Aortic Aneurysm Repair

Reduced Operative Mortality Associated with Maintenance of Optimal Cardiac Performance

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Recent advances in the operative management of aortic aneurysms have resulted in a decreased rate of morbidity and mortality. In 1972, we hypothesized that a further reduction in operative mortality might be obtained with controlled perioperative fluid management based on data provided by the thermistor-tipped pulmonary artery balloon catheter. From 1972 to 1979 a flow directed pulmonary artery catheter was inserted in each of 110 consecutive patients prior to elective or urgent repair of nonruptured infrarenal aortic aneurysms. The slope of the left ventricular performance curve was determined preoperatively by incremental infusions of salt-poor albumin and Ringer's lactate solution. With each increase in the pulmonary arterial wedge pressure (PAWP), the cardiac index (CI) was measured. The PAWP was then maintained intra- and postoperatively at levels providing optimal left ventricular performance for the individual patient. There were no 30-day operative deaths among the patients in this series and only one in-hospital mortality (0.9%), four months following surgery. The five-year cumulative survival rate for patients in the present series was 84%, a rate which does not differ significantly from that expected for a normal age-corrected population. Since the patient population was unselected and there were no substantial alterations in operative technique during the present period, these improved results support the hypothesis that operative mortality attending the elective or urgent repair of abdominal aortic aneurysm can be minimized by maintenance of optimal cardiac performance with careful attention to fluid therapy during the perioperative period.

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ALTHOUGH THE HAZARDS associated with repair of intact abdominal aortic aneurysms have diminished during the past decade, most recent reports document a persistent operative mortality of 3–9%.[1-7] The residual mortality, despite recent improvements in operative technique and subsequent management, is in large part attributable to a high incidence of myocardial infarction associated with expanding criteria for operability in patients with multiple risk factors. In 1972 we hypothesized that a further reduction in operative mortality could be achieved with the aggressive maintenance of optimal cardiac performance throughout the perioperative period. For this reason,, thermistor-tipped pulmonary artery balloon catheters were inserted prior to urgent or elective repair of intact infrarenal abdominal aortic aneurysms. Individual left ventricular performance curves were then determined and formed the basis for subsequent fluid management. This study reports our results with 110 consecutive operations carried out for repair of abdominal aortic aneurysms in patients aggressively monitored with arterial and Swan-Ganz catheters.

Methods

Preoperative Evaluation

From 1972 to 1979 110 consecutive patients with a median age of 68 years (range: 42–94) underwent elective or urgent repair of intact infrarenal abdominal aortic aneurysms. These procedures were all performed by two of the authors (ADW and JAM) using a standardized operative technique. Of 91 men and 19 women, 76 were asymptomatic, 32 complained of abdominal or back pain and 2 had sustained multiple emboli to their lower extremities. With a single exception all patients with aneurysms greater than 5 cm in diameter were offered and subsequently accepted surgical repair. Aneurysm size ranged from 5–6 cm in 26 patients and exceeded 6 cm in 84 patients. The

Presented at the Annual Meeting of the American Surgical Association, Atlanta, Georgia, April 23–25, 1980.

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patient population was characterized by the usual range of associated diseases (Table 1); in particular, a substantial number of the patients (44%) were admitted with clinically evident manifestations of coronary artery disease.

The diagnosis of abdominal aortic aneurysm was usually made on physical examination by the presence of a pulsatile epigastric mass, and the actual size of smaller aneurysms was confirmed by plain film and ultrasonography. Preoperative aortography was obtained in all patients to provide critical information concerning the precise origin of the aneurysm and the status of visceral vasculature including anomalous renal arteries. In those patients with concomitant peripheral vascular occlusive disease, additional studies of the femoropopliteal system were also routinely obtained.

