Handbook of Critical and Intensive Care Medicine

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Second Edition

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With 26 Illustrations

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This book is dedicated to my spouse Sara, and my children Adylle, Jacques, Daryelle, and Michelle for understanding those countless days, nights, and weekends away from home.

Joseph Varon, MD, FACP, FCCP, FCCM

This book is dedicated to my family, for their unconditional support.

Pilar Acosta, MD

Preface

Why write a book on the management of critically ill patients? Over the past few decades we have seen an enormous growth in the number of intensive care units (ICU) across the world. Indeed, it is estimated that a large proportion of health care expenses are devoted to patients in these specialized units. Medical students, residents, fellows, attending physicians, critical care nurses, pharmacists, respiratory therapists, and other health-care providers (irrespective of their ultimate field of practice) will spend several months or years of their professional lives taking care of critically ill or severely injured patients. These clinicians must have special training, experience, and competence in managing complex problems in their patients. Moreover, these clinicians must interpret data obtained by many kinds of monitoring devices, and they must integrate this information with their knowledge of the pathophysiology of disease. Even more important is the fact that anyone working in an ICU or with a critically ill patient must approach patients with a multidisciplinary team. The phrase *there is no I in TEAM* comes to mind.

The second edition of this book* was written for every practitioner engaged in Critical Care Medicine across the world. We have attempted to present basic and generally accepted clinical information, our own personal experiences, facts, and some important formulas as well as laboratory values and tables which we feel will be useful to the practitioner of Critical Care Medicine. The chapters of this book follow an outline format and are divided by organ–system (i.e., neurologic disorders, cardiovascular disorders), as well as special topics (i.e., environmental disorders, trauma, toxicology). Every chapter has been updated and many chapters are completely new.

It is important for the reader of this handbook to understand that Critical Care Medicine is not a static field and changes occur every day. Therefore, this handbook is not meant to define the standard of care, but rather to be a general guide to current clinical practice used in Critical Care Medicine. We wrote this book hoping that it will benefit thousands of critically ill patients, but more importantly that it will aid practicing clinicians to assume a multidisciplinary approach.

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*Note: the first edition of this book, published by Springer in 2002, was titled Handbook of Practical Critical Care Medicine.

Contents

1

Approach to the Intensive Care Unit (ICU)

■ I. WELCOME TO THE ICU

What Is an ICU?

An intensive care unit (ICU) is an area of a hospital that provides aggressive therapy, using state-of-the-art technology and both invasive and noninvasive monitoring for critically ill and high-risk patients. In these units the patient's physiological variables are reported to the practitioner on a continuous basis, so that titrated care can be provided.

As a medical student, resident physician, attending physician, or other healthcare provider, one is likely to spend several hundreds of hours in these units caring for very sick patients. Knowing the function and organization of these specialized areas will help the practitioner in understanding critical care.

Historical Development of the ICU

The origin of the ICU remains controversial. In 1863, Florence Nightingale wrote, "In small country hospitals there are areas that have a recess or small room leading from the operating theater in which the patients remain until they have recovered, or at least recover from the immediate effects of the operation." This is probably the earliest description of what would become the ICU. Recovery rooms were developed at the Johns Hopkins Hospital in the 1920s. In Germany in the 1930s, the first well-organized postoperative ICU was developed. In the United States, more specialized postoperative recovery rooms were implemented in the 1940s at the Mayo Clinic. By the late 1950s, the first shock unit was established in Los Angeles. The initial surveillance unit for patients after acute myocardial infarction was started in Kansas City in 1962.

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Economical Impact of the ICU

Since their initial development, there has been a rapid and remarkable growth of ICU beds in the United States. There are presently more than 60,000 ICU beds in the United States, and critical care consumes more than 2.5% of the gross national product.

Organization of the ICU

ICUs in the United States may be open or closed. Open ICUs may be utilized by any attending physician with admitting privileges in that institution, and many subspecialists may manage the patient at the same time. These physicians do not need to be specifically trained in critical care medicine. A different system is provided in closed ICUs, in which the management of the patient on admission to the unit is provided by an ICU team and orchestrated by physicians with specialized training in critical care medicine. Although consultants may be involved in the patient's care, all orders are written by the ICU team and all decisions are approved by this team.

ICUs may also be organized by the type of patients whom they are intended to treat. In some studies, these "closed" units have shown shorter length of stay for the ICU patients due to the standardization of care.

ICUs can also be divided on the basis of the patients they have. Examples include the neurosurgical ICU (NICU), pediatric ICU (PICU), cardiovascular surgery ICU (CVICU), surgical ICU (SICU), medical ICU (MICU), and coronary care unit (CCU).

Most ICUs in the United States have a medical director who, with varying degrees of authority, is responsible for bed allocation, policy making, and quality assurance, and who may be, particularly in closed ICUs, the primary attending physician for patients admitted to that unit.

■ II. TEAM WORK

Care of the critically ill patient has evolved into a discipline that requires specialized training and skills. The physician in the ICU depends on nursing for accurate charting and assessment of the patients during the times when he or she is not at the bedside and for the provision of the full spectrum of nursing care, including psychological and social support and the administration of ordered therapies.

Complex mechanical ventilation devices need appropriate monitoring and adjustment. This expertise and other functions are provided by a professional team of respiratory therapy practitioners. The wide spectrum of the pharmacopeia used in the ICU is greatly enhanced by the assistance of our colleagues in pharmacy. Many institutions find it useful to have pharmacists with advanced training participate in rounding to help practitioners in the appropriate pharmacologic management of the critically ill. Additionally, technicians with experience in monitoring equipment may help in obtaining physiologic data and maintaining the associated equipment. Without these additional healthcare professionals, optimal ICU management would not be possible.

As many ICU patients remain in these units for prolonged periods of time, additional heathcare providers, such as the nutritional support team and physical/occupational therapy, remain important component of the management of these patients.

■ III. THE FLOWSHEET

ICU patients, by virtue of their critical illnesses, present with complex pathophysiology and symptomatology. In many cases, these patients are endotracheally intubated, with mental status depression, and cannot provide historical information. The physical examination and monitoring of physiology and laboratory data must provide the information on which to base a diagnosis and initiate appropriate treatment in these cases.

The flowsheet is the repository of information necessary for the recognition and management of severe physiological derangements in critically ill patients. A well-organized flowsheet provides around-the-clock information regarding the different organ systems rather than just vital signs alone. In many institutions these flowsheets are computerized, potentially improving accessibility and allowing real-time data. These devices are complex and in many instances expensive.

Major categories appropriate for an ICU flowsheet include

- Vital signs
- Neurological status
- Hemodynamic parameters
- Ventilator settings
- Respiratory parameters
- Inputs and outputs
- Laboratory data
- Medications

■ IV. THE CRITICALLY ILL PATIENT

In general, ICU patients not only are very ill but also may have disease processes that involve a number of different organ systems. Therefore, the approach to the critically ill patient needs to be systematic and complete (see below).

