the Pa_{O_2} only if the cardiac output is maintained at normal levels. To differentiate between arterial hypoxemia and a decrease in cardiac output, analysis of arterial blood gases should be performed. In this infant it was not done because an arterial sample could not be obtained. The lack of response to increasing the FI_{O_2} to 1.0 and the prompt improvement following iv fluid administration confirmed that the change in $P_{tc}O_2$ was secondary to a low cardiac output state.

Also demonstrated are the consequences of instilling a hyperosmolar solution into an extravascular body space. An immediate flux of water from the intravascular and extracellular fluid spaces into the newly formed "third space" occurs. It results in hypovolemia and hyperosmolarity of the body fluids, which can be corrected by administration of hypotonic intravenous fluids. To confirm the presence of a hyperosmolar state, changes in serum osmolality, serum electrolytes, and hematocrit can be measured.[6] We were unable to obtain a blood sample intraoperatively. Postoperatively, the hematocrit obtained was of no significant value because of the major blood loss during the case. The serum sodium and chloride concentrations were elevated postoperatively, showing some degree of hyperosmolarity. Serum osmolality unfortunately was not measured.

In this instance, lactated Ringer's solution and 5% serum albumin were used to correct the intravascular volume deficit, leaving the hyperosmolar state untreated. This could have resulted in intracranial bleeding and renal failure. Fortunately, these consequences were not encountered in this infant.

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Internal Jugular Vein Function after Swan–Ganz® Catheterization

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Thromboembolic phenomena are recognized complications resulting from use of flow-directed (Swan–Ganz®) pulmonary artery catheters,[1–5] and a high incidence (66%) of internal jugular vein thrombosis has been reported in medical patients.[6] Internal jugular vein thrombosis is a potentially devastating complication in patients with neurologic disorders.[7–9] Since we routinely use pulmonary artery pressure monitoring during neurosurgery,[10] we sought to evaluate the incidence and

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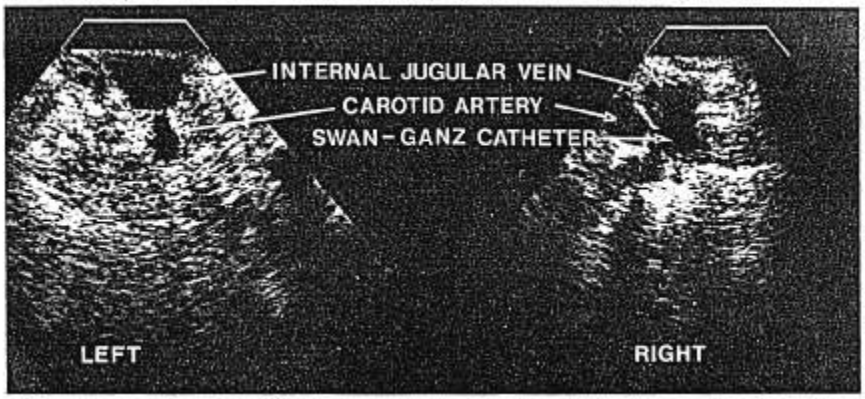

FIG. 1. Transverse ultrasound images of an internal jugular vein with Swan–Ganz® catheter in place and a comparison image of the contralateral internal jugular vein.

severity of thrombosis associated with insertion of Swan–Ganz® catheters via the internal jugular vein for perioperative monitoring.

MATERIALS AND METHODS

Thirty consenting patients (ASA Classification 3 or 4) scheduled for elective cardiovascular surgery utilizing cardiopulmonary bypass (mean age = 54 ± 8 SD years) were studied. The protocol was reviewed and approved by the institution's human investigation committee.

On the morning of surgery a 7 Fr. thermistor-tipped, non-heparin-bonded Swan–Ganz® catheter (Edwards Laboratories Model 93A-131-7F) was inserted via the right internal jugular vein using an Arrow® 8-French Teflon® introducer with side-arm injection port. After successful placement of the Swan–Ganz® catheter, the right atrial and pulmonary arterial ports were flushed continuously at a rate of 3 ml/h with 0.9% sodium chloride solution containing heparin, 0.25 units/ml. The side-arm of the introducer was used both during and after operation for infusion of fluids, anesthetic drugs, and vasoactive compounds, but no heparin-containing solution was administered through it.

