Chapter

Tricuspid Valve Infective Endocarditis

Olina Dagher, Walid Ben Ali, Nils Perrin, Nancy Poirier and Nicolas Dürrleman

Abstract

The tricuspid valve, which has been known as the "forgotten valve", must not be ignored in infective endocarditis. Tricuspid valve infective endocarditis is a very complex condition and occurs in a complex patient population. The causative organisms are often highly virulent and patients usually have a history of intravenous drug abuse. Although the success rate of antibiotic therapy is high, certain features or complications may require surgery. Understanding the therapeutic options, the challenges of surgical intervention and the components of the patient-centered longitudinal care plan is crucial in order to minimize the risk of relapse, which is unfortunately not uncommon in these patients.

Keywords: tricuspid valve, infective endocarditis, tricuspid valve repair, tricuspid valve replacement, intravenous drug use

1. Introduction

In order to feel comfortable with tricuspid valve surgery, one has to have an excellent understanding of the peculiarities of right heart surgery. Surgical interventions on the right heart have many unique characteristics which differ significantly from those of the left heart. These must not be overlooked. Right heart surgery has a false reputation of being more "forgiving" in case of a technical error or a complication. Here are other distorted viewpoints that sometimes resurface: "If the left heart works well, the right heart follows", or "Anything can work on the right heart". Believing that surgery on the right heart is less challenging than surgery on the left heart is a perilous perception. Experience has taught us that this is far from being the case. We would even argue that it's the opposite. Right heart surgery requires additional experience and rigorous technical skills.

The right ventricle is highly compliant and is able to accommodate an important increase in preload conditions (**Figure 1**), such as in tricuspid regurgitation, even in the acute phase. The occurrence of symptomatic right heart failure under these hemodynamic circumstances will therefore be delayed compared to left heart failure secondary to acute mitral insufficiency. However, this pathophysiologic attribute can turn into a hurdle following tricuspid valve repair or replacement: the symptom recovery curve follows the same trajectory as symptom progression and correction of the tricuspid regurgitation may not yield immediate symptomatic improvements. In the meantime,

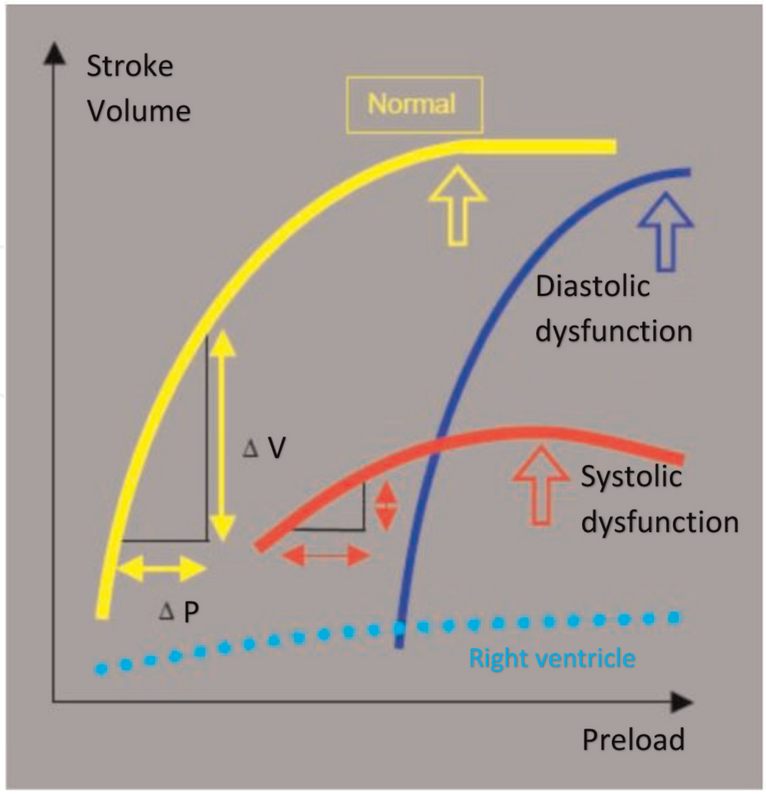

Figure 1.
Frank-Starling curve of the failing right ventricle (dotted line), which is much flatter compared to that of the failing left ventricle: Its stroke volume variation is minimal with the increase in preload.

the right heart, which is afterload-sensitive, must increase its output while facing more resistance. The right ventricle can therefore be more vulnerable than the left ventricle in certain scenarios. This concern feeds to the controversy of appropriate surgical timing for tricuspid intervention [1]. Current evidence seems to be in favor of early intervention [2]. Experts in the field of mitral valve surgery have also studied the progression of tricuspid valve disease following successful mitral valve repair [3]. They highlighted the importance of prophylactic tricuspid annuloplasty during mitral valve surgery for more severe cases of tricuspid annular dilation [3].

Myocardial protection of the right ventricle is very delicate and cross-clamping may subject the right ventricle to deleterious injuries that might not be as well tolerated as the left ventricle. In fact, intuitively, experienced cardiac surgeons will say that if right ventricular function is preserved following aortic unclamping, it indicates that myocardial protection was adequate. In case of suboptimal myocardial protection, signs of myocardial dysfunction will usually be more evident in the right ventricle. It is sometimes thought that right heart "resuscitation" can simply be achieved with replacement fluid therapy. However, the right ventricle is more sensitive to conduction and rhythm disturbances compared to the left ventricle. As mentioned previously, the right ventricle is also highly afterload-sensitive. Right ventricular afterload can be defined by pulmonary vascular resistance. This is why pulmonary hypertension should be aggressively treated perioperatively. The use of milrinone and nitric oxide to achieve afterload reduction have contributed to a significant improvement in outcomes of patients with right ventricular dysfunction. Other vasopressors and inotropes, such as vasopressin, norepinephrine, or epinephrine, can provide additional support and help to recover right heart function. These drugs are especially useful in systemic inflammatory conditions such as infective endocarditis which can be accompanied by hypotension. In addition, acutely elevated inflammatory biomarkers are a strong predictor of short-term adverse outcomes [4]. Therefore, if the patient's clinical state allows it, differing surgical intervention until peak inflammation subsides might improve prognosis.

Lastly, an important technical point to be cognizant of is the delicate tissue manipulation that is required when operating on infected right-sided structures: the latter, being more fragile at baseline compared to left-sided structures, can be easily damaged. In those circumstances, the pericardium, whether autologous or heterologous, becomes an indispensable material.

2. Anatomical characteristics of the tricuspid valve

2.1 The tricuspid valve complex

As its name suggests, the tricuspid valve is generally composed of three cusps or leaflets. The leaflets are named by the position of their annular attachment: septal, anterior and posterior. While the leaflets vary in their circumferential and area sizes, the posterior leaflet is the smallest [5]. The septal leaflet (**Figure 2**) has distinct characteristics: it has a narrow, rectangular, shape and is inserted directly into the membranous septum via many third-order chordae [6].

The subvalvular apparatus of the tricuspid valve is similar to that of the mitral valve: the presence of papillary muscles (contractile function) and chordae tendinae (elastic function) (**Figure 3**) allow for a functionally dynamic behavior [7]. The tricuspid valve apparatus includes 2 main papillary muscles (anterior and posterior), as well as a third variable and rudimentary papillary muscle (septal) [5]. The anterior papillary muscle is typically the largest and the most constant one [8]. It lends chordal support to the anterior and posterior leaflets, and, occasionally, to the moderator band [6]. The posterior papillary muscle supports the posterior and septal leaflets [6]. The four valves, including the tricuspid, lie within the fibrous skeleton of the heart (**Figure 4**). The fibrous continuity occurs through the fibrous annulus of the tricuspid valve, providing a firm support structure for the valve. However, unlike the mitral

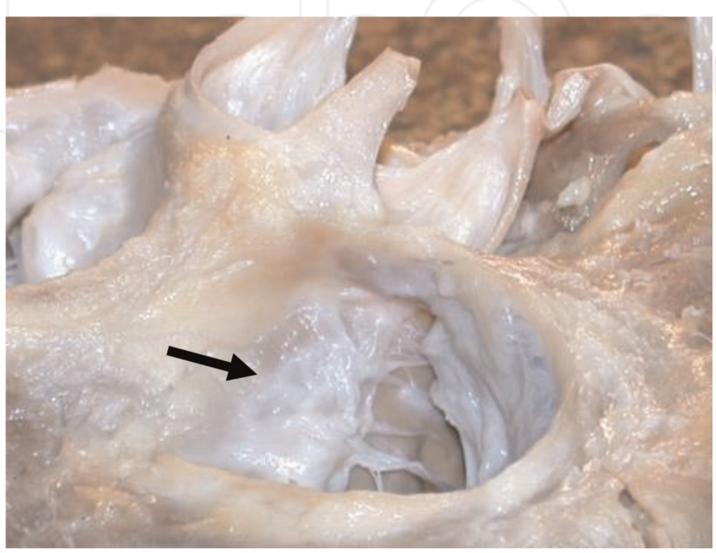

Figure 2.
Septal leaflet of the tricuspid valve (black arrow).