Perioperative Management

On the evening prior to surgery, all patients were transferred to an intensive care unit where pulmonary and radial artery catheters were inserted according to standard techniques. As described in a previous report, mean pulmonary arterial wedge pressure (PAWP) was elevated 8–10 mmHg above baseline levels to approximately 12–14 mmHg by the infusion of salt-poor albumin and lactated Ringer's solution.[8] At each incremental elevation of PAWP cardiac index was determined in triplicate by thermodilution. The slope of the Starling type myocardial performance curve was then derived by plotting cardiac index versus PAWP. As illustrated in Figure 1, the slope showed considerable patient variation to the extent that peak cardiac index occurred in some at PAWP lower than 12–14 mmHg. Further increases of PAWP in these individuals resulted in diminished cardiac performance. An appropriate PAWP was then selected at which cardiac performance would be maximal and every effort was made to maintain the wedge pressure at this predetermined level both intra- and postoperatively (Fig. 2). Each patient received prophylactic antibiotics consisting of a preoperative 2 g dose of cephalothin followed by 1 g in the recovery room. In addition to the usual physiologic parameters followed during the immediate postoperative period, cardiac output and PAWP were carefully monitored to maintain adequate fluid balance and left ventricular performance. On the second or third postoperative day, peripheral and

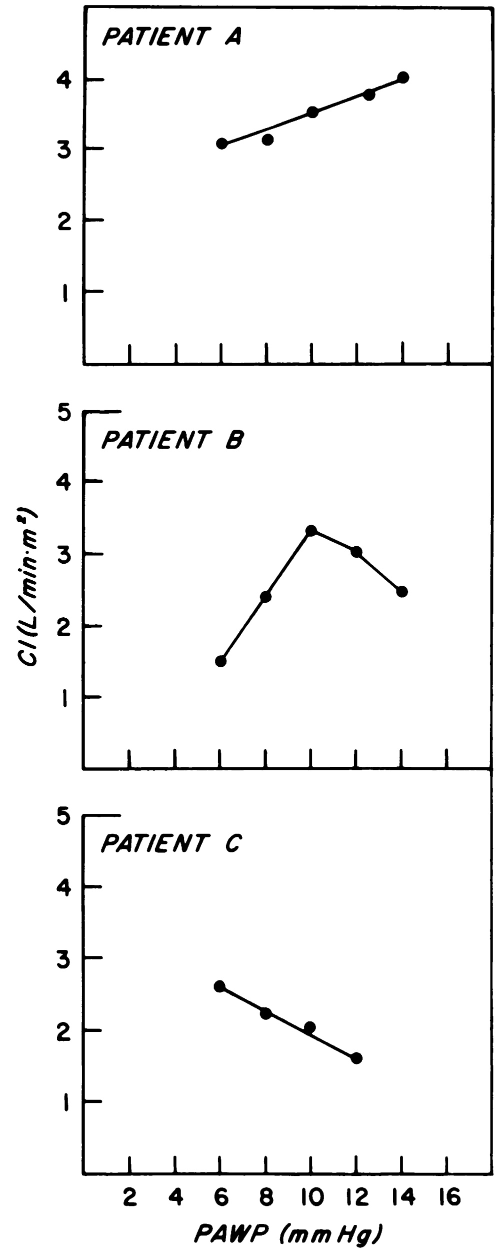

FIG. 1. Three types of preoperative myocardial performance curves are illustrated. During volume infusion, patient A increases cardiac output with each increment in PAWP. In contrast, patient B has a peak in cardiac output such that with further increases in PAWP flow decreases; patient C demonstrates a steady decline in cardiac performance. Volume therapy is designed to raise the PAWP to the point at which cardiac output peaks, or if this does not occur, to a maximum of 12–14 mmHg with cardiac index of more than 2.5.

TABLE 1. *Associated Risk Factors in 110 Patients Operated on for Abdominal Aortic Aneurysm*

Risk Factor	No. Patients	Per Cent
Coronary artery disease	49	44
Hypertension	26	24
Peripheral vascular disease	13	12
Cerebrovascular disease	9	8
Chronic pulmonary disease	8	7
Diabetes	7	6
Chronic renal disease	5	5

