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THE UNIVERSITY OF ALBERTA

A COMPARISON OF PULMONARY ARTERY PRESSURES IN SUPINE AND LATERAL POSITIONS USING THREE ADJUSTMENTS OF THE PRESSURE TRANSDUCER

by

CAROLYN JM ROSS

A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE DEGREE OF

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "A Comparison of Pulmonary Artery pressures in Supine and Lateral Positions Using Three Adjustments of the Pressure Transducer" submitted by Carolyn Ross in partial fulfilment of the requirements for the degree of Master of Nursing.

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L. Pinnell

DEDICATION

This thesis is dedicated with love and gratitude to my dear friend and colleague, Pauline McCormick. One who was always there to offer the kind of support and encouragement that moved me beyond any moments of doubt.

ABSTRACT

It has been thought that in order to obtain accurate pulmonary artery pressure (PAP) data the patient must be supine flat although limited research has been conducted to support this view. Critically ill patients require head-up and side-back-side positioning in order to prevent a number of complications associated with immobility. Since the pulmonary artery pressures are routinely measured in the supine flat position, and patients are not necessarily found in a supine position, a patient with a pulmonary artery (PA) catheter may require more frequent repositioning which may compromise the patient's rest as well as add to the patient's physical and emotional stress. A major problem in monitoring patients in lateral positions is a lack of knowledge of an appropriate zero reference for the adjustment of the height of the pressure transducer. A repeated measures experimental study was conducted on a convenience sample of 40 post-cardiovascular surgery patients to determine the variations in the pulmonary artery systolic and diastolic pressures associated with 30 degree lateral positioning using 3 adjustments of the pressure transducer. The transducer adjustments included the supine phlebostatic axis, the right lateral phlebostatic axis, and the mid-sternum.

Although statistically significant variations in PAP were found using all 3 of the transducer adjustments in the lateral

positions (P=0.000), the PAP variations were clinically insignificant using the supine phlebostatic axis (mean PAP systolic changes < 5 mmHg, mean PAP diastolic changes < 4mmHg). The results of this research indicated that in most subjects, the supine phlebostatic axis may be a useful reference for the transducer adjustment allowing clinically accurate monitoring of the PA systolic and diastolic pressures with the patient in a 30 degree lateral position. A careful record of the patient's position and the PAP obtained may help nurses to identify patients who could be accurately monitored in a 30 degree lateral angle and thus spared some of the disruptive repositioning that is currently recommended in order to obtain PAP data. Replications of this research on a variety of patient populations would have to be conducted in order to strengthen the external validity of the study.

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I am indebted to a number of people who were willing to share their skill and time with me during the research process. The members of my thesis committee aptly guided me through each stage of the research project. Included among those who served on my thesis committee were Dr. Phyllis Giovannetti, who acted as my chairperson, and Dr. Stacey Levine, Dr. Marion Allen, Dr. Richard Jones, and Lynn Pinnell.

The data collection phase was facilitated by the staff of the institution within which the study was conducted. The co-operation of Anne Leighton and the nursing personnel of the cardiovascular intensive care unit allowed me to collect the pulmonary artery pressure data. Lorie Campbell, Carol Heath and the nursing staff of their respective medical units made it possible for me to obtain consents from subjects prior to their surgery. In addition, each of the cardiovascular surgeons (Dr. E. Gelfand, Dr. D. Modry, Dr. J.C. Callaghan, Dr. L Sterns) and their residents extended their support of the project. The staff of the biomedical engineering department (in particular, Dean Olmstead) provided me with the equipment required to carry out the study. Finally, the staff of medical records and film loans supported the access to important additional information.

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Foundation of Nursing Research (AFNR) and the Alberta Association of Registered Nurses (AARN). Neither of these organizations necessarily support the findings and conclusions of the research.

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INTRODUCTION

Background and Statement of the Problem

Continuous monitoring of right and (indirectly) left heart pressures became possible with the introduction of the flow directed balloon tipped, pulmonary artery (PA) catheter developed in 1970 by Swan and his associates. Suitable positioning of this light weight catheter is accomplished by inflating the balloon, located at the tip of the catheter, and allowing the blood flow to carry it through the right heart chambers into a branch of the pulmonary artery (Appendix A). Utilizing this catheter, key indicators of intravascular status including right atrial pressure (RAP), pulmonary artery pressures (PAP); pulmonary artery wedge pressure (PAWP), and cardiac output (CO) by the thermodilutional technique can be obtained (Appendices B & C). This information may then be utilized to monitor and guide therapeutic interventions in critically ill patients (Daily & Schroeder, 1985).

Measuring and assessing data that is provided via the PA catheter has become a common critical care nursing responsibility (Holmes, 1982; Torrez, 1982). Often, during the first 24 hours after catheter insertion, data are required every 30 to 60 minutes and crucial decisions regarding patient management rest on the assumption that these data are accurate (Chulay & Miller, 1984; Woods, Grose, & Laurent-

Bopp, 1982). In order to obtain valid data from the catheter, it has been thought that the patient must be placed supine (Hudac, Lohr, & Gallo, 1977; Klevin,1984; Woods, Grose, & Laurent-Bopp 1982). However, critically ill patients often require placement in positions with their head rest elevated to optimize lung mechanics and prevent aspiration (American Association of Critical Care Nurses, 1985; King, 1984). In addition, they require placement in side-back-side positions to prevent a number of complications associated with immobility such as, pressure sores (Gosnell, 1973; Edmonds, 1967; Kottke, 1965) and emotional deterioration (Wade, 1967). Since the PAP are only measured in the supine position, a patient with a PA catheter requires frequent repositioning which may compromise the patient's rest as well as add to his/her physical and emotional stress (Dlin, Rosen,Dickstein, Lyons, & Fischer, 1971; Downs, 1974).

It would be of benefit if valid PAP readings could be obtained with patients in lateral recumbent positions. Patients with PA catheters may not require the frequent returning to the supine position for the nurse to obtain valid PA data. These patients could be allowed more prolonged periods of uninterrupted rest even at times when pressures are being recorded at frequent intervals. Therefore, it would be helpful to know how valid the PAP readings are

position as compared with PAP readings obtained with the patient in a supine position.

Statement of the Purpose

Critically ill patients with PA catheters require periods of uninterrupted rest as well as accurate assessments of their PAP data. The purpose of this study was to increase our understanding of means by which nurses may obtain valid PAP data.

LITERATURE REVIEW

The purpose of this literature review is to present an overview of previous research that has been done in the area of patient positioning and its effect on measured vascular pressures and flow as well as to identify other factors known to effect the validity of PAP measurements. A brief critique of 18 studies that were reported in the literature are presented in three major sections including: 1) postural changes and CO, 2) backrest positional changes and central vascular pressures, and 3) lateral positioning and PAP. Following the critique which offers the major strengths and weaknesses of these studies, some of the chief recommendations which were drawn from the review of the literature are put forward. This includes a discussion of factors known to effect the validity of PAP measurements. Finally, the assumptions, research objectives, and the theoretical framework upon which the study is based are presented.

Postural Changes and Cardiac Output

Rapaport, Wong, Escobar, and Martinez (1966), Prakash, Parmley, Dikshit, Forrester, and Swan (1973), and Groden (1969) studied the effect of various backrest elevations on cardiac output (CO). Using the thermodilution technique, Rapaport and his colleagues (1966) found a significant decrease in the CO of 8 patients with no cardiovascular

disease following position changes from supine flat to 60 degrees head-up. However they found no significant variation in CO in 8 subjects with congestive heart failure. Rapaport and his associates (1966) suggested that patients with congestive heart failure may not demonstrate drops in CO due to gravitational pooling of blood because they often have an overall expansion of plasma volume secondary to salt and water retention. Furthermore, Rapaport et al. (1966) state that edema as well as possible changes in venomotor tone may decrease the gravitational pooling in the venous system which is thought to cause the changes in CO with postural changes.

Also using the thermodilution technique, Prakash and his co-workers (1973) determined that position variation from supine flat to 70 degrees head-up brought about no significant change in CO in 14 subjects with recent myocardial infarctions (MI). Using the dye dilution technique, Groden (1969) measured CO in 31 subjects with whom he alternated the sequence of backrest positions so that subjects were examined in the 45 degree head-up or the flat position first. Groden's (1969) findings conflict with those of Rapaport et al. (1966), and Prakash et al.(1973) in that he found statistically significant changes in CO in post MI patients who had evidence of pulmonary edema. Because these studies used different methods for determining CO, as well as different patient populations, it is difficult to compare

their results. Only Groden controlled for the potential effect of the sequence of positional changes. All used small samples limiting the generalizability of their results.

Grose, Woods, and Laurent (1981), and Klevin (1984) conducted similar studies in that each group examined the relationship between positional changes (supine flat and 20-degree head-up) and CO measured by the thermodilutional technique in 30 critically ill patients. The results of these two studies conflict. Grose, Woods, and Laurent (1981) found that the CO of their subjects did not significantly vary with position change. Although Klevin (1984) determined that the CO variation of her subjects (.16 Liters per minute) was statistically significant, she concluded that this variation was not clinically significant.

Whitman, Howaniak, and Verga (1982) compared the CO of 50 postoperative adult cardiac surgical patients in supine 20-degree head-up and 20-degree right and left lateral recumbent positions. They randomly assigned subjects to one of six sequences of the three positions. Using analysis of variance, they found CO to be significantly higher only in the left lateral position. However, because Whitman et al. (1984) found no variations in CO greater than .2 liters per minute, they concluded that the variations were not clinically significant.

In a similar study of 51 postoperative adult cardiac

patients, Dracup and Doering (1988) compared the CO variation of subjects as they moved from a supine to a 45 degree angle in the left and right lateral position. These researchers found that 45.1% of their patients demonstrated variations in CO that were greater than 10%. The changes in CO were considered to be clinically and statistically significant. Subsequent subgroup analysis of their data indicated that the presence of the following characteristics tended to be related to significant variation in CO with lateral positioning; temperature less than 37.0 degree centigrade, cardiac index (CI) less than 2.3 L/Min/M2, elapsed time since surgery less than 12 hours, and subjects receiving vasoactive drugs and/or mechanical ventilation.

In summary, seven studies were found which examined the effect of positional changes on CO. Overall these studies indicate that there may be statistically significant changes in CO measurements as a result of positional alterations from supine to moderate head-up angles (0 - 45 degrees) or from supine to lateral angles (20 - 45 degrees). Furthermore, these changes may be large enough to be considered clinically significant given the presence of a number of factors including, a temperature < 37.0 degrees centigrade, a CI < 2.3 L/Min/M2, an elapsed time since surgery < 12 hours, vasoactive drugs, mechanical ventilation.

Backrest Postural Changes and Central Vascular Pressures

Eight studies examined the relationship between central vascular pressure variations and backrest elevation (Chulay, & Miller, 1984; Clochesy, Hinshaw, & Otto, 1984;Laulive, 1982;Nemens, & Woods, 1982;Prakash et al.,1973; Retailliau, McGregor Leding, & Woods,1985; Woods, & Mansfield,1976; Woods, Grose, Laurent-Bopp,1982). Prakash et al. (1973) assessed the variation in PAP with backrest elevation from 0 to 70 degree head-up in 21 post MI patients. Woods and Mansfield (1976) and Chulay and Miller (1984) examined the variation in PAP with backrest elevations including 0, 30, and 45 degrees head-up. In addition Woods and Mansfield (1976) assessed the effect of 90 degree head-up angle on PAP. Clochesy and her colleagues (1984) investigated the changes in PAP of 17 mechanically ventilated patients who were subjected to four randomized positional changes including, 0, 20, 45, and 60 degrees. The results of all four of these investigating teams were similar in that they found no significant changes in PAP with moderate headrest elevation up to 45 degrees (Chulay, & Miller, 1984; Woods & Mansfield, 1976) while extreme elevations of 70 and 90 degrees did cause significant variations in PAP (Prakash et al., 1973; Woods, & Mansfield, 1976). These four groups of researchers used small samples which reduces the generalizability of their results. With the exception of Clochesy et al. (1984), they failed to control

for the potential effect of the sequence of backrest positional changes. Also, with the exception of Chulay and Miller (1984) these groups of researchers did not examine the potential effect of hemodynamic changes over time.

Nemens and Woods (1982) pointed out that PAP may vary at any particular moment in time due to normal fluctuations which must be differentiated from actual changes in the patient's hemodynamic status due to positional changes. In order to define normal fluctuation, they monitored PAP over 30 minutes in 25 critically ill patients in the bedrest angle in which they were found. The patients were in a steady state which was defined as no change in therapy for one hour prior to the study and no changes during the study. Based on the observed ranges of variations in PAP over a 30 minute period, Nemens & Woods (1982) suggested that clinically significant variations in the pulmonary artery diastolic pressure (PADP) and the pulmonary artery systolic pressure (PASP) should be considered to be changes that exceed 4 mmHg and 5 mmHg respectively. Henceforth, references to clinically significant variations in PAP shall refer to variations in PAP that exceed the normal fluctuations in PAP described by Nemens & Woods (1982). These researchers found no statistically significant difference in the range of fluctuation between those ventilated with or witnout positive end expiratory pressure (PEEP) and those not on ventilators.

Woods et al. (1982) and Laulive (1982) conducted and described a number of important measures that were undertaken to assure the reliability and validity of measurements of the PAP of their subjects following position changes. Woods et al. (1982) randomly assigned each of their 126 critically ill subjects to one of two position sequences as follows; 20,0, and 20 degrees head-up, or 0, 20, and 0 degrees head-up. Laulive (1982) examined the variation in PAP of 30 coronary care patients as they were moved through a series of 5 positional changes including; 0, 20, 45, 60, and 0 degrees head-up. By design, both Woods et al. (1982) and Laulive (1982) assessed pressure changes over time by comparing the first and third position pressures and the first and fifth position pressures respectively. Both groups of researchers calibrated their instruments prior to studying each of their subjects and assured the appropriate adjustment of the level of the transducer and the angle of the bed prior to each measurement. In addition, both groups of researchers recorded PAP waveforms, used clear guidelines to interpret the waveforms, and tested interrater reliability. Only Woods et al. (1982) provided subjects with a consistent rest period following each position change. Although Woods et al. (1982) found a statistically significant decrease of 0.3 to 2.4 mmHg with changes of position from supine to 20 degrees head-up, neither group of researchers found a clinically significant

change in PAP using the criteria described by Nemens and Woods (1982).

