Simulation Case Library: The Case of the Coiled Cardiac Catheter

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Original Article

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Abstract

Many medical disciplines participate in the acute care of hemodynamically unstable patients. At WVU we have many opportunities for multidisciplinary critical care group instruction in our simulation facility. The main educational goals of this session are the recognition and management of a pulmonary artery catheter that is coiled in the right ventricle. Recognition of waveforms and identification of catheter malposition are a priority in our critical care education programs. We present the scenario using the METI model C manikin with system 5.5 software. The target audiences for this scenario at WVU include junior house staff from assorted disciplines, masters level physician assistant students, and medical students during the second and fourth years of training. This scenario has also been included in a critical care medicine CME course for a variety of health care practitioners. We present a variety of the manufacturer's pre-packaged hemodynamic instability scenarios. Standard man awake or relaxed with the hypotension-hemorrhage scenario is described in detail. The focus is on catheter misplacement rather than on disease state. Despite prior preparation from lecture with slides, textbook review, ordemonstration without patient context, most students do not recognize a right ventricular waveform when it is simulated in the context of a patient care scenario. Debriefing occurs immediately in the simulation laboratory and includes a review of typical waveform and pressure transitions as the catheter passes from the introducer to the wedge position. Measurement of cardiac output is demonstrated. A variety of electronic resources are suggested for further self-study and more complete review of invasive monitoring principles and techniques. Students over the past 4 years have had an overwhelmingly positive response to this simulation experience.

Background

Controversy about the use of pulmonary artery (PA) catheterization is multidisciplinary and international. Some groups have argued that the risks far exceed the benefits. [1] Catheter related complications are serious and potentially lethal. Misinterpretation of data and irrational therapy may independently produce morbidity or death. Many case reports appeared in the past decade describing morbidity and mortality related to pulmonary artery catheter (PAC) placement. Two case reports describing new, unusual, & serious intra-operative complications appeared recently. [2,3] The principle criticisms of this technology are cost, complications, and absence of proof of benefit to the patient. Proponents of this technology offer guidelines and educational programs to insure maximal safety. [4,5] Conversely, management of many high-risk patients can be facilitated. A new evidence-based report synthetizes the results of 21 different randomized controlled studies of PAC use in the ICU and strongly advocates PAC use before the onset of end organ failure to optimize oxygen delivery. [6]

Educational Objectives

1. To recognize the characteristic PAC waveform associated with the right ventricle (RV).
2. To review waveform sequences visualized during PAC insertion
3. To compare the quantitative and qualitative changes that occur in the PAC trace passing from RV into PA.
4. To identify the measured PAC insertion depth.
5. To associate the appearance of arrhythmias with potential PAC malposition.
6. To discriminate between normal and abnormal PAC pressures.
7. To discuss the correct procedure for repositioning an errant PAC.

Technical Description

The METI *(METI, give city, state)* model C full-scale manikin was used for this case. A patient monitor capable of measuring cardiac output and displaying multiple ($\geq$3) simultaneous invasive pressure traces is essential. Resuscitation drugs and basic airway equipment are available. The PAC is fixed at an insertion depth of 70 cm in our METI manikin. The syringe attached to the catheter hub does result in a wedge trace when the balloon is inflated when the "PA" is selected for catheter position. If one wishes to illustrate a different catheter depth with this type of manikin, a separate non-integral PAC may be positioned and dressed at either the subclavian or internal jugular position. In this exercise the PAC will not wedge in response to balloon inflation because the "RV" is selected for catheter position.

We have run a variety of different shock scenarios to illustrate catheter misplacement. We have used the patients and scenarios provided by METI or have programmed our own. The disease state is not part of the learning objectives. It is simply a backdrop for learning about the invasive monitoring equipment. The pneumothorax, cardiac tamponade and anaphylaxis scenarios decompensate too quickly. Because rapid intervention is needed for manikin survival in these scenarios, they are not appropriate for an exercise where students must have sufficient time to focus on diagnosis and treatment. Any scenario that transitions automatically as a function of time would have the same limitation. Therefore we select a scenario that allows a beneficial learning experience for the group even if the diagnosis of right ventricular catheter position occurs rapidly. The preprogrammed scenarios that we found most useful are hemorrhage, anaphylaxis, sepsis, and congestive heart failure. These scenarios are overlaid on the “standard man awake” or “standard man relaxed” patient.

