MENNEN
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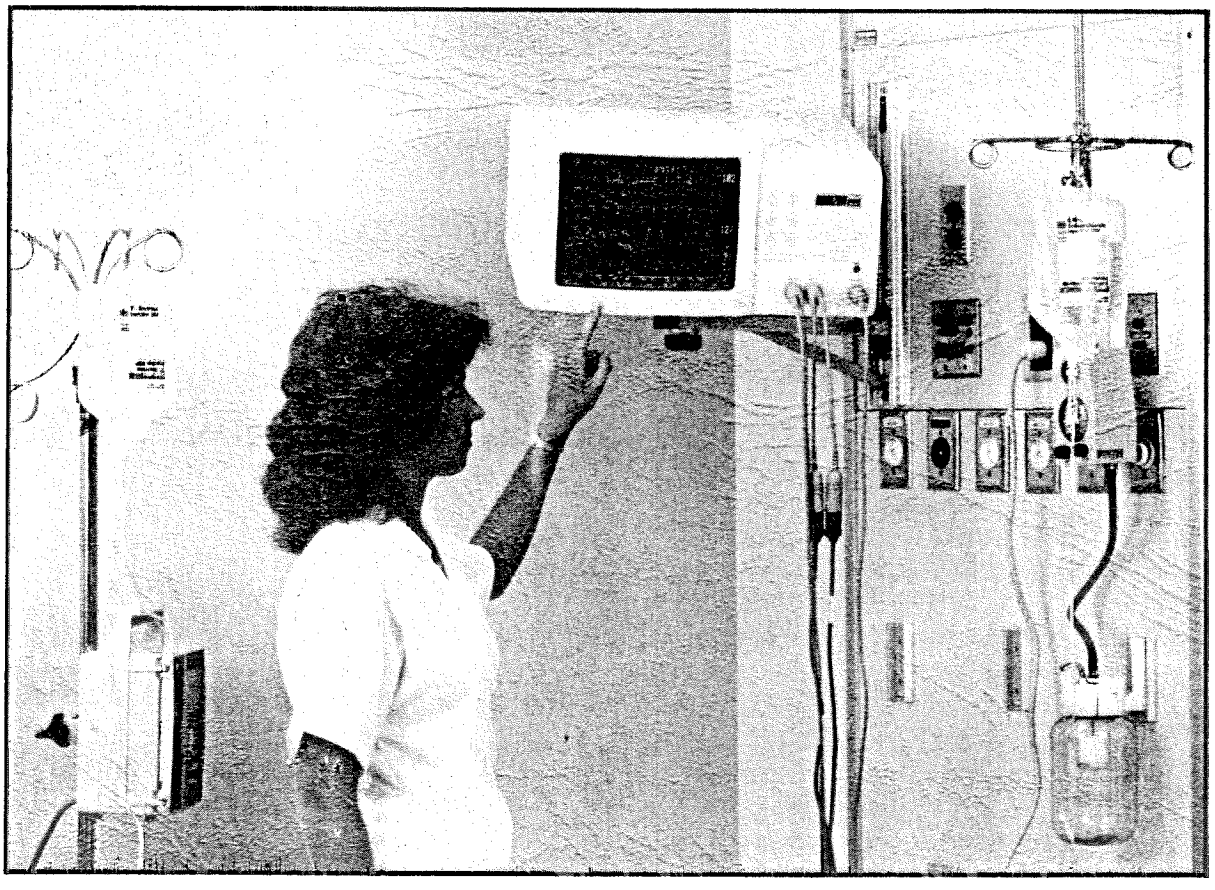
Clinical Guide to Cardiac Function Monitoring



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Manual Use

This Clinical Guide is designed to support clinicians and biomedical technicians in the application of flow-directed catheter monitoring for pressure derivation and calculation of cardiac output.

— FOR THE CLINICIAN:

Section 2 provides the complete instructions for catheter insertion, placement, and monitor set-up to provide PA (and RA) monitoring and PCWP derivation. Section 3 provides set-up and operating instructions for calculation of cardiac output and related hemodynamic parameters. Section 1 is recommended reading for informational purposes; Section 4 provides operating instructions for Ventricular Functional Analysis (optional); Section 5 provides a brief troubleshooting guide for problems in either clinical approach or monitored results.

— FOR THE BIOMEDICAL TECH:

Section 1 provides a detailed explanation of the Swan-Ganz flow-directed catheter, and its application in cardiac function monitoring. It should be carefully studied before evaluating or attempting to correct difficulties experienced with HORIZON 2000 by the clinical staff during invasive monitoring or C.O. calculation. Sections 2 and 3 provide clinical procedure and operating instructions for wedge pressure derivation and C.O. calculation, respectively. Section 5 is a clinical trouble-shooting guide. It should be consulted together by the technician and the clinical staff for clinical solutions to apparent monitor malfunctions. Hardware diagnosis should only be attempted following a review of clinical solutions.

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4	VENTRICULAR FUNCTION ANALYSIS a. Discussion b. Operating Procedure
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Section 1

Hemodynamic Functions Derived in Swan-Ganz Monitoring

1-1 General

1-2 This section is intended to review the role of the Swan-Ganz catheter and its associated monitoring equipment in the derivation of pressures and the calculation of hemodynamic parameters critical to determining cardiovascular function. Its purpose is to familiarize the user with the parameters derived by the MENNEN MEDICAL HORIZON 2000 patient monitor interfaced with the Swan-Ganz* catheter. This knowledge is particularly relevant to calibration and maintenance of critical-care patient monitors, since faulty clinical technique may be diagnosed as faulty monitoring equipment.

1-3 As an introduction to Swan-Ganz catheter monitoring, conventional two-point (CVP/RA and ART) pressure monitoring used in the determination of cardiac function will be reviewed with respect to derived clinical data; limitations of conventional two-point monitoring will also be discussed.

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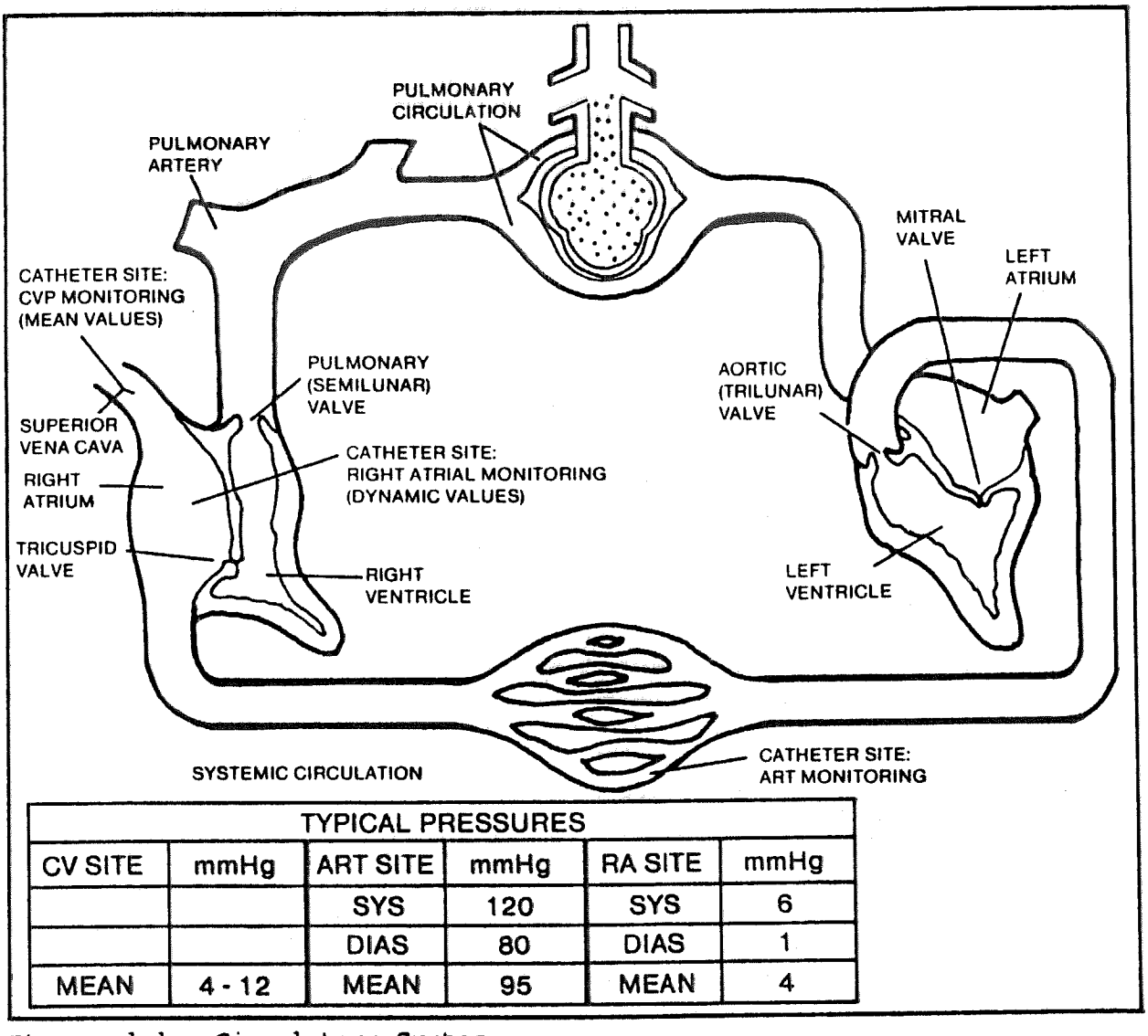
*"Swan-Ganz" is a trademark of the American Edwards Laboratories Division of American Hospital Supply Corporation. No further trademark reference is made in this manual.

1-4 Two-Point Invasive Pressure Monitoring

1-5 Until the development of the Swan-Ganz catheter, conventional invasive pressure monitoring was focused on two sites: the central venous return (typically the superior vena cava) and the arterial system for comparison of mean pressure values. For comparison of waveforms, the right atrial (RA) pressure has been compared with the arterial pressure (ART). These points in the circulatory system are represented in Figure 1-1 and Figure 1-2.



TYPICAL PRESSURES					
CV SITE	mmHg	ART SITE	mmHg	RA SITE	mmHg
		SYS	120	SYS	6
		DIAS	80	DIAS	1
MEAN	4 - 12	MEAN	95	MEAN	4

Figures 1-1. Circulatory System

1-6 The central venous pressure (CVP) is normally monitored in the superior vena cava (Figure 1-1 and Figure 1-2a), the catheter typically being inserted through the sub-clavian vein (Figure 1-2b). Arterial pressure (ART) is typically monitored from a catheter inserted in the radial

artery (Figure 1-2c). In place of the CVP site, the right atrium may be used for right-side monitoring. Note Figure 1-2a. CVP values are virtually constant, and mean CVP is referenced in monitoring; right atrial monitoring, however, would provide a more accurate reference of right heart function. Regardless of the catheter site, the catheter interfaces with a fluid column and transducer (Figure 1-2c), which outputs a voltage proportional to pressure. Virtually all transducers output a signal of 5 μV per volt of excitation per mmHg pressure. Transducer characteristics lie outside this discussion, but a number of relevant monographs are listed in the Bibliography at the end of this section.

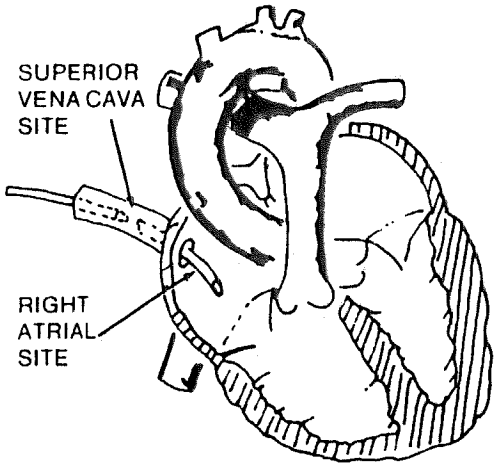


Figure 1-2a.

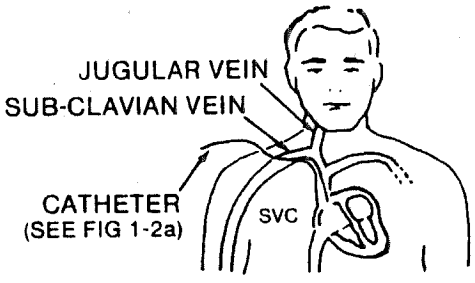


Figure 1-2b.

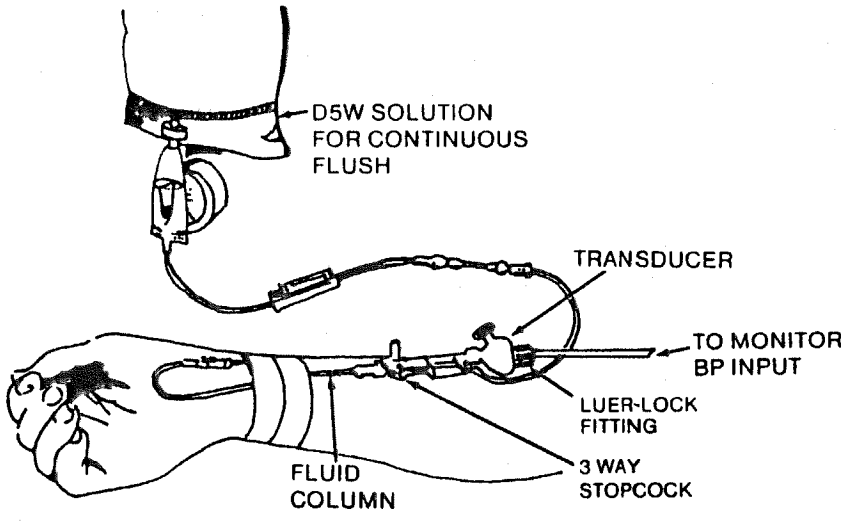


Figure 1-2c.

Figure 1-2. Catheter Sites.

Both CVP and ART monitoring provide critical indicators of cardiac function. The pressure differential between mean ART and mean CVP (see Table in Figure 1-1) represents regulation of blood flow by the arterioles. The relative pressure values of each indicate various cardiovascular conditions, as indicated in Table 1-1.

SYMPTOM	POSSIBLE CAUSE
CVP ↑, ART →	pulmonary congestion; edema; tricuspid valve incompetence; cirrhosis of the liver.
CVP ↑, ART ↑	hypertension; hypervolemia
CVP ↑, ART ↓	pulmonary congestion; edema; mitral or pulmonary valve stenosis; left ventricular infarct.
CVP ↓, ART ↓	hypovolemia; hypotension
CVP ↓, ART →	mild hypovolemia
CVP ↓, ART ↑	stenotic vena cava
CVP →, ART ↑	hypertension
CVP →, ART ↓	left ventricular infarct; pulmonary valve stenosis.

LEGEND: ↑ = **elevated pressure readings**; → = **normal pressure readings**; ↓ = **depressed pressure readings**

Table 1-1. Physiological symptoms associated with relative mean pressure deviations

1-7 In addition to mean pressure values, the RA and ART waveforms, viewed on a non-fade display or recorded on a chart strip, provide indications of specific cardiac failures. This is because each waveform reflects the mechanical activity of the heart, as explained below.

1-8 The Arterial Waveform

The Arterial Pressure (ART) waveform reflects the pumping action of the left ventricle and the overall resistance of the vasculature. Figure 1-3 shows the ART waveform labelled with corresponding cardiac events. Changes in left ventricular pressure are also plotted for comparative purposes. However, this pressure cannot readily be monitored via an invasive catheter.

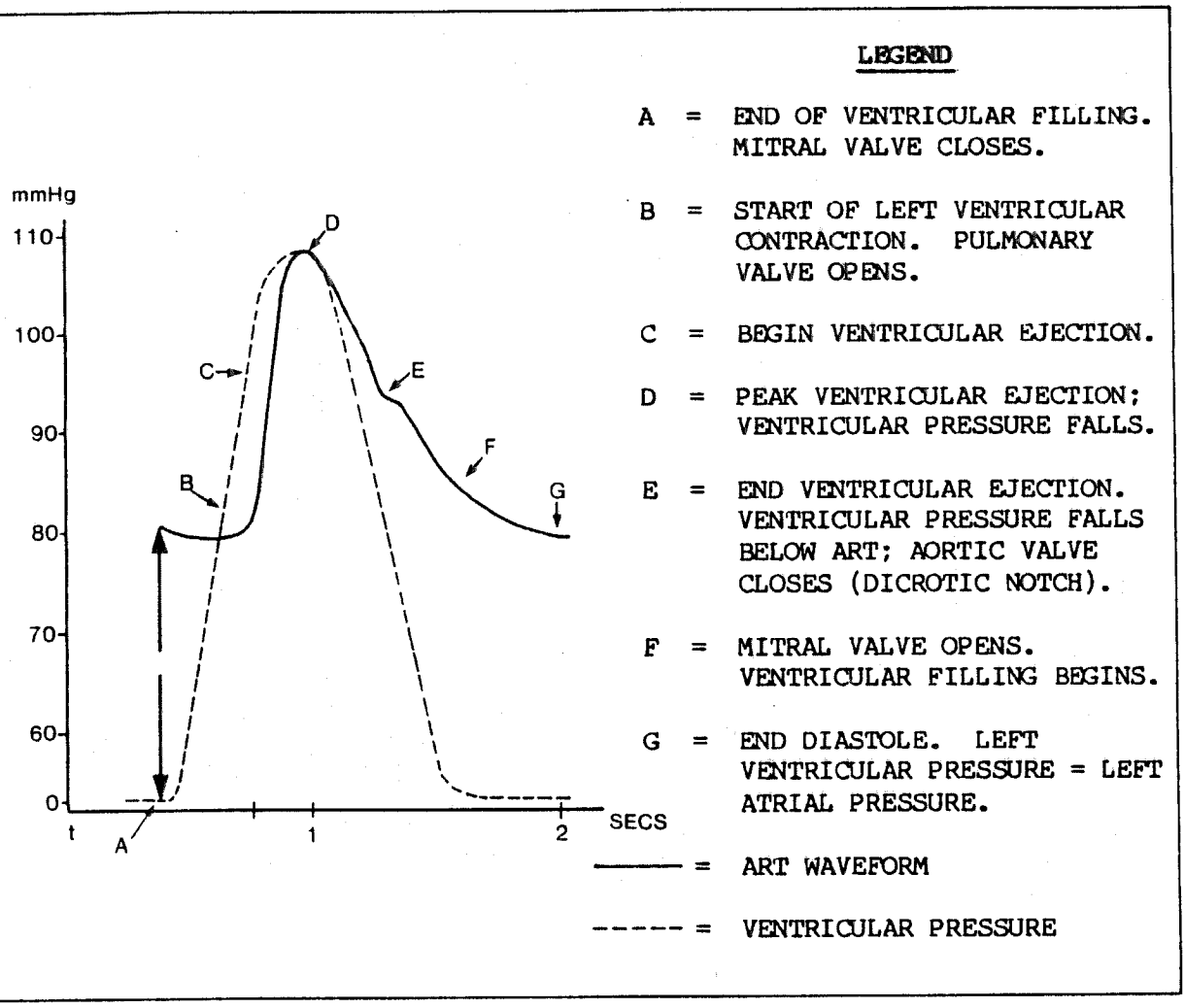


Figure 1-3. ART waveform at HR of 60 BPM.

1-9 Cardiac events occurring when ART is higher than the system-determined diastolic pressure level (80 mmHg in Figure 1-2) are revealed by the ART waveform. Especially visible are mitral valve closure, aortic valve closure (dicrotic notch), and the relation between peak systolic pressure and system arterial pressure. Ventricular infarcts will be indicated by reduced systolic amplitude; valvular incompetence will not only be indicated by reduced waveform amplitude, but by a reduced slope rise because blood flow out of the left ventricle will be restricted (Figure 1-4).

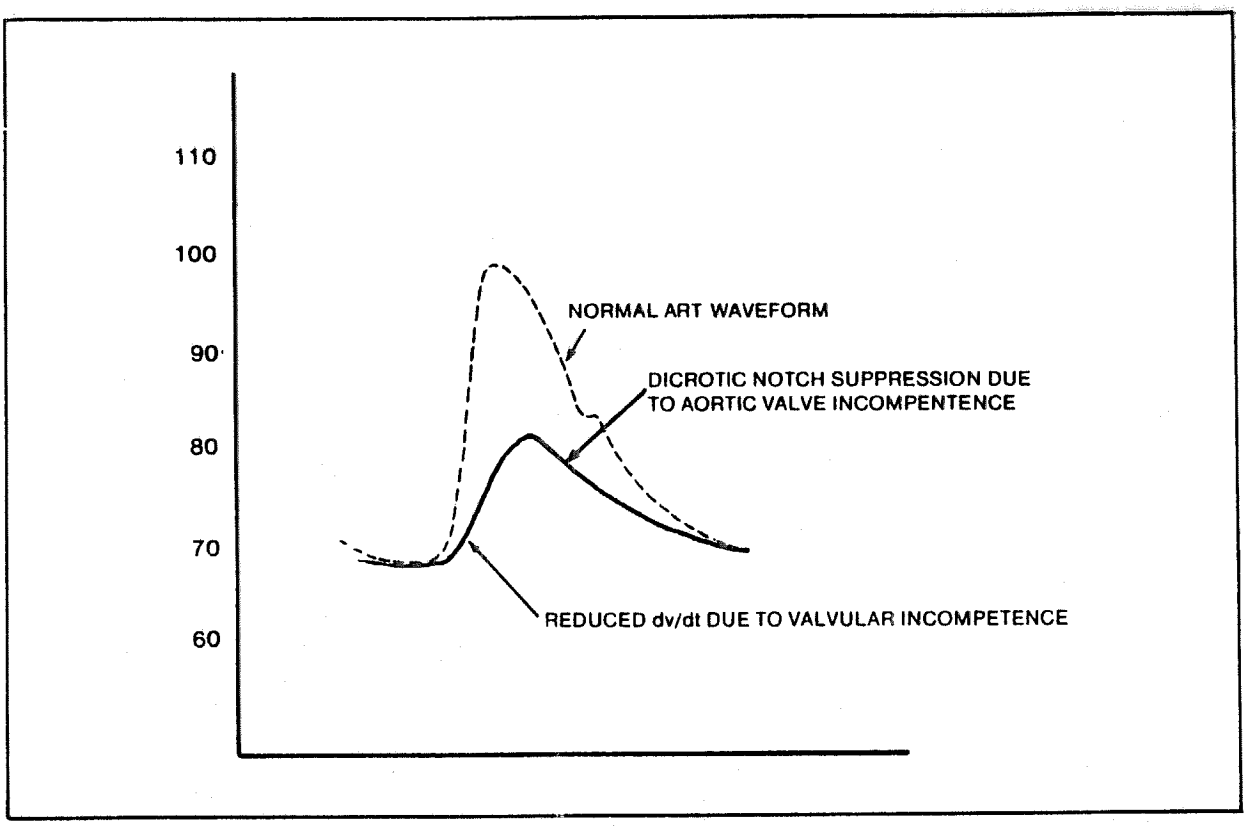


Figure 1-4. Aortic valve incompetence.

1-10 Right Atrial Pressure Waveform

1-11 Right Atrial Pressure (RA) varies only slightly during the cardiac cycle. However, right-side ventricular cycles are reflected in the RA waveform by three significant pressure variations, termed the "a", "c", and "v" waves. These three waves are shown in Figure 1-5.

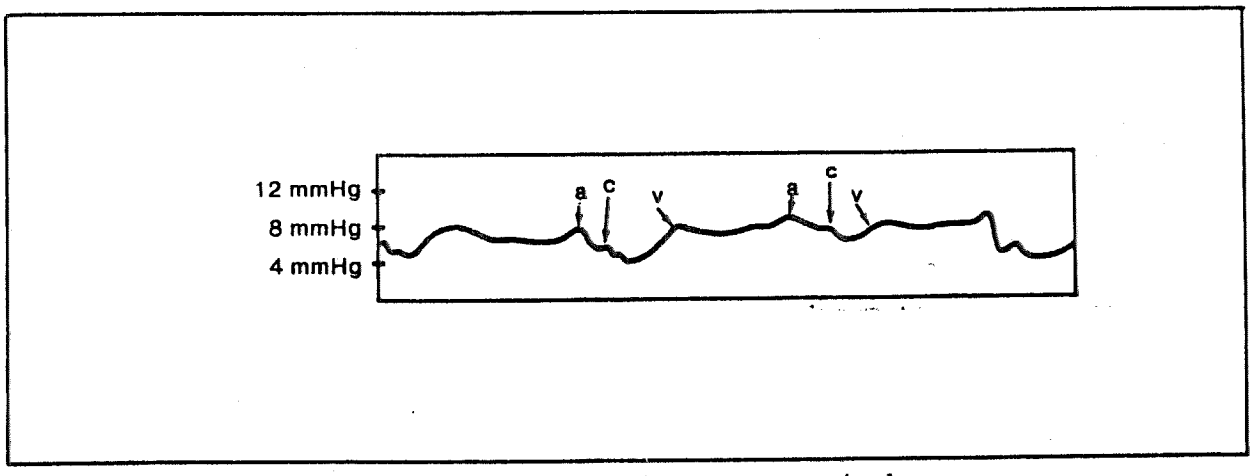


Figure 1-5. RA Waveform with a, c, and v waves marked.

The "a" wave is produced by atrial contraction during atrial systole; the "c" wave (often not visible) is produced during right ventricular systole by the tricuspid valve leaflets bulging back into the atrium, causing a brief rise in RA; the "v" wave corresponds to the gradual refilling of the right atrium following ventricular systole.

1-12 A generally elevated waveform baseline corresponds to hypertension or pulmonary congestion; this elevation may mask the normal a, c, and v waves. Of particular significance are elevated a, c, or v waves. For example, Figure 1-6a indicates tricuspid valve incompetence hindering the complete closure of the valve during right ventricular contraction. Figure 1-6b shows a false c wave riding on a generally elevated RA which appears synchronously with ventricular systole. This waveform indicates possible tricuspid regurgitation.

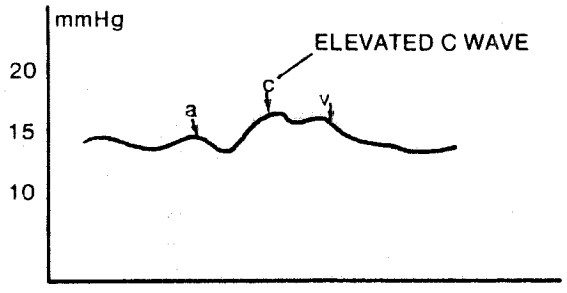


Figure 1-6a.

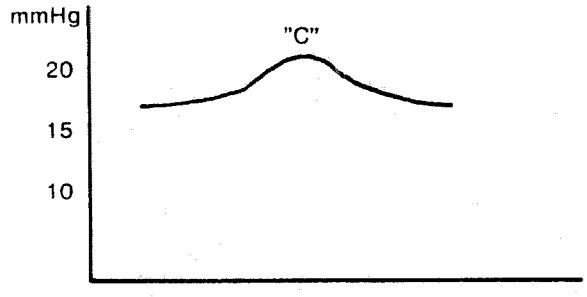


Figure 1-6b.

Figure 1-6. Abnormal RA waveforms.

1-13 Limitations of Two-Point Monitoring

1-14 By comparing the ART waveform with the RA waveform, the physician can assess dynamic interrelationships among cardiac action, vascular tone, and blood volume. However, if the right and left ventricles are not functioning with relatively equal efficiency, the RA waveform does not provide a valid reflection of the myocardium's pumping effectiveness. Nor will the ART waveform necessarily reflect infarcts in the left ventricle. For example, in patients with hypertension, the resultant elevation in ART will compensate for the loss of pressure caused by reduced left ventricle stroke work. That is to say, if system resistance increases in equal proportion to a decrease of blood flow, pressure remains the same. To truly judge left ventricular cardiac function it is necessary to be able to observe two parameters not visible in two-point monitoring: left ventricular diastolic pressure and actual cardiac output. As explained below, the Swan-Ganz catheter enables monitoring of both parameters.

1-15 Another limitation of two-point monitoring is specific to physiological hazards associated with long-term CVP or RA monitoring. In order to obtain good pressure waveform frequency response, CVP catheters are typically of large diameter and stiff construction. If the catheter is inserted too far, so that it penetrates the tricuspid valve, its presence can set off right-ventricular PVCs. A mis-directed catheter can also implant on the right atrial wall, setting off ectopic foci and potentially damaging the endocardium. Embolism is also a potential danger if tubing and Luer-Lok fittings are not air tight. Finally, long-term continuance of cardiac invasion risks infection. Although certain of these hazards also exist in Swan-Ganz monitoring, a rigid catheter tip is not present in the right atrium.

1-16 The Swan-Ganz Catheter: An Overview

1-17 The Swan-Ganz catheter provides for six independent though related monitoring functions:

1) continuous monitoring of pulmonary arterial pressure (PA)
2) derivation of pulmonary capillary wedge pressure (PCWP)
3) continuous monitoring of CVP or right atrial pressure
4) continuous monitoring of cardiac blood temperature
5) calculation of cardiac output via the thermodilution technique
6) intracardiac drug infusion by bolus or IV

Figure 1-7a depicts a 7 French Swan-Ganz catheter with its four lumens and corresponding ports and orifices. Figure 1-7b details the distal end of the catheter with the balloon inflated; Figure 1-7c details the catheter's cross section. Paragraphs 1-18 through 1-26 describe the four catheter lumens and the role they play in cardiac function monitoring.

1-18 **THE DISTAL LUMEN**

1-19 The distal lumen is the transmission path for changes in pulmonary arterial blood pressure. During continuous PA monitoring the distal lumen opening (Figure 1-7b) floats in the pulmonary artery with the associated balloon deflated. The lumen is filled with heparinized normal saline or D5W and interfaces with a standard transducer and a continuous flush device at the distal port. Continuous flush is provided by pressurizing the bag holding the D5W. During wedging (as explained below), the PA waveform converts to provide left ventricular end-diastolic pressure.

1-20 **THE PROXIMAL LUMEN**

1-21 The proximal lumen serves three independent functions:

1) if fluid-filled with heparinized D5W or saline, it can be transducer-interfaced for reading CVP or RA pressure, depending upon where the proximal orifice is sited.

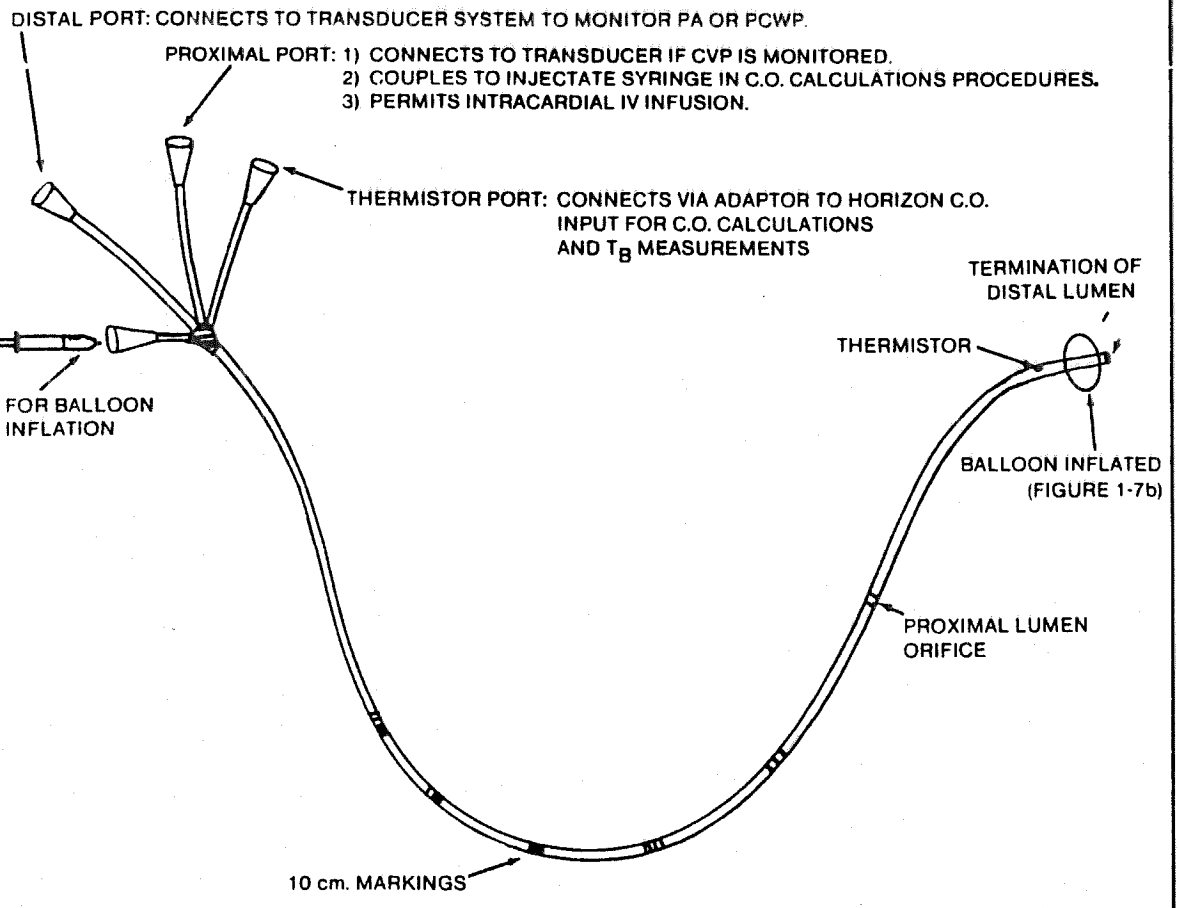
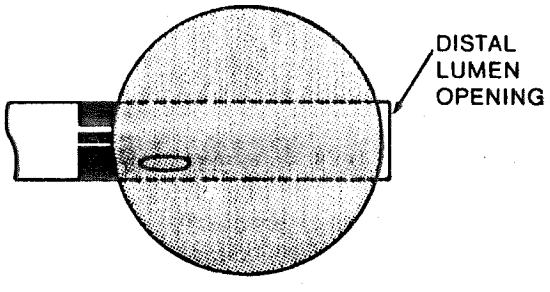
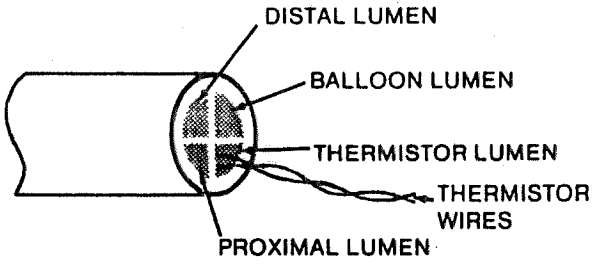


Figure 1-7a.



