Is cardiac surgery safer today than it was in September 1958, when a child with a large ventricular septal defect became the first patient to be operated on using cardiopulmonary bypass in New Zealand? It seems obvious that it must be, but cardiac surgery in good units has been surprisingly safe since its earliest days: For example, in the first 41 infants operated on at Green Lane Hospital for congenital heart disease under deep hypothermic arrest with limited cardiopulmonary bypass, four had uncorrectable conditions and of the remaining 37 (all under 10 kg and 25 under 1 year of age), 33 survived (1). Furthermore, the IQ for 25 of 76 long-term survivors of this approach, matched to an "ideal group" of control children had a mean IQ of 101.4 vs. 106.2 (not significant). For the group as a whole, mean IQ was 92.9. We now know that at least some of these patients have gone on to attend university and many have been able to pursue successful careers in adult life. Early results of adult cardiac and major vascular surgery were also impressive (2,3).

However, these figures do not always convey the whole story. In both adults and children, good cardiac outcomes were occasionally offset by permanent morbidity. Stroke is feared by most patients, and not all studies of outcome have looked closely for evidence of this complication. Renal failure is another potential complication of any major surgical procedure. Even those patients who ultimately do well after surgery sometimes spend a great deal of time in the hospital. In the case of babies and young children, long periods in intensive care and even longer in hospitals can imply months of dislocation for families, and may create prolonged stress and worry; even when the final medical result is satisfactory, social consequences may be serious.

In considering the question of safer cardiac surgery, it is appropriate to place the question of safety into the context of all the elements of quality in healthcare (4,5): These include timeliness, effectiveness, efficiency, equity, and most importantly, patient-centeredness. Within this wider framework, improvements depend on advances in knowledge, technology, and pharmacology, on avoiding error and promoting teamwork, and on the skill and expertise of an individual practitioner; more fundamentally, improvements also depend on the selection of patients, and on ensuring that they are well informed and able to engage in making the decisions best aligned to the outcomes they desire. To know whether one is making progress, it is necessary to measure outcomes, and this implies a database that includes appropriate information about case mix and case management.

**KNOWLEDGE**

Most medical students believe that if they persevere with hard study they will come to know everything that matters, at least within the framework of a chosen specialty, once they have passed the examinations necessary to achieve
senior doctor status (the status of an attending in the United States or a consultant in the United Kingdom tradition). This of course is illusory (5): First, although senior clinicians may end up with apparent encyclopedic knowledge of their field, no one person can know everything relevant to treating all patients who present even within a relatively narrow specialty; second, knowledge changes rapidly, not just through the addition of new information, but also through the discrediting of established fact (6); and third, a great deal of healthcare deals with uncertainty.

Nevertheless, there is no doubt that knowledge is fundamental to safety in clinical practice. In medicine, the investment in instilling knowledge into doctors at undergraduate and postgraduate levels is substantial, and evaluation is rigorous. In perfusion, similarly, it is necessary to acquire a large body of knowledge before qualifying. It is essential that this process of knowledge acquisition continues throughout each practitioner’s career. The establishment of the Australian and New Zealand College of Perfusionist takes this group further along the road to assuring the highest standards of training, and of maintaining professional competence thereafter.

It is also essential that information learned is reliable. This implies a need for ongoing research that is well-designed and conducted with integrity (see accompanying editorial). It is not necessary for every unit to conduct research, but there is a real advantage in being associated with a culture of enquiry in which the team, as a whole, is committed to the pursuit of knowledge. This implies, as a minimum, some facility for the critical appraisal of research reports. Also, there are ways in which even a small and isolated unit with a strong clinical focus can collaborate with other units to this end; in doing so, practitioners in such a unit can become engaged in the culture of research and can contribute not only data but also perspectives grounded in clinical practice under conditions that may be more challenging than those in larger centers: The Perfusion Downunder Collaboration is an excellent example of how this may be possible.