Target Audience

The critical care environment is a prototype for a multidisciplinary team centered approach to patient care. At WVU, we educate a variety of health care personnel, residents, medical students and physician assistants, to perform in this environment. The resident teams include trainees from anesthesia, surgery, surgical subspecialties, emergency medicine and internal medicine. The physician assistants are pursuing masters degrees in either surgery or emergency medicine. The medical students have participated during their 2^{nd} and 4^{th} years. The station is designed to resemble an ICU bay. A clinical monitor with color display and manikin reclining in a patient bed are the only equipment initially present. Students may request drugs and airway equipment for patient management.

This simulation experience has been an integral part of several on-going or repeated courses including the medical student introduction to clinical skills, medical student fourth year required rotation in anesthesiology and Fundamentals of Critical Care Support (FCCS) for the past 3 years. [7] The only groups for whom this exercise has been too simplistic (i.e. who rapidly and accurately identified PA catheter malposition) are CA2-3 anesthesia residents with moderate exposure to intensive cardiovascular management and experienced ICU nurses. The format that we have employed is small group teaching with 6-8 students/group.

Simulation Script (general)

We allow approximately 30 minutes for completion of this simulation exercise. The scenario is terminated after 20 minutes and debriefing begins. The past medical history given is relevant to the pathophysiology selected. The participants are informed that the ICU nurse has requested that they re-evaluate the patient following ICU admission. She is concerned about a low mean PAP. They are also told that neither the systemic arterial pressures nor the systolic PA pressure have changed. The low mean PAP is actually the result of RV positioning with the accompanying decrease in diastolic pressure. Arterial pressure, central venous pressure and PAC traces are displayed. “Right ventricle” is selected for the PAC placement. The monitor scales are initially set at 40 for the CVP and PA catheters and 200 for the arterial catheter. The students have the option to change the display scale at any time.

Transducers are not part of the manikin’s invasive monitoring hardware. We do not emulate the clinical transducer system for this scenario. Transducer function and error are not in the learning objectives for this elementary exercise. There is minimal drift in our Marquette Solar 8000 monitor and METI manikin. Pressures are zeroed before the start of each simulation. The students may ask to check a zero for any of the pressure traces displayed during the simulation.

Most groups do not recognize or comment upon the bizarre waveform. They focus upon medical diagnosis and treatment. If no mention of catheter position is noted for 5 minutes, then the cardiac rhythm changes to include 25% premature ventricular contractions (PVC's). If an additional 5 minutes passes without comment, then short, 10 second, runs of ventricular tachycardia are introduced at a frequency of 1 segment/minute.

Some participants have asked for a diagnostic chest x-ray during the simulation exercise. We employ a realistic 5-10 minute time delay between the request for x-ray services and the actual arrival of equipment and personnel. The scenario continues to progress during this time. There are 2 potential options if an x-ray is ordered very early in the scenario. During initial positioning of the patient for the diagnostic x-ray procedure, the scenario could progress very rapidly to the introduction of runs of ventricular tachycardia. A second option is to have an x-ray of a coiled RV catheter available to display.

If clinical accuracy of the hemodynamic data is important to your teaching session, it is important to check these values well in advance of the session. Werecognized incorrect METI-generated data for cardiac output and systemic vascular resistance during sepsis. The cardiac outputs are lower than expected and the SVR values are relatively normal. The 62 year old simulated patient with atrial fibrillation displays a cardiac output measurement $\geq$ 6.5 l/min with normal systemic and PA pressures.

