

replacement to restore adequate cardiac output. Had the cause of the hemodynamic disturbances not been immediately detected, it is doubtful that our patient would have survived.

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Cardiac Tamponade from Central Venous Catheters

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At least 34 cases of cardiac tamponade resulting from the use of central venous catheters, 78 per cent of them fatal, have been reported since March 1968.¹ We know of another 11 fatal cases that have not been reported in the medical literature, and we suspect, as do others,²⁻⁴ that such accidents often are not reported. Below we review the 34 reported cases. In many of them, the causes, symptoms, clinical courses, and pathologic findings were similar; we have summarized these common features. All investigators agree that a few simple precautions can prevent perforation by catheters or greatly reduce its incidence. We present their suggestions, as well as measures that they found successful in treating tamponade. It is our impression that many of the reported deaths could have been avoided, had the perforations and incipient tamponades been diagnosed more promptly.

CLINICAL COURSE

Of the 34 patients whose cases were reported, 19 had brachial venous catheters, 12 had subclavian-vein catheters, and three had external jugular-vein catheters. Sixteen of the 19 brachial venous catheters were long cannulas of rigid polyethylene with sharp tips inserted through venous cutdowns. The 18 other cannulas (three brachial and 15 jugular or subclavian) were tubings made of nylon or Silastic[®], or commercial units of Teflon[®], soft polyethylene, or polyvinylchloride.

Ten patients in whose cases autopsy showed myocardial perforation as the probable cause of death had died without apparent symptoms of tamponade. Four were found dead in bed,⁵⁻⁷ one died during anesthesia,⁵ and five conscious subjects experienced sudden cardiac arrest minutes to hours after cannulation.^{4,8-10} The other 24 patients had uneventful periods of hours or days (as long as eight days^{1,11}) from insertion of the catheter to onset of tamponade. These patients experienced sudden onset of cyanosis and venous engorgement of the face and neck, complained of nausea, dyspnea, retrosternal or epigastric pain, and became restless, confused, or comatose. Minutes to hours after the appearance of those early symptoms, tachycardia, arterial hypotension, paradoxical pulse, muffled heart sounds, and oliguria developed. The vital signs of those patients with untreated tamponade continued to deteriorate for as long as four hours until cardiac arrest occurred.

DIAGNOSIS

Several patients^{1,5,8,12-16} suddenly manifested abnormally high central venous pressures (CVP) loss of respiratory fluctuations, and absence of venous backflow, but those signs were overlooked because of the absence of physical signs. Normal venous pressure and respiratory oscillations, however, persisted in one patient who had subclavian venous perforation and hydromediastinum.¹⁷ In only five cases in which pericardial effusion was suspected was the diagnosis confirmed by low electrocardiographic voltages,^{16,20} enlarged cardiac outlines on roentgenograms^{6,15,17,20} or on echocardiograms,¹⁷ or injection of dye into the central venous catheter.^{15,16} The relevant medical literature thus shows that in spite of

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TABLE 1. Sites of Perforations in 34 Patients

Site	Perforations	
	Number	Per Cent
Right atrium ^{1,4-6,8,12-14,27}	11	32.3
Right ventricle ^{5,7,9,10,14,15,26}	8	23.5
Superior vena cava ^{18,19}	2	5.8
Subclavian vein ^{12,17}	2	5.8
Pulmonary artery ⁵	1	2.9
Coronary sinus ²⁴	1	2.9
Unknown ^{4,6,11,14,16,20,23}	9	26.4

obvious symptoms of catheter perforation or of tamponade, the correct diagnosis was rarely made before circulatory arrest occurred.

Echocardiography and roentgenography of the chest (plain or after injection of 2-5 ml radiopaque dye through the central venous catheter) are simple and reliable means to confirm the diagnosis, but in most cases they were done too late. Fluid aspirated through the central venous catheter or through a pericardicentesis needle at the time of cardiac arrest, or shortly before, was the diagnostic clue most often reported.

