The ideal cardiac output monitor would have several qualities. It would be noninvasive or minimally invasive; continuous; and immediately, reliably responsive to changes in volume, cardiac function or vascular resistance. It would provide easily reproducible results with minimal technical or operator error. It would be unaffected by arrhythmia or fluctuating stroke volume or heart rate, useful in assessing physiologic responses to therapeutic measures, portable and inexpensive.

No device has all these qualities, some of which are almost mutually exclusive. Following is a brief discussion of the strengths and weaknesses of the minimally invasive monitors that are currently available.

**THORACIC BIOIMPEDANCE, OR IMPEDANCE CARDIOGRAPHY**

This method (Figure 1, below) is completely noninvasive. Electrodes on the thorax measure impedance of electrical current by volume of fluids inside the thorax. The monitor makes a number of mathematical assumptions to calculate impedance. Extravascular tissue volume and changes in pulmonary blood flow with respiration must be accounted for, and electrical noise from operating room or ICU equipment can distort the signal. Hemodynamic instability or arrhythmias with changing stroke volume can create misleading results. Electrode malposition or slippage from wet skin may create errors as well. This method has not been studied for assessment in goal-directed therapy of shock. Improvements in noise filtering, signal processing, and accuracy in dynamic clinical states are needed. There are two FDA-approved devices on the market. Interestingly, thoracic impedance may be useful in outpatient assessment of cardiac output and effects of therapy for congestive heart failure.

**NEAR INFRARED SPECTROSCOPY (NIRS)**

NIRS uses the same noninvasive method as pulse oximetry: It assesses tissue oxygenation through the changing absorption of light by hemoglobin. Unlike pulse oximetry, NIRS penetrates several centimeters into tissue. It has been found to correlate with regional tissue perfusion in adult and pediatric cardiac surgery patients, presaging systemic changes such as lactate or base deficit. It is also used to assess intraoperative regional cerebral perfusion, and cerebral perfusion in status epilepticus and shock resuscitation. Severe tissue edema, jaundice and probe location reduce its efficacy. In cerebral oxygenation monitoring, blood flow changes associated with acute changes in PCO₂ affect NIRS accuracy. NIRS is FDA-approved in both adults and children.

**PULSE CONTOUR WAVEFORM ANALYSIS**

These monitors (Figure 2, next page) attach to indwelling arterial catheters, so the method is considered minimally invasive. The area under the arterial waveform can be used to calculate stroke volume, thus a continuous cardiac output can be calculated. Variations in systolic arterial pressures between inspiration and expiration during mechanical ventilation result in variations in calculated stroke volume (SVV). Normal SVV is less than 10% to 15%. SVV reflects preload responsiveness, or the likelihood that cardiac output will improve with...