Several issues need to be considered in the initial approach to the critically ill patient. The initial evaluation consists of assessment of the ABC (airway, breathing, circulation), with simultaneous interventions performed as needed. An organized and efficient history and physical examination should then be conducted for all patients entering the ICU, and a series of priorities for therapeutic interventions should be established.

■ V. SYSTEM-ORIENTED ROUNDS

In the ICU accurate transmission of clinical information is required. It is important to be compulsive and follow every single detail. The mode of presentation during ICU rounds may vary based on institutional tradition. Nevertheless, because of multiple medical problems, systematic gathering and presentation of data are needed for proper management of these patients. We prefer presenting and writing notes in a "head-to-toe" format (see Table 1.1).

Table 1.1. Minimum Amount of Information Necessary for Presentation During Rounds (See Text for Details)

ICU survival guide for presentation during rounds

1. Identification/problem list
2. Major events during the last 24 h
3. Neurological:
   —Mental status, complaints, detailed neurological exam (if pertinent)
4. Cardiovascular:
   —Symptoms and physical findings, record BP, pulse variability over the past 24 h., ECG, echocardiogram results
   —If CVP line and/or Swan-Ganz catheter in place, check CVP and hemodynamics *yourself*
5. Respiratory:
   —Ventilator settings, latest ABGs, symptoms and physical findings, CXR (daily if the patient is intubated). Other calculations (e.g., compliance, minute volume, etc)
6. Renal/Metabolic:
   —Urine output (per hour and during the last 24 h), inputs/outputs with balance (daily, weekly), weight, electrolytes, and if done, creatinine clearance. Acid–base balance interpretation
7. Gastrointestinal:
   —Abdominal exam, oral intake, coffee-grounds, diarrhea. Abdominal x-rays, liver function tests, amylase, etc.
8. Infectious diseases:
   —Temperature curve, WBC, cultures, current antibiotics (number of days on each drug), and antibiotic levels
9. Hematology:
   —CBC, PT, PTT, TT, BT, DIC screen (if pertinent), peripheral smear. Medications altering bleeding
10. Nutrition:
   —TPN, enteral feedings, rate, caloric intake, and grams of protein
11. Endocrine:
   —Do you need to check TFTs or cortisol? Give total insulin needs per hour and 24 h
12. Psychosocial:
   —Is the patient depressed or suicidal? Is the family aware of his or her present condition?
13. Other:
   —Check the endotracheal tube position (from lips or nostrils in centimeters), and check CXR position. Check all lines, transducers. Note position of the catheter, skin insertion sites
   —All medications and drips must be known. All drips must be renewed before or during rounds

Abbreviations: ABG, arterial blood gas; BP, blood pressure; BT, bleeding time; CBC, complete blood count; CXR, chest x-ray; CVP, central venous pressure; DIC, disseminated intravascular coagulation; ECG, electrocardiogram; PT, prothrombin time; PTT, partial thromboplastin time; TFT, thyroid function tests; TPN, total parenteral nutrition; TT, thrombin time; WBC, white blood cell count.

The ICU progress note is system-oriented, which differs from the problem-oriented approach commonly utilized on the general medicine-surgery wards. The assessment and plan are formulated for each of the different organ systems as aids to organization, but like in the non-ICU chart, each progress note should contain a "problem list" that is addressed daily. This problem list allows the healthcare provider to keep track of multiple problems simultaneously and enables a physician unfamiliar with a given case to efficiently understand its complexities if the need arises.

The art of presenting cases during rounds is perfected at the bedside over many years, but the following abbreviated guide may get the new member of the ICU team off to a good start. A "how-to" for examining an ICU patient and a stylized ICU progress note guide are also presented. Remember that for each system reviewed a full review of data, assessment, and management plan should be provided. Using this simple technique avoids important data to be skipped or forgotten.

When you arrive in the ICU in the morning

1. Ask the previous night's physicians and nurses about your patients.
2. Go to the patient's room. Review the flowsheet. Then proceed by examining and reviewing each organ system as follows:

Identification

— Provide name, age, major diagnoses, day of entry to the hospital, and day of admission to the ICU.

Major Events over the Last 24 h

— Mention (or list in the progress note) any medical event or diagnostic endeavor that was significant. For example, major thoracic surgery or cardiopulmonary arrest, computed tomography (CT) scan of the head, reintubation, or changes in mechanical ventilation.

Systems Review

Neurologic

— Mental status: Is the patient awake? If so, can you perform a mental status examination? If the patient is comatose, is he or she spontaneously breathing?

— What is the Glasgow coma scale score?

— If the patient is sedated, what is the Ramsay score, or what is the score on any other scales (i.e., RASS) used at the institution for patients who are sedated?

— If pertinent (in patients with major neurological abnormalities or whose major disease process involves the central nervous system), a detailed neurological exam should be performed.

— What are the results of any neurological evaluation in the past 24 h, such as a lumbar puncture or CT scan?

Cardiovascular

— Symptoms and physical findings: It is important to specifically inquire for symptoms of dyspnea and chest pain or discomfort, among others. The physical examination should be focused on the cardiac rhythm, presence of congestive heart failure, pulmonary hypertension, pericardial effusion, and valvulopathies.

— Electrocardiogram (ECG): We recommend that a diagnostic ECG be considered in every ICU patient on a frequent basis. Many ICU patients cannot communicate chest pain or other cardiac symptomatology, so that an ECG may be the only piece of information pointing toward cardiac pathology.

— If the patient has a central venous pressure (CVP) line and/or a pulmonary artery (Swan-Ganz) catheter in place, check the CVP and hemodynamics *yourself.* Hemodynamic calculations of oxygen consumption and delivery should be noted if the patient has a pulmonary artery catheter or an oximetric intravascular device. A detailed list of hemodynamic parameters useful in the management of critically ill patients can be found in Chapters 3, "Cardiovascular Disorders" and 13, "Pulmonary Disorders".

— Note the blood pressure (BP) and pulse variability over the past 24 h. Calculate the mean arterial pressure (MAP) changes over the time period.

— If the patient had an echocardiogram, review the findings in detail.

— If the patient is receiving assisted mechanical cardiac support (i.e., intra-aortic balloon pump) or has a temporary pacemaker, the settings need to be recorded and compared to prior days.

Respiratory

— If the patient is on mechanical ventilation, the current ventilator settings need to be charted, including the ventilatory mode, tidal volume, preset respiratory rate and patient's own respiratory rate, amount of oxygen being provided (FiO_2), and whether or not the patient is receiving positive end-expiratory pressure (PEEP) and/or pressure support (PS) and their levels. When pertinent, peak flow settings and inspiration–expiration (I:E) ratio should be noted. Mechanically ventilated patients should have a daily measurement of the static and dynamic compliance, minute volume, and other parameters (see Chapters 2, "The Basics of Critical Care" and 13, "Pulmonary Disorders"). If weaning parameters were performed, they need to be addressed.

— The most recent arterial blood gases (ABGs) should be compared with previous measurements. Calculation of the alveolar-arterial oxygen gradient should be performed in all ABGs.