BALLOON

Figure 1-7b.



CROSS-SECTION

Figure 1-7c.

Figure 1-7. The Swan-Ganz Catheter.

2) as a fluid port it allows injection of the injectate into the right atrium via the proximal orifice during a C.O. calculation trial. The proximal port is coupled to a syringe for the injectate bolus.

3) as a fluid port it permits bolus or IV medication to be introduced into the right atrium through the proximal orifice.

1-22 **THE BALLOON LUMEN**

1-23 The balloon lumen is a column of air driven from a 3 ml syringe which forces air into the balloon surrounding the distal end of the catheter (Figure 1-7b). As explained below, the balloon is inflated with 0.5 - 1.5 ml of air during PCWP derivation. During continuous PA monitoring the balloon is kept deflated.

1-24 The balloon also serves to act as a float (H.J.C. Swan termed it a "sail") during introduction of the catheter into the heart; when inflated, the balloon draws the catheter from the right atrium through to the pulmonary artery during systole.

1-25 **THE THERMISTOR LUMEN**

1-26 The thermistor lumen is a conduit for the wires (Figure 1-7c) which carry bridge current from the monitor through the thermistor. The thermistor rests in the pulmonary artery. Changes in thermistor temperature cause changes in current. HORIZON 2000 utilizes a bridge circuit to scale thermistor current values to equivalent blood temperature values. The thermistor's principle role is detecting changes of blood temperature caused by the injectate passing through the right ventricle during C.O. calculation trials. Previous to sensing blood temperature changes, HORIZON determines average blood temperature from the average thermistor current. The thermistor lumen port is wired to a three-pin miniature connector to which the HORIZON adapter cable is fitted.

1-27 The Swan-Ganz Catheter in PCWP Monitoring

1-28 As explained previously, a significant limitation of two-point monitoring is the inability to read left ventricular diastolic pressure. The Swan-Ganz catheter provides for interpreting end-diastole ventricular pressure when the balloon is inflated and "wedged" in a pulmonary artery. The reason that a balloon-wedged PA catheter yields left ventricular end-diastolic pressure is revealed in Figure 1-8.

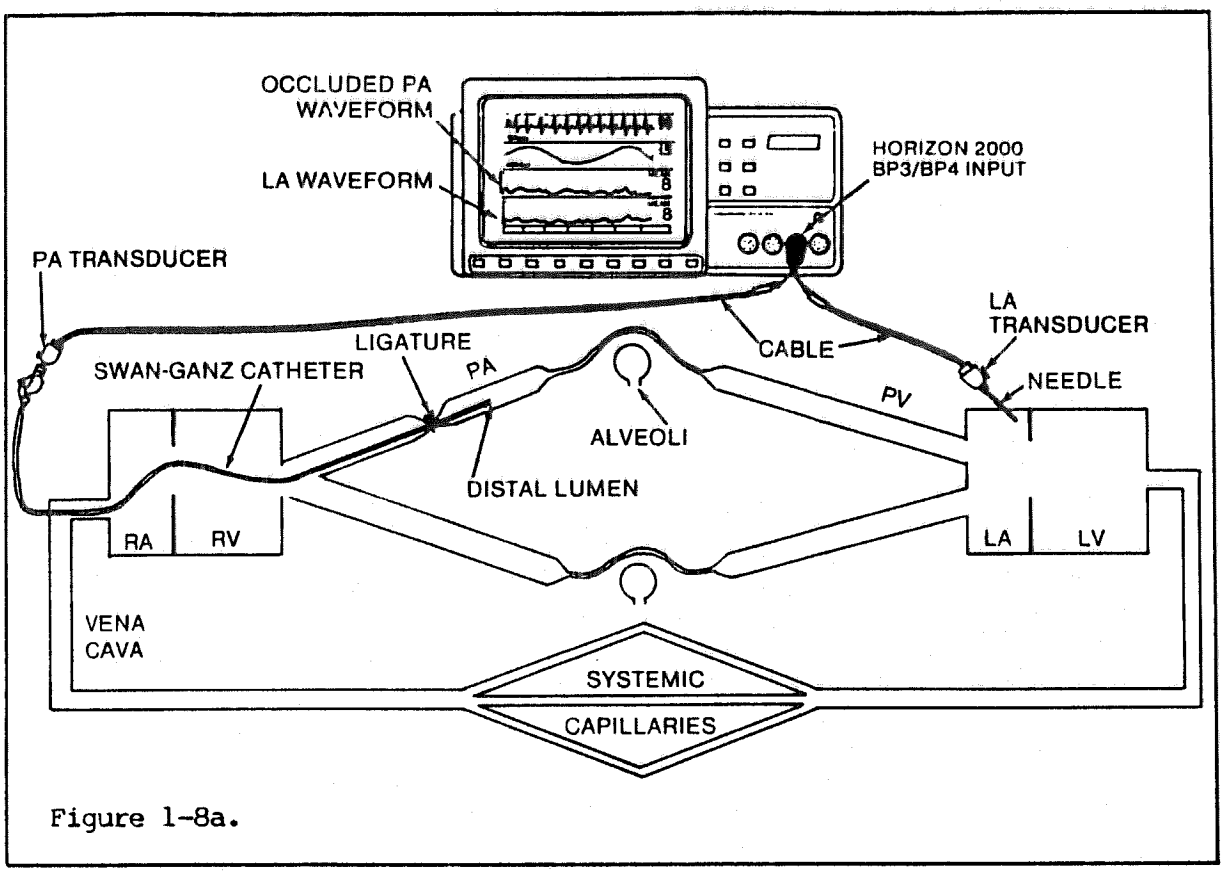


Figure 1-8a.

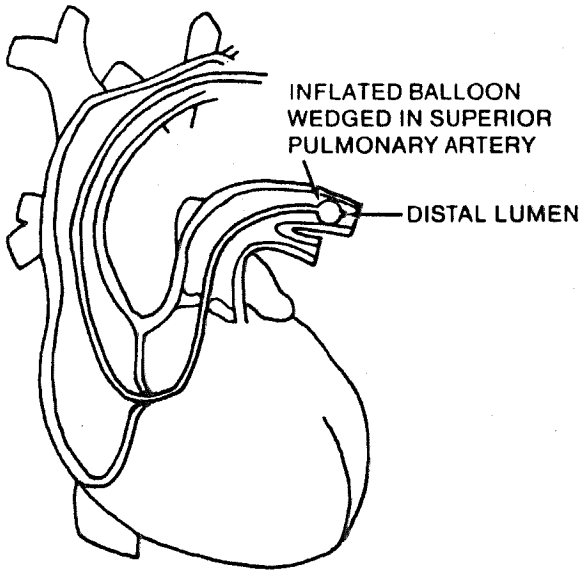


Figure 1-8b.

Figure 1-8. Wedge pressure reflects left ventricular end-diastolic pressure.

1-29 In Figure 1-8a it is imagined that the pulmonary artery has been tied off below the tip of the distal lumen. The pressure sensed by the PA transducer is, therefore, a reflection of left atrial pressure -- the pulmonary system does not normally add a significant pressure gradient to left atrial pressure. By the finish of the end-diastole interval, blood has flowed from the right ventricle through the pulmonary system and left atrium into the left ventricle; pressure throughout is uniform. While the mitral valve remains open, therefore, the displayed PA waveform and corresponding pressure value represent left ventricular pressure. During systole, the mitral valve closes, isolating the distal lumen from left ventricular pressure increase; the ligature (as shown) isolates the distal lumen from the right ventricular pressure increase normally seen in the PA waveform. Therefore, throughout the cardiac cycle, the pressure in the isolated lumen remains close to the left ventricular end-diastolic pressure (LVEDP).

1-30 As shown in Figure 1-8b, inflating the balloon while the catheter is floating in the pulmonary artery will cause it to follow the blood flow up into the arterial system where it will occlude, or "wedge," a principal artery. If the balloon is kept sufficiently inflated so that it remains stationary in the artery, the distal lumen will be isolated from right ventricular contraction; the pressure on the display will be converted to pulmonary capillary wedge pressure (PCWP).

1-31 Clinical Significance of Wedge Pressure Monitoring

1-32 Because PCWP reflects LVEDP (typically 6 - 12 mmHg) it is a good index of left heart function. In conjunction with ART and PA it can narrow down cardiac dysfunctions to ventricular, systemic, or pulmonary causes. However, there are certain limitations in the relationship of PCWP and left ventricular functions. Normally LVEDP and wedge pressure are approximately equal. However, in cases of pulmonary congestion and edema PCWP will be higher than LVEDP; a wedge waveform will not reflect LVEDP in the presence of severe emphysema, for example.

1-33 Additional causes of elevated wedge pressure are mitral valve and aortic valve stenosis or left ventricular failure. In these three instances the right ventricle carries a greater portion of the cardiac load and left atrial pressure will rise accordingly. Causes of elevated wedge pressures may be further distinguished between left heart and pulmonary failure by comparing them with diastolic PA pressures.

1-34 RELATIONSHIP OF DIASTOLIC PA AND PCWP

1-35 The PA diastolic value, like the mean PCWP value, should be relatively close to LVEDP -- typically in a range from 8 to 15 mmHg. Generally the PA diastolic value is slightly higher (2 - 4 mmHg) than wedge pressure, since the wedged lumen is measuring a pressure farther "downstream." This PA-wedge pressure relationship remains constant in the presence of left ventricular disease or valvular stenosis. Thus if a

ventricular failure causes PA diastolic pressure to rise from a normal level of 15 mmHg to a level of 20 mmHg, wedge pressure will correspondingly rise from 12 mmHg to 17 mmHg. It can be said that an equal rise in PCWP and PA diastolic pressure indicates left-heart failure, especially in the presence of decreased ART systolic values.

1-36 In the presence of severe lung congestion, the corresponding increase in diastolic PA pressure will be greater than the increase in PCWP. This greater pressure difference results from the increased work the right ventricle faces in forcing blood through constricted pulmonary capillaries. During wedging, the distal lumen reflects only a portion of the pulmonary back-pressure seen in PA monitoring. The wedge pressure - diastolic PA pressure differential will be greater than 5 mmHg in the presence of lung disease, and both pressures will be elevated. Systolic PA will also be substantially elevated above normal values.

1-37 It is important to keep in mind that mean PA should always be greater than PCWP. If monitoring conditions indicate PCWP greater than PA, the distal orifice may be clotted or lodged against the endocardium, among other problems.

1-38 In summary, it may be said that an equal increase of PA diastolic and wedge pressure indicates left heart failure; a greater increase of PA diastolic pressure relative to wedge pressure indicates pulmonary failure. In both instances wedge and PA pressures can be above 25 mmHg.

1-39 PCWP WAVEFORM

1-40 In the foregoing comparison of PA and PCWP values, the diastolic PA pressure was compared with the mean PCWP. The mean PCWP value is the one derived by the HORIZON patient monitor during wedge pressure averaging. The waveform signal will typically vary only slightly (+5 mmHg) in a normal PCWP waveform, **if respiratory artifact is discounted** (see Paragraph 1-41). It will closely resemble the RA wavefrom (Figure 1-5) and be marked by a, c, and v waves. Of particular significance is the v wave in the RA waveform: mitral valve incompetence will allow blood flow into the left atrium during ventricular systole. This will cause a sharply elevated v wave in the PCWP waveform.

1-41 RESPIRATORY ARTIFACT IN PA AND PCWP WAVEFORMS

1-42 During normal (unassisted) inspiration, pressure in the pulmonary vascular system decreases; expiration causes a corresponding increase in pressure (± 5 mmHg). When the patient is on a ventilator, however, the opposite effect is seen in the waveform -- forced inspiration increases PA pressure — and the pressure deviation is typically greater (± 10 mmHg). These pressure deviations can cause misinterpretation of the PA and PCWP waveform. Proper waveform interpretation is discussed in Section 2.

1-43 The Swan-Ganz Catheter in Cardiac Output Monitoring

1-44 Although pressure readings in conjunction with the patient's ECG provide substantial raw data from which cardiac function can be determined, neither measurement technique provides direct evidence of the left ventricle's pumping ability. This can be obtained by calculating cardiac output via the thermodilution technique. During this calculation the Swan-Ganz thermistor lumen is used first to measure average blood temperature and then to sense the change in blood temperature as injectate flows past the thermistor during right ventricular systole. The injectate is forced into the proximal lumen by a syringe, and flows out the proximal orifice. See Figure 1-9.

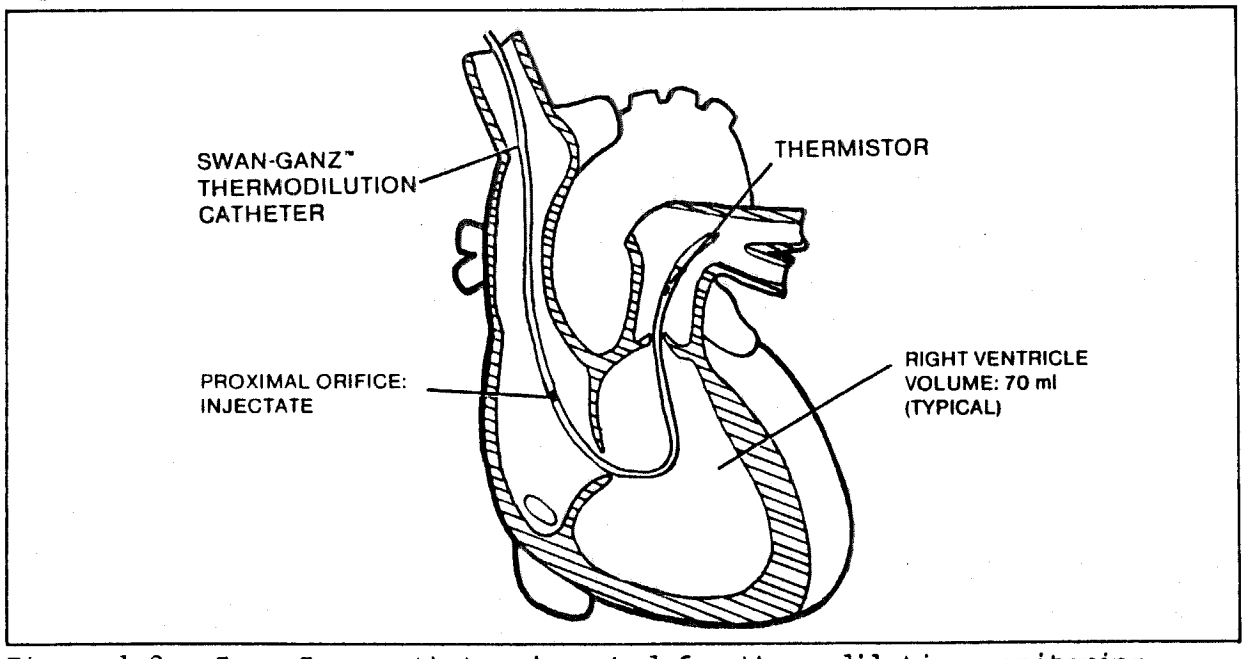


Figure 1-9. Swan-Ganz catheter inserted for thermodilution monitoring.

1-45 The specific interface of the Swan-Ganz catheter with the injectate system and the HORIZON monitor is discussed in Section 3, Preparation and Method for Calculating Cardiac Output. The discussion which follows explains the correspondence between change of blood temperature occurring during a thermodilution trial and left ventricular cardiac output.

1-46 The Thermodilution Curve and the Stewart-Hamilton Equation

1-47 Assume that a 10 ml bolus of D5W at $1^{o}c$ is injected into the right atrium through the proximal orifice (Figure 1-9). The injection of a 10 ml. bolus will typically require 3 - 4 seconds because of the narrow diameter of the lumen. At a heart rate of 60 BPM, therefore, approximately 1/3 of the injectate will be pumped through the right ventricle with each beat and some injectate bolus will be added to the pulmonary artery and accumulate near

the thermistor* following each beat. The result will be a gradual cooling of the thermistor over a time period of 4 - 5 seconds. In another four beats the cooled blood supply will have been replaced by normal-temperature blood, and the thermistor will be returning to its baseline temperature. Because the injectate bolus is gradually admitted to and expelled from the pulmonary artery, the changes of blood temperature will be a fairly uniform dT/dt (incremental temperature change per increment of time) progression, with the lowest temperature point occurring 4 seconds following the injection. The dT/dt progression is plotted in Figure 1-10.

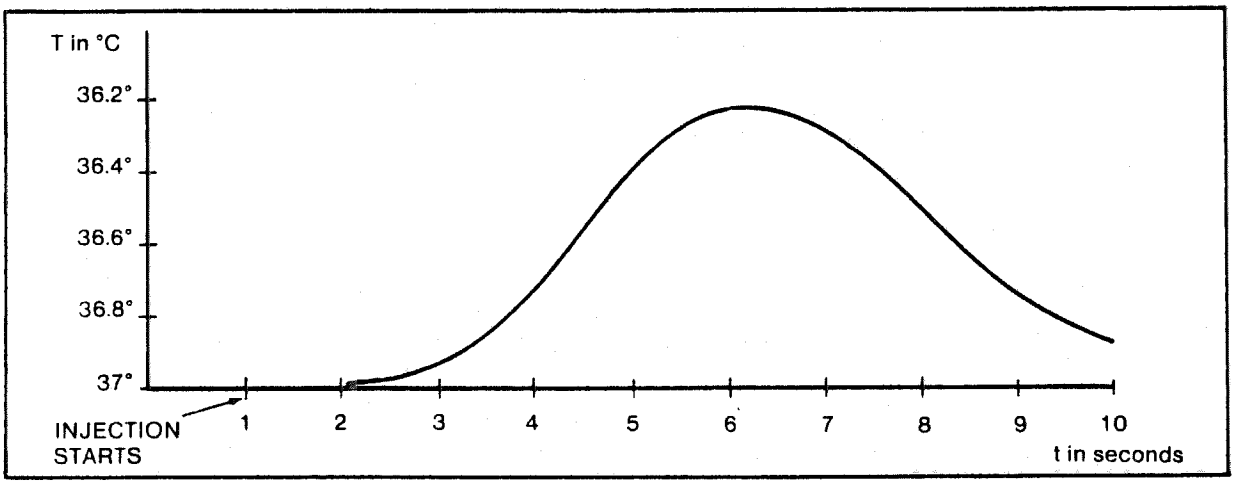


Figure 1-10. Normal thermodilution curve (C.O. = 5.0 L/min.).

1-48 Note that the Y axis of the curve is plotted as a function of decreasing temperature. This is a convention in thermodilution curve representation. The peak temperature change is only 0.7°c because the volume of blood pumped by the right ventricle is only slightly diluted (3.3 ml of injectate per beat cooling 70 ml in the right ventricle).

1-49 Now assume a patient with significant left ventricular failure, reducing the left ventricle's pumping ability by 50%. Figure 1-11 shows the resultant thermodilution curve plotted along with the normal curve from Figure 1-10.

1-50 During systole the right ventricle sees an elevated PA diastolic pressure because left atrial end diatolic pressure has been elevated due to the left ventricle's inability to pump out the normal volumes of blood. This results in the injectate being captured in the pulmonary artery for a longer interval, with subsequently increased thermistor cooling. Note also that the return to baseline temperature takes substantially longer than the initial change due to thermodilution because the injectate transfers more rapidly into the pulmonary artery than it exits from it.

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*The ventricle does not completely empty during systole, but delivers an ejection fraction of the ventricular contents. For purposes of clarification, this fraction is assumed to be 1.0.

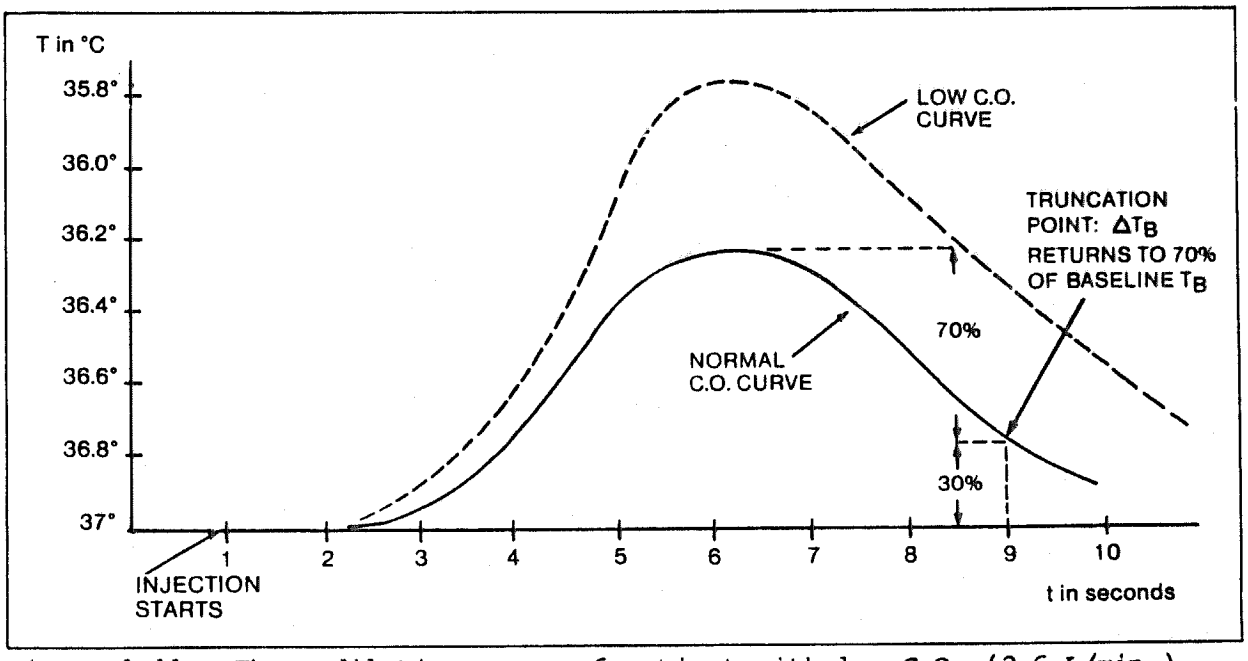

Figure 1-11. Thermodilution curve of patient with low C.O. (2.6 L/min.)

1-51 It can be seen from the above examples that cardiac output is inversely proportional to total thermodilution change, which is represented by the area under the thermodilution curve. The Stewart-Hamilton equation relates the area under the thermodilution curve to cardiac output in liters/minute:

$$C.O. = \frac{(1.08) \times (K) \times (60) \times (V_I) \times (T_B - T_I)}{1.22 \int_0^t T_B dt}$$

WHERE:

1.08 = ratio of density x spec. heat of 5% dextrose to density x spec. heat of blood

K = injectate correction factor. See Paragragh 1-53

60 = converts C.O. to Liters/minute

V_I = volume of injectate in Liters

T_B = baseline blood temperature in ^oC

T_I = temperature of injectate. See Paragraph 1-53

$\int_0^t T_B d_t$ = area under thermodilution curve from point of baseline change (0) to time (t) when curve returns to 70% of baseline T_B. See Paragraph 1-52.

1.22 = truncation correction factor. See Paragraph 1-52

1-52 The constant 1.22 in the denominator of the equation is not part of the Stewart-Hamilton equation, but is a modification to shorten the time of calculation. Since the thermodilution curve decays exponentially, the calculation is truncated when the T_B value returns to 70% of baseline. MENNEN MEDICAL has assigned the factor 1.22 as a constant to represent the truncated portion of the thermodilution curve (see Figure 1-11).

1-53 The injectate is warmed as it passes through the Swan-Ganz catheter. The degree of warming is a function of catheter French size, injectate volume, and injectate temperature. The K factor effectively reduces the $T_B - T_I$ differential, since the T_I value is derived from injectate temperature before injection. The HORIZON patient monitor automatically provides the correct K factor for injectate temperature, catheter French size, and injectate volume for both Edwards and Spectramed separate-bath catheters. Injectate temperature is continuously monitored; injectate volume and French size are operator-entered. Table 1-2 lists a sample of K factors for various injectate parameters using either separate-bath injectate system. A full chart of K-factors for corresponding injectate systems is provided in Section 3.

INJECTATE TEMP RANGE	INJ TMP (°C)	INJ VOL (ml)	FRENCH #s 4,5,6 K-FACTOR		FRENCH #7 K-FACTOR		FRENCH # 7.5 K-FACTOR	
			EDWARDS	SPECTRAMED	EDWARDS	SPECTRAMED	EDWARDS	SPECTRAMED
CHILLED	0-5	10	.899	- -	.837	.566	.870	.566
		5	.841	.279	.764	.270	.793	.270
		3	.788	.160	.681	.151	.736	.151
NON-CHILLED	19-22	10	.925	- -	.892	.628	.898	.628
		5	.901	.316	.846	.309	.854	.309
		3	- -	.188	.792	.180	.802	.180
	23-25	10	.953	- -	.919	- -	.937	- -
		5	.948	- -	.888	- -	.904	- -
		3	.909	- -	.851	- -	.874	- -

Table 1-2. K-factor chart for Edwards and Spectramed Separate-bath Injectate System.

1-54 The calculation of cardiac output for a given patient is subject to a number of variables that affect the thermodilution curve. Seven principal causes of unreliable C.O. calculations can be listed:

1. Thermistor position: the monitor must be checked to verify that the distal end of the Swan-Ganz catheter has not migrated to the intima or otherwise inhibited the lumen's patency. Also, if the thermistor is at too distal a location in the pulmonary artery, insufficient ΔT_B may result.

2. Change in cardiac rhythm: sudden changes in systolic intervals, such as those associated with couplets or PVC's, will cause erratic changes in C.O. values. Note that the Swan-Ganz catheter itself can be a cause of right ventricular PVC's.

3. Motion of distal lumen: the thermistor should remain stationary. "catheter whip" — typically caused by cardiac pumping -- results in varying T_B values. On patients who are ventilator-assisted, forced inspiration may also cause T_B variation or uneven thermodilution bolus mixing. To insure consistency on ventilated patients, injection should take place during end-expiration.

4. Change in patient position: changing the patient's supine angle or limb position may affect venous return and corresponding thermodilution effect.

5. Variation in injectate temperature or blood temperature: the latter factor is especially significant for those patients just returned from cardiac surgery, since suppressed chest cavity temperatures are returning to normal.

6. Changes in medication: these are especially significant as they relate to changes in blood pressure and venous return.

7. Injectate technique: very slow as opposed to rapid injections prolong and flatten the thermodilution curve.

As explained in Section 3, the HORIZON patient monitor applies certain windows of acceptance to ΔT_B, T_B, and T_I during a C.O. calculation to determine whether variations outside of acceptable limits for reliable calculation have occurred. However, the windows are wide enough to allow substantial variations between successive C.O. calculations; for this reason, several C.O. trials are usually run before a C.O. value is accepted.

1-55 CARDIAC INDEX

1-56 C.O. is proportional to the patient's physical size. To obtain a relative comparison between patients of different height and weight, the C.O. is divided by body surface area (BSA) to obtain the Cardiac Index. BSA is calculated by the DuBois and DuBois formula:

$$BSA = W^{0.425} \times H^{0.725} \times 0.007184$$

WHERE: BSA = Body Surface Area (M^2)
W = Weight (kg)
H = Height (cm)

HORIZON automatically calculates BSA and corresponding cardiac indexes if the patient's height and weight were entered previous to C.O. calculation.

1-57 Clinical Application of Hemodynamic Measurements

1-58 The Swan-Ganz catheter permits the physician to obtain right ventricular cardiac output and LVEDP, as well to continuously monitor PA and CVP. Because PA pressure reflects forces in the arterial system due to both vascular tone and cardiac output, the ability to independently determine C.O. by the thermodilution technique provides further information as to whether abnormalities in PA pressure are related to left ventricular or systemic problems. Consider Table 1-3.

CAUSES	SYMPTOMS		
	PA	C.O.	ART
Hypertension	↑	→	↑
Hypervolemia	↑	↑	↑
Left Ventricular Infarct	↑	↓	↓
Pulmonary Edema	↑	→	→
Mitral Stenosis	↑	↓	→

LEGEND: ↑ = elevated
→ = normal
↓ = reduced

Table 1-3. Causes of elevated PA pressure and correlative hemodynamics.

Table 1-3 shows five causes of elevated PA pressure. Comparison of PA with ART demonstrates that the same symptoms (e.g., elevated PA and ART) appear from quite different causes. Note however that a comparison of PA, ART, and C.O. provides a unique symptom chain for each cause.

1-59 STARLING'S LAW AND HEMODYNAMIC MEASUREMENTS

1-60 A properly functioning heart should obey Starling's Law: an increase in diastolic filling produces a corresponding increase in cardiac output. In critically ill patients, however, Starling's Law will not operate in all cases: as venous return increases, the heart is unable to increase C.O. Appropriate therapeutic intervention is based on that procedure which returns the cardiovascular system to the efficiency level necessary to permit C.O. to emulate atrial filling. The relative efficiency of a given cardiac system can be judged by plotting C.O. against PCWP, since wedge pressure corresponds to end-diastolic pressure. This plot is shown in Figure 1-12 for a patient with mitral stenosis.

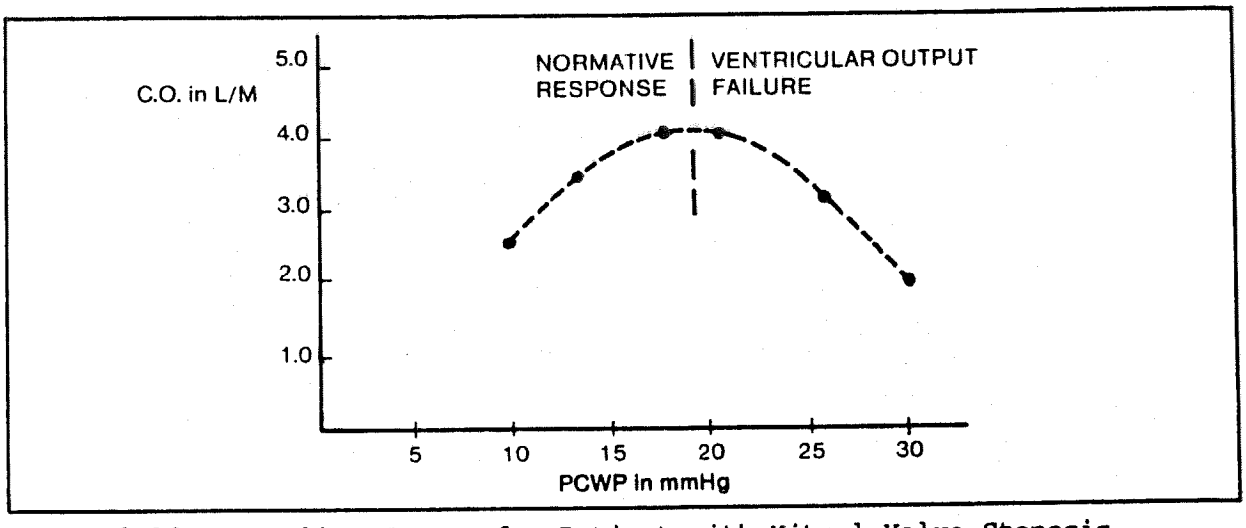

Figure 1-12. Starling Curve of a Patient with Mitral Valve Stenosis.

The increase of PCWP shows normal cardiac response until the defective mitral valve starts cutting back on ventricular filling while simultaneously increasing atrial pressure. Heart rate will also increase (following Starling's Law), adding further mitral stress and increasing stenosis due to trauma. Therapeutic intervention is required under stress conditions to return the patient to a safe region of Starling's Curve until appropriate medical treatment is determined.

1-61 BLOOD VISCOSITY AND ITS EFFECT ON VENTRICULAR FUNCTION

1-62 Another significant factor in cardiac efficiency is the viscosity of the blood. With highly viscous blood (blood with a high concentration of red blood cells), more work is required to push the blood past the intima,

thus increasing the afterload on the heart. Also, increased viscosity tends to aggravate maldistribution of red blood cells (erythrocytes) at the capillary branches. This can lead to anoxia of the tissue, which will result in increased blood-flow demand and a corresponding increase in heart rate. Thus high-viscosity blood decreases cardiac efficiency by increasing afterload and simultaneously increasing heart rate.

1-63 Several techniques are used for reducing afterload by reducing viscosity, including hemodilution (thinning the blood with plasma), and defibrination (fibrin is the agent that links erythrocytes together; fibrin levels correspond to viscosity). With hemodilution, the total blood volume is increased, which also causes a corresponding increase in filling pressure (PCWP).

1-64 A measure of blood visocity is the percentage of hematocrit. Hematocrit is the percentage concentration of erythrocytes in a given volume of blood. The normal hematocrit concentration is 35 to 40%. It can be seen that the higher the percentage of hematocrit, the greater the viscosity of the blood. For a given wedge pressure, a decrease in viscosity will lower the afterload on the heart and thereby increase cardiac output, without increasing heart rate. This change of efficiency is represented in Figure 1-13; the lower curve reproduces the Starling curve for the patient in Figure 1-12; the upper curve represents the relationship of C.O. and PCWP at a lower viscosity level.

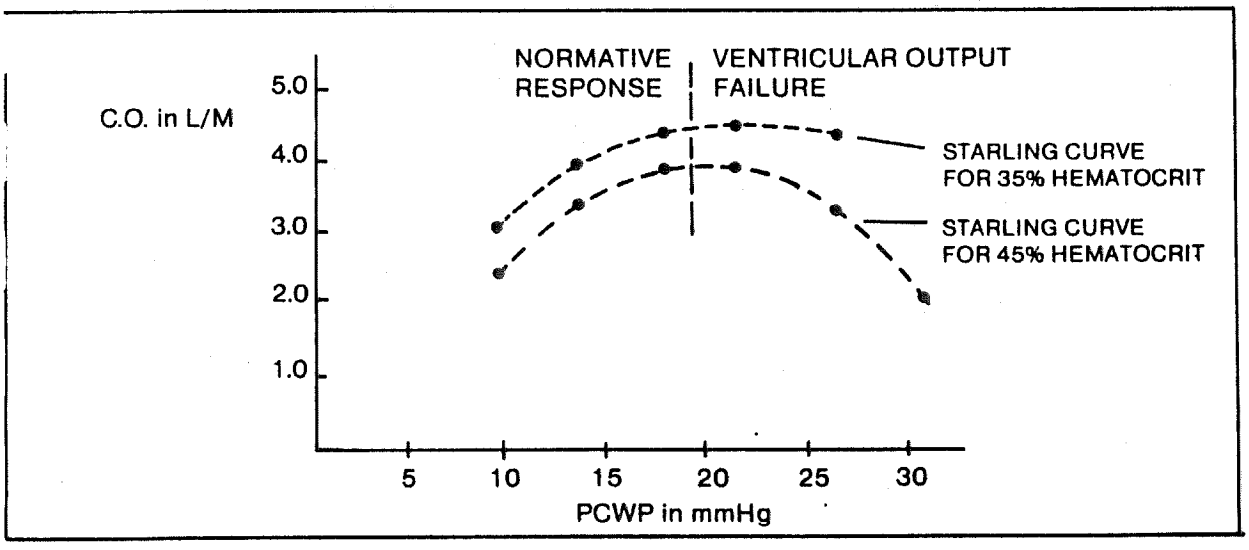

Figure 1-13. Starling Curve of a Patient with Mitral Valve Stenosis for Two Levels of Hematocrit.

