CARDIAC SURGERY AND HAEMODYNAMIC MONITORING*

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INTRODUCTION

IN 1970, the development of the balloon flotation (Swan-Ganz) self-guiding catheter¹ permitted the routine application of the techniques of cardiac catheterization in a clinical setting. In the ensuing decade, measurements made possible by this device have been the cornerstone in the evaluation of the natural history of many forms of cardiopulmonary disease and of the efficacy of various therapeutic modalities. Thus, the role of haemodynamic monitoring in the broad area of clinical investigation has been established. It is appropriate, and perhaps humbling, to recognize that haemodynamic monitoring is merely the application to clinical practice of the most basic (but fundamental) elements of cardiopulmonary physiology developed during the first quarter of the present century.

While the role of haemodynamic monitoring in clinical research is recognized and its significance, in general, accepted, such a level agreement does not pertain to individual clinical application in day to day practice. Some senior surgeons doubt that the benefits of improved management outweigh the risks and inconvenience associated with the procedures. Nevertheless, it can conservatively be estimated on an annualized basis that considerably in excess of one million patients will undergo a variety of "treatments" under conditions of haemodynamic monitoring. The purpose of this article is to review the role of haemodynamic monitoring in patients undergoing cardiovascular surgery. It is also appropriate to generalize somewhat into the broader field of management of the high risk patient.²

Coincidental with the development of a haemodynamic monitoring – and, in part, because of its availability – an increasing number of effective pharmacological agents have be-

come available to the anaesthetist. Because of these simultaneous developments and their rapid acceptance by the modern anaesthetist, sophisticated manipulation of the cardiovascular system may be carried out, analogous in many ways to the growth of knowledge concerning the control of ventilation and of oxygen transfer which characterized the previous decade.

GENERAL APPLICATION OF HAEMODYNAMIC MONITORING IN CLINICAL PRACTICE

Haemodynamic monitoring is based upon the direct and continued measurement of the phasic pressures generated within the systemic arterial and pulmonary arterial systems and the measurement of cardiac output and, hence, of stroke volume. From these variables, the overall performance of the heart may be estimated, including the derived measures of cardiac work. The impedances, or afterloads, of each ventricle can also be determined as a function controlling cardiac performance, while the filling pressures, or preloads, are, under certain circumstances, determinants of ventricular performance. With a knowledge of the systemic arterial and pulmonary arterial oxygen content, estimations of total oxygen delivery to the body and the state of metabolic balance can also be determined. While surface and intracardiac electrographic changes are not included in the present coverage of the subject, clearly the influence of heart rate and rhythm is fundamental to an understanding of the haemodynamic state and its modification in a given patient.

In ischaemic heart disease, depression of global function is usually the result of a severe disorder of regional function, since ischaemic heart disease is, by definition, almost always regional in character.³ Global function is the sum of the positive and negative regional functions of each ventricle. While current methodologies to assess the regional dysfunction non-invasively are available on an investigative basis, methodological and application considerations do not make these modalities suitable for routine haemodynamic monitoring in clinical practice today. Haemodynamic variables com-

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monly measured and their conceptual meanings are listed in Table I.

The broad indications for haemodynamic monitoring are listed in Table II. In regard to application during anaesthesia, the considerations include not only the nature of the operation to be done but the condition of the cardiovascular system in the subject patient. In addition, several other more general issues must be considered. These include a decision that information is necessary for optimal management of such a patient which is not obtainable by noninvasive and observational techniques. Also, to apply haemodynamic monitoring effectively, the physician must be expert and experienced in application of such techniques. While the techniques themselves are relatively simple, high proficiency requires that they be practiced consistently. The physician must possess appropriate levels of knowledge in cardiovascular physiology and pharmacology. The complications⁴ ordinarily associated with invasive procedures on the cardiovascular system must be kept to an absolute minimum by anticipation of their possible occurrence and maintenance of suitable precautions. Also, the potential must exist that a therapeutic plan based on the haemodynamic data will be instituted as appropriate. In a busy surgical institution this requires that non-physician health care personnel be adequately trained to observe for complications of haemo-

TABLE I
HAEMODYNAMIC MONITORING IN CARDIOVASCULAR SURGERY

Haemodynamic measurement	Physiological equivalents
Systemic arterial pressure	Systemic perfusion head. Component of LV afterload.
Pulmonary artery pressure	Pulmonary perfusion head. RV afterload.
Cardiac output	Volume ejected by heart. Volume for organ perfusion.
Systemic vascular perfusion	Geometry of systemic arterial bed. Component of LV afterload.
Pulmonary vascular resistance	Geometry of pulmonary vascular bed. Component of RV afterload.
Pulmonary capillary wedge pressure	Preload left ventricle. Transudation - pulmonary capillary.
Right atrial pressure	Preload right ventricle. Transudation - systemic capillaries.