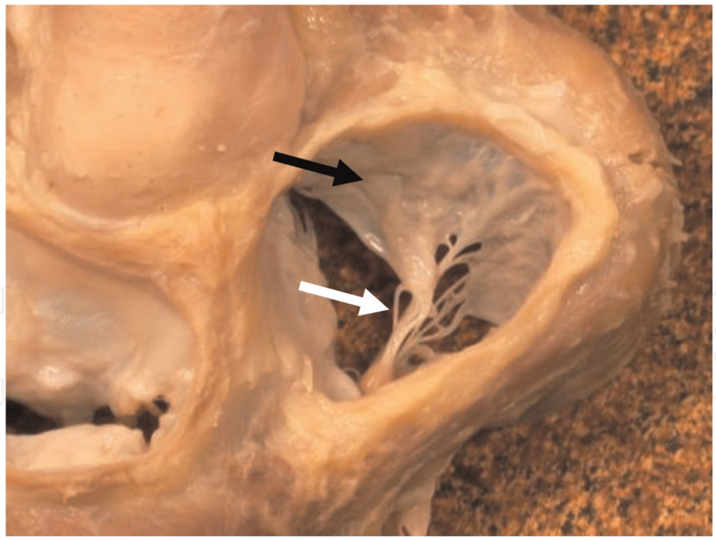

Figure 3.
Chordae tendinae (white arrow) attaching to the anterior leaflet of the tricuspid valve (black arrow).

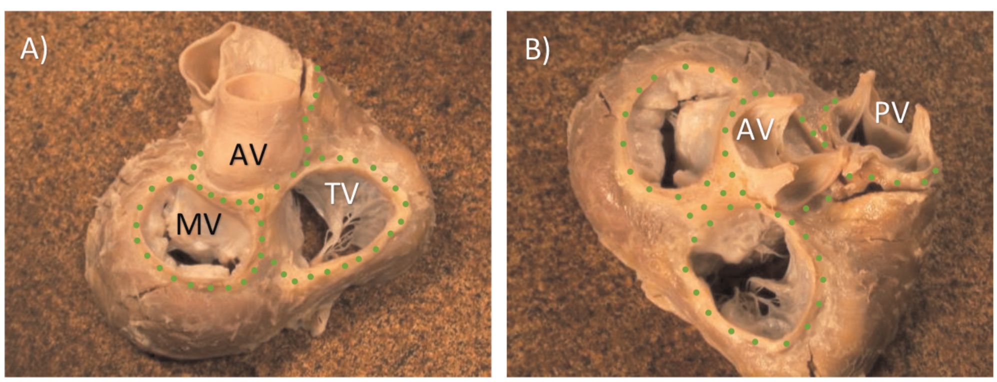

Figure 4.
A and B) fibrous cardiac skeleton (green dots) anchors the four cardiac valves. AV: Aortic valve; MV: Mitral valve; PV: Pulmonary valve; TV: Tricuspid valve.

valve, the tricuspid valve has no fibrous continuity with its corresponding semilunar valve [6]. Despite having different spatial positions and orientations within the cardiac fibrous skeleton, all four cardiac valves are anchored to that inert collagen framework. Understanding the anatomic conformation of the fibrous skeleton is crucial to understanding the structure–function relationships of each heart valve with other cardiac entities, such as heart chambers, coronary arteries or the conduction system. It then becomes intuitive to predict both the natural history of a disease and the iatrogenic complications related to its management.

2.2 Anatomical relationships of the tricuspid valve with other cardiac structures

2.2.1 Right coronary artery

The course of the right coronary artery is intimately related to the anterior and posterior leaflets of the tricuspid valve (**Figure 5**). In the setting of tricuspid valve endocarditis, bacterial invasion can spread into the tricuspid ring and form a periannular abscess. The abscess may cause an erosion of the adjacent tissues such as the coronary artery wall, resulting in coronary-cameral fistulae between the right

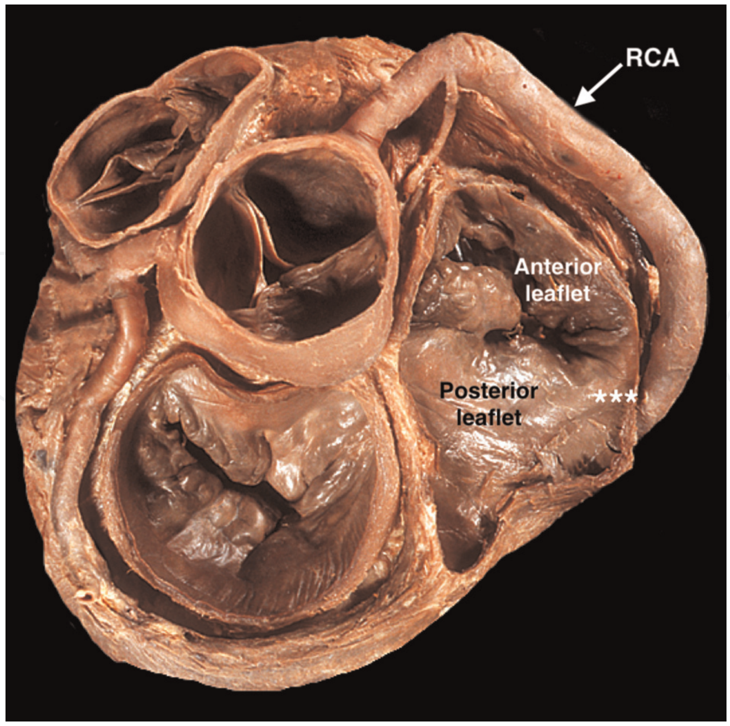

Figure 5.
Superior view of cadaveric heart valves (normal anatomy). The anterior wall of the heart is at the top of the picture and the left and right atria were removed. The coronary arteries were dissected. The right coronary artery (RCA) is in close proximity to the antero-posterior aspect of the tricuspid valve annulus (white asterisks).

coronary artery and the right atrium or the right ventricle [9]. Paradoxically, congenital anomalies of the coronary arteries are a well-recognized risk factor of infective endocarditis [10]. Septic coronary thrombosis is another rare but potential complication since infective endocarditis causes an impairment of immunothrombosis [10]. During tricuspid valve repair or replacement, iatrogenic injury to the right coronary artery (occlusion, thrombosis or dissection) can occur either directly from suturing through or around the artery, or indirectly from the tension placed on adjacent tissue and leading to a kinking mechanism once the sutures are pulled taut [11].

2.2.2 Conduction system

The tricuspid valve complex is closely associated with the conduction system and this has important implications for tricuspid valve repair and replacement.

The anatomy of the conduction system at the atrioventricular junctions has been extensively described by Anderson et al. [12, 13]. The atrioventricular node is located at the base of the septal aspect of the right atrium, just above the tricuspid valve. The bundle of His, which connects the atrioventricular node to the left and right bundle branches, is located just below the postero-superior margin of the membranous septum. The triangle of Koch serves an as an anatomic landmark for the location of the atrioventricular node. The triangle of Koch is delineated by the continuation of the Eustachian ridge as the tendon of Todaro and by the hinge of the septal leaflet of the tricuspid valve. These borders meet at the membranous septum, forming the apex of the triangle. The tendon of Todaro can be identified by gently pulling on the coronary sinus, which will reveal a linear prominence connecting the coronary sinus to the anteroseptal commissure of the tricuspid valve. The apical region of the triangle of Koch contains the atrioventricular node before it becomes a penetrating bundle, the