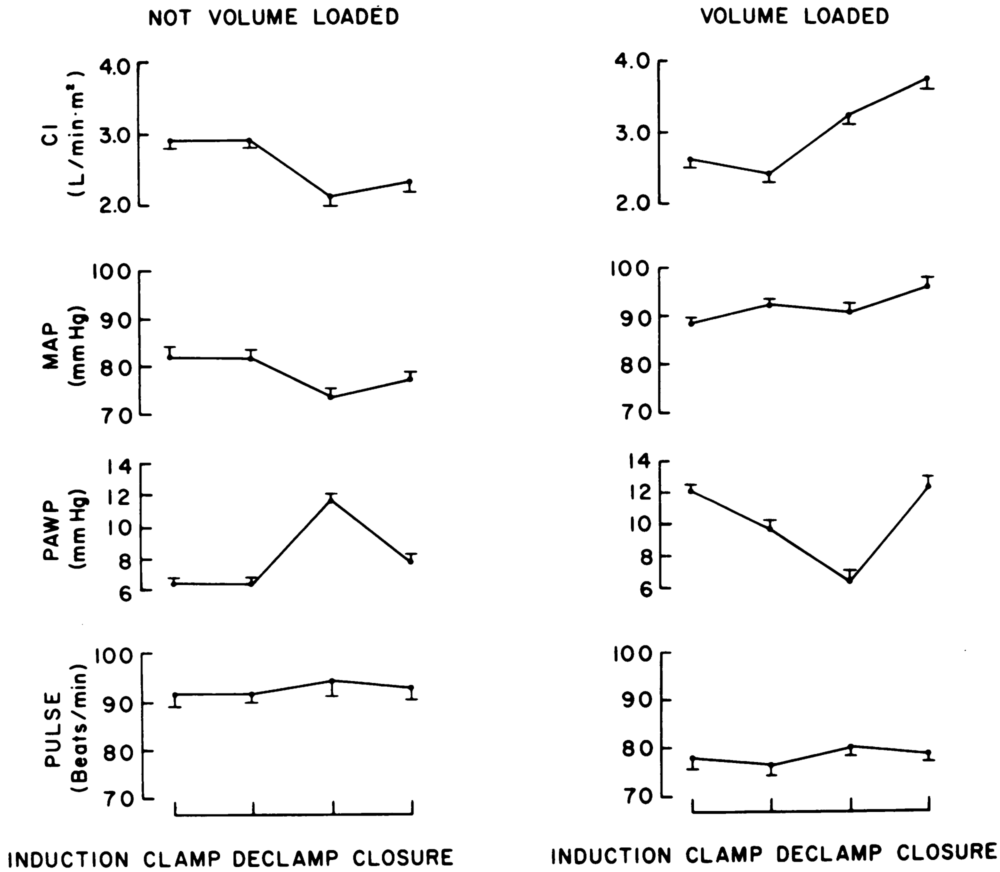

FIG. 2. The intraoperative hemodynamic performance of 10 patients not volume loaded is compared with that of 23 volume loaded patients from the present series. Cardiac index (CI), mean arterial pressure (MAP), pulmonary artery wedge pressure (PAWP) and pulse were measured during induction of anesthesia, 30 minutes following aortic cross-clamping, five minutes after declamping and during closure of the abdominal incision. Vertical bars indicate the standard error of the mean. In contrast to patients not volume loaded preoperatively, the volume loaded group demonstrated improved cardiac performance as evidenced by the increased CI, stable MAP and diminished PAWP following declamping. This improvement was observed in the absence of pharmacologic manipulation.

pulmonary arterial lines were removed and the patient transferred to a stepdown unit.

Operative Technique

Repair of the aneurysm was then carried out using the graft inclusion technique originally described by Javid[9] and Creech.[10] Through a long midline incision the small bowel was eviscerated, the retroperitoneum incised and the duodenum sharply dissected from the aneurysm. Limited dissection was considered essential to minimizing both intraoperative blood loss and postoperative third space sequestration. Only the anterior and lateral aspects of the neck of the aneurysm and iliac arteries were therefore exposed, no attempt was made to control these vessels circumferentially. Following systemic administration of heparin (5000 units), vascular clamps were applied in a vertical manner and the aneurysm opened, laminar clot evacuated, and the orifices of the inferior mesenteric and lumbar vessels suture ligated from within the sac. A woven or knitted Dacron® tube or bifurcation graft of appropriate diameter was then sutured end-to-end to the inside of the proximal aorta at the neck of the aneurysm using continuous 3-0 prolene suture. Since the aneurysm sac was left intact, a double thickness of aortic wall was included in each bite of suture. For tube grafts, a similar anastomosis was carried out distally; otherwise, the iliac orifices were oversewn and the limbs of a bifurcation graft anastomosed to the iliac or femoral arteries. A deliberate effort was made to separate the duodenum from the entire graft with initial closure of the aneurysm wall around the prosthesis followed by approximation of the left leaf of posterior parietal peritoneum to the periaortic tissue adjacent to the venacava. For aneurysms that originated just at the level of the renal arteries, the aorta was clamped at the diaphragm and retrograde visceral arterial bleeding subsequently controlled with a Fogarty intra-aortic balloon inserted through the initial opening in the aneurysm sac. Upon completion of the proximal anastomosis as described above, the balloon catheter was removed and the aortic clamp reapplied to the graft. We have not encountered postoperative renal failure resulting from this maneuver. Distal pulses were evaluated during closure of the abdominal incision; if diminished flow was evident the appropriate femoral artery was exposed and a 4-French Fogarty embolectomy catheter passed in an effort to recover embolized fragments of aneurysm wall.

