Coronary Obstruction in Transcatheter Aortic Valve-in-Valve Implantation
Preprocedural Evaluation, Device Selection, Protection, and Treatment

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The majority of surgical heart valves being implanted during the past decade are bioprosthetic, tissue valves with limited durability.1–4 These tissue valves have limited durability.2–4 Recently, implantation of transcatheter valves inside failed surgically implanted aortic bioprosthesis (valve-in-valve [VIV]) has been reported as a less-invasive alternative to repeat surgery.5 Although procedural success is achieved in the great majority of patients, this therapy is associated with several potential risks, including ostial coronary occlusion.6,7

Coronary obstruction is a serious procedural complication, associated with a high mortality rate.5–9 Importantly, during the recent years, several preprocedural and technical aspects have been described to identify those patients at increased risk. Therefore, in such high-risk patients, a modified VIV procedure, redo surgical valve replacement, or medical treatment only may be considered (Figure 1). We herein review the mechanisms of coronary obstruction, the optimal identification of patients at risk for coronary obstruction, and further describe technical considerations for preventing and treating this life-threatening complication.

Incidence and Mechanism of Coronary Obstruction After VIV

In the setting of native aortic valve stenosis, transcatheter aortic valve replacement (TAVR) is associated with a relatively low risk of coronary ostial obstruction, consistently <1%.8,9 Most commonly, the left main artery is involved, whereas obstruction of the right coronary is infrequent.10 Similarly, acute hemodynamic collapse is common although delayed presentation may also occur.7,11 Importantly, coronary obstruction is 3- to 4-fold more common after VIV TAVR when compared with native valve TAVR.8 The VIV International Data Registry initially reported a coronary obstruction incidence of 3.5% of patients and 2.5% in a recent multicenter registry for coronary obstruction.7,8 Arguably, this phenomenon may be underestimated because coronary obstruction can be incomplete or mitigated by patent bypass grafts. Assessing the risk of coronary obstruction requires understanding the mechanisms involved. Most commonly, coronary obstruction is the consequence of a bioprosthetic leaflet coming in direct, or near-direct, contact with a coronary ostium, or with the aortic root surrounding a coronary ostium (Figure 2A and 2B). This concern is universal to all transcatheter heart valve (THV) designs and is dependent on the characteristics of the surgical bioprosthesis and the relationship of its leaflets with the coronary ostia (Table 1).

The distance between the annulus and the coronary ostia, commonly assessed in the setting of native valve TAVR, is less relevant when evaluating the risk for coronary obstruction associated with VIV implantation. The main predisposing factor in the setting of VIV is the proximity of the coronary ostia to the anticipated final position of the displaced bioprosthetic leaflets after THV implantation. After THV implantation, the surgical valve leaflets typically extend up in a somewhat tubular fashion from the circular frame to which they are attached. To some degree, the 3 commissural posts of a typical stented bioprosthesis may limit the outward displacement of the bioprosthetic leaflets. However, these valve posts are generally easily deflected outward by an oversized THV. Furthermore, cardiac surgeons typically place these posts aligned with the native valve commissures, remote from the coronary ostia, thus limiting its protective role in VIV implantation. In addition, the surgical prosthesis may have been implanted in a slightly tilted position in regard to the long axis of the aortic root, which may lead to the reduction of the distance of the prosthesis to a coronary ostium.
Because coronary obstruction is usually the result of interaction between a surgical bioprosthesis and the coronary ostium, predisposing factors for coronary obstruction may include a supra-annular bioprosthesis valve, a narrow and low-lying sinotubular junction, bulky bioprosthesis leaflets, low-lying coronaries in narrow aortic root (shallow sinuses, previous root reconstruction), and reimplanted coronaries. It should be emphasized that coronary obstruction is not caused by low position of the coronary ostia unless the sinuses are relatively shallow. In addition, coronary obstruction may be more common with stenotic (often bulky), as opposed to regurgitant bioprostheses.6 Stentless bioprosthetic valves or those that are internally stented (eg, Mitroflow, Sorin; Trifecta, St. Jude Medical) may be at a higher risk because the leaflets of these bioprostheses may extend outward in a tubular fashion after VIV implantation beyond the surgical device frame (Figure 2A and 2B).12 Yet, it should be noted that Mitroflow is one of the most common bioprosthesis in the VIVD registry and in majority of setting these VIV cases the procedure was uneventful. Nevertheless, it could be suggested that prevention of coronary
Coronary Obstruction in Aortic Valve-in-Valve

obstruction in VIV starts at the index surgical valve replacement. Device selection during surgery and technical approach inside the aortic root may have a significant clinical effect when these patients are considered for VIV years later.

