

A primer for the student joining the adult cardiac surgery service tomorrow: Primer 1 of 7



Rohun Bhagat, MD,^a Mary A. Siki, BS,^b Nicholas Anderson, BS,^c Lena Trager, BA,^d Edgar Aranda-Michel, PhD,^e Daniel Ziazadeh, MD,^f Ashley Choi, MD, MHS,^g John A. Treffalls, BS,^h Valentino Bianco, DO, MPH,ⁱ Clauden Louis, MD, MS,^j David Blitzer, MD,^k and Marc R. Moon, MD,^{l,m} Cleveland, Ohio; New Orleans, La; Chicago, Ill; Minneapolis, Minn; Pittsburgh, Penn; Rochester and New York, NY; Palo Alto, Calif; San Antonio and Houston, Tex; and Boston, Mass

From the ^aDepartment of Thoracic and Cardiovascular Surgery, Cleveland Clinic, Cleveland, Ohio; ^bTulane University School of Medicine, New Orleans, La; ^cMidwestern University Chicago College of Osteopathic Medicine, Chicago, Ill; ^dUniversity of Minnesota Medical School, Minneapolis, Minn; ^eUniversity of Pittsburgh School of Medicine, Pittsburgh, Pa; ^fDepartment of Cardiac Surgery, University of Rochester, Rochester, NY; ^gDepartment of Cardiothoracic Surgery, Stanford University, Palo Alto, Calif; ^hLong School of Medicine, University of Texas Health Science Center at San Antonio, San Antonio, Tex; ⁱDepartment of Cardiothoracic Surgery, University of Pittsburgh, Pittsburgh, Pa; ^jDivision of Cardiac Surgery, Brigham and Women's Hospital, Boston, Mass; ^kDivision of Cardiac Surgery, Columbia University, New York, NY; ^lThe Texas Heart Institute, Houston, Tex; and ^mDivision of Cardiothoracic Surgery, Baylor College of Medicine, Houston, Tex.

Disclosures: The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

Received for publication Feb 19, 2023; revisions received April 2, 2023; accepted for publication April 3, 2023; available ahead of print May 7, 2023.

Address for reprints: Rohun Bhagat, MD, Department of Thoracic and Cardiovascular Surgery, Heart, Vascular & Thoracic Institute, Cleveland Clinic, 9500 Euclid Ave, Cleveland, OH 44195 (E-mail: rohun.bhagat@gmail.com).

JTCVS Open 2023;14:270-92
2666-2736

Copyright © 2023 The Author(s). Published by Elsevier Inc. on behalf of The American Association for Thoracic Surgery. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

<https://doi.org/10.1016/j.xjon.2023.04.018>



JTCVS, TSRA, & TSMA have created a primer series introducing CTS to medical students.

CENTRAL MESSAGE

JTCVS has partnered with the TSRA & TSMA to make a 7-part primer series introducing medical students to CT Surgery. This, the first installment, focuses on excelling in the Adult Cardiac Surgery rotation.

The adult cardiac surgery service often manages some of the sickest patients in the hospital. This can be a very fast-paced environment with a lot of new information to take in. This primer discusses the nuts and bolts of being on the adult cardiac surgery service, separated into 3 phases of care: preoperative (clinic and consults), intraoperative, and postoperative (patient management).

BASIC SCHEDULE

Below is a brief outline of what a typical day on an adult cardiac surgery service will look like (this is variable by institution, so check with the residents, fellows, and/or attendings). It is recommended that all students contact the senior resident/fellow on the service to know when the team will round and what responsibilities the student should expect.

5:30 AM – Pre-round (as needed).

6:00 AM – Rounding begins with the students, residents, fellows, and overnight intensive care unit (ICU) providers.

7:30 AM – Operating rooms (ORs) begin cases or clinic day begins.

12:30 PM – Case 1 concludes; now is a good time to eat something, read up on the next case, and study.

1:30 PM – Case 2 starts.

6:30 PM – Case 2 ends.

7:00 PM – Go home.

PREOPERATIVE (CLINIC AND CONSULTS)

New clinic patients and inpatient consults are very similar in terms of what to look for and what to ask during a history and physical. Below is a walk-through of what to look for and why each parameter is important.

Before seeing the patient, it is good to review the relevant clinical data including the medical and surgical history. For the most part, by the time the cardiac surgery service is consulted or a patient is seen in the clinic, the history and tentative plan have been established by the referring cardiologist. As such, talking with the patient is mostly to confirm what

has already been established in the chart, discuss what the patient knows about their disease state and why they are seeing a cardiac surgeon, and to go over treatment options. That said, while cardiology may have performed a suitable workup, remember that the surgeon is the one making incision on the patient and, as such, the surgeon and their trainees should approach each patient as if they have not been worked up by anybody else, searching for new and relevant information.

Note that patients transferred from another institution may require a more aggressive approach to make sure outside imaging is available, old operative reports are obtained, and to reconfirm that the correct diagnosis has been made. Important clinic and consult parameters are listed in [Table 1](#).^{1,2}

After gathering all of the data and seeing the patient, the next step is to present to a resident or attending. The key, as with rounds, is to be concise while giving all of the pertinent information. This can be challenging, so an example is provided to follow:

Mr Jones is a 63-year-old male with a history of hypertension and hyperlipidemia who presents to Dr Knight's clinic for evaluation of aortic stenosis (AS). The patient was found to have a murmur by his primary care provider in 2014, which was evaluated by echocardiography at that time and found to be mild AS. The patient was asymptomatic in 2014 and follows up regularly with cardiology. At his last visit to cardiology in March of 2022, the patient reported dyspnea on exertion and a syncopal event. An echo was performed that showed severe AS with a mean pressure gradient of 47 mm Hg, aortic valve area 0.6 cm², and a peak velocity of 5.1 m/s. Mr Jones' cardiologist, Dr Harb, referred him to our clinic for consideration of aortic valve replacement.

Mr Jones and his wife understand the progressive nature of this disease and would like to move forward with surgical aortic valve replacement. They recognize transcatheter aortic valve replacement (TAVR) as an option, although they prefer to proceed with surgery. I recommend we use a mechanical valve, given the longevity of the valve, although we will have to discuss valve options with our patient.

Given Mr Jones' severe, symptomatic AS, this is stage D1 disease, which has a class 1 indication for aortic valve replacement. The calculated Society of Thoracic Surgeons risk of mortality is less than 1%. I believe it is appropriate to proceed with surgery.

Next, look at the "Final Steps" portion of [Table 1](#). After completing those tasks, the clinic visit or consult is complete.

POSTOPERATIVE MANAGEMENT

Pre-Rounding and Writing Notes

Unlike most surgical services, early postoperative patients on the cardiac surgery service are typically managed

in an ICU opposed to a typical hospital floor. This makes pre-rounding and rounding 2 more involved than on most other services.

The first step is to simply ask the residents, nurse practitioners, or physician assistants if there is a template note that is commonly used. If not, it is appropriate to free hand the sections to follow into history of present illness, laboratory values, physical examination, etc. It may be easiest to write everything in a note format upfront rather than gathering all the data in one place and having to translate it to a note later on.

To follow is a list of clinical data and information which is important to consider in every patient. In general, check over all of the patient's clinical data, but focus on the following. Important parameters in postoperative management of the adult cardiac surgery patient are listed in [Table 2](#).^{3-17,18}

Presentations and Rounding

The key is to be concise while giving all of the pertinent information. Anything more than 2 to 3 minutes is usually too much. This can be challenging, so a template and an example are provided to follow (most residents and attendings will not expect master-level presentations on the first day or even the first 2 weeks).

Rounding Presentation Template

The rounding presentation template below serves as an adjunct to [Table 2](#).

1. One liner
 - a. Include the patients name, age, operation, postoperative day, and surgeon who operated on the patient.
2. Interval events
 - a. Includes yesterday's significant daytime and overnight events.
 - b. This section may be interwoven with some objective data and/or subjective data as needed (eg, the example to follow discusses extubation the previous day when discussing current oxygen saturation).
3. Objective
 - a. Vitals (include inotropic/vasoactive drips and respiratory support)
 - b. Ins/outs
 - c. Laboratory values
 - d. Imaging
 - e. Physical examination
4. Subjective
 - a. How the patient is feeling overall.
 - b. Status of nausea, vomiting, bowel function, etc.
5. Assessment/plan

TABLE 1. Clinic and consult important parameters

Parameter	Abbreviation	Notes
Before seeing the patient		
Referring service/ cardiologist	–	Often, an attending will want to know what service is referring the patient (inpatient) or what cardiologist/primary care doctor referred the patient to the clinic (outpatient).
History of present illness	HPI	A focused history on when/why the disease was discovered, follow-up since discovery, and relevant symptoms (including progression of symptoms). More about common pathologies and presentations can be found in the operative portion of this text.
Past medical history	PMH	Consider comorbidities that relate to cardiac pathology or increase surgical risk. Things to think about include general cardiovascular risk factors such as diabetes, hypertension, hyperlipidemia, peripheral artery disease, immunocompromised state, renal disease, liver disease, cerebrovascular disease, cancer within the past 5 y, mediastinal radiation, sleep apnea, syncope, lung disease, heart disease (previous myocardial infarction, aortic stenosis, arrhythmia, endocarditis, etc), and issues with anesthesia.
Past surgical history	PSH	It is important to review any relevant surgical history, including any history of previous chest instrumentation, previous cardiac surgery (for which previous operative notes should be obtained), and previous cardiology procedures such as alcohol septal ablation, PCI, PFO closure, LAA closure, TEE cardioversions, TAVR, mitral valve clipping, etc.
Current medications	Meds	List current medications and get a detailed history on any cardiovascular-related medications. Note that what is listed in the chart is not always what the patient is actually taking or how frequently they are taking it. Often, the most important medications to discuss with the patient are NOACs, clopidogrel, warfarin, and other anticoagulants as well as when these medications were discontinued. Patients may not know their specific medications, however, they will generally know if they are taking “blood thinners” and/or when they discontinued “blood thinners.”
Labs	–	Review labs with a focus on CBC, CMP, coagulation studies, ABGs, etc.
Electrocardiogram	ECG/EKG	Review for irregularities. Note any history of heart block, as this could increase the risk of permanent pacemaker insertion post-operatively. If you are having trouble with interpretation, look for the cardiology official report on the EKG, if available. A more detailed review of EKGs can be found at the following links: https://www.ncbi.nlm.nih.gov/books/NBK549803/ https://www.amboss.com/us/knowledge/ECG/
Echocardiography Transthoracic echocardiography Transesophageal echocardiography	Echo TTE/TEE	Echocardiography is a key dynamic imaging tool used to assess global cardiac function, valvular pathology, and plan for surgical intervention. This modality depicts how the heart is functioning in every chamber (including valves) and measures overall left and right heart function (ejection fraction). Various measurements including heart size, degree of valvular regurgitation or stenosis, and heart function can be obtained quantitatively and qualitatively. Often, you may need to refer to the official report to more clearly understand how each part of the heart is functioning. A more detailed review of echocardiography is covered in the fourth primer within this series, “A Primer for Students Regarding Cardiothoracic Imaging.” In addition, students who are interested in gaining a clearer understanding of the 3-dimensional structures visualized with echo may navigate to the following links: TEE: http://pie.med.utoronto.ca/tee/ TTE: http://pie.med.utoronto.ca/tte/TTE_content/standardviews.html
Cardiac catheterization	Cath	This invasive study is divided into left and right heart catheterization. The left heart catheterization is a coronary angiogram allowing clinicians to obtain high-resolution views of the intraluminal architecture of the coronary arteries. This imaging may elucidate the need to intervene and to revascularize the coronary artery in question. LV function can also be grossly assessed via a ventriculogram. The right heart catheterization provides specific intracardiac and intravascular pressure measurements that allows for calculations of pulmonary vascular resistance, cardiac output, cardiac index, and wedge pressure (left atrial pressure via distal pulmonary artery catheter wedge). It is a critical component of heart failure management and helps guide decision making for volume status, diuretics, need for mechanical support, and type of

(Continued)