— Symptoms and physical findings should be noted, and if pertinent, sputum characteristics should be mentioned.

— Generally, a portable chest x-ray is obtained in all intubated patients daily. Attention is paid to CVP lines, endotracheal tubes, chest tubes, pericardiocentesis catheters, opacities in the lung fields (infiltrates), pneumothoraces, pneumomediastinum, and subcutaneous air.

Renal/Metabolic

- Urine output is quantified per hour and during the past 24 h. In patients requiring intensive care for more than 2 days, it is important to keep track of their inputs, outputs, and overall daily and weekly fluid balance.
- Daily weights.
- If the patient underwent hemodialysis or is on peritoneal dialysis, it is important to include it on the daily note.
- Electrolytes are noted including magnesium, phosphorus, calcium (ionized), and if done, creatinine clearance, urine electrolytes, etc. Any changes in these values need special consideration.
- The ABGs are used for acid–base balance interpretation. The formulas most commonly used for these calculations are depicted in Chapter 14, "Renal and Fluid-Electrolyte Disorders".

Gastrointestinal

- Abdominal examination: A detailed abdominal examination may uncover new pathology or allow one to assess changes in recognized problems.
- If the patient is awake and alert, mention his or her oral intake (e.g., determine whether clear liquids are well tolerated).
- The characteristics of the gastric contents or stool (e.g., coffee-grounds, diarrhea, etc.) should also be mentioned and recorded.
- Abdominal x-rays, if pertinent, are reviewed with special attention to the duration of feeding tubes, free air under the diaphragm, and bowel gas pattern.
- Liver function tests (transaminases, albumin, coagulation measurements, etc.) and pancreatic enzymes (amylase, lipase, etc.) are mentioned and recorded when pertinent, as well as their change since previous measurements.

Infectious Diseases

- Temperature curve: Changes in temperature (e.g., "fever spike" or hypothermia) should be noted as well as the interventions performed to control the temperature. Note fever character, maximum temperature (T-max), and response to antipyretics.
- The total white blood cell count (WBC) is recorded, when pertinent, with special attention to changes in the differential.
- Cultures: Culture (blood, sputum, urine, etc.) results should be checked daily with the microbiology laboratory and recorded. Those positive cultures, when mentioned, should include the antibiotic sensitivity profile, when available.
- Current antibiotics: Current dosages and routes of administration as well as the number of days on each drug should be reported. If an adverse reaction occurred related to the administration of antibiotics, it should be reported.
- Antibiotic levels are drawn for many antibiotics with known pharmacokinetics to adjust their dosage (e.g., peak and trough levels for vancomycin).
- If the patient is receiving a new drug, either investigational or FDA approved, side effects and/or the observed salutary effects are reported.

Hematology

— Complete blood cell count (CBC): When presenting the results, it is important to be aware of the characteristics of the peripheral blood smear.

— Coagulation parameters: The prothrombin time (PT), partial thromboplastin time (PTT), thrombin time (TT), bleeding time (BT), and disseminated intravascular coagulation (DIC) screen (e.g., fibrinogen, fibrin split products, d-dimer, platelet count) should be addressed when pertinent.

— If the patient has received blood products or has undergone plasma exchange, this should be noted.

— In this context special attention is paid to all medications that alter bleeding, both directly (e.g., heparin, desmopressin acetate) and indirectly (e.g., ticarcillin-induced thrombocytopathy, ranitidine-induced thrombocytopenia).

Nutrition

— Total parenteral nutrition (TPN): You need to state what kind of formula the patient is receiving, the total caloric intake provided by TPN with the percentage of fat and carbohydrates given. The total amount of protein is mentioned with an assessment of the anabolic or catabolic state (see Chapter 10, "Nutrition").

— Enteral feedings: These are reported similar to TPN, with mention of any gastrointestinal intolerance (e.g., diarrhea).

— For both of the above, the nutritional needs of the patient and what percentage of these needs is actually being provided must be reported.

Endocrine

— Special attention is paid to pancreatic, adrenal, and thyroid function. If needed, a cortisol level or thyroid function tests are performed. In most situations these determinations are not appropriate in the ICU except under special circumstances (e.g., hypotension refractory to volume resuscitation in a patient with disseminated tuberculosis, Addisonian crisis), and the results are usually not available immediately.

— Glucose values: The data are clear that good glycemic control helps patients in the ICU. Therefore, you must include the glycemic variation that the patient has over the past 24 h.

— Insulin: The total insulin needs per hour and per 24 h as well as the blood sugar values should be reported. The type of insulin preparation being used should be specified.

— In patients with hyperosmolal states and diabetic ketoacidosis, it is necessary to determine calculated and measured serum osmolality as well as ketones. The values for these are charted and compared with previous results.

Psychosocial

— Patients in the ICU tend to be confused and in many instances disoriented. Although these symptoms and signs are reviewed as part of the neurological examination, it is important to consider other diagnoses (e.g., depression, psychosis).

— For drug overdoses and patients with depression, specific questions need to be asked regarding the potential of new suicidal and homicidal ideations.

Other

Other parameters also must be checked daily before the morning (or evening) rounds:

— Check the endotracheal tube size and position (from the lips or nostrils in centimeters), and check its position on chest x-ray, as mentioned above.

— If the patient has a nasotracheal or orotracheal tube, a detailed ear, nose, and throat examination should be performed (because patients with nasotracheal tubes may develop severe sinusitis).

— Check all lines with their corresponding equipment (e.g., transducers must be at an adequate level). Note the position of the catheter(s) both on physical examination and on x-ray, as well as the appearance of the skin insertion site(s) (e.g., infection).

— All medications and continuous infusions and their proper concentrations and infusion rates must be known and recorded.

— At the time of "pre-rounding," all infusions must be renewed. TPN orders need to be written early, with changes based on the most recent laboratory findings.

— At the end of rounds every morning, it is important to keep a list of the things that need to be done that day, for example, changes in central venous lines or arterial lines, performing a lumbar puncture, etc.

■ VI. DO NOT RESUSCITATE (DNR) AND ETHICAL ISSUES

Ethical issues arise every day in the ICU. For example, should a particular patient be kept on mechanical ventilation when he has an underlying malignancy? Should the patient with acquired immune deficiency syndrome (AIDS) receive cardiopulmonary resuscitation (CPR) in the event of a cardiorespiratory arrest? Should the family be permitted to terminate mechanical ventilation or tube feedings?

These and similar questions are frequently asked and in reality may have no single correct answer. Patients must be allowed the opportunity to express their wishes about resuscitation. ICU physicians need to educate the patient and the family regarding prognosis. Physicians are not obliged to provide futile interventions, but communication is the key to avoiding conflicts in this arena.

Do not resuscitate (DNR) orders have become widely used in US hospitals. A DNR order specifically instructs the patient's healthcare provider to forego CPR if the patient undergoes cardiac or respiratory arrest. Various levels of support may be agreed upon by patients, their physicians, and family.

Different institutions have distinct categories of support. Examples include the following:

— Code A or Code I: Full support, including CPR, vasopressors, mechanical ventilation, surgery, etc.