In a similar two part study, Retailliau, et al.(1985) examined the variation in left atrial pressure (LAP) in 32 post cardiac surgery patients over a period of 30 minutes in the position in which they were found. These researchers then examined the PAP variation with positional changes from 0 degree supine to head-up at 30 degrees. As in the study by Woods et al., (1982), Retailliau et al. (1985) presented similar measures to assure reliability and validity of their measurements. In addition, Retailliau et al.(1985) attempted to reduce bias that could be introduced by the researchers' selection of waveforms for pressure analysis by having the researchers calculate the mean pressures over one minute rather than over one respiratory cycle. The results of this study indicated that there were no significant differences between the mean fluctuations in LAP over time and the mean changes in LAP due to positional changes.

In summary, of eight groups of researchers who investigated the effect of head-up positions on central vascular pressures (Chulay & Miller, 1984; Clochesy et al., 1982; Laulive, 1982; Nemens & Woods, 1982; Prakash et al., 1973; Retailliau et al., 1985; Woods & Grose, 1982; Woods & Mansfield, 1976), four groups of investigators found that

moderate head-up elevations resulted in no significant variation in PAP (Chulay & Miller, 1984; Clochesy et al., 1984; Prakash et al., 1973; Woods, & Mansfield, 1976). However, only one controlled for either the potential effect of the sequence of the positional changes, or hemodynamic changes over time. Three studies (Laulive, 1982; Woods et al., 1982; Retailliau et al., 1985) provided sufficient evidence of the validity and reliability of their measurements to give the reader confidence in their results. The results indicated that moderate head-up positions may result in statistically significant changes in central vascular pressures but these changes are not likely to be considered clinically significant using the criteria established by Nemens and Woods (1982).

Lateral Positioning and Pulmonary Artery Pressures

Three studies were found which examined the effect of lateral positional changes on central pressures (Keating, Bolyard, Eichler, & Reed, 1986; Kennedy, Bryant, & Crawford, 1984; Wild, 1984). Kennedy et al. (1984) examined the effects of 90 degree lateral recumbent body positioning on PAP and PAWP in 25 male patients none of whom were on ventilator support. Prior to undertaking this study , Kennedy et al. (1984) had to resolve the methodological problem of transducer placement for subjects placed in a lateral position. Winsor

and Burch (1945) first described the phlebostatic axis (fourth intercostal space mid-axillae) as a suitable zero reference level that approximates heart level for patients placed in a supine position. However, this landmark is not considered to be suitable for lateral positions (Keating et al., 1986; Kennedy et al.,1984). An equivalent estimate of the level of the atrium for a lateral position is not known. Based on knowledge of the anatomical anchoring of the atrium to central pulmonary structures behind the mid-sternum, the researchers hypothesized that a shift in the atrium when a patient turns on his/her side would result in a shift in the carina.

Kennedy et al. (1980) studied the shift in the carina on the roentgenograms of 10 patients in 90 degree right and left lateral positions and found the shift, when corrected for x-ray magnification, was statistically insignificant. They concluded that suitable landmarks for transducer leveling for patients in lateral positions would be the intersections of imaginary lines crossing at ; a) the fourth intercostal space (ICS) and the mid-sternum anteriorly and b) the fourth spinous process and the mid-spinal column. A convenience sample of 25 subjects were randomly assigned to one of two sequences of positional changes (supine, 90 degree right lateral & left lateral or supine, 90 degree left lateral & right lateral). Using the mid-sternum as a zero reference for the transducer

in the lateral position, the researchers compared the PASP, PADP, and PAWP obtained in the lateral position with supine control PAP. They found no significant variation in pressures related to these positional changes. In this study individual mean PAP and mean PAWP did not vary greater than 2 mmHg. There is no mention of whether or not there was a constant rest period following positional changes. Also, no mention was made of the catheter tip position which is an important determinant of PAP variation found in lateral positioning. The sample was small so that before results could be generalized, further study on larger samples would have to be conducted.

Wild (1984) and Keating et al. (1986) conducted studies in which they examined the effect of lateral positioning on the PAP of general ICU patients using the mid-sternum and the phlebostatic axis as reference points. Wild (1984) randomly assigned her 30 subjects to one of 2 position sequences (supine, left lateral 30 degrees, right lateral 30 degrees, supine or supine, right lateral 30 degrees, left lateral 30 degrees, supine) while Keating et al. (1986) did not vary the position sequences (supine, right lateral 45 degrees, supine, left lateral 45 degrees) in her sample of 20 subjects. Only Wild (1984) used a 30 degree foam wedge to attempt to maintain consistency in the lateral angle of her subjects. Both groups of researchers utilized a consistent rest period

following positional changes and used strip chart recordings to measure pressure. The findings of these 2 studies indicated that PAP readings in the lateral positions may be significantly different from readings taken in the supine position. Wild (1984) found that although mean group differences in pressures did not exceed normal fluctuation as described by Nemens and Woods (1982), clinically significant differences were found in the mean PAP measurements of 93 percent of the individual subjects. Keating et al. (1986) found clinically and statistically significant changes in the PADP and PAWP measured in the lateral positions when compared to those pressures measured in the supine position. They suggest that the mid-sternal intersection with the fourth ICS may not be a suitable anatomical landmark for transducer adjustment in lateral positions.

The majority of pressure monitoring systems transmit pressure from the pressure source to a transducer via a series of fluid filled noncompliant tubing. Hydrostatic principles dictate that in order to eliminate a hydrostatic head of pressure, both ends of the plumbing system must be adjusted to the same level (Appendix D). Failure to do so could mean that the measured pressure may be falsely high or falsely low (Appendix E). Conventionally, when the patient is in a supine position, the level of the right atrium has been used as a zero reference for the transducer adjustment, rather than the

catheter tip. The phlebostatic axis is the standard anatomical landmark used to estimate the level of the atrium. Because the tip of the catheter may be higher or lower than that point, hydrostatic error will occur as a result of a hydrostatic head of pressure. Provided the same point is always used as a reference, and the patient is supine, this error should be relatively constant so that pressure variations may be assumed to be due to physiological changes. However, when the subject is turned in a lateral position, the error due to catheter tip position may no longer be constant. If the transducer were left at the level of the supine phlebostatic axis, and the catheter tip was located to the right of the mid-sternum, one would expect to observe less error in PAP with the right lateral position than with the left lateral position (Appendix F).

Benumof, Saidman, Arkin, & Diamant (1977) examined the intrathoracic distribution of the tips of 314 pulmonary arterial catheters which at insertion were determined by waveform analysis to be in ideal position. These researchers concluded that a statistically significant majority of these catheters were located in the right middle or lower lung field in an area less than 9 cm. from the mid-sternum. The range was from 10 cm to the right of the sternum to 11 cm to the left of the mid-sternum. The largest peak in the frequency distribution was at a point 5 cm to the right of the mid-

sternum. If PA pressures are monitored from a catheter tip which is located to the right of the mid-sternal line, then the mid-sternum at the junction of the fourth ICS may not be the most appropriate anatomical landmark to use as a reference point for the leveling of the transducer when the patient is in either the right or left lateral position. Kennedy et al. (1980) utilized the mid-sternal landmark as a zero reference for the transducer in patients placed in a 90 degree sidelying position and found that the PAP pressures did not significantly vary . Wild (1984) and Keating et al. (1986) utilized the same landmark but examined the pressures in 30 degree and 45 degree lateral positions respectively. Both groups of researchers found that the measured pressures in the lateral positions did vary significantly from the PAP measured in the supine position. None of these researchers mention the catheter tip position which could have a significant effect on the hydrostatic error. At angles less than 90 degrees, the catheter tip in relation to the vertical height of the mid-sternum changes. When using the mid-sternum as a zero reference, the more shallow the lateral angle, the greater the potential variation in pressure measurement due to a hydrostatic head of pressure (Appendix F). Also, the greater the lateral distance between the catheter tip and the mid-sternum, the greater the potential difference between the hydrostatic error in the right versus the left lateral PAP

readings.

In summary, three groups of researchers studied the effect of lateral positioning on PAP (Keating et al.,1986; Kennedy et al., 1984; Wild, 1984). The results of these studies conflict in that two found a significant variation in PAP associated with lateral positioning (Keating et al., 1986; Wild, 1984) while one found no significant variation in PAP associated with lateral positioning (Kennedy et al.,1984). Due to concerns regarding the zero references utilized for adjustment of the transducer in lateral positions, the author suggests that further research is needed in this area. It is likely that the use of the mid-sternum as a reference for the transducer level may cause significant errors in PAP measurements in lateral positions at angles less than 90 degrees. In addition, hydrostatic error may vary between the right and left lateral positions depending on the catheter tip position.

It is the author's view that in future studies it may be prudent to utilize the PADP to assess variation in measured PAWP from supine to lateral positions. This would minimize the potential risk that frequent wedging of the catheter imposes, for example, rupture of the balloon, and damage to the PA (Bodai & Holcroft, 1982; Daily & Schroeder, 1985; Kaye, 1983; Pace,1977). PADP may be used as a reasonable estimate

of PAWP except in the presence of pulmonary hypertension (Falicov & Resnekov, 1970; Jenkins, Bradley & Branthwaite, 1970; Rahimtoola, Loeb, Ehsani, Sinno, Chuquimia, Lal, Rosen, & Gunnar, 1972). Subjects with acute or chronic hypoxia (PaO2 less than 60 mmHg.), acidosis (pH less than 7.35), or PEEP in excess of 10 cm of H2O would need to be excluded from studies examining variations in PADP measurements. Hypoxia and acidosis may cause a sudden increase in the pulmonary vascular resistance (Green, 1987). Also, it has been observed that the PAP, in subjects with PEEP in excess of 10 cm of H2O, may be more likely to reflect variations in alveolar pressures than left ventricular end diastolic pressure (King, 1979; Marini, 1986).

Assumptions

It is assumed that accurate PA data collection may be obtained with the patient placed in a supine position with head-up at an angle of 20 degrees. A further assumption is that the catheter tip is located at the level of the phlebostatic axis when the patient is supine. Finally, it is assumed that a 30 degree lateral position will not significantly alter the actual central vascular pressures or flow. Variations in PAP observed following 30 degree lateral positioning are due to a hydrostatic head of pressure created by incorrect adjustment of the vertical height of the

transducer in relation to the tip of the catheter.

Research Objectives

The first objective of this research was to assess the hydrostatic effect on PAP of three different references for the transducer by comparing the PASP and the PADP of subjects in three positions; supine, and 30 degree right and left lateral. The second objective was to determine the most valid zero reference for lateral patient positioning. This could be accomplished by comparing control PASP and PADP obtained from the patient in a supine position with the PASP and PADP obtained in lateral positions using the mid-sternum and the phlebostatic axis as references for the transducer adjustments.

Theoretical Framework

The body attempts to sustain relatively constant vascular pressures. Within the cardiovascular system there are three main determinants of the pressure which include; the pumping competence of the ventricles of the heart, the circulating volume, and the vascular resistance (Guyton, 1975; Smith & Kampine, 1984). When located in the ideal position, the PA catheter allows continuous monitoring of the pulmonary artery pressures. The pulmonary vascular resistance is low and relatively constant. Upstream in relation to the

catheter tip is the pulmonary valve. Downstream from the catheter tip is the left atrium and ventricle (figure 1). When the ventricles of the heart are in end diastole, the mitral valve, downstream from the catheter tip, is open exposing the left ventricle which is at rest. Upstream from the catheter tip, the pulmonary valve is closed. Therefore, none of the pressure at the catheter tip during end diastole is due to ventricular contraction of the heart. Thus, since the ventricles are at rest, and the pulmonary vascular resistance is low and relatively constant, the major source of pressure at pulmonary artery end diastole (PAEDP) is due to the volume in relation to the capacity of the vessels between the pulmonary valve and the left ventricle. The PAEDP represents the preload of the left ventricle (Daily, & Schroeder, 1985) or the circulatory volume.

According to the Frank Starling Law, the greater the volume in the left ventricle during diastole, the greater the stretch of the muscle. In turn, the more the ventricular muscle fibres are stretched, the greater will be the force of contraction and thus output (Smith, & Kampine, 1984). However the myocardial muscle can be overstretched with volume at which point the CO will fall. A major use of the PA data is to determine the best PA pressure (or volume) which will yield the best CO. This is often crucial information in

patients with compromised left ventricular function.

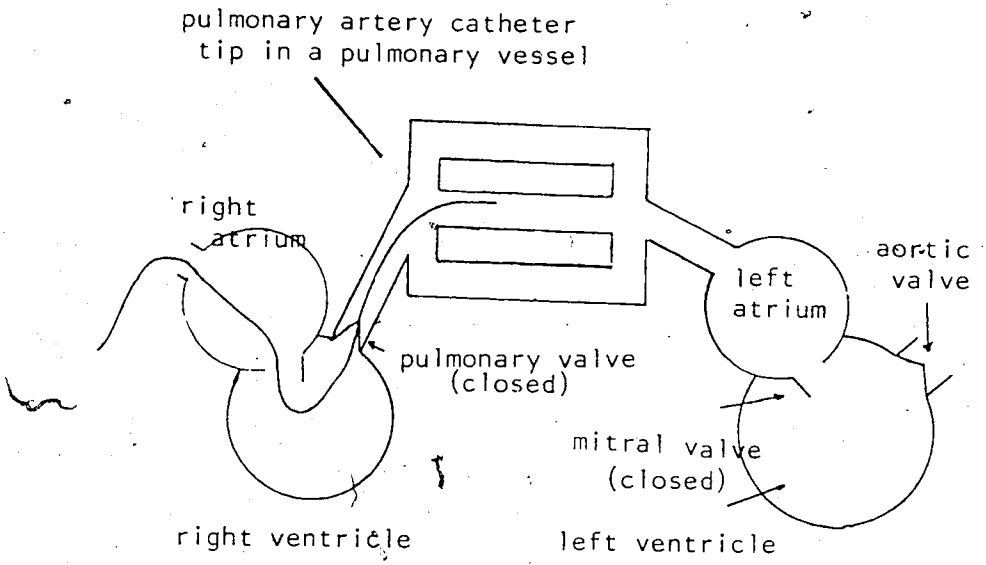

Figure 1. Monitoring Central Vascular Pressures

Postural changes bring about marked changes in vascular pressures and volumes. These changes depend on the vertical height of the heart in relation to the lower torso. A change from supine to erect posture causes a shift of about 500 ml. of volume from mainly the thoracic circulation to the lower torso due to gravitational forces (Smith, & Kampine, 1984).