TABLE II

BROAD INDICATIONS FOR HAEMODYNAMIC MONITORING IN THE SURGICAL SETTING

I.	<i>Cardiac surgery</i>
II.	<i>Vascular procedures</i> Thoracic aneurysm Dissecting aneurysm Extensive multi-organ atherosclerotic disease
III.	<i>Prostatic resection - (age)</i> Suspect or known ischaemic heart disease
IV.	<i>Extensive bowel resection</i>
V.	<i>Prolonged orthopedic procedures in the elderly</i>
VI.	<i>"Surgical sepsis"</i>
VII.	<i>Severe burns</i>
VIII.	<i>Multiple Injuries</i>
IX.	<i>Severe debilitating metabolic states</i>

dynamic monitoring and to implement treatment when and as indicated.

Haemodynamic monitoring characterized the beginning of cardiovascular surgery in this country. McGoon, Moffitt and colleagues described a variety of responses in patients undergoing surgery for repair of congenital malformations in 1960.⁵ With the development of valvar surgery, it became evident that the measurement of pressures and assessment of the efficacy of repair during operation was an intrinsic part of the surgical procedure. By these means it was recognized that digital fracture of the mitral valve was only partially successful in the majority of patients suffering from mitral stenosis and that residual gradients across the valve were common. In like manner the efficacy of various procedures on the diseased aortic valve could be assessed. In the great majority of instances the relief of obstructive lesions was far from complete and valvar insufficiency was frequently added to the haemodynamic disturbance. In the 1960's the introduction of prosthetic valvar devices permitted a more consistent, if not perfect, haemodynamic result. Yet surgeons depended almost completely upon the magnitude of valvar gradients and reduction in pulmonary artery pressure for conclusions as to the efficacy of their efforts. In the late 1960's and early 1970's the development of a rational operation for the management of ischaemic heart disease broadened the field of application of operative procedures on the heart enormously. Not only were the numbers of patients who could potentially benefit from surgical procedures

greatly increased, but anaesthetists, physicians, surgeons and support personnel were faced with a population considerably older and subject to additional diseases.

For many years, anesthesiologists and surgeons regarded haemodynamic monitoring before, during and after operation as "learning experiences," to be discarded when appropriate clinical skills were developed. This optimistic viewpoint probably will not prevail since, with the almost unlimited reservoir of seriously ill patients with cardiovascular diseases, the need to provide the potential of surgical treatment in even sicker and older patients will remain a challenge for cardiovascular practice.⁶ If, as some believe, the clinical application of an artificial heart may become a reality by the late 1980's or early 1990's, it would appear that virtually all patients with serious heart disease may become potential subjects for surgical intervention.

CARDIOVASCULAR SURGERY

Before discussing current practice, it is worthy of comment that haemodynamic monitoring was not applied routinely on the cardiac surgical service of Dr. Jack Matloff at Cedars-Sinai Medical Center up to the year 1976. This was due to the conclusion that haemodynamic monitoring was neither necessary or overtly beneficial, in terms of patient outcome. In valvar heart disease a polyethylene catheter was inserted into the left atrium and, if appropriate, advanced through the mitral valve into the left ventricle. If serious post-operative complications occurred, then a balloon-flotation catheter was inserted post-operatively in the Intensive Care Unit. With acceptance of progressively older and sicker patients with ischaemic heart disease, it became necessary to re-evaluate this policy and, in 1977, the Section of Cardiovascular Anaesthesiology undertook responsibility for placement of flotation catheters immediately before induction of anaesthesia. This, together with the introduction of procedures to preserve myocardium during operation, has allowed the acceptance of progressively older and sicker patients for operative treatment, as will be defined below. One may estimate that between 50 to 90 per cent of cardiovascular surgical patients currently are monitored. However many of the larger referral clinics apply monitoring to a much lower proportion of patients, in part associated with the long-established skills and

capabilities of such surgical groups. Nevertheless a gradually increasing proportion of patients are subjected to haemodynamic monitoring, even in these institutions.

CURRENT APPLICATION OF HAEMODYNAMIC MONITORING (TABLE III)

With the codicils outlined in the first part of this paper relative to an understanding of haemodynamic principles and their modification and with appropriate skills, equipment and expertise, it is possible to postulate a rationale for application of haemodynamic monitoring in the anaesthetic and post-operative suites.

Congenital Heart Disease

The simple forms of congenital malformations – atrial septal defect, patent ductus – seldom require haemodynamic monitoring except, perhaps, in the presence of pulmonary hypertension and equivocal operability. Haemodynamic monitoring by the surgeon during operation with the chest open suffices in the great majority of instances. Fundamentally, this is related to the fact that the coronary circulation is usually intact and myocardial damage has not occurred in such patients.

Valvar Heart Disease

Uncomplicated patients with simple valvar disease, including pure mitral stenosis or pure aortic stenosis, probably do not require haemodynamic monitoring. However, in patients with multi-valvar disease, in the older patient, in patients with valvar disease in the presence of known coronary atherosclerosis, or associated with additional vascular disease, haemodynamic monitoring should be considered. The objectives of monitoring are to avoid inappropriate overload in the presence of obstructive or regurgitant valvar lesions, and to allow for optimal management of the patient during the phase of rewarming and in the first 24–48 hours after operation. This is particularly true in patients who have a history of excessive cigarette smoking or, for whatever reason, have significant pulmonary hypertension.