— Code B or Code II: Full support except CPR (no endotracheal intubation or chest compressions). However, vasopressor drugs are utilized in these cases.

— Code C or Code III: Comfort care only. Depending on the policies of the institution, intravenous fluids, antibiotics, and other medications may be withheld.

A patient who is DNR may be in either of the last two groups. It is important then that a full description of a particular triage status is provided and carefully explained to the patient and/or family and discussed as needed. Remember to document all your discussions with the family on the medical record.

As mentioned, the level of resuscitative efforts will therefore depend on the patient's wishes. When the patient cannot express his or her wishes, then these questions are asked to the closest family member or designated individual. For example, would the patient have wanted full mechanical ventilatory support for a cardiopulmonary arrest? Were provisions made for a healthcare surrogate if the patient became incompetent?

Ethical problems often can be resolved by seeking consultation with a group of individuals who are experienced in dealing with these issues. In many institutions an ethics committee is available to provide consultation to practitioners and families regarding moral and ethical dilemmas.

2

The Basics of Critical Care

Critical and intensive care medicine is an integrated discipline that requires the clinician to examine a number of important basic interactions. These include the interactions among organ systems, between the patient and his or her environment, and between the patient and life-support equipment. Gas exchange within the lung, for example, is dependent on the matching of ventilation and perfusion—in quantity, space, and time. Thus, neither the lungs nor the heart are solely responsible; rather, it is the cardiopulmonary interaction that determines the adequacy of gas exchange.

Critical care often entails providing advanced life support through the application of technology. Mechanical ventilation is a common example. Why is it that positive pressure ventilation and positive end-expiratory pressure (PEEP) can result in oliguria or reduction of cardiac output? Many times clinical assessments and your therapeutic plans will be directed at the interaction between the patient and technology; this represents a unique "physiology" in itself.

■ I. CARDIAC ARREST AND RESUSCITATION

Resuscitation from death is not an everyday event but is no longer a rarity. The goal of resuscitation is restoration of normal or near-normal cardiopulmonary function, without deterioration of other organ systems.

A. Etiology

The most common causes of sudden cardiac arrest are depicted in Table 2.1.

B. Pathogenesis

1. Ventricular fibrillation (VF) or pulseless ventricular tachycardia (VT).
2. Asystole.
3. Pulseless electrical activity (PEA) (electromechanical dissociation). Patients arresting with PEA can have any cardiac rhythm but no effective mechanical systole (thus, blood pressure [BP] is unobtainable).
4. Cardiogenic shock: No effective cardiac output is generated.

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Table 2.1. Common Causes of Sudden Nontraumatic Cardiac Arrest

1. Primary cardiac event
   a. CAD
   b. Dysrhythmias due to
      (1) Hyperkalemia
      (2) Severe acidemia
      (3) Other electrolyte disturbances
   c. Myocarditis
   d. Tamponade
2. Secondary to respiratory arrest (e.g., children)
3. Secondary to acute respiratory failure
   a. Hypoxemia
   b. Hypercapnia
4. Extreme alterations in body temperature
5. Drug effects
   a. Digitalis
   b. Quinidine
   c. Tricyclic antidepressants
   d. Cocaine

5. The central nervous system (CNS) will not tolerate >6 min of ischemia at normothermia.

C. Diagnosis
1. Unexpected loss of consciousness in the unmonitored patient.
2. Loss of palpable central arterial pulse.
3. Respiratory arrest in a patient previously breathing spontaneously.

D. Differential Diagnosis
1. Syncope or vasovagal reactions
2. Coma
3. "Collapse"
4. Seizures

E. Management
1. Cardiopulmonary resuscitation
   a. The main indications for cardiopulmonary resuscitation (CPR) in the ICU include
      (1). Cardiovascular collapse
      (2). Respiratory arrest with or without cardiac arrest
   b. Mechanisms of blood flow during CPR
      (1). Direct compression of the heart between the sternum and vertebral column "squeezes" blood from the ventricles into the great vessels.
      (2). Changes in intrathoracic pressure generate gradients between the peripheral venous and arterial beds, resulting in forward flow.
      (3). During CPR, the dynamics of the chest compression process may play a major role in determining outcome of the resuscitation effort. Indeed, chest compressions by themselves may provide ventilation.

(4). Interposed abdominal compression CPR increases aortic diastolic blood pressure, improving blood perfusion to the coronary arteries.

c. Technique

(1). Establish an effective airway (see Chapter 15 , "Special Techniques").

(a). Assess breathing first (open airway, look, listen, and feel).

(b). If respiratory arrest has occurred, the possibility of a foreign body obstruction needs to be considered and measures taken to relieve it.

(c). If endotracheal intubation is to be performed, give two breaths during a 2 s pause every 30 chest compressions.

(d). The respiratory rate during cardiac or respiratory arrest should be 8–10 breaths per minute. Once spontaneous circulation has been restored, the rate should be 10–12 breaths per minute.

(e). Ventilations should be performed with a tidal volume of 5–7 mL/kg of ideal body weight.

(f). The highest possible concentration of oxygen (100%) should be administered to all patients receiving CPR.

(2). Determine pulselessness (if no pulse, start CPR immediately).

(3). Chest compressions, current advanced cardiac life support (ACLS) recommendations:

(a). Rescuer's hand located in the lower margin of sternum.

(b). Heel of one hand is placed on the lower half of the sternum and the other hand is placed on top of the hand on the sternum so that the hands are parallel.

(c). Elbows are locked in position, the arms are straightened, and the rescuer's shoulders are positioned directly over the hands, providing a straight thrust.

(d). The sternum is depressed $1^1/_2$–2 in. in normal-sized adults with each compression at a rate of 100/min.

(e). The American Heart Association addresses alternative techniques to standard manual CPR, specifically mechanical devices (i.e., vest CPR, LUCAS). This new device is with the purpose to enhance compression and diminish exhaustion of the person delivering CPR.

(4). Cardiac monitoring and dysrhythmia recognition (see also Chapter 3, "Cardiovascular Disorders")

(a). Distinguish between ventricular and supraventricular rhythms.

i. Most rapid, wide QRS rhythms are VT.

ii. Initiate therapy immediately (see below).

(5). Defibrillation is the major determinant of survival in cardiac arrest due to VF or pulseless VT.

(a). Integrating early defibrillation and CPR provides better outcome.

(b). Resume chest compressions after delivering one shock.

(6). Drug therapy during CPR may be given by the following routes:

(a). Peripheral vein (antecubital or external jugular are preferred).

(b). Central venous line (subclavian or internal jugular): On occasion a long line that extends above the diaphragm can be started in the femoral vein.

(c). Intraosseous (IO) cannulation provides access that is safe and effective for drug delivery, fluid resuscitation, and blood sampling.

(d). Endotracheal: Medications should be administered at 2–2.5 times the recommended intravenous (IV) dose and should be diluted in 10

mL of normal saline or distilled water. A catheter should be passed beyond the tip of the endotracheal tube, and the medication sprayed quickly followed by several quick insufflations.