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METHODS AND PROCEDURES

A description of the study design, definitions, hypotheses, sample and setting is presented. This is followed by a discussion of data collection procedures and the major results of the pilot study, as well as a description of data analyses. Measures taken to assure reliability and validity of the data collection are explicated. Finally, some of the ethical considerations that were associated with this study are addressed.

Research Design

A repeated measures experimental design was used to investigate the changes in PAP readings associated with the use of three adjustments of the vertical height of the PAP transducer while monitoring the PAP of patients in left and right 30 degree lateral positions. Counterbalancing was utilized to reduce the potential influence that the order of positional changes and transducer adjustments may have had on the results. Each subject was randomly assigned to one of two groups based on the sequence of positional changes: a) supine, right lateral, supine, left lateral, or b) supine, left lateral, supine, right lateral. Also, members within each body position sequence group were randomly assigned to one of two transducer adjustment sequences: 1) P1, P2, P3 or 2) P3, P2, P1. Change in PAP was quantified by comparing

the PASP and PADP recorded in the right and left lateral positions with the PASP and the PADP recorded while the patient was in a supine position.

Definitions

The following terms were operationalized or defined for this study:

Pulmonary artery systolic pressure (PASP) is the highest pressure of each end-expiratory pulmonary arterial waveform recorded on a strip chart and and averaged over 10 respiratory cycles

Pulmonary artery diastolic pressure (PADP) is the lowest pressure of each end-expiratory PA waveform immediately prior to the right ventricular ejection phase of the PA configuration recorded on a strip chart and averaged over 10 respiratory cycles

End-expiration is the highest point immediately preceding a downward pattern in a respiratory waveform display of chest wall movement. Chest wall movement is measured on the basis of changes in the electrical resistance detected via electrodes monitoring the electrical activity of the heart.

End-expiratory pulmonary artery pressure refers to those PAP which occur at the end of the expiratory phase of respiration as determined by the analysis of a

simultaneous graphic display of the PAP and the respiratory waveforms.

Right lateral position (R. Lat.) is a position in which the subject is placed on his/her right side with a 30 degree foam wedge for support of the patient's back, one pillow beneath the patient's head, and the head-up angle of the bed at 20 degrees.

Left lateral position (L.Lat.) is a position in which the subject is placed on his/her left side with a 30 degree foam wedge for support of the patient's back, one pillow beneath the patient's head, and head-up angle of the bed at 20 degrees.

Supine position is a position in which the subject is placed on his/her back with the chest wall at 20 degrees elevation and one pillow beneath the patient's head

Mid-sternum is a point located at the junction of the fourth intercostal space (ICS) and an anterior mid point of the sternal width.

Phlebostatic axis is the point of junction between the fourth ICS and the mid-way position between the posterior surface of the body and the base of the sternum.

Position 1 (P.1) using a carpenter's level, the vertical height of the transducer is adjusted to the right

phlebostatic axis when the patient is in a supine position.

Position 2 (P.2) using a carpenter's level, the vertical height of the transducer is adjusted to the level of the right phlebostatic axis when the patient is in a lateral position.

Position 3 (P.3) using a carpenter's level, the vertical height of the transducer is adjusted to the vertical level of the mid-sternum when the patient is in a lateral position.

Pulmonary hypertension is defined as a PA systolic equal to or greater than 40mmHg and/or a PA diastolic pressure equal to or greater than 20mmHg.

Hemodynamically stable refers to a subject who meets the following criteria; a) no changes in therapy for the period including one hour prior to and during the time of data collection, b) intravenous fluids and medications at a constant rate of administration during the study c) a pulse rate which does not vary more than 20 beats per minute during the study and d) a respiratory rate which does not vary more than 10 breaths per minute during the study (changed to 20 breaths following the pilot study)

Hypotheses

Given a pulmonary artery catheter tip located to the right of the mid-sternum, and in consideration of hydrostatic principles discussed above (p. 15), the following hypotheses were formulated:

1. With the transducer level with the supine phlebostatic axis (P.1)
   a) PASP and PADP will not significantly vary in the right lateral position from PASP and PADP in the supine position
   b) PASP and PADP will be significantly higher in the left lateral position than the PASP and PADP in the supine position.
2. With the transducer level with the right lateral phlebostatic axis (P.2)
   a) PASP and PADP will be significantly higher in the right lateral position than the PASP and PADP taken in the supine position.
   b) PASP and PADP will be significantly lower in the left lateral position than PASP and PADP in the supine position.
3. With the transducer level with the mid-sternum (P.3)
   a) PASP and PADP will be significantly lower in the right lateral position than the PASP and PADP in

the supine position .

b) PASP and PADP will be significantly lower in the left lateral position than the PASP and PADP in the supine position.

Population and Sample

A convenience sample was drawn from a population of cardiovascular surgical patients during the initial 48 hours of their post-operative care in a large western Canadian teaching hospital. Originally, the criteria for inclusion in the study were;

a) 18 years of age or older at the time of the study

b) able to read, write, and speak in the English language

c) no contraindications for 20 degree head-up or right or left lateral positioning as determined by the investigator in consultation with the nurse assigned to the patient.

d) no PEEP or PEEP less than 1 cm. of water

e) PA catheter in a branch of the right pulmonary artery as established by a daily anterior posterior chest x-ray

f) hemodynamically stable (e definitions p.27)

g) no evidence of PA hypertension (see definitions p.27)

h) normal pH (7.34-7.45), or hydrogen ion content (35-46)

i) PaO2 60mmHg or greater

The first two criteria provided a cutoff for defining adults who would be able to communicate with the investigator and understand the full intent of the study. The third criterion assured that the investigator established whether or not head-up or lateral positioning was associated with hemodynamic alterations in the individual patient. The remaining criteria were included in order to eliminate the potential effect of some of the known confounding variables.

Following a pilot study and further discussion with members of the advisory committee, the researcher changed one of the criteria as follows:

e) PA catheter in satisfactory position as established by the report of the anterior-posterior chest x-ray on the day of the study

In addition, criteria g) and h) were deleted (see discussion of the pilot study procedures p.36).

Although sample size tables (Cohen, 1977) were used to derive an appropriate study sample size, practical concerns related to the time available to the researcher also had to be considered. A sample size of 40 was used which resulted in a power of .6 for detecting medium sized differences between means. The level of significance criterion was set at .05 (two tailed).

Setting

The setting for this study was a 10 bed cardiovascular

intensive care unit (CVICU) within a large acute care facility located in a western Canadian city. Each staff member in the unit is assigned to one or two patients depending on the hemodynamic stability of the patients. Patient repositioning, on a one to two hourly basis, is part of the routine responsibility of the nurses. The most appropriate time to investigate each subject was negotiated between the nurse in charge of the unit and the investigator prior to each case studied. The majority of subject testing was conducted between 0900 and 1200 hours. Staff were asked to volunteer their help with patient positioning during the study. In this study assistance with turns was required 5 times in the course of approximately 48 minutes for each case and no additional staffing was needed in order to conduct the study.

The researcher provided the staff with a brief overview of the study and the staff's role in the research prior to a pilot study. Since none of the changes in the protocol which resulted from the pilot study changed what was essential for the staff to know, further staff teaching sessions were not provided prior to data collection.

Data Collection Procedures

The procedures for data collection described below represent the protocol that was followed after the analysis of the results of a pilot study. All steps described in this

procedure were conducted by the researcher with the exception of positioning the patient which was done by the researcher with the assistance of the subject's nurse.

Pre-operative cardiac surgical patients are routinely admitted to a medical unit prior to their surgery. On a daily basis the investigator reviewed the charts of the preoperative patients to determine which patients appeared to meet the criteria for entering the study. These patients were then approached to obtain a voluntary informed consent (appendix G). Once consent had been granted the researcher gathered and recorded some demographic and biographic data including chest wall circumference, chest wall depth and width; information that would be necessary in the PA data analysis. Within +8 hours following the subject's surgery the investigator consulted the nurse in charge of the CVICU about an appropriate time, in terms of the unit activity, to collect data. The status of the patient was assessed by means of a chart review and an interview of the staff to determine if the subject met the criteria for entry into the study.

Provided the subject met the criteria for entrance into the study, the subject was then assigned with a numeric identification code (1-40). Also, patients were assigned by coin toss to one of two position sequences; group a) supine, right lateral, supine, left lateral, supine or group b) supine, left lateral, supine, right lateral, supine. A

similar procedure was followed to assign the subjects within each of the groups to one of two transducer adjustment sequences for lateral positions; P1,P2,P3, or P3,P2,P1 (Appendix H). Successive subjects were assigned to alternate position sequence groups and transducer adjustment subgroups. The assigned position sequence and transducer adjustment sequence were then circled on the biographic and demographic form (Appendix I). Numeric codes were assigned to each of a set of nine PAP strip-recordings to be obtained during the study. This was done by randomly drawing numbers (1-9) without replacement (Appendix I) and then entering the numbers onto the biographic and demographic form.

The PAP data collection process then began, using the PAP protocol as a guideline (Appendix J). All patients were catheterized by a physician using a 7 french flow directed PA catheter. PAP was measured by the investigator using the pressure transducers (Hewlett Packard model 1290-a, or model 1290-c) which are routinely attached to each PA catheter in the CVICU. The PAP transducer was disconnected from the patient's bedside monitoring system and connected to the researcher's portable monitoring system which consisted of a four channel Gould 2400s recorder and which had been temporarily adapted to a Hewlett Packard 78810 neonatal monitor. A machinery warm-up period of at least twenty minutes was allowed to elapse before the portable system was

used for PAP recording. An extra set of electrocardiographic leads were applied to the subject's chest wall and connected to the portable monitor (Appendix K).

The graphic recorder and the transducer were calibrated using a mercury manometer before beginning data collection in order to provide some assurance of the consistency in the measurements of PASP and PADP (Appendix L). Anatomical landmarks for transducer adjustments were marked with a pen. The angle of the head of the bed was adjusted to 20 degrees using a 20 degree wedge and then was left at that angle for the duration of the individual's study. If the patient was not found in a supine position, the researcher and the patient's nurse positioned the patient supine. The transducer was adjusted to the supine phlebostatic axis (Pl) and after a 5 minute rest period, the PAP was recorded. The subject was then assisted to move into a lateral position by the researcher and the patient's nurse. A firm 30 degree foam wedge was used to support the midline of the subject's shoulders at an approximate 30 degree angle. With each position change the zero reference position on the transducer was adjusted to the vertical level of the appropriate anatomical landmark using a carpenter's level (Appendix D). A stopwatch was used to measure a five minute rest period that followed each position change. In the lateral positions three PAP recordings were made for each of the three transducer

adjustments (P1, P2. P3). Each recording consisted of a simultaneous graphic record of the electrical activity of the heart, PASP, PADP, and the respiratory waveforms over ten respiratory cycles. A total of nine pressure recordings were made for each patient as they were moved through the series of five positional changes. Each recording was marked with the subject's numerical code and the pressure record code which were pre-assigned. The nine recordings were separated and then stored in the correct numerical order.

Upon completion of data collection, the patient was reattached to the bedside monitoring system and the extra electrocardiographic leads were removed. The remainder of the biographic and demographic record was completed. This included details regarding the patient's drug and respiratory therapy, as well as age, name, height, weight, diagnosis, and hospital number (Appendix I). The researcher viewed the subject's most recent anterior posterior chest x-ray to determine and record the position of the PA catheter using the spinal processes, and the lung margins as reference points (Appendix M). The catheter position was categorized as either mid-line, left, or right depending on whether or not it was found to be within two centimeters on either side of the spinal process or, greater than two centimeters to the left or right of the patient's spinal process respectively. Prior to categorizing catheter tip position, the distance in

centimeters of the catheter tip from the mid-spinal process was converted to actual distance based on a calculation considering the x-ray magnification (Appendix N).

Using a standard approach, graphic printouts were interpreted once a group of at least five complete records of subjects was available. Ten end-expiratory PASP and PADP were entered on the data collection sheet for each of the nine combinations of position and transducer adjustments (Appendix O). Each recording for a given transducer and position sequence combination was randomly given a number and the analyses were done according to those random number order (not necessarily in the order performed). Each subject's record was interpreted in the sequence in which the patients were studied. Once the data was interpreted, the codes were broken and the data was entered into a computer program for statistical analyses.

Pilot Study Procedures

The objectives of the pilot study were to; a) assess the feasability of the research protocol including the forms for data collection and consent, as well as the technical aspects of the data collection procedure and b) to make appropriate modifications in the research protocol.

Although the original intent was to conduct a pilot study on a sample of five subjects, only three patients were entered

in the pilot study. A number of factors resulted in an unplanned and prolonged delay in progressing with data collection including; a delay in obtaining equipment, problems experienced with negotiating a suitable time for conducting the research, and a nursing strike. In consideration of these unforeseen delays, and the information learned conducting the pilot study on three patients, it was decided to proceed with the assessment of the pilot study.

The experience exposed a number of technical and strategic problems which were subsequently resolved. As a result of the pilot study a number of modifications were made to the procedure and the forms used for data collection. Only the major modifications to the procedure that resulted from the pilot study are described.

Modifications to the Procedure for Data Collection

Modifications to the procedure were related to concerns identified in the following areas; the adjustment of the transducer and the sample selection criteria.

The adjustment of the transducer

The adjustment of the transducer to the anatomical landmarks (P1, P2, & P3) could not be made using a carpenter's level alone. An intravenous pole with tape along its vertical axis was used in conjunction with a carpenter's level in order to align the transducer with landmarks when the patient was turned away from the transducer, and when the lateral sequence

started with recording pressures with the transducer level with the mid-sternum (Appendix P).

Selection criteria

Patients who had PA hypertension prior to surgery were not always PA hypertensive following open-heart surgery so exclusion of those patients pre-operatively was not prudent. In addition, it was decided that PA normotension should not be used as a criteria for entrance into the study because of a concern for potential difficulty in obtaining an adequate sample size within a time period that was reasonable fror student researcher's perspective.

