3. HEMODYNAMIC EVALUATION OF CONGENITAL HEART DISEASE

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A fundamental understanding of basic instrumentation and cardiovascular physiology is essential to competently assess the hemodynamic status of patients with congenital heart disease. The following is a very superficial view of these topics and readers should consult any of a number of more detailed texts 1-3. The contents of this chapter are presented in the following sequence.

1. PRESSURE MEASUREMENTS.
2. BLOOD OXYGEN MEASUREMENTS AND SHUNT DETECTION.
3. BLOOD GAS MEASUREMENTS.
4. CARDIAC OUTPUT MEASUREMENTS.
5. SHUNT, RESISTANCE AND VALVE AREA MEASUREMENTS.

1. PRESSURE MEASUREMENTS

Beautiful pressure tracings, like the Ode to Joy in Beethoven’s ninth symphony, stir the heart and soul of the true catheterizer. The pressure at the catheter tip is transmitted via the catheter and tubing to a transducer, converted to an electrical signal which is passed to a multichannel recorder and then by an optical beam to photographic paper. The principles of intravascular pressure measurement were described by Stephen Hale who in 1733 inserted a brass pipe into the femoral artery of a supine mare and connected it to a second pipe nine feet in height 4. Currently, an inelastic tube, the catheter, is inserted into the vasculature, filled with an incompressible air-free fluid and the pressure generated displaces a fluid column (generally mercury) against gravity. Soft catheters expand and contract slightly with changing pressures thus altering the actual pressure contour. Very small catheters clot at the tip, impairing pressure transmission, as does any blood that adheres to the wall along the length. Heparinization and frequent flushing reduce these problems, as does use of thin walled inelastic catheters with relatively large lumens and short lengths and as few stopcocks as possible. End-hole catheters are used to measure wedged pressures in the pulmonary vascular tree and double lumen catheters to precisely localize gradients. Side-hole and pigtail catheters, used also for angiography are less likely to develop tip obstruction from either blood or tissue and more accurately represent true systemic pressure than end hole catheters.

Transducers are not essential to pressure measurement. One could simply leave the vertical column open to air and, provided that the clear tubing was at least 6 feet high, one could watch the blood move up and down the tubing with each heart beat. For convenience, a transducer is used in which the column of fluid stops at a membrane. This membrane moves only a very small amount (less than 1 - 2 mm) with large changes in pressure. This movement is linear: the movement induced by
20mmHg of pressure will be 20% of that produced by 100mmHg. Membrane movement is converted into an electrical signal by a wheatstone bridge and the current is then amplified and recorded. All modern recording systems allow calibration and changes in signal range and paper speeds.

The entire system of catheter/transducer/recorder must meet certain requirements to represent intravascular pressures accurately. It must respond fast enough to inscribe pressures that change 60 to 180 times a minute (1-3 cycles per second or 1 - 3 cps). In fact, it must respond faster; atrial, arterial and ventricular pressure tracings have several contour changes for every heartbeat; a simple sine wave curve whose peak occurs at the top of the pressure tracing will reflect pressure tracings very poorly. Fourier demonstrated that if one keeps adding up sine waves whose frequency is higher than that of the previous sine wave, one will eventually represent accurately any complex curve. By convention, the first sine wave curve has the same frequency as the heart rate; for a heart rate of 60 beats/min, that sine wave frequency will be 1 cps. Subsequent frequencies (or harmonics) for this “Fourier analysis” will be multiples of the first frequency, i.e. for a heart rate of one beat per second, the 6th harmonic will have 6 cps (Fig. 3-1).

![Figure 3-1: An example of a Fourier analysis, or transformation, of a biologic pressure curve. (Reprinted with permission from W.R. Milnor. In Cardiovascular Fluid Dynamics, Vol, 2, Academic Press, New York, 1972.)](image)

The first harmonic contributes the most and each subsequent harmonic less and less. For most cardiovascular pressures the 10th harmonic (with a frequency 10 times faster than the heart rate or 35 cps) contributes less than 1% of the pressure curve (Figure 3-1). Thus, a catheter /transducer /recorder system that has a frequency response of 35 cps can accurately reproduce intravascular pressure curves. The natural frequency is directly proportional to the radius of the catheter system lumen and inversely proportional to the catheter length and compliance and density of the fluid filling the system. The highest natural frequency would occur with a short catheter of large lumen filled with low density fluid and connected directly to the transducer. Such a system would be very “underdamped”: damping is necessary to keep the frequency response flat. The Fourier transform method of analyzing