TECHNOLOGY

Over the years, advances in technology have included (amongst many other examples) dramatic changes in the design and quality of equipment for cardiopulmonary bypass; the advent of pulse oximetry and capnography in anesthesia; various approaches to monitoring cardiac output; improved surgical equipment, notably for retraction of the sternum and for facilitating off-pump surgery; point of care laboratory testing; and even the development of improved sutures for wiring the chest. In some cases the benefits of these advances are relatively obvious, and adoption of the improvements makes sense from first principles. In others, rigorous evaluation of the technology is appropriate. Training is also a requirement when new technology is introduced. There is a difference between efficacy and effectiveness (7), and it is the latter that is of most interest clinically.

An example of a technological advance which has been introduced in the absence of universally implemented training and which may or may not have impacted favorably on outcome is the pulmonary artery catheter. It may be that the greatest value of a Swan-Ganz catheter is the estimation of left-sided cardiac pressures through occlusion of right-sided pulmonary-arterial vessels, but these catheters are most commonly used primarily to measure cardiac output. Their use is not without risk, both direct (e.g., of rupturing a pulmonary artery) and indirect (e.g., through changes in management predicated on misinterpretation of the information provided). The acquisition and interpretation of the data from these catheters is not straightforward (8), and concern over the level of understanding of this technique by many of the practitioners who use it has been expressed on several occasions (9–11) (similar concerns have been raised over transesophageal echocardiography (12)). It remains the case that no prospective randomized trial has shown an outcome benefit for the use of pulmonary artery catheters (13–15), even in the context of protocol driven therapy (16). Although complications certainly do occur (17), there do not seem to be undue grounds for concern: The only thing that has been shown to increase is cost (18). In the end, context is critical, and extrapolating from one unit and clinical situation to another may not be valid. Pulmonary artery catheters in the hands of well-informed physicians (19) and in appropriate contexts may provide information in difficult clinical situations, which may assist clinical decisions, at least in individual patients (20,21). This debate is very illustrative of the wider issues: safer cardiac surgery depends on the sophisticated evaluation of difficult questions and the thoughtful application of research evidence to the management of particular patients.

Various less invasive methods of estimating cardiac output have been developed to reduce the invasiveness of pulmonary artery catheterization (and for that matter, the direct Fick method). These include esophageal Doppler monitoring, the derivative Fick method (using partial carbon dioxide rebreathing) and pulse contour and pulse power analysis (22). Even if the risk, cost, and skill associated with estimating cardiac output is reduced, it will still be important to understand the assumptions underlying the methods used, and to make clinical decisions which integrate the cardiac output measurements into the overall clinical picture in a way that actually improves outcomes. It will probably remain true that it is not the method that matters, but the clinical acumen of the people using it.
Understanding technology is fundamental to perfusion, and important contributions have been made by practicing perfusionists in evaluating new equipment and identifying aspects of performance critical to the safety of cardiac surgery (23–25).

**MEDICATIONS**

New medications have become available for managing different aspects of cardiac surgery over the years, but despite considerable investment in pharmacological research the gains made have been somewhat disappointing. The holy grail of a drug to reduce cognitive dysfunction remains elusive (26). It is interesting that alternatives to heparin for anti-coagulation in cardiac surgery have only recently become available, and these have disadvantages, including cost (27). Its disappointing that early evidence that bivalirudin might actually contribute to improved graft patency following coronary artery surgery (28) has not been investigated further.

**REDUCING ERROR AND PROMOTING TEAMWORK**

Iatrogenic harm has been identified as a major contributor to the global burden of disease, in general, and more recently in relation to surgery in particular (29,30). Cardiac surgery does not seem to have been the specific focus of much incident reporting, but certainly many of the medication administration errors identified in recent studies relate to cardiac operations (31). Certain surgical errors have achieved notoriety (32,33), and perfusion disasters are known to have occurred from time to time, albeit infrequently.