TABLE 1. Continued

Parameter	Abbreviation	Notes
Chest radiograph	CXR	<p>circulatory support (LV, RV, or BiV support). Should patients require a continuous assessment of the above such as in cardiogenic shock, a PA catheter is left in via central vein access for adequate diuresis and cardiac pharmacological titration of medications. This catheter is known as a Swan–Ganz catheter (Edwards Lifesciences).</p> <p>Both echocardiography and catheterization are quite difficult to master interpreting, but reading the report will at least summarize the most relevant information. It is always beneficial to open the imaging first and correlate what is seen on the report.</p> <p>A more detailed review of cardiac catheterization is covered in the fourth primer within this series, “A Primer for Students Regarding Cardiothoracic Imaging.”</p> <p>The patient may have a CXR. CXRs can detect disease of thoracic structures (lung, heart, pleura, spine, diaphragm, etc) and are standard practice before most operations. It is important to compare the preoperative and immediate postoperative CXR to assess placement of new catheters, drains, breathing tubes, and lung parenchyma, given the need to wean mechanical ventilation. In addition, one can assess for injury to other structures that have occurred (eg, phrenic nerve resulting in hemidiaphragm paralysis/elevation). One may look for pulmonary edema, pleural effusions, widened mediastinum, infiltrates, pneumothorax, and other findings. A more extensive discussion (with illustrations) of cardiothoracic imaging can be found later in this primer series in the Cardiothoracic Imaging primer.</p> <p>Note that some patients have dozens of previous imaging studies, and it isn’t necessary to look at every one. Try looking at the most recent one or two and compare them with additional imaging to help with preoperative planning.</p>
<p>After assessing the aforementioned information, it is often possible to piece together most of the assessment and plan. It is best to know as much as possible about a patient and the potential plans for treatment before speaking with them. The next step is to speak with the patient.</p>		
Talking to your patient		
Chief complaint	CC	<p>Consider why the patient has come to clinic or why the cardiac surgery team has been consulted (this is often due to a symptom). Common examples include, chest pain, shortness of breath, fatigue, syncope, lower extremity swelling, etc.</p> <p>Ask the patient what specifically brought them into the hospital/clinic. This could include symptoms related to the cardiac problem, test results prompting admission (eg, critical disease on left heart catheterization), or some other complaint for which cardiac disease was incidentally found. Importantly, it is important to understand when the symptoms began and when/how they have worsened to the point of hospitalization. Seek to identify if this was a process which took days, weeks, months, or years to progress.</p>
HPI, PMH, Meds	–	Acquire and correlate the information in the chart and the interview of the patient or historian
Review of systems	ROS	This is often part of the HPI but can be expanded into its own section for symptoms that are likely unrelated to the presenting cardiac pathology (eg, chronic eczema).
Surgical history	–	Any previous surgeries, regardless of time since surgery. In particular, a cardiac surgery history will have strong influence for a cardiac surgical plan and must be closely considered. One must exhaust all efforts to acquire all original cardiac operative reports for size of valve, previously bypassed vessels, and CT imaging to confirm patient anatomy in light of previous surgery.
Family history	FHx	<p>History of heart disease.</p> <p>History of premature heart disease (direct blood relatives <55 y in a male patient, <65 y in a female patient).</p> <p>Cancer.</p> <p>Issues with anesthesia in the past.</p>
Social and occupational history	–	<p>What does the patient do on a daily basis and how is this disease pathology impacting their daily life? This is important because most surgeons only operate to treat symptoms or prolong life, that is, to improve quality or length of life.</p> <p>Ascertain alcohol use, smoking history, and other drug use.</p> <p>Are there risk factors in the patient’s occupation that could change decision making (eg, they work in construction and are prone to cutting themselves and want to avoid long term anticoagulation)?</p> <p>Who is at home to help take care of this patient if needed?</p>

(Continued)

TABLE 1. Continued

Parameter	Abbreviation	Notes
Other questions to ask	–	<p>What is the patient’s understanding of their disease process?</p> <p>What is the patient’s understanding of treatment options?</p> <p>Is surgery something the patient is open to?</p> <p>Does the patient plan to become pregnant (this can impact whether or not surgical options requiring anticoagulation can be considered)?</p>
Physical examination		
The physical examination is primarily focused on the cardiovascular and pulmonary systems.		
Overall		Does the patient look comfortable, uncomfortable, or in significant distress?
Cardiac		Auscultate cardiac listening areas and assess for murmurs. Assess distal pulses for discrepancy that might suggest peripheral vascular disease.
Respiratory		Auscultate and assess for decreased breath sounds at the bases or crackles that could suggest pleural effusions or pulmonary edema, respectively.
Skin		Look for evidence of lower extremity edema (heart failure), classical endocarditis signs (if relevant), signs of previous surgery (scars), etc.
The following examinations are important, but should be done in a concise format (eg, it is unnecessary to conduct a complete neurologic examination in most patients).		
Body mass index/weight		Usually entered at time of admission. In postoperative patients, tracking a patient’s weight is a useful tool in assessing fluid balance and effects of diuretics.
Neurologic		Is the patient alert and oriented? Are there any gross deficiencies of strength or facial drooping? Are there any signs of previous stroke or TIA?
Musculoskeletal		Does the patient have any gross motor abnormalities?
Abdominal		Inspection, auscultation, and palpation of the abdomen is usually sufficient.
Assessment and plan		
Combine the aforementioned information to decide what treatment options are most appropriate for the patient.		
It is very important to look at formal indications for performing/not performing a certain operation. Formal indications are more comprehensively covered in the Operations portion of this text.		
Calculate the STS Risk Score (this can be found at https://riskcalc.sts.org/stswebriskcalc/calculate). ¹		
Presentation to resident/attending		
See an example presentation following the table.		
Final steps		
This comes after presenting and finalizing whether the patient will receive an operation or not.		
<ul style="list-style-type: none"> • Patient is not having surgery: Schedule follow-up as indicated. Should additional testing or surveillance be indicated, appropriate follow-up with cardiac surgery, cardiology, and/or the primary care provider should be set up in advance. • Patient is having surgery: Complete any of the following that have not been completed (this is institution specific, but an example workup is provided below). 		
Cardiac catheterization		A cardiac cath/coronary angiogram is important in all patients older than 40 years old considering heart surgery. Understanding coronary anatomy is important for specific valvular operations and CABG can be added on to the primary operation if the patient has moderate atherosclerotic disease and is having heart surgery for another reason (eg, valve replacement).
Vein mapping (pending cath) - optional		If the cath reveals indication for coronary artery bypass graft, it may be useful to map the veins (specifically the saphenous veins) to ensure they are physically present and viable for grafting. This test is optional and may be more useful in patients with peripheral vascular disease who may have had a saphenous vein used as a conduit for a prior operation.
Echocardiogram		As discussed previously, this imaging modality characterizes wall motion abnormalities, valve function, and overall heart function.
CXR		Obtain if not already obtained. Relevance of CXR discussed previously in this table.
Pulmonary function tests (PFTs)		Assesses for chronic pulmonary disease (included in STS Risk Score). Note that studies have shown that poor pulmonary function can increase the risk of postoperative morbidity and prolonged ventilation. Note that PFTs are not necessary without underlying lung disease or symptoms of respiratory limitations.

(Continued)

TABLE 1. Continued

Parameter	Abbreviation	Notes
Ankle-brachial indices		Assesses for peripheral vascular disease (included in the STS Risk Score).
Carotid Doppler - optional		Assesses for carotid artery stenosis (included in the STS Risk Score), given its risk for stroke. Carotid artery disease may also assist the surgeon regarding preferential hemodynamics during cardiopulmonary bypass to assure cerebral perfusion. This test is optional and often low yield in patients without bruits, symptoms of carotid disease, or left main coronary artery disease. From a perspective of systems-based practice, it is important not to order unnecessary expensive tests. Discussion with the attending surgeon on what tests are essential may be beneficial.
Labwork		CBC (with differential if concern for infection at admission) CMP (includes glucose, Ca, Na, K, HCO ₃ , Cl, albumin, protein, alkaline phosphatase, ALT, AST, bilirubin, BUN, and Cr) Coagulation Studies (often includes platelets (in CBC), PT/INR, PTT, and fibrinogen) Urinalysis MRSA swab
Medication changes		The patient may be asked to discontinue (“hold”) certain medications the day of surgery and/or days before surgery. Common examples are as follows ² : Discontinue 7 d before surgery: prasugrel Discontinue 5 d before surgery: clopidogrel, ticagrelor, warfarin Discontinue 60 h before surgery: fondaparinux Discontinue 48 h before surgery: NOACs (dabigatran, apixaban, rivaroxaban, edoxaban) Discontinue 24 h before surgery: abciximab, low molecular weight heparin (LMWH) Discontinue 4 h before surgery: unfractionated heparin, tirofiban, eptifibatide Discontinue 1-2 h before to surgery: bivalirudin Discontinue morning of surgery: ACEi/ARB (refractory hypotension/vasoplegia), diabetic medications, diuretics
Oral examination		Aortic or valve procedures that involve implantation of a prosthetic device usually require an oral examination. If the patient has oral pain, redness, rotten teeth, or other cause for concern, formal dental clearance may be considered.

PCI, Percutaneous coronary intervention; PFO, patent foramen ovale; LAA, left atrial appendage; TAVR, transcatheter aortic valve replacement; NOACs, non-vitamin K antagonist oral anticoagulants; CBC, complete blood count; CMP, comprehensive metabolic panel; ABG, arterial blood gas; LV, left ventricle; RV, right ventricle; BiV, biventricular; PA, pulmonary artery; CT, computed tomography; TIA, transient ischemic attack; STS, Society of Thoracic Surgeons; Ca, calcium; Na, sodium; K, potassium; HCO₃, bicarbonate; Cl, chloride; ALT, alanine aminotransferase; AST, aspartate aminotransferase; BUN, blood urea nitrogen; Cr, creatinine; PT, prothrombin time; INR, international normalized ratio; PTT, partial thromboplastin time; MRSA, methicillin-resistant *Staphylococcus aureus*; ACEi/ARB, angiotensin-converting enzyme inhibitor/angiotensin II receptor blocker.

- a. Students should discuss plans for each system and be sure to include specific plans for any abnormalities noted within the presentation (eg, if the patient has low chest tube output, the student may suggest removing the chest tube).
- i. It is okay to be wrong about proposed plans; the resident/fellow/attending will likely help you understand their thinking and why it may differ from your plan; putting forth a plan for a problem is an important step in the learning process.

The following example would take ~2 minutes to say but is fairly comprehensive—residents and attendings may ask for more or less detail after the first few presentations.

Ms Louis is a 77-year-old female postoperative day 1 from a 3-vessel coronary artery bypass grafting (CABG) with Dr DeBakey. Blood pressure is stable at ~120/80 mm Hg on 0.02 µg/kg/min of epi and 50 µg/min of phenylephrine. Heart rate is stable at ~80 beats/min without pacing. Electrocardiogram is normal sinus without ST changes.

Ms Louis was extubated yesterday without complications and has a saturation of oxygen of 98% on 2 L of nasal cannula. Temperature is normal. White blood cell count is 14. Hemoglobin/hematocrit dropped to 7/20 yesterday, now stable at ~8/24 after 1 transfusion of packed red blood cells overnight. Platelets 320. Lactate 2.1, creatinine 1.2, and urine output of ~1.2 mL/kg/h. Comprehensive metabolic panel is normal except for sodium of 132. Over the past 24 hours, the right chest tube put out 100 mL of serosanguinous fluid and the left chest tube put out 400 mL of serosanguinous fluid. Chest radiograph shows patchy infiltrates bilaterally, with mild improvement from postoperative yesterday.