PATHOLOGIC FINDINGS

Table 1 shows the sites of perforation and table 2, the sites, natures, and volumes of the extravasates. There was a surprisingly high rate (23.5 per cent) of right ventricular perforations, and there were four cases of hydromediastinum^{5,12,17,18} producing tamponade similar to that resulting from pericardial effusion. The autopsy results suggested that 300 ml blood or 500 ml perfusate in the pericardium or in the mediastinum suffice to produce fatal tamponade. Only five autopsy reports^{1,5,7,9,14} included

microscopic studies: they showed endocardial thrombi or fibrin clots, a necrotic tract through the myocardium, and a small epicardial wound.

PHYSIOPATHOLOGY

The clinical courses of the patients and the autopsy results described in the cases reported suggest two modes of perforation: 1) immediate puncture of the vena cava^{18,19} or the heart during cannulation, which is rare and occurs only with stiff, sharply-beveled catheters. 2) late perforation, hours or even days after cannulation, which is more frequent. In the latter: a) the catheter tip is in the atrium: it damages the endocardium with each atrial contraction and becomes fixed to the thrombus it produces; rarely, it is trapped in the heart pillars.⁹ The fixed tip then slowly necroses the atrial wall, especially when it is weakened by fatty infiltration or distended by heart failure.¹⁵ Or, b) the catheter, initially correctly placed in the vena cava, is advanced by head, arm, or trunk movements, the tip then punctures the vein, or enters the right atrium, the right ventricle, or the pulmonary artery,⁵ and immediately pierces the wall.

There is some experimental evidence for such catheter migration: Flexion of the heads of infant cadavers pushes Angiocaths[®] 2 to 6 cm downward, with a 60 per cent rate of caval or atrial punctures.²⁰ Intracardiac pressures measured during neurosurgical procedures suggest that flexion of the neck may push an atrial catheter into the ventricle.²¹ Fluoroscopic examination of patients and direct observations in cadavers show that adduction and, especially, abduction, of the arm,^{11,14,22} flexion of the elbow,²² and rotation of the trunk^{11,14} can force the tip of a loosely attached brachial venous catheter from the

TABLE 2. Sites, Natures, and Volumes of Extravasates in 34 Patients

Nature of Extravasate	Extravasates					
	Pericardium		Mediastinum		Total	
	Number	Per Cent	Number	Per Cent	Number	Per Cent
Intravenous perfusate	18 (Average volume 500 ml) ^{4-6,8,10-12,14,15,26}	52.9	4 (Average volume 500 ml) ^{5,12,17,18}	11.8	22	64.7
Blood or grossly bloody fluid	7 (Average volume 300 ml) ^{1,6,7,9,19,20}	20.6	0		7	20.6
Dye	2 (Average volume 500 ml) ^{16,23}	5.9	0		2	5.9
Unknown	1 ²⁷	2.9	0		1	2.9

vena cava into the heart. In addition, it has been alleged^{3,23} that the fast caval blood flow can entrain the tip of a poorly anchored central venous catheter, but experimental proof for this claim is not presented.

Long, rigid, brachial venous cannulas with sharp tips and jugular-vein or subclavian-vein over-the-needle beveled cannulas caused 24 of the 34 reported perforations, and thus these types of cannulas would seem unacceptable for use in clinical practice. Commercial central venous catheters produced nine punctures.^{6,10,17,18} A Silastic cannula in a baby's atrium wedged itself into the coronary sinus and caused fatal venous obstruction and hemopericardium.²⁴

Some investigators believe other factors may increase the risk of cardiovascular perforation by central venous catheters. It has been suggested that catheters that have rough surfaces or are covered with talc from surgical gloves may promote thrombus formation and thus, perforation.^{5,25} Infusion pressures of more than 15–20 cm H₂O may damage or puncture venous or cardiac walls.¹⁸ Rapid injection of large amounts of dye through the central venous catheter to locate its tip may also lead to perforation and to tamponade.^{16,23,24} In addition, extravasated hyperosmotic solutions may draw as much as five times their volumes in free water from the surrounding tissues into the pericardium or mediastinum.⁶

PREVENTION

Most investigators believe that simple precautions can prevent puncture of the heart by the central venous catheter. The following measures have been proposed:

1) Central venous catheters must not be used to deliver rapid, massive infusions when other venous routes exist, because of the increased risk of myocardial perforation and of tamponade when the catheter tip enters the heart.^{1,3,14,20,23,26}

2) With a few exceptions,^{11,15,22,26} all authors of the reports reviewed urge that central venous catheters not be placed in the right atrium. Accurate measurement of CVP does not require cardiac invasion,^{5,15,25,27} and the value of intracardiac catheters to treat surgical air embolism remains unproven: in dogs such catheters retrieve only an insignificant portion of the air injected in a peripheral vein,²⁸ and aspiration produces no higher survival rate than other treatments.²⁹

3) Only routine roentgenographic control of insertion of radiopaque catheters can insure that the tip does not enter the heart.^{1,3,5,6,10–14,17,20,25,27} Introducing a length of catheter equal to the external distance between the insertion site and the jugular

notch or the sternal manubrium (*i.e.*, the assumed level of the superior vena cava) is grossly misleading,^{1,5,14,25} especially with brachial venous cannulas. Twenty-four per cent of catheter tips judged to be in the vena cava by such external measurements actually had entered the heart.^{5,13,14,25,26} Roentgenograms of brachial venous catheters must be obtained with the arm abducted 90 degrees, as that position pushes the cannulas in a caudad direction.^{14,20,22} Since movements of the arms, head, and trunk also advance the catheters, the tips must remain in the upper segment of the superior vena cava, or even in the innominate vein, above a roentgenographic plane drawn through the third rib or the T5–6 vertebral interspace, or 2 cm below the inferior clavicular border.^{6,11,26}

4) Catheters, especially those in the arm, must have the distal ends securely taped or sutured to the skin.^{3,12,23}

5) Since antecubital-vein cutdowns often necessitate the use of long, rigid cannulas with sharp tips, some investigators do not use the arm for central venous cannulation, and recommend the subclavian route.^{13,14} Beveled, over-the-needle catheters in the jugular or subclavian vein are also very dangerous.^{19,20}

6) Frequent checks of the central venous catheter for absence of venous backflow^{10,11,14} or of respiratory oscillations^{6,8,10,13,14} and for appearance of grossly abnormal CVP values, atrial or ventricular pulsations, or dysrhythmias⁶ will give early warning that the catheter has left the central vein.

7) Slow injection of a 2–5-ml volume of radiopaque dye through the central venous catheter confirms the position of the tip.¹⁷

TREATMENT

Delays in recognition of the perforations represented the main cause of the 78 per cent mortality rate reported. Perforation must be anticipated whenever a central venous catheter is used and investigated at the earliest evidence of ominous changes in CVP or clinical symptoms. The cardiac outline and the position of the catheter tip must be checked at once by echocardiography¹⁷ and roentgenography of the chest, preferably after injection of dye through the central venous catheter.^{3,15–17,23} Treatment of perforation must be rapid and aggressive: 1) Central venous perfusion must be stopped immediately.^{5,14,20,25} 2) Lowering the perfusion container to below the level of the patient's heart or aspirating the central venous catheter through a stopcock generally empties the pericardial sac or the mediastinum sufficiently to restore adequate cardiac output.^{5,6,11,12} At the end of aspiration the catheter is slowly withdrawn into the

right heart. A few milliliters of radiopaque dye are injected to detect a myocardial leak,⁶ after which the catheter is removed. 3) When catheter aspiration yields little fluid and causes no improvement of the patient's condition, needle pericardicentesis is done immediately.^{5,6,11,12,25} The subxyphoid route is safer, as it avoids the coronary vessels, but a parasternal approach may be more effective in the presence of hydromediastinum.^{4,11,17,18} 4) A dry tap in the presence of clear signs of tamponade justifies prompt pericardiectomy.^{3,23} 5) Once resuscitated, the patient should be transferred to an intensive care unit for a few days and observed for clinical, roentgenographic, electrocardiographic, and echocardiographic signs of recurrent hemopericardium.^{5,6,9,14,16,25} Two patients in the reported cases needed a second tap on the second¹⁶ or third⁶ day after the initial accident.

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