Postoperative Follow-up

Of the 110 patients in this series, follow-up information was available for 106. Each of the 97 patients surviving was contacted directly by telephone or had been seen as an out-patient within three months of this writing. Cumulative five-year survival data was determined using life-table methodology as described by Cutler.[11]

Results

At the time of aortic aneurysm repair, a variety of simultaneous procedures were carried out in 20 patients (19%) as indicated in Table 2. Two such patients presented with symptomatic aneurysms and severe cardiac disease. During the same anesthetic prior to aneurysm repair, one required coronary artery bypass for crescendo angina and the other valve replacement for critical aortic stenosis. Nephrectomy was indicated in four patients with renin-mediated hypertension associated with contracted atrophic kidneys. One renal artery was revascularized for symptomatic stenosis and 2 anomalous renal vessels were reimplanted. One patient with asymptomatic celiac and superior mesenteric artery occlusion associated with an ectatic suprarenal aorta required reimplantation of the enlarged, meandering inferior mesenteric artery. An inferior vena caval clip was placed in a patient with antecedent multiple pulmonary emboli and eight patients required femoral embolectomy. Splenectomy was carried out for a laceration sustained during aortic clamping at the diaphragm, and the resection of what proved to be pheochromocytoma was fortunately uneventful. The early complications occurring during the 30-day postoperative period are listed in Table 3. Of the three patients with postoperative renal failure, two patients developed reversible mild high output renal failure, and a third patient an obstructed ureter which was relieved by the insertion of a temporary indwelling ureteral catheter. Only three patients sustained myocardial infarctions, one of which contributed substantially to the single in-hospital mortality in this series. Five patients developed pneumonia, two of whom required prolonged ventilatory support.

TABLE 2. *Secondary Procedures During Repair of Abdominal Aortic Aneurysm*

Procedure	Number of Patients
Cardiac	
coronary artery bypass	1
aortic valve replacement	1
Renal	
nephrectomy	4
renal artery reconstruction	3
Other vascular	
femoral embolectomy	8
reimplantation of IMA	1
IVC clip	1
Miscellaneous	
splenectomy	1
resection of pheochromocytoma	1
Total	21

TABLE 3. *Early Postoperative Complications*

Complications	Number of Patients	
Cardiovascular		7
myocardial infarction	3	
arrhythmia	2	
peripheral emboli	2	
Renal		3
acute renal failure	3	
chronic renal failure	0	
Pulmonary		7
pneumonia	5	
pulmonary embolus	0	
prolonged ventilation (>48 hr)	2	
Gastrointestinal		5
small bowel obstruction	1	
protracted ileus	2	
pancreatitis	1	
diverticulitis	1	
Miscellaneous		4
urinary sepsis	1	
re-exploration for hemorrhage	3	
Deaths		1

There were no 30-day postoperative deaths among 110 patients in this series. The single in-hospital mortality occurred in a patient with angina decubitus who required repair of his painful, expanding aneurysm. During the evening of surgery, he sustained a massive myocardial infarct, required prolonged ventilatory support, and ultimately died from pneumonia four months following surgery.

Two patients died during the first six months following operation secondary to problems directly related to surgery. The first patient developed a drug-induced pancytopenia three weeks following uneventful aneurysm repair and subsequently formed a perirectal abscess with Klebsiella. Two weeks after exploration was required for perforated diverticulitis at which time the aortic graft was found incorporated within an abscess cavity proven again to contain Klebsiella. Despite resection of the prosthesis and revascularization with an axillobifemoral graft, subsequent disruption of the aortic closure led to the patient's death. A second patient developed an anastomotic suture line disruption and ultimately died with rupture of the associated false aneurysm. The remaining six deaths are listed in Table 4 of which only one was due to myocardial infarction.