The Safe Surgery Saves Lives initiative (34) is an important response to this problem by the World Health Organization. In January this year, a study arising from this work demonstrated that the introduction of a Surgical Safety Checklist (the Checklist) in eight pilot sites around the world significantly and substantially reduced harm associated with surgery (35). The pilot study was not a randomized controlled trial, but it was prospective, and fairly large (data from almost 4000 patients collected at baseline were compared with data from a similar number after the introduction of the Checklist). A grant application has been submitted for a study designed to confirm these findings in a context relevant to practice in New Zealand and Australia, but the message is clear: The checklist is well construed, specifically designed to improve teamwork, backed by guidelines based on a careful consideration of the available evidence (36), and very inexpensive to implement. It can be modified for local purposes, and the case for its universal adoption in cardiac surgery is compelling.

**INFLUENCE OF CLINICIANS**

It is well accepted that there are differences in the results of different units and different surgeons; the adoption of scoring systems (37) to correct for casemix has assisted in monitoring results and various statistical approaches are available to assist in the early detection of deviation from accepted rates of poor outcomes (38). Less work has been done on other members of the team. It has been clearly shown that results may vary between anesthesiologists (39,40), but few if any units track the performance of this group, or of perfusionists.

**SELECTION OF PATIENTS**

When a patient presents with an operable cardiac condition, the primary objective is to achieve the outcomes he or she desires; it is not simply to conduct a safe or even a successful operation, however satisfying this may be for the surgical team. In many instances, there are major prognostic gains to be made through surgery—a number of correctable congenital heart conditions are incompatible with a full life for example. However, this is not always true, and, as noted above, even when it is these gains typically come at a cost. Cardiac surgery carries an up-front risk of death, and of neurological damage, and for a patient to have a realistic possibility of a net gain from an operation, a reasonable expectation of at least a few years of postoperative survival is a pre-requisite; this may not be the case in the very elderly, or in the face of certain serious co-morbidities. Some cardiac operations carry little or no prognostic benefit, and are carried out primarily for the relief of symptoms. Coronary artery bypass grafting (CABG) often falls into this category, and given the volume of this type of surgery, it is worth more detailed consideration.

There has been a dramatic increase in percutaneous intervention (PCI) for angina pectoris in recent years, associated with advances in stent technology. Typically, there is debate over the relative merits of PCI and CABG (41,42); the real question however is whether either approach is superior to modern medical therapy for chronic stable angina pectoris (43). This question may be quite difficult to answer—some of the best known randomized controlled trial data are over 20 years old (44), and important changes have occurred in all three modalities since then. In the recent MASS II study, 611 patients with angiographically documented proximal multivessel coronary stenosis of >70% and documented ischemia in whom revascularization was thought attainable by either surgery of PCI were randomized to surgery, PCI, or medical management. There was no difference in survival at 5 years, although surgery performed a little better than the other two groups in terms of the predefined primary end point—the incidence of overall
mortality, Q-wave MI, or refractory angina requiring revascularization (45). The conclusion, that both PCI and CABG should be reserved for patients whose symptoms cannot be adequately managed with optimal medical treatment, is consistent with that of investigators in other recent trials, particularly when cost (typically expressed in relation to achieved differences in Quality Adjusted Life Years) is taken into account (46). The incidence and impact of neurological damage adds weight to this view. New lesions on diffusion-weighted magnetic resonance imaging have been found in 43% of patients after intercardiac surgery, and are likely to be associated with cognitive decline; stroke was seen in 5% (47) and, as observed above, is much feared by patients.

This viewpoint raises the question of what constitutes optimal medical management. Innovative work in Liverpool in the United Kingdom suggests that impressive results can be obtained in reducing symptoms and healthcare costs with patient-centered education and cognitive behavioral therapy for chronic angina pectoris (48,49). Spinal cord stimulation (as a supplement to medication) has had impressive results in comparison with CABG in higher risk patients with no prognostic indication for surgery (50,51). There is unlikely to be a single answer to the question of how any particular patient with angina should be managed, but the importance of placing each patient at the center of his or her care is now well recognized. Patients who make their choices with their physicians on the basis of an adequate explanation of the implications of the available alternatives, explained in the context of their own particular medical and social circumstances, are more likely to achieve the outcomes they really value and more likely to accept complications when they arise. In the end, outcomes that the patients themselves desire are the most meaningful endpoint of the pursuit of safer cardiac surgery.

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