Ms. Louis says she feels well, with mild chest pain near the incision characterized as sore and not similar to her myocardial infarction pain. She has passed gas and is on a clear liquid diet without nausea or vomiting. She did not ambulate yesterday. On my examination, she is alert and oriented ×3 with normal heart sounds. The incision site is covered with a bandage but seems dry and intact. There are bilateral crackles on auscultation of the lungs anteriorly in the lower

TABLE 2. Important parameters in the postoperative management of the adult cardiac surgery patient

Parameter	Abbreviation	Normal values	Notes
General/vitals			
Postoperative day	POD	-	Know what day the patient is postoperatively (POD 0 is the day of surgery, POD 1 is the day after surgery, etc).
Blood pressure	BP	120/80 mm Hg (highly variable) ³	Know whether the patient is on any vasoactive/inotropic medications (eg, epinephrine, norepinephrine, milrinone, phenylephrine). Any patient on these medications generally should have an arterial line for continuous BP monitoring.
Heart rate	HR	60-100 beats per minute ⁴	Know if the patient has a permanent pacemaker or temporary pacing wires that were put in during the operation. For example, patients may be AV-paced at 60, or A-paced at 80 depending on surgeon preference. AV-paced means pacing stimulus delivered to both the atrial and ventricles, using separate atrial and ventricular wires. A-paced means the patient is being paced only with an atrial wire, and may or may not have an additional ventricular wire (that is not being used). A-pacing is critical for patients dependent on atrial kick who have a competent AV node with AV synchrony. Check the electrocardiogram (ECG/EKG) and compare it with previous ones (especially important following CABG surgery) to assess for arrhythmias, new ST elevations, bundle branch blocks, or evidence of repolarization abnormalities suggestive of reperfusion injury.
Respiratory rate (RR)/saturation of oxygen	RR/SpO ₂	12-20 breaths per minute ⁴ >95% SpO ₂ ⁵	The patient's breathing may be supported by a ventilator, nasal cannula, etc. Know which, if any, of these are being used, and to what extent they are being used (eg, how many liters of air is the patient on if they are using a nasal cannula).
Ventilator	Vent	Initial vent settings ² FiO ₂ : 0.4 (if >95% SpO ₂ on 1.0) PEEP: 5 cm H ₂ O RR: 10-12 breaths/min Vt: 6-8 mL/kg	Know if the patient is on a ventilator and, if so, what the FiO ₂ , positive end expiratory pressure (PEEP), tidal volume (Vt), and respiratory rate (RR) are set to. Vents can be set to various modes. Volume-limited mode: Vent delivers a preset tidal volume. Assist control (A/C): If a patient initiates a respiratory effort, the vent will deliver a preset tidal volume. The vent will also deliver a preset tidal volume at preset intervals if no breath is attempted by the patient. There are many more vent settings beyond the scope of this text. Alter Pao ₂ : Reduce Pao ₂ via reducing FiO ₂ or PEEP. Increase Pao ₂ via increasing FiO ₂ or PEEP. Alter Paco ₂ : Reduce Paco ₂ via increasing RR or tidal volume (Vt). Increase Paco ₂ via reducing RR or Vt. Providers in the ICU will often discuss weaning patients off ventilators in multiple ways. "Spontaneous breathing trial" means testing to see whether the patient is able to breathe with minimal vent support. This could be in the form of pressure support or CPAP, among others. "Pressure support" means the patient triggers each breath and the ventilator delivers minimal positive pressure (PEEP 5-8) to ease the work of breathing. "Trach collar" means that the patient is disconnected from the ventilator and allowed to breathe either room air or supplemental oxygen through a tracheostomy for a certain amount of time without ventilatory support—if the patient continues trach collaring indefinitely while remaining at an appropriate oxygenation status, they have been weaned off the ventilator. The team may opt to support the trach collaring with increased FiO ₂ air.
Hemodynamics and mechanical circulatory support			
Central venous pressure	CVP	8-12 mm Hg ⁶	Denotes the pressure in the right atrium and is a surrogate for right heart volume status.

(Continued)

TABLE 2. Continued

Parameter	Abbreviation	Normal values	Notes
Pulmonary artery pressure	PAP	Systolic: 20 mm Hg ⁷ Mean PA Pressure: 12 ⁷	The systolic pressure is that of the RV contracting. The diastolic pressure is that of the pulmonary artery at the time of RV relaxation, often a rough estimate of the left atrial pressure (though a true left atrial pressure is found from a formal pulmonary capillary wedge pressure). This is a useful marker of pulmonary hypertension and can guide treatment decisions to use inhaled nitric oxide or inhaled prostaglandin for pulmonary vasodilation, potentially preventing RV failure by reducing RV afterload.
Cardiac output and cardiac index	CO and CI	CO: ~5 L/min at rest ⁸ CI: 2.5-4.0 L/min/m ¹⁸	CO = stroke volume × heart rate CI = cardiac output/body surface area
Extracorporeal membrane oxygenation	ECMO	<p><i>Note that ECMO, LVAD, IABP, Impella, and RVAD are advanced topics and one should not spend too much time on this for initial rotation preparation. A brief description is provided next. A more extensive discussion of this can be found later in this primer series in the Advanced Topics primers.</i></p> <p>ECMO can be either venoarterial (VA-ECMO) - taking blood from the venous system and putting it back in the arterial system or venovenous (VV-ECMO) - taking blood from the venous system and putting it back in the venous system. VA-ECMO helps assist the function of both the heart and lungs (oxygenating and propelling blood forward). VV-ECMO helps assist only the function of the lungs (only oxygenating the blood). Typically, VA-ECMO is used for patients in cardiogenic shock with the added benefit of providing oxygenation whereas VV-ECMO is used for patients solely in respiratory failure.</p> <p>FiO₂: Controls the amount of oxygen provided to the ECMO circuit and can be adjusted to maintain optimal oxygen saturations in the body.</p> <p>Sweep: Controls how much CO₂ is removed by the ECMO circuit.</p> <p>Flow: Amount of blood flow the ECMO circuit is generating. Measured in liters per minute (L/min). A patient's normal cardiac output is ~5 L/min, and ECMO may support as little or as much of that cardiac output as is necessary.</p> <p>Rotations per minute (RPM): The pump speed of the ECMO circuit.</p> <p>ECMO differs from traditional cardiopulmonary bypass (CPB) because ECMO is a closed circuit with no venous reservoir whereas CPB has a large reservoir that allows volume to be removed for the circulatory system. ECMO is designed for more long-term use and is generally much more portable. Because ECMO has continuous flow without a reservoir, it can be run with little or no heparin as long as the flow rates are high enough to prevent clotting in the circuit. In contrast, CPB requires full heparinization because there is stasis of blood in the venous reservoir.</p>	
Left ventricular assist device	LVAD	<p>LVADs are implanted in patients with failing left ventricles. LVADs take blood from the apex of the left ventricle and use an internally placed pump to send blood into the aorta via an outflow graft (bypassing the aortic valve). The below settings are based off of the HeartMate3 model of LVAD.⁹</p> <p>Speed: 3000-9000 revolutions per minute. Although typical speeds are +/- 5000.</p> <p>Power: Measure of pump motor voltage and current. Can be impacted by changes in pump speed, flow, or physiological demand.</p> <p>Flow: An estimate derived from speed, power, and hematocrit.</p> <p>Pulsatility index (PI): When the LV contracts during systole, the increased pressure causes increased pump flow. Flow pulses are averaged over 15 s and a normal PI is 1-10. PI should not vary significantly during rest. When otherwise not altered, a significant drop in PI may denote a decrease in blood volume.</p>	
Intra-aortic balloon pump	IABP	<p>The IABP decreases myocardial oxygen demand while increasing coronary perfusion pressure. It does so through a reduction of LV afterload by deflation just before systole (reduced myocardial oxygen demand) and increased diastolic coronary perfusion by inflation after aortic valve closure, thus sending blood back to the coronary arteries.²</p>	
Impella	–	<p>The Impella is a mechanical percutaneous ventricular support device (which provides LV support via the CP, 5.0, and 5.5 model; or RV support via the RP model). The models which support left ventricular function have one end (inlet) that is positioned in the LV and one end (outlet) that sits in the aorta distal to the aortic valve. The device pumps volume from the LV to the aorta via a small rotary pump. Depending on how much support the patient requires, the flow (P-level) may be augmented by the provider.</p>	

(Continued)

TABLE 2. Continued

Parameter	Abbreviation	Normal values	Notes			
Right ventricular assist device	RVAD	Various devices are employed as RVADs. The basic principle is to help or entirely take over the function of the right ventricle. Typically, blood is retrieved from the right atrium or right ventricle and pumped into the pulmonary artery. Some RVADs oxygenate blood via an ECMO oxygenator after removing it from the body, while others do not. Some examples include Impella RP and Protek Duo.				
Swan–Ganz catheter	Swan	Also known as pulmonary artery catheters, these devices are inserted through a central vein and advanced through the right heart to rest in the pulmonary artery. These catheters are used to assess hemodynamics via waveform analysis and blood draws. Important parameters include: CO: 4-8 L/min CVP: 2-6 mm Hg Mixed venous oxygenation (Svo ₂): 65%-70% Pulmonary artery pressure (PAP): 10-20 mm Hg (mean) Pulmonary capillary wedge pressure (PCWP): 8-12 mm Hg				
		CVP	PCWP	PAP	CO	
		RV failure	↑		↑	↓
		LV failure		↑		↓
		Tamponade	↑	↑		↓
		Hypovolemic shock	↓	↓	↓	↓
		Cardiogenic shock	↑	↑		↓
		Distributive shock	↓	↓		↑
		Pulmonary hypertension	↑		↑	
Infection/inflammation						
Temperature	Temp	36.5-37.5 °C ⁴	Temperature can be indicative of inflammation or infection. It is important to note that patients may not mount a temperature in the setting of ECMO or CRRT so it is important to investigate other infection/inflammation parameters. Note that low-grade temperature may be a consequence of atelectasis which is treated with increased respiratory effort, coughing, and incentive spirometry.			
White blood cell count	WBC	4.5-11 × 10 ⁹ cells/L ³	Imbalance in WBCs can point to inflammation or infection.			
Brain natriuretic peptide	BNP	<100 pg/mL ³	BNP is released by the ventricles as a result of high ventricular filling pressures. This value may be elevated in patients who have symptomatic or asymptomatic LV dysfunction. BNP has several uses, some of which are presented below. ¹⁰ One may obtain BNP for patients with dyspnea of uncertain origin. Those who's dyspnea is caused by heart failure will often have elevated values, whereas those who have a normal BNP are very unlikely to be dyspneic due to heart failure. ¹⁰ BNP can be used prognostically in patients with chronic heart failure. Several studies have shown correlations with BNP and risk of mortality, with higher BNP values correlating with increased risk. ¹⁰			
Blood cultures	BCx	–	If the patient had blood cultures drawn on them, review closely for the gram stain which may come earlier than speciation. Check to see if the gram stain is positive or negative and if sensitivities to antibiotics/antifungals are available.			
Postoperative antibiotics	Postop Abx	–	Institution specific. Often, institutions will have a standard protocol for this.			