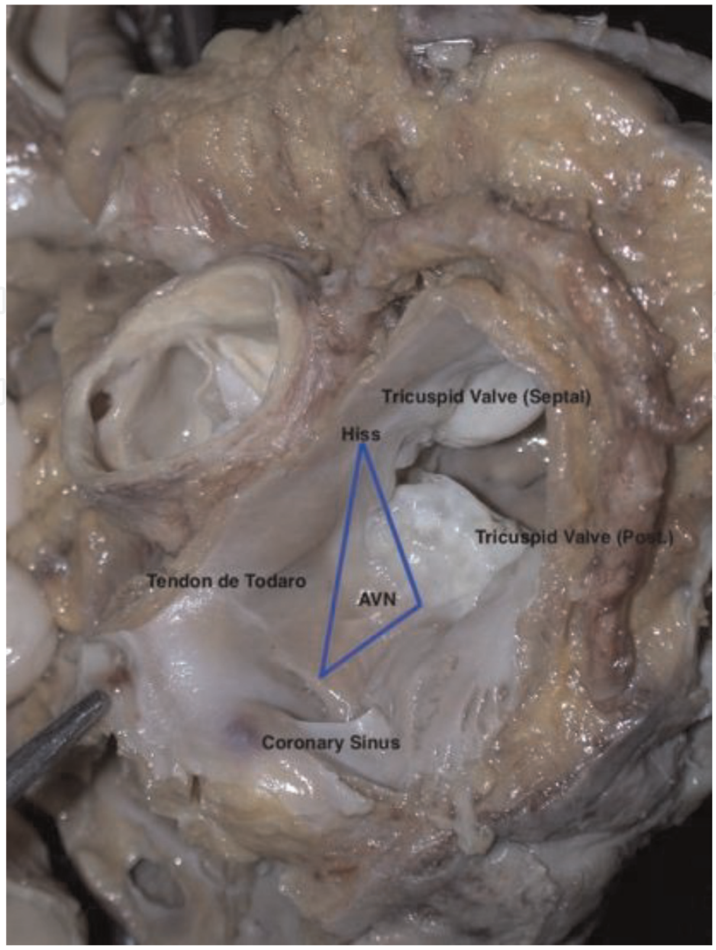

Figure 6.
Triangle of Koch (blue).

bundle of His, and enters the membranous septum at the apex (**Figure 6**). The atrioventricular conduction axis is surrounded with the insulating tissues of the central fibrous body. One should therefore keep in mind that any traumatic lesion to the conduction system around the atrioventricular junction could lead to a complete atrioventricular block, necessitating a permanent pacemaker implantation. Indeed, during tricuspid annuloplasty, the use of an open "C" ring avoids the necessity of suturing near the atrioventricular node, reducing the risks of complete heart block.

2.2.3 Left atrium

Right to left inter-atrial shunts related to tricuspid valve endocarditis and subsequent severe tricuspid regurgitation have been previously reported [14, 15]. In these cases, the regurgitant jet was being directed across an inter-atrial defect, patent foramen ovale or atrial septal defect, causing an acute right to left shunt. Depending on the magnitude of the shunt, patients can develop significant symptoms from refractory hypoxia and heart failure.

2.2.4 Right coronary sinus of Valsalva

Involvement of the right coronary sinus of Valsalva in the context of infective endocarditis is typically seen with double-valve endocarditis involving both the aortic

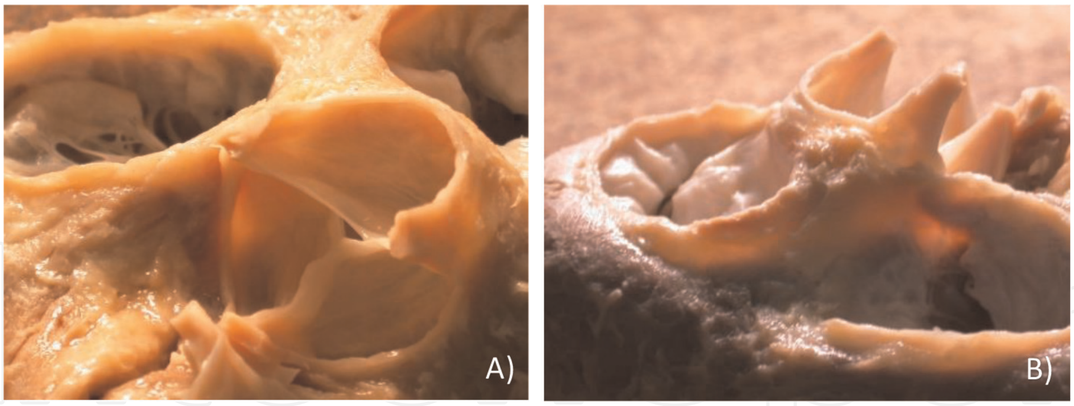

Figure 7.
Anatomic relationship between the right coronary sinus of Valsalva and the septal aspect of the tricuspid valve from the a) aortic view and B) the tricuspid view.

and the tricuspid valves [16]. The infection may originate from the aortic leaflets and invade the tricuspid valve through the periannular structures abutting the right coronary sinus of Valsalva (**Figure 7**). This should be suspected in cases of aortic valve endocarditis associated with a heart block, even after a reassuring echocardiogram that had no signs of tricuspid regurgitation. During surgical intervention, careful exploration should be undertaken to exclude the presence of a contiguous abscess. Lastly, the right coronary sinus may develop aneurysmal dilatation caused by mycotic degeneration of the arterial wall [16].

3. Preoperative evaluation

3.1 Clinical evaluation

Performing a clinical baseline assessment is important not only to allow for a coherent medical surveillance, but also to rule out a left-sided endocarditis and therefore a systemic dissemination. Any sign of left-sided or systemic infection in the context of tricuspid valve infective endocarditis should raise suspicion for the presence of a patent foramen ovale, a multisite infective endocarditis, a contiguous spread of infection or an endocarditis complicated by perforation. A proper clinical evaluation should also include an assessment of the criteria for sepsis. Concomitant sepsis and the patient's hemodynamic tolerance will affect timing of surgery. The clinician should look for pathophysiological changes associated with infective endocarditis, such as those enumerated in the modified Duke Criteria [17], but also for indicators of prognosis. Examples of combined diagnostic and prognostic findings include right-heart failure caused by tricuspid insufficiency, hepatocellular dysfunction, splenomegaly and cachexia. Another essential role of careful physical examination is to identify or confirm a source of infection or portal of entry. Up to 90% of infective endocarditis cases are caused by the bacteria staphylococci and streptococci, which typically enter the bloodstream from the skin or mucosal surfaces [18, 19]. In 35 to 60% of cases, a portal of entry cannot be ascertained [18, 19]. In patients with known substance use disorder, a wide spectrum of cutaneous manifestations of parental drug abuse may be observed at injection sites. Examples include skin popping (subcutaneous injection), muscle popping (intramuscular injection), ulcers, hyperpigmentation or track marks on the arms, legs, neck, genitalia, inguinal area or between the fingers and toes [20].

3.2 Laboratory testing

The routine preoperative laboratory testing ordered for patients undergoing cardiac surgery should be performed. This includes complete blood count, platelet count, identification of blood group, coagulation panel, as well as a comprehensive metabolic panel. In the context of infective endocarditis, a baseline procalcitonin and C-reactive protein levels should be obtained. These two inflammatory markers can have an influence on decisions regarding management. In the preoperative period, they have a prognostic value correlating with disease severity and can provide another argument for optimal surgical timing. In the postoperative period, they have a prognostic value correlating with resolution of illness and can therefore help monitor treatment response, either hinting towards a recovery or recurrent infection and treatment failure [21–23].

Serum albumin is closely linked to the patient's metabolic status. Hypoalbuminemia can indicate a hepatic insult, an immune disorder or a sepsis-induced catabolism [24]. Low serum albumin levels can also affect pharmacokinetics and pharmacodynamics by decreasing the extent of antibiotic bound to albumin, which increases the unbound fraction of the drug. Unlike the bound fraction of the drug, the unbound fraction is the only fraction available for distribution and clearance from the plasma. Low serum albumin is likely to increase the total volume of distribution and clearance of an antibiotic, which would translate to lower antibacterial exposures that might compromise the efficacy of the treatment [25].

Preoperative liver function tests are essential when planning for surgery of right-sided endocarditis, mainly for two reasons: (i) Right-sided endocarditis in non-drug addict patients without significant medical history is very uncommon; the average patient affected by tricuspid valve endocarditis often has a debilitated medical condition: immune disorder, substance use disorder (drugs and alcohol), cirrhosis, hemodialysis, poor nutritional status and cachexia. (ii) Tricuspid valve endocarditis can, if associated with significant tricuspid insufficiency or right-heart failure, alter hepatic function secondary to hepatic venous congestion. A liver panel should still be performed even in the absence of ascites or jaundice to rule out a subclinical liver insult: thrombopenia, abnormal increase in international normalized ratio (INR), hypoalbuminemia, hepatic cytolysis, pancreatic enzymatic reaction and decrease in factor V. Such findings should warn of an increased risk to develop an acute liver failure or significant coagulopathy during or after the surgery.