Fluoroscopic Assessment
Aortic root angiography can be extremely helpful in identifying patients at risk for coronary occlusion (Table 2). Unfortunately, aortic root angiography is often not performed or
Alignment of bioprosthesis posts (1-2 vs 1-1-1)

Semiselective coronary injections

Perpendicularity to coronary ostium (if unknown an attempt in LAO-cranial

Large amount of contrast (especially in regurgitant valves, in selective cases

Contrast injection slightly above the surgical valve

Collimated high frame rate imaging of a magnified area

for Coronary Occlusion in Valve-in-Valve

Table 1. Possible Risk Factors for Coronary Obstruction After Valve-in-Valve Implantation

Anatomic factors
Low-lying coronary ostia
Narrow sinotubular junction/low sinus height
Narrow sinuses of Valsalva
Previous root repair (eg, root graft and coronary reimplantation)

Bioprosthetic valve factors
Supra-annular position
High leaflet profile
Internal stent frame (eg, Mitroflow, Trifecta)
No stent frame (homograft, stentless valves)
Bulky leaflets

Transcatheter valve factors
Extended sealing cuff
High implantation

Table 2. Optimal Fluoroscopic and Angiographic Assessment for Coronary Occlusion in Valve-in-Valve

Collimated high frame rate imaging of a magnified area

Contrast injection slightly above the surgical valve

Large amount of contrast (especially in regurgitant valves, in selective cases

Simultaneous double catheter injections

Perpendicularity to the bioprosthesis

Perpendicularity to coronary ostium (if unknown an attempt in LAO-cranial

projection for left main)

Semiselective coronary injections

Alignment of bioprosthesis posts (1-2 vs 1-1-1)

Injection above an inflated aortic balloon (before device implantation)

If the bioprosthesis is radiolucent, then a perpendicular view may be identified when angiography demonstrates 3 symmetrical cusps.

Finding a projection perpendicular to the coronary ostia is more complex. A simple maneuver that provides perpendicularity to the coronary ostia is the 1-2 technique (Figure 4). The fundamental principle is that surgeons typically implant aortic bioprostheses in a fashion that avoids positioning the commissural posts directly in front of the coronary ostia. The coronary ostium are typically mid distance between 2 posts (Figure 2A); consequently, a projection perpendicular to a coronary ostium is usually achieved when the 2 adjacent posts are perfectly superimposed (Figure 3). In a 1-2 view, the superimposed posts are located both anterior and posterior to the surgical valve leaflet that extends more laterally. However, the surgical valve leaflet will commonly not extend more lateral than the most lateral position of the ring (Figure 4C and 4G). The 1-2 maneuver maybe performed for either the left main or for the right coronary ostium. Usually 1 combination will allow for perpendicularity for the left main, whereas another combination will enable perpendicularity for the right coronary ostium. Obviously, this technique is of little value when the bioprosthetic valve posts are radiolucent (ie, Mitroflow). However, in this case, the radiopaque and saddle-shaped valve ring will often bear a constant relationship to the valve posts, facilitating easy identification of an equivalent view (Figure 5).

Coronary Angiography

Coronary angiography can suggest high risk for occlusion and can also reveal the size of the territory at risk if occlusion occurs. Ostial coronary stenosis may probably add to a risk of complete occlusion in some cases. Patency of bypass grafts, significant collateral flow, and right versus left coronary dominance may alter the clinical significance of coronary occlusion.

