Hemodynamic considerations in the postoperative management of the cardiovascular surgical patient

Richard O. Russell, Jr., M.D.
Nicholas T. Kouchoukos, M.D.
Robert B. Karp, M.D.
Birmingham, Alabama

In this communication we shall highlight certain aspects of the postoperative management of the cardiovascular surgical patient as developed and practiced at the University of Alabama in Birmingham. The considerations that we shall emphasize have been inspired and led by Dr. John Kirklin and Drs. Nicholas Kouchoukos, Robert Karp, Albert Pacifico, and members of the cardiovascular surgical team at this medical center.

In our postoperative cardiac intensive care unit, we routinely measure certain parameters to assess the function of the cardiovascular system in the early postoperative period. Arterial pressure is obtained with an indwelling cannula usually placed percutaneously in the radial artery. Heart rate and rhythm are determined from standard electrocardiographic leads. Left and right arterial pressures are determined from fine polyvinyl catheters placed at the time of operation. Measurements of arterial and atrial pressures are obtained at 5- to 15-minute intervals in the first 24 to 48 hours following operation. In our experience, the use of these indwelling arterial and cardiac catheters for this period of time has been associated with an extremely low complication rate. The

volume of drainage from pericardial, mediastinal and pleural tubes, the amount of blood infused, and the output of urine from a urethral catheter are recorded at hourly intervals. All the above measurements can be obtained, analyzed, and displayed automatically with a digital computer (*Fig. 1*). Use of such an automated system has greatly facilitated the management of patients following cardiac surgical procedures.

Cardiac output is usually determined by the indicator dilution technique by injecting indocyanine green dye into the left atrial catheter and sampling from the arterial catheter or alternately, injecting into the right atrial catheter and sampling from a catheter placed in the pulmonary artery at the time of operation. The latter system is preferred when the left-sided cardiac chambers are large and the cardiac output is low. This latter technique will minimize distortion of the dilution curves and errors in the calculated value for cardiac output. When the thermodilution technique is employed, cold saline is used as the indicator and is injected into the right atrium with measurement of temperature change of the blood in the pulmonary artery by means of a thermistor-tipped catheter.

TIME	1636		
SYSTOLIC	196	MM HG	101
DIASTOLIC	137	MM HG	43
HEART RATE	95	PER MIN	136
CENT TEMP	34.9	DEG CEN	37.1
RIGHT ATRIAL	9	MM HG	14
LEFT ATRIAL	12	MM HG	12
BLOOD	40	ML	60
CHEST DRAIN	193	ML	96
CHEST DRAIN	134	ML/HR	0
URINE OUTPUT	1051	ML	0
URINE OUTPUT	920	ML/HR	0

Fig. 1. Oscilloscopic display of hemodynamic data from a 3-second interval obtained from two patients connected to an automated monitoring system. Chest drainage and urine output are expressed as total milliliters and as milliliters for the previous clock hour. (Reproduced with permission from Kouchoukos NT, Sheppard LC, Kirklin JW: Automated patient care following cardiac surgery. Cardiovasc Clin **3:** 109–120, 1971, FA Davis Company.)

The measurement of cardiac output is required in many circumstances to assess accurately cardiac function. Some patients do not manifest the signs of low cardiac output, that is, restlessness or agitation, cool, moist, cyanotic extremities, weak or absent peripheral pulses, and low urine flow. In adult patients following mitral valve replacement, a mean postoperative cardiac index of 1.5 L/min/M^2 or less was associated with 10% or greater probability of death. The probability of death rose steeply in both groups at indices below these values (*Fig. 2*).

In patients with low cardiac output and impaired left ventricular function, as evidenced by abnormally elevated mean left arterial and left ventricular end-diastolic pressures, the mortality and morbidity rates early after operation are significantly increased. *Figure 3* demonstrates the cardiac outputs and mean left atrial pressures of 30 adult patients in the first 4 hours following a variety of cardiac surgical procedures. Of 16 patients with cardiac indices less than 2.2 L/min/M^2 and left atrial pressures greater than 15 mm Hg, three died within 24 hours of operation of irreversible ventricular arrhythmias, and two others continued to have low cardiac outputs and died 2 weeks later of ventricular arrhythmias. Among the 14 patients with lower left atrial pressures and generally higher cardiac indices, there was only one postoperative death. In our experi-