1-65 If cardiac index (C.O./BSA) is plotted as a function of both hematocrit and wedge pressure, and both are altered in steps (through hemodilution, for example) a WVC plot -- Wedge pressure, Viscosity, Cardiac index -- can be graphed which will represent changes in cardiac output resulting from a decrease in viscosity. This is represented in Figure 1-14, the WVC plot. Note that hemodynamic and oxygenation data are listed for one point in the plot. Successive hemodilutions should generate successive data tables which indicate reduction in afterload and improvement in oxygen delivery. Thus, as the blood is diluted progressively in Steps 2, 3, and 4 in Figure 1-14, one would anticipate a decrease in systemic resistance, a decrease in heart rate, and an increase in oxygen consumption.

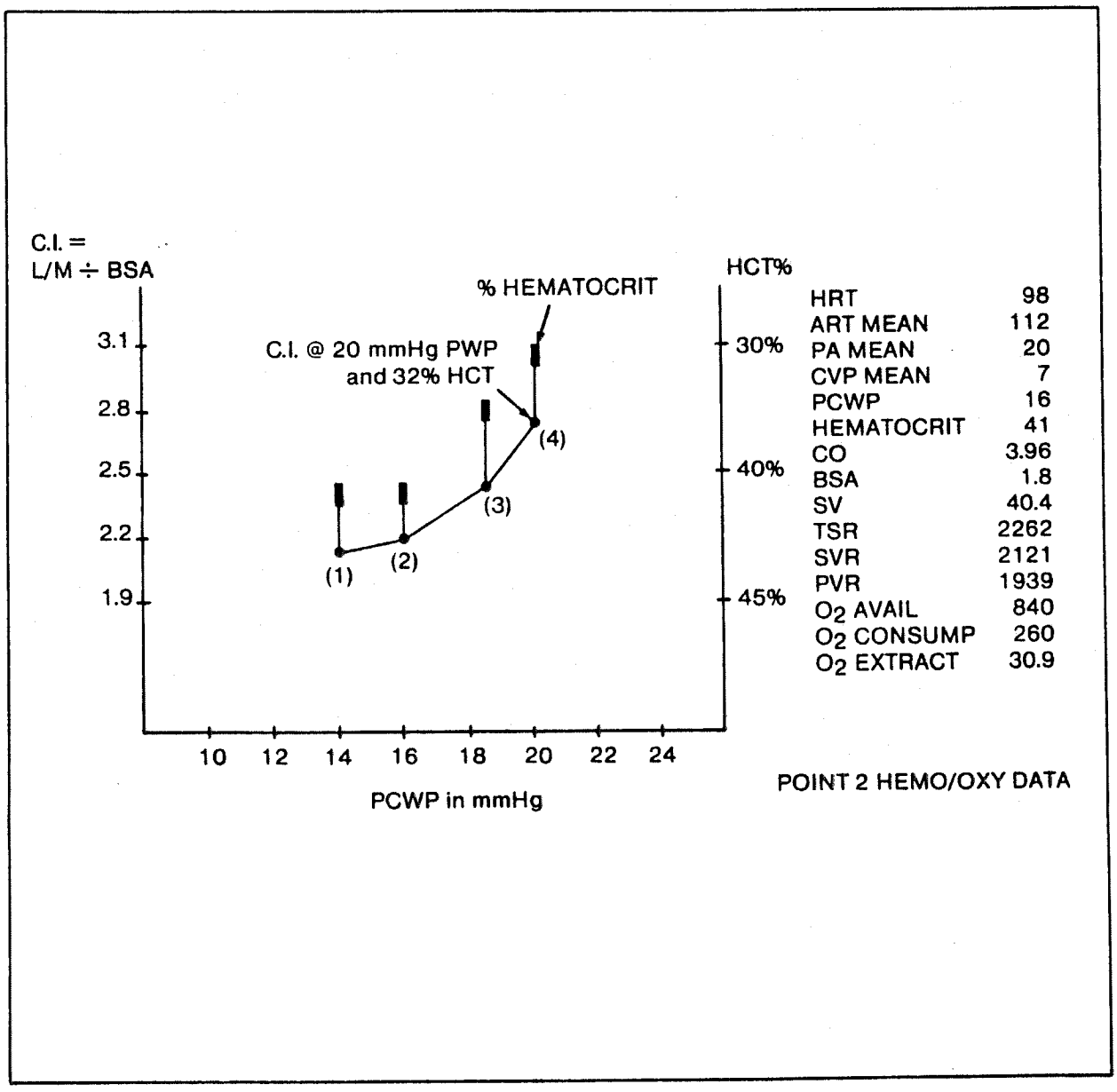

Figure 1-14. WVC Plot and One-point Data.

1-66 The HORIZON 2000 Patient Monitor equipped with Option -003, Data Management, provides for ventricular function analysis via both Starling curves and WVC plots. The procedure for obtaining these graphs is explained in Section 4: Ventricular Function Analysis.

1-67 Derived Hemodynamic Parameters

1-68 **SYSTEMIC RESISTANCE**

1-69 Since blood pressure is a measure of pumping force and C.O. is a measure of blood flow, the systemic resistance (SR) will always be a ratio of pressure and C.O. This parallels Ohm's Law:

$$R = \frac{E}{I} \quad ; \quad SR = \frac{BP}{C.O.}$$

Specific resistances can be obtained by measuring the difference between two pressure points and dividing by C.O.

1-70 **STROKE VOLUME AND STROKE WORK**

1-71 Stroke volume -- the amount of blood output by the ventricle during each systole -- is obtained by dividing C.O. by heart rate. Differing stroke volumes for patients of different size may be correlated by dividing S.V. by BSA, which yields Stroke Index (similar to Cardiac Index -- see Paragraph 1-55).

1-72 Stroke work is the product of blood pressure and stroke volume. It corresponds to the electrical Formula: P = EI. Stroke work may be specified for left or right ventricles by factoring in the appropriate pressure. If C.O. is substituted for S.V. as a factor, the product is cardiac work, which is proportional to heart rate.

1-73 Hemodynamic Function Table

1-74 Table 1-4 (Page 1-23) lists the hemodynamic functions mathematically derived from ART and Swan-Ganz measurements in conjunction with heart rate. An optional Data Management Package (260-OPT-003) available with the HORIZON Patient Monitor automatically performs the calculations listed in Table 1-4 if the required parameters are monitored or manually entered.

1-75 In addition, the HORIZON monitor automatically calculates the most commonly used hemodynamic parameters and displays them following acceptance of C.O. Calculations in a Hemodynamic Summary. An example of the Summary is presented in Figure 1-15.

1-76 Specific instructions relative to obtaining hemodynamic parameters from the HORIZON Patient Monitor are provided in Section 3.

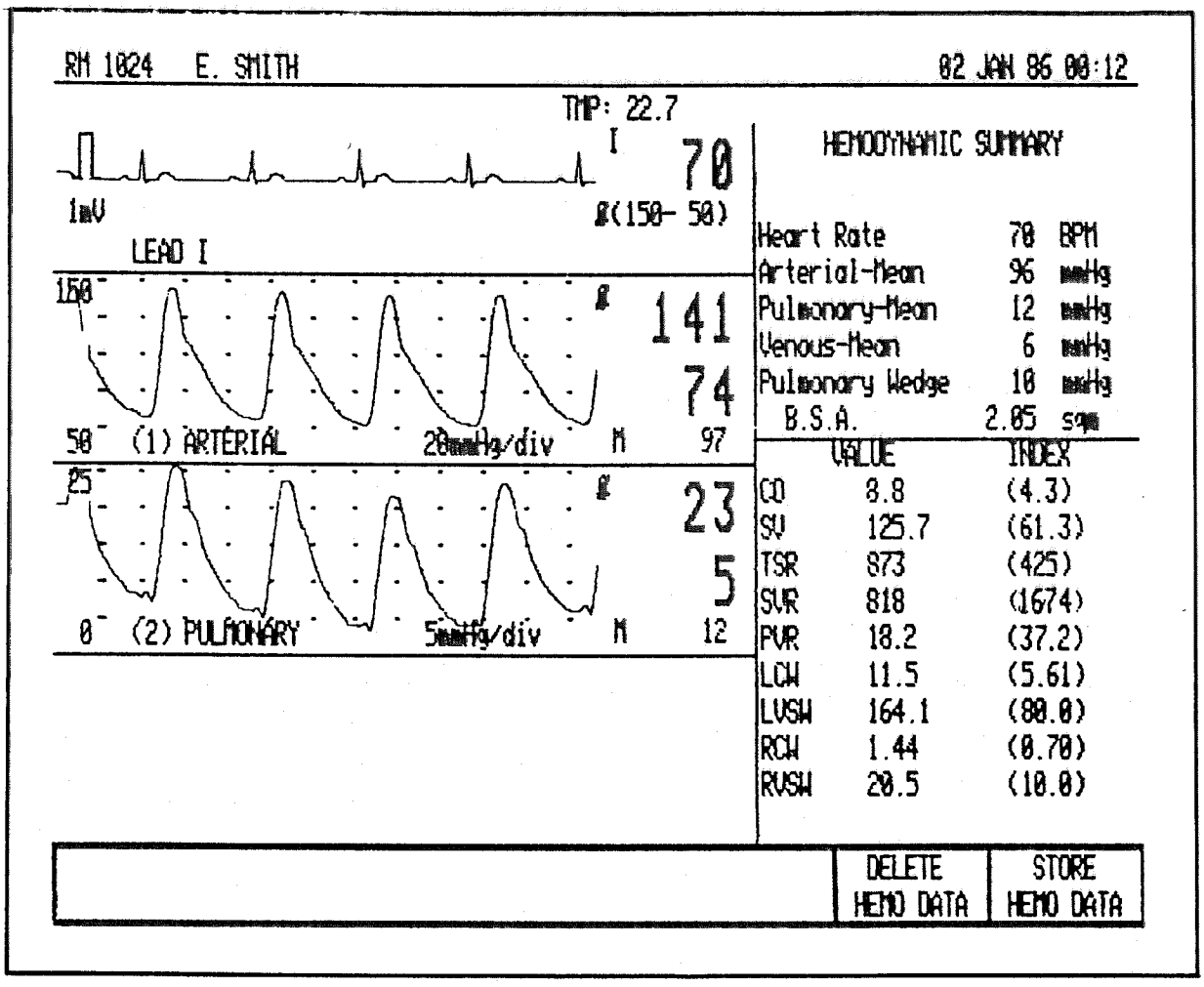

Figure 1-15. Hemodynamic Summary.

HEMODYNAMIC FUNCTIONS

PARAMETER	ABBREV	EQUATION	RANGE OF NORM VALUES	UNITS
Heart Rate	HRT			beats/min
Arterial Blood Pressure	ART			mmHg
Systolic				
Diastolic				
Mean	MAP			mmHg
Pulmonary Artery Pressure	PAP			mmHg
Systolic				
Diastolic				
Mean	MPAP			mmHg
Wedge	PCWP			mmHg
Central Venous Pressure	BP3			mmHg
Height	Ht			cm
Weight	Wt			Kg
Body Surface Area	BSA			m^2
Cardiac Output	CO	$(1.08(60)V_I K(T_B-T_I))/1.22/Tdt$ 1.22 Tdt	4-7	L/min
Cardiac Index	CI	CO/BSA	3-4	$L/min/m^2$
Stroke Volume	SV	(CO/HRT) x 1000	50-115	ml/beat
Stroke Index	SI	(CI/HRT) x 1000	35-70	$ml/beat/m^2$
Total Systemic Resistance	TSR	80 MAP/CO		$dyne\ sec/cm^5$
Systemic Vascular Resistance	SVR	80 (MAP-CVP)/CO[1)]	770-1500	$dyne\ sec/cm^5$
Systemic Vas. Resistance Index	SVRI	80 (MAP-CVP)/CI		$dyne\ sec\ m2/cm^5$
Pulmonary Vascular Resistance	PVR	80 (MPAP-PWG)/CO	20-120	$dyne\ sec/cm^5$
Pulmn. Vas. Resistance Index	PVRI	80 (MPAP-PWG)/CI		$dyne\ sec\ m2/cm^5$
Left Cardiac Work	LCW	CO x MAP x 0.0136		kg m
Left Cardiac Work Index	LCWI	LCW/BSA	3.6-4.4	$kg\ m/m^2$
Left Ventricular Stroke Work	LVSW	SV(MAP - PWP) x 0.0136		gm m
Left Ventric. Stroke Work Index	LVSWI	SI(MAP - PWP) x 0.0136	45-57	$gm\ m/m^2$
Right Cardiac Work	RCW	CO x MPAP x 0.0136		kg m
Right Cardic Work Index	RCWI	CI x MPAP x 0.0136	0.44-0.56	$kg\ m/m^2$
Right Ventric. Stroke Work	RVSW	SV x MPAP x 0.0136		gm m
Rt. Ventric. Stroke Work Index	RVSWI	SI X MPAP X 0.0136	5-7	$gm\ m/m^2$

NOTES: 1) Where (MAP - CVP)/CO = mmHg/L/min

Table 1-4. Calculation of Hemodynamic Parameters.

Bibliography of Additional Sources

A comprehensive overview of critical-care blood pressure monitoring is provided in: Hemodynamic Monitoring in a Coronary Intensive Care Unit, by Charles E. Rackley and Richard O. Russell, Jr., (Futura Publishing Co., Mount Kisco, NY, 1974).

In addition, the following articles and monographs provide detailed analysis of Swan-Ganz catheter applications:

1. Berk J.L., Sampliner J.E., Artz J.S. and Vinocur B. Handbook of Critical Care. Boston: Little, Brown and Company. 1976.

2. Bolognini V. The Swan-Ganz Pulmonary Artery Catheter: Implications for Nursing. Heart and Lung. 3 November-December 1974.

3. Buchbinder N. and Ganz W. Hemodynamic Monitoring: Invasive Techniques. Anesthesiology 45:1976.

4. Chun G.M., and Eilstad M.H. Perforation of the Pulmonary Artery by a Swan-Ganz Catheter. New England Journal of Medicine 284: 1041-1042. 1971.

5. Fegler G. The reliability of the thermodilution method for determination of the cardiac output and the blood flow in central veins. Q J Exp. Physiol. 42:254, 1957.

6. Forrester J.S., Ganz W., Diamond G., McHugh T., Chonette D.W., and Swan H.J.C. Thermodilution cardiac output determination with a single flow-directed catheter. Am. Heart J. 83:306, 1972.

7. Ganz W., Donoso R., Marcus H., Forrester J.S., and Swan H.J.C. A new technique for measurement of cardiac output by thermodilution in man. Am. J. Cardiol. 27:392, 1971.

8. Ganz W., and Swan H.J.C. Measurement of blood flow by thermodilution. Am. J. Cardiol 29:241, 1972.

9. Goslinga H., DeVries H.W., Appelboom D.K., Wesseling K.H., and Zimmerman A.N.E. Oxygen transport to the tissue and blood viscosity, in Blood Viscosity and Shock. Springer Verlag, Berlin, 1985, 23 - 31.

10. Hamilton W.F., Riley R.L., Attyah A.M., Cournand A., Fowell D.M., Himmelstein A., Noble R.B., Remington J.W., Richards D.W. Jr., Wheeler N.C., and Witham A.C. Comparison of the Fick and dye injection methods of measuring cardiac output in man. Am. J. Physiol. 153:309, 1948.

11. Hamilton W.T., Moore J.W., Kinsman J.M., and Spurling R.G. Simultaneous determination of the pulmonary and systemic circulation times in man and of a figure related to the cardiac output. Am. J. Physiol. 84:338, 1928.

12. Larson C.A., and Woods S.L. Effect of injectate volume and temperature on thermodilution cardiac output measurements in acutely ill adults. Circulation 66:11-98, 1982. (Abstr.)

13. Lipp H., O'Donoghue K. and Resnekov L. Intra-Cardiac Knotting of a Flow-Directed Balloon Catheter. New England Journal of Medicine 284: 220, 1971.

14. Malin C.G., and S. Schwartz. Starling curves as a guide to fluid management in the critically ill. Heart and Lung 4(4):588-592, 1975.

15. Manifold S. A comparison of two alternate methods for the determination of cardiac output by thermodilution: Automatic vs manual injections. Heart Lung 13:304, 1984.

16. Meisner H., Hagl S., Heimisch W., Mayr N., Mendler N., Struck E., Walther V., and Sebening F. Evaluation of the thermodilution method for measurement of cardiac output after open-heart surgery. Ann. Thorac. Surg. 18:504, 1974.

17. Pries A.R, Gaerthgens P. and Kanzow G., Microvascular distribution of blood volume flow and hematocrit as related to oxygen delivery, in Oxygen Transport to Tissue. Pergamon Press, Budapest, 1984.

18. Riedinger M.S., and Shellock F.G. Technical aspects of the thermodilution method for measuring cardiac output. Heart Lung 13:215, 1984.

19. Rosselli R.J., Talbot L., and Abbott J.A. Evaluation of the thermal dilution technique for the measurement of steady and pulsatile flows. J. Biomech. 8:157, 1975.

20. Sharefkin J.B., and MacArthur J.D. Pulmonary Arterial Pressures as a Guide to the Hemodynamic Status of Surgical Patients. Archives of Surgery 105: 699-704, 1972.

21. Swinney R.S., Davenport M.W., Wagers P.W., Sebat F., and Johnston W.D. Iced versus room temperature injectate for thermodilution cardiac output. Crit. Care Med. 8:265, 1981. (Abstr.)

22. Woods M., Scott R.N., and Harken A.H. Practical considerations for the use of a pulmonary artery thermistor catheter. Surgery 79:469, 1976.

Glossary of Terms

Terms below are derived in part from:
Taber's Cyclopedic Medical Dictionary, F.A. Davis, 1981.

algorithim – A procedure for solving a mathematical problem in a finite number of steps that frequently involves repitition of a procedure or reiteration of steps.

alveoli – Plural of alveolus. A small hollow. A pulmonary alveolus is one of the terminal sacules of an alveolar duct where gasses are exchanged in respiration.

arterioles – A minute artery, esp. one which, at its distal end, leads into a capillary.

artifact – Anything artificially produced. In histology and radiography, any structure or feature produced by the technique used and not occurring naturally.

aspiration – Aspiration; to draw in or out by suction.

bolus – A mass of masticated food ready to be swallowed. A rounded preparation of medicine for oral ingestion. A concentrated mass of a diagnostic substance given intravenously, such as an opaque contrast medium, or an intravenous medication.

cardiac work – The product of blood pressure and cardiac output, expressed in Kilogram-meters.

catheter – A tube passed through the body for evacuating or injecting fluids into body cavities. Made of elastic, elastic web, rubber, glass, metal, or plastic.

catheter whip – Uncontrollable motion of a catheter within the pulmonary artery.

couplet – A pairing of a premature systole and normal systolic beat, just following the normal beat.

cubital fossa – Triangular area lying anterior to and below the elbow, bounded medially by the pronator teres and laterally by the brachioradialis muscle.

dicrotic notch – In a pulse tracing, a notch on the descending limb.

distal – Farthest from the center, from a medial line, or from the trunk. Opposed to proximal.

ectopic – In an abnormal position. Opposite of entopic. With reference to the endocardium, relates specifically to foci abnormally positioned, causing abnormal intervals between beats.

edema – A local or generalized condition in which the body tissues contain an excessive amount of tissue fluid.

embolism – Obstruction of a blood vessel by foreign substances or a blood clot. Diagnosis depends upon predisposing factors. Arteriosclerosis favors a diagnosis of thrombosis while atrial fibrillation, bacterial endocarditis, or thrombophlebitis point to embolism. Embolism is usually due to blood clots.

end-expiration – Interval following exhalation when no further decrease in tidal volume takes place previous to inhalation.

endocardium – Serous lining membrane of inner surface and cavities of the heart. It is continuous with the intima or interior coat of arteries.

erythrocyte – A mature red blood cell or corpuscle.

exhalation – The process of breathing outward; emanation of a gas or vapor.

French scale – A system used to indicate the outer diameter of catheters. Each unit on the scale is approximately equivalent to 0.33 mm (French size 7 is 2.2 mm diameter catheter).

hematocrit – The volume of erythrocytes packed by centrifugation in a given volume of blood, expressed on a percentage of total volume.

heparinize – To inhibit coagulation of blood with heparin.

hypervolemia – Plethora of blood; abnormal increase in the volume of circulating blood.

hypovolemia – Insufficiency of blood; opposite of hypervolemia.

infarct – An area of tissue in an organ or part which undergoes necrosis following cessation of blood supply. May result from occlusion or stenosis of the supplying artery or more rarely from occlusion of the vein that drains the tissue.

inspiration – Inhalation; drawing air into the lungs.

intima – Innermost coat of a blood vessel. SYN: tunica intima.

ligature – Process of binding or tying. A band or bandage. A thread or wire for tying a blood vessel or other structure in order to constrict it. Cord or material used may be catgut, q.v., synthetic suture materials such as nylon or dacron, dangaroo gut, polyglycollic acid, and natural fibers such as silk or cotton. Some times strips of fascia obtained from the patient are used as a ligature.

Luer-Lok fitting – A glass syringe fitting made to permit rapid and firm attachment of the needle.

lumen – The space within an artery, vein, intestine, or tube.

myocardium - The middle layer of the walls of the heart, composed of cardiac muscle.

orifice - Mouth, entrance, or outlet to any aperture.

patency - The state of being freely open.

proximal - Nearest the point of attachment, center of the body, or point of reference. Opposite of distal.

pulmonary stenosis - Narrowing of the opening into the pulmonary artery from the right cardiac ventricle.

PVCs - Ventricular extrasystolic beats. They occur after a normal contraction of the ventricle has ceased, usually followed by a long compensatory pause.

radial artery - Small artery extending along the inner forearm branching into the hand.

semilunar - Shaped like a crescent. Referent to the shape of the pulmonary valve.

Starling's Law of heart - The force of the heartbeat is determined primarily by the length of the fibers comprising its muscular wall; an increase in diastolic filling increases force of heartbeat.

stroke volume - The amount of blood ejected by the left ventricle at each beat. Amount varies with age, sex, and exercise.

stroke work - The product of blood pressure and stroke volume, expressed in gram-meters.

sub-clavian vein - Large vein draining arm. It unites with the interior jugular to form the innominate vein.

thrombosis – The formation, development or existence of a blood clot or thrombus within the vascular system.

thrombus – A blood clot that obstructs a blood vessel or a cavity of the heart. Anticoagulants are being used in prevention and treatment of this condition.

tidal – Periodically rising and falling, increasing and decreasing.

transducers – A device which converts one form of energy to another. Used in medical electronics to receive the energy produced by sound or pressure and relay it as an electrical impulse to another transducer which can either convert the energy back into its original form or make a record of it on a recording device.

tricuspid valve – Right atrioventricular valve.

truncate – Having a square end as if it were cut off; lacking an apex. To shorten by cutting off the end; to amputate.

vasculature – The arrangement of veins in the body or any part of it, including their relationship and functions.

vena cava – The principal vein draining the upper portion of the body. It is formed by the junction of the right and left innominate veins and empties into the right atrium of the heart.

ventilator – A mechanical device for artificial ventilation of the lungs. The mechanism may be hand operated or machine driven, and in the latter case may be automatic.

Section 2

Deriving Pulmonary Capillary Wedge Pressures

2-1 Introduction

2-2 This section provides instructions on insertion of the Swan-Ganz catheter for PCWP and C.O. monitoring, as well as operating procedures for PCWP derivation with the HORIZON 2000 patient monitor. In addition, clinical precautions (Paragraph 2-34 ff.) describe common problems in obtaining wedged pressure waveforms.

2-3 Swan-Ganz Catheter Insertion and Monitor Set-up

2-4 Initial Steps

2-5 **CATHETER PREPARATION**

2-6 Flush heparinized saline or D5W through all ports. The PA transducer (distal lumen) should be saturated with solution, as should the CVP transducer (proximal lumen), if CVP is to be monitored. If CVP is not to be monitored, proximal lumen patency will be maintained by continous flushing at a minimum flow rate. Insure that there are no air bubbles in the Intraflow chamber.

2-7 Attach the distal and proximal ports to stopcocks and flush. Throughflush distal and proximal lumens to ensure patency. After flushing, submerge the catheter tip in a basin of sterile saline or water to maintain surface lubrication. Alternately, the catheter tip may be wiped with a sponge wetted with saline just previous to insertion.

2-8 With the catheter tip submerged in the basin of water (Paragraph 2-7), inflate the balloon with approximately 1.0 ml* of air to test for leaks. Be alert for air bubbles. Obtain another catheter if air bubbles appear around the ends of the balloon where they surround the catheter tip. Deflate the balloon following confirmation of balloon integrity. The catheter is now ready for insertion.

2-9 PATIENT MONITOR SETUP

2-10 The following monitoring set-up procedure assumes familiarity with operation of HORIZON 2000 patient monitors. However, cross reference is made throughout to relevant instructions (Tab numbers) in the HORIZON 2000 User's Guide. If the operator is not familiar with HORIZON 2000's interactions, the User's Guide should be at hand before continuing. For complete product familiarity, it is recommended that the operator carefully review Section 7, Deriving PCWP/C.O., of the HORIZON 2000 Operating Manual.

2-11 Before insertion of the Swan-Ganz catheter the HORIZON should be displaying the patient's ECG and Resp waveforms (User's Guide, Tab 4). The HORIZON can simultaneously monitor ART and PA waveforms, in addition to ECG and Resp.

2-12 In clinical situations where ART and PA are being monitored on BP inputs 1 and 2, and CVP monitoring is additionally desired via the proximal lumen, the HORIZON 2200 Monitor permits the addition of CVP via BP input 3 or 4 (User's Guide, Tab 6). HORIZON 2100 also permits intermittent monitoring of CVP by substituting proximal lumen pressure for distal lumen pressure.

2-13 Display the ECG waveform on Lead II (unless another lead provides a better QRS) in Display Field 1 and Respiration in Display Field 2 (User's Guide, Tab 5). Display Fields 3 and 4 will provide an expanded PA waveform. Press [SPECIAL FUNCTIONS], then [DERIVE CO/PCWP]. Fields 3 and 4 will reformat to present the PA channel waveform scaled for 0 - 50 mmHg (Figure 2-1). This waveform will be used to follow the progress of the catheter through the cardiovascular system. **Zero the transducer before inserting the catheter (User's Guide, Tab 7).**

---

*With narrower Swan-Ganz catheters (less than 7 French), balloon size will require smaller air volumes. Check manufacturer's specifications before inflation.

2-15 The physician will insert the catheter at the insertion site and advance the catheter the appropriate distance, based on site of insertion. Table 2-1 shows typical insertion lengths at corresponding sites.

SITE	INSERT LENGTH (IN CM)
Left cubital fossa	50 cm
Right cubital fossa	40 cm
sub-clavian or jugular	15 cm

Table 2-1. Catheter Insertion site/length of catheter inserted.

2-16 The catheter should now be in the vicinity of the right atrium. Observe the waveform in the PA field (Fields 3 and 4) to confirm entry of the catheter into the right atrium. Pressures should be nominally in the 1 - 20 mmHg range; the RA waveform will usually present a, c, and v waves. Note Figure 2-1.

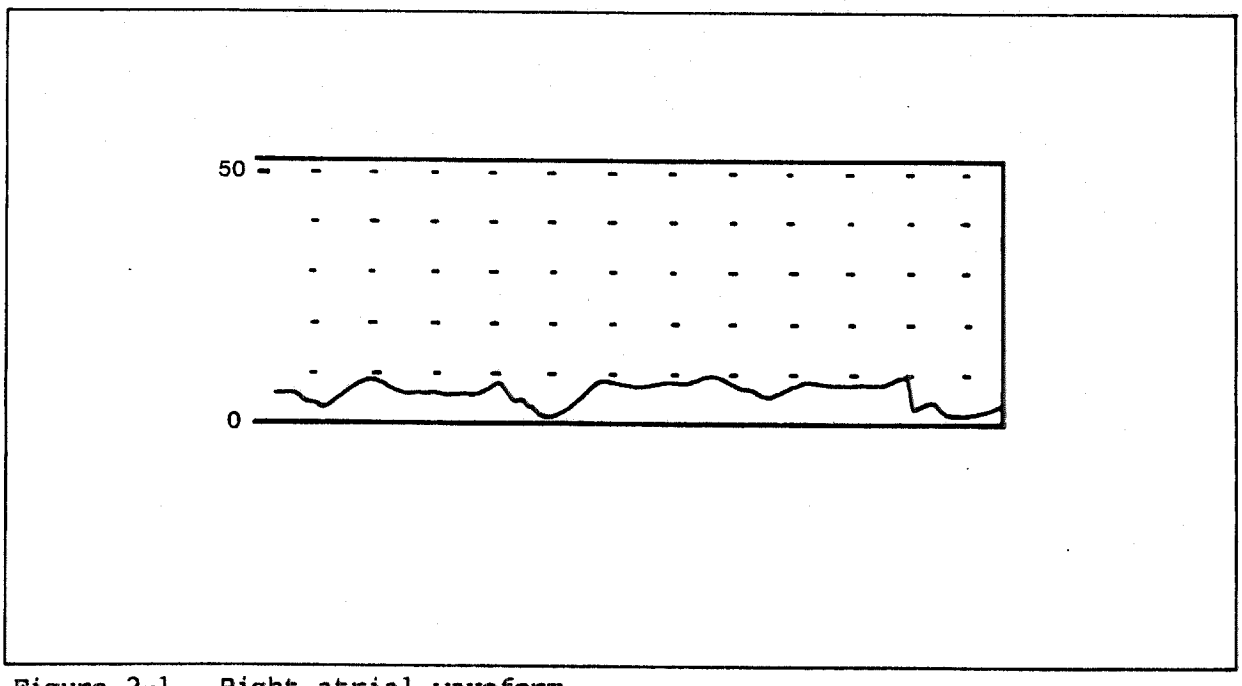

Figure 2-1. Right atrial waveform.

2-17 Now inflate the balloon to its recommended volume (typically 1.0 ml). 15 cm of catheter is advanced to permit the balloon to be carried through to the pulmonary artery. The catheter tip will initially be drawn from the right atrium into the right ventricle through the tricuspid valve. Passage through this valve can incite right ventricular PVC's: observe the ECG waveform for ectopic events. The balloon should advance through the pulmonary valve during systole. The waveform will show a relatively rapid sequential conversion from the right atrial to the right ventricular to the PA waveform (Figure 2-2).

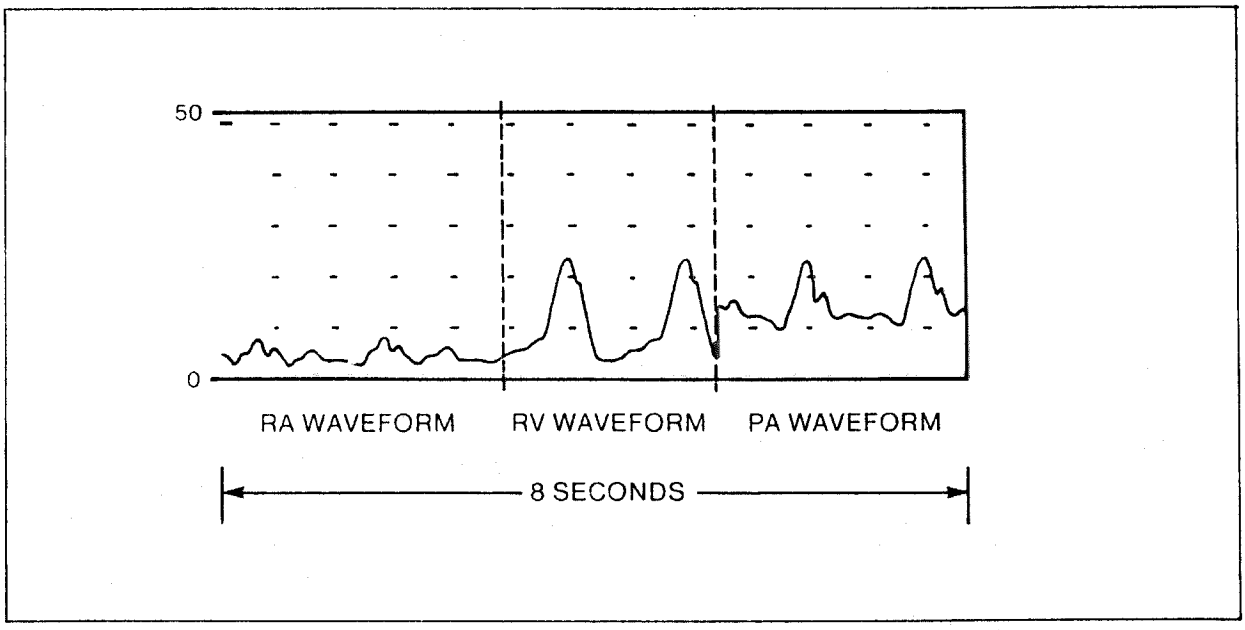

Figure 2-2. Change in distal lumen pressure waveform as catheter advances.

2-18 Right ventricular end-diastolic pressure (RVEDP) should be the same as right atrial pressure. Pulmonary arterial end-diastolic pressure is typically 5 mmHg above RVEDP because of left-atrial back pressure. However, higher pressure differentials can be present in cases of pulmonary congestion or edema.

2-19 If the waveform does not convert from RA to RV to PA, the distal orifice may be trapped in the right ventricular endocardium, or the catheter may have looped on itself, preventing passage through the tricuspid or pulmonary valve. Note Figure 2-3. If 15 cm of catheter have been advanced and the pressure signal has not fully converted to the PA waveform, the balloon should be deflated and the catheter should be carefully withdrawn.

NOTE

If resistance to withdrawal is experienced, an X-ray should be taken to confirm the catheter's position. The catheter is radio-opaque.