(e). The different drug dosages utilized during CPR and in the immediate postresuscitation period are depicted in the appendix.

(7). The algorithm approach

(a). ABCD (see Figure 2.1).
(b). Call for defibrillator at once.
(c). If no circulation, start CPR (see Figure 2.2).
(d). Assess rhythm (see Figures 2.1 and 2.3).
(e). If VT/VF are present, follow the algorithm presented in Figure 2.3.
(f). If PEA is present, follow the algorithm in Figure 2.4.
(g). If asystole is present, follow the algorithm in Figure 2.4.
(h). For bradycardia, follow the algorithm in Figure 2.5.
(i). For tachycardia, follow the algorithms presented in Figures 2.6, 2.7, 2.8 and 2.9.

d. Cerebral resuscitation

(1). The primary goal of cardiopulmonary resuscitation is a neurologically intact patient.
(2). Mild therapeutic hypothermia (>33°C) improves neurological outcome, as demonstrated in many clinical trials. Therapeutic hypothermia (TH) decreases metabolic rate and decreases the release of free oxygen radicals (see Chapter 15, "Special Techniques").
(3). Optimize cerebral perfusion pressure by maintaining a normal or slightly elevated mean arterial pressure and by reducing intracranial pressure, if increased (see Chapter 9, "Neurologic Disorders").

2. Predictors of poor outcome in resuscitation

a. Preterminal illness (i.e., sepsis, malignancies)
b. Catastrophic events (i.e., massive pulmonary embolism, ruptured aneurysms, cardiogenic shock, etc)
c. Delayed performance of basic life support (BLS)/ACLS

■ II. THE AVEOLAR AIR EQUATION

A. Dalton's law states that the partial pressure of a mixture of gases is equal to the sum of the partial pressures of the constituent gases. Thus, the total pressure of alveolar gases must equal the sum of its constituents and, in turn, equilibrate with atmospheric pressure. We are most often concerned with the respiratory gases, O_2 and CO_2.

B. The alveolar air equation is based firmly on Dalton's law but is expressed in terms that emphasize alveolar O_2 and CO_2:

$$P_AO_2 = (P_{ATM} - P_{H2O})FiO_2 - PCO_2/RQ$$

P_AO_2 = partial pressure of O_2 in the alveolus under present conditions. P_{ATM} = current, local atmospheric pressure. PH_2O = vapor pressure of water at body temperature and 100% relative humidity. FiO_2 = fraction of inspired O_2. PCO_2 = partial pressure of CO_2 in arterial blood. RQ = respiratory quotient.

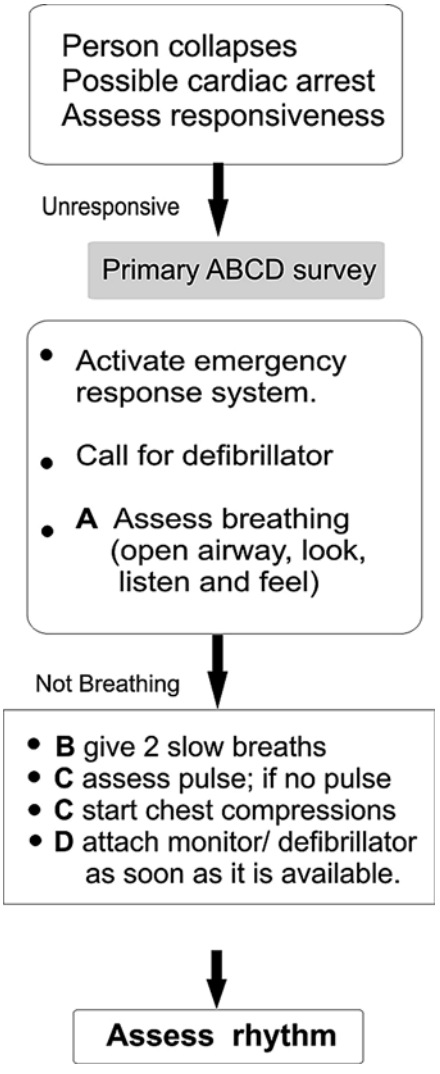

Figure 2.1. The algorithm approach.

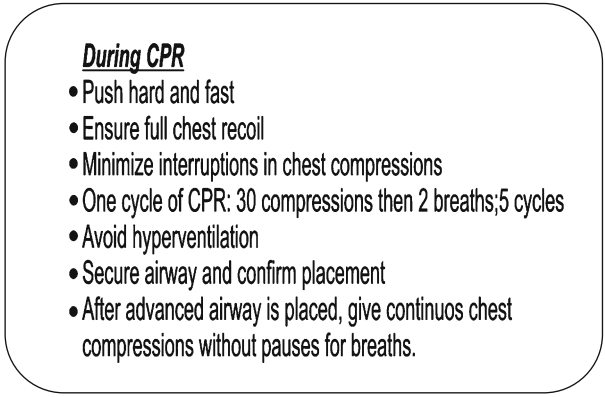

Figure 2.2. The algorithm approach.

C. Many clinical and environmental influences are immediately obvious when considering the terms of the equation:
   1. P_{ATM}: Altitude per se can clearly result in hypoxemia. A given patient's PO_2 must be considered in the context of location. A "normal" arterial PO_2 is not the same in Denver (average = 73 mmHg) as it is at sea level (average = 95 mmHg).
   2. FiO_2: While atmospheric air is uniformly about 21% O_2, one must ask: 21% of what? The FiO_2 on a mountaintop at 11,000 feet is also 21%, but there is not enough total O_2 in the rarefied air to sustain an arterial PO_2 above 60 mmHg.
   3. PCO_2: Although CO_2 coming into the alveolus does not displace O_2 (this would not obey Dalton's law), the blood PCO_2 does equilibrate with alveolar gases. Simultaneously, O_2 is taken up from the alveolus. When patients hypoventilate, not only does CO_2 accumulate but also alveolar O_2 becomes depleted. Thus, elevated PCO_2 is associated with low P_AO_2 and sometimes hypoxemia. Similarly, hyperventilating patients (excess CO_2 elimination, low PCO_2, frequent replenishment of alveolar O_2) can have higher than normal P_AO_2 and arterial PO_2.
   4. RQ is the ratio of CO_2 production to O_2 consumption. The ratio of alveolar gas exchange—CO_2 coming into the alveolus and O_2 leaving the alveolus—not unexpectedly, also reflects the RQ. Given a particular ratio of alveolar gas exchange, the ultimate value for P_AO_2 will also be affected by the rate of CO_2 elimination from the alveolus, i.e., alveolar ventilation.

D. The A-a Gradient
   1. While the alveolar air equation predicts the partial pressure of O_2 in the alveolus (P_AO_2) under current conditions, it is not necessarily true that arterial blood will have an identical partial pressure of O_2 (PaO_2). We can, however, measure the PaO_2 directly and compare it with the calculated value for P_AO_2. When we subtract arterial from alveolar PO_2, we obtain the A-a gradient.