Poor contrast opacification of the aortic root is relatively common in patients with failed bioprostheses. Aortic regurgitation leads to a rapid clearing of contrast from the aortic root and is common, being at least moderate in 61% of failed bioprosthesis in the IVIV International Data registry. Semiselective injection of contrast in coronary ostia may provide optimal assessment of the geometric relationship between the failed surgical valve and the coronary ostia with little contrast (Figures 4 and 5). As outlined above, injection should be performed in a projection that will be both perpendicular to the surgical valve and to the coronary ostium. When faced with no or an inadequate aortic root angiogram, a review of the diagnostic selective coronary angiograms, particularly left anterior oblique cranial injection of the left coronary, will occasionally reveal adequate reflux to allow for assessment of the relationship between the bioprosthetic valve and the ostium of the left main.

Computed Tomographic Evaluation

Multidetector computed tomography (CT) is an important tool for assessing the risk of coronary occlusion in native valve
Although the optimal methodology for CT screening of the risk of coronary occlusion in the context of VIV is still in evolution, the integration of CT screening has already been shown to enable a reduction in the incidence of coronary occlusion in VIV.\textsuperscript{14} CT allows for 3-dimensional assessment of the aortic root dimensions and assessment of the relative position of the components of the surgical prosthesis as they relate to anatomic landmarks. Analogously to CT assessment before native TAVR, relevant anatomic measurements include the

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**Figure 3.** Common technical issues limiting fluoroscopic assessment of the risk for coronary obstruction after valve-in-valve.

A, Catheter location is too high. B, Limited contrast volume in a regurgitant bioprosthesis. C, The view is not perpendicular to the surgical bioprosthesis. D, The view is not perpendicular to the left main ostium (picture in circle shows the aortic root in a view perpendicular to the left main).

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**Figure 4.** Fluoroscopic evaluation of coronary obstruction risk in a mosaic (A–D) and a Perimount (E–H) bioprostheses.

A, The small eyelets in the top of the posts are aligned in 1-1-1 fashion. Even though the projection is perpendicular to the bioprosthesis, coronary obstruction risk is difficult to define (Movie I in the Data Supplement). B, Semi-selective injection in the left main ostium after aligning 2 posts together (arrow) in 1-2 fashion (Movie II in the Data Supplement). C, Reconstruction of the bioprosthesis position in the root reveals that coronary flow will be maintained after valve-in-valve (arrow). D, Semi-selective injection to the right coronary ostium after aligning 2 posts together (arrow) in 1-2 fashion show that the risk for coronary obstruction is low. E, Bioprosthesis posts are aligned in 1-1-1 fashion. Even though the projection is perpendicular to the bioprosthesis, coronary obstruction risk is difficult to define (Movie III in the Data Supplement). F, Semi-selective injection in the left main ostium after aligning 2 posts together (arrow) in 1-2 fashion (Movie IV in the Data Supplement). G, Reconstruction of the bioprosthesis position in the root reveals that coronary flow will be maintained after valve-in-valve (arrow). H, Semi-selective injection in the right coronary ostium after aligning 2 posts together (arrow) in 1-2 fashion show that the risk for coronary obstruction is low.
Coronary distances may confer, at least mechanistically, a sequel of lateral displacement of the leaflets but may still for the sometimes eccentric position of a slightly tilted surgical prosthesis.

Similarly, assessment of the height of the coronary ostia, while helpful in native valve TAVR, seems not as relevant for VIV procedures because of the variable relationship between the native annulus and the bioprosthetic leaflets. It is important to understand the specific structural details of the bioprosthesis in question; annular versus supra-annular, internally versus externally stented, stented versus nonstented (Figure 6).

Typically, the bioprosthetic leaflets extend close to, but not above the top of the bioprosthetic commissural posts. When the coronary ostia originate below the level of the tip of the posts further evaluation is needed to determine the maximal extent of potential lateral displacement of the surgical valve leaflets. Rarely, surgical valve leaflets extending above the sinotubular junction can seal off the aortic root at that level. CT evaluation should identify patients at risk, in whom the planned THV would extend above the sinotubular junction.