Simulation Script (specific example)

We prefer to keep the exercise relatively simple from a programming perspective. We select either "standard man awake" or "standard man relaxed". We overlay the hypotension-hemorrhage scenario. This scenario allows the loss of intravascular volume in 500 ml increments from 500-3000 ml total volume. We initially select either "-500" or "-1000ml". We have included graphics (tables 1 & 2) to demonstrate the cardiovascular changes that occur with this combination of patient simulation scenarios. The exact numbers may not be seen using other monitors or different ambient temperatures but the relative changes are more important. Average data are listed for each volume state. The data were recorded while the manikin was breathing. Respiratory variations were noted to exert a greater effect if the volume selected was $\geq$ 1500 ml. Measured cardiovascular pressures stabilized within 15 seconds of the selection of a volume state. A significant delay, 2 minutes for spontaneous respiration and 2.25 minutes for positive pressure ventilation, was noted in the effect on cardiac output and systemic vascular resistance.

If "standard man relaxed" is selected, an endotracheal tube is in proper position and the manikin is receiving positive pressure ventilation. Our initial mandatory ventilation settings are tidal volume = 600 ml, FIO_2 = 0.4%, RR = 10, I:E = 1:2, PIP = 24/2 mm Hg. Initial respiratory monitoring shows $ETCO_2$ = 35 and SAO_2 = 100%. The exhaled carbon dioxide does decrease during the exercise as progressive loss of intravascular volume leads to a decrease in cardiac output.

Simulation Case Stem

Bob is a 26 year old man with a longstanding history of Crohn's disease who underwent emergency repair of a bowel perforation 12 hours previously. His pre-surgery medications were prednisone 40 mg qd and fexofenadine . He was febrile, hypotensive, and dehydrated at time of initial presentation. Invasive monitoring, arterial line and PAC were inserted during surgery to facilitate anesthetic and hemodynamic management. Blood loss was recorded as 500 ml during the procedure. He received 2500 ml of balanced salt replacement fluid. The patient was extubated in the OR (or not) and has been drowsy but arousable in the ICU.

Behavioral Performance Expectations

The participants are expected to

- identify the abnormal location of the PAC
- verbalize the required steps to reposition the catheter
  - ascertaining that the PAC balloon is deflated
  - maintaining the sterile sheath over the catheter
  - gently withdrawing the catheter to a depth of 20 cm.
  - inflation of the balloon and advancement of the catheter with attention to waveform, rhythm, and depth of insertion.

This can be also demonstrated at a station separate from the manikin but within view of the patient monitor utilizing a PAC and introducer sheath inserted into a blind pocket.

Debriefing

The correct technique of PAC insertion is reviewed with emphasis on normal pressures, waveforms and average insertion depth. Differentiation of the RV from the PA traces is highlighted. Participants are asked to note the rounded symmetric waveform of the RV change to the more gradual descent characteristic of the pulmonary and other peripheral arteries. Minimal or no change in the systolic pressure is seen but there is a dramatic step-up in right sided diastolic pressure after crossing the pulmonary valve. The third characteristic change, i.e. the appearance of a dicrotic notch in the PA tracing, is not noticeable with the current METI technology. Potential acute complications are discussed. Deflation of the balloon after achieving satisfactory position in the pulmonary artery is the final step.

For further self-study, participants are referred to 2 educational web sites. Manbit is an Australian site that offers both software and hardware pulmonary artery catheter simulators. [8] Their extensive hypertext study guide is available on-line. It includes more than 300 references. The pulmonary artery catheter education project (PACEP) is a comprehensive self-instruction program. [5] It is a collaborative project sponsored by seven different distinguished organizations. When completed, four different levels of instruction will be available. Currently level 1 is on-line with learning objectives. It contains 6 lessons on PAC topics. The concepts covered by these lessons are physiology, interpretation of hemodynamic data, therapeutic interventions, waveform analysis, technical aspects and complications. Each lesson contains an introduction, slide show, pre-test, post-test, and slide gallery. Many sections also include mini case studies that enhance adult learning through the addition of clinical context and problem solving. A short current review of the development and progress of this collaborative education project is available. [9]

Validity

This simulation exercise has been demonstrated as a workshop for the International Meeting on Medical Simulation, January 2000 *(authors, give location).* Using the same equipment and METI scenarios described above, an international group of 15-18 anesthesiology faculty promptly recognized the catheter malposition and verbalized the correct steps to correct the problem.