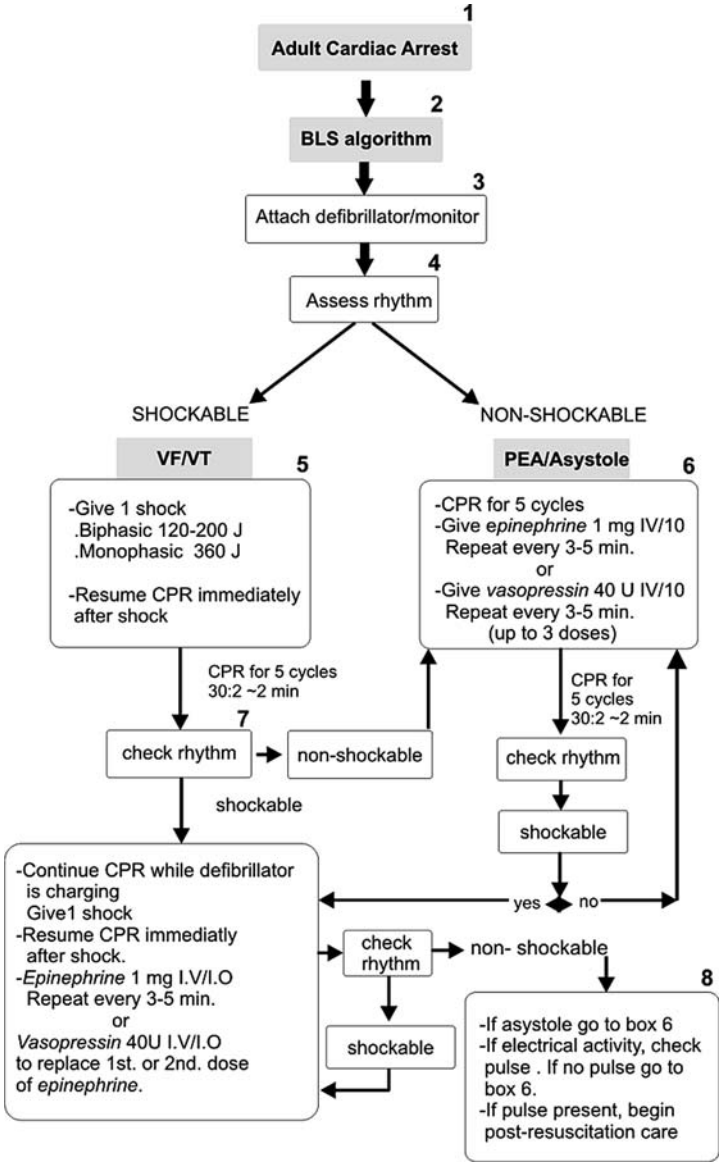

Figure 2.3. Algorithm for ventricular fibrillation (VF) and pulseless ventricular tachycardia (VT).

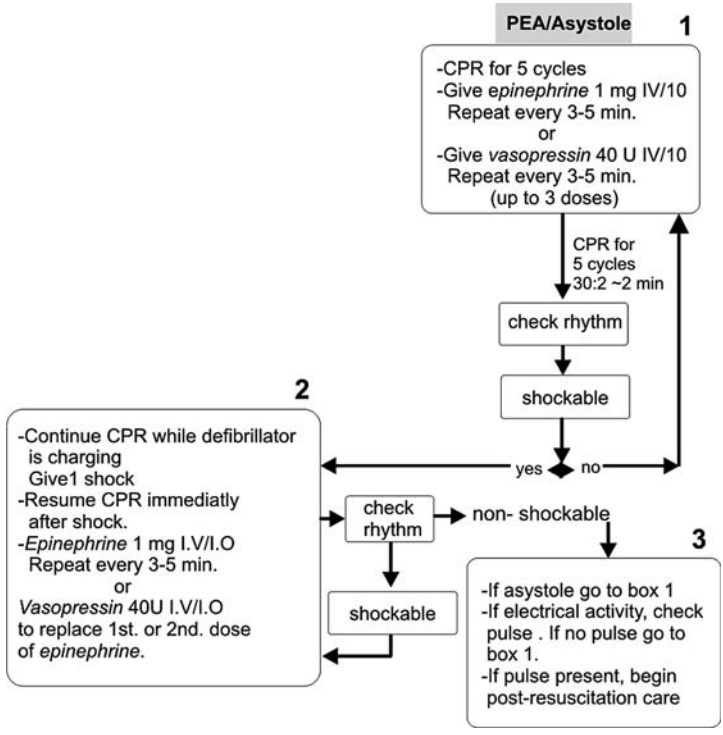

Figure 2.4. Algorithm for pulseless electrical activity (PEA) (also known as electromechanical dissociation).

Example 1: A healthy young adult breathing room air at sea level:

Arterial blood gases (ABGs): pH = 7.40, $PaCO_2 = 40$, $PaO_2 = 95$

(assume RQ = 0.8)
$P_AO_2 = (760 - 47).21 - 40/0.8$
$PAO_2 = 150 - 50 = 100$
A-a gradient = $P_AO_2 - PaO_2$
A-a gradient = 100 – 95 = 5 mmHg

This person has an A-a gradient of 5 mmHg, which is normal (0–10)

Example 2: An elderly patient in respiratory distress secondary to pulmonary edema breathing 40% O_2 ($FiO_2 = 0.4$):

ABGs: pH = 7.43, $PaCO_2 = 36$, $PaO_2 = 70$
$P_AO_2 = (760 - 47).40 - 36/0.8$
$P_AO_2 = 285 - 45 = 240$
A-a gradient = $P_AO_2 - PaO_2$

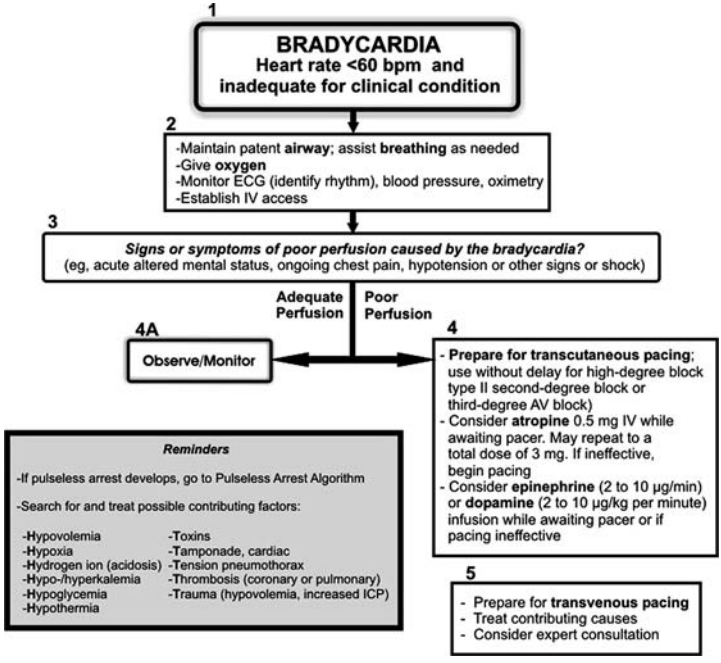

Figure 2.5. Bradycardia treatment algorithm.