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Table 3. Computed-Tomographic Assessment for Coronary Occlusion With Valve-in-Valve

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Risk Level</th>
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<tr>
<td>Coronary and bypass graft parameters</td>
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<tr>
<td>Stenosis in coronary ostia</td>
<td>High risk &lt;3 mm</td>
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<tr>
<td>Patency of bypass grafts</td>
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<td>Aortic root parameters</td>
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<td>Sinus of Valsalva diameter</td>
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<td>Sinus height</td>
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<td>Bioprostheses</td>
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<tr>
<td>Leaflet thickness, significant pannus calcification, or bulkiness</td>
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<tr>
<td>Post height</td>
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<tr>
<td>Bioprosthetic–root relationship</td>
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<td>Sewing ring plane to coronary ostial height (if below coronary ostia less important)</td>
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<tr>
<td>Distance from a virtual ring defined by the posts to the sinus of Valsalva</td>
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<tr>
<td>Distance from a virtual ring defined by the posts to coronary ostia</td>
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<td>VTC distance: virtual THV to coronary ostia (ring at the level of the top of the posts and in a size of THV device to be implanted): high risk &lt;3 mm, intermediate risk 3–6 mm, low risk &gt;6 mm</td>
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THV indicates transcatheter heart valve; and VTC, virtual THV-coronary distance.

height of the coronary ostia in relation to the sewing ring, the width and height of the sinus of Valsalva, and the width of the sinotubular junction (Table 3). However, these aforementioned measurements do not account for the relative position of the surgical prosthesis component toward the coronary ostia. For VIV, the positioning and angulation of the bioprosthesis can result in significantly higher risk for coronary occlusion than would be predicted by the positioning and configuration of the sewing ring. As a result, after identifying the sewing ring plane or the basal ring, it is essential to evaluate the geometric axis of the surgical prosthesis at the level of the coronary artery ostia, which is usually divergent from the long axis of the aortic root. Furthermore, the anticipated distance of the THV to the coronary ostia can be estimated (virtual THV-coronary distance). This is optimally performed by superimposing a virtual ring simulating the diameter of the anticipated, fully expanded THV centered along the geometric center of the surgical prosthesis followed by a caliper measurement from the ring toward the coronary ostium (Figure 6). This measurement provides a marker of the capacity of the root to accommodate the THV while maintaining flow to the coronary arteries and also accounts for the frequent eccentric position of the surgical prosthesis within the aortic root. Smaller virtual THV-coronary distances may confer, at least mechanistically,
When the risk of coronary occlusion is high, general anesthesia should be considered. This may facilitate rapid institution of hemodynamic support and controlled reperfusion (angioplasty or bypass) should coronary occlusion occur. Similarly, transesophageal echocardiography could be beneficial and may enable prompt diagnosis (eg, new wall motion abnormality) of this complication. There are other procedural considerations that may influence complication risk, including the size, position, and type of implanted THV.

Deliberate selection of a smaller diameter THV or underfilling and thus underexpansion of a balloon expandable THV will result in less lateral displacement of surgical valve posts and leaflets. The smallest available THV device currently available is 20 mm Sapien XT, which will result in the least amount of lateral displacement on surgical valve leaflets and may reduce coronary obstruction risk when implanted in small failed surgical valves. Similarly, a THV positioned low within the bioprosthesis may cause less outward displacement of the surgical valve posts and leaflets than a THV implanted high although postprocedural gradients may be higher in these cases.

The type of THV may also be of relevance. Having a THV device that could be easily retrieved after device implantation is advantageous (eg, Evolut-R, Portico, Lotus, etc). In cases at risk for coronary obstruction, deployment of these THV devices could be followed by clinical and angiographic assessment for coronary flow status. In cases where coronary flow is impaired, the THV device could be removed from the aortic root with relief of the coronary obstruction (Figure 7C and 7D). It should be noted that some devices are retrievable even after