Ischaemic Heart Disease

By definition patients with ischaemic heart disease are undergoing surgery to relieve them of pre-existing obstructive coronary stenosis and are at particular risk for ischaemic cardiac damage during induction of anaesthesia and throughout their operation. In many institutions

TABLE III
RELATIVE INDICATIONS FOR HAEMODYNAMIC MONITORING IN CARDIOVASCULAR SURGERY

I.	<i>Congenital cardiac malformations</i> Complex forms only Pulmonary hypertension
II.	<i>Mitral valve disease</i> Elderly Severe pulmonary vascular disease
III.	<i>Aortic valve disease</i> Elderly Heart Failure
IV.	<i>Coronary artery disease</i> Left main or triple vessel disease Prior (recent) myocardial infarction Unstable angina, rest angina Reoperation Acute perf. — ventricular septum — ruptured mitral apparatus
V.	<i>Ischaemic heart disease with additional complications</i> Aortic or mitral valve disease, or both Ventricular aneurysm Carotid disease or aortic disease
VI.	<i>Miscellaneous indications</i> Intra-aortic balloon Requiring dialysis Extensive multi-system infections Bacterial endocarditis Associated pulmonary vascular disease — cor pulmonale

all patients with ischaemic heart disease are subjected to haemodynamic monitoring. The concept of an "all-or-none" law in this regard is not illogical. Nursing personnel become dependent upon physiological parameters to appropriately judge the condition of the post-operative patient and, in many institutions, the routine monitoring of all patients with atherosclerotic heart disease is accepted. Nevertheless it would appear to be equally rational to exclude from haemodynamic monitoring younger patients (less than 55 years) with stable angina pectoris who have suffered no previous myocardial infarction, with good ventricular function, and with severe obstructive disease of not more than two coronary vessels. The other extreme, the patient with angina at rest, left main or severe triple vessel disease, prior myocardial infarction, and poor ventricular function, should be subjected to careful haemodynamic monitoring to avoid further myocardial damage. Obviously, differing priorities for monitoring apply between these two extremes.

Complex Ischaemic Heart Disease

Since coronary artery bypass grafting is essentially an extracardiac operation, the intrinsic risk in terms of operative mortality is small. The same considerations do not pertain to patients within three months of acute myocardial infarction, those undergoing reoperation, or those with additional cardiac disease. In particular patients with acute mitral regurgitation or ventricular septal perforation secondary to acute myocardial infarction require haemodynamic monitoring for optimal care. Patients who are candidates for aortic valve replacement with coronary artery bypass grafting or resection of ventricular aneurysm have severe ventricular stresses, additional ischaemic heart disease, and both extra-cardiac and intra-cardiac operational trauma to sustain. In all probability all such patients should undergo operation under conditions of haemodynamic monitoring. In the same category are patients with multi-system atherosclerotic disease, including in combination coronary artery disease, thoracic or abdominal aneurysm, aortofemoral or popliteal obstruction, or obstructive carotid disease. Whether carotid or aneurysm, surgery should be done coincidental with, before or after coronary revascularization is not yet clear. However, it is obvious that multiple systems are in jeopardy and the careful maintenance of systemic arterial pressure is vital for the overall success of the therapeutic plan. In all of these more complex cases, haemodynamic monitoring has much to offer. It is a challenge to the discipline of anaesthesia to maximize the likelihood of operative survival and to minimize post-operative morbidity in such patients.

CONCLUSION

It has been suggested, both by American, but particularly by British, surgeons that haemodynamic monitoring is unnecessary for adequate patient care. Without desiring to precipitate an international crisis, it is the opinion of the latter group that the American surgeons are "too slow" in the operating room. However, the record of the American cardiovascular surgeon speaks for itself, and speaks eloquently. Nevertheless, this writer had the opportunity recently to put the question to a distinguished panel of practicing anaesthetists and surgeons, "If you had to abandon haemodynamic monitoring, how would this affect your practice?" All of the surgeons indicated that they would have to anticipate significant increases in both operative mortality and

morbidity, in particular, of course, in the higher risk patients. It was their opinion that the magnitude of operation was not the primary determinant of risk, but more the ever-changing condition of the critical patient in the operating room. Thus, they would have to offer a less optimistic prognosis and decline operation in a greater proportion of patients because of the reduced likelihood of favourable outcome. The anaesthetists on the panel had similar viewpoints, related more to their inability to affect outcome in the operating room favourably. An increased morbidity and difficulties in post-operative care were also anticipated.

As a generality, therefore, haemodynamic monitoring appears to have an important place in modern cardiovascular surgery. The complex patient with coronary disease and many of the patients with valvar heart disease alone, particularly when the patient is older and the lesions multiple, benefit from careful haemodynamic monitoring. It is certainly possible to develop a rational list of exclusions; nevertheless, it appears that haemodynamic monitoring will become an increasingly accepted part of the prac-

tice of cardiovascular anaesthesia and surgery in years to come.

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