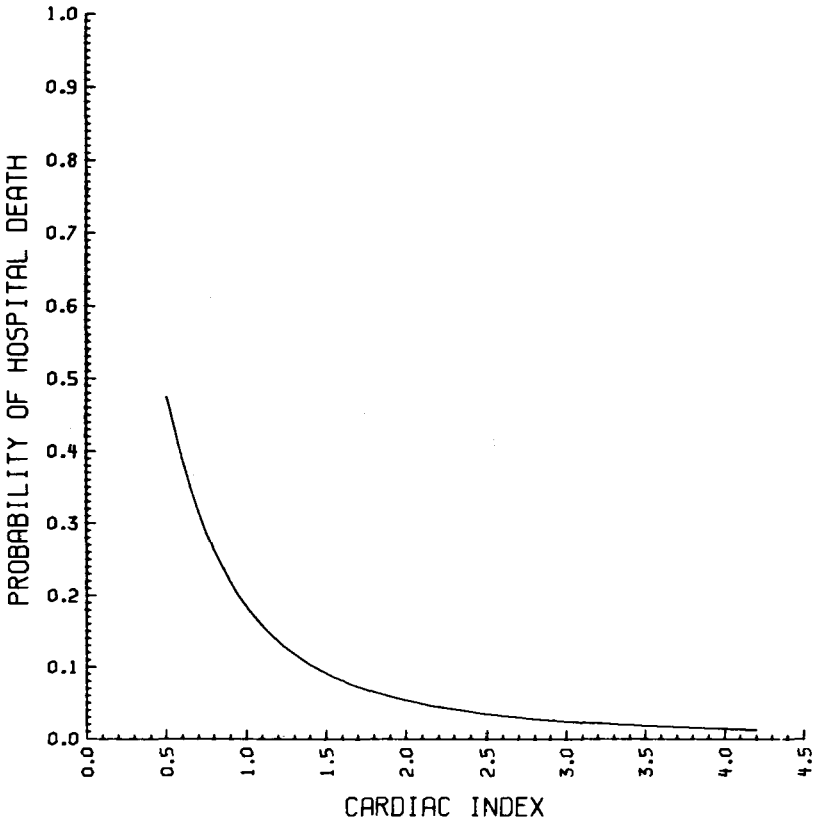

Fig. 2. Probability of death from acute cardiac failure from the average cardiac index (L/min/M^2) of 125 patients following mitral valve replacement. (Reproduced with permission from Appelbaum A, Kouchoukos NT, Blackstone EH, et al: Early risks of open heart surgery for mitral valve disease. Am J Cardiol **37:** 201–209, 1976, American College of Cardiology, the Dun-Donnelly Publishing Corporation.)

ence, measurement of cardiac output combined with measurement of arterial pressure and mean left atrial pressure—in the absence of stenosis or incompetence of the mitral valve—allows a more accurate assessment of cardiac function and response to various therapeutic interventions than does measurement of arterial and central venous pressures.

To combat hypovolemia, generally blood is infused from the pump-oxygenator at the termination of perfusion to achieve a mean left atrial pressure of 14 to 18 mm Hg in adults. These levels of left atrial pressures result in optimal stretching of the sarcomeres—that is, preload—and do not produce pulmonary congestion or edema. The left and right atrial pressures generally decrease to more normal levels in the early postoperative period. In adult patients with valvular heart disease, blood volume is decreased and whole body venous tone increased following operation. These changes are maximal 24 to 48 hours following operation and approach the preoperative values by the fourth postoperative day.

Left ventricular filling pressure determined as mean left atrial pressure

or pulmonary wedge, or pulmonary arterial end-diastolic pressure is the most reliable guide to the adequacy of volume replacement during the postoperative period. The effects of blood infusion on left atrial pressure and cardiac output early after surgical procedures for acquired heart disease are shown in *Figure 4*. In nine patients with normal mean left atrial pressures, that is, less than 12 mm Hg, infusion of blood to increase left atrial pressure an average of 3.4 mm Hg produced a statistically significant increase in cardiac index (2.52 to 2.93 L/min/M²) while heart rate remained constant. In nine patients with mean left atrial pressures before blood infusion of greater than 12 mm Hg (mean 15.6 mm Hg), comparable increase in left atrial pressure was produced, but cardiac index did not increase and the mean value actually decreased (2.58 to 2.41 L/min/M²). Thus, if cardiac output is low and left atrial pressure is low or normal (less than 12 to 14 mm Hg), infusion of blood will generally increase cardiac output early postoperatively. If left atrial pressure is already elevated above this level, further augmentation of blood volume and filling pressure does not usually increase cardiac output.

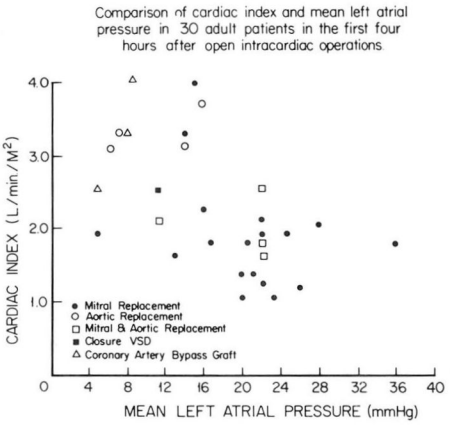

Fig. 3. Relation of cardiac index and mean left atrial pressure early after open intracardiac operation. Increased mortality occurred in patients with cardiac indices less than 2.2 L/min/M² and left atrial pressure greater than 15 mm Hg. (Reproduced with permission from Kouchoukos NT, Karp RB: Management of postoperative cardiovascular surgical patient. Am Heart J **92:** 513–531, 1976, CV Mosby Company.)