**Figure 6.** Contrast-enhanced ECG-gated computed tomography for the assessment of coronary occlusion risk. A–C, Failed Mitroflow 23 bioprosthesis at high risk for coronary occlusion. Sinuses are effaced and the coronary to ring distance is short. Short axis at the level of the top of the posts (arrows, D). A virtual 23-mm ring at the level of the coronaries revealing virtual THV-coronary (VTC) distance of only 1.98 mm (C; <3 mm considered high risk). D–F, Failed Mitroflow 23 bioprosthesis at high risk for coronary occlusion. Fluoroscopic image suggested high risk for coronary occlusion (D). Short axis at the level of the top of the posts (arrows, E) and virtual 23-mm ring revealed VTC distance of 9.33 mm (F; >6 mm considered low risk). Valve-in-valve was performed without coronary obstruction. G–I, Failed Peri-mont 25 bioprosthesis at high risk for coronary occlusion. Fluoroscopic image suggested low risk for coronary occlusion (G). Short axis at the level of the top of the posts and virtual 26-mm ring revealed VTC distance of only 2.54 mm (I; <3 mm considered high risk). Valve-in-valve was performed with coronary obstruction treated by stent implantation.
full implantation (ie, Lotus), whereas others can be removed only before full implantation (ie, Portico). In rare cases, coronary obstruction may occur in the last stage of THV device implantation and, therefore, the ability to remove the THV device after full implantation seems beneficial. THV device removal after full deployment maybe performed also in nonretrievable THV devices, using an inflated aortic balloon inside the THV device or a snaring device. In these cases, the balloon is inflated without rapid pacing, and mechanical pulling of the device is performed (Figure 7E and 7F). The required balloon should be of a similar size to the THV size, or larger.

Other THV devices have unique clipping mechanism (ie, Jena, Engager) that may prevent coronary obstruction by grasping surgical valve leaflets and attaching them firmly to the THV device (Figure 7G and 7H). However, clipping surgical valve leaflets with device fillers could be associated with elevated postprocedural gradients when performed inside small surgical valves. The benefit of using devices with clipping mechanism in high-risk cases for coronary occlusion should be studied further.

Balloon Valvuloplasty
Although balloon inflation is typically safe in the setting of native TAVR, there is a significant risk of tearing degenerated bioprosthetic leaflets. Nevertheless, balloon dilatation inside a failed surgical valve is an extremely useful technique for evaluating the geometric relationship between the surgical valve and the coronary ostia. Balloon inflation results in temporary displacement of the bioprosthetic leaflets in a fashion similar to that occurs with the subsequent THV implantation. Ideally, the diameter of the inflated balloon should be similar to that of the intended THV, and contrast injection should be performed only after full inflation of the balloon (Figure 7A and 7B). Simultaneous aortography allows visualization of the radiolucent bioprosthetic leaflet between the contrast filled balloon and the contrast filled aortic root. Ideally, this is done in a projection perpendicular to the bioprosthetic basal ring and revealing the left coronary ostium (left anterior oblique cranial or 1:2 projection), as previously described.

The used balloon should be compliant (ie, PTX or Tyshak) to not deflect the bioprosthesis leaflets at high pressure. Aggressive balloon dilatation of a degenerated surgical valve should only be performed when a THV implantation can be accomplished rapidly should hemodynamic compromise occur. Balloon dilatation maneuver before VIV can assist in recognizing cases in which coronary stent protection can be used. Alternatively, in cases where the risk of coronary obstruction seems to be high, substitute treatment options may be considered. Redo surgery, or medical treatment alone, is alternative options if the patient remains hemodynamically stable post valvuloplasty and coronary risk is prohibitive.

Active Protection
If no preventive measures are taken, coronary obstruction by a displaced surgical valve leaflet after VIV is a therapeutic challenge. Patients with coronary obstruction are commonly unstable and delivery of a wire and subsequently a stent toward the coronary vasculature is challenging, especially if in addition to surgical valve leaflets there are overlying THV device struts. A more controlled measure, in cases at high-risk for coronary obstruction, is to place a wire and a stent in the coronary vasculature before THV implantation.