Recent follow-up information was available for 96% of the 110 patients comprising this series; four have been lost to follow-up and a total of nine patients have died. Survival data subjected to life-table analysis

TABLE 4. *Late Postoperative Deaths*

Cause	Number of Patients
Myocardial infarction	1
Pneumonia	1
Cirrhosis	1
Metastatic carcinoma	1
Graft infection	1
Rupture of anastomotic aneurysm	1
Undetermined	2
Total	8

(Table 5) yielded a five-year cumulative survival rate of 84%. If the assumption is made that the four patients lost to follow-up are, in fact, dead, the cumulative survival rate becomes 80%, a statistically insignificant difference ($p = 0.387$). As illustrated in Figure 3, the postoperative survival curve so constructed did not significantly differ ($p = 0.157$) from that expected for an age and sex adjusted nonsurgical population as derived from HEW life-table statistics.[12]

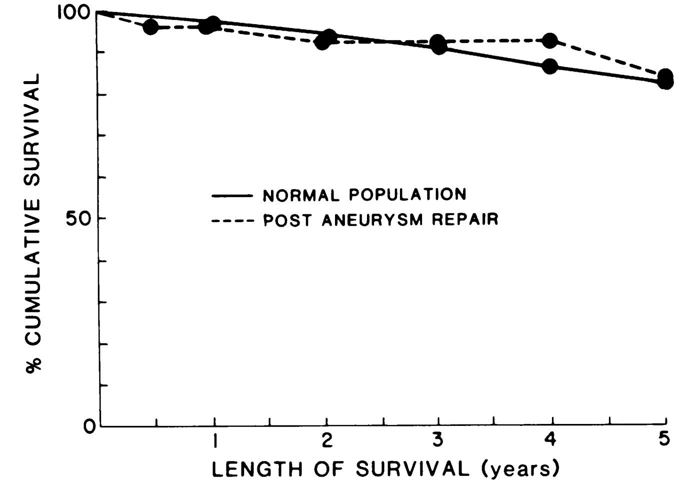

FIG. 3. Five-year cumulative survival curve for 110 consecutive patients operated on for infrarenal abdominal aortic aneurysms as compared to a similar curve for nonsurgical, age and sex adjusted population derived from HEW life table statistics.[12] The observed difference was not statistically significant ($p = 0.157$).

Discussion

Since the first resection of an abdominal aortic aneurysm more than a quarter of a century ago, the mortality rate has steadily declined. The 4–9% operative mortality reported in the early 1970's[1-3,5] represented a substantial reduction from the 9–18% rate prevalent during the prior decade.[13-16] During the past five years, however, a further decline in 30-day operative mortality (0–6%) has become apparent (Table 6).[2-7,17,18] The lack of operative mortality in the present series and the single in-hospital death, while not unique to this report, serve to underscore a trend which appears independent of patient selection. Although the majority of patients in this series had large (6 cm) aneurysms, no patient with an aneurysm greater than 5 cm was denied surgery. The age range included seven patients beyond 80 years of age, and the incidence of antecedent coronary artery disease paralleled that of other recent reports.[3,5]

The observed reduction in mortality undoubtedly reflects the influence of many factors. The increasingly sophisticated fluid management of patients with marginal cardiac compensation may emerge as one of the most important of these factors. Repair of an abdominal aortic aneurysm requires adequate cardiac reserves during several phases of the perioperative period. Significant myocardial dysfunction may be induced by inappropriate volume therapy[8] (Fig. 1), anesthesia,[19,20] increased "afterload" during aortic crossclamping,[21] hypotension with aortic declamping,[8,22-24] multiple blood transfusions,[25,26] and rapid fluid shifts attending operative blood loss and fluid sequestration with subsequent mobilization in the early postoperative period.[24-28] The maintenance of improved cardiac performance with closely monitored fluid management may enable the myocardium to better tolerate these stresses. The causal relationship of our close attention to volume therapy and the reduced operative mortality must, however, remain speculative. Careful fluid management results in high cardiac outputs and the maintenance of arterial perfusion pressure. It is likely

TABLE 5. *Cumulative Five-year Survival Following Repair of Abdominal Aortic Aneurysm*

Postop Interval	Patients Entering Interval	No. Deaths	No. Lost	No. Withdrawn	Cumulative Fraction Surviving Interval	±SEM
6 mo	110	4	1	12	.96	±0.02
1 yr	93	0	2	14	.96	±0.02
2 yr	77	3	0	18	.92	±0.03
3 yr	56	0	0	12	.92	±0.03
4 yr	44	0	1	11	.92	±0.03
5 yr	32	2	0	18	.84	±0.06

