

Missed Connection: A Case of Inadequate ECG Oversight in Cardiac Surgery

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Debra Bakerjian, PhD, APRN, RN; Christian Bohringer, MBBS; Manuel Fierro, MD; Patrick Romano, MD, MPH; Ulfat Shaik, MD and Sandhya Venugopal, MD for this Spotlight Case and Commentary have disclosed no relevant financial relationships with ineligible companies related to this CME activity.

Learning Objectives

At the conclusion of this educational activity, participants should be able to:

- Recognize the importance of maintaining sinus rhythm in patients with left ventricular hypertrophy.
- Identify the prerequisites for performing successful synchronized cardioversion.
- Describe the reasons for greater safety with synchronized as compared to asynchronized cardioversion and cardiac pacing.
- Explain basic requirements for using defibrillators successfully.

The Case

A 77-year-old man was admitted to the hospital with acute chest pain and shortness of breath. He underwent cardiac catheterization, which showed 3-vessel coronary artery disease and severe aortic stenosis. He was deemed a surgical candidate and was transferred to another facility for coronary artery bypass graft surgery with aortic valve replacement (CABG/AVR) the next morning. His case was delayed by an hour while the surgeon found and reviewed the angiogram video from the referring hospital. The patient felt cold on the operating room (OR) table, so multiple blankets were placed. Induction of general anesthesia proceeded without further delay or complications. The operation went smoothly, and the patient came off cardiopulmonary bypass on a low-dose norepinephrine drip.

During removal of the venous cannula, the patient went into atrial fibrillation with hypotension. The surgeon took the internal paddles and requested the circulating nurse to get ready for synchronized cardioversion. The nurse acknowledged and the patient was shocked at 10 Joules. Due to the number of pieces of equipment in the room, the defibrillator screen was visible only to the circulating nurse. Since the patient did not convert to sinus rhythm, the surgeon requested 20 Joules synchronized cardioversion, after which the patient went into ventricular fibrillation. He was immediately and successfully defibrillated with 20 Joules. When the drapes came down and while the patient was being transferred to his gurney, the OR team noticed that the electrocardiogram cable that enables synchronized cardioversion was never connected to the patient's defibrillator. The anesthesia resident had only connected ECG leads into the anesthesia monitor, and not into the defibrillator.

The Commentary

By Christian Bohringer, MBBS, Manuel Fierro, MD, and Sandhya Venugopal, MD

Background

Aortic stenosis and coronary artery disease frequently coexist in older patients,¹ and both can present with chest pain on exertion. Combining aortic valve replacement (AVR) with coronary artery bypass grafting (CABG) is associated with higher mortality and morbidity than either individual procedure. The Society of Thoracic Surgeons (STS) has therefore developed a composite hospital performance measure specifically for the combined procedure.² As in this case, combined operations cannot be performed in every hospital that has a cardiac catheterization laboratory; transfer to a regional center is often necessary. Inter-hospital transfers are an important pathway toward improving outcomes for critically ill patients who present to rural or safety net hospitals with limited capabilities. Delays in such transfers, perhaps resulting from implicit clinician biases, have been identified as a factor contributing to racial disparities in outcomes of acute coronary syndromes.^{3,4}

The staff referring the patient to a cardiac surgical service should ensure that the coronary angiogram is transferred together with the patient to avoid delay in treating the patient, as occurred in this case. The angiogram file needs to be in a format that can be readily accessed by the receiving cardiac surgical team. A simple verbal report is not sufficient; the angiogram video must be available to allow the surgeon to plan the operation precisely. Whenever possible, the angiogram should be reviewed the day before the planned operation to prevent delays in starting the procedure, and to ensure that the surgical team is able to obtain informed consent in the patient's preferred language, with professional interpretation if needed.

Atrial fibrillation (AF) has been reported to occur in 5-40% of operations involving cardiopulmonary bypass.⁵ Combined valve replacement and CABG procedures have higher rates of AF than either procedure alone.⁶ The onset of AF occasionally occurs in the OR when separating the patient from cardiopulmonary bypass. Precipitating factors include direct irritation of atrial tissue by the venous cannula (as appears to have happened in this case) or by the sutures inserted into the right atrium to stop bleeding when the cannula is removed. Unintended mechanical overdistension of the atria when blood is re-infused from the bypass machine back into the cardiovascular system may also play a role. Electrolyte disturbances are also common before coming off bypass. The serum potassium concentration, in particular, may be elevated as an after-effect of repeated administration of cardioplegia solution to stop the heart from beating during bypass.