It was noted that many mechanically ventilated patients would breathe at the common mechanical control rate of 6-8 breaths per minute while they slept. However, when these patients were moved during the study, they would begin to ventilate at a more natural rate of 15-20 breaths per minute. Therefore, the criterion related to respiratory variation for discontinuing the study was reevaluated. It was decided that an increase in the respiratory rate of greater than 20 breaths per minute would be a more reasonable criterion for withdrawing a patient from a study. This was based on a normal adult breathing rate of fifteen to twenty breaths per minute.

The primary reason for using a normal pH as a selection criterion was that changes in pH may bring about a

considerable change in pulmonary vessel resistance. However, the ph could only be determined from the results of the most recent arterial blood gas analysis. No means of obtaining a continuous analysis of the pH was available to the researcher. Since the isolated measurement of the pH was of limited value in assessing the acid-base status of the patient throughout the time of the study it was decided that the most recent pH would be recorded and a normal pH would not be considered necessary for entrance of a subject into the study.

It was not possible to obtain a report of the position of the PA catheter prior to the study. Immediate feedback from e radiologist only occured if the catheter was malpositioned. Otherwise, written reports related to catheter position took two days to reach the charts in CVICU . It was decided that the researcher would view the anterior posterior chest x-ray obtained on the day of the study in order to determine catheter placement. It was realized that the placement of the catheter tip in the right pulmonary artery might be a severely restrictive criterion in terms of obtaining the sample size in a reasonable period of time. Routine placement of the catheter in this unit was more central than anticipated.

The bifurcation of the right and left branches of the pulmonary artery is located two centimeters to the left of the patient's mid-sternum (Paul, 1981). Although the catheter

could be in the right main PA, it was not as displaced from the mid-sternum as the catheter tip placement expected based on previous research. Many of the physicians in this setting are satisfied to leave the catheter tip in a very central position in relation to the mid-sternum. The hypotheses were based on the theory that variation in PAP found when a subject moves from a supine to a lateral position are due to a hydrostatic head of pressure. Furthermore , based on the work of Benumof et al.(1977) it was assumed that the majority of PA catheter tips would be located in a branch of the PA to the right of the mid-sternum. The researcher, in consultation with an advisory committee, decided that the position of the catheter tip would not be a criterion for entrance into the study. Furthermore it was decided that those patients found to have the catheter tip located to the left of the mid-sternum would be replaced by subjects with a catheter tip located to the right of the mid-sternum unless it became evident that this was the case in more than 10% of the subjects obtained in this setting.

Data Analysis

The data collected have the properties of ratio scales which include magnitude, equal intervals between adjacent units and an absolute zero (Pagano, 1986). Therefore, the pressures obtained from graphic printout were analyzed

using descriptive statistics to obtain the mean, and the standard deviation. The mean of each subject's 3 supine PASP and PADP was calculated and compared to each of the means of the subject's six sets of PAP recorded in the lateral positions. This was done in order to determine each individual subject's PAP variation.

Using paired t-tests the means of the first, second, and third supine PAP were compared to determine if there were any statistical or clinical variations between the three supine PAP. The purpose of that analysis was to assess the hemodynamic stability of the subjects over time.

Multiple paired t-tests were also used to test the hypotheses. The data were subjected to t-tests in order to detect any statistically significant differences between the mean PASP and PADP recorded in the supine versus the lateral positions using the supine phlebostatic axis (P1), the right lateral phlebostatic axis (P2), and the mid-sternum (P.3) for transducer adjustments.

A similar series of paired t-tests as described above were conducted on a number of subgroups including: ventilated versus non-ventilated subjects, subjects with a normal pH versus an abnormal pH, and subjects with catheter placement at the mid-sternum, versus those to the right and those to the left of the mid-sternum. The purpose of those tests was to determine if there were any underlying differences between

the results of the analyses of the subgroups compared to the results of the analyses of the whole group. Given the theoretical potential effect on the PAP that pH, ventilatory status, and catheter position could have on the PAP, it was anticipated that the results of the subgroup analyses might differ from the results of the analyses of the group as a whole.

In addition, the Pearson r correlation was calculated to determine whether either the catheter tip position or the chest width were related to the total changes in PADP. Only PADP was assessed in terms of the correlation because it was reasoned that PASP would more likely be influenced by variations in ventilatory rate and pressure.

The level of significance was set at .05 for the statistical analysis of the data. Using the criteria established by Nemens and Woods (1982), data were also analyzed in terms of the clinical significance.

The researcher recognizes the inherent weaknesses of conducting multiple t-tests. A multivariate test might have been a more efficient test in that it would have avoided the problems that multiple t-tests create in terms of an increased probability of type I error. Ultimately, the choice of test was made based on more practical reasons. The researcher's skills were limited in terms of manipulating the data within the statistical package chosen. At the time, the use of a t-

test appeared to lend itself more readily to the format of the data and the researcher's proficiency in utilizing the statistical package.

The Validity and Reliability of Measures

A number of steps were undertaken to provide some assurance of the validity of measures. The calibration of the transducers and the graphic recorder were tested before beginning data collection. With each position change the transducer was adjusted to the vertical level of the appropriate landmarks using a carpenter's level (Appendix F). A stopwatch was used to measure the five minute rest periods that followed each position change. Care was taken to assure that the positional changes were conducted in the same manner by preparatory teaching of the nursing staff who assisted with the positional changes. A four channel strip recorder was used to obtain an electrocardiographic as well as a respiratory and a PAP waveform so that end-expiratory pressures could be recorded and variations in PAP due to arrhythmias could be detected. All graphic printouts were interpreted by the investigator using a standard procedure to convert the analog display of PAP to a digital record.

The use of the selection criteria provided some assurance that changes observed in the PAP measured in the lateral position compared to the supine PAP measurments were

not likely due to other coincidental physiologic or mechanical variables such as hemodynamic instability, excessive PEEP, or the malpositioning of the catheter. The potential effect that the sequence of positional change or the transducer height adjustment may have had on the outcome was controlled for by the random assignment of subjects to one of two position sequences for each of those variables. In addition, the pressures in the first, second, and third supine position were statistically compared to determine the stability of the subjects physiological status. Subgroup analysis using t-tests were used to determine if any differences in PAP between positions could have been due to confounding variables such as ventilatory status, pH, and catheter position. The design using the patient as his/her own control reduced the potential effect differences between individual subjects could have had on the results of the study.

In order to control for the effect that the stimulus of turning may have on pressure variation, a constant rest period of five minutes was allowed to elapse before pressures were measured. The PASP and PADP were measured at end-expiration over 10 respiratory cycles. The use of randomly assigned codes to identify the graphic waveform printouts reduced the possibility that the experimenter would recall which postural or transducer position the graphic record represented until the data were processed.

The external validity of the study is limited to populations which have similar attributes to those of the convenience sample. Biographic and demographic data were collected in order to establish the characteristics of the group.

Interrater reliability was determined using a second expert PAP waveform interpreter. Using the same standard for interpretation as the investigator, the second expert analyzed a random sample of 200 end-expiratory recorded PAP waveforms from a randomly selected group of five of the first 34 subjects. A difference of 1mmHg or greater was considered an indication of disagreement. The second expert disagreed with three percent of the researcher's interpretations of pressures based on the standards used (table 1). No changes were made in the recorded pressures based on these disagreements. None of the differences between PAP interpretations exceeded 1mmHg.

Table 1.

Number of Disagreements in Waveform Interpretation

Case	Disagreements		Number of Readings
	Diastolic	Systolic	
1	1	2	40
5	0	0	40
24	0	0	40
26	2	1	40
33	0	0	40
Total	3	3	200

Ethical Considerations

Prior to data collection, the researcher obtained ethical clearance from the Faculty of Nursing of the University of Alberta, and from the institution in which the study was conducted.

In order to protect volunteers from harm, care was taken in the methods of this study to reduce the potential risk to the patient. Nothing was added to the normal care of the critically ill patients with a PA catheter with the exception of the series of turns which took place over a period of

approximately 60 minutes. To assure that the patient was not exposed to any potential harm from this added measure, it was required to establish that the patient could tolerate the series of positional changes. This was determined by reviewing the patient's chart and discussing, with the patient's nurse, any noted hemodynamic effect of similar postural changes. In addition, if the patient demonstrated a lack of tolerance of these positional changes during the study through an increase in heart rate greater than 20 beats per minute, or an increase in respiratory rate of greater than 20 breaths per minute, the patient was to be withdrawn from the study. No patients were withdrawn from the study for those criteria. Informed consents were obtained from all participants prior to their surgery (Appendix G). The subjects were assured of complete anonymity and were informed that if they wished to withdraw from the study at any point, they could do so without fear of compromise to their standard of care.

RESULTS

The characteristics of the sample studied are described. This is followed by a presentation of the results of the tests of the hypotheses, and the analysis of subgroups including, mechanically ventilated versus non-mechanically ventilated subjects, subjects with a normal versus an abnormal pH, groups based on catheter tip position, and subjects with pulmonary artery hypertension.

Sample Characteristics

A convenience sample of 40 post-operative cardiac patients was included in the study. Table 2 includes a list of the surgical procedures that the subjects had sustained. The majority (90%) of these patients had undergone a coronary artery bypass (CAB) procedure. Of the group of CAB patients, four subjects had at least one additional surgical procedure. The remainder of the subjects included three who had at least one heart valve replaced, and one subject who had undergone a Bental procedure. All studies were conducted 8 to 32 hours after surgery (M = 18.45 hours) and took a mean period of 49.5 minutes to complete (range = 35 - 70 minutes)

Table 2.

Summary of Surgical Procedures

Patient Diagnoses	Frequency
Coronary artery bypass	32
Coronary artery bypass +	
Aortic valve replacement	3
Pericardectomy	1
Aortic valve repalacment	2
Triple valve replacement +	
Annuloplasty	1
Bental procedure	1

The subjects ranged in age from 38 to 71 years with a mean age of 59 years. There were 31 males and 9 females included in the study. All subjects had a 7 French PAP catheter inserted via the right internal jugular vein. In 13 (32.5%) of the cases the catheter tip was located beyond 2 cm to the right of the subject's mid-sternum. In 7 of the 13 cases the catheter tip was greater than 3 cm beyond the mid-sternum. In 21 cases (52.5%) the catheter tip was located within 2 cm of the patient's mid-sternum. In the remaining 6 cases (15%), the catheter was located beyond 2 cm to the left of the patient's mid-sternum. A summary of the catheter tip location is provided in Table 3.

Table 3.

Summary of Catheter Tip Locations

Right of Mid-Sternum (> 2 cm)	Mid-Sternum	Left of Mid-Sternum (> 2 cm)
32.5% (n=13)	52.5% (n=21)	15% (n=6)

A total of 31 subjects were on at least one vasoactive medication drip. Furthermore, 25 subjects were given at least one of 2 commonly used intermittant medications (morphine, potassium) within a period of one hour prior to or during the PAP study. However, only one subject (case 34) demonstrated clinically significant changes in PASP and or PADP between the three supine readings (Table 4 & 5) That subject was given morphine 45 minutes prior to the study.

Table 4.

Individual Changes From Supine
Systolic Pressures in mmHg

Case	Supine 1	2	3	Analgesic Given
14	48.6	48.4	54.8	no
20	39.5	35.9	34.1	no
34	34.0	35.8	39.2	yes

Table 5.

Individual Changes From Supine Diastolic Pressures in mmHg

Case	Supine 1	Supine 2	Supine 3	Analgesic Given
13	09.0	11.0	11.0	no
20	21.9	22.1	19.3	no
14	20.2	21.7	20.3	yes
15	1[illegible]	21.22	19.0	no
19	[illegible]	23.3	21.4	no

3

In 8 cases the subjects presented with a mean supine PASP > 40 mmHg and a PADP > 20 mmHg. In an additional 3 cases the PADP was > 20 mmHg while the PASP was [illegible] 40 mmHg (Table 5). Of these 11 cases with PAP hypertension only 4 subjects (cases 14, 20 & 14) demonstrated clinically significant changes between the three supine PAP readings (Table 4 & 5).

Table 6.

Summary of Cases with PAP Hypertension

Case	Mean Supine Pressures	
	PASP (mmHg)	PADP (mmHg)
11	43	26
13	47	25
14	51	26
20	36	22
27	38	21
32	58	26
34	36	23
39	47	26
42	47	20
43	36	21
45	36	20

There were 25 subjects who were classified as being mechanically ventilated (MV) during the study. The MV patients included 21 who were on intermittant mandatory ventilation (IMV), and 4 who were on continuous positive airway pressure (CPAP). Of those subjects who were on IMV, 71% tended to have a respiratory rate that closely matched the rate set on the ventilator. The inspiratory pressure of those subjects on IMV ranged from 15 to 45 cm of H2O, with a mean of 35.2 cm. of H2O. The majority (93%) of non-mechanically ventilated (NMV) cases were on cold nebulization (Table 7). A total of 9 subjects presented with a H+ concentration <35 at the time of the study.

Table 7.

Ventilatory Status

Type of Airway Assistance	Frequency
Intermittant mandatory ventilation	21
Continuous positive airway pressure	4
Cold nebulization	14
Nasal prongs	1

Although a total of 47 subjects were investigated only 40 cases were entered into the study. Seven cases were removed from the study following the interpretation of the PAP waveforms. In Table 8 a list of rationale for the deletion of each of those 7 subjects is provided. The majority (71.4%) of subjects who were dropped from the study demonstrated large decreases in the pulse pressure in at least one of the 9 waveform recordings. One subject (case 36) was removed from the study because of PAP variation attributed to intermittant heart pacing. It was not possible in that subject, to obtain end-expiratory PAP that were consistantly associated with either paced or sinus originated heart beats. During the recording of the PAP of case 10, one of the vasoactive drug infusion rates was changed so that that subject no longer fit the criterion of hemodynamic stability.

Table 8.

Rationale for Removing Cases from the Study

Case	Rationale
10	Hemodynamic instability
15	All PAP waveforms were dampened, suggesting that the catheter tip was too peripheral
17	PAP waveforms in the right lateral position were dampened
23	PAP waveforms in the right lateral position were dampened
29	PAP waveforms in the left lateral and the third supine position were dampened

Tests of the Hypotheses

It was hypothesized that the PASP and PADP recorded in the supine position would not significantly differ from the PASP and PADP recorded in the right lateral position when using the supine phlebostatic axis (Pl) as a reference for the positioning of the the transducer (Hypothesis 1a). The results indicated that there was a mean increase of 1.74 mmHg in PASP and 1.35 mmHg in PADP recorded in the lateral position compared to the supine. Although these changes were statistically significant ($P = < 0.001$), neither were considered to be clinically significant based on the normal

fluctuation in PASP and PADP as described by Nemens and Woods (1982). Mean PASP variations less than 5 mmHg or mean PADP variations less than 4 mmHg were considered to be clinically insignificant.