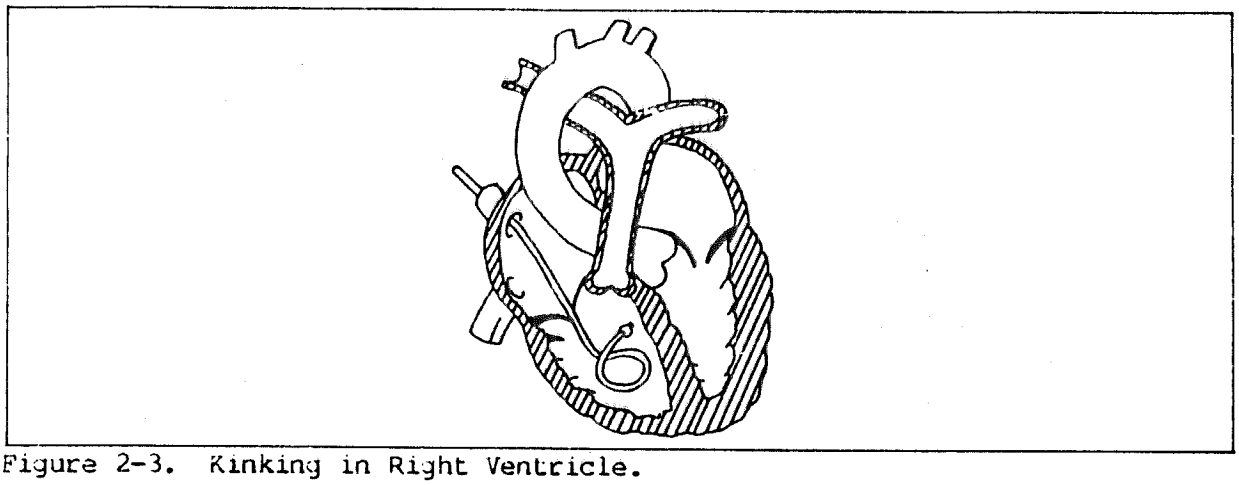

Figure 2-3. Kinking in Right Ventricle.

2-20 The catheter is positioned for continuous PA monitoring when the pressure waveform displays typical PA values. If the balloon is maintained in its inflated state, the catheter will be drawn into the pulmonary artery until wedging occurs. Conversion to a wedge pressure waveform confirms appropriate positioning of the catheter. See Figure 2-7. It is assumed here that the wedge pressure waveform is obtained solely for purposes of establishing catheter position. If it is further desired to derive mean PCWP, see Paragraph 2-23. The balloon should then be permitted to passively deflate (see Paragraph 2-21). PA is thereafter continuously monitored.

Press to return to the main menu.

Continuous monitoring conditions should be observed for four possible problems:

1) **ARRHYTHMIAS:** The ECG waveform should not indicate the presence of PVC's or other severe ectopic events. Runs of right ventricular PVC's in particular will substantially elevate PA readings; left ventricular PVC's will alter wedge pressure.

2) **RESPIRATORY ARTIFACT:** The balloon should be relatively stationary. Some respiratory artifact is always present in PA and PCWP waveforms. Note Figure 2-4.

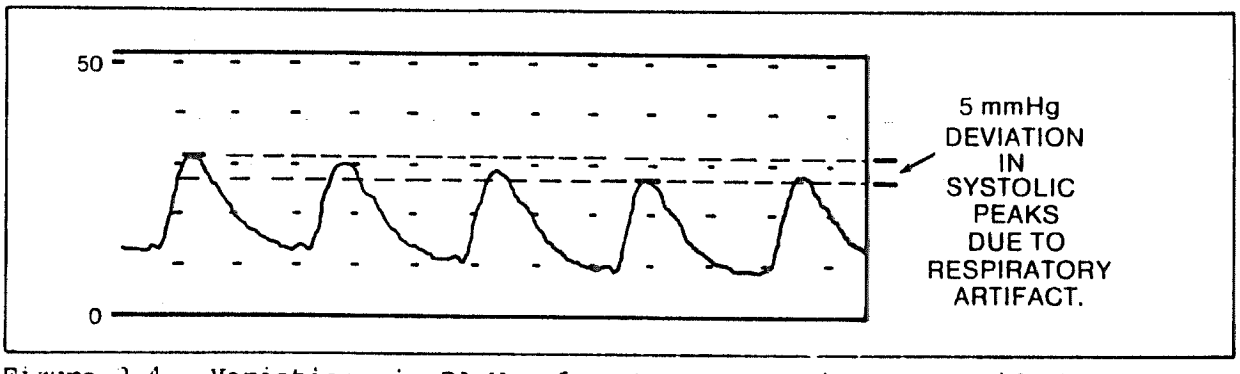

Figure 2-4. Variations in PA Waveform Due to Respiratory Artifact.

HORIZON 2000 Patient Monitors employ a unique filtering algorithm which minimizes the effect of respiratory artifact on the derived PA values (systolic, mean, diastolic). However, for best PCWP derivation, overall deviation of the PA waveform due to respiratory artifact should not exceed ±5 mmHg. If the patient's breathing is being supported by a ventilator, forced inspiration should be maintained at the minimum necessary tidal volume.

3. **NOISE AND RINGING.** Some noise is always present in the PA waveform because of the high sensitivity of the amplifier setting necessary to observe the PA waveform. However, excessive catheter whip -- due to balloon location too close to the pulmonic valve — or small air bubbles in the distal lumen will cause excessive ringing, as shown in Figure 2-5. Consult the Troubleshooting Chart (Section 4) for procedures to reduce noise.

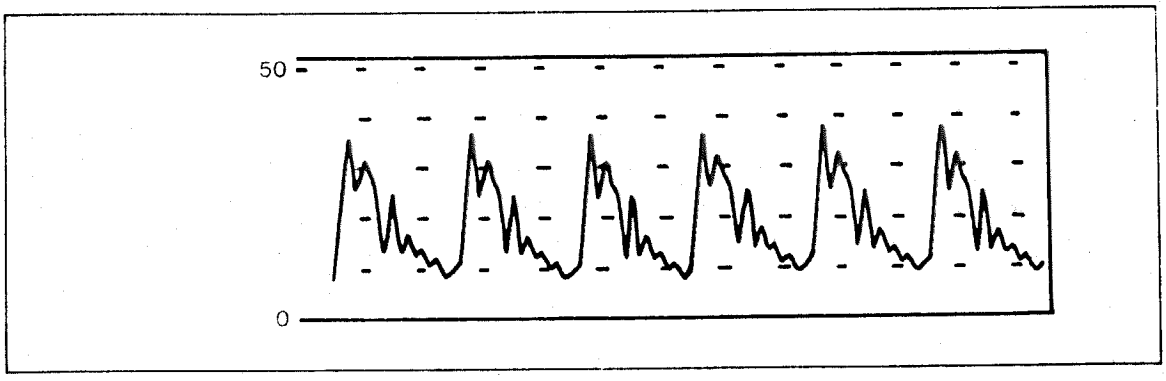

Figure 2-5. Excessive Ringing in PA Waveform.

4. **DAMPED WAVEFORM.** The RV waveform will typically show a pressure differential of 25/0; the corresponding PA differential will approximately 20/10 (Figure 2-2). If RV and PA waveforms are not clearly differentiated on passing through the pulmonary valve, or if the waveforms are flattened, there may be air bubbles or clots in the catheter, or the catheter may be wedged. Additionally, if pressure bags (or infusers) are below required pressure, clotting may develop in the catheter. See the Troubleshooting Chart (Section 4).

NOTE

If a damped waveform appears in place of the PA waveform, deflate the balloon immediately. Do not fast-flush the catheter to remedy clotting; this can cause pulmonary embolism.

2-21 **DEFLATING THE BALLOON**

2-22 The balloon will deflate by itself (passive deflation) if syringe pressure is released by the operator. The operator should allow balloon deflation to occur passively, rather than manually withdrawing the syringe plunger.

2-23 Obtaining the Wedge Pressure

2-24 The following procedure incorporates the operating instructions in the HORIZON 2000 Operating Manual. For rapid familiarization, reference is made to the HORIZON 2000 User's Guide. A copy of this guide may be kept at the HORIZON 2000 bedside.

2-25 Unless the display is already formatted for wedge pressure derivation (Figure 2-6) enter the wedge pressure program by pressing SPECIAL FUNCTIONS, then DERIVE CO/PCWP (User's Guide, Tab 3). The PA waveform will occupy both Fields 3 and 4 (Figure 2-6).

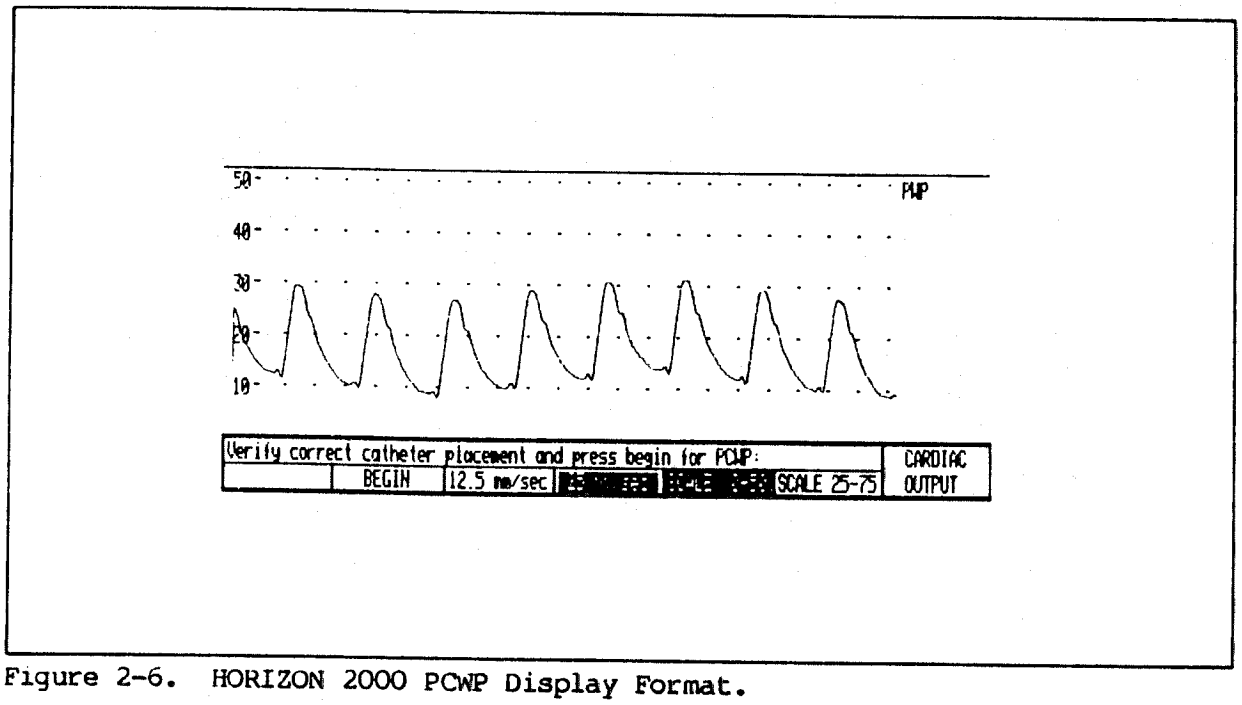

Figure 2-6. HORIZON 2000 PCWP Display Format.

If a valid PA waveform is present, and pressures are within a window of 0 - 40 mmHg, the operator may advance to wedging. However, if the PA systolic peak is above 50 mmHg, pulmonary congestion or left ventricular failure may be present, and the wedged pressure waveform may also not lie in the 0 - 50 mmHg field. Select the 25 - 75 mmHg scale in these instances.

2-26 **RECORDING THE WEDGED WAVEFORM**

2-27 The PCWP waveform will be recorded during the wedging procedure automatically, if so configured.* Record speed is either 12.5 mm/sec or 25 mm/sec, as selected (User's Guide, Tab 8). The recording will run following depression of the BEGIN key, until the FREEZE key is pressed.

2-28 **WEDGING THE PULMONARY ARTERY**

2-29 When the appropriate range has been selected for the wedge waveform (Paragraph 2-25), press BEGIN (User's Guide, Tab 8). Begin inflating the balloon with air; the catheter will advance from blood flow. Observe the PA waveform. As the balloon floats into an arterial branch, it will lodge in and occlude (wedge) it. The PA waveform will convert to the wedge waveform.

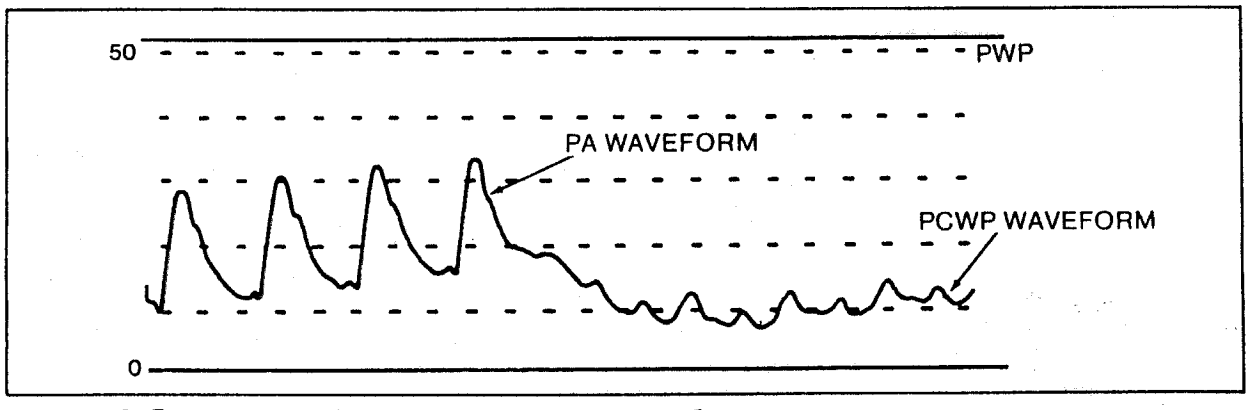

Figure 2-7. Conversion of PA to PCWP Waveform.

If the balloon does not lodge in an arterial branch following inflation, an X-ray should be taken to ascertain catheter position.

2-30 When the wedge condition is obtained, press FREEZE and IMMEDIATELY DEFLATE THE BALLOON (CAUTION: ALLOW PASSIVE DEFLATION — SEE PARAGRAPH 2-21) . The wedge waveform will remain frozen on the display, and the level at which the PCWP is derived will be marked by a red cursor. The PCWP value will appear above the ACCEPT key. If it is desired to obtain the PCWP value from a point on the wedge waveform other than the mean level indicated by the red cursor, use ▽ and △ keys to alter the cursor position.

---

* Reference HORIZON 2000 Operating Manual, Page 8-32, for HORIZON PCWP configuration settings.

2-31 The ability to shift the cursor is particularly useful in determining relative a and c wave levels, especially when the c wave is elevated. Note that the cursor will change from red to yellow when moved, indicating that mean PCWP is no longer displayed. When the desired PCWP value has been found, press [ACCEPT].

2-32 If wedging is not firm, as indicated by the presence of systolic complexes or excess artifact in the PCWP waveform, the monitor will prompt the operator to "VERIFY WEDGE PRESSURE." Repeat the wedging procedure: press [REPEAT], and reinflate the balloon. If this is the first attempt at wedging (trial waveform conversion after catheter insertion), it may be necessary to advance the catheter to obtain a firm wedge.

2-33 Accepting the PCWP value enters that value into the Patient Chart (User's Guide, Tab 10) and advances the operator to the Cardiac Output Calculations program.

2-34 Clinical Precautions in PCWP Derivation

2-35 Certain precautions should always be kept in mind during wedge pressure monitoring. Improper balloon inflation can lead to infarcted or ruptured pulmonary arterioles; improper catheter advancement may cause tangling of the catheter and require surgical intervention. Precautions below are listed in order of procedure.

2-36 **CATHETER ADVANCEMENT**

2-37 Following insertion, advance only the length of catheter needed to reach the right atrium (see Table 2-1). In order to ascertain position, have the patient cough periodically. When the catheter is in the right atrium, coughing will cause an approximate 40 mmHg jump in the RA waveform.

2-38 **BALLOON INFLATION**

2-39 Maintain an air volume in the balloon inflation syringe less than the maximum balloon volume. When inflating the balloon, a resistance should be felt on the plunger. If resistance decreases during inflation, withdraw the plunger to deflate the balloon. During the catheter transition period maintain only enough balloon pressure (0.5 - 0.75 ml) to cause the balloon to pass through to the pulmonary artery. However, do not inflate to less than 50% of the balloon's recommended volume, as this may cause wedging at a too distal arteriole site. See Paragraph 2-43.

2-40 When the PA waveform is displayed, allow the balloon to deflate and anchor the catheter at the insertion site if a wedge pressure reading is not to be derived immediately. Continue to observe the PA waveform during monitoring; be alert to waveform flattening -- this indicates possible

formation of clots in the distal lumen or migration of the catheter to the pulmonary arterial wall. Turn the patient on his side or stimulate coughing to dislodge a catheter wedged in the endocardium. It is also possible that the distal lumen may migrate to the right ventricle. Observe the PA waveform to confirm that systolic and diastolic values are within PA ranges. RV systolic values will be higher; diastolic values lower (see Figure 2-2).

2-41 **WEDGING**

2-42 The balloon should be inflated in small increments while observing the PA waveform. Once wedging is achieved, do not further inflate the balloon. Excessive inflation can damage the artery in which the balloon is lodged. A symptom of overinflation is a continuing rise in PCWP after wedging. Note Figure 2-8.

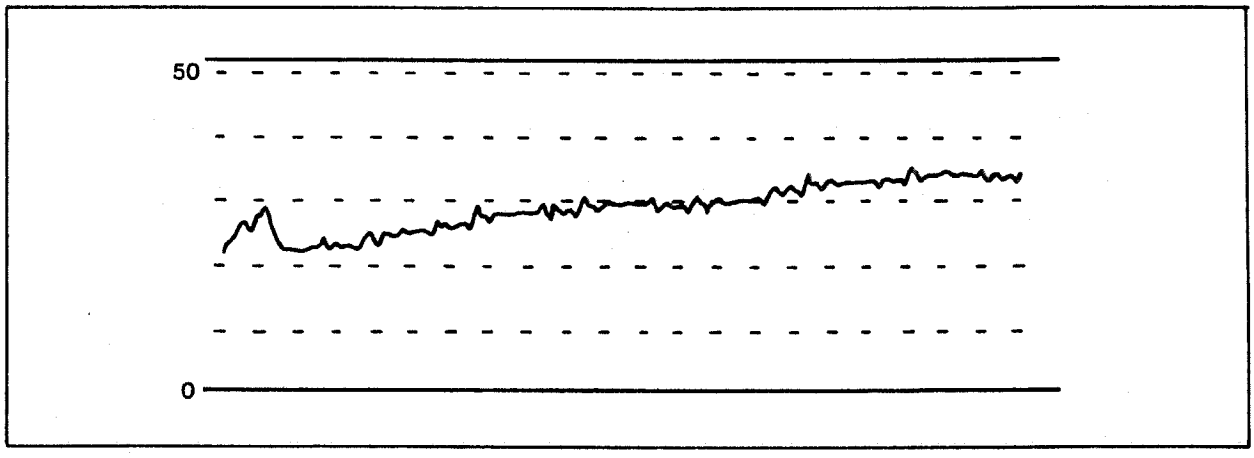

Figure 2-8. Excessive Balloon Inflation Following Wedging.

2-43 When the balloon is wedged, inflation volume should be approximately the rated full inflation volume. If inflation volume is substantially less than the rated maximum for wedging, the catheter distal end will have advanced too far into the artery, and may wedge in an arteriole. Wedging in an anteriole can appear as an excessively elevated PCWP value. If arteriole wedging is suspected, deflate the balloon, and repeat the procedure with a greater inflation volume.

2-44 **CATHETER WITHDRAWAL**

2-45 Any difficulty experienced in withdrawing the catheter (PVC's, patient respiratory difficulty, pain) should be checked by x-raying the catheter position. Normally catheter withdrawl is easiest if the balloon is fully deflated, but a slight inflation may be maintained in order to reduce the possiblity of catheter knotting during withdrawal.

Section 3

Preparation and Method for Calculating Cardiac Output

3-1 General

3-2 Instructions provided in this section require that the Swan-Ganz catheter already be in place for monitoring PA, and that the proximal orifice is in the right atrium. The balloon must not be inflated in any way. The clinician should confirm the presence of a proper PA waveform. If the catheter is too far advanced, it may lodge in the intima of the artery. This will inhibit proper recording of changes in blood temperature. Swan-Ganz insertion techniques are explained in Section 2, which is prerequisite reading to this section. It is moreover assumed that a PCWP value has already been obtained; PCWP and C.O. are both required for certain hemodynamic parameter calculations (see Table 1-4 on Page 1-22).

3-3 The HORIZON 2000 User's Guide is referenced throughout by Tab number. This section also incorporates the operating procedures provided in Section 7, Deriving PCWP/C.O., in the HORIZON 2000 Operating Manual. For the operator who wishes to learn all of HORIZON's capabilities in Cardiac Output Monitoring, a complete review of Section 7 in the Operating Manual is suggested.

3-4 HORIZON 2000 patient monitors permit the use of either closed-injectate or separate-bath systems. The closed-injectate system for which the monitor has been optimized is the Edwards Model 93-500 Cold Injectate Delivery System. The separate-bath system requires a YSI Series 400 temperature probe for continuous monitoring of injectate temperature. Either Edwards or Spectramed separate-bath systems may be used.

3-5 Iced, chilled, or room temperature injectate may be used for the thermodilution bolus. See Table 3-1 (Page 3-4) for a listing of acceptable injectate temperatures.

NOTE

HORIZON 2000 is configured to derive injectate temperature from either the Edwards Co-Set™ or the YSI 400 separate-bath probe. Use of an improperly configured injectate probe will cause erroneous C.O. calculations. See the Operating Manual, Page 8-32, to determine configuration of the HORIZON monitor under use.

3-6 Set-up Procedure

3-7 **SEPARATE-BATH INJECTATE TEMPERATURE MEASUREMENT**

3-8 Prepare the number of syringes to be used for the C.O. trials, one sterilized syringe per trial. Each syringe should be filled with the amount of injectate appropriate to the stroke volume of the patient, and to the French number of the catheter to be used. HORIZON provides for a choice of 3, 5, or 10 ml injections. **NOTE! Not all French sizes can be used for all injectate volumes. Consult Table 3-1 on Page 3-4 for a schedule of standard French sizes and corresponding injectate volumes and temperatures.**

3-9 Stand the prepared syringes in a beaker assembly filled with sterile D5W or normal saline. See Figure 3-1. For chilled injectates, allow ample time (45 minutes) for the syringe case temperature to come down to injectate temperature. Place the injectate bath temperature probe (PN 800-060-010) interfaced with the C.O. adaptor cable (PN 800-030-190) into the injectate bath; the ideal probe position will be in an open, fluid-filled syringe (Figure 3-1).

3-10 When ready for an injection, remove the syringe from the bath and connect it to the syringe fitting near the proximal lumen stopcock (Figure 3-1).

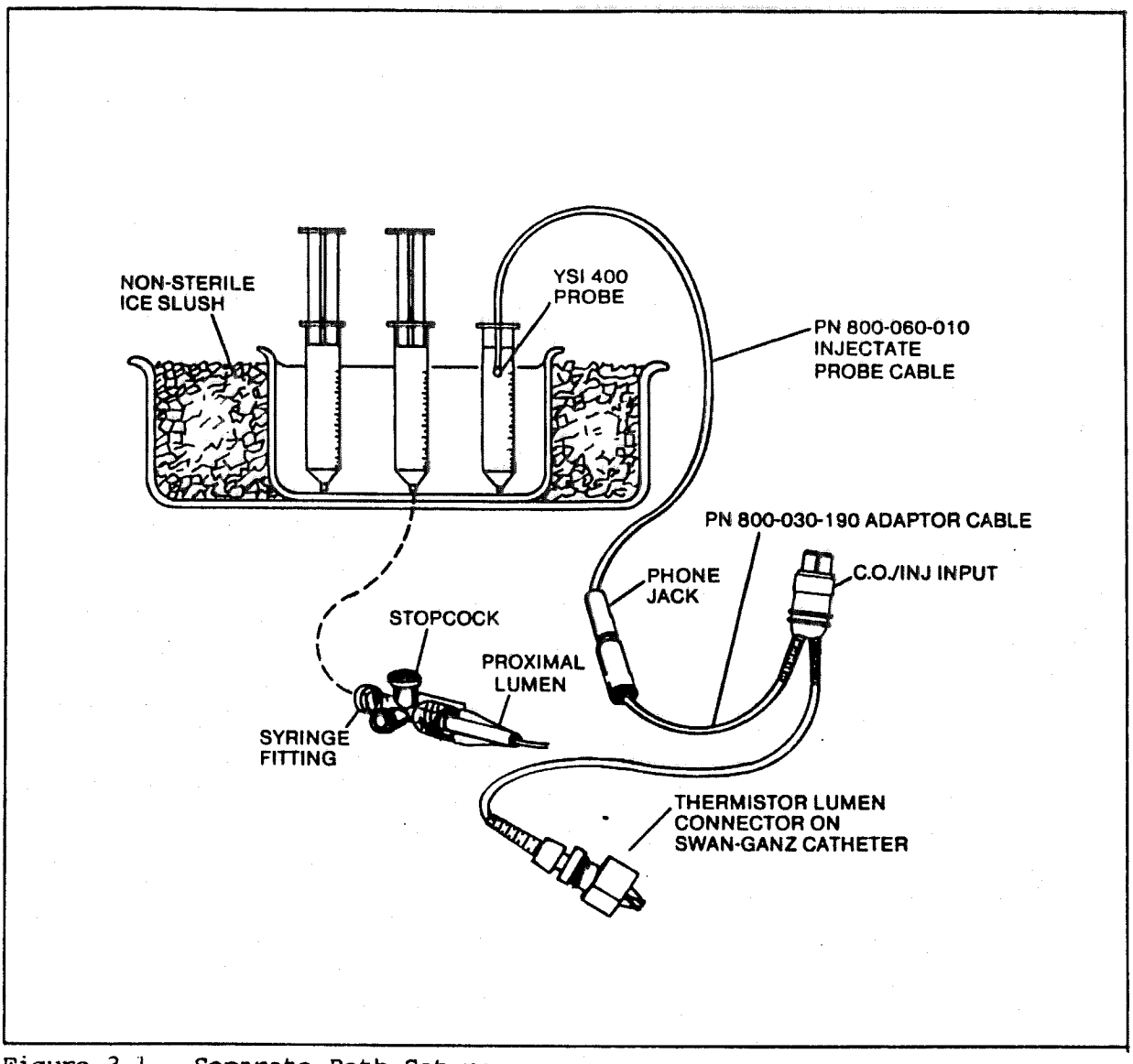

Figure 3-1. Separate Bath Set-up.

3-11 EDWARDS CO-SET™ CLOSED INJECTION SYSTEM

3-12 The Edwards Co-Set™ system provides the user with two distinct advantages over the separate-bath system:

1. The injectate remains in a sealed, sterile conduit between the bag and the proximal lumen port.

2. As many trials may be run as desired without changing syringes.

Preparation of the Co-Set is indicated in Figure 3-2.

INJECTATE TEMP RANGE	INJ TEMP (°C)	INJ VOL (ml)	FRENCH #s 4, 5, 6 K-FACTOR		FRENCH #7 K-FACTOR		FRENCH #7.5 K-FACTOR	
			EDWARDS	SPECTRAMED	EDWARDS	SPECTRAMED	EDWARDS	SPECTRAMED
Iced (Separate Bath Only)	0 - 5	10	.889	- -	.837	.566	.870	.566
		5	.841	.279	.764	.270	.793	.270
			.788	.160	.681	.151	.736	.151
Chilled (CO-Set Only)	6 - 12	10	- -	- -	.866	- -	.886	- -
	8 - 16	5	.880	- -	.799	- -	.886	- -
Non-Chilled (Separate Bath Only)	19-22	10	.925	- -	.892	.628	.898	.628
		5	.901	.316	.846	.309	.854	.309
		3	- -	.188	.792	.180	.802	.180
	23-25	10	.953	- -	.919	- -	.937	- -
		5	.948	- -	.888	- -	.904	- -
		3	.909	- -	.851	- -	.874	- -
Non-Chilled (CO-Set Only)	18-25	10	- -	- -	.938	- -	.918	- -
		5	.948	- -	.929	- -	.920	- -

Table 3-1. Table of French numbers, injectate volumes, and injectate temperatures for Separate-bath and Edwards Co-Set™ injectate systems.

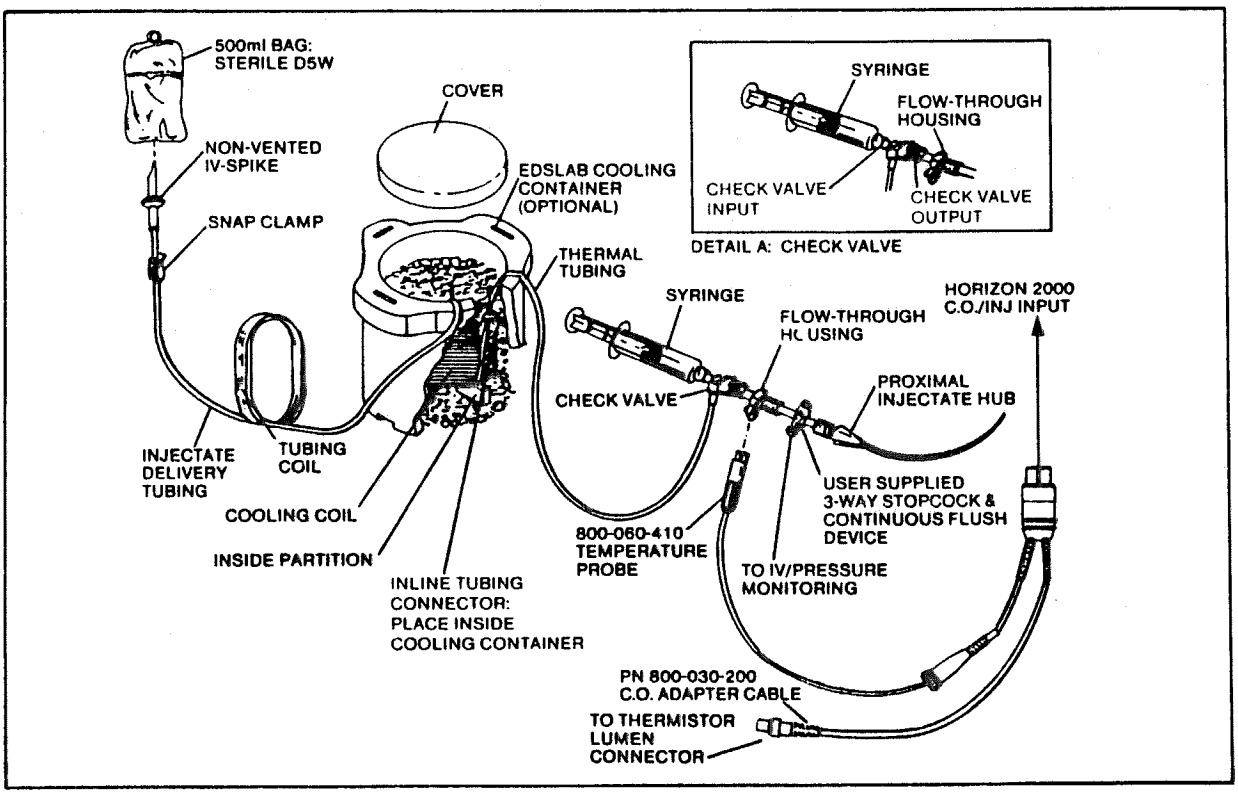

Figure 3-2. Edwards Co-Set.

3-13 The injectate bag should be hung not more than three feet above the injection site. The cooling coil may be placed in any suitable container which will permit the cooling medium to entirely surround the coil. The tubing coil permits the injectate bag to be hung at a distance from the cooling coil. The check valve is a one-way port which permits fluid to be drawn into the syringe, but prevents it from reentering the tubing during an injection. The tubing and syringe are connected to the check valve, as shown in Detail A of Figure 3-2. NOTE! insure that the syringe is connected to the check valve input, as shown in Detail A. If the syringe is connected to the output port of the flow-through housing, damage can result.

3-14 Open the snap-clamp on the bag and pull solution into the tubing by pulling back on the syringe plunger. Depress the plunger to force the withdrawn fluid out the flow-through housing port. Repeat the process at least six times in order to ensure that no air remains in the system. Following system priming the snap clamp should be again closed and the injectate permitted to remain in the cooling coil with cooling solution (iced or otherwise) for at least 15 minutes.

3-15 When the temperature of the injectate is sufficiently chilled, attach the flow-through housing to the proximal lumen port stopcock. Attach the temperature probe (PN 800-060-410) to the flow-through temp fitting. Secure the system so that moving the plunger and valve do not cause strain at the catheter insertion site. Finally, open the snap-clamp at the bag.

3-16 Performing a C.O. Calculation

3-17 **ENTERING THE C.O. CALCULATION PROGRAM**

3-18 If a wedge pressure has just been derived, HORIZON is already in the C.O. program (Figure 3-3). If wedge pressure has not been derived, entry to the C.O. program is made from the default menu:

- Press [SPECIAL FUNCTIONS], then [CALCULATE CO/PCWP], then [CARDIAC OUTPUT] (User's Guide, Tab 9). The C.O. menu will be displayed, and the screen will reformat to present the C.O. Curve Field, Error Field, Data Field, and Trial Table (Figure 3-3).

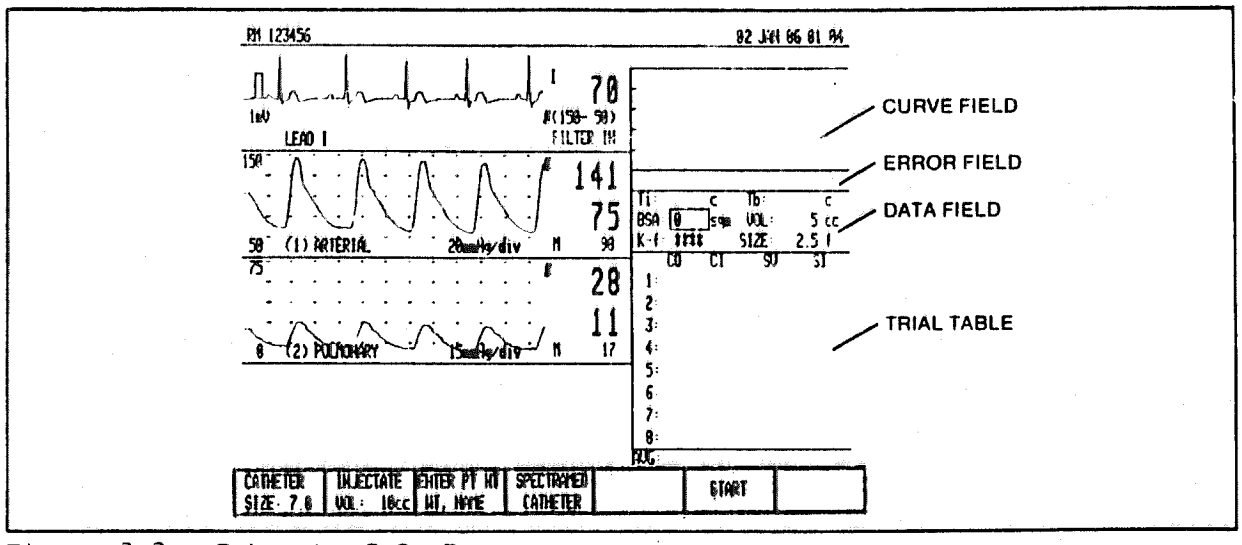

Figure 3-3. Entry to C.O. Program.