TABLE 6. *Operative Mortality for Repair of Intact Abdominal Aortic Aneurysms*

Year	Authors	Number of Patients	Operative Mortality
1975	Hicks, et al.[3]	113	4.2%
1975	Thompson, et al.[4]	108	5.5%
1976	Volpetti, et al.[16]	254	0.8%
1977	Young, et al.[5]	123	5.7%
1977	Scobie, et al.[6]	137	4.0%
1978	Baird, et al.[7]	160	5.6%
1978	Gordon-Smith, et al.[17]	51	0%
1979	Crawford, et al.[2]	329	3.0%
1980	Present series	110	0%

that the latter effect is important in assuring adequate coronary blood flow, thereby protecting the heart with significant coronary occlusive disease. This may be one explanation of the low incidence of lethal myocardial infarctions reported in this series.

In addition to careful fluid therapy, other measures were taken to improve cardiac performance. These include the use of inotropic support and careful regulation of pH and serum potassium, insertion of pacing wires, as well as more complex preliminary cardiac surgery. Our experience with the patient suffering from severe angina and impending rupture of his abdominal aneurysm indicated to us that these patients and others with similar limiting disease of the cardiovascular system would require combined cardiac and aortic surgery if significant salvage were to be achieved. Our subsequent experience with two patients proved that combined procedures can, indeed, be performed with good results.

The increased arterial pressure often seen with aortic clamping was initially treated with nitroprusside. Monitoring of CI and PAWP indicated that this was seldom necessary and indeed might be hazardous.[29] Declamping hypotension was minimized by preoperative volume loading and accurate intraoperative fluid replacement.[8] Total transfusion requirements were 3–4 units, while 3.5–4 L balanced salt solution were infused on the operative day. Volume loss was minimized by the limited dissection required for clamping without circumferential control and the graft inclusion technique.

In 1950, Estes' study of the natural history of abdominal aortic aneurysm reported a 19% five-year survival,[30] a figure independently confirmed in 1966 and again in 1972 by Szilagyi who found a 17% five-year survival in patients treated nonsurgically.[15,31] These important studies form the basis for recommending repair of infrarenal abdominal aortic aneurysms since the cumulative survival five years following such repair has ranged from 50 to 65%.[1,3,15,16] The 84% five-year survival rate reported in this series represents a substantial improvement in overall prognosis. Although the explanation remains unclear, for octogenarians and patients with small aneurysms to be considered operative candidates, such an improvement is critical. Since the life expectancy of an octogenarian normally exceeds five years,[12] and since the risk of rupture of small aneurysms approximates 25%,[15,31] a minimal operative mortality and normal postoperative survival rate support the extension of operative criteria to include these two subgroups.

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Discussion

Dr. Watts R. Webb (New Orleans, Louisiana): This paper emphasizes a most important concept to us in the management of our patients. The wisdom of the body, or at least its responses, has not always been adequate. We have had a million or so years to learn to physiologically adjust to the various stresses and strains and trauma of our external environment. We have had scarcely more than a generation to learn to adjust to modern surgery, and particularly to modern pharmaceuticals to which it is subjected.

My only difference, I think, would be in emphasizing that any given patient in their own cardiac performance is not represented by a single Starling curve, but by a whole family of Starling curves, depending on the various anesthetic depression that may occur, depending on the various sympathomimetic stimulation that may occur. So we have been more interested in modifying the contractility of the heart and the afterload than we have in the preload.

Certainly one cannot emphasize too much the importance of maintaining adequate volume, so that there will be an adequate preload available. However, we do prefer to maintain an adequate cardiac output, thereby assuring adequate peripheral perfusion at the same time we are minimizing the work that the heart has to do.

This usually means, particularly when one is going to massively increase the afterload and peripheral resistance by cross-clamping the abdominal aorta, that we reduce the peripheral resistance. We do this for the most part with nitroprusside, our preference being nitroprusside, because it works more directly on the peripheral arterioles. Nitroglycerin also works there, but more effectively on the venules and the postarteriolar bed as well.

Then if we need contractility increased, we would use dopamine or dobutamine.

This likewise reduces tremendously the pulmonary wedge pressure, because about 60% of the pulmonary resistance is caused by the left atrial resistance; so if one can reduce the left atrial pressure, one can thereby protect the lungs as well.