3.3 Toxicology screening

In cases where illicit drug use is still suspected (but denied by the patient), a urine drug screen can be done. It will detect evidence of recent cocaine, cannabis, opioids, barbiturates and benzodiazepines use. Detecting and assessing illicit drug use is very important to ensure a proper and individualized therapeutic approach. The perioperative management of patients suffering from drug addiction is fundamentally different from that of non-drug addict patients, both from a medical and surgical perspective. This will be discussed in detail in a subsequent section.

3.4 Microbiology

A systemic infection workup should be performed in order to obtain a complete microbial profile: nasal and rectal swabs, cytobacteriological examination of urine

(CBEU), cytobacteriological examination of the sputum (CBES), blood cultures and serology testing. As a general rule, two sets of blood cultures should be collected immediately and a third one at least 1 hour apart. These blood cultures should be obtained within the first 24 hours of hospital admission. It is well recognized that the sensitivity of blood cultures is largely related to antibiotic uptake prior to blood collection, but also to the volume of the blood sample: 10 mL per blood culture bottle is needed for optimal diagnostic sensitivity [26].

Approximately 5% of case of suspected infective endocarditis yield negative blood culture results, which is often due to prior antibiotic therapy [27]. This should prompt an extension in the duration of incubation of blood culture bottles and ordering a list of molecular tests for culture-negative endocarditis [27]. Two molecular techniques can be used: polymerase chain reaction (PCR), which can either be broad-range or pathogen-specific, and serologic assays, which are especially useful in the presence of intracellular organisms such as Coxiella or Bartonella spp. [28].

While the most common etiologic organism of tricuspid valve endocarditis is Staphylococcus aureus (**Table 1**), polymicrobial infections are also frequent [29]. Fungal endocarditis is a rare but life-threatening condition with a poor prognosis and a mortality rate up to 54% [30]. It should be suspected in the following clinical scenarios: illicit drug use, immunosuppression and/or neutropenia, malignant hemopathies or long-term central venous catheter use. In these cases, serology tests

Organism	Incidence	Risk factors	Other features
Staphylococcus aureus	40–45%	Skin lesion, IVDU (especially MRSA), indwelling prosthetic device (vascular catheters, intracardiac devices, orthopedic prostheses)	Most prevalent pathogen
Coagulase-negative Staphylococcus	5%	Alcoholism, prosthetic valves, indwelling vascular catheters	
Streptococci (especially *Streptococcus pneumoniae*)	30–35%	Alcoholism, prosthetic valves, indwelling vascular catheters, poor dentition	More dominant in left-sided IE
Pseudomonas aeruginosa and other gram-negative bacteria	10%	Neutropenia or other immunodeficiency, advanced age, pancreatobiliary tract disease, severe burns, indwelling central venous or urinary catheter, traumatic wounds that have been contaminated with fresh water	Commonly hospital-acquired (especially in ICU)
Fungi	1–10%	Indwelling central venous catheters, IVDU, prosthetic heart valves or other valvular disease, cancer chemotherapy	Relatively high mortality, incidence rising due to immunocompromised, aging population and intracardiac devices

ICU: intensive care unit; IE: infective endocarditis; IVDU: intravenous drug use; MRSA: methicillin-resistant S. aureus.
Adapted from "Preeminence of S. aureus in infective endocarditis: a 1-year population-based survey," by C. Selton-Suty et al., 2012, Clin Infect Dis., 54(9):1230–9. and from "Trends in Infective Endocarditis in California and New York State" by N. Toyoda et al., 2017, JAMA, 25;317(16):1652–1660. CC BY-NC.

Table 1.
Common causative microorganisms for right-sided infective endocarditis.

for Aspergillus and Candida spp. should be obtained, in addition to the serum galactomannan antigen test (Aspergillus spp). In case of a negative preliminary workup for fungal infections, β-d-Glucan is an attractive antigen found in cell walls of a broad range of fungal agents and can then be considered [31].

Serological testing for human immunodeficiency virus (HIV)-1 and HIV-2 should be obtained, especially in patients with drug use disorders. Preoperative testing not only helps with patients' management, but it also raises awareness among healthcare providers and prepares them to readily apply the principles of postexposure management in the event of occupational exposure to blood.

3.5 Imaging investigations

3.5.1 Echocardiographic imaging

Transthoracic echocardiogram is the diagnostic procedure of choice and is often sufficient to assess and characterize the pathologic lesions [32, 33]. This is especially true in patients with tricuspid valve endocarditis since this patient population is typically young, has a lower body habitus and larger vegetations [34]. Despite the good performance of transthoracic echocardiogram, transoesophageal echocardiogram has a higher sensitivity −90% compared to 50% for transthoracic echocardiogram- and is better for detecting certain diagnosing features of endocarditis [34]. It is particularly useful for: (i) recognizing subaortic complications, abscesses or fistulas, (ii) ruling out pulmonary valve endocarditis and (iii) better visualizing pacemaker leads and prosthetic valves [35]. It is essential to obtain a detailed anatomical assessment of all the cardiac valves and surrounding structures prior to surgery in order to avoid finding unexpected tissue damage during surgical exploration and avoid unplanned surgical steps. For that reason, transoesophageal echocardiogram should be seen as complimentary to transthoracic echocardiogram [36, 37].

3.5.2 Other imaging workup

In theory, cerebral imaging has little value in right-sided infective endocarditis but it should be done in the presence of any focal neurologic deficit. Cerebral lesions, depending on their extent and severity, may affect timing of surgery or may even be a contraindication to surgery. In addition, any sign of brain involvement in right-sided infective endocarditis suggests a concomitant left-sided endocarditis or the spread of the infection from a right-sided valve to left-sided structures.

With tricuspid valve endocarditis, a computer tomography scan of the chest, abdomen and pelvis must be obtained to evaluate for septic emboli, infarcts or abscesses (**Table 2**).

^{18}F-fluorodeoxyglucose positron emission tomography-computed tomography (FDG PET-CT) has been included into the recommended workup for patients with suspected infective endocarditis, according to major society guidelines [38, 39]. In the context of inflammation or infection, ^{18}F-fluorodeoxyglucose, an analogue of glucose, is primarily taken up by activated neutrophils which exhibit enhanced glycolysis, hence acting as a radiotracer. There are two main indications for performing an FDG PET-CT: (i) to supplement the echocardiogram in characterizing intracardiac infections, especially in the endocardium, and (ii) to detect clinically silent disseminated disease [40]. However, ambiguity remains regarding the optimal use and timing of this imaging modality [38, 39]. In addition, FDG PET-CT is non-contributory for

Valvular/Local	Nonvalvular/Peripheral
Tricuspid insufficiency Tricuspid stenosis Valve destruction Leaflet perforation Periannular abscess formation	Pulmonary: embolism, infiltrates, exudates, abscess, cavitation, aneurysms, pleural effusion. Systemic embolism and infarcts (most often paradoxical embolus via patent foramen ovale or intracardiac shunt) High degree atrioventricular block Septic shock Multiorgan failure

Table 2.
Major complications of tricuspid valve infective endocarditis.

cerebral imaging in this setting given the principles of brain metabolism. Its usefulness is also very limited in the early postoperative period owing to the acute sterile inflammatory changes induced by surgical insults, which increase the likelihood of a false-positive finding [41].

The addition of radiolabeled white blood cell scintigraphy looks promising, especially for differentiating between active infection and inflammation. However, its complexity, limited availability and lack of adaptation are the main challenges to its use [42].

3.6 Intraoperative investigations

In cases in which definitive microbiologic diagnosis cannot be established preoperatively based on culture or serology alone, tissue samples must be collected intraoperatively from the infected valve/tissues or vegetations. These specimens should be sent fresh in appropriate sterile containers for both histopathological and microbiological examinations, but the largest sample should be sent to the molecular diagnostic unit to perform a broad-range PCR. This highly sensitive technique amplifies small quantities of 16SrDNA (for bacteria) or 18SrDNA (for fungi), which can then be sequenced for specific pathogen identification [43].

Achieving quality verbal and written communication between the pathologist, biologist and surgeon is crucial to avoid any loss of information, diagnostic error, and patient harm. Multiple components should be clarified, including pertinent clinical information, intraoperative observations, precise location of tissue removal, diagnostic uncertainty, specific tests that are required, expectation of report turnaround time, etc. [44, 45]. The pathologist and biologist should understand the role of the requested laboratory tests in the diagnostic process and therapeutic strategy, and their importance for antibiotic stewardship.