(Continued)

TABLE 2. Continued

Parameter	Abbreviation	Normal values	Notes
Hematologic			
Hemoglobin (Hb)/ hematocrit (Hct)	H/H or H&H	Hb: 14-17 g/dL (M), 12-16 (F) ³ Hct: 41%-51% (M), 36-47 (F) ³	Hb is the amount of hemoglobin protein in red blood cells (RBCs). Hct is the percentage which is the volume of RBCs/total blood volume. Often, patients on the service will be anemic and most hospitals will transfuse RBCs to the patient if their Hb is below 7 and/or Hct is below 21 (H/H below 7/21). Restrictive transfusion strategies have been shown in multiple studies to be beneficial and non-inferior to liberal thresholds.
Platelets	Plts	150-350 × 10 ⁹ /L ³	Platelets can be helpful to understand risk of bleeding, risk of heparin-induced thrombocytopenia, and inflammation (remember that platelets are an acute phase reactant). At times, patients with mechanical circulatory support will have a consumptive mechanical process from the circuit that leads to thrombocytopenia from shear force.
Lactate dehydrogenase	LDH	60-160 U/L ³	This can be indicative of cell breakdown, such as RBC breakdown. It is common for this to be elevated in patients on bypass/ECMO as these mechanical systems can lyse cells.
Prothrombin time/ International normalized ratio	PT/INR	PT: 11-13 s ³ INR: ~1.0 ¹¹	Tests for extrinsic pathway clotting cascade function. Warfarin primarily impacts this pathway; hence, INR is checked to assess the function/effect of Warfarin.
Activated partial thromboplastin time	aPTT	30-40 s ³	Tests for intrinsic pathway clotting cascade function. One can monitor heparin or bivalirudin function and adjust the infusion parameters accordingly in the ICU.
Activated clotting time	ACT	70-120 s ¹²	Tests for the intrinsic pathway clotting cascade function. Used to monitor unfractionated heparin anticoagulation (primarily in the intraoperative setting). ACT is far more commonly used in the operative setting than in the ICU or on the floor. When used in the setting of transitioning from bivalirudin, ACT may be falsely elevated.
End organ perfusion			
Lactate	–	Venous: 0.5- 2.2 mmol/L ¹³ Arterial: 0.5- 1.6 mmol/L ¹³	When tissues don't receive enough blood flow, they switch from aerobic to anaerobic metabolism, thus producing more lactate. A rising lactate can help clinicians understand and trend end-organ perfusion.
Creatinine	Cr	0.7-1.2 mg/dL (M) ³ 0.5-1.0 mg/dL (F) ³	This is helpful to determine if the patient is having acute kidney injury (AKI) and is an important marker for renal function. Note that patients may have an elevated Cr at baseline due to chronic kidney disease (CKD).
Urine output	UOP	0.5-1.5 mL/kg/h ¹⁴	This is another metric of understanding kidney function and organ perfusion. Generally speaking, the patient's urine output (in milliliters) should equal or exceed their body weight (in kilograms) in a 2-h period. NOTE: this may be less in the immediate postoperative period due to increases in ADH and aldosterone from the insults of surgery. Additionally, many cardiac patients are volume overloaded (often symptomatic pulmonary/peripheral edema)—it is important to have adequate diuresis to help expel excess volume.
Mixed venous O ₂	Svo ₂	Svo ₂ >75% ¹⁵	This is good for understanding details of consumption of O ₂ via perfusion. Svo ₂ is the percentage of oxygen bound to hemoglobin in blood returning to the right side of the heart and it reflects the amount of residual oxygen after tissue extraction. An increase in Svo ₂ may indicate greater organ perfusion. Mixed venous blood gas is preferentially taken from the pulmonary artery just before oxygenation.

(Continued)

TABLE 2. Continued

Parameter	Abbreviation	Normal values	Notes
Venous blood gas	VBG	pH: 7.32-7.43 ¹⁶ pCO ₂ : 36-49 mm Hg (M); 39-52 (F) ¹⁶ pO ₂ : 43-68 mm Hg ¹⁶ Lactate: 0.5-2.2 mmol/L ¹³	This helps in assessment of a patient's acid/base status as it provides an accurate assessment of pCO ₂ . It also provides a measurement of lactate, although arterial lactate is more sensitive to end organ perfusion.
Arterial blood gas	ABG	pH: 7.35-7.45 ¹⁷ pCO ₂ : 35-45 mm Hg ¹⁷ HCO ₃ ⁻ : 22-26 mmol/L ¹⁷ pO ₂ : 75-100 mm Hg ¹⁷ Sao ₂ : >95% ¹⁷ Lactate: 0.5-1.6 mmol/L ¹³	Acid/base status is best understood through an ABG. pO ₂ can be helpful in assessing the efficacy of the lungs to oxygenate the blood. ABGs also provide an arterial lactate (more useful than a venous lactate). Whole blood arterial gas also provides measurements of hemoglobin, sodium, potassium, and glucose.
Electrolytes Review CMP, magnesium (Mg), and phosphorus (P) for abnormal findings. No specifics here.			
Drains	Chest tube Blake Pigtail Jackson-Pratt (JP)	Most, if not all, patients will have drains postoperatively. These serve as a gauge for bleeding, coagulopathy, and volume status and are placed to prevent complications of cardiac tamponade and pleural effusions postoperatively. In general, less than 150-300 mL over 24 h or 50-100 mL over 8 h is an indication to remove the chest tube (varies by institution).	
Imaging	-	It is important to check for any new imaging (radiographs, CT, MRI, echocardiography, etc). Most patients will at least have a POD 1 CXR, which you can compare to the one from the day before. Regarding CXRs, you can try and identify chest tubes, central lines, pulmonary artery catheters, endotracheal tubes, pulmonary edema, pleural effusions, cardiomegaly, etc. A more complete explanation of imaging and what to look for can be found in Primer 4 of this primer series.	
Interfacing with the patient			
Overnight	Talk to the overnight provider and the patient's nurse. See if any major events happened overnight—the overnight providers and nurses are an invaluable resource. When stuck or unsure about anything, the nurses and advanced practice providers are extremely knowledgeable and have likely dealt with similar situations many times.		
Overall Condition	How does the patient feel? Worse than yesterday, better, about the same?		
Pain	Try to differentiate if this fits a musculoskeletal (MSK) picture (incisional pain or related to sternotomy/thoracotomy) or if this pain is different (eg, if this is a patient who had a myocardial infarction [MI], does this feel like when they had their MI? If so, this patient might be having another MI).		
Breathing	Often, patients will take shallow breaths due to diaphragm or MSK irritation. It is often advantageous to encourage them to take bigger breaths to help prevent atelectasis, which can lead to pneumonia. This is achieved with the use of an incentive spirometer which helps quantify the volume of inspiration they are able to achieve.		
Ambulation	Did the patient get out of bed at all (even to use the bathroom, etc). If so, how much did they ambulate? Did they shower? Showering can be a good sign that the patient is making progress.		
Genitourinary (GU)	Has the patient passed gas or had a bowel movement? Is the patient voiding by themselves or using a Foley?		
Diet	Has the patient been eating/drinking? If so, have they been able to keep it down? Does the patient complain of nausea?		
Physical examination			
Overall	How the patient looks overall (eg, toxic, acute pain, calm, resting in bed, etc).		
Neurologic	Stroke should always be assessed for via cranial nerves, communication skills, and motor strength in all extremities compared with baseline. Note that in the first day or two, the neurological evaluation can be altered by pain medication and postanesthesia lethargy.		
Cardiac	Interpret the EKG. Assess for new murmurs or persistent murmurs which should have subsided after the operation. Correlate these findings to the operation performed.		

(Continued)

TABLE 2. Continued

Parameter	Abbreviation	Normal values	Notes
Respiratory			If on a ventilator, assess for ventilation settings and listen for bilateral breath sounds. If not on a ventilator, auscultate both sides anteriorly and posteriorly. Check how often the patient is using the incentive spirometer (also ask the patient to use it in front of you so you know if they are using it correctly). Ask for help when repositioning a patient.
Skin			Assess the patient’s incision site(s) for color, fluid draining, dryness, hematoma, dehiscence, etc. Overall, is the incision intact? Remember that the patient often has more than just a sternotomy or thoracotomy incision (eg, leg incisions for saphenous vein harvest, supraclavicular for axillary access). Check with the nurse/resident before removing any dressings and ask for help in removing and replacing dressings.
Drains			Note the amount and color of fluid. Check for air leaks (explanation of air leak assessment is beyond the scope of this text).
Abdominal			Palpate while checking for distention or bloating which could be indicative of bowel obstruction. Auscultate to help discern bowel function.
Other			Two big risks in cardiac surgery are hypoperfusion and embolism. As such, the physical examination should be tailored to assessing these risks. In addition, visceral ischemia should be interrogated with an abdominal examination. Visceral ischemia, and its natural course of acute abdomen, are grave complications in cardiac surgery and carry a significant morbidity and mortality. The extremities of the toes and fingers should always be examined. Heparin is the mainstay in anticoagulation in this patient population and heparin induced thrombocytopenia is not a rare occurrence. Key physical examination signs will be a dusty or dark appearance of the fingers or toes.
Assessment and plan			
Neurologic/pain			Discuss the neurologic status of the patient. Also, if there is a plan for neurological intervention or specific monitoring, that can be noted here. This is also a good place to discuss what pain medications the patient is on and any changes that are needed.
Cardiovascular			Discuss vasoactive/inotropic infusions and the plan to maintain or wean these. Other medications, pacing, etc, may also be discussed here.
Respiratory			The patient may need pulmonary hygiene, extubation, weaning of nasal cannula, etc.
Renal			State Cr, UOP. If a change in diuresis is needed, note this here. List relevant labs to monitor, such as CMP.
Gastrointestinal/nutrition			Discuss diet advancement, bowel regimen, liver function, etc.
Infectious disease			State the patient’s most recent temperature, current antibiotics, and plan for antibiotics/infectious workup, as necessary.
Hematologic			State the patient’s H/H, platelet count, and transfusion criteria. List relevant labs to monitor, such as CBC.
Endocrine			Discuss the patient’s insulin/diabetes management, as needed.
Skin			Discuss the patient’s incision and whether there are any major skin breakdowns/findings.
Lines/tubes			This is a good place to talk about which lines/tubes/AV wires will remain and which will come out (eg, chest tube).
Disposition			Where is the patient likely to go today (stay in ICU, transfer to floor, discharge to rehab, discharge home, etc.)

AV, Atrioventricular; CABG, coronary artery bypass grafting; FIO₂, inspired oxygen fraction; PaO₂, arterial oxygen tension; PaCO₂, arterial carbon dioxide tension; ICU, intensive care unit; CPAP, continuous positive airway pressure; RV, right ventricle; LVAD, left ventricular assist device; IABP, intra-aortic balloon pump; RVAD, right ventricular assist device; CRRT, continuous renal-replacement therapy; INR, international normalized ratio; ADH, antidiuretic hormone; PCO₂, carbon dioxide tension; PO₂, oxygen tension; SaO₂, arterial oxygen saturation; CT, computed tomography; MRI, magnetic resonance imaging; CMP, comprehensive metabolic panel.

lobes. Distal pulses are intact in the upper and lower extremities bilaterally. Findings of the abdominal examination are normal.

Regarding the plan, her pain control is good. We can wean epi, phenylephrine, and nasal cannula as tolerated. We’ll keep her atrioventricular wires and keep back up at 60. We should encourage ambulation and advance her diet as tolerated. We can pull the right chest tube and transfer her to the floor pending successful wean of epi and phenylephrine.

A list of common cardiac surgical complications can be found in Table 3.

Hand-Offs and Sign-Out

Hand-offs can occur postoperatively with the surgical intensive care unit/cardiovascular intensive care unit team

as well as day to day when patients are eventually transferred to the non-ICU floors. Some cardiac surgery services will have students complete hand-offs with the night/morning teams—it is best to clarify this on day 1 of the rotation.

For hand-offs on or after postoperative day 1, it is important to briefly summarize the patient’s overall care and what to do if there are any sudden changes in patient status that would require urgent or emergent evaluation and management. Also note what the team is monitoring or concerned about (mean arterial pressure goals, laboratory values pending, chest imaging, chest tube output, etc). A good hand-off will state a task such as “monitor for complete heart block,” but a great hand-off will further comment on tasks with, “monitor for complete heart block (at high risk given XYZ operation), consider consulting the electrophysiology team, patient has permanent epicardial pacemaker lead,

TABLE 3. Common postoperative complications following cardiac surgery

System	Complication	Treatment
Incisional	Superficial wound infection	Standard wound care, antibiotics
	Deep sternal wound infection	Debridement, sternal wire removal, drainage, irrigation, open packing, antibiotics, reconstruction with muscle flap
	Sternal dehiscence or nonunion	Debridement, stable fixation of bony fragments and chest wall
Respiratory	Pulmonary embolism	Anticoagulation, catheter-directed thrombolysis, or thrombectomy
	Pulmonary edema	Supplemental oxygen, diuresis, blood pressure management, inotropes, nitroglycerin
	Pneumonia	Antibiotics, supplemental oxygen, supportive care
Cardiac—cardiotomy	Exacerbation of chronic obstructive pulmonary disease	Supplemental oxygen, scheduled short-acting bronchodilators, systemic corticosteroids, antibiotics
	Cardiac tamponade	Pericardiocentesis, pericardial window, inotropes
	Pericarditis	Nonsteroidal anti-inflammatories, colchicine, and/or glucocorticoids
	Arrhythmia (eg, atrial fibrillation or ventricular tachycardia)	Rate or rhythm control agents, electrical defibrillation, vasopressors
Cardiac—cardiopulmonary bypass	Low cardiac output	Inotropes, antihypertensives, short or long-term mechanical circulatory support devices
	Acute kidney injury	Supportive care, diuresis, dialysis
	Coagulopathy (eg, heparin-induced thrombocytopenia)	Anticoagulation, fresh frozen plasma, platelets, prothrombin complex concentrate, depending on coagulopathy
	Stroke	Thrombolysis, thrombectomy, antiplatelet agents, supportive care
	Air embolism	Placement in Trendelenburg and left lateral decubitus position, hyperbaric oxygen therapy
Cardiac—coronary	Stanford type A aortic dissection	Aortic root, arch, or hemiarch replacement
	Perioperative myocardial infarction	Supplemental oxygen, antihypertensives, antiplatelet or anticoagulation, possible revascularization
Cardiac—valve	Endocarditis	Intravenous antibiotics, valve replacement, catheter-directed vegetation aspiration
	Valve thrombosis	Anticoagulation and thrombolysis
	Complete heart block	Placement of permanent pacemaker or implantable cardioverter defibrillator

which can be used for temporary pacing, but will need a patient–prosthesis mismatch in that case.”