I agree that the morbidity is commendably low and certainly they have had beautiful results. I believe these results can be attributed to multiple factors. I know, in our own hands, virtually all of our aneurysmal patients would be screened at this time for coronary disease, and a number of them will have their coronary vessels taken care of beforehand.

I think it is important, as the authors have emphasized, that we achieve the goal of adequate perfusion at a minimum work load of the heart. I would differ only in paying more attention to the afterload and contractility than we would to the preload.

Dr. Louis R. M. Del Guercio (Valhalla, New York): I would like to make two comments. The first is that it is not only the patient undergoing a cardiac operation or having major aneurysms resected who will benefit from this approach. (slide) The national statistics are based on the material from the Michigan Commission on Professional and Hospital Activities studies. This is a review of 40% of all the hospital discharges from the United States during the period from 1974 to 1975, a very large statistical sampling. Some 23 million patients in the United States are older than the age of 65 years, amounting to about 10% of the population, but they accounted for 17.5% of all operations.

The absolute mortality for all of those patients older than 65 years of age undergoing operations was 4.88%, far in excess of the average mortality in reported series of major operations. When the patients had more than one preoperative diagnosis such as gastric ulcer plus diabetes, or something else, then the mortality was much higher, regardless of what operation was performed. This review included hernias, cataracts, hemorrhoids, everything.

Specifically, certain types of operations carried much higher mortalities: subtotal gastrectomy, 12.5%; pulmonary resections, over 10%; cholecystectomy, 3.4% and so on.

The cost-benefit analysis of Dr. Whittemore's approach of preoperatively putting in the Swan-Ganz catheter, and being forewarned about potential problems, means that if the average cost of a postoperative death, as shown by David Cullen at Massachusetts General Hospital a few years ago, is $25,000, avoidance of just one death through preoperative assessment pays for all of the Swan-Ganz catheters used and for their insertion.

The second point I would like to make (slide) is that if you go to the trouble to put in the Swan-Ganz catheter you should get the maximum amount of information from the procedure. From the pulmonary wedge pressure, cardiac output and mean arterial blood pressure we plot the Sarnoff curve, which takes all of the four determinants of cardiac output into account, that is, preload, afterload, contractility and pulse rate.

In addition, once the catheter is in the pulmonary artery, and the balloon is deflated, a mixed venous blood sample should be obtained. Then the circulation has been bracketed, and one can calculate, using a minicomputer or a hand-held calculator, a complete profile of cardiac dynamics for the right and left sides of the heart, pulmonary function and oxygen transport stress.

Whenever you see that there is inadequate oxygen transport because of a low mixed venous oxygen saturation, the patient preoperatively is already using up a portion of his mixed venous oxygen reserve. For that patient a small decline in cardiac output is serious.

I believe one should get the maximum advantage from the Swan-Ganz catheter, including oxygen transport and utilization, as well as ventricular function studies, and then use these to optimize the physiologic status of the patient preoperatively.

My associates and I insert Swan-Ganz catheters in all patients older than the age of 65 years undergoing major noncardiac thoracic or abdominal operations.

Dr. Dennis B. Dove (New York, New York): I wish to share with you an experience of ours which we think is complementary to some of the data that Dr. Whittemore just presented.

At New York Medical College, Metropolitan Hospital Center, under the leadership of Dr. Del Guercio, we have been inserting Swan-Ganz catheters, as has been previously described, in all preoperative patients who are scheduled for elective operations that we consider to be high risk. Advanced age is decidedly considered to a high risk factor in our patients.

Our vascular service reviewed 75 consecutive patients who were scheduled for major vascular operations. Data derived from the Swan-Ganz catheterization indicated that 50 of these 75 patients had abnormalities in their left ventricular function.

(slide) The curve, as just described by Dr. Del Guercio, shows a plot of left ventricular stroke work against the preload, here represented as the pulmonary artery wedge pressure. Twenty-five of the 50 patients who showed some abnormality in left ventricular function are shown here, on this portion of the curve, representing decreased left ventricular stroke work on the basis of low preloads. All of these patients could be optimized, as shown by the darker dots here, on to the Sarnoff curve, so that their ventricular work was now optimized merely by increasing their preload.

Unlike Dr. Whittemore and his group, we prefer to use blood as our volume replacement, followed by crystalloids.