3.7 Postoperative investigations

Treatment response must be assessed postoperatively with serial complete blood counts, procalcitonin and C-reactive protein levels. After hospital discharge, both clinical and echocardiographic follow-up are recommended to monitor potential complications, such as recurrence of infection, persistent valve dysfunction, heart failure, development of new vegetations, etc. International guidelines recommend obtaining a baseline transthoracic echocardiogram at the completion of antimicrobial therapy, followed by serial examinations at 1, 3, 6 and 12 months [46]. In the presence of prosthetic valve or other biomaterial, a PET scan can be obtained 3 months after surgery to rule out a recurrent infection with higher sensitivity. However, it should be interpreted carefully by an experienced user and images should be compared to any previously obtained sequence to avoid any false-positive result caused by normal postsurgical aseptic inflammatory changes [41].

4. Guidelines on the surgical management of tricuspid valve endocarditis in adults

4.1 Indications

Any decision about surgical intervention should be made by a heart valve multidisciplinary team. Decisions on surgical intervention are complex and depend on many clinical and prognostic factors that vary among patients, including causative organism, vegetation size, presence of perivalvular infection, presence of embolism or heart failure, age, noncardiac comorbidities, and available surgical expertise. Decisions on the indication and timing of surgical intervention should be determined by a multispecialty team with expertise in cardiology, imaging, cardiothoracic surgery, and infectious diseases. Indications for surgical intervention in right-sided infective endocarditis include the following [39, 47]:

- Presence of highly resistant organisms;
- Persistent bacteremia for >5–7 days despite adequate antimicrobial therapy;
- Right heart failure due to severe tricuspid regurgitation with poor response to medical therapy;
- Paravalvular abscess or destructive penetrating lesions;
- Heart block;
- Recurrent septic pulmonary emboli;
- Large, persistent vegetations (>20 mm).

The first five clinical scenarios are a Class I indication for early surgery according to the 2020 American College of Cardiology/American Heart Association guidelines for the management of valvular heart disease [48]. Early valve surgery represents a surgery that is done during the initial hospital course, prior to completion of antimicrobial therapy. Reasons to consider early surgery are to avoid progressive heart failure and irreversible structural damage caused by the infection. Early surgery for recurrent pulmonary emboli is a class 2a indication according to those same guidelines, while early surgery for large (>20 mm) vegetations is a class 2b indication. In patients with implanted electronic devices, infection of the entire system is likely and this mandates complete removal of leads and generator in order to eradicate the infection (Class I). Because of its high success rate and low complication rate, interventional transvenous extraction of pacemaker leads is favored over surgical extraction.

The 2015 European Society of Cardiology guidelines for the management of infective endocarditis list three Class IIa indications for surgical intervention of right-sided infective endocarditis [38]:

- Right heart failure due to severe tricuspid regurgitation with poor response to medical therapy;
- Presence of highly resistant organisms that are difficult to eradicate;
- Persistent bacteraemia >7 days despite adequate antimicrobial therapy;
- Tricuspid valve vegetations >20 mm that persist after recurrent pulmonary emboli.

4.2 Contraindications

In theory, there are very few contraindications to surgical intervention for endocarditis. However, in practice, some clinical scenarios present difficult dilemmas. Patients >65 years of age have an increased risk of infective endocarditis and their overall outcome is less favorable due to the presence of comorbidities, delayed presentation and frequent history of antimicrobial use. However, age per se is not a preclusion to surgical intervention [49]. Risk stratification models such as the Society of Thoracic Surgeons Endocarditis Score are available to predict morbidity and mortality risks and to assist in patient-centered decision-making.

Recurrent endocarditis due to continued drug abuse is not an absolute contraindication to surgery, but many surgeons may see this intervention as futile. The ESC guidelines recommend avoiding surgical intervention in patients who continue to inject drugs, except in the situations mentioned previously that prompt early intervention [38]. As part of decision-making about reoperation, the ACC/AHA guidelines include a Class I recommendation to consult with experts in addiction medicine about the patient's long-term ability to refrain from drug use before deciding on surgical candidacy. Cardiac surgery is contraindicated for at least one month after intracranial hemorrhage unless neurosurgical or endovascular intervention can be performed to reduce bleeding risk [48]. After an ischaemic stroke, surgery is only contraindicated if there is extensive neurological damage and if the neurological prognosis is judged too poor.

5. General principles of surgical management

Those principles follow the basic rules of the surgical management of contaminated and infected operative fields.

1. Whenever possible and if permitted by hemodynamic status, surgery should be delayed until bacterial shedding is decreased. This is usually achieved within a couple days of effective antibiotic therapy. That being said, a surgical delay that is justified by the vain hope of achieving a sterile operative field and that results in cardiac tissue destruction and deterioration in the overall clinical condition may cause significant harm to the patient.

2. Be aware that preoperative imaging always underestimates the severity of the lesions. In other words, one should expect to find more tissue damage and destruction.

3. "It's like going to war.": surgery for infective endocarditis has a higher burden of unexpected findings and complications compared to other types of cardiac procedures.

4. Regarding cannulation strategy for cardiopulmonary bypass, a bicaval cannulation is a safer choice owing to its versatility.

5. Regarding cardioplegia, cases should be considered individually since multiple strategies are possible. The chosen approach should however be shaped around the surgeon comfort level and should allow to safely perform a complex surgery.

6. Retrograde cardioplegia may wash out distal emboli from the coronary ostia and is therefore an attractive option in combined aortotricuspid valve endocarditis.

7. Minimal manipulation of cardiac structures until cardioplegic arrest to avoid embolism.

8. Complete extraction of prosthetic material and debridement of all infected and necrotic tissue.

9. Generous irrigation of the operative field with antibiotic solution and scrubbing of healthy tissue with antibiotic-soaked gauze.

10. A non-antibacterial lavage with non-antibacterial solutions (povidone iodine, superoxidised water, etc.) may also be used but has been shown to be less effective at reducing surgical site infection compared to antibacterial solutions [50].

11. Thorough intraoperative histology and microbiology testing; this must be done even if a causative agent was identified preoperatively in order to rule out a polymicrobial infection or the presence of fastidious microorganisms that did not grow on initial blood cultures. The results of these microbiology tests will influence duration of therapy. Guidelines suggest that if resected valve tissue is culture positive or if a perivalvular abscess is found, then an entire course of antimicrobial therapy is reasonable after surgery [39]. All appropriate containers as well as specimen collection and transportation supplies should be available to avoid wasting samples. These should also be clearly labeled.

12. The surgical instruments that are used for the first part of the surgery- until the debridement of infected tissue- should be replaced for the second half of the procedure to avoid contaminating the operative field.

13. For tricuspid valve repair strategies:

    - Avoid the use of braided sutures as they are more prone to bacterial adherence [51];

- Favor the use of interrupted sutures [52, 53];
- Use pericardium strips or pledgets to consolidate suture lines.

14. Providing an adequate nutritional support is crucial owing to the hypermetabolic state seen in sepsis [54, 55].

15. Insertion of a peripherally inserted central catheter (PICC) line or port-a-cath should be seriously considered and discussed among the multidisciplinary team for postoperative continuation of antibiotic therapy.

16. The risk of reinfection or recurrent infective endocarditis is a major concern; however, this risk decreases over time [56].

5.1 Characteristics of tricuspid valve infective endocarditis

5.1.1 Surgical approach

In the majority of cases, a midline sternotomy is performed. However, a minimally invasive surgical approach has been described for isolated tricuspid valve intervention [57]. Through our experience, we find that both techniques can be safely and effectively performed, but each has its own advantages and disadvantages. Ultimately, the choice of approach should take into consideration the surgeon's comfort level, patient's characteristics and patient's preference. Minimally invasive surgery is an excellent option for both redo and primary surgery cases. However, as stated previously, tissue damage and destruction if often found to be more severe than expected; the operative field should therefore be accessible enough to perform a complete debridement and repair.

5.1.2 Cardiopulmonary bypass

- Bicaval cannulation provides an unobstructed surgical field. These cannulas typically have a right-angled tip to facilitate exposure.
- Vacuum-assisted veinous drainage will facilitate venous drainage, especially for the subdiaphragmatic venous circulation which can be subjected to congestion secondary to the retrograde flow from tricuspid regurgitation [58]. Adequate cardiac decompression can even be achieved without snaring the vena cava [59].
- Vasoplegic syndrome following cardiopulmonary bypass remains a serious and relatively frequent occurrence that will further complicate postoperative hemodynamic management. Adding hemofiltration, leukocyte-depleting filters and/or cytokine filters (CytoSorb®) to the pump circuit is particularly appealing in this patient population because of their pro-inflammatory state and hypervolemic status. However, evidence to support their use is still lacking [60, 61].