3-19 If the patient is being monitored for CVP or RA, shut-off the stopcock connecting the transducer to the patient. Flush the proximal lumen via the fast-flush on the Interflow (if IV drip is being administered).

3-20 Calculating the K Factor

3-21 The K factor is automatically calculated when catheter size and injectate volume are entered, if the catheter uses standardized K factors (User's Guide, Tab 9). K-factors have been standardized for Edwards or Spectramed catheters. Select [SPECTRAMED CATHETER] if that catheter is used.

NOTE: Only separate bath Spectramed injectate systems may be used with HORIZON 2000.

To enter the appropriate catheter French number, Press [CATHETER SIZE:] . With each key depression the displayed catheter size advances to the next available number in the menu: 2.5, 5, 7, 7.5. If the catheter French size is not provided in the menu, continue depressing [CATHETER SIZE:] until "OTHER" appears. Then consult Paragraph 3-23.

3-22 To enter the injectate volume, press [INJECTATE VOL:] . Each key depression advances the menu of standard injectate volumes: 5 and 10 ml. When the correct catheter size and injectate volume are displayed in their respective key windows, HORIZON is ready to calculate the K-factor. Proceed to Paragraph 3-25. **NOTE! Do not enter an injectate volume if the key reads "OTHER," or if the catheter does not use standard K-factors (e.g.: Sorensen Model 7485-010). Non-standard catheters require the K-factor to be entered manually. See Paragraph 3-23.**

3-23 MANUAL ENTRY OF K FACTOR

3-24 The K factor must be entered manually only if the catheter size is different from the standard French numbers provided in the CATHETER SIZE: menu, or if the catheter does not use standard K factors. Manual entry requires the use of the optional Hand-Held keypad (PN 260-150-010). Moreover, the monitor must be configured for Hand-Held keypad use. Consult the HORIZON 2000 Operating Manual, Page 7-47, for instructions in entering K factors manually.

3-25 Running a C.O. Trial

3-26 When the correct catheter size and injectate volume are displayed, Press START to initiate the C.O. calculation program. The program begins by measuring the baseline blood temperature (T_B) in the pulmonary artery. While this measurement is in progress, prepare the injectate bolus by pulling the appropriate volume into the syringe (Co-Set System), or fitting the pre-filled syringe into the Luer-Lok fitting on the proximal lumen stopcock (separate bath system). The operator is prompted by a tone and displayed message to "BEGIN INJECTION" following baseline calculation. Twelve seconds will be allowed following the BEGIN INJECTION prompt for the injection to begin. As a general rule, injection should take place during the end-exhalation period; particularly if the patient's respiration is ventilator-assisted.

IMPORTANT

Inject the injectate as rapidly and smoothly as possible. Optimum results require the injection to be completed in less than four seconds. A pneumatic injector will provide smooth delivery and uniform injection time for repeated trials. If for any reason the injection does not proceed satisfactorily, the C.O.

3-27 If the injection has not begun within twelve seconds, the message NO CURVE DETECTED will be displayed in the Menu Area (Figure 3-4). Press REPEAT to perform another trial.

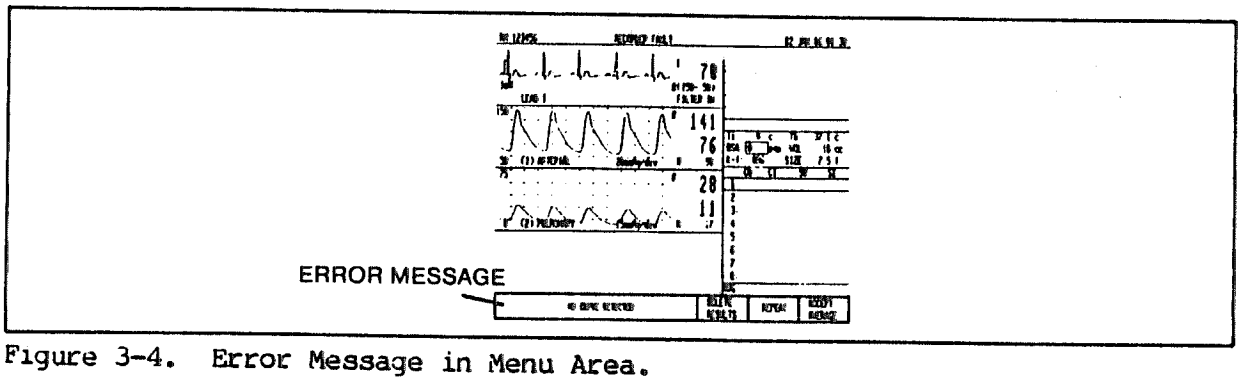

Figure 3-4. Error Message in Menu Area.

3-28 Following successful calculation, cardiac output and stroke volume values will be displayed in the Trial Table under a representation of the C.O. waveform ($\Delta T_b/t$). This waveform will appear in red; the corresponding C.O. and S.V. values will be surrounded by a cursor (Figure 3-5).

3-29 HORIZON also provides for calculation of Cardiac Index (C.I.) and Stroke Index (S.I.), as explained in Section 1. Calculation of both indexes requires the patient's height and weight to have been previously entered during registration or at the start of the procedure (User's Guide, Tab 5).

3-30 REPEATING TRIALS

3-31 As many as eight trials may be run to derive a more consistent average C.O. value. The first trial typically yields a C.O. value higher than true value because the proximal lumen will provide slightly more warming to the injectate on the first trial. As a general rule, at least three C.O. trials should be run before accepting an average C.O. value. To begin another trial, press REPEAT (Figure 3-5). Repeat the steps in Paragraph 3-26. Each trial will successively present calculated values in the Trial Table, corresponding to the trial number. The trial corresponding to the most recent run will present a red C.O. curve; the curves of previous trials will be shown in blue.

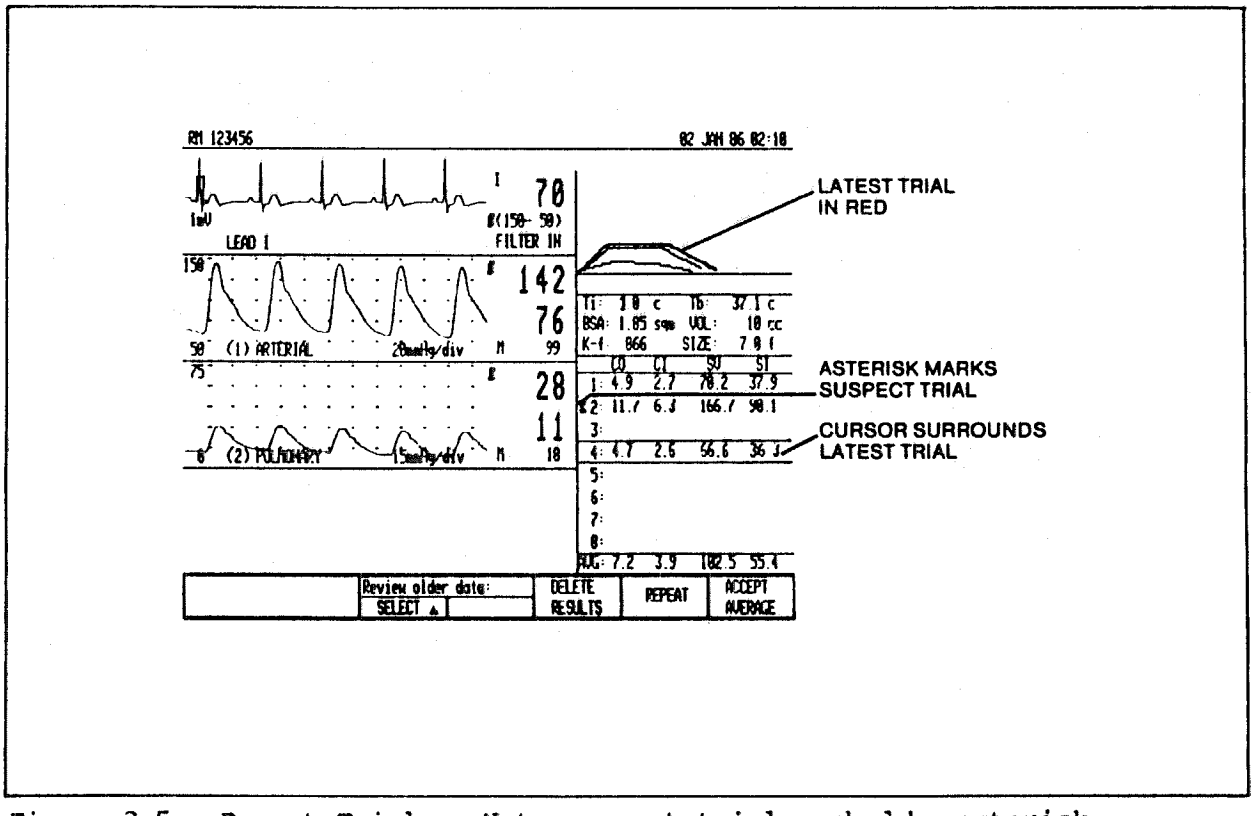

Figure 3-5. Repeat Trials. Note suspect trial marked by asterisk.

3-32 **ERROR MESSAGES DISPLAYED DURING A C.O. RUN**

3-33 The C.O. program provides error messages which prompt the operator that an equipment problem exists (e.g., catheter not connected), or that monitoring conditions are not suitable for accurate C.O. determination (e.g., excessive catheter whip). Messages which indicate that a C.O. calculation is suspect because of compromised monitoring conditions appear in the Error Message field; compromised values are marked by an asterisk (Figure 3-5). Messages which indicate that C.O. cannot be computed appear in the menu area. Error messages are summarized below.

3-34 **CABLE OUT:** This message appears if the C.O. adaptor cable (PN 800-030-190 or 800-030-200) is not plugged into the monitor, or if the cable is defective. No C.O. calculation will be attempted.

3-35 **INJECTATE PROBE FAULT:** This message appears if the injectate bath temperature probe (PN 800-060-010) is not connected, or is defective. No C.O. calculation will be attempted.

3-36 **INJECTATE TEMP ERROR:** This message indicates that the injectate temperature (for Edwards Co-Set^{TM}) or the injectate bath temperature (for YSI 400 injectate bath probes) lies outside the acceptable window for C.O. calculation. Acceptable temperature ranges are shown in Table 3-1 on Page 3-4. An asterisk will be placed in the Trial Table to mark a suspect trial (Figure 3-5).

3-37 **BASELINE TEMP ERROR:** This message appears if blood temperature has varied more than 0.067°C within the two second interval immediately preceding the "BEGIN INJECTION" prompt. A typical cause is catheter whip, due to cardiac pumping (thermistor too close to pulmonary valve). An asterisk will be placed in the Trial Table to mark a suspect trial (User's Guide, Tab 8).

3-38 **NO CURVE DETECTED:** This message appears if the blood temperature does not change sufficiently to enable C.O. to be computed. Typical causes are false starts (small amount of injectate prematurely injected), insufficient injectate (quantity of injectate less than volume shown in calculations field) or injection too slow. No C.O. calculation will be attempted.

3-39 **TIMEOUT ON CURVE:** This message indicates that HORIZON has accepted the initial change in temperature as the beginning of a thermodilution curve. However, it did not detect a valid end of the curve within a predetermined time. When this message is displayed, HORIZON will compute the C.O. value using the data it has and will display the data in the Trial Table with an asterisk, indicating suspect data.

3-40 Editing and Averaging C.O. Trials

3-41 When a sufficient number of trials has been run in order to determine a valid C.O.. average, the operator has the option of averaging all

trials shown, or editing the Trial Table. Editing permits deletion of trials which are invalid. Note that HORIZON will indicate trials associated with procedural errors by an asterisk next to the corresponding value (Figure 3-5).

3-42 To edit the Trial Table: Press [SELECT △] to review C.O. values during previous trials. The cursor will surround previous values and the corresponding thermodilution curve will be displayed in red. Press [DELETE RESULTS] to remove any line of calculations not desired in the final averaging. The line of data will be deleted, and the cursor will surround the previous data. The average will also automatically update.

3-43 To average edited trial values: Press [ACCEPT AVERAGE]. The averages shown will be entered in the Hemodynamic Summary. The time of averaging and averaged values will be listed in the Hemodynamic Summary (Figure 3-6). Display of the Hemodynamic Summary completes the C.O. calculations routine. The operator may either store the displayed hemodynamic data in the HEMO SUMMARY or delete the hemodynamic data. Choosing either option results in a return to normal monitoring.

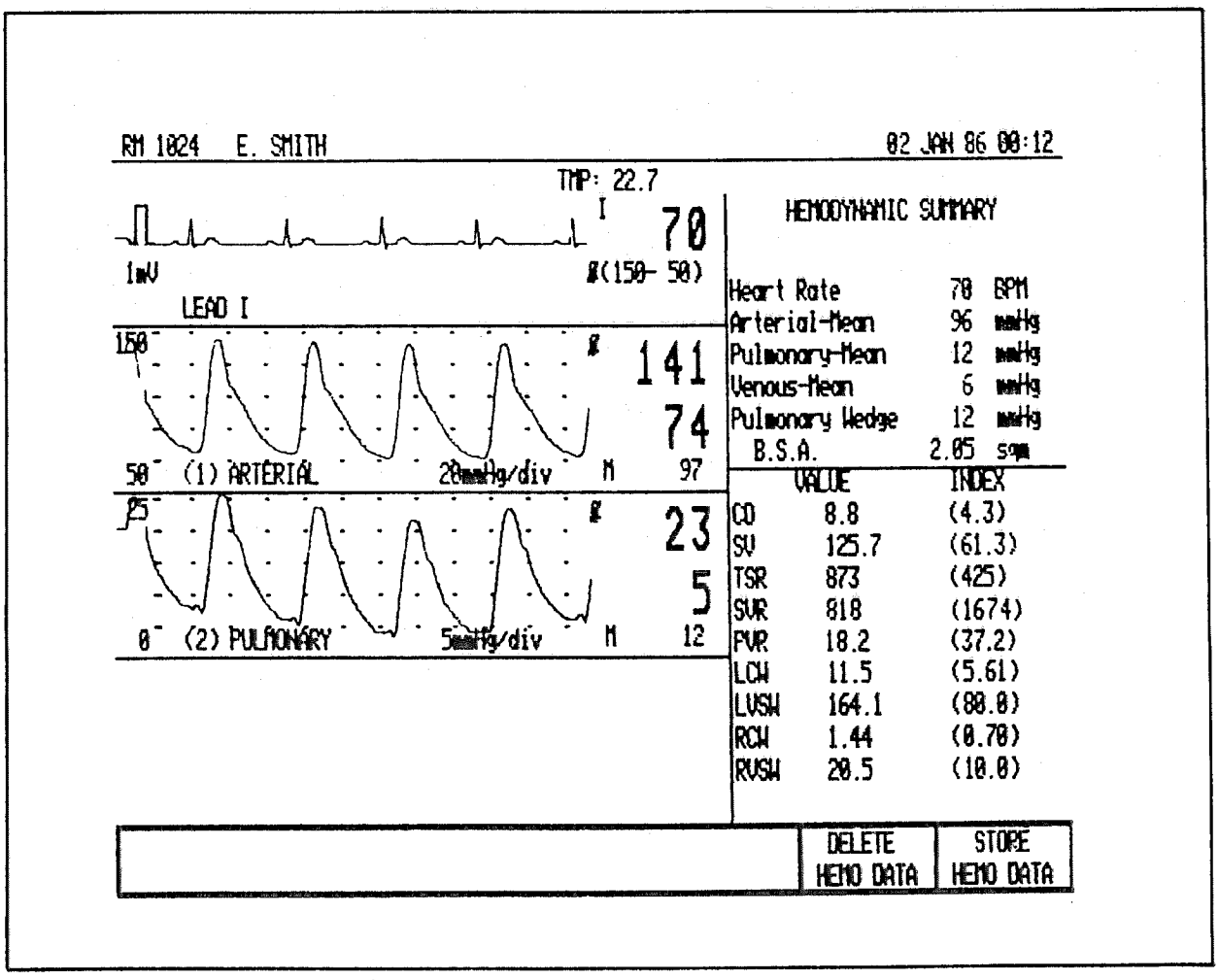

Figure 3-6. Hemodynamic Summary.

3-44 Improving Accuracy of C.O. Trials

3-45 So long as cardiac function remains uniform during C.O. trials, C.O. calculations should remain within 10% of each other, from trial to trial. However, a number of procedural errors or monitoring variables can cause wide divergences in trial values. A list of monitoring variables which cause unreliable C.O. monitoring is provided in Section 1, Paragraph 1-54.

3-46 **ICED OR ROOM TEMPERATURE INJECTATE?**

3-47 Iced injectate is the generally preferred indicator. However, room-temperature injectate is also acceptable so long as the temperature is not above 25.0°C. With room-temperature injectate, the K factor will be greater for a given trial.

3-48 Of greater significance than the absolute temperature of the injectate is warming of the injectate caused by syringe handling. In separate bath systems especially, the syringe barrel should not be in continuous contact with the hand.

3-49 Hemodynamic Summary

3-50 Following acceptance of the average C.O. value derived from the trial tables, the HORIZON will display the results in the Hemodynamic Summary (Figure 3-6). The Hemodynamic Summary presents a display of calculated hemodynamic parameters for bedside review of the patient's cardiovasular functions. See Section 1, Page 1-23, for a tabular summary of formulas used in hemodynamic calculations.

3-51 **STORING HEMODYNAMIC VALUES IN THE PATIENT CHART**

3-52 The patient chart (User's Guide, Tab 10) will be updated with the values for C.O., S.I., and SVR displayed in the Hemodynamic Summary, if configured. Press STORE HEMO DATA to store the displayed data in the Hemodynamic Summary. Press DELETE HEMO DATA to return to normal monitoring without saving the averaged data.

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PIPPA Breathing Monitor

Clinical Investigation

Copy No 9

15 Whitsand Road, Grosvenor Park, Manchester, M22 4ZA

Managing Director: D W Brown BA(Dunelm) ACII ACIArb MLIA(dip) MInstD
Registered Company Number 04092923

Section 4

Ventricular Function Analysis

4-1 Introduction

4-2 **VENTRICULAR FUNCTION PLOTS: THE STARLING CURVE AND WVC PLOT**

4-3 As explained in Section 1 (Page 1-20), the efficiency of the heart is a function of afterlaod and filling pressure. Filling pressure is reflected by PCWP, and therefore, a plot of cardiac outputs measured for particular wedge pressures, taken over several successive measurements, will yield a plot which reveals relative cardiac efficiency. If the plot points are interconnected the result is a Starling Curve. In order to normalize data so that C.O. variations due to height and weight differences are factored out, the graph will plot C.I. (C.O./BSA) over PCWP.

4-4 Blood viscosity is a significant factor in afterload. If the hematocrit (proportional to viscosity) is plotted as a vertical axis against PCWP on the horizontal axis, and cardiac index is plotted as the resultant on the opposite vertical axis, the graph produced will be a WVC plot (Wedge pressure, Viscosity, Cardiac output). Interconnected plot points will be indicative of the effectiveness of hemodilution or defibrination in reducing afterload.

4-5 When HORIZON 2000 Monitors are provided with Option -003, Data Management, a graphics program, Ventricular Functions, is provided for the plotting of Starling Curves or WVC plots. The choice is made by configuration (Figure 4-1). The [STANDARD] configuration provides automatic plotting of a Starling Curve. With successive wedge/C.O. measurements a graph will be drawn indicating changes in cardiac index as a function in changes in wedge pressure. Correlative hemodynamic data will be provided for each measurement, so long as the required parameters were monitored at the time of wedge/C.O. acquisition.

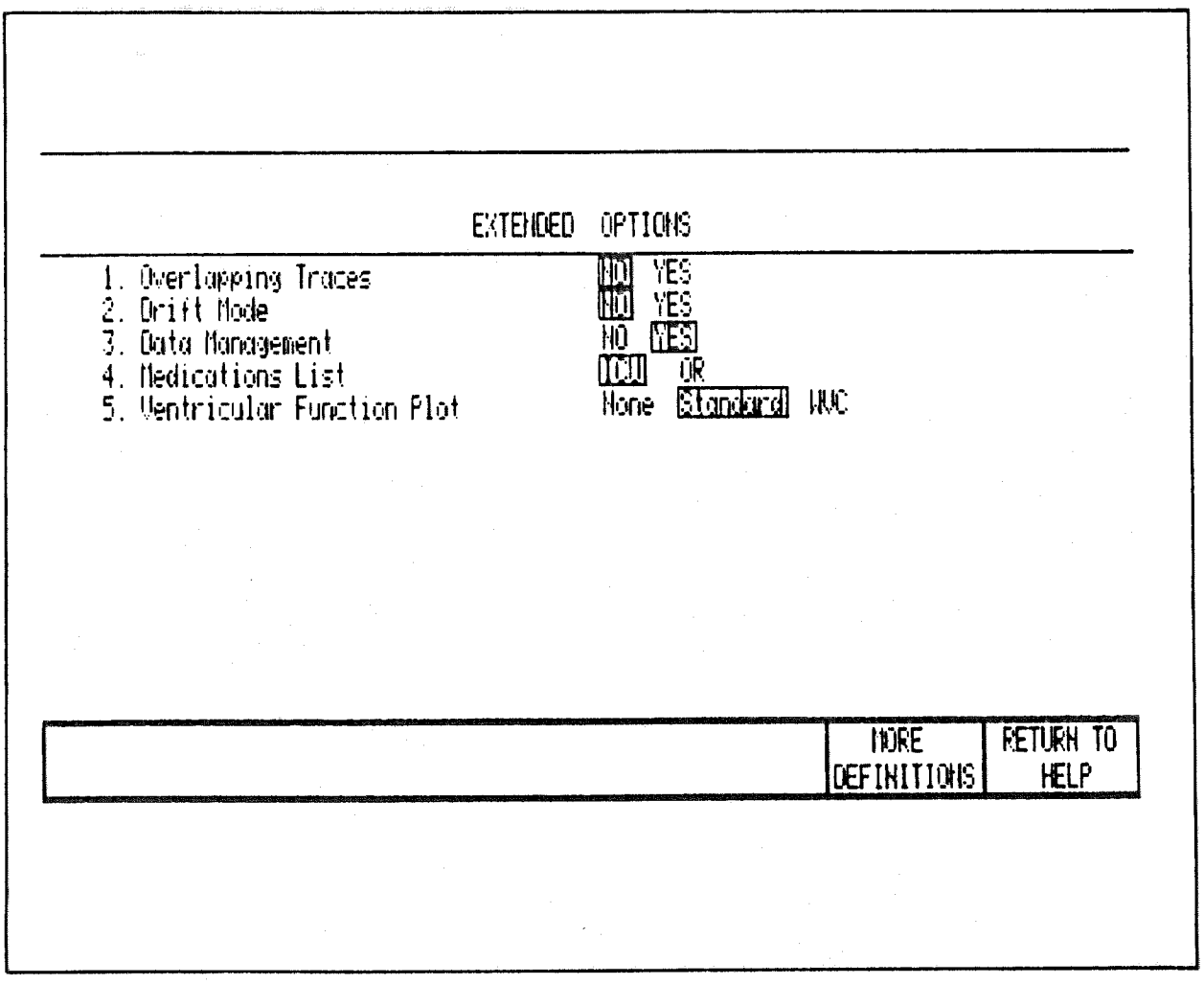


Figure 4-1. Ventricular Function Plot Configuration Choices.

4-6 If [WVC] is configured, the function plot will graph C.I. against PCWP and hematocrit. Hematocrit data is entered manually. As with the Starling curve plot, each plot point will be provided with correlative hemodynamic data. Oxygen availability and consumption are also calculated, if appropriate data is entered in the Oxygenation Calculations program.

4-7 Configuration Instructions

4-8 The configuration of the monitor is determined at time of installation, and can only be changed by authorized personnel. Contact the Biomedical Engineering Department if it is desired to alter the monitor's configuration from **STANDARD** to **WVC**.

4-9 Steps to Plot a Starling Curve

4-10 The Starling Curve is a retrospective presentation of the patient's response to treatment, as evinced by successive PCWP/C.O. measurements. The following steps should be completed in order.

1. Ensure that the patient's height and weight have been entered. C.I. cannot be calculated otherwise. If height and weight need to be entered, the user can access data entry via the ENTER PT HT, WT, NAME key in Cardiac Output set-up menu (Figure 4-2).

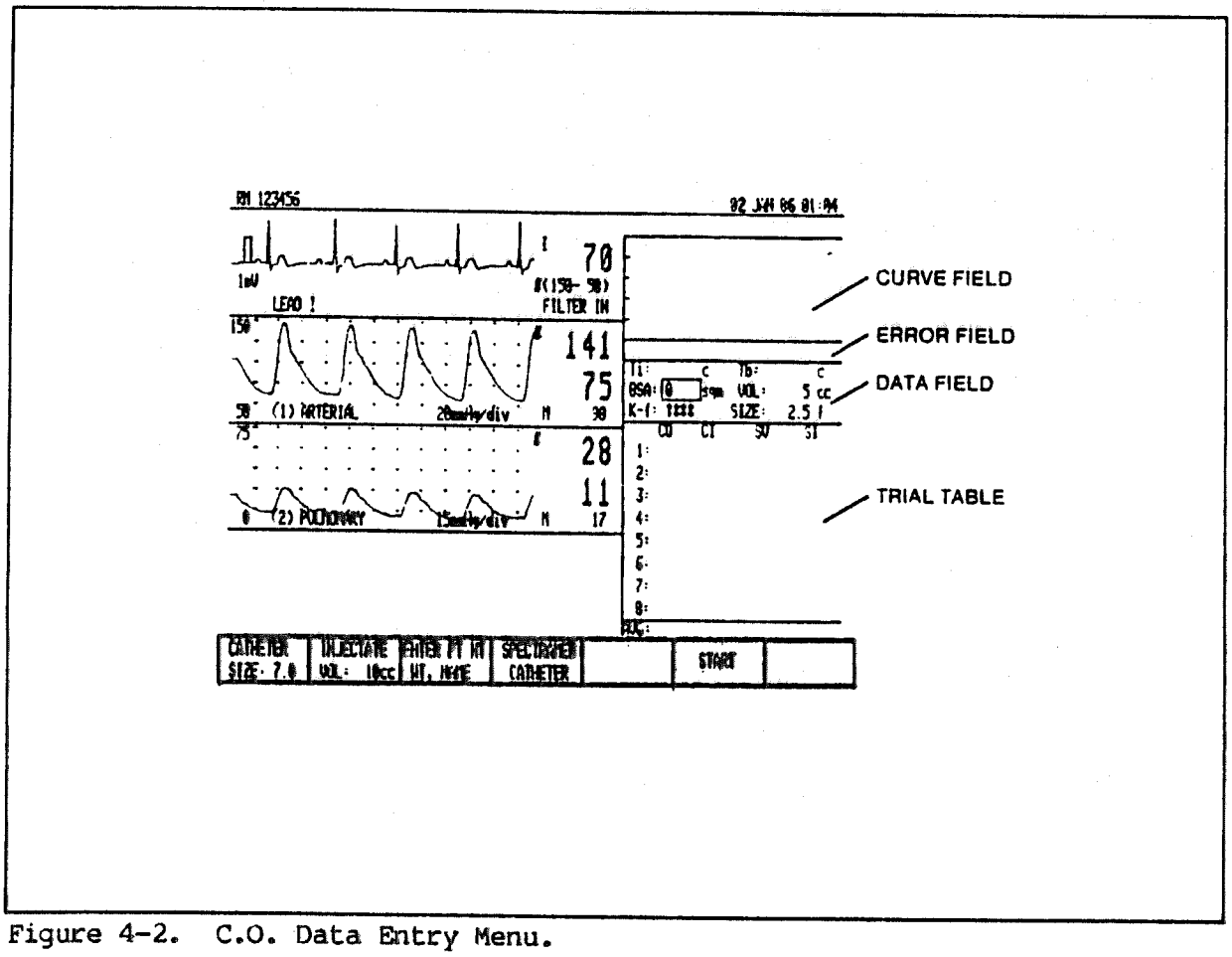


Figure 4-2. C.O. Data Entry Menu.

2. Take PCWP and C.O. measurements. Accepting the C.O. measurement will enter hemodynamic data in the Hemodynamics Calculations Edit Field (Figure 4-3).

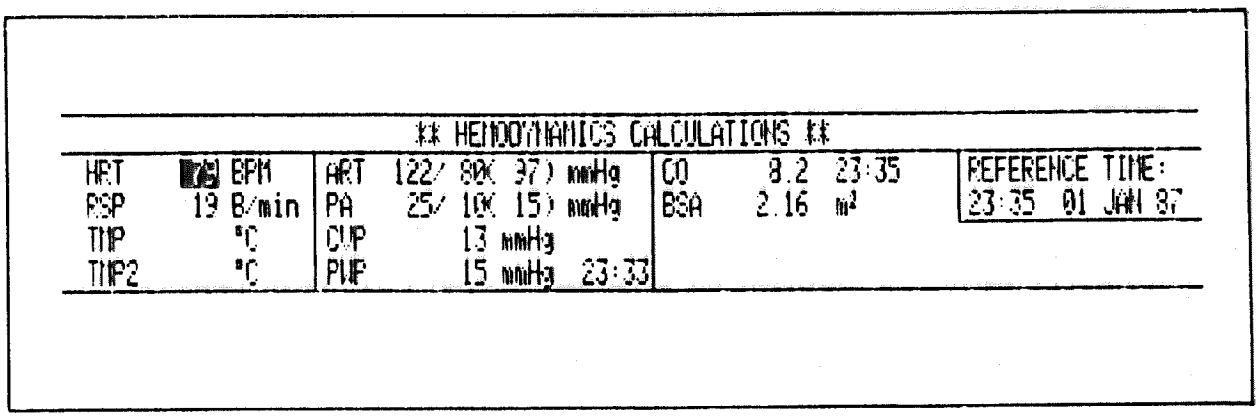


Figure 4-3. Hemodyanmic Calculations Edit Field.

Edit the data (if necessry) and calculate hemodynamics. Review Pages 17 - 23 of the Data Management Package Operating Manual for operating procedures on hemodynamic calculations, if necessary. Upon completion of calculations,

- Press STORE CALCULATION to save calculated data in the patient chart. Data must be stored if it is desired to edit it at a later date.

3. The Starling Curve is plotted if both wedge and C.O. measurements have been taken. However, resistances and cardiac work can only be calculated for a corresponding plot point if the appropriate parameters were monitored at the time wedge and C.O. values were acquired. For convenience, the parameters which must be monitored for corresponding hemodynamic calculations are listed in Table 4-1.

HEMODYNAMIC FUNCTIONS	REQUIRED PARAMETERS
Stroke Volume	HRT, C.O.
Total Systolic Resistance	ART, C.O.
Systolic Vascular Resistance	ART, CVP, C.O.
Pulmonary Vascular Resistance	PA, PCWP, C.O.
Left Cardiac Work	ART, C.O.
Left Ventricular Stroke Work	HRT, ART, C.O.
Right Cardiac Work	PA, C.O.
Right Ventricular Stroke Work	HRT, PA, C.O.
All Indexes	BSA

Table 4-1. Monitoring Requirements for Hemodynamic Function Calculations.

4-11 VIEWING THE STARLING CURVE

4-12 To view the Starling Curve,

- Press SPECIAL FUNCTIONS , PATIENT CHARTS , VENTRICULAR FUNCTION .

The display will present the Starling Curve, plotting the relationship between the four most recently acquired PCWP/C.O. measurements. The most recent measurement will be marked by the cursor; its number indicates the total number of PCWP/C.O. measurements taken (Figure 4-4). The monitored and calculated hemodynamic data for the corresponding plot point are provided in the columns to the right of the graph. Indexes are shown in parentheses. The time and date shown at the right represent the point in time when the C.O. data was accepted (See Page 3-43).

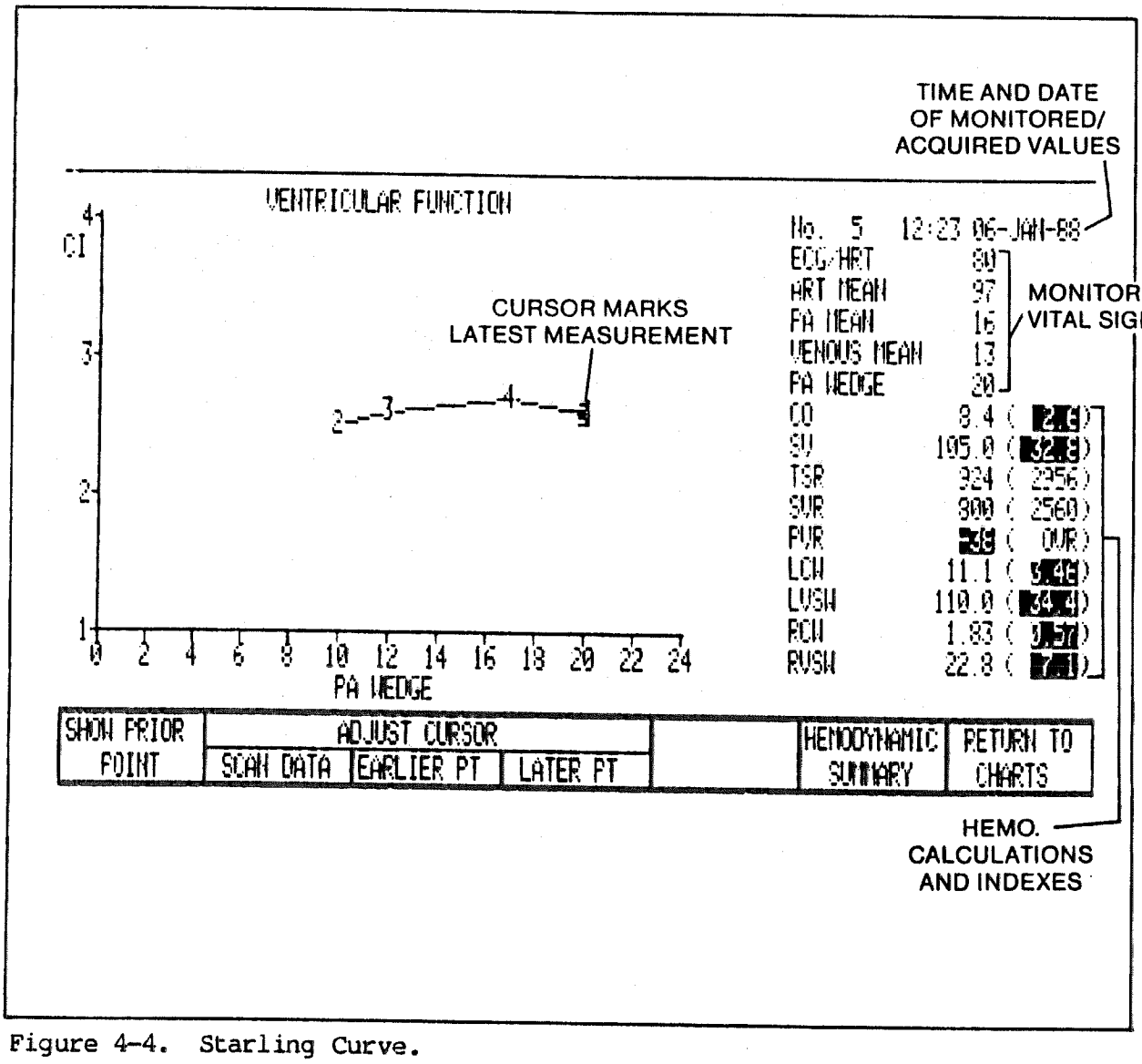


Figure 4-4. Starling Curve.