For the AM sign-out, try to pre-round on the assigned patients before sign-out so new information/updates from the night team may be readily incorporated. For the PM sign-out, make sure to-do lists for the day have been completed and reviewed. Try to leave as little “day work” for the night team as possible. This may include making sure all orders (medications and morning labs) are placed and tubes/drains pulled, if possible.

Template: Hand-Off to the Night Team

- One liner: [Name] is a [X] month/y old [sex] who underwent [operation], postoperative day (ie, POD) #X.¹⁹
- Any significant events during the day that could influence further management

- Anticipatory guidance: If [X] happens, page [this team/fellow/attending], and order [labs/imaging/meds].
- Specific tasks to follow up on: wean epi to X, follow-up computed tomography angiography overnight, etc.

INTRAOPERATIVE

Preparing for Cases

Preparing for a case comes down to a few major points: reading the preoperative note, understanding the indications for the procedure, viewing the imaging (and the associated report, as the imaging can be difficult to read by itself), and understanding the critical steps of the case. Imaging is key. For CABG, knowing the coronary angiogram allows the surgical team to know the patient’s atherosclerotic burden in the arteries, the indication for the surgery, how many anastomoses will need to be done, and which conduits

will be used for bypass grafting. For valvular procedures, the echo is vital—it depicts the pathology and the hemodynamics across the valve, which are used for surgical indication and planning. However, regardless of the case, a student should review all relevant imaging. Although the main indication for surgery may be aortic valve stenosis/regurgitation, significant coronary artery disease, even in a single vessel, may warrant concomitant CABG surgery where otherwise isolated CABG surgery would not be indicated.

Knowing previous cardiothoracic surgical/procedural history is also important. For example, for a patient undergoing CABG surgery, it is important to know if the patient has stents. In addition, for a patient undergoing valve replacement/repair, it is important to know if any previous surgical valve replacement/repair has occurred and/or if there has been transcatheter intervention on the valve (some transcatheter therapies include TAVR and mitral valve clipping, although further discussion of these topics are beyond the scope of this primer).

If there are opportunities to attend preoperative conferences (TAVR conference, catheter conference with cardiac surgery and cardiology, etc) they may provide a rich educational experience for trainees.

In the OR

There are many key team members in the adult cardiac OR that help prepare the patient for the procedure. Every member of the OR team serves a vital role in ensuring a smooth and safe operation, as outlined in [Table 4](#).

When a junior (medical student) trainee arrives at the OR, the first thing for the trainee to do is to introduce themselves to the OR staff (nurses, tech, etc), residents, surgeon (if they are there), and the anesthesiologist. When first introducing themselves to the surgeon (or senior resident), this is a great time for the trainee to *ask for permission* to scrub in the case. In addition, the trainee can show that they prepared for the case by *briefly* explaining to the surgeon their understanding about the patient and the indications for why the patient is having this operation.

Once the patient is brought back to the OR and transferred to the operating table, anesthesia will start induction. After intubation and central venous catheter placement, a Foley catheter is placed to measure urine output throughout the procedure. A transesophageal echocardiography probe is also inserted to monitor cardiac function throughout the procedure. The patient is positioned and sterilely prepped, usually with chlorhexidine prep, and then draped. Once all of this has been completed, the team will time out and the operation can begin.

When first scrubbing in, junior trainees may be tempted to jump in and “make yourself useful” by providing suction or something else. As a rule of thumb, **do not touch anything without being specifically asked to touch something**. Once a junior trainee has been around for a few

cases and the OR staff get used to them, the OR staff, residents, and surgeon may involve the trainee more in the case.

A word on sterility. The sterile field includes the operating table, instrument tables, cardiopulmonary bypass (CPB) tubing, sterile drapes, and all scrubbed in personnel (see [Figure 1](#)). Students should do their best to follow direction to ensure they do not break sterility. However, if the student breaks sterility, it is important to say this so that members of the team can help the student become sterile again. Students may feel embarrassed or shy saying that they broke sterility; however, nobody should react poorly to disclosure of losing sterility. After all, the patient’s health and safety should come first, and maintaining sterility is in line with patient-centered care. Lastly, remember that breaking sterility happens to even the most experienced surgeons, it is nothing of which to be ashamed.

When to ask questions: when first starting, it is best to save questions for before or after the case (or before or after the attending surgeon scrubs in). Junior trainees can always walk over to an *unscrubbed* attending and ask a question. However, when the attending surgeon is scrubbed in, that likely means that this is a critical portion of the case, whether the junior trainee realizes it or not (sometimes this can be difficult to discern, so it’s best to play it safe). Once a trainee is more experienced, they may find appropriate times to ask questions, even when the attending surgeon is scrubbed in.

Surgery is a team activity. Whether inside or outside of the OR, there are many ways to be helpful. For example, within the OR, when the patient is moving from their bed to the OR table, ask the nursing staff if there is any way you can be helpful. Outside the OR, an example of exemplary teamwork is readying the tape when you see a resident/fellow about to change out a dressing. These small, yet helpful, things can help a student stand out.

Handing off to the ICU From the OR

Surgical teams may ask medical students to give a postoperative presentation of the patient’s case to the ICU team as a hand-off. Depending on the institution, the ICU may be open or closed. Closed ICUs, which are becoming increasingly common, admit patients under the full responsibility of an intensivist that enacts their own plans with guidance from the surgical team. However, in an open ICU, the patient typically remains under the responsibility of the surgical team, with intensivists available for consultation.

Template: OR to ICU Hand-Off

- One liner: (name) is a (X) month/y old (sex) with a past medical history (ie, PMHx) of (reason for operation).
- Procedure: We performed (state procedures performed, including if CPB used, circulatory arrest, etc)
- Intraoperative findings, significant events: (if relevant)

TABLE 4. Operating room (OR) team members/equipment and roles

OR team Member/Equipment	Role
Primary/Attending/operating surgeon	This person is the supervising surgeon, who is ultimately in charge of all decisions made in the operating room. This person is the main surgeon operating on the patient. This individual usually stands on the right side of the operating table.
First assistant (resident, fellow, APP, RNFA, medical student)	This person is the assistant to the surgeon who aides the surgeon in performing operative steps that require more than one set of hands. This person usually stands on the left side of the operating table.
Second assistant (resident, fellow, APP, RNFA, medical student)	This person is an assistant who is usually more in an observatory role, sometimes aiding the attending surgeon as directed by the rest of the team. This is typically the role of a medical student/junior trainee. The location of this person varies based on operating room setup (it is important that you ask the resident where to stand, do not make any assumptions).
Anesthesiologist	The anesthesiologist and their team stand at the head of the bed behind the sterile drapes. This team is responsible for initially bringing the patient into the OR, placing hemodynamic monitoring lines in the patient (arterial line, central line), and putting the patient under general anesthesia (“to sleep”). Throughout the operation, this team provides pharmacological and respiratory support as needed to keep the patient in a safe, operable state. In addition, throughout the operation this team regularly performs real-time echo (TEE) to assess heart function before and after surgical interventions are made.
Scrub nurse/scrub tech	This person is scrubbed into the operation and is in charge of all of the instruments, sutures, and any other objects that come onto the sterile field. This person keeps track of all objects on the sterile field and hands the surgeon the correct instruments as needed throughout the operation. This individual usually stands at the level of the legs of the patient on either side depending on operating room set up.
Circulating nurse	This person is not scrubbed into the operation and documents everything related to the procedure, including start/stop times, people in the room, equipment brought into the room, and equipment used in the operation. In addition, this individual functions in any other way which the surgeon deems necessary. This person usually is located at a computer within the room, where they can readily document the aforementioned.
Perfusionist	This person is not scrubbed into the operation and is in charge of running the cardiopulmonary bypass machine, “the pump,” at the direction of the surgeon. This individual is usually seated directly behind the cardiopulmonary bypass machine, which is located to one of the sides of the operating table.
Cardiopulmonary bypass machine—“the pump”	This is the machine that functions as the patient’s heart and lungs during the operation, oxygenating the blood and providing flow back to the patient at a desired rate (rate is variable based on what is happening in the operation, determined by the surgeon).
Ventilator	Although this machine provides several functions, its main function is to provide positive pressure lung ventilation to the patient while the patient is <i>not</i> on the cardiopulmonary bypass machine.
TEE machine	This machine allows for real-time TEE data to assess heart function before and after surgical interventions. For example, TEE can confirm severe aortic stenosis before incision and also confirm suitable aortic valve function following aortic valve replacement.

APP, Advanced practice provider; RNFA, registered nurse first assistant; TEE, transesophageal echocardiography.

- Crossclamp time: (X minutes)
- Bypass time: (X minutes)
- Defibrillation required?
- Lines/drains:
- Pacing wires + settings:
- Chest tubes + locations:
- (Advanced) Specific things for the ICU team to watch out for, with suggested plans. Examples include:
 - Keep on 0.02 epinephrine gtt (drip), given depressed preoperative left ventricular ejection fraction (LVEF), keep cardiac index >3, mean arterial pressure goals, lumbar drains

- Specify if prefer fast-track extubation (Enhanced Recovery after Surgery, if relevant)
- If pulmonary artery pressure rising, continue or increase Flolan (epoprostenol)

Case Descriptions (Types, Indications, and Steps)

Many of the common operations performed are discussed to follow. Note that, while this text discusses Class I indications, most operations also have Class IIa, IIb, etc, indications, which are beyond the scope of this text. In addition, although each operation can be performed in many ways, this text depicts one possible way to perform each case.