5.1.3 Cardioplegia

Aortic cross-clamping and cardioplegic arrest are not required in isolated tricuspid valve disease; the procedure can therefore be done off-pump. This has several advantages:

- It avoids triggering a second "inflammatory hit" that would otherwise exacerbate the hyperinflammatory state and vasoplegia caused by the bacteremia;

- It avoids inducing myocardial ischemia associated with the use of cardiopulmonary bypass;

- It allows real-time monitoring of the cardiac rhythm, thus allows to troubleshoot rhythm disturbances when suturing around the triangle of Koch.

If a more complex surgery is needed (e.g. homograft replacement), aortic cross-clamping becomes necessary; it will allow the surgeon to work on an immobile field, thus enhance precision of hand gestures. If the infection affects other valves, the tricuspid valve should be the last one to address, and if possible, after unclamping. Aortic cross-clamping and cardioplegic arrest are also required when a patent foramen ovale is diagnosed on echocardiogram in order to prevent venous air embolism or embolic debris from the vegetations to paradoxically enter the systemic circulation. If there is uncertainty regarding the extent of tissue lesions, a safe approach would be to perform the surgery while on-pump, still with bicaval cannulation, which will allow for any valvular correction. The choice of cardioplegia should be at the discretion of the surgical team.

5.1.4 Incision and exposure

The right atriotomy is performed in parallel to the atrioventricular groove, at least 1 cm away from it in order to avoid injury to the right coronary artery during closure. In case of a redo operation, the atrioventricular groove is often difficult to visualize because of adhesions. The atriotomy can then be caried out along the virtual line that connects the two venous cannulas. A proper exposure will help achieve a thorough inspection of the cardiac structures and tissues. It includes a functional assessment of the tricuspid valve, which can be achieved using hand-held retractors, a valve retractor system such as the Cosgrove retractor, or multiple suspension sutures. This step is crucial as it will determine the optimal surgical approach (repair or replacement) to address the valvular pathology.

5.1.5 Surgical closure

Most often, a single continuous prolene suture is enough to close the right atriotomy. However, the free edges of the atriotomy might appear very thin with right atrial enlargement, in which case a double running suture might be necessary, with or without surgical adhesive.

6. Surgical management of tricuspid valve infective endocarditis

Two scenarios can be encountered when determining optimal surgical treatment for tricuspid valve endocarditis:

1. If the endocarditis is considered sterile: The main concerns at that point are potential hemodynamic instabilities and the risk of embolism. The purpose of surgery is therefore to correct the tricuspid valve pathology but it will typically

not be performed in emergent situations. Surgical timing remains a key element to optimize outcomes: surgery must be offered early, whenever indications are met, but before patients develop right heart failure. The choice of surgical technique should take into consideration the degree of tissue damage, the patient's clinical status, their age, their burden of comorbidities and their risk of recurrence.

2. If the endocarditis is not considered sterile: The main objective is to debride all devitalized and infected tissue, such as vegetations or abscesses. Tissue that appears edematous or abnormal should also be debrided. In addition to correcting the tricuspid valve pathology, the goal of surgery is to also avoid implanting any prosthetic material into an infected area.

6.1 Therapeutic options

6.1.1 Tricuspid valvulectomy

Proposed by Arbulu and colleagues [62], this surgical technique is rarely performed today. The goal is to excise the tricuspid valve without replacing it. It was performed mostly in patients with intractable endocarditis and ongoing drug abuse who had a high risk of relapse or recurrent infection. Results were better than expected and the reported mortality —29% on the first case series- was mainly due to non-cardiac complications. The team of surgeons who pioneered this operation still defend its merits, but its adoption has been largely decreased with the advent of tricuspid valve repair techniques that do not involve the use of prosthetic material [63]. The rapid advances in transcatheter heart valve interventions might give tricuspid valvulectomy a second chance in cases of severe and complex tricuspid valve infective endocarditis: in a double-stage procedure, a tricuspid valvulectomy, performed first, would allow for an effective control of the infection, followed by a transcatheter valve intervention to address the tricuspid regurgitation.

6.1.2 Tricuspid valve repair

Tricuspid valve repair can be achieved using different techniques:

6.1.2.1 Vegetectomy/suture/patch

Vegetations are often found on the valve leaflets. Resection of the vegetation at its base can lead to a leaflet defect (depending on the level of leaflet involvement). A small defect can be sutured directly [64, 65]. As long as there is no chordal resection, larger defects may require pericardial patching (e.g. glutaraldehyde-treated autologous pericardium) in order to avoid leaflet distortion. Patching can be done using either interrupted or continuous sutures [66]. In case of annular erosion or abscess, all infected tissue should be debrided until a healthy circumference of tissue is visualized. The remaining defect should be patched, and the annulus, reconstructed: the preserved tricuspid leaflet can then be reattached to the neo-annulus.

6.1.2.2 Chordal damage

Rupture of chordae tendineae is rare and is usually associated with a free edge destruction of the leaflet. This can be addressed with a leaflet reconstruction using a patch and Gore-Tex chordoplasty. Artificial chords made of polytetrafluoroethylene (PTFE) have good long-term durability and are relatively resistant to infection [67].

6.1.2.3 Annuloplasty

In the setting of annular abnormality (i.e. dilation or distortion), an attempt should be made to restore annular rigidity, both for short-term and long-term benefits. The following techniques can be used: (i) commissural plication or (ii) DeVega annuloplasty. For commissural plication, an X suture is placed at the level of the postero-septal and/or anteroposterior commissure. The depth of the suture determines the degree of annular size reduction. The DeVega annuloplasty consists of running two parallel sutures between the postero-septal commissure to the antero-septal commissure. The two sutures should run in opposite directions, the first suture starting on the postero-septal commissure and the second, on the antero-septal commissure. The sutures are then tied using pledget reinforcement, while using an angled Hegar dilator or a ring sizer (32 mm for men and 28 mm for women) to help accurately size the annulus. Synthetic pledgets can be replaced with pericardial pledgets to further reduce the risk of reinfection [68].

6.1.2.4 Annuloplasty ring

The decision to implant a prosthetic ring should be considered with caution and weighed against the risk of reinfection.

6.1.2.5 Suture bicuspidization

The Kay technique is one way to achieve bicuspidization. It involves an annulorrhaphy of the posterior segment which results in obliterating the posterior leaflet. The Alfieri stitch, originately described for the mitral valve, can also be used for the tricuspid valve, with satistifying results [69, 70]. It consists in suturing together the middle point of the free edges of the tricuspid leaflets in order to create a coaptation zone in the center. This also results in 2 or 3 tricuspid orifices, giving the valve a clover shape. Indeed, this technique is sometimes referred to as "the Clover Technique. Bicuspidization of the tricuspid valve seems to be well tolerated by patients [71]. These techniques and their principles are being applied to the field of transcatheter intervention [72].

6.1.2.6 Tricuspid valve replacement

The key point is to avoid injury to the conduction system. In order to achieve that, two suturing techniques have been described: (i) placing the stitches into the fibrous tissue along the septal leaflet or (ii) implanting the prosthetic valve above the level of the coronary sinus, leaving the latter on the ventricular side.

6.2 Selection of a substitute

6.2.1 Mitral homograft replacement

A tricuspid homograft is difficult to preserve because the leaflets are very thin and the chordae tendinae, too numerous. The surgical technique is also challenging, making it a suboptimal option in emergent situations. On the opposite, tricuspid valve replacement with mitral valve homograft is feasible [73, 74]. The chords can be implanted before fixing the homograft to the tricuspid annulus, or vice versa [73]. The homograft can either be placed in the anatomical or the anti-anatomical position; the optimal orientation being controversial, the choice remains at the surgeon's discretion. However, the benefits of adding an annuloplasty ring are well established [75]. A main disadvantage of this substitute is that it's not widely available in the required sizes for the tricuspid annulus.

6.2.2 Inverted aortic valve xenograft

Implantation of a stentless aortic root prothesis using an inversion technique has been described as an alternative to mitral homograft replacement [76]. The sinuses of Valsalva should be trimmed prior to implantation, leaving only the commissural posts suspending the aortic valve within. These posts will serve as chordal attachments. The xenograft is positioned, sutured in place and the commissures are attached to the right ventricular cavity.