Prompts indicate incomplete calculations (INC), calculations with resultants too large to display (OVR), or values which lie outside normal physiological ranges (backlighted numbers). Consult the HORIZON 2000 Data Management Package Operating Manual, Page 89, for a definition of normative ranges.

To view earlier plot points,

- Press [SHOW PRIOR POINT] . The plot will be extended back to the previous measurement (Figure 4-5).

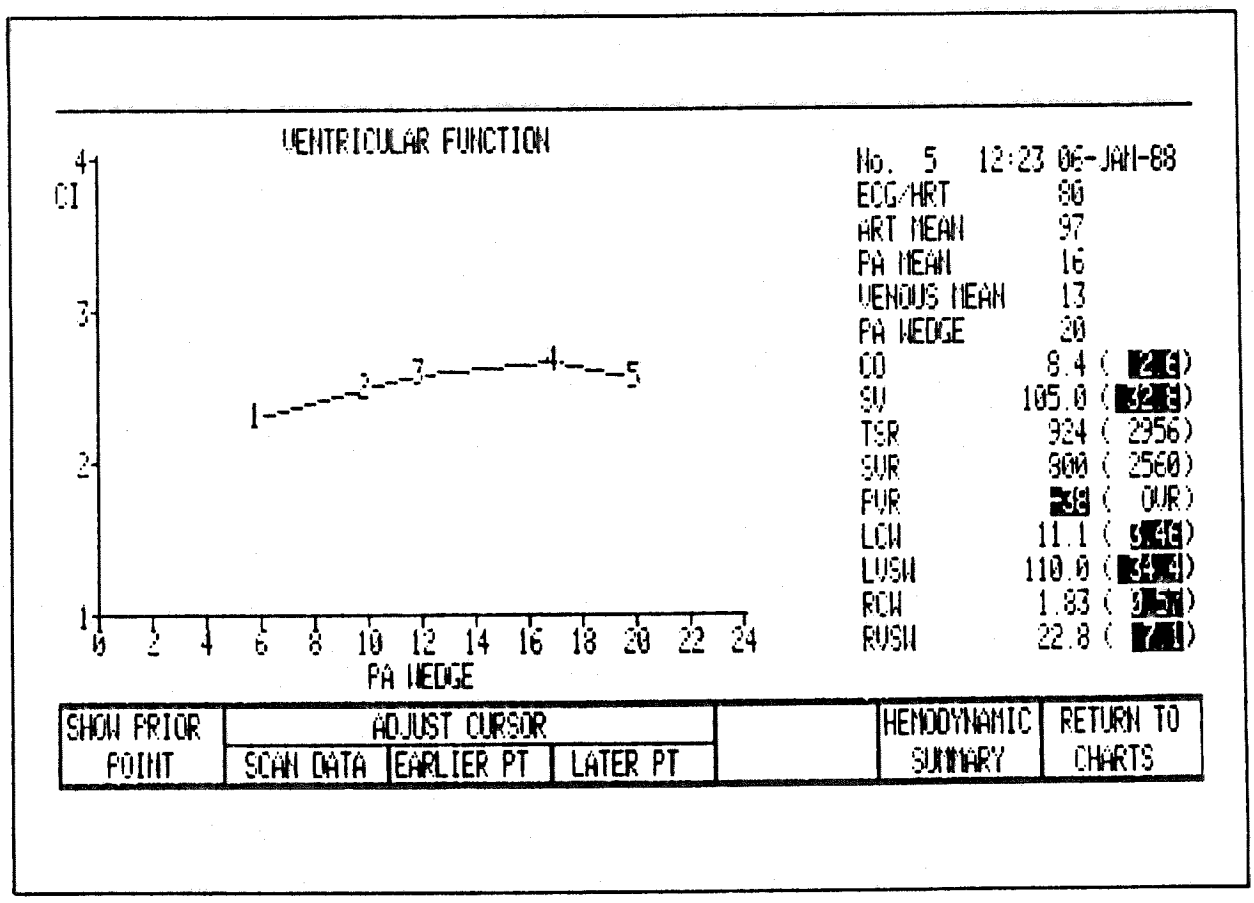


Figure 4-5. Starling Curve Extended Back to Prior Point.

To view hemodynamic data for any point:

- Press [EARLIER PT] to view hemodyanmic data for the point numbered previous to the point on which the cursor rests.
- Press [LATER PT] to view data for the next higher number point.
- Press [SCAN DATA] for a progressive scan of all points. The display will leaf through data for all points in numerical order.

4-13 **DELETING POINTS FROM THE GRAPH**

4-14 To delete a point, note the time and date at which the measurement was taken. The corresponding time and data will be looked up in the Vital Signs Chart, and the data deleted.

When time and date have been noted:

- Press [LEADING] , [VITAL SIGNS] .

The display reformats and presents the Vital Signs Chart where the corresponding data is listed.

- Press [DELETE ENTRY] . Use the cursor keys to mark the line with the the previously noted date and time; then,
- Press [DELETE] , [YES] . The chart entry will be marked with a red DELETE message; the data will still be displayed for reference. However, upon returning to the Starling curve the corresponding point will have been removed and the graph redrawn.

4-15 Steps to Graph a WVC Plot

4-16 **PRELIMINARY**

4-17 The monitor must be configured for WVC before these graphs will be drawn.

NOTE

WVC plots cannot be drawn for any patient data entered or calculated before reconfiguration. Reconfiguration will destroy all patient data in memory. Do NOT reconfigure the monitor unless the patient has been discharged.

4-18 **PROCEDURE**

4-19 The WVC graph is generally plotted on a point-by-point basis; a single reading is taken, with further trials dependent upon studying the response to each reading. Follow the steps listed below in order: These instructions assume that the user has already reviewed steps for plotting the Starling Curve.

1. Ensure that the patient height and weight have been entered. C.I. cannot be calculated without height and weight, unless BSA is entered manually.

2. Assure that parameters necessary for full hemodynamic calculations are being monitored. See Table 4-1, above.

3. Take the first PCWP and C.O. measurement. Accepting the C.O. measurement will enter hemodynamic data in the Hemodynamics Calculations Edit Field. Edit the data (if necessary) and calculate hemodynamics. Upon completion of calculations,

   - Press [STORE CALCULATION] to save the calculated data in the patient chart. Data must be stored if it is desired to edit it at a later date.

   - Press [SPECIAL FUNCTIONS] to continue the procedure.

   - Press [CLEAR] to exit the procedure. Exiting the procedure is recommended if blood oxygen data is not readily available from the lab.

4. Obtain blood oxygen data required for oxygenation calculations. See Page 41 of the HORIZON 2000 Data Management Package Operating Manual for the list of parameters to be entered. In addition to the listed data, hematocrit percentage concentration must also be obtained.

5. Set up to calculate oxygenation data:

   - Press [CALCULATION FUNCTIONS], [OXYGENATION].

   Enter and calculate the oxygenation data. Note the REFERENCE TIME in the upper right corner of the Edit Field (Figure 4-6). This is the time at which the previous PCWP/C.O. measurement was acquired. Oxygenation data will, therefore, be made to correspond to hemodynamic data derived from this measurement. See Pages 41 - 47 in the Data Management Package Operating Manual for calculation instruction familiarization, if necessary.

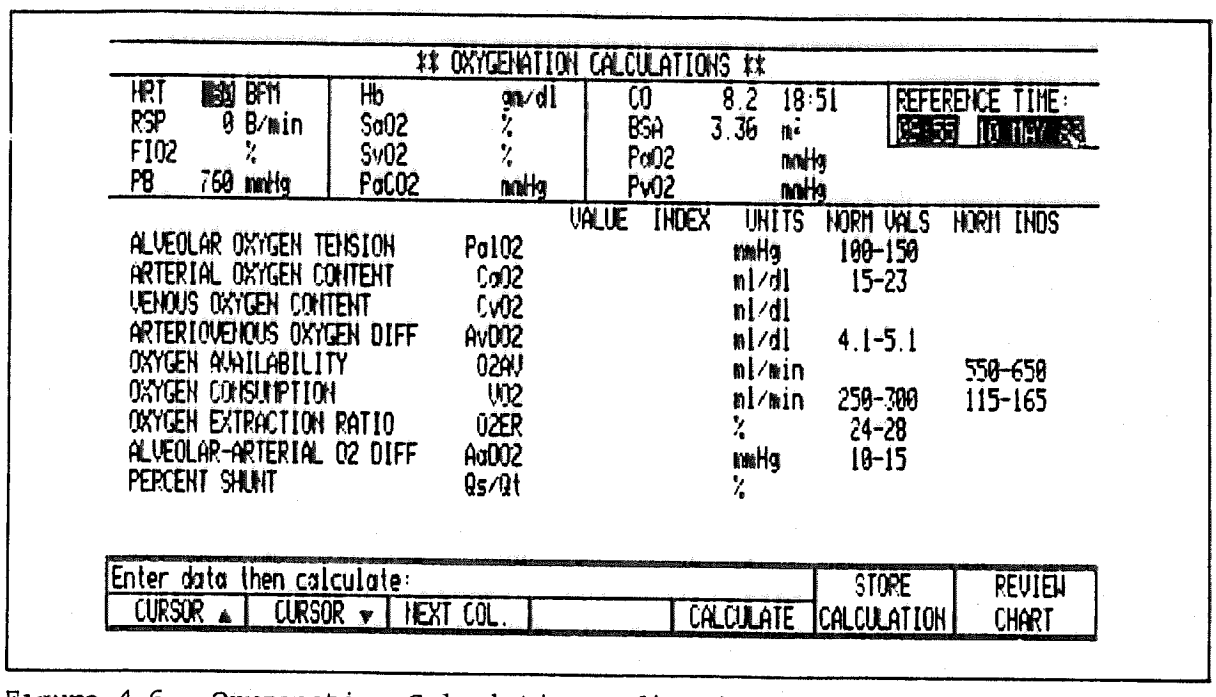


Figure 4-6. Oxygenation Calculations Edit Field.

- Press STORE CALCULATION . The oxygenation values corresponding to the calculated hemodynamic values will be stored in the patient chart.

- Press SPECIAL FUNCTIONS to continue the procedure. The menu prompts to enter the hematocrit percentage.

6. Enter the hematocrit concentration (Figure 4-7).

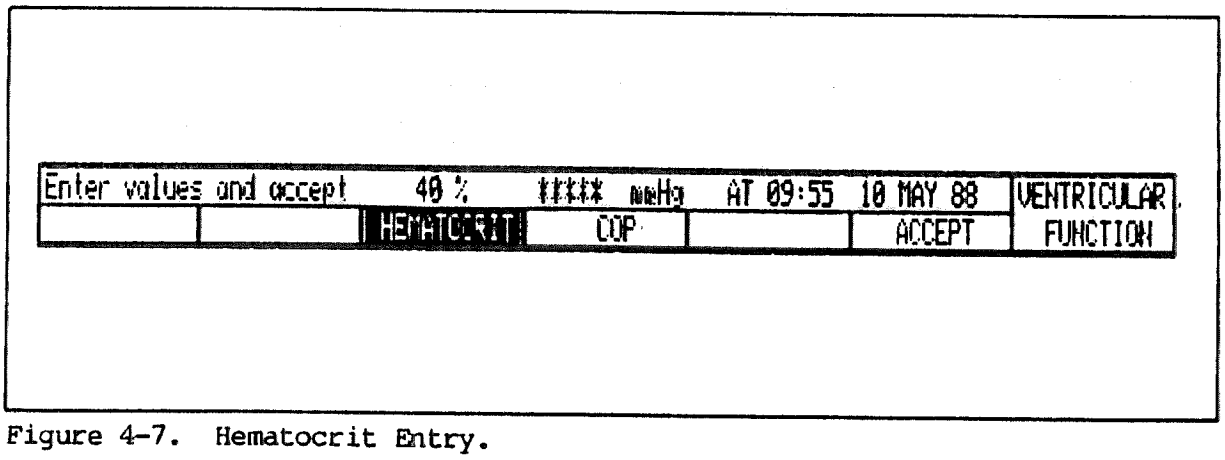


Figure 4-7. Hematocrit Entry.

If a C.O. value has not been acquired to which the hematocrit entry will correspond, the menu prompts for C.O. acquisition (Figure 4-8).

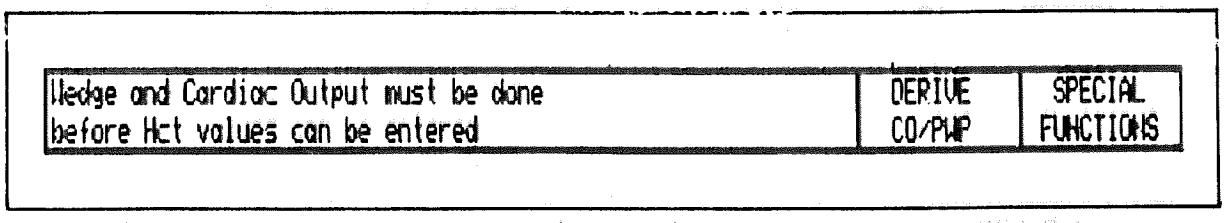


Figure 4-8. No C.O. Has Been Acquired Which Corresponds to HCT Entry.

Following hematocrit entry, press COP and enter colloid osmolar values, if desired. COP values have no influence on the WVC plot. When values are entered,

- Press ACCEPT . The display immediately presents the WVC plot (Figure 4-9). The vertical line indicates that HCT (top of square) and C.I. correspond to the same PCWP.

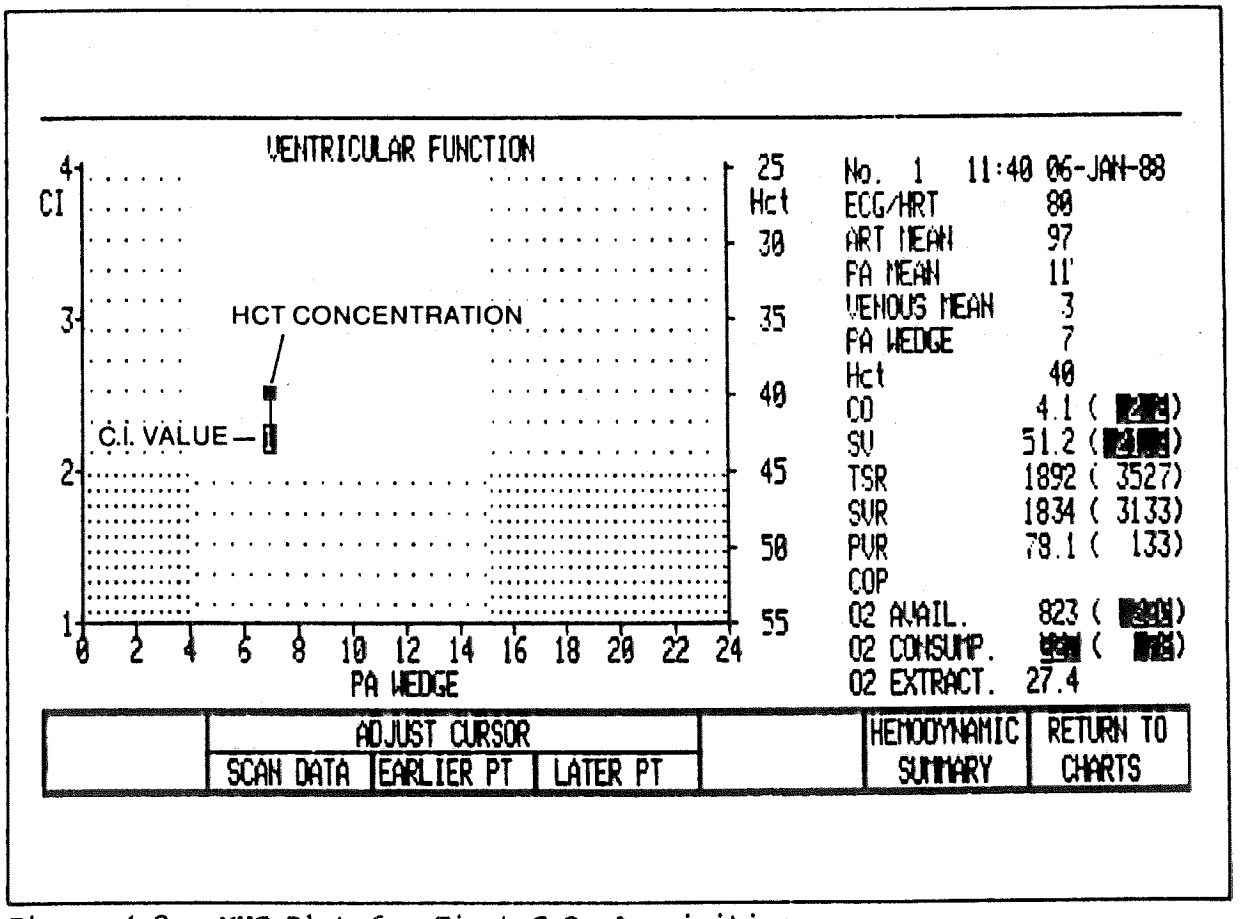


Figure 4-9. WVC Plot for First C.O. Acquisition.

4-20 GRAPHING ADDITIONAL PLOT POINTS

4-21 Follow Steps 1 - 6, above, for successive plot points. Figure 4-10 shows that a second reading has been taken following hemodilution (PCWP elevated, hematocrit reduced).

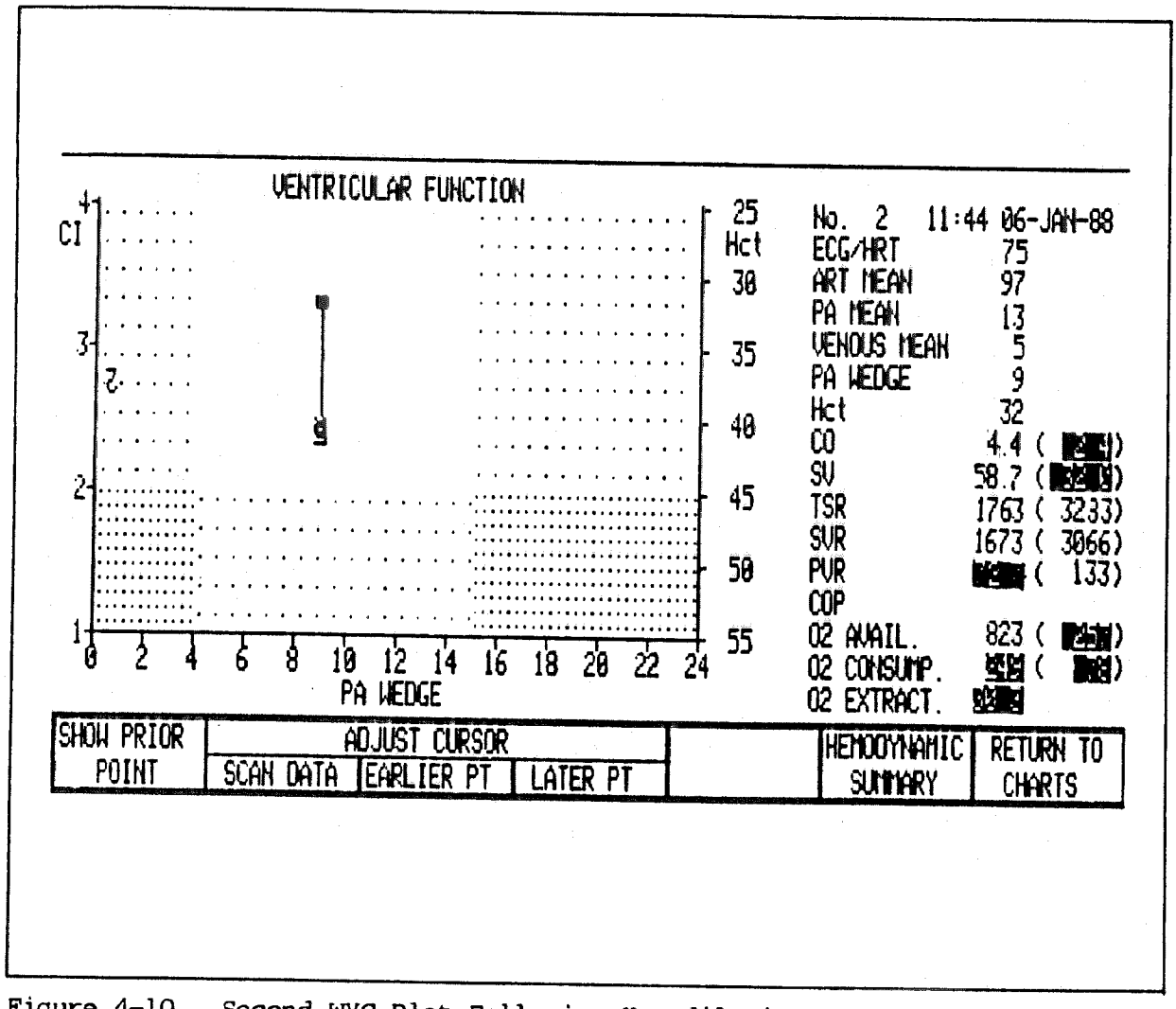


Figure 4-10. Second WVC Plot Following Hemodilution.

- Pressing [SHOW PRIOR POINT] reveals the improvement in C.I. between Reading #1 and Reading #2, due to hemodilution (Figure 4-11).

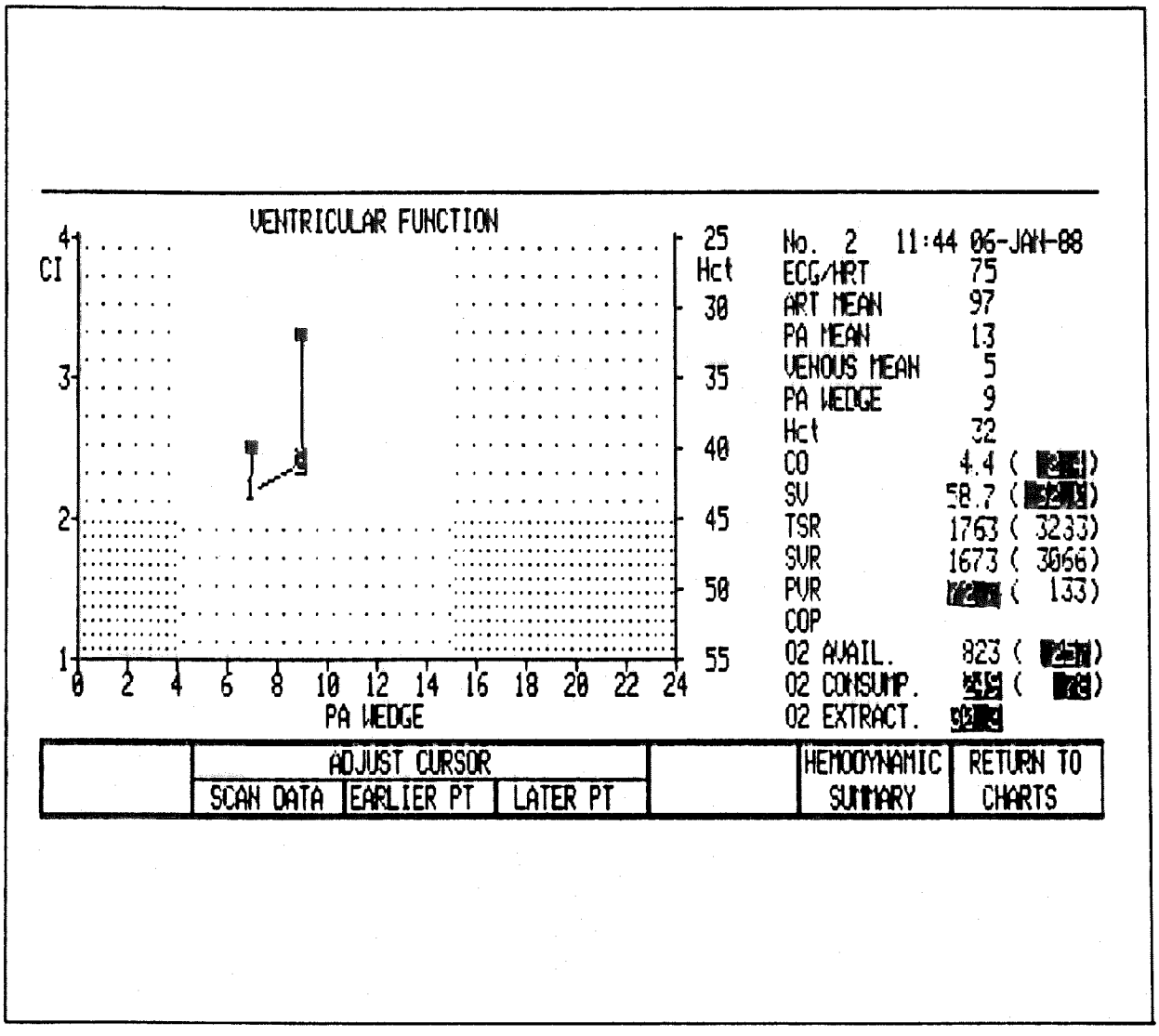


Figure 4-11. Connecting Line Between Points 1 and 2 Shows C.I. Gain.

4-22 EDITING THE GRAPH

4-23 Editing the graph for a WVC plot is identical to editing a Starling Curve plot. See Paragraph 4-13.

Section 5

Quick Reference Troubleshooting Chart

5-1 General

5-2 This section is intended as a quick look-up guide in solving monitoring problems encountered in hemodynamic parameter derivation or calculations. It is divided into two parts: **CLINICAL PROCEDURE** and **MONITORING PROCEDURE.** Although complications can occur with clinical procedure when the staff is relatively new to Swan-Ganz monitoring, most difficulties will be encountered in monitoring procedures.

5-3 The Quick Reference Troubleshooting Chart is intended only as a supplement to the detailed analysis of catheter insertion and parameter monitoring techniques discussed in Sections 2 and 3.

5-4 **CHART USE**

5-5 Determine whether the difficulty encountered is with Clinical Procedure (Chart 1) or with use of the HORIZON 2000 Patient Monitor (Chart 2). Chart 2 is further sudivided into columns for PCWP monitoring and C.O. calculation. Find the problem in the appropriate chart, and take corrective actions listed. Also, refer to manual sections listed (in parentheses) for each corrective action.

CHART 1.
TROUBLESHOOTING CHART:
CLINICAL PROCEDURE

PROBLEM	CAUSES	CORRECTIVE ACTION (REF. BY PARENTHESES NUMBER)
Difficulty in catheter insertion; resistance to insertion in venous system.	Excessive catheter friction; excessive insertion force causing kinking.	Lubricate catheter before insertion, check catheter French number. (2-7).
Arrhythmias (APC's or PVC's)	Irritation of atrial or ventricular myocardium; irritation of tricuspid valve; catheter knotting; excessive catheter length.	Suture catheter at insertion site if catheter migrates easily. X-ray upper chest for possible catheter knotting, lodging. (2-20).
Pulmonary infarction or hemorrhage.	PA infarction or rupture due to overdistension of arterial walls during wedging. Distal end of catheter lodged in PA vessel wall, causing thrombosis.	Inflate balloon slowly during wedging. Do not advance catheter until balloon is at proper volume; do not underinflate balloon. (2-36).
Pulmonary thromboembolism	Migration of thrombus from catheter into pulmonary circulation. Thrombus created by overwedging, too frequent wedging, or wedging in arteriole.	Inflate balloon only long enough to derive PCWP, and not exceeding 12 seconds. NOTE! Do not fast-flush catheter if embolism is suspected or to free catheter from clotting. Aspirate blood, or employ anticoagulation therapy. (2-39).
Air embolism	Balloon rupture due to excessive pressure in balloon lumen or weak balloon due to loss of elasticity: balloon latex absorbs lipoproteins and loses elasticity.	Do not exceed manufacturer's inflation volume spec. Do not inflate more than 50 times. Do not leave catheter in site for more than 48 hours. (2-36).
Difficulty in catheter withdrawl.	Balloon still inflated; knotting in catheter; catheter lodged in endocardium.	Take x-ray before continued withdrawal attempt. If catheter lodged, have patient cough while extending arm with catheter incision. (2-42).

CHART 2.
TROUBLESHOOTING CHART:
MONITORING PROCEDURE FOR PCWP DERIVATION

PROBLEM	CAUSES	CORRECTIVE ACTION
Transducer will not zero. HORIZON requests rezero.	Vibration in catheter interface with transducer. HORIZON will not accept "zero" waveform with more than ±2 mmHg variation.	Keep transducer/mount fittings firm. Check for vibration in transducer or tubing caused by ventilator, infusion pump, or associated equipment. (User's Guide, Tab 7).
No right atrial waveform upon catheter insertion.	- waveform range on monitor too wide. - air bubbles in tubing/ catheter. - clotting.	Use 25 mmHg range. Check Intraflow, stopcock, and transducer for bubbles. Gently flush to remove bubbles. (2-21, Step 4). See "Damped PA waveform."
Damped PA waveform: systolic amplitude decreasing while diastolic increasing.	- air bubble in tubing or transducer. - catheter kinked or lumen tip wedged against endocardium: NOTE: kinking/ wedging causes sharp and immediate damping of pressure. - clotting in lumen. NOTE: clotting is typically associated with progressive waveform dampening.	See "No right atrial waveform." Have patient cough and/or extend limb with inserted catheter to free catheter tip. If no progress achieved, obtain x-ray. (2-19). DO NOT FLUSH! Fast flush may result in pulmonary thromboembolism. Aspirate blood until thickening decreases. If aspiration is successful, flush gently to restore patency. Also, check that pressure in flush bags is sufficient to maintain patency. If aspiration unsuccessful, withdraw catheter (2-21, Step 4).

CHART 2.
TROUBLESHOOTING CHART:
MONITORING PROCEDURE FOR PCWP DERIVATION

PROBLEM	CAUSES	CORRECTIVE ACTION
Excessively noisy PA signal	Respiratory artifact. NOTE: HORIZON BP data averaging circuits filter out waveform variations due to artifact. S, D, M values will remain stable even though waveform varies.	Reduce tidal volume on ventilator. Anti-hypertension therapy may also be required. (2-20, Step 2).
Wedge pressure waveform not obtainable.	- balloon damaged.	CEASE ATTEMPTED INFLATION IMMEDIATELY IF BACK PRESSURE NOT SENSED ON SYRINGE DURING INFLATION! WITHDRAW CATHETER.
	- insufficient air in balloon.	Deflate and start again. If balloon not at rated inflation volume, increase volume. If waveform still will not convert to wedge, x-ray patient to determine catheter position. (2-26).
	- catheter insufficiently advanced.	X-ray patient to determine catheter position (2-25).
PA waveform remains wedged after balloon is deflated	End of lumen wedged in arterial wall.	see "Damped PA waveform," above.

CHART 2.
TROUBLESHOOTING CHART:
MONITORING PROCEDURE FOR C.O. CALCULATION

PROBLEM	CAUSES	CORRECTIVE ACTION
No prompt tone or "BEGIN INJECTION" message following entry of START	cable or probe fault.	Observe display for fault message in menu. Follow corrections in Section 3. (3-34, 3-35).
No C.O. calculated following injection. No C.O. curve in display.	insufficient change in T_B for C.O. determination.	Check catheter position by observing PA waveform. Increase speed of injection; increase injectate volume; decrease injectate temperature. (3-38; 3-48).
Calculated data marked with asterisk. Error message displayed in error field.	- injectate temperature out of range for K factor. - catheter whip. - injection too slow.	Consult Table 3-1 on Page 3-4 (3-36). Examine PA waveform for excessive (>± 5 mmHg) variation. Reduce ventilator tidal volume (3-37). Inject faster and more smoothly (3-39).
No C.I. or S.I. values	patient height and weight not entered during registration.	Enter patient's height and weight (3-29).
Large variations in C.O. values between successive trials, even though clinical evidence suggests cardiac function is stable.	- injectate temperature changing between trials. - catheter whip.	Keep syringes at constant temperature (separate bath). Flush flow-through system several times before connecting to proximal lumen port (Co-Set™). Change distal lumen position (2-20).

DERIVE PCWP/CO

TOPIC	PAGE
— Introduction	7-29
— Pulmonary Wedge	7-31
— Cardiac Output	7-39

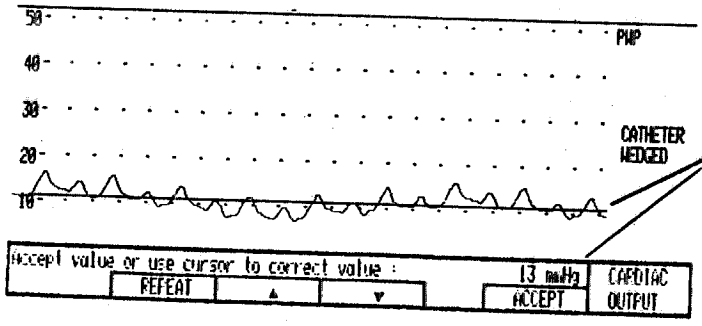


Figure 7-11a.

