this same group developed a simpler double-lumen, single-cannula technique. The next innovation was a technique using sapheno-saphenous cannulation to access to the inferior vena cava. This approach utilized superficial dissection and reduced the risk of bleeding. It also eliminated the need for distal drainage, and allowed for ligation of the saphenous veins during...
decannulation, a less complex procedure than venous repair. In 1990, Pesenti et al.\textsuperscript{20} first reported the technique of percutaneous cannulation for placement of femoral or jugular vein spring-wire-reinforced catheters; other reports followed.\textsuperscript{19–21} The amount of bleeding from the cannulation sites was dramatically reduced. Our approach was developed from these ideas and was modified to our method of extracorporeal support.

During ECLS, it is important to use a drainage cannula with the largest lumen and the shortest length possible because venous drainage is only achieved by gravity siphon. In this system, if the preload is adequate, the limiting factor determining the maximum flow is cannula resistance that is directly proportional to the length, and inversely proportional to the fourth power of the luminal radius. This simple relationship becomes more complicated for nonuniformly shaped devices. Cannula size is reported in a standard manner according to the outer diameter. Identically sized cannulas may vary in inner diameter according to the wall thickness of the material used. In our laboratory, we have developed a simple method to describe the pressure/flow characteristics of vascular cannulas. The catheters are tested for their pressure/flow relationship, and an M-number is assigned to designate a resistive factor that can then be used to approximate the resistance of the material used. In our laboratory, we have recently questioned the superiority of nonuniformly shaped devices. Cannula size is reported in a standard manner according to the outer diameter. Identically sized cannulas may vary in inner diameter according to the wall thickness of the material used. In our laboratory, we have developed a simple method to describe the pressure/flow characteristics of vascular cannulas. The catheters are tested for their pressure/flow relationship, and an M-number is assigned to designate a resistive factor that can then be used to approximate the expected flow at a specific pressure difference.\textsuperscript{8,9} The values for a typical ECLS situation using a pressure gradient of 100-cm H$_2$O siphon are demonstrated in Table 1.

Though the majority of patients underwent drainage from the right atrium via an internal jugular cannula with reinfusion into a femoral venous cannula, we have recently questioned the superiority of this approach. Rich et al.\textsuperscript{7} have recently reported preliminary results comparing atriofemoral (AF) and femorocaval (FA) flow in adults managed with venovenous ECLS. They suggested that the recirculation of ECLS associated with AF flow results in a reduction in oxygen delivery. The factors that they identified that govern flow and recirculation were cannula placement, volume status, intravascular spacial orientations, intrathoracic pressure, and flow direction. They compared the data on five adult patients placed on venovenous ECLS using FA bypass and AF bypass. Surprisingly, the FA bypass provided higher maximal flow rates than the AF bypass in four of five patients. In addition, in four of five patients, FA bypass produced higher pulmonary artery oxygen saturation and similar SvO$_2$ levels with a lower ECLS flow. They concluded that FA bypass may provide enhanced support and higher flows, and it may allow for a flow-rate reduction in some patients.\textsuperscript{7}

Percutaneous access for venovenous ECLS was successful in 94% of the attempts in this series. Although it is generally suggested that a flow of 70 to 100 mL/kg/min is required to adequately support adult respiratory failure patients with venovenous bypass, this was not our experience. We initially used a 21F arterial cannula (Bio-Medicus) for venous drainage, but later we designed a short (37 cm) 23F cannula that was then used preferentially. Arterial cannulas were used because they are shorter than venous cannulas (37 vs 50 cm), and so cause less resistance to flow. It is interesting to note that although the internal jugular vein will commonly accommodate a 29F cannula, the M-number of the short (arterial) 23F cannula is similar to the long (venous) 29F cannula which is the only 29F cannula manufactured (see Table 1). Therefore, the short 21F or the 23F cannula was used preferentially.

There are several benefits of percutaneous cannulation, including less cannulation site bleeding and the ease of bleeding control when using a simple pursestring suture. Because no dissection is required, the procedure time is reduced. Adjusting the position of the cannula is a simple matter of replacing the skin suture, rather than reopening the cannulation wound and temporarily discontinuing bypass to prevent an air embolus. Proximal venous drainage is not necessary because venous patency is preserved. Since the vein is never ligated, the vein may remain open after decannulation. If the vein thromboses, the potential for recannalization exists. We have demonstrated the patency of one FV that was cannulated for a 48-day ECLS course.

The complications of percutaneous cannulation included three arterial injuries. Although this represented only a small proportion of our series, these injuries may be devastating if they are unrecognized. In two cases, the injuries occurred because of initially unrecognized arterial punctures. In one case, the cannula passed through the full thickness of the femoral artery at the apex of the femoral triangle, where the femoral artery lies directly superficial to the vein. In the former cases, this could be avoided by the careful observation of the blood return from the initial needle puncture, and by pressure transduction if one is uncertain whether arterial or venous puncture has occurred. In the latter case, the puncture of the vessel at a more proximal location, just below the inguinal ligament, would have avoided this complication. Though not used in this series, the use of ultrasound during guidewire placement may enhance the technical ease and may reduce arterial complications of percutaneous cannulation.\textsuperscript{22,23} Venous-related complications included a tear in the jugular vein. This was most likely related to the posterior location of the vein puncture that created a tangential force on the vein wall. The only proce-
procedure-related fatality was from the perforation of the SVC by a jugular cannula. This was probably caused by the kinking of the guidewire during dilation, which resulted in the dilator exiting the vessel and perforating the SVC. This can be avoided by ensuring that the wire moves freely within the dilator during dilation. It is essential when using this technique that any difficulty with placement or recognized misadventure is followed by a cutdown and exploration with cannulation, and the correction of what is almost always an easily addressed problem. For these reasons, we strongly suggest that this procedure should only be performed by surgeons with vascular surgical expertise who can incorporate percutaneous placement of these large drainage cannulas into their routine approach to the cannulation of adult patients for ECLS. However, based on this experience, we conclude that percutaneous cannulation may be effectively utilized to provide venous ECLS in adults.

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