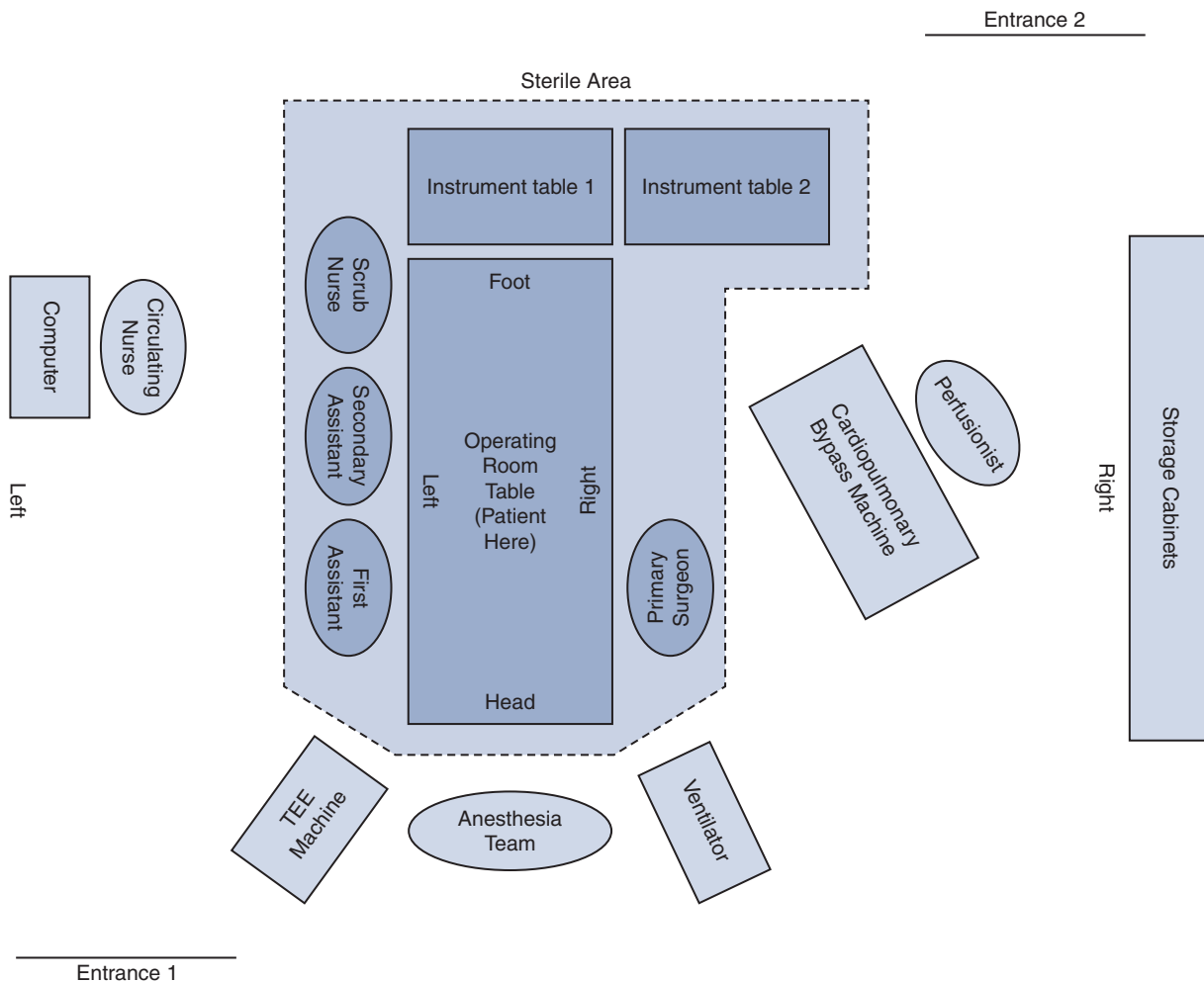


FIGURE 1. Schematic of a typical arrangement of a cardiac surgery operating room. *TEE*, Transesophageal echocardiography.

Note: Students should be aware that considerable variability across surgeons and institutions exists for how to perform each operation. This text depicts gross steps of only one of many possible ways to perform each operation.

Glossary of Words Often Used in the Cardiac OR

- **Angiogram**—Also known as cardiac catheterization, it is an image produced by injecting contrast into the left and right coronary arteries to visualize anatomy and areas of stenosis.
- **Cardioplegia**—A solution given to temporarily arrest the heart. Although there are numerous formulations, each typically contains high concentrations of potassium.
- **Crossclamp**—The act of placing a clamp across the ascending aorta, typically to allow direct perfusion of the coronary arteries with cardioplegia.

- **Retrograde**—Often used in reference to cardioplegia administration and refers to infusion of fluid into the coronary sinus to perfuse the coronary arteries (ie, backwards from physiologic flow).
- **Root**—The most proximal portion of the ascending aorta, including the aortic valve annulus, sinuses of Valsalva, aortic leaflets, and sinotubular junction.
- **Vent**—A catheter, typically placed in the left ventricular apex, used to minimize cardiac distension and removed air trapped in the ventricular cavity.

Cardiopulmonary Bypass (CPB)

This is a key step in almost every cardiac surgery operation (the only exception is with “off-pump” cases such as off-pump CABG). Most cardiac surgery operations will require the patient’s heart to be operated on in a fashion that requires a machine (heart–lung machine) to act as the heart and lungs. As such, knowing the cadence of this

procedure will lend itself to familiarity in the OR for most cardiac procedures.

Operative Sequence (Central Cannulation)

1. Median sternotomy, exposure of heart, and creation of the pericardial well.²⁰
2. Development of the aortic pulmonary plane (necessary for safe aortic crossclamping).
3. Heparin is given and an activated clotting time (measure of coagulation) is checked (activated clotting time >480 per most institutions).
4. Purse string sutures on the aorta with cannulation.
5. Purse string and incision of the right atrium with dual-stage cannula or cannulation of the superior vena cava (SVC) and inferior vena cava (IVC) separately (bi-caval cannulation).
6. Antegrade cardioplegia line is placed in the aorta or retrograde cardioplegia line is placed posteriorly in the right atrium into the coronary sinus.
 - a. Retrograde means that the flow is reversed from the normal flow. This cannula is placed in the coronary sinus and blood is flowed opposite through the venous drainage of the heart.
7. Aortic, left ventricular, and/or pulmonary artery vent is placed (any can be used to keep the heart empty during crossclamping and to help deair after removing the clamp).
8. Crossclamp placed and cardiopulmonary bypass initiated.
9. Cardioplegia is started (which arrests the heart).
10. Heart and ECG tracing are observed to ensure cardiac silence and then the specific operation is started.

Notes

- Generally, the aortic cannulation is done first, as it then allows for rapid administration of fluids. If venous cannulation is done first and there is a complication, it is hard to resuscitate.
- The use of bi-caval venous cannulation is generally predicated on if the mitral valve needs to be addressed or if manipulation of the heart will cause significant and prolonged compression of the confluence of the SVC and IVC with the right atrium.
- Different institutions may use different solutions for their cardioplegia. In general, the solution will be high in potassium, reducing the cellular potential, and will be cold (4 °C) facilitating a quiet, noncontracting heart with minimal oxygen requirements.²
- Discussion of deep hypothermic circulatory response as well as the pathophysiologic sequelae of CPB are

discussed in detail in the advanced topics articles within this series.

Often, viewing multimedia detailing operative steps allows for an additional dimension of understanding. Students are advised to visit the following links (note that there may be operative technique variations within the below examples, though they are still useful for getting an idea of the overall procedure):

Setup for CPB through Central Cannulation: <https://mmcts.org/tutorial/1663>.

Central Cannulation: <https://www.ctsnet.org/article/ctsnet-step-step-series-central-cannulation>.

Coronary Artery Bypass Grafting (CABG)

This operation is performed to revascularize the coronary artery system. The left/right internal mammary/thoracic artery is often the conduit of choice, given its high basal nitric oxide production (vasodilation), nonfenestrated internal elastic lamina (atherosclerosis protection), lack of vasoconstriction response to norepinephrine, and vasodilation with nitroglycerin. Other graft options include the saphenous vein, radial artery, and gastroepiploic artery (uncommon).

Class I Indications for CABG

- $\geq 50\%$ stenosis of the left main coronary artery.²¹
- Three-vessel $\geq 70\%$ stenosis with or without proximal left anterior descending involvement.
- Two-vessel $\geq 70\%$ including the left anterior descending with one other major vessel.
- Multivessel coronary artery disease in a patient with diabetes.
- Stenosis $\geq 70\%$ in 1 or more coronary arteries in a patient with significant symptoms of angina despite maximal medical therapy.
- One vessel disease with $\geq 70\%$ stenosis in a survivor of sudden cardiac death with ischemia-related ventricular tachycardia.

Operative Sequence of CABG

1. Incision, median sternotomy, and dissection to expose the heart and coronary vessels.²²
2. Simultaneous harvesting of the left internal mammary artery and saphenous vein for grafting.
3. Initiate bypass (performed “off-pump” at some centers without the use of bypass).
4. Distal anastomosis grafting begins by puncturing the diseased coronary vessels distal to the obstructed coronary artery segments to allow for the creation of an anastomosis.
5. After distal anastomosis is complete, a proximal anastomosis of the graft to the proximal aorta will be created

via artificially created ostia (punched out hole of the aorta).

- a. Note that in the case of multivessel disease, often all distal grafts will be completed first followed by the proximal anastomosis of all grafts.
6. Cardioplegia washout and electrical stimulation of the heart for restitution of spontaneous contractions.
7. Checking of the grafted vessels for adequate blood flow and for leakage.
8. Reperfuse the heart, decannulate, and close chest in layers, including closure of the sternotomy using sternal wires.

Recommended multimedia links for CABG (note that there may be operative technique variations within the below examples, though they are still useful for getting an idea of the overall procedure):

Image of completed CABG: <https://www.ahajournals.org/doi/10.1161/01.CIR.0000048896.72317.49>.

CABG with all arterial conduits: [https://www.optechtc.com/article/S1522-2942\(16\)30071-X/fulltext](https://www.optechtc.com/article/S1522-2942(16)30071-X/fulltext).

CABG without use of the cardiopulmonary bypass machine (off-pump): [https://www.optechtc.com/article/S1522-2942\(16\)30082-4/fulltext](https://www.optechtc.com/article/S1522-2942(16)30082-4/fulltext).

Aortic Valve Replacement (AVR)

The aortic valve is the “exit” valve of the heart; normally this valve is “trileaflet” with 3 tissue cusps connecting at points known as commissures. Pathologies can include AS, aortic insufficiency, and endocarditis. Congenital variants (bicuspid, unicuspid) are at increased risk for developing these pathologies and typically present at younger ages than trileaflet valves.²³ Transcatheter therapies also exist as an alternative to surgical AVR for severe AS; for more information, see the Advanced Topics articles in this series. Indications for AVR include symptomatic severe AS, symptomatic severe aortic insufficiency, or endocarditis. Endocarditis indications for AVR are beyond the scope of this text.

Class I Indications for AVR in the Setting of AS

Class I Indications²⁴

- Severe AS (mean pressure gradient ≥ 40 mm Hg, peak systolic velocity ≥ 4.0 m/s, aortic valve area ≤ 1 cm²).
 - With symptoms
 - Without symptoms with LVEF $< 50\%$
 - Without symptoms in the setting of a concomitant cardiac surgery already scheduled/indicated

Class I Indications for AVR in the Setting of Aortic Insufficiency/Regurgitation

Class I Indications²⁴

- Severe aortic regurgitation (regurgitant volume ≥ 60 mL/beat, regurgitant fraction $\geq 50\%$, LV dilation, holodiastolic aortic flow reversal, vena contracta > 0.6 cm, or effective regurgitant orifice ≥ 0.3 cm²).
 - With symptoms
 - Without symptoms and LVEF $< 50\%$
 - Without symptoms in the setting of a concomitant cardiac surgery already scheduled/indicated

Operative Sequence of Surgical AVR

1. Incision, median sternotomy, and establishment of CPB.²⁵
2. Crossclamp, cardioplegia, and transverse aortotomy (cut open the aorta to look down on the aortic valve).
3. Excision of diseased valve.
4. Size annulus and determine correct valve replacement size based on the valve’s specific effective orifice area compared with patient body surface area to prevent patient–prosthesis mismatch.
5. Place subannular (or supra-annular) sutures 2-0 braided sutures. These can be pledgeted or nonpledgeted depending on surgeon preference.
6. Pass sutures through the valve’s sewing ring with appropriate spacing.
7. Parachute the valve down and seat prosthesis in the annulus.
8. Tie down sutures to secure the valve in place hand-tie or use an automated knot device.
9. Close aortotomy using with PROLENE (possibly 4-0 or 5-0) with minimal air in aorta before closure.
10. Reperfuse, wean bypass, and close chest in layers including closure of the sternotomy using sternal wires.