Patients with significant aortic stenosis usually develop left ventricular hypertrophy, which makes the left ventricular wall thick and non-compliant. These patients are therefore especially dependent on normal contraction of the left atrium to provide adequate preload to the left ventricle and optimal perfusion of the tissues. When patients with left ventricular hypertrophy develop AF, the cardiac output may drop by as much as 30%. For this reason, the clinicians in this case were trying to rapidly cardiovert the patient back to sinus rhythm as soon as they noticed the onset of AF. The outcome of AF has been shown to be worse in patients with aortic stenosis than in patients with a normal aortic valve.⁷

New onset AF in the OR is often treated with synchronized cardioversion. The internal paddles delivering the electric shock should be applied directly to the atria to minimize the risk of inducing ventricular fibrillation (VF). Systemic anticoagulation is not necessary in this acute situation because insufficient time has elapsed for blood clots to form in the left atrial appendage. The defibrillator analyzes the patient's electrocardiogram (ECG) and times the shock so that it is not applied during the period of repolarization (T-wave). If an asynchronous electric shock is applied on the T-wave, ventricular fibrillation (VF) may be induced by attempted cardioversion.⁸ It is therefore very important to connect the ECG leads to the defibrillator so that cardioversion can be synchronized with the patient's heartbeat. With synchronized cardioversion, the shock does not occur immediately when the button is pressed but is briefly delayed, ensuring that it does not coincide with the relative refractory period corresponding to the later part of the T-wave.⁹

VF can also be inadvertently induced when the heart is paced with an asynchronous pacing mode. This may take place in the electrophysiology lab or in the operating room where pacing via epicardial leads is often necessary when coming off cardiopulmonary bypass.¹⁰⁻¹³ Asynchronous pacing is preferred in the OR because synchronized pacing spikes may be inhibited by the current emanating from the electrocautery unit used to control bleeding. When the pacemaker is in a synchronous pacing mode, it frequently misinterprets the electrocautery current as electrical impulses originating from the heart. To avoid this problem, the pacing box is switched to asynchronous mode so that the pacemaker continues to pace the heart while electrocautery is in use. As soon as electrocautery is no longer needed, the setting on the pacing box should be changed back to synchronous to prevent inadvertently pacing on the T-wave and potentially inducing VF.

Tachydysrhythmias and VF can be treated calmly while the patient is still on cardiopulmonary bypass because cerebral perfusion is provided by the bypass machine. Lowering the serum potassium and

administering antiarrhythmic medications such as amiodarone or dexmedetomidine may terminate the arrhythmia. Dexmedetomidine and amiodarone are preferred to beta blockers as antiarrhythmic drugs in this setting because they do not have a negative inotropic effect on the heart. Dexmedetomidine has also been shown to reduce the incidence of AF after cardiac surgery.¹⁴⁻¹⁶ However, when the venous cannula has already been removed, as in this case, VF must be terminated rapidly to reestablish blood flow and prevent brain damage.

If a stable cardiac rhythm cannot be restored rapidly, the right atrial appendage should be re-cannulated emergently so the patient can be placed back on cardiopulmonary bypass. If heparin anticoagulation has already been reversed with protamine, the patient must be re-heparinized and the activated clotting time must be checked to ensure that the patient is safe to go back on bypass.

Implanted devices delivering electricity are used frequently, including pacemakers and automated implantable cardioverter defibrillators (AICDs) for cardiac arrhythmias, vagal nerve stimulators and deep brain stimulators for epilepsy and Parkinson's disease, spinal cord stimulators for chronic pain, and hypoglossal nerve stimulators for sleep apnea. Anesthesia care providers and others working in the OR should become familiar with the effect of electrical interference from electrocautery on these devices. Care must also be taken when manipulating central venous lines because micro-shocks from static electricity have been reported to cause VF.^{17,18} In an experimental study, a current as small as 550 micro-amperes could induce VF.¹⁹

Approaches to Improving Patient Safety

Adequate preparation

In this case, the delay caused by the surgeon having to look for the angiogram video for an hour, combined with the patient's resulting discomfort, probably made the OR team hurry to make up for lost time. This time pressure likely contributed to the team forgetting to check that the cardioverter/defibrillator had been hooked up correctly to the ECG leads. Coronary angiograms should be reviewed, and the bypass operation should be planned well ahead of the operation to prevent delays in starting time and subsequent time constraints on staff. All team members, especially trainees with limited experience, should understand their respective roles and responsibilities. Proper planning and execution of the CABG operation has been shown to prolong life by reducing rates of myocardial infarction.²⁰

Connect defibrillators to the ECG leads

When the defibrillator has been connected correctly, the ECG trace will be displayed on the defibrillator screen. The selector switch should be turned to synchronous, and the anesthesiologist should make sure that the system is ready to deliver a synchronized shock.⁹

The anesthesiologist is responsible for ensuring that the connection and the settings on the cardioverter/defibrillator are correct because the surgeon cannot break sterility to change the machine settings. The ECG can also be slaved off the anesthesia monitor, which is then connected to the defibrillator. With this set-up, a separate pair of chest leads directly connected to the defibrillator is no longer necessary. With either set-up, however, the anesthesiologist should verify that the ECG is displayed

on the defibrillator screen so that the shock can be synchronized. When transcutaneous pacing pads are used, OR staff need to verify that the pads sense the ECG so that synchronized pacing and shocks are possible. When changing from transcutaneous chest pads to internal defibrillation paddles, the defibrillator must be connected to the paddles to deliver the shock. In the prehospital environment, paramedics can monitor the ECG directly via external defibrillator paddles applied to gel pads on the patient's chest and deliver a synchronized shock. In the cardiac OR, the chest wall is in the sterile field and direct monitoring via the defibrillator paddles is impossible.