Course evaluation forms for the FCCS sessions have been routinely distributed to the WVU course participants. They are asked to specifically rate the simulation experience and the simulation instructors on a 5 point scale. Excellent was the descriptor for a score of 5 and good for a score of 4. Average, fair, and poor were 3, 2, and 1. During the most recent 2002 presentation, the course and instructor received an average score of 4.2 and 4.3 respectively. Only one rating of average and a single rating of fair were noted for each category out of a total of 16 evaluations. The scores for this FCCS session are representative of previous courses.

Summary

Don't be fooled by the apparent simplicity of this simulation exercise. We had initially introduced the catheter misplacement as part of a larger shock/critical care scenario. In the first 6 months, no one recognized this clinical dilemma. We realized that PA catheter malposition needed a scenario of its own. All of the groups to experience this scenario had received lectures, learning objectives and a textbook on this topic prior to the simulation. Over half of the students had had a demonstration of the typical waveform changes utilizing the same equipment within the previous 48 hours. Despite this classic preparation, very few students (1-2%) recognized the right ventricular trace in a clinical context. Approximately 100-150 students participate in these sessions each year. Only 5 students have commented on the waveform during the past 3 years.

Pulmonary artery catheters have many potential complications. Acute complications are associated with central venous access and PAC floatation. Long-term problems include infection, thrombosis, arrhythmias, cardiovascular rupture, catheter entrapment, pulmonary infarction, and iatrogenic. The misinterpretation of PAC data is not uncommon or benign. The abundant literature sources citing PAC complications reflect the international nature of this crisis. Morbidity, mortality and misuse of PAC were the basis for a proposal to withdraw approval and limit usage of this technology only a decade ago. [1] Intensive efforts have begun to improve PAC safety through development of policy statements and education programs [4,5] and evidence-based review of PAC utilization. [6] In our program, traditional instruction didn't translate to recognition and appropriate action in the context of crisis simulation. We have not yet studied the impact of these simulation sessions on learning and retention. However, it is suggested that three session attributes, namely repetition, clinical context, and use of multi-modal sensory input, are key to improving learning outcomes.

Table 1: Cardiovascular values as a function of hemorrhage for "standard man awake"

Scenario state	HR	**ABP s/d**	**PAP s/d (m)**	**RV s/d (m)**	**CVP**	**CO**	**SVR**
Baseline	69	117/54	27/15 (21)	26/8 (15)	8	7.6	750
deficit = 500 ml	71	113/52	24/12 (18)	24/5 (12)	5	6.5	885
deficit = 1000ml	75	110/51	20/9 (15)	20/2 (9) 1	6.4	940	
deficit = 1500ml	79	104/52	17/6 (11)	17/-1 (6)	-1	6.3	975
deficit = 2000ml	88	93/51	13/5 (9)	13/-3 (4)	-3	5.7	1040
deficit = 2500ml	101	80/50	9/1 (4)	8/-4 (1) -4	4.8	1115	
deficit = 3000ml (ischemia)	109	55/35	4/1 (2)	3/-5 (0) -4	3.2	1215	
deficit = 3000ml (no ischemia)	111	62/42	5/1 (3)	3/-5 (1) -5	3.7	1190	

Table 2: Cardiovascular values as a function of hemorrhage for "standard man relaxed"

Scenario state	HR	**ABP s/d**	**PAP s/d (m)**	**RV s/d (m)**	**CVP**	**CO**	**SVR**
Baseline	68	116/53	27/15 (21)	27/7 (15)	10	6.3	890
deficit = 500 ml71	113/52	24/12 (18)	24/6 (13)	8 6.2	910		
deficit = 1000ml	74	107/52	21/10 (15)	21/3 (9) 5	6.1	950	
deficit = 1500ml	81	100/52	18/8 (13)	17/1 (8) 3	5.9	985	
deficit = 2000ml	92	87/51	14/7 (11)	14/1 (6) 2	5.0	1065	
deficit = 2500ml	106	75/50	9/5 (7)	10/1(4) 1	4.2	1140	
deficit = 3000ml (no ischemia)	109	50/35	6/3 (4)	4/-3 (1) -2	2.8	1185	

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