Notes

- In cases of severe aortic insufficiency, antegrade cardioplegia may not provide adequate cardioplegia and may cause harmful LV distension. In this instance, either retrograde cardioplegia can be used alone or an aortotomy may be performed and handheld cannulas used to deliver cardioplegia directly down the left and right coronary arteries through direct engagement with the coronary ostia either alone or after retrograde cardioplegia.
- In the case of calcific aortic stenosis or endocarditis, depending on extent of diseased tissue, additional annular debridement may need to be performed using waste suction and rongeurs.
- As with any case, it is important to review the cardiac catheterization findings before operating on the patient. While the main indication for surgery may be aortic valve stenosis/regurgitation, significant coronary artery disease, even in a single vessel, may warrant concomitant

CABG surgery where otherwise isolated CABG surgery would not be indicated.

Bioprosthetic versus mechanical valves. Choice of valve should involve shared decision-making between the surgeon and patient, as each valve type has important clinical nuances to consider. Bioprosthetic valves do not require long term anticoagulation with warfarin and are compatible with TAVRs, pending size/anatomical constraints. However, bioprosthetic valves will typically require replacement within 8 to 12 years (the actual length is variable based on patient characteristics, but this is an estimate). As such, these valves typically are not recommended for younger patients (<60 years) unless the patient is a woman of childbearing age planning to become pregnant (due to anticoagulation risks). Mechanical valves typically have lifetime durability and usually do not require replacement unless infected or thrombosed. However, these valves require anticoagulation with warfarin and are not compatible with TAVR, meaning any replacement of this valve would require another open surgery.^{25,26}

Recommended multimedia links for AVR (note that there may be operative technique variations within the below examples, though they are still useful for getting an idea of the overall procedure):

AVR with bioprosthetic and prosthetic valves: [https://www.optechts.com/article/S1522-2942\(00\)80024-0/fulltext](https://www.optechts.com/article/S1522-2942(00)80024-0/fulltext).

AVR using single interrupted annular sutures: <https://mmcts.org/tutorial/1601>.

Mitral Valve Replacement (MVR) or Repair (MVr)

Mitral valve (MV) pathology has multiple etiologies and can be primary or secondary in nature. Primary MV disease is due to disease of the valve leaflets, the chordae tendineae, or the papillary muscles resulting in prolapse, insufficiency, or stenosis. Etiologies of primary disease include calcification of the leaflets, rheumatic heart disease, infective endocarditis, collagen vascular disease or papillary muscle rupture after myocardial infarction.²⁷ Secondary disease is due to abnormalities in size or function of the left ventricle that cause dilation of the mitral annulus.

Open surgical MVR is typically reserved for symptomatic mitral valve disease in patients who are not candidates for MVr.²⁸ Considerations before surgery should take into account patient risk stratification based on age and functional capacity. The decision to use mechanical or bioprosthetic valves must consider multiple factors as discussed in the section “Aortic Valve Replacement (AVR).”

In the overwhelming majority of patients with degenerative, myxomatous mitral regurgitation, MVr is performed. In this procedure, various complex techniques can be used to fix a torn chordae tendineae (flail leaflet) or prolapsing leaflet segment. An annuloplasty ring (full annular

circumference) or annuloplasty band (partial annular circumference, mainly supporting the posterior annulus) is included to support the repair.

Class I Indications for MVR or MVr in the Setting of Mitral Stenosis (MS)

Class I Indications¹⁸

- Severely symptomatic (New York Heart Association class III/IV) patients with severe MS (mitral valve area $\leq 1.5 \text{ cm}^2$ or pressure half-time ≥ 150 milliseconds) who are not high risk for surgery and who are not candidates for percutaneous mitral balloon commissurotomy.
- Patients with severe MS in the setting of a concomitant cardiac surgery already scheduled/indicated.
- Percutaneous mitral balloon commissurotomy is recommended for symptomatic patients with severe MS in the setting of favorable valve morphology, no LA clot, and no/mild mitral regurgitation (MR).

Class I Indications for MVR or MVr in the Setting of Primary MR

Class I Indications (Primary MR)¹⁸

- Severe MR (regurgitant volume $\geq 60 \text{ mL/beat}$, regurgitant fraction $\geq 50\%$, LV dilation, vena contracta $\geq 0.7 \text{ cm}$, or effective regurgitant orifice $\geq 0.4 \text{ cm}^2$)
 - With symptoms
 - Without symptoms and LVEF $\leq 60\%$
 - Without symptoms and LV end systolic dimension $\geq 40 \text{ mm}$

Operative Sequence of Surgical MVR

1. Approach via median sternotomy.^{29,30}
2. Cannulation and initiation of CPB.
3. Exposure of the mitral valve via longitudinal left atrial incision through Waterson's/Sondergaard's interatrial groove or via transseptal approach (right atrial incision then atrial septum).
4. Split the anterior leaflet of the mitral valve into two and remove it from its attachment to the annulus. Leave the posterior leaflet in situ.
 - a. Preservation of the portion of the anterior leaflets that are attached to the chordae allows for preservation of the subvalvular apparatus.
5. The mechanical or bioprosthetic valve is then secured using sutures. Sew the native anterior valve leaflets between the annulus and the sewing ring. The needle bite goes from the annulus to the appropriate native leaflet to the sewing ring of the prosthetic valve.
6. Examination of the motion of the prosthetic valve.

7. Reperfuse, decannulate, and close chest in layers including closure of the sternotomy using sternal wires or sternal plates.

Notes

- As with any case, it is important to review the cardiac catheterization findings before operating on the patient. While the main indication for surgery may be mitral valve regurgitation, significant coronary artery disease, even in a single vessel, may warrant concomitant CABG surgery where otherwise isolated CABG surgery would not be indicated.

Recommended multimedia links for MVR and MVr (note that there may be operative technique variations within the below examples, although they are still useful for getting an idea of the overall procedure):

MVR with a calcified annulus: [https://www.optechtcs.com/article/S1522-2942\(03\)70030-0/fulltext](https://www.optechtcs.com/article/S1522-2942(03)70030-0/fulltext).

Mitral valve implantation: [https://www.optechtcs.com/article/S1522-2942\(00\)80023-9/fulltext](https://www.optechtcs.com/article/S1522-2942(00)80023-9/fulltext).

MVr: [https://www.optechtcs.com/article/S1522-2942\(07\)700806/fulltext](https://www.optechtcs.com/article/S1522-2942(07)700806/fulltext).

MVr after failed transcatheter mitral valve intervention: <https://mmcts.org/tutorial/1195>.

Ascending Aorta/Hemiarch Replacement

Aortic pathologies, such as aneurysm and dissection, require resection of the diseased tissue and reconstruction using a prosthetic graft. In many cases, the aortic valve and distal ascending aorta are also pathologic, and so aortic repair may include replacement of the valve or ascending arch/hemiarch.

If the pathology doesn't include the aortic root, then repair can be isolated to the ascending aorta. Hemiarch repairs take part of the lesser curve of the aortic arch in order to resect the maximum amount of pathologic aortic tissue possible. Because this requires removal of the aortic cross-clamp, hypothermic circulatory arrest with cerebral perfusion is used. This procedure may include an AVR if there is evidence of valvular disease.

Indications for Ascending Thoracic Aortic Aneurysm (TAA) or Aortic Root Aneurysm Repair

- Symptomatic aneurysm, either ruptured or unruptured.^{31,32}
- Asymptomatic ascending TAA/aortic root aneurysm.
 - Diameter >5.5 cm.
 - Growth of aneurysm 5 to 10 mm/y.
 - Aortic size index (aortic diameter [cm]/body surface area [m²]) ≥2.75 cm/m².

- Patients who have connective tissue disorders (Marfan, Loeys–Dietz, Ehlers–Danlos), positive family history of dissection, or bicuspid aortic valve may be considered for elective repair at smaller diameters.
- If the patient is undergoing AVR or CABG, concomitant TAA repair is indicated for end diastolic diameters >4.5 cm.

Operative Sequence for Ascending Aorta/Hemiarch Replacement

1. Approach via median sternotomy.³³
2. Cannulate and initiate CPB. Begin cooling to 18 to 22 °C.
 - a. In the current era, deep hypothermic circulatory arrest (DHCA) is generally performed with selective cerebral perfusion, which can be performed one of two ways: deep HCA with retrograde cerebral perfusion (RCP) or moderate HCA with antegrade cerebral perfusion. Here, we will describe DHCA with RCP.
3. Apply crossclamp and create complete transverse aortotomy, just above the level of the sinotubular junction.
4. While cooling, size the proximal graft. This will be a straight Dacron graft. Perform proximal anastomosis using running 4-0 PROLENE suture.
5. When cooled to target temperature, pause CPB and initiate DHCA with RCP.
 - a. Neurologic function during hypothermic circulatory arrest can be monitored using intraoperative electroencephalography monitoring or near-infrared spectroscopy.
6. Remove crossclamp and resect the lesser curve of the arch. Tailor a second Dacron straight graft to create a beveled distal end to the graft, which will align flush with the resected arch. Perform distal anastomosis using running 4-0 PROLENE suture.
7. Recannulate distal graft and resume CPB. Begin rewarming.
8. Perform graft-to-graft anastomosis.
9. Reperfuse, decannulate, and close chest in layers including closure of the sternotomy using sternal wires.

Recommended multimedia links for ascending aorta/hemiarch replacement (note that there may be operative technique variations within the below examples, though they are still useful for getting an idea of the overall procedure):

Hemiarch replacement (Figures 1-6): [https://www.optechtcs.com/article/S1522-2942\(19\)300273/fulltext](https://www.optechtcs.com/article/S1522-2942(19)300273/fulltext).

Aortic Root Replacement

When pathology of the aorta includes the aortic root, an aortic root replacement may be warranted. In aortic root replacement, if the replacement uses a conduit of Dacron graft and prosthetic valve, you may hear this referred to as a Bentall procedure—Bio-Bentall, if bioprosthetic valve, or Mechanical Bentall, if mechanical valve. Of note, there are some occasions in which although the aortic root is diseased, the aortic valve is not and is thus able to be spared. This is known as a valve-sparing root replacement. Indications for aortic root replacement can be found in the previous section on ascending aorta/hemiarch replacement. If the valve or aortic root is infected, one may elect to avoid implantation of prosthetic material with the use of a homograft (human donor tissue), though this practice varies by institution.

Operative Sequence of Aortic Root Replacement (Button Bentall Technique)

1. Approach via median sternotomy.³³
2. Cannulate and initiate CPB, apply crossclamp, and create complete transverse aortotomy, just above the level of the coronary sinuses. Cool to 32 to 34 °C.
3. Place 4-0 pledgeted stay sutures at each commissure and resect valve leaflets.
4. Using sharp scissors, resect each sinus segment, leaving a small border of full-thickness aortic tissue around each coronary ostia, with one silk stay suture placed at each superior pole. These are referred to as the coronary buttons.
5. Size the annulus and prepare Valsalva graft conduit. Running 4-0 PROLENE suture is used to attach the prosthetic valve to the Dacron graft.
6. Pass 2-0 braided pledgeted sutures circumferentially through the annulus tissue. These sutures are then passed through the conduit. The valve is then parachuted down and seated on top of the annulus.
7. Create openings in the graft across from the coronary arteries using handheld battery-operated cautery and attach each coronary button, first the left followed by the right, using 5-0 or 6-0 PROLENE suture.
8. While rewarming, perform graft-to-aorta or graft-to-graft anastomosis, depending on distal extent of repair, using 4-0 PROLENE suture.
9. Reperfuse, decannulate, and close chest in layers including closure of the sternotomy using sternal wires.

Notes

- Proper mobilization of the coronary buttons is important to prevent the coronary artery anastomoses from being under tension in the completed repair.
- Certain companies now make valve-graft conduits, eliminating the need to create a custom conduit during the procedure.

- Some surgeons use a running 4-0 PROLENE suture for the proximal anastomosis instead of passing interrupted sutures.

Recommended multimedia links for aortic root replacement (note that there may be operative technique variations within the following examples, although they are still useful for getting an idea of the overall procedure):

Aortic root replacement button Bentall procedure: [https://www.optechtc.com/article/S1522-2942\(18\)30118-1/fulltext](https://www.optechtc.com/article/S1522-2942(18)30118-1/fulltext).

Valve-sparing aortic root replacement: [https://www.optechtc.com/article/S1522-2942\(09\)00097-X/fulltext](https://www.optechtc.com/article/S1522-2942(09)00097-X/fulltext).