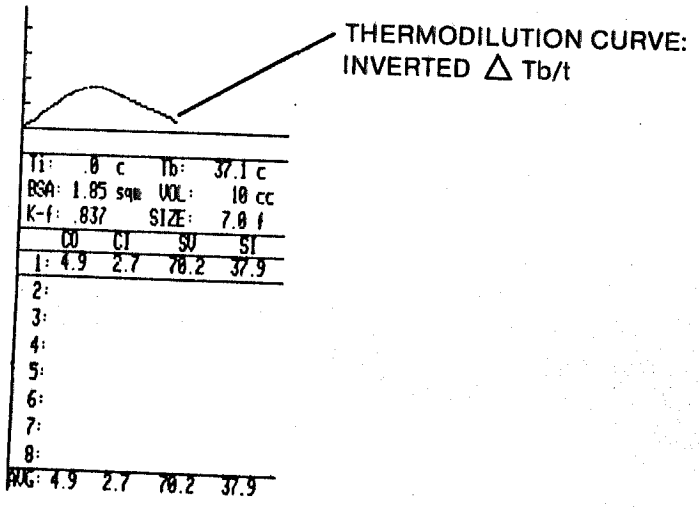


Figure 7-11b.

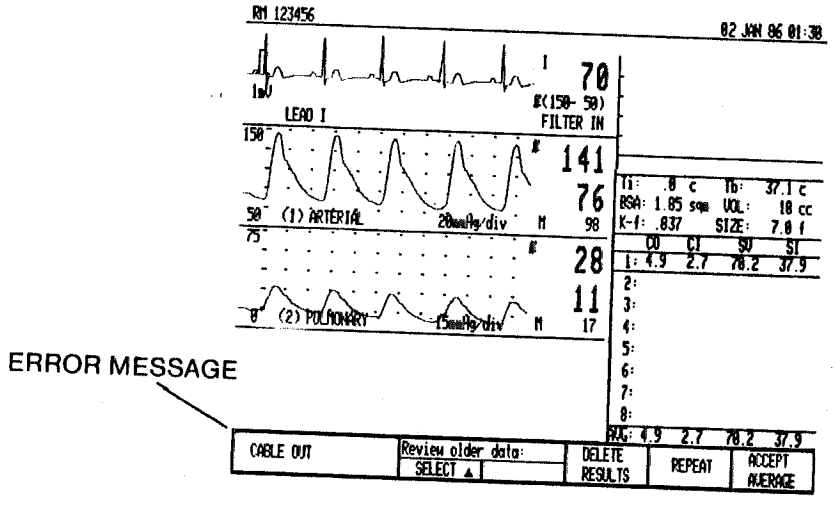


Figure 7-11c.

Figure 7-11. PCWP and C.O. Calculations.

CARDIAC OUTPUT AND PCWP CALCULATIONS

INTRODUCTION

The HORIZON 2000 family of monitors permits optional calculation of cardiac output and derivation of pulmonary capillary wedge pressure (PCWP).

PCWP is read from the distal lumen of the Swan-Ganz* catheter following inflation of the ballon. Previous to mean PCWP calculation, the user may range the pressure waveform for optimal presentation. Calculation of mean PCWP during wedging is automatic; following deflation of the balloon, the operator can alter the point on the wedge waveform from which mean PCWP is derived (Figure 7-11a).

Cardiac output can be calculated from blood temperature changes caused by right ventricular output of the injectate. Body surface area and K-factor can be entered manually or calculated automatically. If body surface area has been entered manually or calculated, corresponding cardiac indexes will also be calculated for each C.O. trial. Each C.O. trial also results in the display of a thermodilution curve, representing blood temperature deviation (Figure 7-11b). Up to eight trial injections may be compared for thermodilution response curves and corresponding data. The operator can average all trials, or selected trials, to derive the accepted C.O. value. The operator is also notified of invalid trials, or other procedural problems preventing trials (Figure 7-11c).

The HORIZON may be configured to interface with two types of injectate systems. Configuration also permits automatic charting of accepted C.O. values, and recording of the C.O. waveform during a trial. See Page 8-33 for a description of configurable C.O. options.

*"Swan-Ganz" is a trademark of the American Edwards Laboratories' Division of American Hospital Supply Corporation. No further trademark reference is made in this manual.

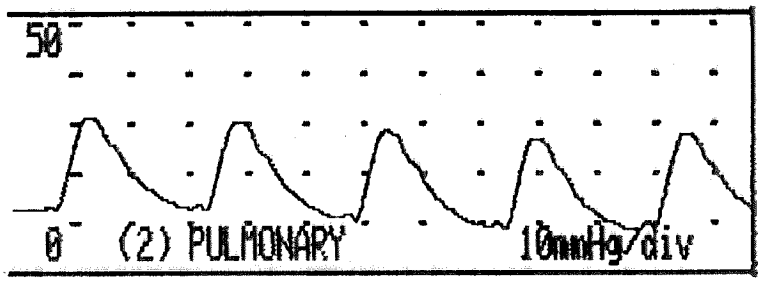


Figure 7-12a.

SET UP THE MONITOR	ADJUST VITAL SIGNS	WRITE OUT ON RECORDER	STORE DATA IN CHART	ZERO BLOOD PRESSURES	VIEW OTHER PATIENTS	SPECIAL FUNCTIONS

Figure 7-12b.

			VITAL SIGNS TRENDS	PATIENT CHART	DERIVE CO/PWP	DEFIB SYNC ADJUST

Figure 7-12c.

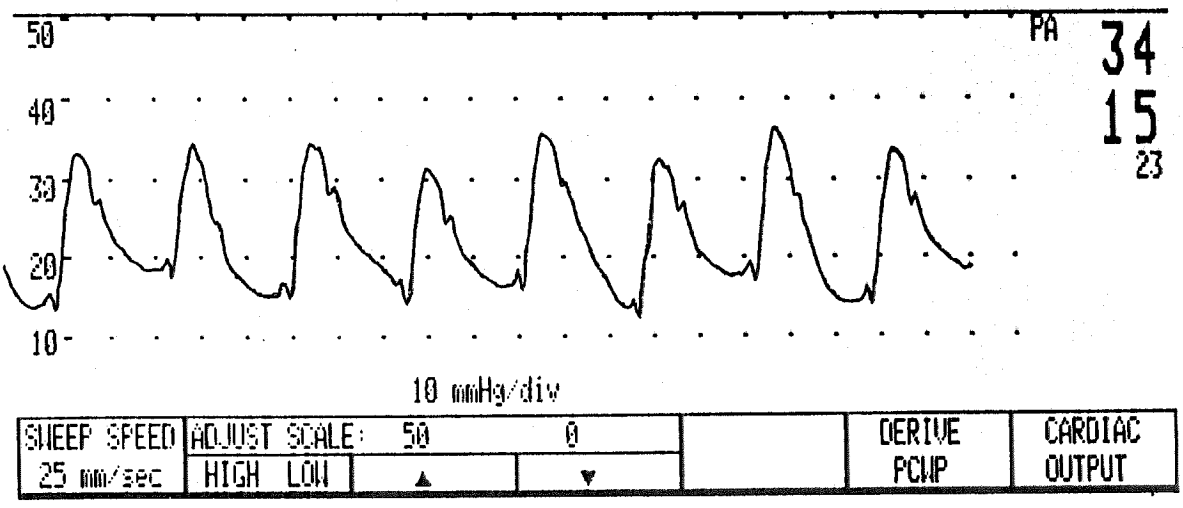


Figure 7-12d.

Verify correct catheter position and select PCWP or CVP.					CARDIAC OUTPUT
SCALE 0-50	SCALE 25/75	12.5 mm/sec	CVP from PA	DERIVE PCWP	

Figure 7-12e.

Figure 7-12. Entry into PCWP Program.

PULMONARY CAPILLARY WEDGE PRESSURE CALCULATIONS

CLINICAL PRECAUTIONS

Proper clinical procedure for placement of the Swan-Ganz catheter and inflation of the balloon is critical for correct wedge pressure derivation. Improper inflation of the balloon and/or extended wedging of pulmonary arterioles can cause wall damage and/or respiratory distress. For operators not familiar with wedging techniques, MENNEN MEDICAL publishes the "Clinical Guide to Cardiac Function Monitoring." A copy of this Guide is provided with the HORIZON 2000 Operating Manual. Additional copies of the "Clinical Guide to Cardiac Function Monitoring" are available from your MENNEN MEDICAL representative at no charge.

STEPS TO DERIVE PULMONARY CAPILLARY WEDGE PRESSURE

PRELIMINARY

The Swan-Ganz catheter balloon must be properly situated in the pulmonary artery, with the balloon initially deflated. A PA waveform, corresponding to pressure variations at the distal lumen, will appear as shown in Figure 7-12a. Ensure that this waveform has been obtained before proceeding to the next step.

PCWP DERIVATION PROCEDURE

-Press [SPECIAL FUNCTIONS] in the default menu (Figure 7-12b).

HORIZON 2000 will provide the Special Functions menu (Figure 7-12c). To derive PCWP,

-Press [DERIVE CVP CO/PWP] or [DERIVE CO/PWP] .

(Figure 7-12c-- Configuration determines key label).

The display will reformat to Full Waveform mode, and the PA waveform will be presented in Fields 3 and 4 (Figure 7-12d). This mode allows for viewing the expanded waveform as the catheter is advanced during initial placement.

The default pressure range for PCWP is the same as the range previously set for P.A. monitoring. However a different range may be selected, as desired.

-Press [HIGH LOW] until the desired scale limit is backlit. Use the increment ▲ and decrement ▼ keys to set the desired limit values. The upper scale limit is from 0-300 mmHg, and the lower scale limit is from -25 to 50 mmHg.

The default display speed is 25 mm/sec., presenting 8 seconds of PCWP waveform for averaging. The average may be derived from 16 seconds of PCWP waveform by selecting the 12.5 mm/sec. speed or 4 seconds of the PCWP waveform by selecting the 50 mm/sec. speed.

To modify the sweep speed: -Press [25m/sec.] .

This will cause HORIZON 2000 to cycle to the next higher display speed setting and present it in the key label.

Changing the sweep speed affects all displayed waveforms. Once a sweep speed is selected, it is retained until changed by operator interaction or tne default menu is returned. For speeds other than 25 mm/sec., the speed is annotated in the header just before the time.

-Press [DERIVE PCWP] when display speed and pressure range have been selected, and the operator is ready to inflate the balloon (Figure 7-12e).

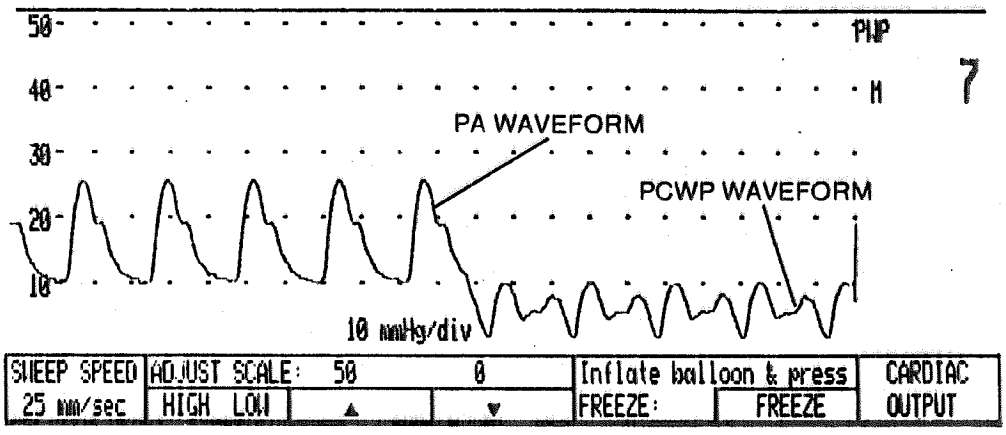


Figure 7-13a.

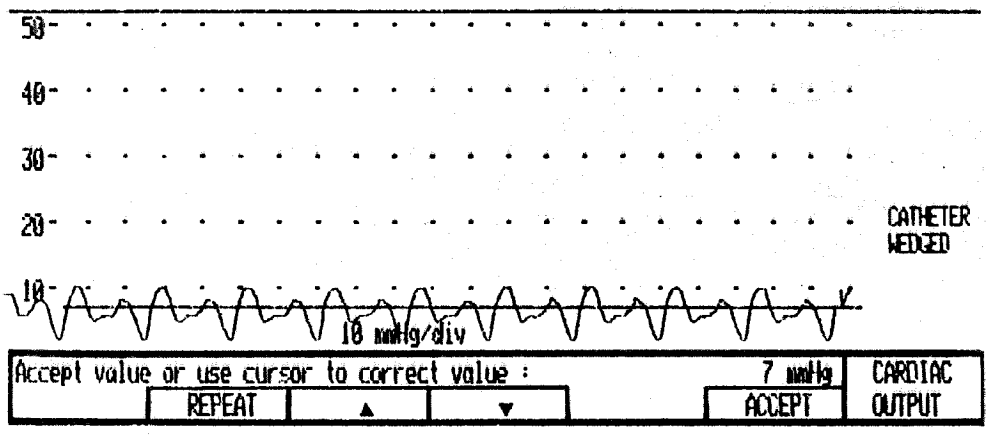


Figure 7-13b.

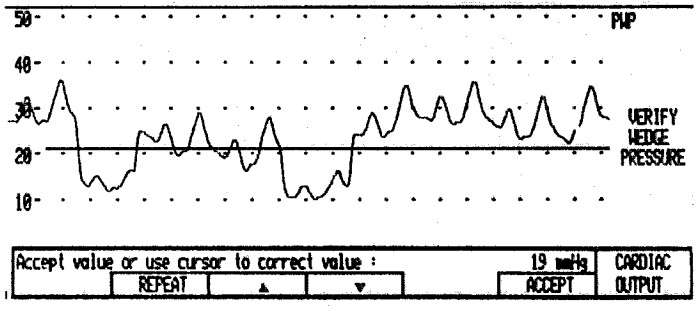


Figure 7-13c.

Figure 7-13. Catheter Wedge and PCWP Derivation.

The menu reformats to that shown in Figure 7-13a; the operator is prompted to inflate the balloon. Inflate the balloon and observe that the PA Waveform converts to a PCWP waveform (Figure 7-13a). When the wedged pressure waveform fills the entire display:

-Press FREEZE .

The PCWP waveform will be frozen, and the mean PCWP value will be calculated and displayed above the ACCEPT key. Upon mean PCWP derivation, the message "CATHETER WEDGED" will be displayed to the right of the waveform. A red cursor line will mark the pressure level at which the mean PCWP is derived (Figure 7-13b).

If the FREEZE key is depressed while the catheter is still in motion, or if the arteriole is not fully wedged, HORIZON will alert the operator via the "VERIFY WEDGE PRESSURE" prompt that the PA waveform is excessively pulsatile for a wedged pressure (Figure 7-13c). This message may also be displayed for correctly wedged waveforms with excessive respiration artifact. In these cases, manual positioning of the cursor may be necessary to correctly determine end-expiratory wedge pressure. See Page 7-35.

If the displayed waveform is acceptable for PCWP calculation (even though pulsatile),

-Press ACCEPT (Figure 7-13c). The PCWP value will be derived from the displayed waveform.

If it is desired to attempt further wedging to stabilize the waveform,

-Press REPEAT . Return to "PCWP Derivation Procedure" on Page 7-31.

WARNING!

DO NOT CONTINUE TO FURTHER INFLATE THE BALLOON AFTER THE FREEZE KEY HAS BEEN DEPRESSED. OVER INFLATION RISKS BALLOON BREAKAGE AND SUBSEQUENT EMBOLISM.

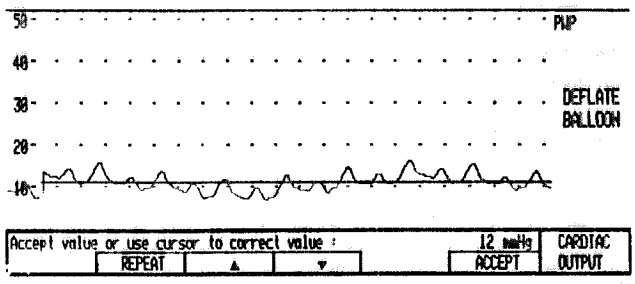


Figure 7-14a.

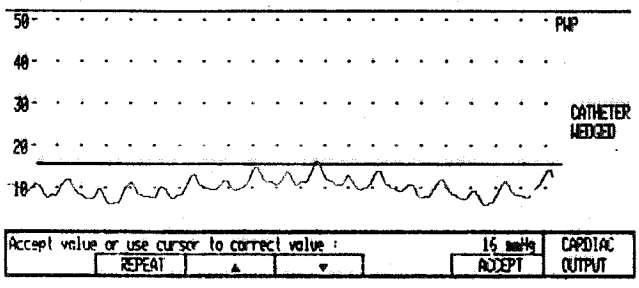


Figure 7-14b.

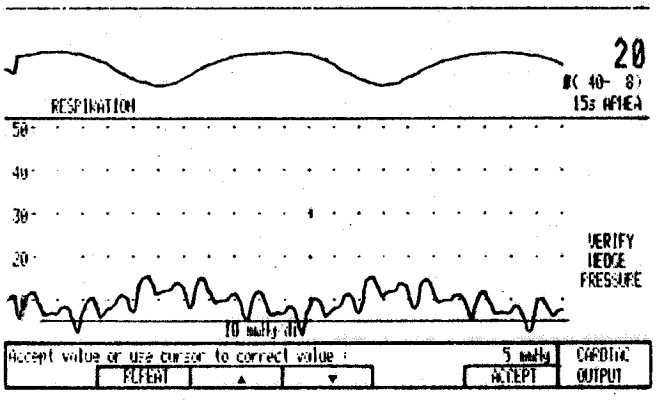


Figure 7-14c.

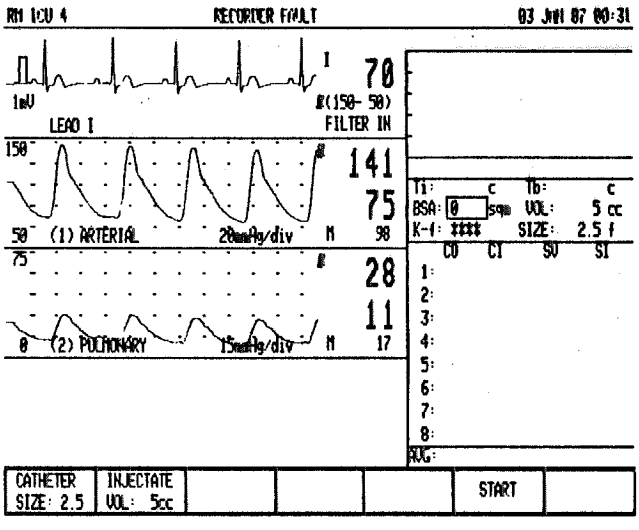


Figure 7-14d.

Figure 7-14. Termination of PCWP Program.

Following display of the "CATHETER WEDGED" message,

- Deflate the balloon.

WARNING!

DEFLATE THE BALLOON IMMEDIATELY UPON SEEING THE "CATHETER WEDGED" MESSAGE. EXTENDED WEDGING OF THE PULMONARY ARTERY CAN CAUSE WALL DAMAGE OR RESPIRATORY DISTRESS.

Twelve seconds after the FREEZE key has been depressed, HORIZON will begin flashing a "DEFLATE BALLOON" prompt (Figure 7-14a). This message reminds the operator that the balloon must be deflated; it will continue flashing until the operator presses ACCEPT or REPEAT .

If it is desired to read PCWP at some point on the waveform other than that indicated by the red cursor,

- Press ▲ or ▼ to alter the cursor line and the corresponding PCWP value (Figure 7-14b). The cursor and corresponding value will change color from red to yellow whenever the operator has moved away from the derived value. To return to the mean PCWP value derived by HORIZON:

- Press ▲ or ▼ until the cursor line returns to a red color.

EVALUATING RESPIRATORY ARTIFACT

In selecting the point where the PCWP is read, the presence of respiratory artifact should be taken into consideration. For patients on respirators, in particular, mean PCWP readings will be influenced by tidal volume and peak-inspiratory pressure settings.

It is generally desirable to read mean PCWP during the end-expiratory period. This assures a stable value unaffected by pressure elevation due to forced inspiration.

- Select RESP for the Field 2 waveform (see Page 3-7).
- Adjust the cursor so that it crosses the PCWP waveform during end-expiration. Observe the patient chest motions to determine the inspiration/expiration pattern, and verify the waveform segment corresponding to exhalation. (Figure 7-14c).

Note that the monitor can be configured to display RESP in Field 2 automatically upon entrance to the wedge program. See Page 8-31.

The operator-selected or derived PCWP value can be stored in the Patient Chart. To store data in the Patient Chart:

- Press ACCEPT (Figure 7-13c). Data will be stored in the Patient Chart with the time of acceptance (see Page 7-21). The most recently accepted PCWP value will also be provided in the lower right hand corner of the half-screen display.

Accepting the displayed PCWP value will cause automatic exit from the PCWP derivation program; the display will switch to the start of the cardiac output calculations program (Figure 7-14d), if configured, or will return to the default menu.

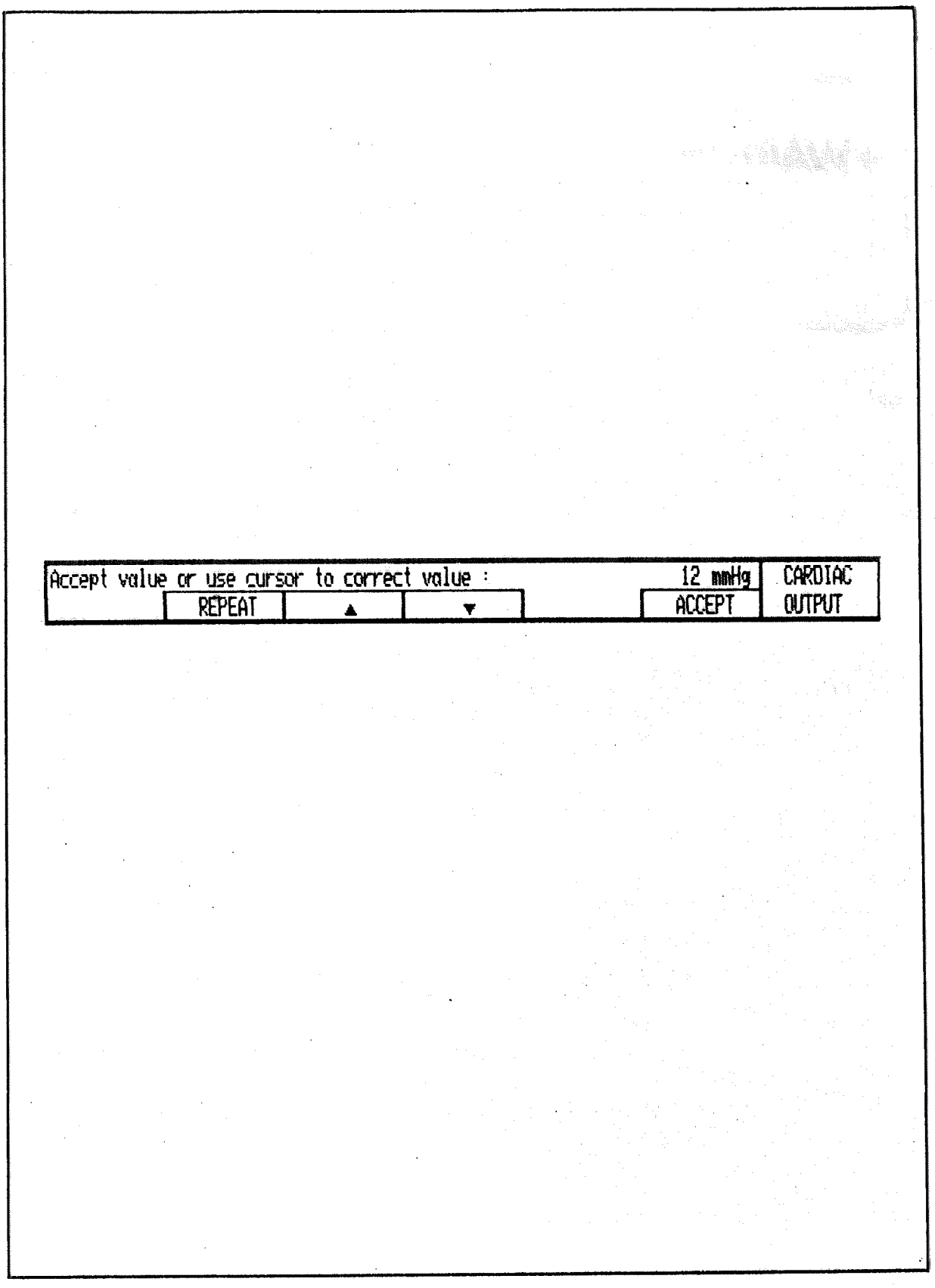


Figure 7-15. Repeating PCWP Calculations.

If it is desired to reposition the catheter, or if additional pressure readings are desired for the same catheter site, the entire PCWP derivation can be repeated. To derive an additional PCWP reading:

-Press [REPEAT] (Figure 7-15). Return to Page 7-31 and repeat the entire procedure.

NOTE

Pressing [REPEAT] will cause the currently displayed PCWP value to be lost. Successively saved PCWP values will be distinguished by the time of day at which they were saved in the Patient Chart. See Page 7-21 for further details on the Patient Chart.

RECORDING THE PCWP WAVEFORM

If configured (see Page 8-31), the PCWP waveform will be automatically recorded on a dedicated recorder. The recording will start when [DERIVE PCWP] is pressed, and will run until the operator selects [FREEZE].

CALCULATING CARDIAC OUTPUT VIA THE THERMODILUTION TECHNIQUE

CLINICAL PRECAUTIONS

The accuracy of the C.O. calculation is dependent upon the proper placement of the Swan-Ganz catheter. Advancing the distal lumen too far into the pulmonary artery may lead to an insufficient thermodilution curve; respiratory artifact may also prevent an accurate C.O. calculation. Retracting the distal lumen too far toward the pulmonary valve may also cause calculation errors due to catheter whip. In any instance, improper placement of the Swan-Ganz catheter will typically cause one or more error messages to be displayed.

For users not familiar with proper Swan-Ganz placement techniques for Cardiac Output monitoring, the MENNEN MEDICAL "Clinical Guide to Cardiac Function Monitoring" is recommended reading. A copy of this Guide is available from your local MENNEN MEDICAL representative at no charge.

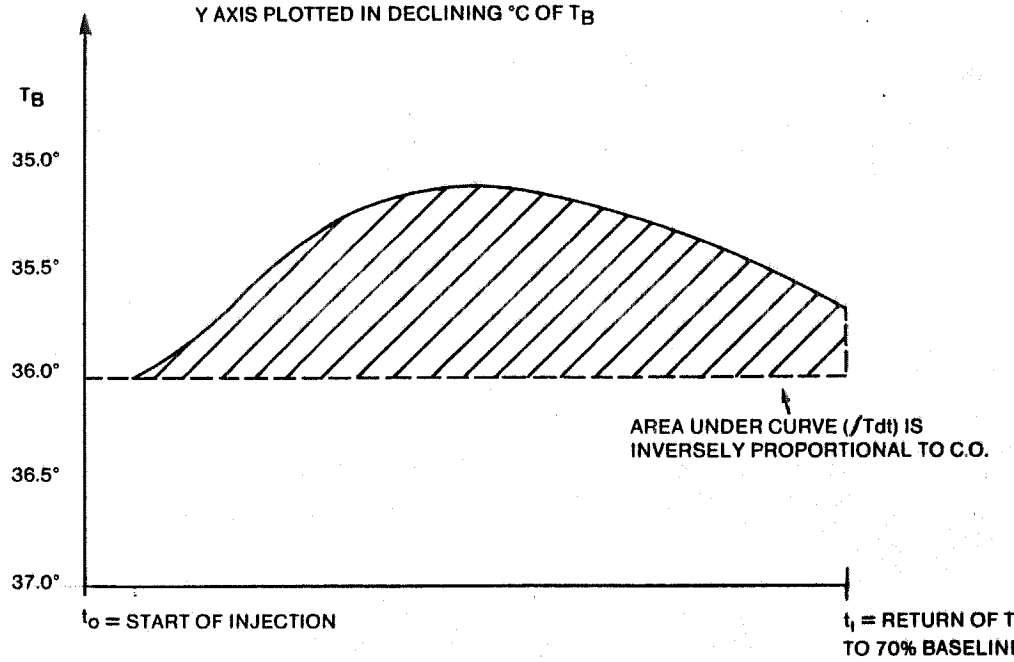


Figure 7-16a.

STANDARD K FACTORS: AUTOMATICALLY COMPUTED BY HORIZON 2000

NON-STANDARD K FACTORS: MUST BE MANUALLY ENTERED

	INJ TMP (°C)	INJ VOL (ml)	FRENCH #s 2.5, 5		FRENCH #7		FRENCH #7.5		SPECTRAMED		SORENSEN 74085-010	
			K-FACTOR	COMP CONST	K-FACTOR	COMP CONST	K-FACTOR	COMP CONST	FRENCH #5	FRENCH #7	K-FACTOR	COMP CONST
Iced (Separate Bath Only)	0 - 5	10	.889	.576	.837	.542	.870	.563	-	.566	.910	.589
		5	.841	.272	.764	.247	.793	.257	.279	.270	.830	.269
		3	.788	.153	.681	.132	.736	.143	.160	.151	.787	.153
Chilled (CO-Set Only)	6 - 12	10	-	-	.866	.561	.886	.574	-	-	-	-
	8 - 16	5	.880	-	.799	.259	.886	.287	-	-	-	-
Non-Chilled (Separate Bath Only)	19 - 22	10	.925	.599	.892	.578	.898	.582		.628	.892	.578
		5	.901	.292	.846	.274	.854	.277	.316	.309	.839	.272
		3	-	-	.792	.154	.802	.156	.188	.180	.782	.152
	23 - 25	10	.953	.618	.919	.596	.937	.607	-	-	.920	.596
		5	.948	.302	.888	.288	.904	.293	-	-	.864	.280
		3	.909	.177	.851	.165	.874	.170	-	-	.818	.159
Non-Chilled (CO-Set Only)	18 - 25	10	-	-	.938	.608	.918	.595	(C. C. Not Applicable)		-	-
		5	.948	.307	.929	.301	.920	.298			-	-

Table of computation constants and corresponding K-factors for given volumes and temperature ranges of injectate through different size catheters.

Figure 7-16b.

Figure 7-16. Mathematical Derivation of C.O.

SUMMARY OF FEATURES

The following is a summary of the features which are a part of HORIZON 2000's cardiac output calculations program capability.

AUTOMATIC K-FACTOR

Utilizing either a separate bath probe, or the injectate probe associated with the Edwards CoSet™, HORIZON automatically determines the injectate temperature. For separate bath systems, HORIZON supports either Edwards 93A - series catheters or Spectramed 5100 -and 5500 - series catheters. The choice between Edwards and Spectramed catheters is made by a menu entry. In response to prompts in the Instruction Area, the operator enters the catheter French number and injectate volume. HORIZON 2000 automatically provides the correct K-factor for 2.5, 4, 5, 6, 7, and 7.5 French catheters, where the catheter manufacturer uses standard K-factor values (see Figure 7-16b). K-factor is utilized in the calculation of cardiac output; the K-factor adds a coefficient, based on catheter French size, injectate volume, and injectate temperature, which compensates for the warming of the injectate as it passes through the catheter lumen.

Calculation of cardiac output is provided by a modified form of the Stewart-Hamilton equation:

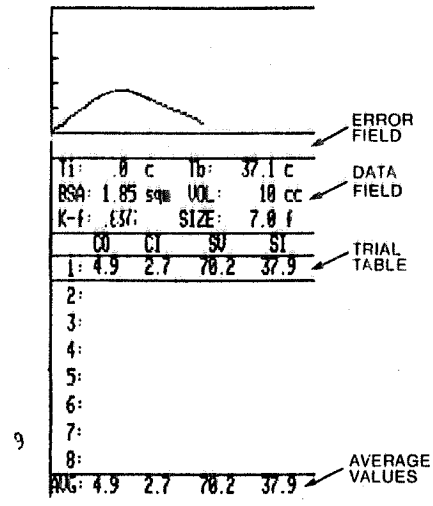
$$C.O. = \frac{1.08 \times 60 \times V \times K \times (T_B - T_I)}{1.22 \times \int T_B dt}$$

WHERE:

- C.O. = Cardiac Output in liters/minute.
- 1.08 = Conversion constant; expresses specific gravity and heat of blood in terms of specific gravity and heat of 5% dextrose.
- 60 = Converts C.O. to liters/minute from liters/second.
- V_I = Injectate volume in cc.
- K = K-factor.
- T_B = Temperature of blood in pulmonary artery, °C.
- T_I = Temperature of the injectate: valid between 0° (iced), and 25° C (room temperature).
- $\int T_B dt$ = Area under the thermodilution curve (see Figure 7-16a).
- 1.22 = Extrapolation factor for 30% cutoff (see Figure 7-16a).

MANUAL ENTRY OF K-FACTOR (COMPUTATION CONSTANT CONVERSION)

HORIZON allows the manual entry of K-factor for catheter of other than standard French size (2.5, 5, 7, 7.5), or for catheters not using normative K-factors for standard French size. When entering or accepting K-factors in HORIZON, verify that K-factors are being used and not Computation Constants, which some manufacturers provide with the catheter. The Computation Constant combines four terms in the Stewart-Hamilton equation, including the K-factor, into one number which differs significantly from K-factor values. To convert a Computation Constant to a K-factor, use the K-factor Conversion Table in Figure 7-16b, or calculate the correct K-factor using the following formula:



$$\text{C.O. IN LITER/MINUTE} = \frac{1.08 \times 60 \times V_I \times K \times (T_B - T_I)}{1.22 \times \int T_B\,dt}$$

$$\text{C.I.} = \frac{\text{C.O.}}{\text{BSA}}$$

$$\text{S.V.} = \frac{\text{C.O.}}{\text{HR}} \times 1000$$

$$\text{S.I.} = \frac{\text{S.V.}}{\text{BSA}}$$

CARDIAC FUNCTION FORMULAS

Figure 7-17a.