Swan–Ganz® catheters and introducers remained in place until the patients were discharged from the intensive care unit 1 day (16 patients), 2 days (eight patients), or 3 days (six patients) postoperatively. At that time, the right and left internal jugular veins were evaluated by ultrasound imaging using an ATL Mark II ultrasound unit equipped with a 5 MHZ transducer with the patient lying supine or with the head slightly elevated.[11] Ultrasound images were examined for normal vessel wall motion and for presence of abnormal structures both before and after removal of the Swan–Ganz® catheter and its introducer.

Ten of the patients underwent venography during removal of their Swan–Ganz® catheters. Venograms were performed with a 15-ml hand injection of Conray

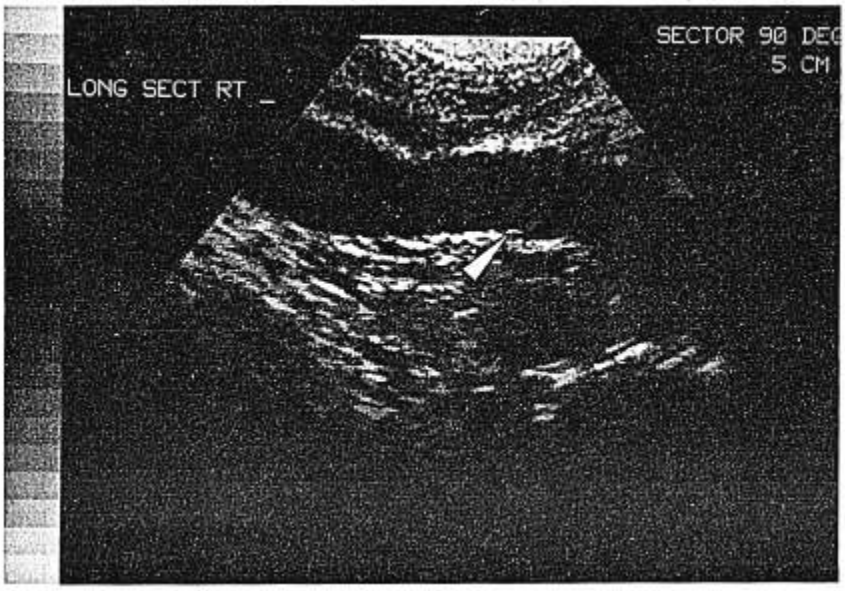

FIG. 2. Representative longitudinal ultrasound image of a previously cannulated internal jugular vein. A valve is seen at the internal jugular–subclavian junction (*arrow*) but there is no evidence of thrombus.

FIG. 3. Internal jugular venogram performed as a Swan–Ganz® catheter was withdrawn. Although valves are visualized at the internal jugular–subclavian vein junction, no thrombus is seen. There was rapid washout of contrast from the vein indicating normal blood flow.

60® contrast solution administered through the sidearm of the Teflon® introducer while the patients were lying supine on an angiography table. Venograms were evaluated for the presence of blood flow, valves, thrombus, or other lesions.

RESULTS

Figure 1 demonstrates typical sonographic findings obtained while Swan–Ganz® catheters were in place. Both the cannulated and contralateral internal jugular veins are widely patent, and the catheter introducer can be seen occupying only a small fraction of the vessel lumen. What cannot be appreciated in a still photograph is the active motion of the wall of the normal internal jugular vein. All veins were found to be widely patent and actively moving, both while catheters were in place and after they were removed. After decannulation, the ultrasound probe could be adjusted without contaminating the cannulation site and a longitudinal view of the internal jugular vein could be obtained (fig. 2). Again, normal wall motion was observed, and, in addition, small structures such as valves were readily apparent. No thrombi were found.