Heart Transplant

A heart transplant is the only definitive treatment for end-stage heart failure. All other therapies, including pharmacologic and mechanical circulatory support, are primarily used to either delay heart failure progression, increase the time one can stay on the transplant list, or provide palliative care. Patients are placed on the transplant list based on a multidisciplinary committee. As such, there is no absolute list of indications that would be ubiquitous throughout the country. Generally, patients are in end-stage heart failure, on maximum medical support, and have the social support necessary to be successful in the postoperative period. Moreover, the comorbidities of the patient should also be conducive to a successful operation and immediate recovery. What is equally as important as the initial indication is the patient's position on the heart allocation list. This is important to realize as the number of hearts available for transplantation is not equal to the number of hearts needed. Up to 20% of those on the transplant list will die on the waiting list. Some of the common adult heart allocation status criteria are listed to follow, with status 1 being the most urgent and status 7 being the least urgent (this is not an exhaustive list). Status 1 includes criteria such as venoarterial extracorporeal membrane oxygenation and mechanical circulatory support with life-threatening arrhythmia. Status 2 includes intra-aortic balloon pump and other endovascular mechanical circulatory support treatments. Status 3 includes multiple continuous inotropes. Status 4 includes dischargeable, stable left ventricular assist device.

Operative Sequence for Procurement of Donor Heart

Cardiectomy, the process of removal of the donor's heart, is achieved through a median sternotomy and creation of a pericardial cradle, followed by isolation and mobilization of the superior and inferior caval vessels, aorta, and pulmonary artery. Once this dissection is complete, the procedure will continue as follows³⁴:

1. Expose the left atrium via inferior retraction.

2. Incise the posterior aspect of the left atrium and insert pool-tip suction to drain blood.
3. Divide the IVC near the insertion to the right atrium, insert second pool-tip suction device.
4. Crossclamp the distal ascending aorta and administer cardioplegia and pulmonary perfusate.
5. Apply cold saline or slush (no ice) to surface of heart.
6. Continue to closely monitor aortic root pressure and ventricular distension.
7. Sharply divide SVC, creating single orifice with azygous vein.
8. Fully mobilize aortic arch by dividing all head vessels.
9. Divide proximal descending aorta at level of ligamentum arteriosum, exposing the pulmonary artery.
10. Open the anterior pulmonary artery at the location of the perfusion cannula.
11. Retract heart leftward and incise the left atrium.
12. Lift heart superiorly and extend original posterior left atrial incision with the incision just created.
13. With both venous cuffs now well defined, complete cardiectomy.

Operative Sequence for Removal of Recipient Native Heart and Implantation of Donor Heart

Cardiectomy, the process of removal of the recipient's heart, is achieved through a median sternotomy and creation of a pericardial cradle, followed by isolation of the superior and inferior caval vessels, aorta, and pulmonary artery. Once this dissection is complete, the patient will then be put on cardiopulmonary bypass with bicaval cannulation. The procedure will then continue as follows.³⁴

14. Transect the SVC and IVC near their insertions to the right atrium.
15. Expose the left atrium via inferior retraction.
16. Open the left atrial dome and circumferentially incise about the mitral valve annulus.
17. Remove the recipient's native heart.
18. Implant the donor heart.
19. Anastomose the recipient left atrium to the donor atrial cuff.
20. Place the donor heart into the recipient pericardial cradle.
21. Trim the recipient's caval, aortic, and pulmonary vessels to prevent redundancy.
22. Anastomose the pulmonary artery and aorta (arrested heart) then IVC and SVC (beating heart) to minimize cold ischemic time.
23. Reperfuse, decannulate, and close chest in layers including closure of the sternotomy using sternal wires.

Notes

- Timing of the operation is an important factor for cardiac transplant surgery in order to minimize ischemic damage

to the donor heart as well the recipient's time on cardiopulmonary bypass. Ideally, the cold ischemic time of the donor heart is less than 4 hours, with longer times associated with greater mortality risk.³⁵

- Procurement of the donor heart requires close communication with other procurement teams, including lung and liver, to minimize risk to all potential recipients and ensure fair allocation of tissue margins.
- The recipient operation should begin before arrival of the donor heart to allow for sufficient recipient preparation and surgical dissection time before initiating bypass.
- Steroids may be given before closure.
- Adequate reperfusion before coming off bypass requires approximately 15 minutes per hour of ischemic time.³⁴ Cardiac and anastomotic function can be monitored intraoperatively using transesophageal echocardiogram.

Recommended multimedia links for heart transplant (note that there may be operative technique variations within the below examples, though they are still useful for getting an idea of the overall procedure):

Orthotopic heart transplant: [https://www.optechtcs.com/article/S1522-2942\(10\)00036-X/fulltext](https://www.optechtcs.com/article/S1522-2942(10)00036-X/fulltext).

Heart transplantation donor operation for heart and lung transplant: [https://www.optechtcs.com/article/S1522-2942\(10\)00038-3/fulltext](https://www.optechtcs.com/article/S1522-2942(10)00038-3/fulltext).

References

1. Online STS risk calculator. Accessed March 19, 2023. <https://riskcalc.sts.org/stswebriskcalc/>
2. Bojar RM. *Manual of Perioperative Care in Adult Cardiac Surgery*. Wiley Blackwell; 2021.
3. Merck Manuals. Global medical knowledge 2022. [internet]. Accessed March 19, 2023. <https://www.merckmanuals.com/professional/resourcespages/global-medical-knowledge>
4. Sapra A, Malik A, Bhandari P. Vital sign assessment. In: StatPearls [internet]. StatPearls Publishing; 2022.
5. Hafen BB, Sharma S. Oxygen saturation. In: StatPearls [Internet]. StatPearls Publishing; 2022.
6. Shah P, Louis MA. Physiology, central venous pressure. In: StatPearls [internet]. StatPearls Publishing; 2022.
7. Institute of Medicine (US). *Committee on Social Security Cardiovascular Disability Criteria. Cardiovascular Disability: Updating the Social Security Listings*. National Academies Press (US); 2010. 11, Pulmonary Hypertension.
8. Patel N, Durland J, Makaryus AN. Physiology, cardiac index. In: StatPearls [internet]. StatPearls Publishing; 2022.
9. *Cardiovascular Education and Training*. Abbott; 2020.
10. Colucci WS, Chen HH. *Natriuretic Peptide Measurement in Heart Failure. UpToDate*; 2022.
11. Shikdar S, Vashisht R, Bhattacharya PT. International Normalized Ratio (INR). In: StatPearls [internet]. StatPearls Publishing; 2022.
12. "Activated coagulation time." Activated coagulation time - Health Encyclopedia - University of Rochester Medical Center. Accessed March 19, 2023. <https://www.urmc.rochester.edu/encyclopedia/content.aspx?contenttypeid=167&contentid=act>
13. Antonione R, Kress T. Measuring serum lactate. *Nurs Crit Care*. 2009;4:56.
14. Centers for Disease Control and Prevention. Hydration status. 2022 [internet]. Accessed March 19, 2023. https://www.cdc.gov/dengue/training/cme/ccm/Hydration%20Status_F.pdf
15. Chetana Shanmukhappa S, Lokeshwaran S. Venous oxygen saturation. In: StatPearls [internet]. StatPearls Publishing; 2022.

16. Ress KL, Koerbin G, Li L, Chesher D, Bwititi P, Horvath AR. Reference intervals for venous blood gas measurement in adults. *Clin Chem Lab Med*. 2020;59:947-54. <https://doi.org/10.1515/cclm-2020-1224>
17. Castro D, Patil SM, Keenaghan M. Arterial blood gas. In: StatPearls [internet]. StatPearls Publishing; 2022.
18. Tillquist MN, Maddox TM. Cardiac crossroads: deciding between mechanical or bioprosthetic heart valve replacement. *Patient Prefer Adherence*. 2011;5:91-9.
19. Lecker SH, Chang BJ. *The Ultimate Medical School Rotation Guide*. Springer; 2021.
20. El-Sherief AH, Wu CC, Schoenhagen P, Little BP, Cheng A, Abbara S, et al. Basics of cardiopulmonary bypass: normal and abnormal postoperative CT appearances. *Radiographics*. 2013;33:63-72.
21. Hillis LD, Smith PK, Anderson JL, Bittl JA, Bridges CR, Byrne JG, et al. 2011 ACCF/AHA guideline for coronary artery bypass graft surgery: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. *Circulation*. 2011;124:e652-735.
22. Bachar BJ, Manna B. Coronary Artery Bypass Graft. In: StatPearls [internet]. StatPearls Publishing; 2022.
23. Bravo-Jaimes K, Prakash SK. Genetics in bicuspid aortic valve disease: where are we? *Prog Cardiovasc Dis*. 2020;63:398-406. <https://doi.org/10.1016/j.pcad.2020.06.005>
24. Otto CM, Nishimura RA, Bonow RO, Carabello BA, Erwin JP III, Gentile F, et al. 2020 ACC/AHA guideline for the management of patients with valvular heart disease: executive summary: a report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. *Circulation*. 2021;143:e35-71.
25. Emery RW, Voeller RK, Emery RJ. *Aortic Valve Replacement with a Mechanical Cardiac Valve Prosthesis*, Cohn LH and Adams DH, *Cardiac Surgery in the Adult*. 5th ed. McGraw Hill; 2017.
26. Yanagawa B, Verma S, Christakis GT, Stented bioprosthetic aortic valve replacement. Cohn LH, Adams DH. *Cardiac Surgery in the Adult*. 5th ed. McGraw Hill; 2017.
27. Ancona R, Pinto SC. e-Journal of cardiology practice; mitral valve incompetence: epidemiology and causes. Vol. No. 16; 2018. Accessed February 12, 2023. <https://www.escardio.org/Journals/E-Journal-of-Cardiology-Practice/Volume-16/Mitral-valve-incompetence-epidemiology-and-causes>
28. Bonow RO, Carabello B, de Leon AC Jr, Edmunds LH Jr, Fedderly BJ, Freed MD, et al. Guidelines for the management of patients with valvular heart disease: executive summary. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Management of Patients with Valvular Heart Disease). *Circulation*. 1998;98:1949-84.
29. Dominik J, Zacek P. *Heart Valve Surgery: An Illustrated Guide*. Springer-Verlag Berlin Heidelberg; 2010. 214-20.
30. Okita Y, Miki S, Ueda Y, Tahata T, Sakai T, Matsuyama K. Mitral valve replacement with maintenance of mitral annulopapillary muscle continuity in patients with mitral stenosis. *J Thorac Cardiovasc Surg*. 1994;108:42-51.
31. Erbel R, Aboyans V, Boileau C, Bossone E, Di Bartolomeo R, Eggebrecht H, et al. 2014 ESC guidelines on the diagnosis and treatment of aortic diseases: document covering acute and chronic aortic diseases of the thoracic and abdominal aorta of the adult. The Task Force for the Diagnosis and Treatment of Aortic Diseases of the European Society of Cardiology (ESC). *Eur Heart J*. 2014;35:2873-926.
32. Hiratzka LF, Bakris GL, Beckman JA, Bersin RM, Carr VF, Casey DE Jr, et al. 2010 ACCF/AHA/AATS/ACR/ASA/SCA/SCAI/SIR/STS/SVM guidelines for the diagnosis and management of patients with thoracic aortic disease: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines, American Association for Thoracic Surgery, American College of Radiology, American Stroke Association, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of interventional Radiology, Society of Thoracic Surgeons, and Society for Vascular Medicine. *Circulation*. 2010;121:e266-369.
33. Brown CR, Bavaria JE, Desai ND, Ascending and arch aortic aneurysms, Cohn LH, Adams DH. *Cardiac Surgery in the Adult*. 5th ed. McGraw Hill; 2017.
34. Cheng A, Slaughter MS. Heart transplantation. *J Thorac Dis*. 2014;6:1105-9.
35. Kilic A, Emami S, Sai-Sudhakar CB, Higgins RS, Whitson BA. Donor selection in heart transplantation. *J Thorac Dis*. 2014;6:1097-104.