There are specific technical considerations with regard to coronary intervention equipment used in these cases. The optimal guide catheter should approach the coronary ostia from above (ie, Judkins left versus Extra back up) to not interfere with THV device implantation. A short tip guiding catheter can
be pulled more easily out of the left main ostium during THV implantation. A large caliber guiding catheter should be considered in these cases (≥7Fr). In many cases, the guide catheter could be used instead of the pigtail that is commonly used during THV device implantation. Guiding catheter jailing by long THV devices (ie, CoreValve, Portico) could be performed because the THV radial strength above the annulus is typically not high. Guide wires used in these cases should enable optimal support for stent implantation in face of mechanical obstruction by a displaced leaflet. Obstruction of the coronary ostium by a bioprosthetic leaflet with an overlying THV may result in a significant difficulty in delivering a stent, especially when a patient is hemodynamically unstable. Positioning the stent exactly in the coronary ostium during THV deployment has been performed. However many operators prefer to place an undeployed stent in the distal coronary, ready to be pulled back and implanted in the ostium if needed.20

**Coronary Intervention**

THV implantation in high-risk cases for coronary obstruction may be optimally performed in a projection perpendicular to both the surgical valve and the coronary ostium at risk (left anterior oblique cranial in high-risk left main obstruction cases or 1-2 bioprosthesis post alignment), to assess coronary patency after THV implantation rapidly. In the exact time of THV implantation, the operator should look for a wire sign: any movement of the coronary wire near the coronary ostium during implantation could be a warning sign for having coronary occlusion (Figure 8A and 8B; Movie VII in the Data Supplement). After THV implantation, contrast injection in several projections and echo evaluation of new wall motion abnormality (if transesophageal echocardiography is used) can reveal if coronary obstruction has occurred. It should be emphasized that coronary obstruction could be partial, and stent implantation in these cases may be considered as well. The operator should obtain several angiographic pictures from different projections while the guide is not directly engaged to the coronary ostium, to evaluate for obstruction and must not rush with removal of coronary wire and stent. We also recommend repeating the angiography after undeployed stent removal, before removing the wire, because hypothetically the stent delivery shaft can maintain coronary patency. When an undeployed stent is parked in the coronary vascular bed, implantation in the coronary ostium is usually straightforward and can be performed rapidly by pulling the stent back to the correct location. In cases where obstruction is above ostium location (ie, sinotubular junction), a long stent is required. However, using a long stent may make it difficult to cannulate that coronary in the future. Therefore, long stents, extending above the sinotubular junction, should be implanted in selected cases only. The rule is that meticulous assessment of stent position, before its implantation, should be undertaken to verify the stenosis at and proximal to the coronary ostium is covered well. THV device implantation in a projection perpendicular to the coronary ostium may facilitate rapid stent deployment if a complication occurs. High-pressure implantation should be performed, followed by aggressive postdilation with a non-compliant balloon, including flaring of the stent in the ostium. Contrast injections from several projections should ensure good flow to the coronary vasculature. Because this coronary intervention is for mechanical, nonatherosclerotic, complication, the risk for stent thrombosis is probably higher and effective antiplatelet therapy should be routine. In addition, double antiplatelet therapy duration after this treatment should be prolonged.

The use of supportive measures, such as intra-aortic balloon pump, extracorporeal membrane oxygenator, and emergent surgery, is less defined in cases with coronary occlusion. However,
it should be stressed that the focus should be on restoring flow toward the occluded vessel. Intra-aortic balloon pump must be used only if no significant leakage of the THV device is noted.

Conclusions
Aortic VIV is associated with several potential risks, including ostial coronary occlusion. This is a serious procedural complication, associated with a high mortality rate. This concern is universal to all THV designs. The main predisposing factor, in the setting of VIV, is the proximity of the coronary ostia to the anticipated final position of the displaced bioprosthetic leaflets after THV implantation. Metabolic fluoroscopic and cardiac CT assessment may identify most cases at risk. There are numerous strategies that should be used in high-risk cases after excluding the option for redo cardiac surgery. These may include using a retrievable THV device, a device with clipping mechanism or simply undersizing/balloon-underfilling of the THV device. Coronary protection, and intervention, when needed, should be undertaken in high-risk cases to maintain coronary flow and improve clinical outcome. In general, we speculate that by adhering to careful assessment and treatment strategies, as detailed, the risk of coronary obstruction will decrease. New and creative bioprosthetic valve designs and attention, during the index surgical valve replacement, to the potential risk of coronary obstruction with VIV could further prevent this life-threatening complication.

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References

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