A-a gradient = 240 – 70 = 170 mmHg

This person has an A-a gradient of 170 mmHg, which is markedly elevated.

2. Significance: The presence of an A-a gradient tells you that *something is wrong: gas exchange is impaired.* It does not tell you what is wrong, nor does it tell you the etiology of hypoxemia when present. A widened A-a gradient simply indicates that alveolar O_2 tension is not successfully reflected in arterial blood.
   a. Note that at a given FiO_2, P_AO_2 varies inversely as the $PaCO_2$. Thus at any A-a gradient a high $PaCO_2$ is associated with a low P_AO_2 and vice versa A patient who hyperventilates (low $PaCO_2$) may do so purposely to improve his or her P_AO_2 and thus his or her PaO_2.

Example 3: An emergency room patient breathing room air:

ABGs: pH = 7.50, $PaCO_2$ = 30, PaO_2 = 65

What would the patient's PaO_2 be with the same A-a gradient and a $PaCO_2$ of 40?

Room Air:

$P_AO_2 = (760 - 47).\ 21 - 30/0.8 = 150 - 35 = 115$
A-a gradient = 115 – 65
A-a gradient = 50

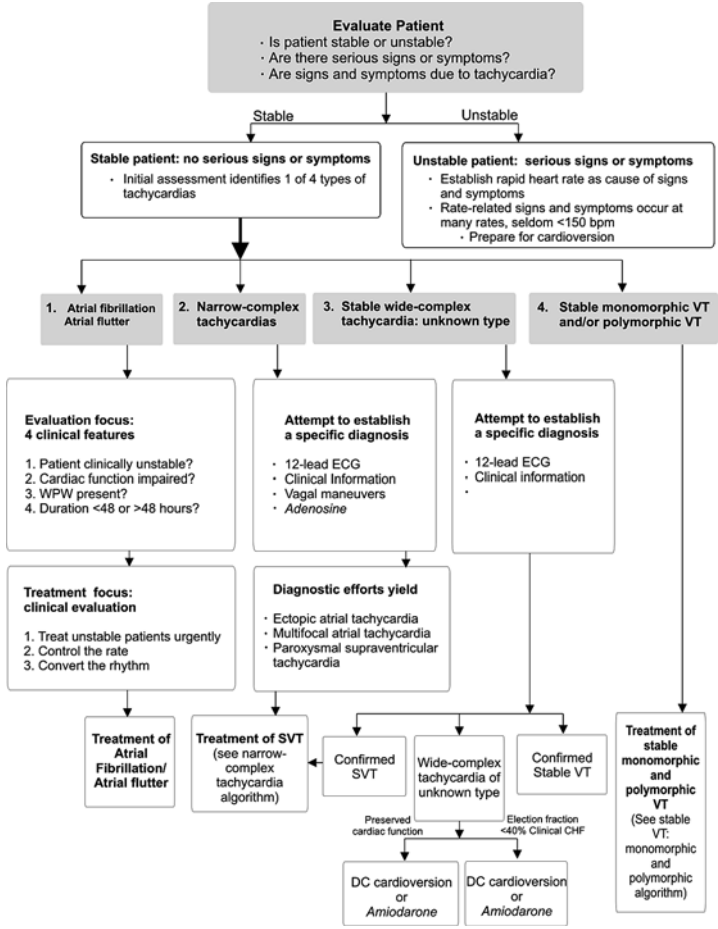

Figure 2.6. Tachycardia algorithm.

Now, what if the PCO_2 were 40?
$P_AO_2 = (760 - 47).21 - \mathbf{40}/0.8 = 150 - 50 = 100\ P_AO_2 = 100$
A-a gradient = 50
Therefore $PaO_2 = \mathbf{50}$

PaO_2 would be **50** if the patient were not hyperventilating. "Normal" ventilation ($PaCO_2 = 40$) would be associated with hypoxemia, but with hyperventilation, the patient's PO_2 is above 60. Note that it is also possible for a patient to have

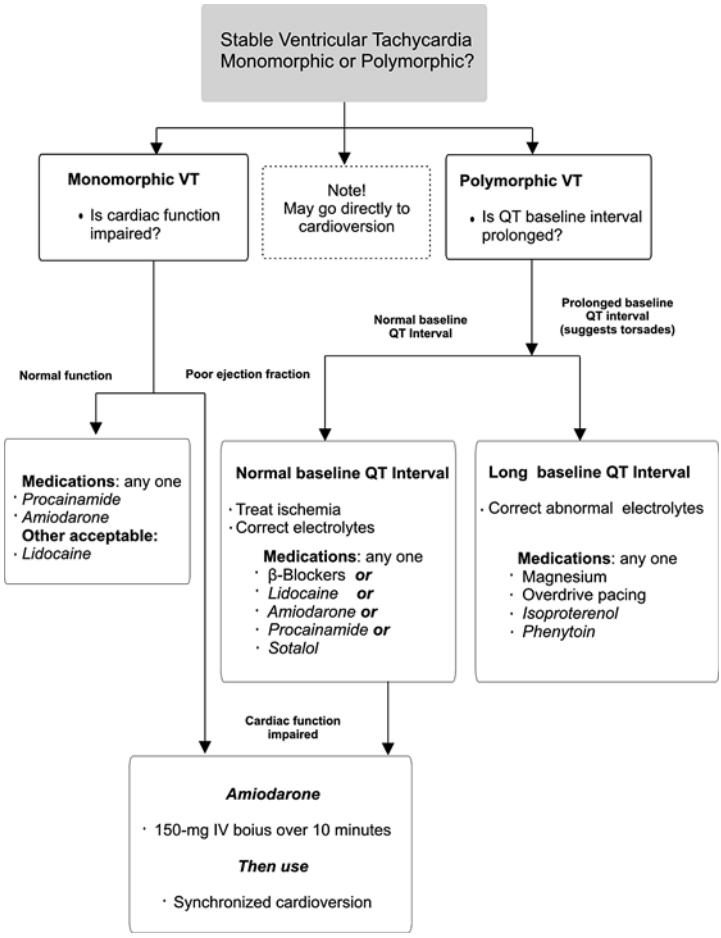

Figure 2.7. Tachycardia algorithm.

hypoxemia without a widened A-a gradient. There are two important examples: high altitude and alveolar hypoventilation.

Example 4: A normal adult breathing room air at an altitude of 11,000 feet:

A-a gradient = 0
$PaO_2 = (\mathbf{510 -} 47).21 - 40/0.8 = 47$
A-a gradient = 0
$PaO_2 = 47$
This patient has hypoxemia without an A-a gradient.