6.2.3 Mechanical prosthesis

The main challenge is the requirement for lifelong oral anticoagulation using a vitamin K antagonist. This is a serious concern, especially in the tricuspid position because the tricuspid valve is a low flow valve, which increases the risk of thromboembolic events. During implantation, particular care must be taken to ensure normal leaflet excursion.

6.2.4 Bioprosthesis

These do not require lifelong anticoagulation; however, vitamin K antagonists should be considered in all patients for 3 to 6 months after surgery. Other advantages include:

i. A good long-term durability in the tricuspid position given the low flows;

ii. An excellent anchoring frame for future transcatheter valve therapy;

iii. In case of a recurrent endocarditis, the infection will tend affect the leaflets rather than the annulus.

During implantation, the struts of the bioprosthesis should be positioned so they straddle the conduction tissue, which helps to avoid heart block.

6.3 Transcatheter valve therapy

Many cases of infective endocarditis post-transcatheter heart valve interventions have been described, but literature specifically describing the use of transcatheter valve therapy to address endocarditis remains scarce. The reason probably stems from the fact that infective endocarditis often involves tissue damage which requires surgical debridement. In addition, transcatheter tricuspid valve therapy is still in its early stages of development [77]. Current tricuspid valve catheter devices can be divided into four categories, according to their mode of action: annuloplasty devices, edge-to-edge repair devices, coaptation devices and caval valve devices. These devices can address the tricuspid regurgitation, but not the tissue lesions, thus representing an incomplete therapeutic solution to a complex condition. Recently, a percutaneous vacuum-assisted device coupled with a veno-venous extracorporeal system (AngioVac, AngioDynamics) was introduced for the removal of right-sided intracardiac masses. The system is inserted through the femoral vein and consists of a 22 French coil-reinforced drainage canula. Several case series showed a high success rate for debulking large vegetations (2 cm on average), leaving small residual vegetations which can be treated with antibiotics [47, 77]. This promising therapeutic avenue could certainly benefit patients who have a prohibitive surgical risk and those in whom implantation of prosthetic material is to be avoided (e.g. ongoing drug abuse). Furthermore, percutaneous aspiration of vegetations may help reduce the immediate risk of septic embolization while allowing surgeons to postpone definitive intervention at a later date, once the clinical status is improved. In cases where there is no need for surgical debridement, this definitive intervention could even be a transcatheter heart valve intervention. However, percutaneous vacuum-assisted devices have their own potential adverse effects, including vascular access complications or disruption of the vegetation leading to pulmonary embolization [47, 77]. Larger prospective studies are needed to determine their safety and efficacy.

6.4 Outcomes

The clinical outcomes of surgical interventions on the tricuspid valve are difficult to interpret. This is in part explained by the fact that most published data come from small case series, while larger studies often do not exclude combined mitral and tricuspid cases [78–81]. Operative mortality for tricuspid valve infective endocarditis ranges between 6% and 30% but is rarely precipitated by the tricuspid intervention itself. The most common risk factors for operative mortality include multivalvular endocarditis and preoperative multiorgan failure. The postoperative and middle-term prognosis are influenced by right ventricular function and the presence of pulmonary arterial hypertension.

7. Specific management considerations

7.1 Intravenous drug users

Drug use disorder is the persistent and compulsive use of drugs despite substantial harm and adverse consequences as a result of their use. Patients suffering from this disorder become dependent on the intense but short-lived feelings of pleasure derived from surges of activation of the brain’s reward system. Despite the knowledge of certain risk factors, there is not a definitive socio-professional or psychological profile that perfectly predicts drug addiction. Drug addiction can affect anyone. However, it is rarely openly disclosed by patients, and is instead presented as being occasional/recreational. People with substance dependency often report feelings of guilt and shame. There are many barriers to getting help, including discrimination, misunderstanding or fear of possible criminal consequences. Patients with drug addiction who are diagnosed with infective endocarditis often present at an advanced stage that requires emergent management. This context is not suitable for an abrupt drug discontinuation. A proper drug weaning and tapering should be consensual and carefully planned. It is a long and difficult process that should not be disrupted by a concomitant disease.

The provider-patient interaction in the presence of drug addiction can be defined on three levels: (a) relational, (b) medical and (c) social.

7.1.1 Relational considerations

The context is certainly delicate. Unconscious bias may lead to poorer interactions. Concomitant psychological or psychiatric disorders may be precipitated into a crisis state or an acute phase of symptoms during hospital admission. Health care providers will have to face many interpersonal challenges: establishing trust and showing compassion while setting strict relational boundaries and therapeutic principles. It is a competent adult's prerogative to give, refuse or withdraw consent to health care, and this must be a voluntary decision free of any coercion or pressure. Ethical uncertainty can arise for health care providers when patients decline treatments that appear to be in their best interests, however, there is a strong obligation to honor the patient's wishes. In order to avoid any ethical conflicts and to prevent patient harm, continued and open discussions with the patient must occur along every step of the therapeutic process to demonstrate mutual respect and even out power imbalances.

Health care providers should also be appropriately trained in withdrawal management, including recognizing the physical and psychological symptoms of withdrawal, applying behavioral management strategies and using the right medications for alleviating common withdrawal symptoms. Drug withdrawal can occur at any stage of the hospital stay, including postoperatively. In order to maximize patient and worker safety, patients with drug abuse disorder should be enrolled in an inpatient withdrawal management program. These services are staffed by an experienced and dedicated multidisciplinary team that may include nurses, nurse practitioners, physicians, social workers, recreational therapists, counselors and spiritual care professionals. In terms of logistics, visitors on the unit should be closely monitored as they may smuggle drugs to patients. Patients may also leave the unit to obtain substances outside on hospital property. Having institutional policies about visitors and patients' entries and exits might facilitate collaboration with staff, as well as optimize effective prevention of relapse during inpatient therapy.

7.1.2 Medical considerations

7.1.2.1 Serology

Obtaining serology testing is crucial, not only to help with patients' management (morbidity status, immunodeficiency versus immunocompetence), but to also protect healthcare providers in the event of occupational exposure to blood.

7.1.2.2 Surgery

Tricuspid valve repair techniques should be the preferred approach in this patient population despite the presence of a fastidious organism, because the risks of a recurrent infection are very high. The implantation of prosthetic material should be seen as a last resort.

7.1.2.3 Prescription drug interactions

Identification of potential drug interactions must be part of the preoperative evaluation. It is very important to gather a detailed and complete drug history (name, type, frequency), including of illicit drugs, over-the-counter and herbal products. Opiate addicts may have a skewed perception of pain and may have developed resistance to analgesic therapy [82]. The latter can easily become a source of tension, or even conflict, between the patient and primary care team: on one hand, the patient may be convinced that staff is intentionally letting them suffer (paranoid thinking), while on the other hand, the staff believe that the patient is exhibiting an exaggerated pain behavior in order to obtain more opioid analgesics. In addition, providers are often caught between a rock and a hard place: dosages should be high enough to prevent withdrawal while avoiding an overdose.

7.1.2.4 Venous access

Obtaining venous access is often difficult owing to the chronic damage to the peripheral venous system from intravenous drug use and frequent sites of vein thrombosis. A peripherally inserted central catheter (PICC) line or an implanted port (also called a “port” or “port-a-cath”) placement could therefore be necessary for the completion of long-term antibiotic therapy. Paradoxically, these indwelling catheters provide a tempting access for continued drug abuse and are therefore a significant risk factor for recurrent infection in patients who decide to misuse them.

7.2 Social considerations

The follow-up of intravenous drug abusers after hospital discharge should include: wound care, antibiotic treatment, psychological support and drug rehabilitation. Without this follow-up, management remains incomplete and will most likely fail. Indeed, prognosis of drug addicts following hospital discharge worsens over time because they are in a more vulnerable state: the accumulated desire to abuse will be maximal. This increased risk of relapse following hospital discharge should be openly discussed with the patient as soon as possible, even as early as hospital admission.

7.3 Cardiac implantable electronic devices

7.3.1 Epidemiology and diagnosis

The reported prevalence of cardiac device-related infective endocarditis is between 0.5% and 7% [83]. This phenomenon is on the rise despite strict sterile surgical techniques and infection prevention and control practices such as systematic antibiotic prophylaxis. The increased incidence of cardiac device-related infective endocarditis is certainly linked to an aging population with multiple chronic conditions and increased metabolic and functional vulnerability [83]. Other patient-related risk factors include female gender, diabetes mellitus, heart failure, active cancer and long-term glucocorticoid therapy [84]. Procedure-related risk factors include fever at the time of device implantation, prior temporary internal pacing, implantation of more than two electrodes and hematoma formation at the pocket region [84, 85]. The risk of infection is multiplied by two after a generator replacement or a surgical reexploration [84, 85]. Admission mortality rates associated with cardiac device-related infective endocarditis have been reported to be between 3% and 8% [86]. The financial costs associated with this condition are also significant (length of hospital stay, investigations, long-term antibiotic treatment, surgery, etc.) and reflect the potential severity of the infection burden [87].