Venography confirmed the ultrasound studies (fig. 3). All veins were widely patent both before and after removal of the Swan–Ganz® catheters, while normal structures such as valves at the internal jugular–subclavian junction were readily apparent. No thrombi were visualized, and contrast material rapidly cleared from the veins, indicating normal blood flow.

DISCUSSION

Thromboembolic complications involving the subclavian veins and pulmonary arteries are recognized hazards related to the use of Swan–Ganz® catheters, but the report of internal jugular thrombosis in 22 of 33 patients after Swan–Ganz® catheterization[6] is particularly ominous. Occlusion of the internal jugular vein is known to be associated with serious neurologic consequences.[7] Some neurosurgeons have questioned the advisability of using Swan–Ganz® catheters if the patient's neurologic outcome might be compromised by such a common complication.§ Fortunately, the present study indicates that internal jugular vein thrombosis need not be a common occurrence after this route is used for introduction of a Swan–Ganz® catheter.

A possible explanation for the difference in the results of these studies may be that they examined two different patient populations, even though similar catheters were used for a similar duration of time. All the patients in the present study underwent anticoagulation during cardiovascular surgery, whereas the medical patients in the report by Chastre *et al.*[6] received only low-dose heparin therapy. "Fibrin sheath" formation is a common finding when Swan–Ganz® catheters are examined *in situ*[5,12] during open heart operations, however; and we doubt, therefore, that patient selection alone accounts for the differences in our results.

Perhaps differences in the techniques used to detect venous thrombosis may explain the differing results. In the study by Chastre *et al.*,[6] retrograde transfemoral venography was performed after the Swan–Ganz® catheters were removed. Although no attempt was made to document blood flow or to quantitate the amount of thrombus present in the jugular veins before or after decannulation, a representative venogram demonstrated what appeared to be a thrombus in the shape of a cast of the catheter. Both ultrasonography[9] and the "pull-

§ Winn HR, Persing JA: Personal communication.

back" technique of venography[14,15] used in the present study can reliably detect internal jugular vein flow and small vascular structures such as valves, and have been used previously to identify internal jugular vein thrombi. We feel, therefore, that it is unlikely that we would have failed to visualize significant amounts of intravascular thrombus if it had been present.

A more likely explanation for the differences between our results and those of Chastre *et al.*[6] may have been the presence of a Teflon® introducer sheath. We suture the introducer in place after successful pulmonary artery catheterization and use the side-arm for the continuous infusion of fluid and medications.[16] In contrast, Chastre *et al.*[6] removed the introducer sheath immediately after insertion of the Swan–Ganz® catheters. This may have permitted fibrin sleeve on the catheter surface to attach to the intima of the vein and allowed thrombus to accumulate in the lumen as the catheter was withdrawn. This phenomenon has been observed previously with other central venous catheters.[14,15] A Teflon® introducer sheath is much less thrombogenic than the polyvinyl chloride body of a Swan–Ganz® catheter[17] and would tend to separate fibrin sheath on the catheter surface from the intima of the internal jugular vein. During venography we specifically looked for evidence of fibrin sleeve being stripped off of the catheters at the time of decannulation but observed none. Thrombus may have been released from the catheter during injection of contrast solution, but we found no clinical evidence of pulmonary embolization in any of these patients. Alternatively, thrombi on the catheters may have become affixed to the superior vena cava and right atrium, as has been observed post mortem in patients who underwent cardiac surgery with Swan–Ganz® catheters in place for a mean duration of 6–7 days.[18]

Ideally, we would have liked to have studied patients both with and without Teflon® introducers in place. This would have required retrograde femoral venography, however, and our institution's human studies committee could not approve this technique. Furthermore, our departmental colleagues were reluctant to abandon the use of side-arm introducers because they find them extremely useful as a reliable intravenous route.

In conclusion, we found that the internal jugular vein can be used safely for the introduction of Swan–Ganz® catheters with minimal risk of causing internal jugular vein thrombosis in the perioperative period. We believe that keeping a Teflon® catheter introducer sheath in place during pulmonary artery pressure monitoring may help to prevent formation of thrombus in the internal jugular vein.

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