When internal paddles are used for cardioversion, the surgeon is responsible for applying them correctly and for making good physical contact with the cardiac chambers to be shocked. The surgeon also needs to choose the energy to be applied with every shock. If an asynchronous shock is required, as for VF in this case, the settings on the defibrillator must be changed to asynchronous mode or the defibrillator will not deliver the shock in the absence of coordinated electrical activity.

In this case, the patient was fortunate that defibrillation was immediately successful in restoring sinus rhythm. There is never any guarantee that shocking the ventricle will terminate VF. If this patient had remained in VF, the team would have had to re-cannulate the right atrium, re-heparinize the patient and go back onto cardiopulmonary bypass. To avoid such situations, the cardioversion shock must be synchronized with the ECG to prevent the shock from inadvertently falling on the T-wave and inducing VF, as in this case. Similarly, external pacing boxes should be set to synchronous mode as soon as electrocautery is no longer required. Temporary pacing is often used to maintain hemodynamic stability after coming off bypass.²¹ Defibrillation in this setting is not always successful and refractory VF is a common and life-threatening problem in clinical practice.^{22,23}

Be familiar with the location and the operation of the defibrillator

Anesthesia clinicians and circulating nurses in the operating room should be familiar with the location and the operation of defibrillators. There should never be any delay with cardioversion or defibrillation because staff cannot find the defibrillator or do not know how to use it. Operation of the defibrillator should be practiced regularly under controlled conditions (e.g., simulations), allowing the staff to feel comfortable when they must use this equipment in an emergency. This practice prevents delays in treatment and is necessary because defibrillators are used less often in the OR than in the coronary care unit. "Teaching defibrillators" are now available that reduce the cost of training equipment and eliminate the risk of staff accidentally electrocuting themselves when learning how to use the equipment.²⁴

Check the defibrillator regularly

Defibrillator maintenance is very important. While defibrillators are used infrequently in the operating room, their correct functioning is of critical and life-saving importance during an emergency. Staff need to verify regularly that the defibrillator can be charged and discharged. It should remain plugged into an electrical outlet so that the battery is fully charged. Institutions should have protocols and specific checklists for maintaining important resuscitation equipment. Studies have shown however that staff often fail to routinely check that their defibrillators function properly.²⁵

Be prepared for urgent bypass

OR personnel should always be prepared to go back on cardiopulmonary bypass emergently in case of hemodynamic deterioration that does not immediately respond to resuscitation. If further shocks had not been effective in this patient, the surgeon would have had to cannulate the right atrial appendage again to resume cardiac bypass. Rapid anticoagulation with heparin would have been necessary and the activated clotting time would have had to be checked to make sure it was safe to put the patient back on an extracorporeal perfusion circuit. Working in the operating room requires a high degree of mental flexibility. Staff must be able to respond rapidly to changing circumstances with a new treatment plan. It is very important to make sure that the patient is hemodynamically stable before taking out the cannulas for the bypass machine. Tachydysrhythmias should be treated with dexmedetomidine or amiodarone and bradycardia with pacing before removing the cannulas.

Investigate unexpected events immediately

The failure to connect the cardioverter/defibrillator to the ECG in this case was not recognized until the end of the procedure when the drapes were taken down. This incident was due to human error rather than equipment failure, although there were likely multiple contributing factors. Staff should be inquisitive whenever treatment delivers unexpected results. VF after a synchronized cardioversion for AF should have raised a red flag that something was wrong with the defibrillator set-up. The connections should have been checked immediately after this event to determine why the shock was not synchronized with the patient's ECG. This is the primary responsibility of the anesthesiologist because (s)he is free to move around the OR and troubleshoot the defibrillator. The surgeon in this case could not see the screen and therefore was not in a position to correct the error. If this patient had needed another cardioversion for recurrent AF, VF may have been induced a second time because the team did not correct the problem after the first episode.

Summary

This patient did not experience any lasting harm because his VF could be terminated rapidly with two additional shocks, without returning to cardiopulmonary bypass. However, VF can sometimes be refractory to defibrillation. Applying unsynchronized shocks or unsynchronized pacing should be avoided whenever possible to reduce the chance of inadvertently inducing VF. OR staff should use consistent processes to ensure that all equipment is set up correctly. Use of a checklist may be an important tool in preventing this type of error.

Take-Home Points

- Thorough preparation before cardiac surgery avoids delays and errors from trying to make up for lost time.
- Cardioverters/defibrillators must be connected to the ECG to enable synchronized shocks as a shock or pacing spike on the T-wave can induce VF. Synchronized shocks and pacing should be used whenever possible to reduce this risk.
- Use of a checklist and regular defibrillator maintenance is important.
- Operating room staff need to be familiar with the location and operation of defibrillators.
- Unexpected treatment outcomes should be investigated immediately to avoid recurring complications if the treatment must be repeated.

- Cardiac OR staff should always be prepared to put their patient back on bypass urgently if VF or other life-threatening arrhythmias persist.

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