In postoperative adult patients

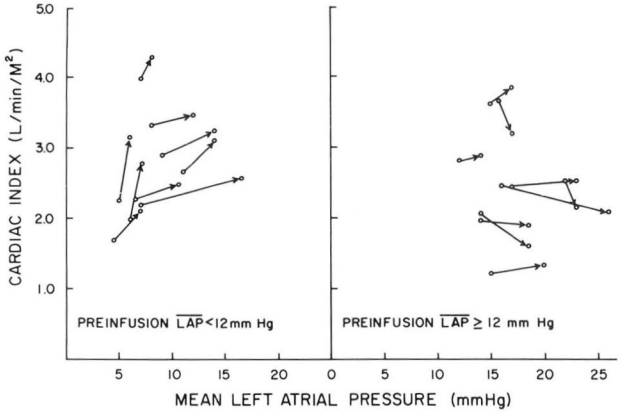

Fig. 4. Effect of elevation of left atrial pressure by blood infusion on cardiac index in adult patients early after open intracardiac operations (heart rate constant). (Left) Nine patients with preinfusion mean left atrial pressures (LAP) of less than 12 mm Hg. (Right) Nine patients with preinfusion mean left atrial pressures of greater than 12 mm Hg. (Reproduced with permission from Kouchoukos NT, Karp RB: Management of the postoperative cardiovascular surgical patient. Am Heart J **92:** 513–531, 1976, CV Mosby Company.)

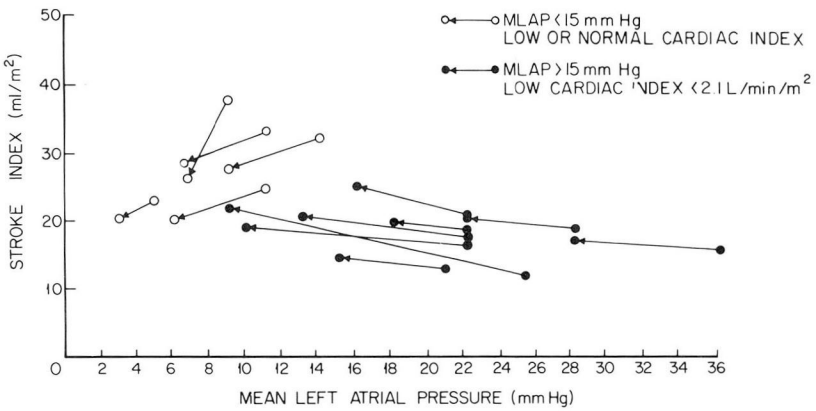

Fig. 5. Effect of infusion of trimethaphan camsylate (Arfonad) on mean left atrial pressure (MLAP) in patients within 6 hours after intracardiac operation. The eight patients in the group with poor cardiac performance (cardiac index less than 2.1 L/min/M², mean left atrial pressure greater than 15 mm Hg) had undergone mitral or mitral and aortic valve replacement. (Reproduced with permission from Kouchoukos NT, Sheppard LC, Kirklin JW: Effect of alterations in arterial pressure on cardiac performance early after open intracardiac operations. J Thorac Cardiovasc Surg **64:** 563–572, 1972, CV Mosby Company.)

with elevated mean arterial pressure, high peripheral vascular resistance and low cardiac output, improvement in cardiac output has been achieved by reduction of arterial pressure. This results in reduced impedance to left ventricular ejection or systolic wall stress, that is, afterload. In a group of patients with high mean arterial pressure (greater than 100 mm Hg) and evidence of impaired cardiac performance (cardiac index less than 2.1 (L/min/M² and mean left atrial pressure greater than 15 mm Hg), infusion of trimethaphan camsylate (Arfonad) produced a significant increase in stroke index and cardiac output in all patients studied, averaging 18% and 15% respectively (*Fig. 5*). Comparable reduction of arterial pressure in patients with higher cardiac indices and lower left atrial pressures, suggesting more normal left ventricular function, resulted in a decrease in stroke volume, presumably as a result of decrease in left ventricular filling pressure (preload). Similar observations have been made using sodium nitroprusside, a potent vasodilator, in adult patients with significantly impaired ventricular function. In postoperative patients when cardiac index is low and left atrial pressure, mean aortic pressure, and peripheral vascular resistance are elevated, reduction of arterial blood pressure or afterload will allow more effective emptying of the left ventricle with reduction of left ventricular end-diastolic pressure.

In summary, certain important principles of postoperative management have been learned. Measurement by many physiological parameters may be systematized and determined automatically. Cardiac output is inaccurately assessed clinically and must be measured. Measurement of cardiac output, left ventricular filling pressure and arterial pressure allows a more accurate assessment of cardiac function and response to various therapeutic interventions than does

measurement of arterial and central venous pressures. Infusion of blood to a left ventricular filling pressure of 12 to 14 mm Hg early postoperatively will optimize cardiac function. Impedance reduction with vasodilators for left ventricular dysfunction allows improved left ventricular performance.