It was hypothesized that the PASP and PADP recorded in the supine position would be significantly less than the PASP and PADP recorded in the left lateral position when using the supine phlebostatic axis (P1) as a reference for the transducer adjustment (Hypothesis 1b). The results indicated that there was a mean increase of 2.59 mmHg in PASP and 1.94 mmHg in PADP recorded in the left lateral position compared to supine. Again these mean differences were determined to be statistically significant but not clinically significant.

Hypotheses related to the use of the right lateral phlebostatic axis (P2) and the mid-sternum (P3) as references for the transducer adjustments were supported both clinically and statistically (Hypotheses 2a & b, 3a & b respectively). Using the right lateral phlebostatic axis (P2) as the transducer adjustment in the lateral position: a) PASP and PADP was found to be significantly higher in the right lateral position than the PASP and PADP in the supine position and b) PASP and PADP was found to be significantly lower in the left lateral position than PASP and PADP in the supine position. Using the mid-sternum (P3) as a reference for the transducer

adjustment in the lateral position: a) PASP and PADP were found to be significantly lower in the right lateral position than in the supine position and b) PASP and PADP were found to be significantly lower in the left lateral position than in the supine position.

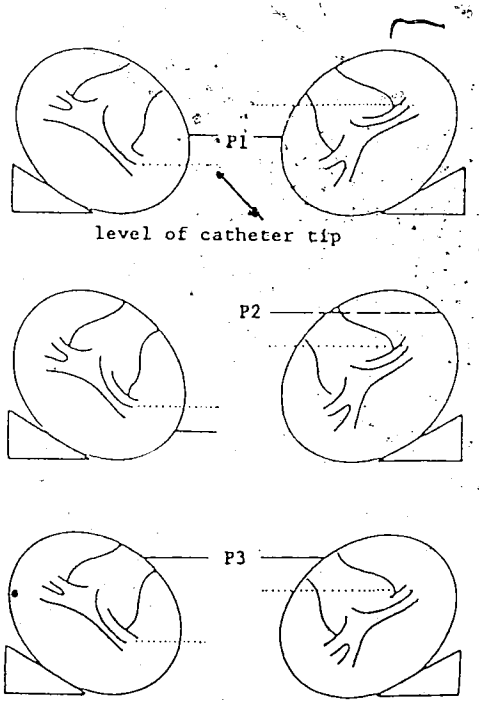
A summary of the results of the tests of the hypotheses is presented in Table 9. With the exception of hypotheses 1a, all the hypotheses were supported by results of the t-tests (two-tail, $P = < 0.001$). Furthermore, with the exception of hypothesis 1b, all the hypotheses were supported by the clinical criteria based on the work of Nemens and Woods (1982). Using the supine phlebostatic axis (P1) and the mid-sternum (P3) as references for the transducer adjustments, the mean PASP and PADP measured in the left lateral position were consistently higher than those pressures measured in the right lateral position (Table 9).

Table 9.

Summary of Tests of the Hypostheses

Positions

Right Lateral Left Lateral



Hypotheses	Results of T-tests (n=40; df=39)					
	Supine		Lateral			
	Pressure (mmHg)	Standard Deviation	Pressure (mmHg)	Standard Deviation	Mean Difference	T value
1. With the transducer at P1:						
a) Right lateral PASP - Supine	31.58	9.26	33.31	9.78	-1.74	- 5.74*
Right lateral PADP - Supine	17.52	4.57	18.87	4.57	-1.35	- 5.54*
b) Left Lateral PASP > Supine	31.58	9.26	34.16	9.50	-2.59	- 7.81*
Left Lateral PADP > Supine	17.52	4.57	19.46	4.54	-1.94	- 8.60*
2. With the transducer at P2:						
a) Right lateral PASP > Supine	31.58	9.26	38.31	9.92	-6.74	-18.01*
Right lateral PADP > Supine	17.52	4.57	24.04	4.88	-6.52	-20.36*
Left lateral PASP < Supine	31.58	9.26	25.96	9.77	5.61	15.76*
Left lateral PADP < Supine	17.52	4.57	10.99	4.62	6.52	26.53*
3. With the transducer at P3:						
a) Right lateral PASP < Supine	31.58	9.26	24.47	9.85	7.11	16.14*
Right lateral PADP < Supine	17.52	4.57	10.08	4.60	7.43	22.10*
b) Left lateral PASP < Supine	31.58	9.26	25.16	9.64	6.41	19.81*
Left lateral PADP < Supine	17.52	4.57	10.28	4.57	7.24	29.8*

* P - < 0.001

The result of an assessment of individual PAP changes revealed that there were 7 cases (subjects 4,7,12,13,14,20,35) who demonstrated a clinically significant pressure change in a lateral position using P1 (Table 10). In only one subject (35) was more than one clinically significant pressure change found using P1 in the lateral positions. In that case, the significant changes were the PASP and PADP recorded in the right lateral position (Appendix Q & R).

Table 10.

Individual Pressure Changes from Supine to Lateral Using the Supine Phlebostatic Axis (P1)

Position/Pressure	Range (mmHg)	Mean (mmHg)	Number Exceeding Normal Clinical Variations in Mean Pressure (n = 160)
Right Systolic	0.06-6.80	1.74	3
Left Systolic	0.00-6.07	2.59	2
Right Diastolic	0.00-6.17	1.35	1
Left Diastolic	0.23-5.20	1.94	2

T-tests conducted to compare the variation in lateral PADP and PASP from the mean supine pressures are summarized in tables 10 and 11 respectively. PADP did not significantly vary, statistically or clinically between the three supine positions. However, statistically significant differences in

the PASP were exhibited between supine 1 and supine 2, and between supine 1 and supine 3. These PASP variations were not clinically significant. Based on these results, it was decided to use the mean of the PASP and the mean of the PADP from the three supine PAP as the control variables.

Table 11.

Mean Differences Between Supine Diastolic Pressures

Comparison Using T-test	Probability (2-tailed)	Mean Pressure Differences (mmHg)
Supine 1 vs Supine 2	0.072	- 0.47
Supine 1 vs Supine 3	0.188	- 0.50
Supine 2 vs Supine 3	0.938	- 0.02

Table 12.

Mean Differences Between Supine Systolic Pressures

Comparison Using T-test	Probability (2-tailed)	Mean Pressure Differences (mmHg)
Supine 1 vs Supine 2	0.023	- 0.76
Supine 1 vs Supine 3	0.037	- 0.87
Supine 2 vs Supine 3	0.748	- 0.12

Subgroup Analyses

Mechanically Ventilated and Non-mechanically Ventilated

The results of the series of t-tests on the subgroup analysis comparing mechanically ventilated subjects (n=25) with non-mechanically ventilated subjects (n=15) were similar to the results described in the tests of the hypotheses with one exception. Only the non-mechanically ventilated subjects displayed statistically significant differences in the mean PASP between the means of supine 1 and supine 2, and between the means of supine 1 and supine 3. However, these differences were not clinically significant.

Normal pH

The results of the series of t-tests carried out on subjects with a normal pH (n=33) were essentially no different from those conducted on the whole group (n=40).

Catheter Position

The results of the series of t-tests conducted on the three subgroups differentiated by the position of the tip of the catheter were no different from the results of the t-tests conducted on the whole group. Also, the Pearson r correlation for the relationship between the total change in PADP in the lateral positions (using P1) and the catheter position in cm from the mid-sternum was .0662. The Pearson r correlation for the relationship between the total change in PADP in the lateral positions (using P1) and chest width was .0833.

Pulmonary Artery Hypertension

Of the 11 cases of PA hypertension (PASP > 40 mmHg and/or PADP >20 mmHg), only 3 cases (13,14,20) demonstrated clinically significant variations in a lateral position using the supine phlebostatic axis as a reference for the transducer (Table 4, Appendices R & S). In none of those cases was there more than one clinicially significant PAP in the lateral position using the supine phlebostatic axis (P1).

DISCUSSION

A brief overview of the major findings relating to the hypotheses is presented. This is followed by a description of other findings associated with the subgroup analyses as well as a summary of the major limitations of the study. In addition, the implications of this research for nursing practice and for future nursing research are proposed.

Major Findings

One major finding of the study surrounds the results of the tests of the hypotheses that referred to the use of the supine phlebostatic axis (P1) as a reference for a transducer adjustment in lateral positions. The hypothesis that PAP recorded in the right lateral position would not significantly differ from PAP recorded in the supine position using the supine phlebostatic axis as a reference for the transducer was supported clinically but not statistically. The hypothesis that PAP recorded in the left lateral position would be significantly greater than PAP recorded in the supine position using the phlebostatic axis for the transducer adjustment was supported statistically but not clinically.

Statistically significant changes in PAP could be expected when moving a patient from a supine to a lateral

position using a constant transducer adjustment (phlebostatic axis) because of changes in the vertical height of the catheter tip in relation to the vertical height of the transducer. Given a constant physiological state, it was reasoned that the amount of change in pressure would be influenced by the location of the catheter tip in relation to the mid-sternum , as well as the subject's chest width. However, the calculated Pearson r coefficient between PADP changes and the catheter position (r=.0662) and the chest width (r=.0833) did not support that notion. Less than 1% of the variability in PADP in the lateral position was explained by either the chest width or the distance of the catheter tip from the mid-sternum.

There may have been other factors that brought about changes in PAP in lateral positions in this study. For example, previous researchers have found both clinically and statistically significant increases in the cardiac output in the left lateral position (Doering et al., 1988; Whitman et al., 1982). Although not clinically significant, the mean PASP and PADP were consistently higher in the left lateral position than in the right lateral position, using the supine phlebostatic axis (P1) and the mid-sternum (P3) as references for the transducer. This would support the findings of Doering et al. (1988) and Whitman et al. (1982). An increase in CO in the left lateral position could be reflected in an increase in

adjustments. In the sample studied, neither landmark for the transducer adjustment was indicated as useful for obtaining accurate PASP or PADP measurements with the patient in a 30 degree lateral position with the head-up 20 degrees. The direction and the similarity in the magnitude of the pressure changes using both the right lateral phlebostatic axis and the mid-sternum as landmarks for the transducer adjustment in 30 degree lateral positions lend support to the theory that the pressure changes observed may be due to hydrostatic error alone. It should be noted that no correlation was found between catheter tip position for total pressure change however, as explained above, the catheter tips were more central than predicted. The results of the use of the mid-sternum (P3) as a reference for the transducer adjustment support the work of previous researchers (Keating, 1986; Wild, 1984) who examined PAP in lateral positions less than 90 degrees.

In summary, the major findings of the study indicate that the supine phlebostatic axis may be a useful reference for the transducer adjustment which allows for the collection of reasonably accurate PASP and PADP in 30 degree lateral positions in some patients.

Other Findings

Although previous researchers have found no differences

in PAP between mechanically ventilated versus non-mechanically ventilated subjects following various head-up positional changes (Chulay, 1984; Nemens, Woods, 1982; Woods et al., 1982), it was expected that lateral positioning might demonstrate significant differences between the 2 groups. Any unilateral chest wall restrictions that might occur when a subject lies on one side could potentially increase inspiratory pressures particularily in mechanically ventilated subjects on positive end expiratory pressure (PEEP). Increases in intrathoracic pressures could then be reflected in changes in central vascular volumes and flow which in turn would be reflected in PAP variations. This was not supported by the results. The only important difference exhibited between the non-mechanically ventilated subjects and the mechanically ventilated subjects was in the changes in the PASP between the 3 supine control measurements.

Only the non-mechanically ventilated subjects demonstrated statistically significant differences between the PASP recorded in the first and the second supine positions. This could be explained by the researcher's observation that non-mechanically ventilated subjects tended to be more awake than the ventilated subjects. Thus, non-mechanically ventilated subjects would tend to be more aroused physiologically by the series of positional changes that followed the first supine measurements.

There were no differences in the results when subjects with an abnormal pH (n=7) were selected out of the series of statistical analyses. As long as the pH remained constant in all subjects, even in those subjects who had a low pH, one would not anticipate a variance in PAP resulting from a low pH.

It was expected that subjects with pulmonary hypertension might demonstrate a different physiological response to lateral positioning which in turn would be reflected in variations in PAP. However, there was little evidence that this was the case when individual variations in PASP and PADP of the 11 subjects with PA hypertension were examined (Table 4,& Appendix S). This may be due to the fact that none of the subjects were severely hypertensive. Another possible explanation is that there is no difference in the physiologic response to the lateral positioning between these two groups.

Limitations

The major limitations of the study relating to the instruments utilized as well as the sampling technique are presented.

Instruments

The criteria to include only subjects with a PA catheter in the right pulmonary artery had to be abandoned because of a concern for lack of subjects. It was observed that in the unit in which the study was conducted, PA catheter placement tended to be more central than anticipated.

The results of the statisitical analyses used to demonstrate differences between groups based on catheter position should be viewed with caution due to the limitations related to the interpretation of the catheter position. The catheter position was determined by calculations based on supine anterior posterior chest x-rays that were done within a minimum of one hour after the study. Pulmonary artery catheters tend to migrate over time, and/or during positional changes (Benumof et al., 1977; Daily, 1985). Thus, the catheter position recorded following the chest x-ray may not have been representative of the catheter position throughout the study. Also, the actual vertical height of the catheter tip in the supine position could not be determined using an anterior posterior chest x-ray. It was assumed that supine catheter tips were at the level of the supine phlebostatic axis. This assumption may have been false. Furthermore, no attempt was made to correct for error in chest x-ray interpretation that may have resulted from slight degrees of patient rotation.

Although a 30 degree firm foam wedge was used to offer some consistency in the sidelying position, there may have been some element of change in the true lateral angle due to the variety of patient sizes. Also, some degree of change in the actual level of the catheter tip in relation to the transducer adjustment may have occured as a result of the patient slipping down in bed. In 19 subjects the average change in the vertical height of the supine phlebostatic axis was 1.6 cm. This was documented by marking the 3 vertical heights of the supine phlebostatic axis along the vertical axis of an intravenous pole. However, subtle differences in the supine position may have resulted in some error in terms of recording the vertical heights of the phlebostatic axis.