The most common causative agents are coagulase-negative staphylococci (40–60%), S. aureus (20–30%), gram-negative bacilli such as Klebsiella pneumoniae, Pseudomonas aeruginosa or Proteus mirabilis (10%), and more rarely, polymicrobial. In 30% of cases, there is no identifiable organism, which is typically seen when empiric antibiotics are started before collecting blood cultures (38). Many recent studies have highlighted the added value of fluorine-18-fluorodeoxyglucose (18F-FDG) positron-emission tomography (PET)/computed tomography (CT) for clinically suspected cardiac device-related infective endocarditis infection cases with diagnostic uncertainty or equivocal findings, to the point where its use has been endorsed by guidelines [88, 89].

7.3.2 Management

Management should be based on a multidisciplinary strategy, involving anesthesia, electrophysiology, cardiac surgery and microbiology [38]. The primum movens is to apply the general principles of management of any prosthesis infection:

1. Intravenous antibiotic treatment (pre and post extraction);

2. Complete extraction of the prosthesis (generator and leads/electrodes);

3. Microbiology testing during the extraction procedure for antibiotic stewardship. Pocket swabs, lead tips and blood samples should be cultured onto a range of media.

The step-by-step approach of the extraction procedure will be determined by the patient's baseline rhythm, the presence or absence of pacemaker dependency, the presence or absence of vegetations on native valves, and the length of time since insertion. The electrophysiologist will help to decide on other factors such as the pacemaker model, type of leads/electrodes, timing of surgery and the location of the new generator. A complete surgical extraction of the material should be performed in order to achieve eradication of the infection and reduce mortality. However, it remains a relatively high-risk intervention. Operative risks are associated with a risk of septic shock secondary to the dissemination of infection from tissue manipulation, surgical wound infection, major hemorrhage from vascular injury, iatrogenic damage to the tricuspid valve, subclavian vein tear or hemothorax [90]. When it comes to lead extraction, the "age" of the lead matters. With early lead infection, the lead will often be covered in vegetations with little adherence to the tricuspid valve; that scenario can be addressed with complete device extraction, vegetation debulking and epicardial

Figure 8.
Infected pacemaker lead with vegetation.

lead placement. On the contrary, an “old” infected lead will often be entrapped to the tricuspid valve by encapsulating fibrous tissue, which significantly complicates the extraction. If the tricuspid valve cannot be safely reconstructed and repaired due to severe adherence, tricuspid valve replacement becomes necessary.

Once the infected leads are removed (**Figure 8**), a decision should be made about replacing them. This will depend on the patient’s baseline rhythm and the adopted strategy:

1. No immediate lead reimplantation, as long as the triangle of Koch is left intact. A comprehensive postoperative evaluation should be obtained (electrocardiogram, Holter, electrophysiology study, etc.) to determine if lead reimplantation (endocardial approach or leadless) should be planned at a later stage.

2. Epicardial lead implantation.

3. Endocardial lead and pacemaker reimplantation during the same procedure. The new generator can be placed in the left abdominal wall, behind the insertion of the rectus muscle at the thoracoabdominal junction. Through experience, we found that this anatomical location offers many advantages: it is easily accessible via midline sternotomy, it prevents pacemaker exteriorization and it is generally well tolerated by patients.

Regarding the types of endocardial leads, these can either have a passive fixation or an active fixation (**Figure 9**). Active-fixation leads, also called screw-in leads, are usually preferred. They have extendable screws that can be deployed and fixed on the inside surface of the cardiac chamber. It is worth noting that he stimulation thresholds are usually higher with active-fixation leads compared to passive-fixation leads. If the threshold is too high, the lead should be unscrewed and repositioned. However, the number of attempts is not unlimited; repeated screwing/unscrewing can easily damage the thin wall of the right ventricle. One should also avoid over-torquing to minimize the risk of perforation. This is especially relevant in the context of an infection where tissues are more fragile.

Epicardial leads can also have high stimulation thresholds in the following cases: pericarditis, myocardial inflammation, myocardial edema (prolonged

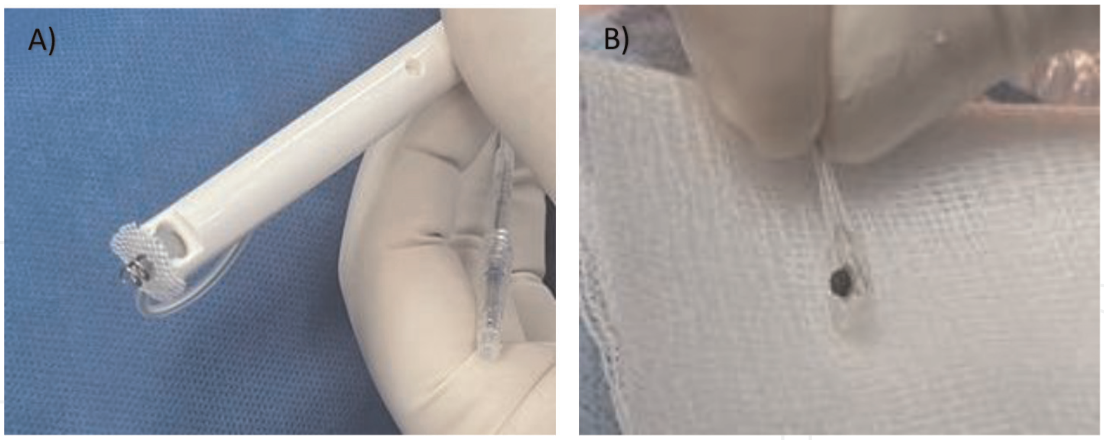

Figure 9.
Active-fixation (A) and passive-fixation (B) pacemaker leads.

cardiopulmonary bypass times or cardioplegia). Repositioning the epicardial leads is challenging in these scenarios given the risk of laceration of the right ventricle; tolerating a sub-optimal threshold is therefore acceptable. Furthermore, adjustments to the pacemaker settings can be made later from the external generator. Having an electrophysiologist or a pacemaker technologist at the time of epicardial lead implantation is therefore not necessary.

Lastly, infection prevention and control measures should be rigorously applied to minimize the risk of recurrence: skin antiseptic preparation, aseptic practices in the operating room, prophylactic antibiotics with coverage against S. aureus and Staphylococcus epidermidis. Local antibiotic usage for infection prophylaxis, in particular pocket irrigation or absorbable antibacterial envelopes, remains controversial but limited reports suggest they may have a benefit, especially in select high-risk patients [91–93].

8. Conclusion

Tricuspid valve infectious endocarditis is an uncommon condition, especially when compared to left-sided endocarditis. However, it is characterized by high morbidity and mortality. The prognosis will be determined by the control of the infection (medical and surgical), surgical timing, appropriate prophylaxis and the risk of recurrence. The therapeutic management is complex and should be provided by a multidisciplinary team, including cardiologists, cardiac surgeons, pathologists, microbiologists and imaging specialists. Patients with a substance use disorder should be referred to addiction services in order to the start the rehabilitation process while in hospital. A close medical and psychosocial follow-up should be offered after hospital discharge. A collaborative multidisciplinary approach is crucial to manage patients with infective endocarditis effectively and was shown to significantly improve their prognosis [94]. This concept, of the so-called "Endocarditis Team", is at the heart of contemporary cardiovascular care and is encountered in other areas, such as transcatheter valve implantations (e.g., the "TAVI Team"). The advent of transcatheter interventions may bring new therapeutic options that will benefit patients who are deemed unfit for surgery.

Author details

Olina Dagher[1,2], Walid Ben Ali[1,3], Nils Perrin[3,4], Nancy Poirier[1,5]
and Nicolas Dürrleman[1,3]*

1 Department of Surgery, Montreal Heart Institute, Montreal, Canada

2 Department of Cardiac Sciences, Libin Cardiovascular Institute, Calgary, Canada

3 Structural Heart Program, Montreal Heart Institute, Montreal, Canada

4 Cardiology Division, Geneva University Hospitals, Switzerland

5 Sainte Justine Hospital, Montréal, Canada

*Address all correspondence to: nicodurr@hotmail.com

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