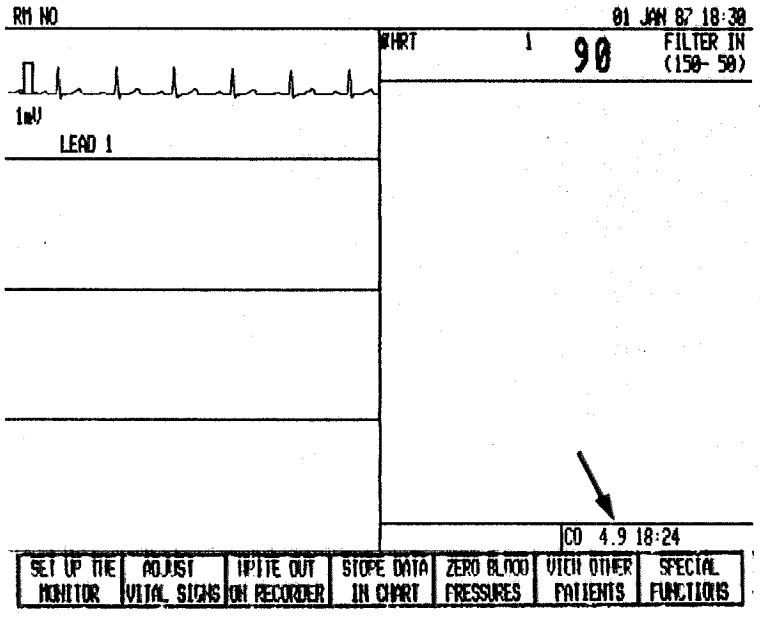


Figure 7-17b.

Figure 7-17. Cardiac Output Calculations Display.

$$K = \frac{CC \times 1000}{1.08 \times 60 \times V_I}$$

WHERE: K = The K-factor

CC = The Computation Constant.

V_I = The Injectate Volume in cc.

NOTE

Manual entry of the K-factor requires a hand-held keypad (PN 260-150-010). If the HORIZON in use is not configured for a hand-held keypad (see Page 8-13), the monitor must be reconfigured. Contact the Biomedical Engineering Department for assistance.

AUTOMATIC CALCULATION OF BODY SURFACE AREA (BSA)

If indexes are desired, BSA must be calculated or manually entered before the C.O. calculation routine. HORIZON 2000 will automatically calculate BSA from patient height and weight, using the DuBois and DuBois formula:

$$BSA = W^{0.425} \times H^{0.725} \times 0.007184$$

WHERE: BSA = Body Surface Area (M2)

W = Weight (Kg)

H = Height (cm)

Upon completion of the C.O. calculation, HORIZON 2000 will display cardiac index and stroke index as well as cardiac output and stroke volume. Figure 7-17a shows the C.O. and indexes Data Field, with calculated values for one trial shown in the Trial Table. Individual trials can be deleted from the Trial Table. All trials are automatically averaged; the average can be added to the Patient Chart, if desired. The formulas applicable to C.O., C.I., S.V., and S.I. calculations are listed adjacent to the Trial Table (Figure 7-17a). Note that S.V. is calculated using the monitored heart rate at time of trial.

DISPLAY OF BLOOD TEMPERATURE (PULMONARY ARTERY)

HORIZON 2000 will display the thermistor temperature (nominally blood temperature in the PA) as "Tb" in the Data field at the time a C.O. trial is being run (Figure 7-17a). If it is desired to monitor blood temperature continuously, as a core temperature, HORIZON can be configured to display TB in place of T2, or in addition to T1. See Page 8-35.

DISPLAY OF TIME OF ENTRY/COMPUTATION

When the average of C.O. trials are accepted, the time of averaging and C.O. value will be indicated on the display if the half-waveform screen format is selected (Figure 7-17b). Time of averaging will also be indicated in the Patient Chart (Page 7-21), if the operator elects to save C.O. data.

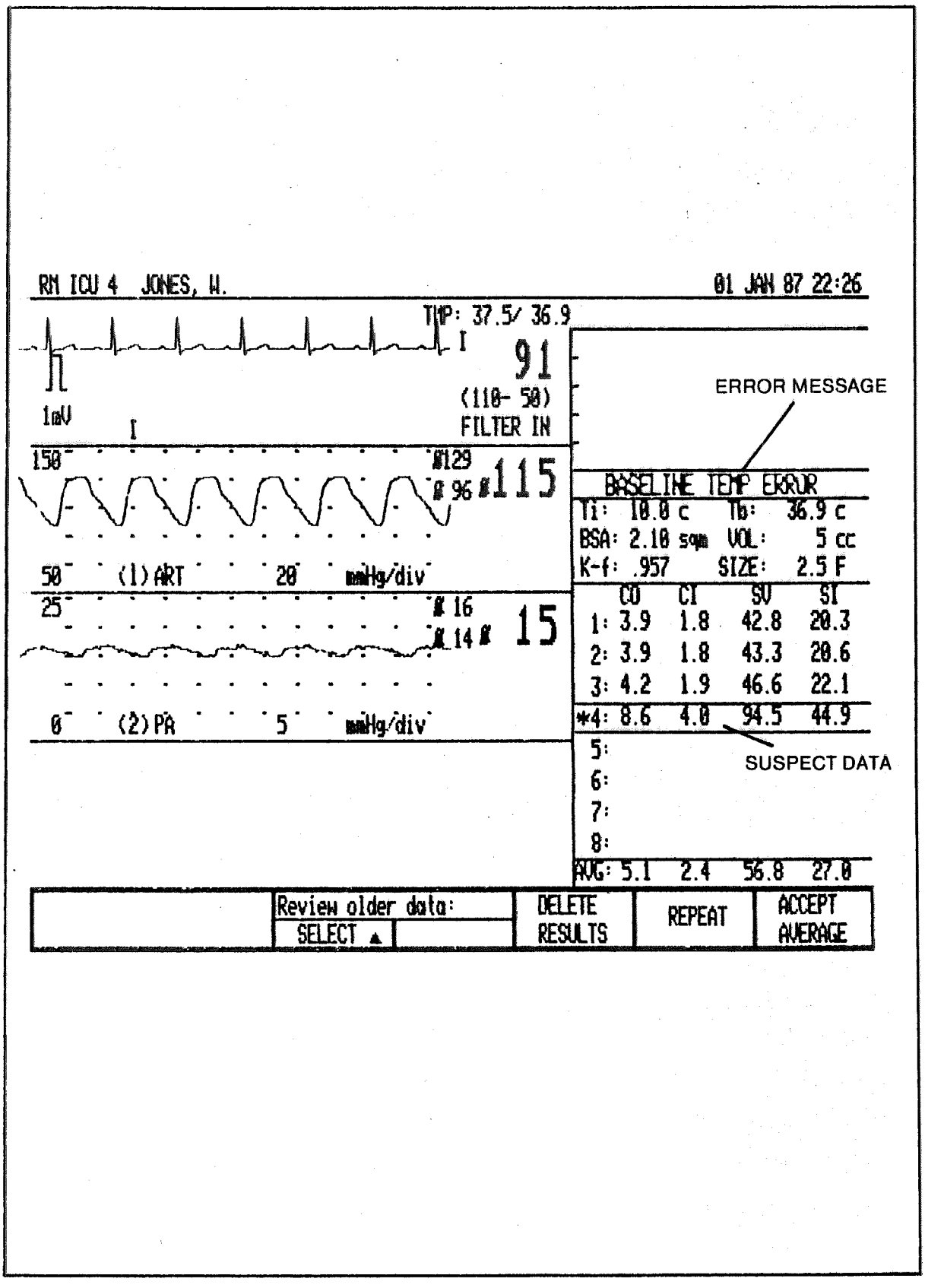


Figure 7-18. Error Messages.

ERROR MESSAGES DISPLAYED DURING THE C.O. ROUTINE

The C.O. program provides error messages which prompt the operator that an equipment problem exists (e.g., catheter not connected), or that monitoring conditions are not suitable for accurate C.O. determination (e.g. excessive catheter whip). Messages which indicate that a C.O. calculation is suspect because of compromised monitoring conditions appear in the Error Message field (Figure 7-18). Messages which indicate that C.O. cannot be computed appear in the menu area. Error messages are summarized below.

CABLE OUT:	This message appears if the C.O. adaptor cable (PN 800-030-190 or 800-030-200) is not plugged into the monitor, or if the cable is defective. No C.O. calculation will be attempted.
INJECTATE PROBE FAULT:	This message appears if the injectate bath temperature probe (PN 800-060-010) is not connected, or is defective. No C.O. calculation will be attempted.
INJECTATE TEMP ERROR:	This message indicates that the injectate temperature (for Edwards Co-Set™) or the injectate bath temperature (for separate bath injectate probes) lies outside the acceptable window for C.O. calculation. Acceptable temperature ranges are shown in the Acceptable Temperature Range Table (Figure 7-19a), which is part of the table of Computation Constants (Figure 7-16b). An asterisk will be placed in the Trial Table to indicate suspect data (Figure 7-19c).

	INJ TMP (°C)	INJ VOL (ml)
Iced (Separate bath only)	0 - 5	10 5
Chilled (CO-Set Only)	6 - 12 8 - 16	10 5
Non-chilled (Separate bath only)	19 - 25	10 5
Non-chilled (CO-Set Only)	18 - 25	10 5

TABLE OF ACCEPTABLE TEMPERATURE RANGES FOR INJECTATE VOLUMES

Figure 7-19a.

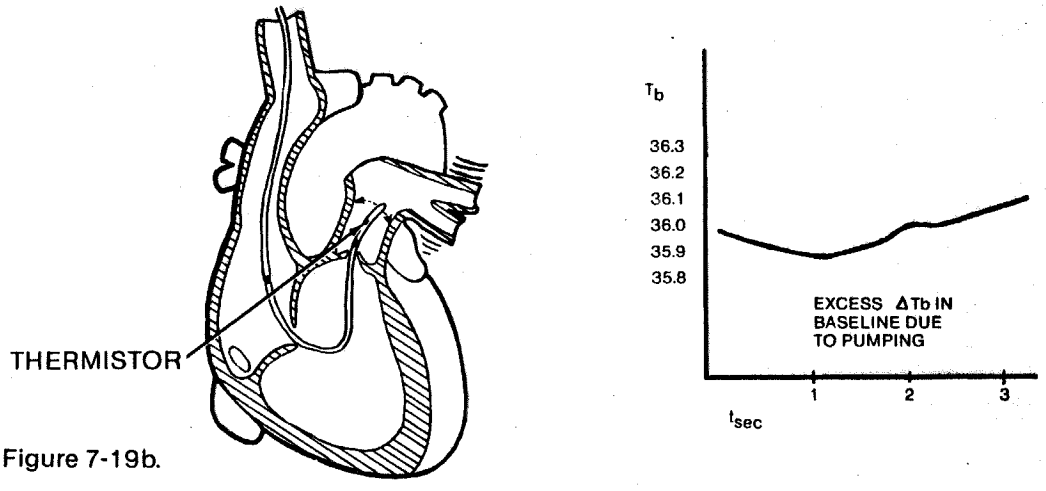


Figure 7-19b.

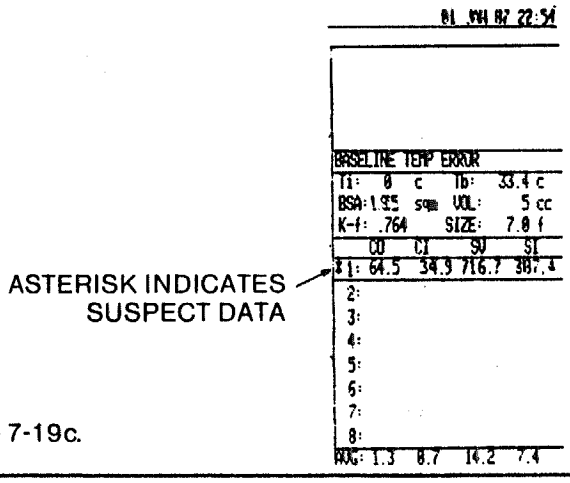


Figure 7-19c.

Figure 7-19. Error Messages Status.

BASELINE TEMP ERROR: This message appears if blood temperature has varied more than 0.067° C within the two second interval immediately preceding the "BEGIN INJECTION" prompt. A typical cause is cardiac pumping which causes the baseline temperature to vary. See Figure 7-19b. An asterisk will be placed in the Trial Table to indicate suspect data (Figure 7-19c).

NO CURVE DETECTED: This message appears if the blood temperature does not change sufficiently to enable C.O. to be computed. Typical causes are false starts (small amount of injectate prematurely injected), insufficient injectate (quantity of injectate less than volume shown in data field), or injection too slow. No C.O. calculation will be attempted.

TIMEOUT ON CURVE: This message indicates that HORIZON has accepted the initial change in temperature as the beginning of a thermodilution curve. However, it did not detect a valid end of the curve within a predetermined time. When this message is displayed, HORIZON will compute the C.O. value using the data it has and will display the data in the Trial Table with an asterisk (Figure 7-19c). indicating suspect data.

SET UP THE MONITOR	ADJUST VITAL SIGNS	WRITE OUT ON RECORDER	STORE DATA IN CHART	ZERO BLOOD PRESSURES	VIEW OTHER PATIENTS	SPECIAL FUNCTIONS

Figure 7-20a.

			VITAL SIGNS TRENDS	PATIENT CHART	DERIVE CO/PWP	DEFIB SYNC ADJUST

Figure 7-20b.

SWEEP SPEED	ADJUST SCALE: 50		0	MEASURE CVP	DERIVE	CARDIAC
25 mm/sec	HIGH	LOW	▲	FROM PA	PCWP	OUTPUT

Figure 7-20c.

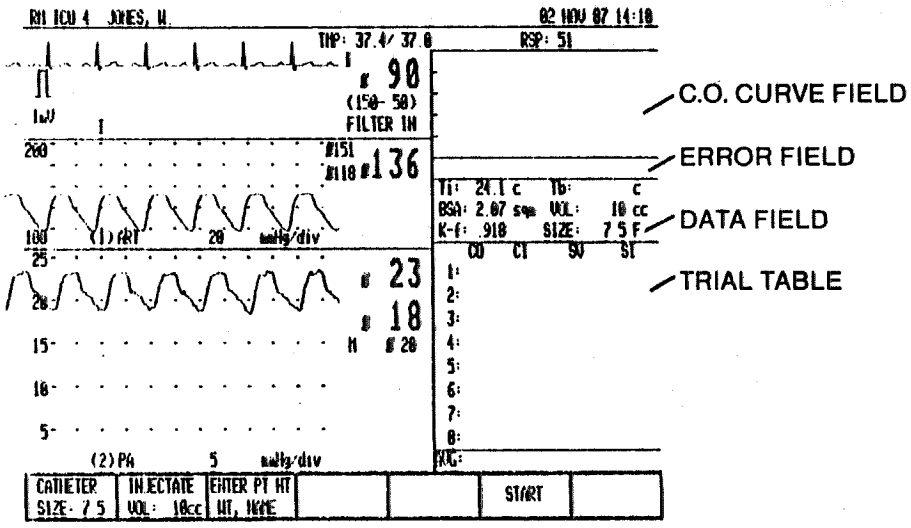


Figure 7-20d.

Figure 7-20. Performing C.O. Calculations.

CALCULATING CARDIAC OUTPUT

Cardiac Output calculation is provided under Special Functions. To select C.O. calculation:

- Press [SPECIAL FUNCTIONS] in the default menu (Figure 7-20a).

The Special Functions menu is displayed. To enter the C.O. calculations routine:

- Press [DERIVE CO/PWP] or [DERIVE CVP CO/PWP] (Figure 7-20b), then [CARDIAC OUTPUT] (Figure 7-20c).

  The C.O. menu will be displayed, and the screen will reformat to present the C.O. Curve Field, Error Field, Data Field, and Trial Table (Figure 7-20d).

NOTE

If a PCWP has just been accepted, HORIZON 2000 will already be in C.O. calculation mode. If PCWP has not been derived, values for Pulmonary Vascular Resistance (PVR) will be calculated using mean Left Atrial Pressure (LAP), if monitored. Otherwise the value will be represented by asterisks in the Hemodynamic Summary.

Figure 7-21a.

SEPARATE BATH SYSTEM	INJ TEMP (°C)	INJECTATE VOLUMES: 3, 5, 10ml	FRENCH SIZES: 2.5, 5, 7, 7.5
	0 - 5	5, 10 ml	ALL
	19 - 22	5 AND 10 ml	ALL
	23 - 25	5, 10 ml	ALL
CO-SET SYSTEM	INJ. TEMP	INJ. VOL: 5, 10 ml.	FRENCH SIZE: 2.5, 5, 7, 7.5
	6 - 12	10 ml ONLY	7 AND 7.5 ONLY
	8 - 16	5 ml ONLY	ALL
	18 - 25	5 ml	ALL
		10 ml	7 AND 7.5 ONLY

Table of injectate volumes and French sizes for which K factors will be calculated.

Figure 7-21b.

Figure 7-21. Manual Entry of K-factor.

The operator is next prompted to indicate catheter type (if Spectramed), French size, injectate volume, and patient height and weight (Figure 7-21a). Catheter size, type, and injectate volume must be entered in order to accurately compute the K-factor (see Page 7-39). To enter the catheter size and injectate volumes:

-Press [CATHETER SIZE:] until the appropriate value appears in the menu space. Figure 7-21b lists the selectable catheter sizes.

-Press [INJECTATE VOL:] until the appropriate value appears in the menu space. Figure 7-21b lists the allowable injectate volumes for given French sizes with Co-Set™ and separate-bath systems.

If the catheter is an Edwards model no operator entry is required. If the catheter is a Spectramed separate-bath type (Models 5105, 5107, 5107S, 5507, 5507S, 5527),

-Press [SPECTRAMED]. If a Spectramed separate bath catheter is used and this selection is not made, K-factor will be calculated incorrectly.

The K-factor for French sizes 4, 5, and 6 are identical. If a 4 or 6 French catheter is used, the 5 French entry will provide the appropriate K-factor.

HORIZON will automatically calculate the K-factor from the injectate temperature, volume, and catheter size and type selected.

NOTE

HORIZON 2000 provides K factors only for catheters utilizing standard instrument values. If the catheter is not optimized for standard K-factors, its applicable K factor must be manually entered. The table in Figure 7-16b provides K-factors for one non-standard catheter, the Sorensen 74085-010. Its K-factors must be entered manually via the hand-held keypad.

Patient height and weight need only be entered if indexes are to be calculated. See Page 7-55.

If the catheter size, catheter type, injectate volume, and patient height and weight (optional) have been selected, proceed to CALCULATION OF CARDIAC OUTPUT (Page 7-53). If the K-factor must be manually entered, proceed to MANUAL ENTRY OF K FACTOR (Page 7-53).

Figure 7-22a.

Figure 7-22b.

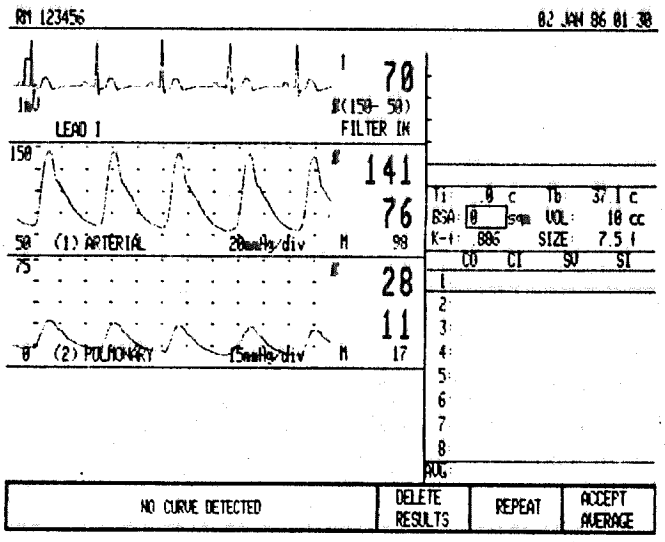
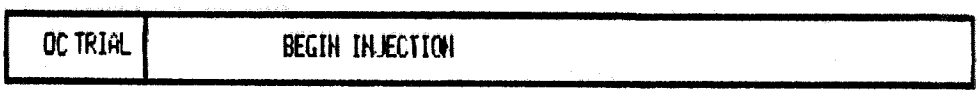


Figure 7-22c.



Figue 7-22d.

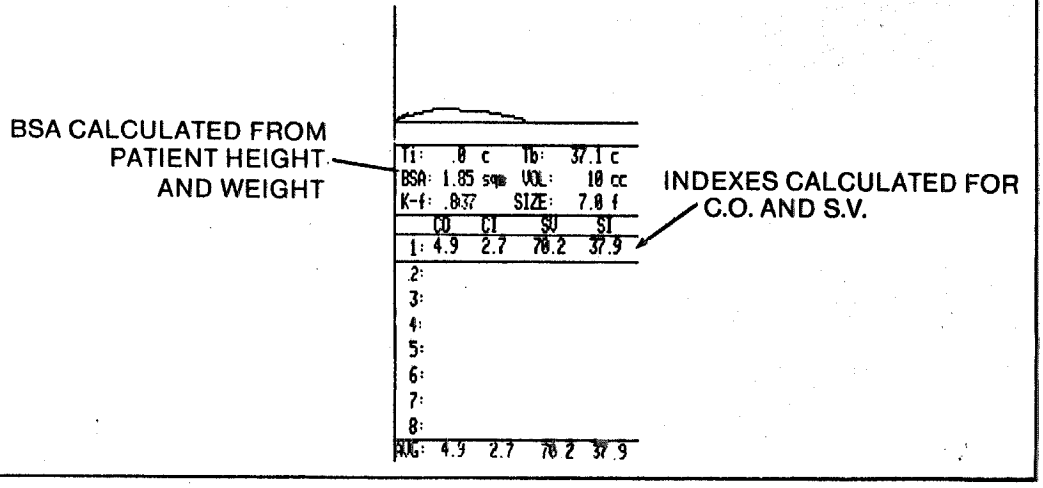


Figure 7-22e.

Figure 7-22.

MANUAL ENTRY OF K-FACTOR

K-factor need be entered only if the catheter employed uses non-standard K factors for the given injectate volume, or if the French number and corresponding injectate volume to be injected are not provided in the table in Figure 7-21b.

To enter the K-factor (if known) from the hand-held keypad:

-Press [CATHETER] until "OTHER" is displayed in the menu (Figure 7-22a). Enter the K-factor via the hand-held keypad. If the K-factor for the catheter is not known, it can be determined by referring to the chart in Figure 7-16b (Page 7-40). Note that this chart lists Computation Constants as well as K-factors for various infectate volumes and temperatures. Some vendors provide the Computation Constant instead of the K-factor for purposes of C.O. calculation. If the K-factor corresponding to a computation constant is not provided by the chart in Figure 7-16b, it may be calculated using the formula on Page 7-43.

CALCULATION OF CARDIAC OUTPUT

Cardiac Output may be calculated following selection of catheter size, type and injectate volume or manual entry of the K-factor.

To begin a Cardiac Output calculation procedure:

-Press [START] (Figure 7-22a).

Determination of the patient's baseline temperature (TB) begins immediately. Following determination of TB, HORIZON 2000 is ready to calculate Cardiac Output. A tone and prompt message will signal the operator to begin the injection. When the prompt "BEGIN INJECTION" is displayed in the menu area:

--Inject the injectate. HORIZON 2000 allows 12 seconds following the prompt tone to begin the injection. If the injection has not begun within 12 seconds of the prompt, the message "NO CURVE DETECTED" is briefly displayed in the error field (Figure 7-22c).

Press [REPEAT] to perform another trial. The above sequence is repeated (Figure 7-22a).

--Once started, the injection must be performed smoothly and as rapidly as possible. Optimum results are achieved if the injection is completed within four seconds. A pneumatic injector will provide consistency for repeated trials.

Note that the menu provides a "DC TRIAL" prompt for "DISCONTINUE TRIAL" (Figure 7-22d). If an injection is not performed properly, or if the clinician suspects the trial will be invalid, simply press [D/C TRIAL] during the trial. The menu will reformat and prompt for another start (Figure 7-22b).

Following successful calculation, C.O. and S.V. (Stroke Volume) values will be displayed in the Trial Table under a representation of the C.O. waveform ($\Delta TB/t$). This waveform will appear in red (Figure 7-22e). The corresponding C.O. and S.V. values will be surrounded by a cursor.

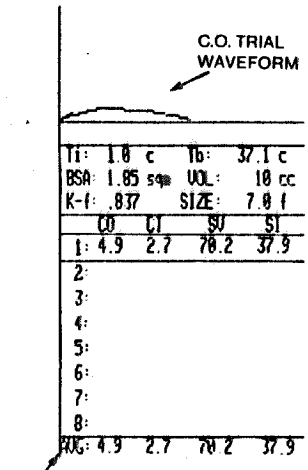


Figure 7-23a.

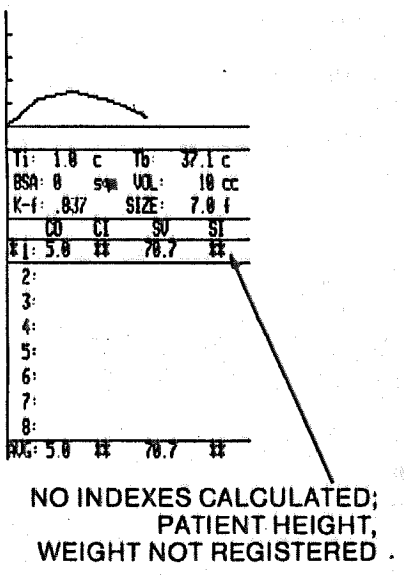


Figure 7-23b.

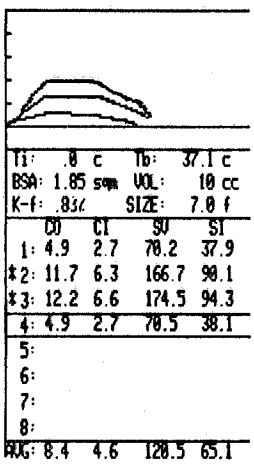


Figure 7-23c.

Figure 7-23. Editing the C.O. Trial Table.

In addition to values for C.O. and S.V., the Trial Table will also list corresponding indexes, if the body surface area(BSA) has been calculated (Figure 7-23a). Otherwise, C.I. and S.I. values will be replaced by asterisks (Figure 7-23b).

NOTE!

Calculation of BSA requires patient height and weight to be entered.

If height and weight were not entered during registration, they may be entered at this time. To enter height and weight,

-Press [ENTER PT HT. WT. NAME]

-Turn to Page 3-15 for data entry instructions.

Values for C.O., S.V., C.I., and S.I. will also be shown in the AVG column (Figure 7-23a). The values are updated to represent the average of all trials displayed in the Trial Table as each new trial is added.

To perform an additional trial,

- Press [REPEAT] . The sequence is repeated (Figure 7-22a). Inject the injectate when prompted. The new trial will be represented by a red thermodilution curve, and the corresponding values will be surrounded by a cursor. Previous trials will be represented by blue thermodilution curves. Trial results are listed in sequential order; up to eight trials can be averaged (Figure 7-23c).

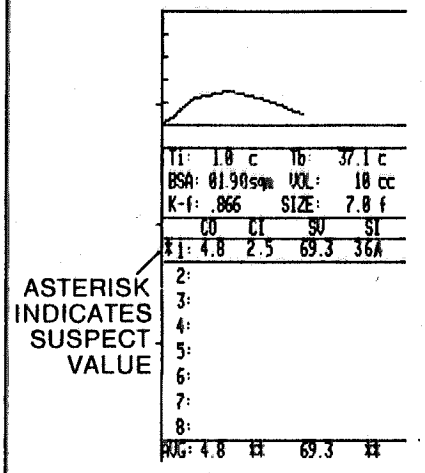


Figure 7-24a.

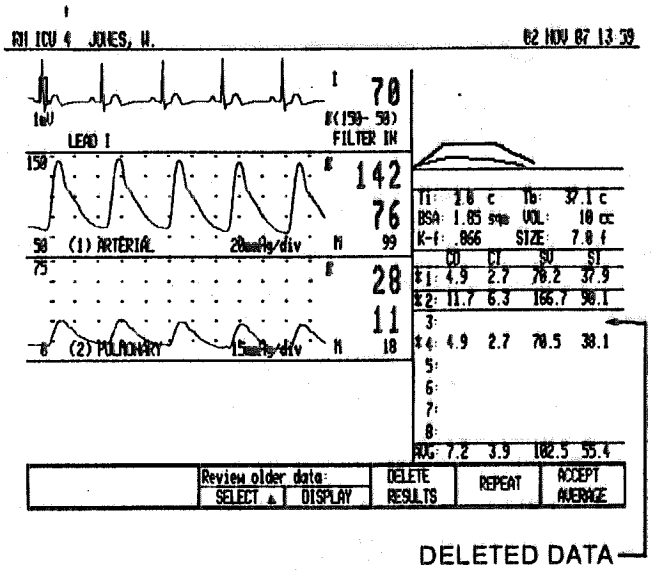


Figure 7-24b.

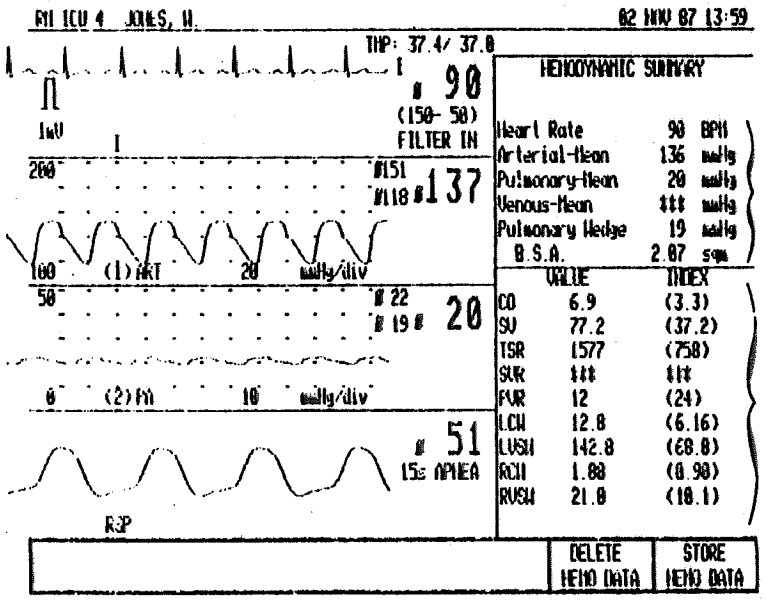


Figure 7-24c.

Figure 7-24. Editing the C.O. Trial Table.

EDITING AND AVERAGING C.O. TRIALS

When the number of trials is sufficient to determine a valid C.O. average, the operator has the option of averaging all trials shown, or editing the Trial Table. Editing permits deletion of trials which are suspect. Note that HORIZON will indicate trials associated with procedural errors by an asterisk next to the corresponding value (Figure 7-24a).

To edit the Trial Table:

- Press SELECT ▲ to review C.O. values during previous trials. The cursor will surround previous values and the corresponding thermodilution curve will be displayed in red.

- Press DELETE RESULTS to remove any line of calculations not desired in the final averaging. The line of data will be deleted, and the cursor will surround the previous data (Figure 7-24b). The average will also automatically update.

To summarize edited trial values:

- Press ACCEPT AVERAGE . The time of averaging and averaged values will be listed in the Hemodynamic Summary (see below), and displayed in the lower right corner of half-waveform default screens.

HEMODYNAMIC SUMMARY

Upon command to accept the averages displayed in the AVG column, HORIZON calculates correlative hemodynamics parameters and displays these in addition to the accepted average values in a Hemodynamic Summary (Figure 7-24c).

Calculations used in determining Hemodynamic Summary values, and the clinical significance of these values, are provided in MENNEN MEDICAL's "Clinical Guide to Cardiac Function Monitoring." A copy of the Guide is provided with this operating manual; additional copies are available at no charge from your MENNEN MEDICAL representative.

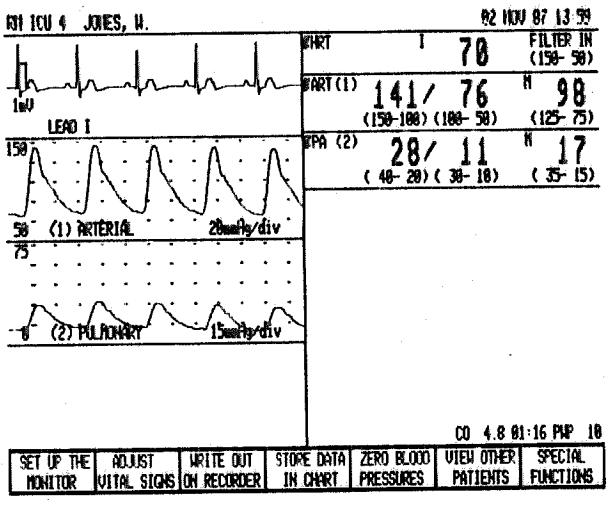


Figure 7-25a.

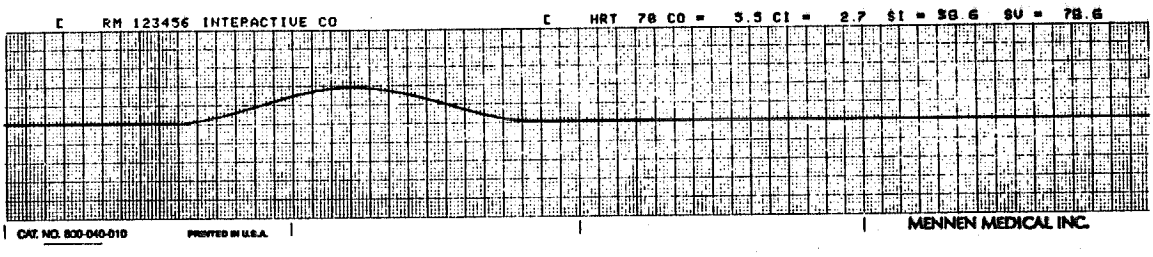


Figure 7-25b.

Figure 7-25. Default Display/C.O. Chart Strip.

Display of the Hemodynamic Summary completes the C.O. calculations routine. The operator may additionally store all displayed values in the Hemodynamic Summary Chart (see Page 7-25).

To store values in the Hemodynamic Summary Chart:

-Press STORE HEMO DATA .

To return to normal monitoring without saving the averaged data:

-Press DELETE HEMO DATA .

If the default display is half-screen format, the most recently averaged C.O. value will be displayed in the lower-right corner, along with the time of averaging. If previously determined, the PCWP value will also be displayed with time of acquisition (Figure 7-25a).

RECORDING THE THERMODILUTION CURVE

If HORIZON is so configured, C.O. recording of the thermodilution curve will be performed automatically on a dedicated bedside recorder when the injection begins. The recorder will run at 5 mm/sec. and stop automatically at the end of the trial. Calculated C.O. values and time of recording will be printed across the top of the strip (Figure 7-25b).

See Page 8-35 for the configuration menu applicable to C.O. Contact the Biomedical Engineering Department if the monitor requires reconfiguration to support C.O. recording.