Sample

The study was conducted on a convenience sample of 40 subjects. Generalizing the results should be restricted to other groups with similar attributes. Replications of this research on a variety of patient populations would have to be conducted in order to strengthen the external validity of the study.

Implications for Practice and Research

Implications for Practice

In most patients with similar attributes to the sample studied, the supine phlebostatic axis may be a useful

reference for the transducer adjustment that will allow the nurse to obtain reasonably accurate PASP and PADP while they are in an approximate 30 degree lateral position with the head-up at 20 degrees. Patients with similar attributes would include both male and female post cardiac surgical patients in whom time elapsed since surgery is greater than 8 hours, and who range in age from 38 to 71 years. An increase in PASP (< 5 mmHg) and PADP (< 4mmHG) in both the right and left lateral position should be expected. If the changes observed represent decreases in PASP and PADP and /or exceed a change of 5mmHg and 4 mmHg respectively when compared to the supine readings, the author recommends that all PAP should be taken in the supine position.

Because some patients may show clinically significant changes in PASP and/or PADP when moved from a supine to a 30 degree lateral position, it is recommended that a careful record of the PAP change and the position should be kept to determine which patients could have valid PADP and PASP measured in a 30 degree lateral position. This would allow nurses to refrain from subjecting some patients with PA catheters to the stress of frequent repositioning.

It should be emphasized that the results would only apply to the measurements of PASP and PADP. The effect of lateral positioning on PA wedge pressure (PAWP) was not examined in this study and thus it is advised that nurses should continue

to obtain PAWP with the patient in a supine position. When the balloon on the tip of the PA catheter is inflated to obtain PAWP, the catheter is thought to float more peripherally. This could potentially exaggerate hydrostatic error when the patient is in a lateral position. However, where PADP could be used as a relative indication of PAWP, the direct measurement of PAWP could be reserved for the supine position, and estimated from the PADP when the patient is in a 30 degree lateral position.

Implications for Further Research

Replication of this research using different patient populations would be necessary in order to generalize the results across critical care units. Also, further research examining different lateral angles would help to determine the extent to which the use of the supine phlebostatic axis may be useful as a zero reference for the transducer adjustment in lateral positions.

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pulmonary artery and pulmonary capillary wedge pressures in acutely ill patients. Heart and Lung, 11(5), 393-398.

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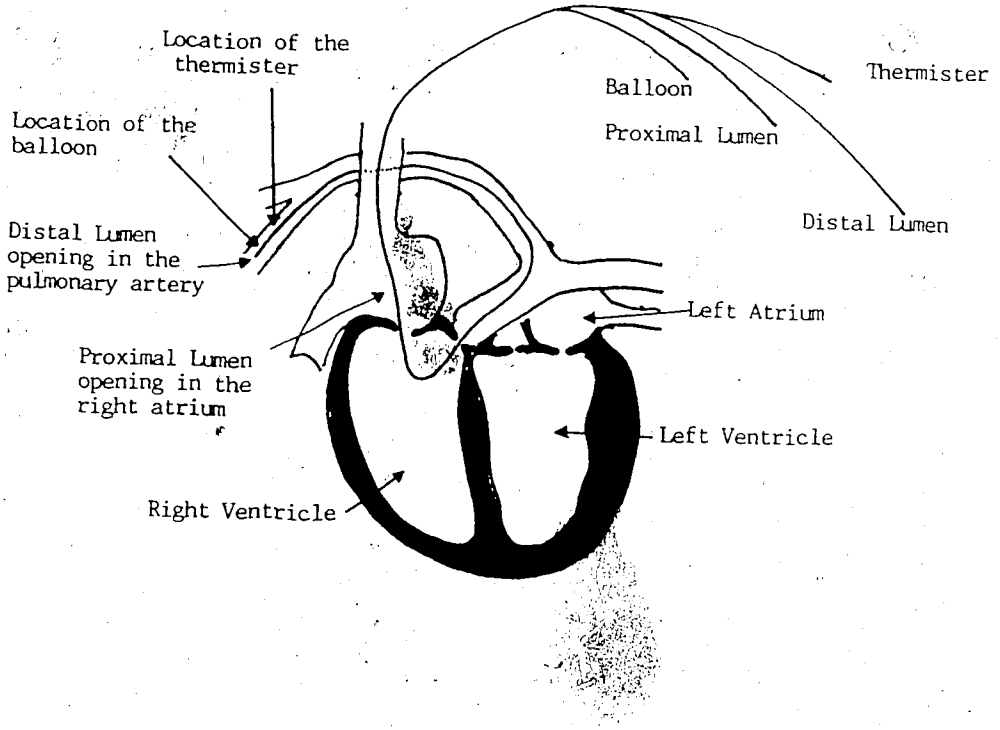
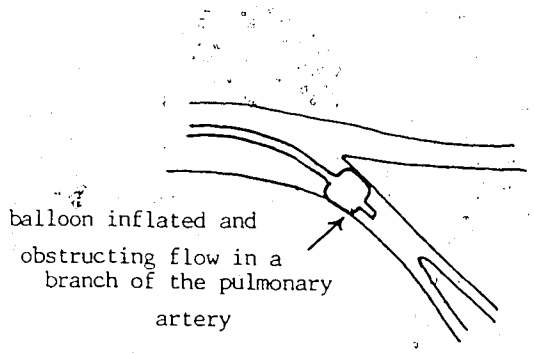
APPENDIX A

A Four Lumen Pulmonary Artery Catheter
In Proper Position

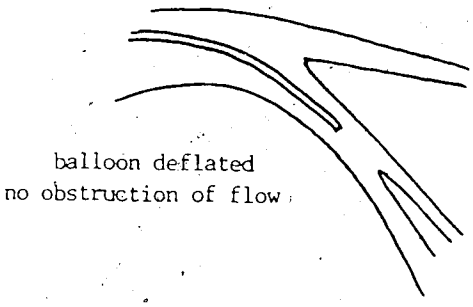


APPENDIX B

Obtaining Pulmonary Artery and Pulmonary Wedge Pressures



Pulmonary Wedge Pressure Procedure



Pulmonary Artery Pressure

APPENDIX C

Vascular Pressures and Volumes that may be Monitored Using a Pulmonary Artery Catheter

Pulmonary Artery Pressure

This pressure may be obtained from the distal lumen of the catheter located in a branch of the pulmonary artery.

Pulmonary artery systolic pressure (PASP)

normal PASP = 20-30 mmHg
reflects the force generated by the contracting right ventricle_during the ejection phase and the pulmonary vascular resistance which is a function of Poiseuille's law of resistence (vascular resistence = viscosity, tube length, and 1/tube radius (4th power)

Pulmonary artery end diastolic pressure (PAEDP)

normal PADP = < 12 mmHg
Because the pulmonary vasculature is a low resistance bed, the PAEDP generally does not exceed left atrial pressure (LAP) by more than 2-4 mmHg and thus has been used as a relative indication of LAP. The correlation between PAEDP and LAP is unreliable if there is pulmonary hypertension (Marini, 1986; Daily, Schroeder, 1985; Pace, 1977) or if there is a tachycardia > 130 beats per minute (Daily, Schroeder, 1985).

Pulmonary Artery Wedge Pressure (PAWP)

This pressure may be obtained from the distal lumen of the catheter when the balloon located near the tip is inflated so that it obstructs flow from the right heart past the tip of the catheter. In normal subjects, PAWP, LAP, and left ventricular end diastolic pressure (LVEDP) are interchangeable (Pace, 1977). Normal PAWP = 5-12 mmHg

Right Atrial Pressure (RAP).

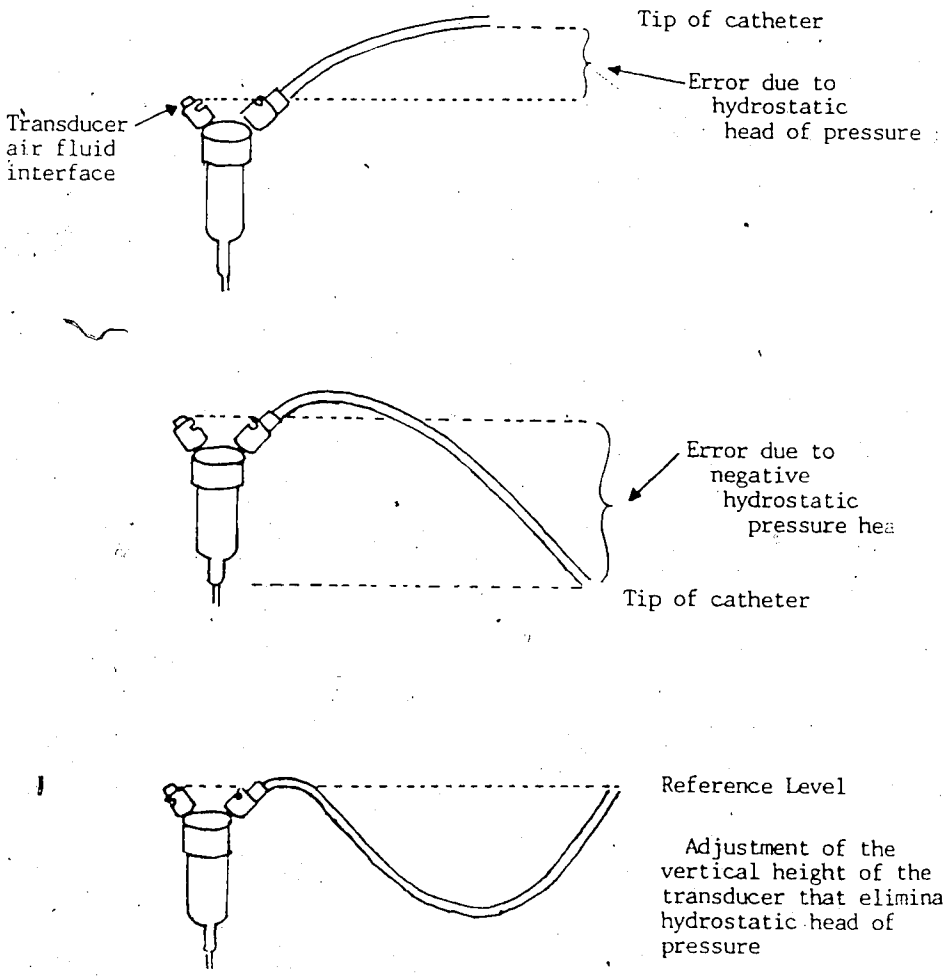
This pressure reflects right ventricular end diastolic pressure (RVEDP) which is an indication of the preload or volume in the right ventricle. Normal = 2-5 mmHg.

Cardiac Output by the Thermodilutional Technique

Normal resting cardiac output = 4-8 L/minute
A solution of known volume and temperature is injected into the right atrium in less than 4 seconds. A thermister situated near the distal lumen of the catheter, records the temperature changes as the solution flows past the thermister. Provided a cardiac output computer is connected to the thermister wire, is calibrated, and is operated appropriately, the cardiac output is calculated by the computer on the basis of the temperature changes detected by the thermister.

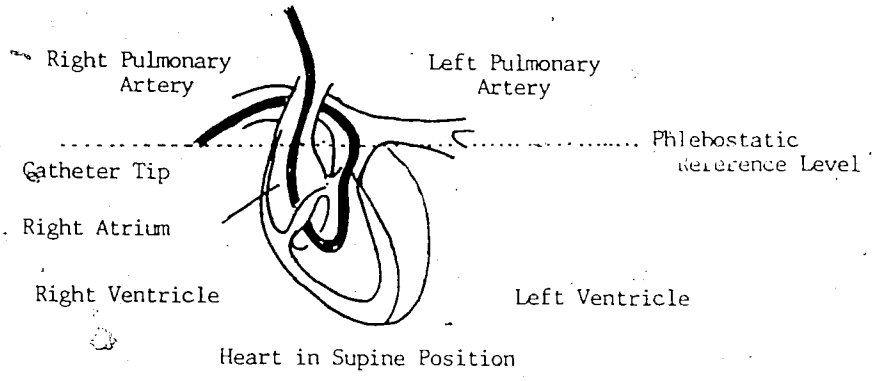
APPENDIX D

Sources of Error Due to Hydrostatic Head of Pressure

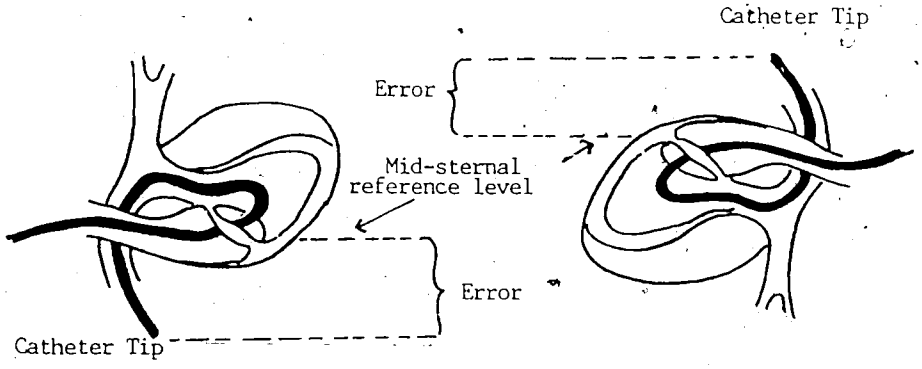


APPENDIX E

Sources of Error Due to Mid-sternal Reference Level



Heart in Supine Position

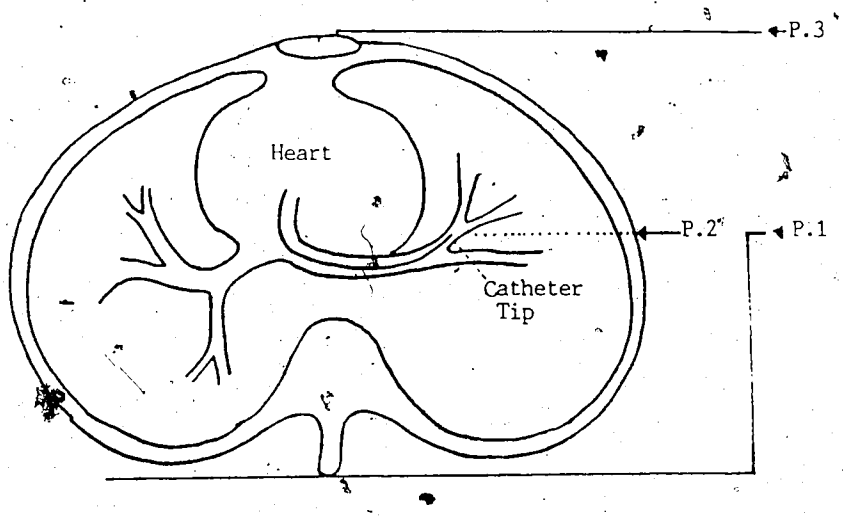


Heart in Right Lateral Position(90°)