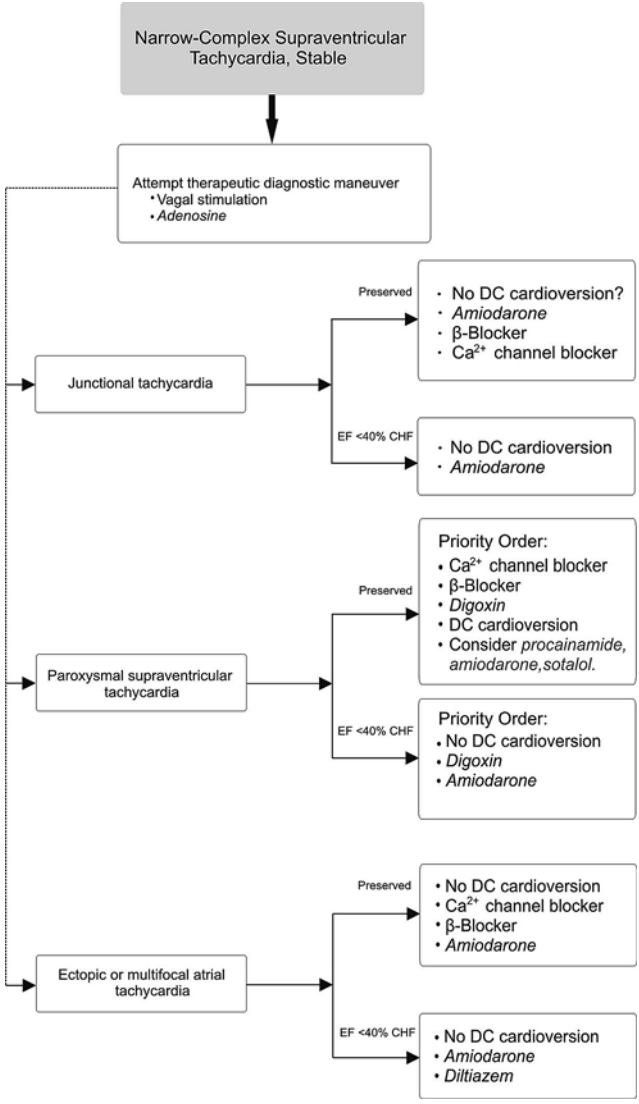

Figure 2.8. Tachycardia algorithm.

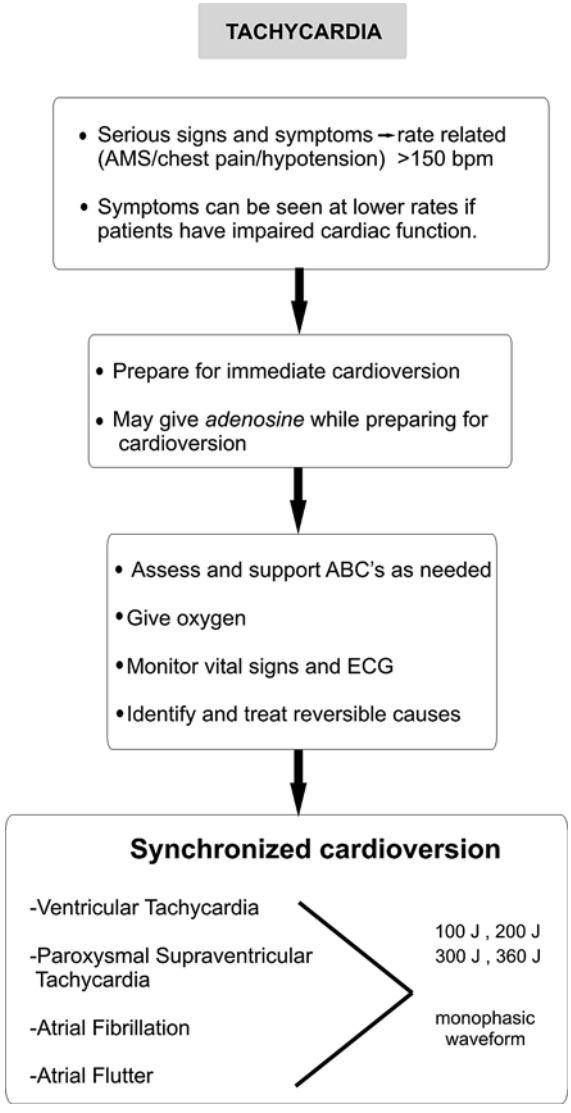

Figure 2.9. Electrical-synchronized cardioversion algorithm.

Example 5: A patient with pure alveolar hypoventilation secondary to narcotic overdose breathing room air:
$PCO_2 = 80$; A-a gradient = 0
$P_AO_2 = (760 - 47).21 - 80/0.8$
$P_AO_2 = 50$
A-a gradient = 0
$PaO_2 = 50$

This patient has hypoxemia without an A-a gradient.

3. Summary
   a. The alveolar air equation shows the relationships among atmospheric pressure, FiO_2, $PaCO_2$, and alveolar O_2 tension (P_AO_2).
   b. When alveolar O_2 tension (P_AO_2) is not reflected faithfully in arterial blood (PaO_2)—i.e., a widened A-a gradient—the calculation indicates that gas exchange is impaired, but it does not tell you how or why.
   c. Calculation of the A-a gradient is a useful bedside tool for evaluation of patients with respiratory distress or abnormal ABGs and to follow their progress.
   d. It is possible to have hypoxemia without a widened A-a gradient. High altitude and hypoventilation (elevated $PaCO_2$) are examples.

■ III. OXYGEN TRANSPORT

A. Oxygen Delivery: Calculations
1. Calculation of oxygen delivery ($\dot{D}O_2$) and oxygen consumption (VO_2) are useful bedside techniques in the ICU.
2. $\dot{D}O_2 = CO \times CaO_2$
   Oxygen delivery = Cardiac output × Arterial O_2 content
3. $CaO_2 = Hb \times SaO_2 \times K$
   Arterial O_2 content = Hemoglobin × Arterial O_2 saturation × a constant*
   *We will use 1.34 mL O_2/g Hb.
4. Resolving the units:
   $\dot{D}O_2$ [mL O_2/min] = CO [mL/min] × Hb [g/100 mL] × 1.34 [mL O_2/g] × SaO_2 [scalar]
5. Normal values (70-kg man at rest)
   $\dot{D}O_2$ = 5,000 mL/min [CO] × 15 g/100 mL [Hb] × 1.34 mL O_2/g [constant] × 1.00 [SaO2]
   $\dot{D}O_2$ = 1,005 mL O_2/min
6. This value does not take into account dissolved O_2 in the plasma: 0.003 mL O_2/100 cc/mmHg PaO_2, which adds another 15 mL O_2 of arterial O_2 content.
7. Values to remember:
   Normal CaO_2 (15 g Hb, 100% SaO_2) = 20.4 mL O_2/100 cc (20.4 vol %)
   Normal $\dot{D}O_2$ (70-kg man, at rest, CO = 5,000 mL/min) = 1,020 mL O_2/min

B. Oxygen Transport: Concepts
Only three clinical variables can affect
$\dot{D}O_2$: cardiac output, hemoglobin, and oxygen saturation.