Heart in Left Lateral Position (90°)

APPENDIX F

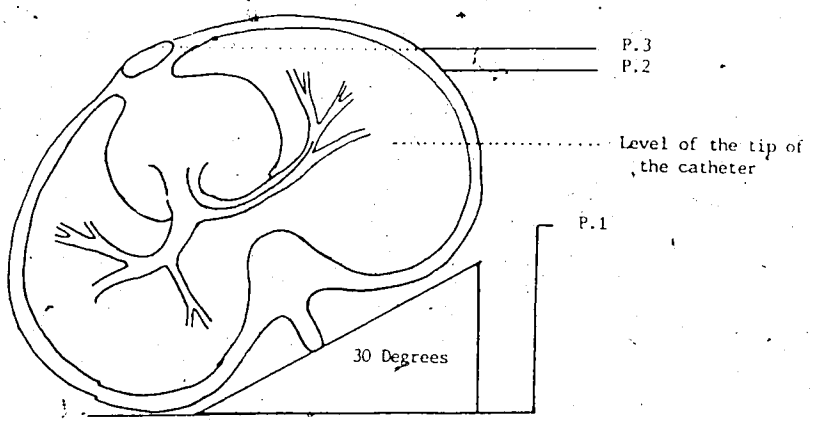
Transverse Views of the Thorax



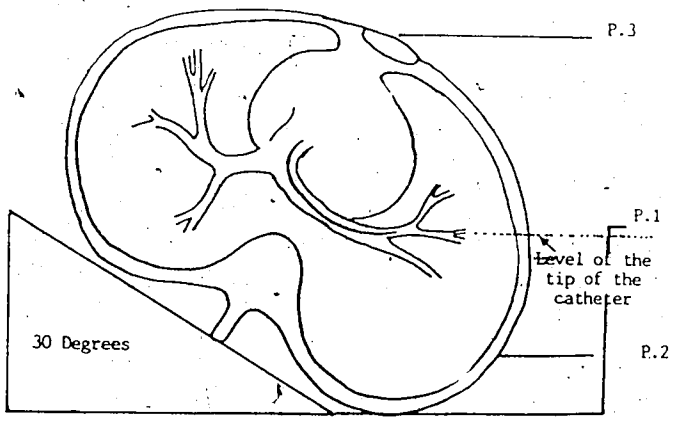
Supine Position

P.1 represents the vertical height of transducer when the patient is in a supine position.
P.2 represents the vertical height of the phlebostatic axis.
P.3 represents the vertical height of the mid-sternum.

APPENDIX F



Left Lateral Position



Right Lateral Position

APPENDIX G

Consent

CONSENT FORM
UNIVERSITY OF ALBERTA FACULTY OF NURSING

Project Title: A Comparison of Pulmonary Artery Pressures in Supine and Lateral Positions using Three Adjustments of the Pressure Transducer.

Investigator: Carolyn J.M. Ross MN Candidate

I _____(print name) have had the study entitled "A Comparison of Pulmonary Artery Pressures in Supine and Lateral Positions using Three Adjustments of the Pressure Transducer" explained to me verbally by Carolyn Ross. I understand that: a) a special line is placed in the blood stream as part of the routine care of patients who have operations such as the one I will have; b) this special line, called a pulmonary artery catheter, provides the staff with important information about the performance of my heart; c) accurate information from this line can be obtained while patients are lying on their backs; d) it is not known if accurate information can be obtained from this line when patients are lying on their sides. I understand that the purpose of this study is to help determine if accurate information can be obtained from this line when patients are lying on either their right or left sides.

The study will be carried out within 24 hours after my surgery. I understand that my participation in this study will require my doing one thing which is not routinely done. Over a period of about one hour, I will be required to change the position in which I am lying 5 times as follows: back, side, back, side, back. A rest period of about 10 minutes will follow each position change. During the study the head of my bed will be kept up about two pillow heights, and when I am on my side, a firm foam wedge will be placed behind by back for support. To test the information obtained from the line, 2 points on my chest will be marked with a felt pen that has washable ink.

I understand that if I do not participate in this study it will not influence my medical or nursing care. I understand that I may withdraw from the study at any time. Also, I understand that any information which may identify me will be kept only by the researcher and will be destroyed at the end of the study. I understand that I will remain anonymous in any research report that may result from this study.

I realize that there may be no direct benefit to me for participating in this study, but that the results of this study may benefit the nursing care of patients in the future.

I have been given the opportunity to ask questions about this study, and all such questions have been answered to my satisfaction.

I agree to take part as a volunteer in the above study.

Signatures:

Subject: _____ Witness: _____

Date: _____

APPENDIX H

Randomly Assigned Sequence of Positional Changes and Transducer Adjustments

Case	Position Sequence	Transducer Sequence	Case	Position Sequence	Transducer Sequence
1	A	1,2,3	21	A	1,2,3
2	B	3,2,1	22	B	3,2,1
3	A	3,2,1	23	A	3,2,1
4	B	1,2,3	24	B	1,2,3
5	A	1,2,3	25	A	1,2,3
6	B	3,2,1	26	B	3,2,1
7	A	3,2,1	27	A	3,2,1
8	B	1,2,3	28	B	1,2,3
9	A	1,2,3	29	A	1,2,3
10	B	3,2,1	30	B	3,2,1
11	A	3,2,1	31	A	3,2,1
12	B	1,2,3	32	B	1,2,3
13	A	1,2,3	33	A	1,2,3
14	B	3,2,1	34	B	3,2,1
15	A	3,2,1	35	A	3,2,1
16	B	1,2,3	36	B	1,2,3
17	A	1,2,3	37	A	1,2,3
18	B	3,2,1	38	B	3,2,1
19	A	3,2,1	39	A	3,2,1
20	B	1,2,3	40	B	1,2,3

APPENDIX I

Biographic and Demographic Data

Biographic and Demographic Data

Patient's Name:_____ Hospital No._____
Admission date:_____ Date study completed:_____
Patient id. code:____ Age:____ Sex:___Height:____Weight:____
Chest: circumference _____ width ___ depth ___
Location of catheter: _____
Diagnosis:

Current fluids and medications: IV intake/hr._____
PRN med (given 1 hr before or during study) _____
Routine med: Dopamine_____ Nipride _____ Nitroglycerin_____
Other

Mechanical ventilator assistance___yes___no (If yes describe)
Mode:_____ Rate:____ Inspiratory pressure:____ Peep _____
Fio2:_____ H+:____ PaO2:_____ Suctioning during study_____

Time study started_____Time study completed_____

Codes randomly assigned for 10 breath pressure recordings

*Group A / Group B Position Sequence	Transducer Adjustment Sequence	Code	Pressure Mean	PASP	PADP	Pulse	Resp.
Supine 1	P.1	____	____	____		____	____
R./L. Lat.	P.1 or P.3	____	____	____		____	____
	P.2	____	____	____		____	____
	P.3 or P.1	____	____	____		____	____
Supine 2	P.1	____	____	____		____	____
L./R. Lat.	P.1 or P.3	____	____	____		____	____
	P.2	____	____	____		____	____
	P.1 or P.3	____	____	____		____	____
Supine 3	P.1	____	____	____		____	____

*Circle the assigned group and transducer sequence used. Note: Patients are assigned alternately to position sequences A or B following the random assignment of the first patient. Within the groups, patients are alternately assigned to one of two sequences of transducer level adjustments.

R./L. Lat. (right or left lateral position)
P.1 (transducer is level with the supine phlebostatic axis)
P.2 (transducer is level with the lateral phlebostatic axis)
P.3 (transducer is level with the mid-sternum)

APPENDIX J

Pulmonary Artery Pressure Protocol

Protocol for the Pulmonary Artery Pressure Study

1. A portable Hewlett-Packard Neonatal Monitor (78801B) and Gould 22400s four channel strip recorder will be brought to the subject's bedside, attatched to a power source, turned on, and allowed a 15 minute warm up period.

2. The subject's PA transducer will be detatched from the bedside monitor and attatched to the portable monitor.

3. An electrocardiographic cable will be attatched to three electrodes that will be placed on the patient's chest wall as follows: the black connector will be attatched to an electrode placed between the 2nd and 7th intercostal space on the right mid-axial line, the green connector will be secured to an electrode placed between the 6th intercostal space and the waist on the left mid-axial line, and the white connector will be attatched to an electrode placed in the 2nd intercostal space on the left side of the sternum.

4. The subject's right phlebostatic axis and mid-sternal landmarks will be located and marked with a water soluble felt pen.

5. The subject will be placed in the supine position.

6. The angle of the head of the bed will be adjusted to a 20 degree angle using a 20 degree wedge.

7. The graph recorder and the transducer will be calibrated using a mercury manometer.

8. The air-fluid interface of the transducer will be adjusted to P.1.

9. A stopwatch will be utilized to signal the elapse of five minutes from the completion of the position change.

APPENDIX J

10. A recording of the electrocardiogram (lead I), respiratory waveforms and the pulmonary artery waveforms will be done over 10 consecutive patient breaths. The printout will be assigned a code and then removed from the recorder.

11. Subjects in group A will then be placed in the right lateral position (group B in the left lateral position)

12. During a 5 minute rest period (timed by a stopwatch) the researcher will adjust the transducer to either P.3 or leave it at P.1

13. Repeat step 10.

14. Adjust the transducer to P.2 and then repeat step 10.

15. Adjust the transducer to either P.1 or P.3 and repeat step 10.

16. Place the subject in the supine position and repeat steps 8-10.

17. Subjects in group A will be placed in the left lateral position (group B in the right lateral) and repeat steps 12-15.

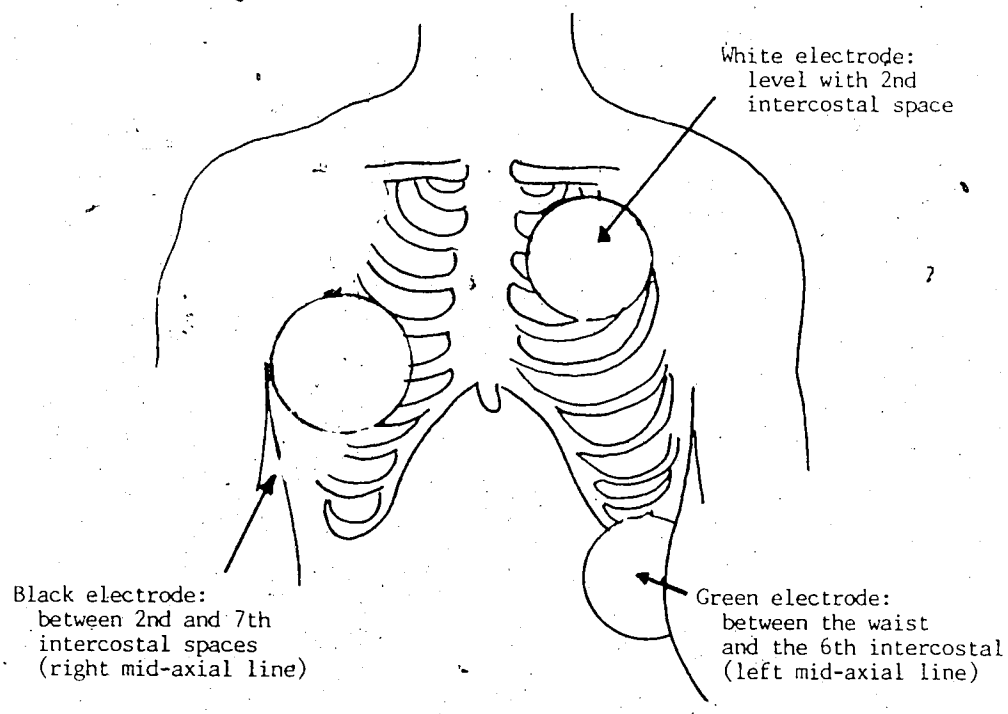
18. Place the subject in the supine position and repeat steps 8-10.

19. The PA transducer cable will be reconnected to the bedside monitor and recalibrated.

20. The randomly numbered graphic printouts will be stored and interpreted once five studies have been completed.

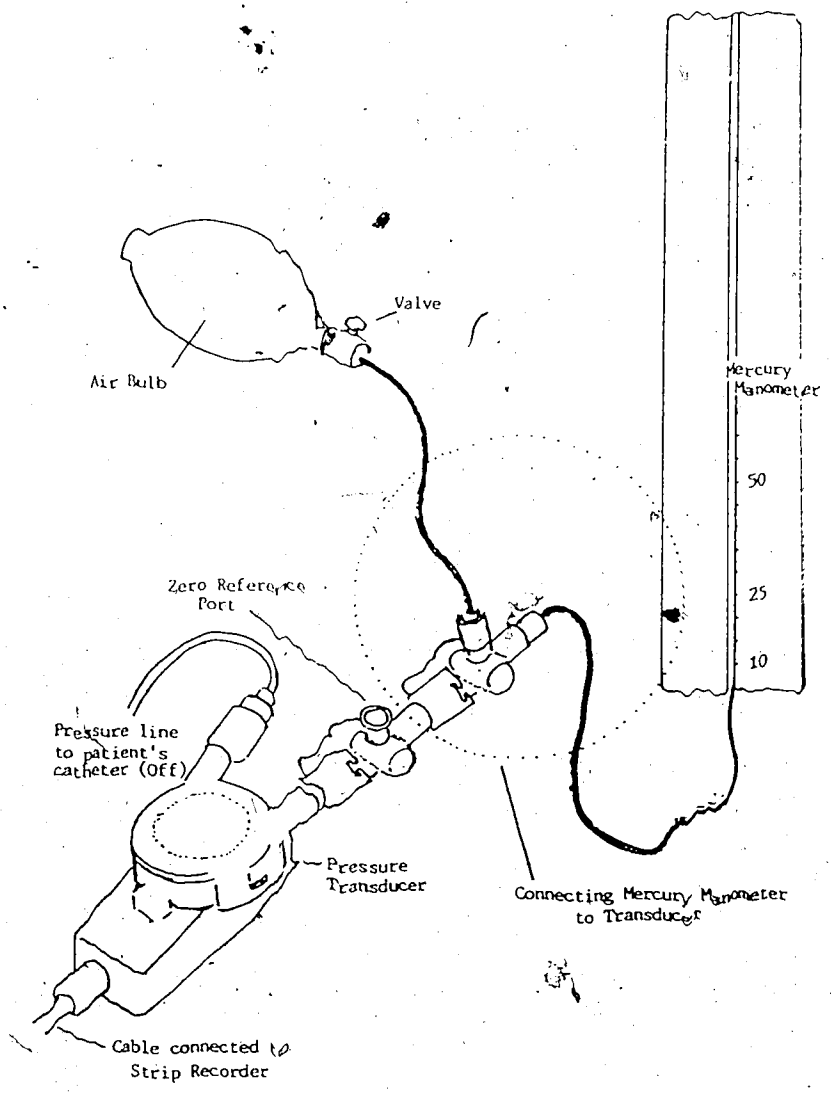
APPENDIX K

Electrode Positioning



APPENDIX L

Calibration

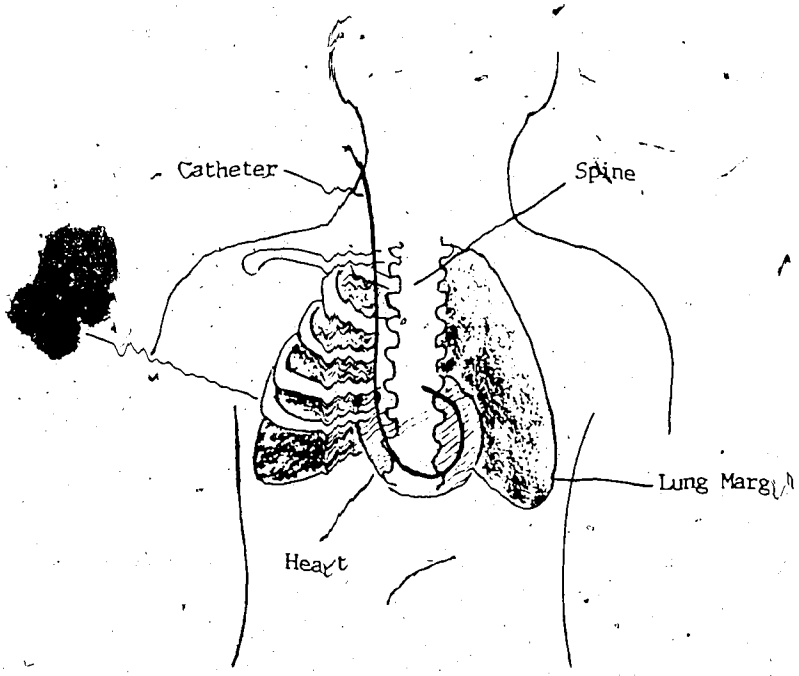


Schematic of the system used to calibrate the pressure transducer

-the squeeze bulb was used to provide a a pressure on the mercury manometer and the output of the transducer was adjusted to an appropriate level on the strip chart using the gain control

APPENDIX M

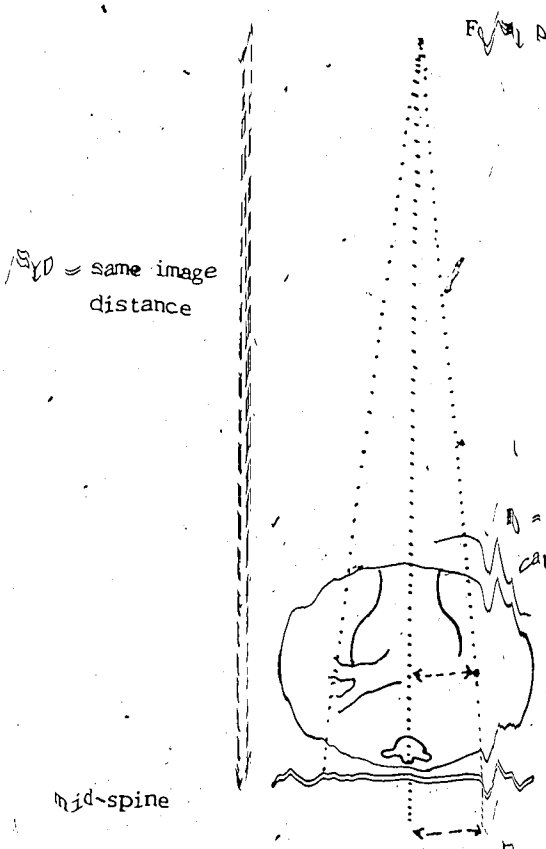
Locating the Catheter Tip Using Chest X-ray Landmarks



X-Ray Landmarks

APPENDIX

X-Ray Magnification



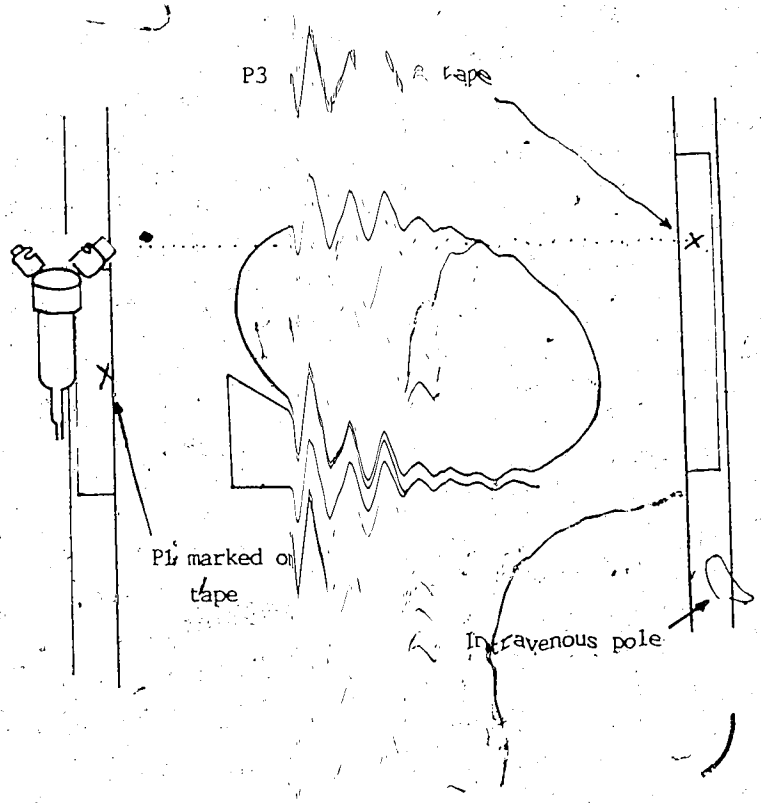
To determine D = DI $\left(\frac{SID}{SI}\right)$

APPENDIX O

Data Collection Sheet

Appendix P

Transducer Adjustment to the Mid-sternum (P3) and the Supine Hydrostatic Axis (P1)



APPENDIX Q

Individual Mean Changes in the Lateral Systolic Pressures Compared to Mean Supine Readings

Case	Supine Mean	Right Lateral P1	Right Lateral P2	Right Lateral P3	Left Lateral P1	Left Lateral P2	Left Lateral P3
1	25.06	0.06	-2.14	11.26	-3.94	5.66	7.06
2	30.33	1.33	-3.47	11.63	-2.27	3.53	4.43
3	24.70	-1.80	-7.20	5.20	-1.20	8.70	5.50
4	35.33	-3.37	-4.47	12.33	-6.07	2.03	7.63
5	21.03	-1.17	-5.97	7.63	-0.77	6.23	8.53
6	24.33	0.23	-6.67	4.83	-0.57	7.93	6.33
7	24.67	-1.23	-4.43	8.17	-3.33	4.77	8.57
8	33.47	-0.73	-4.73	12.37	-3.53	5.97	8.67
9	29.33	-1.17	-3.97	7.33	-2.07	6.83	9.93
11	43.07	-1.73	-6.53	9.27	-0.13	4.87	9.67
12	31.73	-1.87	-5.17	11.13	-5.17	4.83	4.23
13	47.00	1.30	-5.60	8.70	-4.80	6.20	8.50
14	50.60	-5.30	-9.50	4.40	-1.00	4.50	4.10
16	32.30	-3.80	-7.50	9.70	-4.40	8.70	6.80
18	20.00	-0.50	-8.60	7.30	-2.00	5.50	6.90
19	21.80	0.80	-3.20	11.70	-1.70	6.80	8.70
20	36.50	-6.80	-12.00	3.90	-2.90	4.10	7.10
21	22.57	-3.53	-7.03	5.47	-3.43	3.17	4.57
22	36.17	-2.13	-8.23	5.07	-4.33	2.57	3.77
24	25.33	-0.97	-8.07	8.23	-1.77	5.43	7.33
25	34.80	-2.40	-6.80	6.00	-2.60	6.10	9.30
26	24.60	-1.50	-7.50	5.90	-2.50	5.80	5.70
27	37.57	-2.13	-6.73	4.87	-3.63	-0.03	3.77
28	27.20	-2.40	-3.80	4.40	-4.60	4.40	3.50
30	20.20	-1.90	-12.80	3.90	0.00	7.60	7.40
31	23.90	-1.30	-6.80	7.20	-1.80	5.40	2.40
32	58.17	-3.63	-10.63	6.17	-2.93	3.37	2.97
33	20.10	-1.10	-5.80	9.10	-4.80	3.10	5.10
34	36.33	-0.67	-7.07	5.63	-4.07	4.43	3.33
35	36.13	-5.57	-10.97	2.33	-4.67	4.03	6.53
37	23.03	-2.57	-5.67	6.03	-2.17	9.03	6.33
38	33.87	-4.63	-8.83	1.67	-1.63	5.27	4.77
39	47.23	0.13	-6.07	8.13	-4.67	9.93	7.13
40	24.57	-1.63	-7.43	10.07	-3.93	6.17	8.17
41	25.20	-1.30	-6.90	5.00	-2.80	6.50	7.80
42	46.70	2.60	-3.30	8.80	-3.90	3.20	3.60
43	35.80	-3.10	-7.70	3.00	1.30	4.60	6.60
44	29.40	-0.60	-5.10	7.60	-2.30	6.80	7.40
45	35.93	-2.77	-7.17	7.23	3.93	11.43	8.53
47	26.93	-0.67	-7.97	5.63	-3.97	5.33	4 13

Negative number indicates that the lateral pressure is greater than the supine pressure (Supine - Lateral)

APPENDIX R

Individual Mean Changes in the Lateral Diastolic Pressures Compared to Mean Supine Readings

Case	Supine Mean	Right Lateral P1	Right Lateral P2	Right Lateral P3	Left Lateral P1	Left Lateral P2	Left Lateral P3
1	12.57	-0.43	-2.93	9.87	-2.03	6.97	8.57
2	16.17	-0.93	-5.53	9.07	-2.13	5.27	5.07
3	15.60	-1.20	-6.30	5.70	-1.40	8.20	5.50
4	18.83	-3.07	-5.07	10.03	-3.37	5.23	8.33
5	10.70	-2.40	-7.80	5.8	-2.00	5.10	7.10
6	10.87	-1.53	-7.93	3.57	-1.13	7.87	6.87
7	16.60	0.30	-3.30	9.20	-5.20	3.50	7.50
8	12.93	-3.87	-8.27	7.83	-1.97	6.63	8.43
9	13.07	-1.13	-4.83	7.07	-1.33	6.57	8.17
11	25.70	1.30	-3.60	11.20	-0.90	7.90	10.50
12	20.00	-0.90	-4.30	10.00	-1.20	8.40	8.60
13	24.87	0.27	-6.53	7.27	-4.53	6.87	7.87
14	25.93	-1.27	-6.73	7.73	1.23	8.63	8.13
16	18.70	-2.40	-6.40	10.20	-3.70	8.60	6.20
18	11.40	-1.10	-9.10	6.70	-2.30	5.20	6.90
19	13.00	0.00	-4.00	10.60	-2.00	7.00	9.10
20	21.77	-3.53	-8.33	6.97	-1.13	5.77	9.47
21	14.63	-2.77	-6.37	5.53	-3.37	5.23	6.23
22	19.77	-2.63	-8.83	5.57	-2.23	4.87	6.47
24	16.30	1.30	-5.40	10.30	-2.00	6.30	8.30
25	19.06	-1.54	-5.94	7.26	-3.14	6.26	9.06
26	15.33	-0.57	-6.47	7.43	-2.27	6.33	6.33
27	20.73	-2.27	-7.07	5.43	0.53	5.33	8.73
28	15.13	-3.17	-8.87	3.83	-2.17	5.63	5.13
30	11.93	-1.27	-12.27	5.93	-1.57	6.33	6.03
31	15.17	-1.23	-6.03	6.97	-0.33	7.27	4.07
32	25.80	1.10	-8.90	8.40	0.40	5.90	7.20
33	11.10	-1.20	-5.90	8.10	-3.60	4.60	6.60
34	23.40	-1.60	-7.90	5.40	-1.40	7.30	6.20
35	18.73	-6.17	-10.77	5.83	-3.67	6.13	7.83
37	11.17	-2.93	-5.43	5.47	-2.13	8.37	6.17
38	19.13	-2.47	-7.77	4.83	0.23	7.83	7.23
39	26.20	1.00	-4.50	10.20	-3.50	8.60	5.40
40	18.07	-1.23	-5.93	10.47	-2.03	7.67	8.97
41	14.33	-0.17	-6.17	6.63	-2.17	6.83	8.13
42	20.03	0.93	-5.97	7.33	-2.87	4.73	5.53
43	20.83	-2.67	-6.77	4.23	-1.87	2.03	5.13
44	16.20	-0.20	-4.50	8.30	-1.10	8.60	7.70
45	20.07	0.47	-3.83	10.27	0.97	9.17	9.97
47	18.83	-0.77	-8.37	5.23	3.37	5.83	4.93

Negative number indicates that the lateral pressure is greater than the supine pressure (Supine - Lateral)