A hybrid strategy is a combination of catheter-based therapy and traditional surgical intervention. This concept of combining the tools available only in the catheterization laboratory with the tools available only to the surgeon in order to minimize surgical morbidity has evolved since its implementation in the 1990s. Over the past decade, with advancement in stent technology and refinement of minimally invasive surgical approaches, a hybrid strategy has become an attractive alternative to standard surgical or catheter-based techniques. The indications, patient selection, and standardization of these procedures are still under way. Currently, there are no randomized clinical trials on hybrid procedures, and the clinical practice is based on single institutional experiences. The National Heart, Lung, and Blood Institute has just launched the first observational trial on hybrid coronary intervention to define the population eligible for hybrid coronary revascularization (HCR). Until more data become available, the hybrid strategy depends on close collaboration between the surgeon and the cardiologist at single institutions and should be tailored to individual patient needs.

HCR

Both coronary artery bypass graft (CABG) surgery and conventional percutaneous coronary intervention (PCI) offer certain advantages in the treatment of patients with multivessel coronary artery disease (CAD). Although CABG provides superior clinical outcomes compared to PCI in certain high-risk patients, including most with diabetes, the majority of patients with left main CAD, and many patients with reduced cardiac function, it is likely that the major aspect of CABG that confers these benefits is the left internal mammary artery (LIMA) graft to the left anterior descending artery (LAD). The LIMA-to-LAD graft has excellent patency at 10- to 20-year angiographic follow-up, setting the gold standard with which other revascularization strategies should be compared. It is important to emphasize that although all patients with significant multivessel coronary disease benefit from the LIMA-to-LAD graft, the incremental benefit of concomitant saphenous vein grafts (SVGs) placed to other myocardial territories is less clear. This is also reflected in the lack of survival benefit in reoperative CABG surgery when the LIMA is already patent. This is probably due to early SVG failure, which ranges from 6.2% to 30% at 12 months. In addition, at 10 to 15 years, only 50% to 60% of the SVGs have been reported to be patent. Conversely, the early restenosis and thrombosis rate of the drug-eluting stents (DES) in non-LAD vessels is lower than that reported for SVG failure.

Sole multivessel PCI with DES offers a much less-invasive revascularization modality with faster recovery times and lower stroke rates than sole CABG. However, PCI does carry higher target-vessel revascularization rates than CABG, and importantly, it is particularly high with PCI using DES in the LAD. Thus, for CABG patients, the benefits of the LIMA-to-LAD graft are potentially mitigated by the use of SVG for non-LAD territories. Similarly, the benefits of sole multivessel PCI are undermined by stenting the LAD instead of grafting it with the LIMA. Coupling the positive features of CABG (the LIMA-to-LAD graft) with the positive features of PCI (DES to non-LAD territories) is the fundamental rationale of HCR.

Over the past 10 years, several small retrospective series of hybrid minimally invasive direct CABG (MIDCAB)/PCI have reported low morbidity and mortality. Despite these initial encouraging results, HCR remains limited to select or high-risk patients largely because of concerns about the timing of each procedure, logistical limitations, and the increased need of repeated revascularization in the era of bare-metal stents. To date, there are no randomized trials on HCR, which is performed in only a few centers. HCR, however, may represent a potential alternative revascularization strategy to standard CABG surgery as stent technology continues to improve.

Clinical Outcomes

Since 1996, approximately 814 patients have undergone HCR. These series, although representing retrospective single-center studies, have shown that HCR is technically feasible and safe, with low mortality rates (0% to 2%) and morbidity. Few series have compared the outcomes of HCR to standard CABG surgery. These series have reported similar clinical outcomes for both procedures at 30 days and 6 months.
Data from these hybrid series are heterogeneous; some series reported follow-up data anywhere between 1 to 44 months with various end point assessments. From these hybrid series, the event-free survival at 6 to 12 months is between 83% to 92%.14–21 In one of the largest of these hybrid series (117 patients), the incidence of major adverse cardiac events at 12 months was 15%.21 The data from these hybrid series need to be interpreted with caution because most of the series have used bare-metal stents instead of DES. Moreover, in most of the earlier series of MIDCAB, percutaneous transluminal coronary angioplasty of the coronary vessels without stenting was the strategy adopted. In these hybrid series, the stent restenosis at 6 months is 2.3% to 23%, with an average across the literature of 11%.14–21

Table 1 summarizes the results of recently published series on HCR that used only DES. The reported stent restenosis at average follow-up of 6 to 33 months is only 0% to 6.6%, and incidence of major adverse cardiac events is between 0% and 4.2%.15–18

Table 1. Results of Hybrid Coronary Revascularization for Series Using Only DES for PCI

<table>
<thead>
<tr>
<th>Author, Publication Year</th>
<th>No. Patients</th>
<th>30-Day Mortality</th>
<th>In-Hospital Morbidity, %</th>
<th>LIMA Patency Rate Immediate, %</th>
<th>Mean Follow-Up, mo</th>
<th>Stent Restenosis, %</th>
<th>Event-Free Survival, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIDCAB and PCI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gilard et al, 200715</td>
<td>70</td>
<td>1.4</td>
<td>4.2</td>
<td>na</td>
<td>33</td>
<td>2.3</td>
<td>97</td>
</tr>
<tr>
<td>Kon et al, 200816</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>12</td>
<td>3</td>
<td>93</td>
</tr>
<tr>
<td>TECAB and PCI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vassiliades et al, 200617</td>
<td>47</td>
<td>0</td>
<td>0</td>
<td>99</td>
<td>7</td>
<td>6.6</td>
<td>90</td>
</tr>
<tr>
<td>Bonatti et al, 200718</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>6</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

TECAB indicates totally endoscopic coronary artery bypass.

Techniques and Patient Selection

MIDCAB refers to a procedure in which the LIMA mobilization is undertaken in an open fashion through a limited anterior or left thoracotomy incision. The LIMA-to-LAD anastomosis is then performed by hand on the beating heart, using specially designed stabilizers and retractors.

Thoracoscopic Endoscopic Atraumatic Coronary Artery Bypass

An endoscopic atraumatic coronary artery bypass is a procedure in which the LIMA is mobilized with the use of thoracoscopy through a port-access approach. The anastomosis is then performed on the beating heart in a manner similar to the MIDCAB procedure.

Robotic Assisted CABG

Robotic assisted CABG refers to robotic assistance with the LIMA takedown followed by a hand-sewn anastomosis performed on the beating heart.

Beating Heart Totally Endoscopic CABG

The LIMA takedown and the anastomosis is performed endoscopically with the robot. The anastomosis can be performed on the beating heart or on cardiopulmonary bypass on an arrested heart.

Sternotomy Approach

The LIMA is mobilized and the anastomosis performed using a sternotomy incision. Although the minimally invasive surgical component is not present in this approach, this technique can still be used successfully for HCR depending on surgeon preference or whether there is concern that a minimally invasive approach could compromise anatomic exposure.

Adult patients with multivessel CAD and a clinical indication for revascularization who have at least 2-vessel disease (LAD and 1 non-LAD target) are potentially eligible for HCR. Hybrid therapy is ideal in scenarios where technical or anatomic limitations to surgery or PCI alone may be present and where minimizing the need for surgical intervention is preferred.20 Such scenarios include situations where there is a lack of suitable conduits, poor conduit quality, a porcelain aorta, a coronary vessel not amenable to be bypassed but amenable to PCI, and a PCI that is not indicated because of an excessively tortuous vessel or chronic total occlusion. Additionally, high-risk patients who require minimizing the magnitude of the surgery could benefit from hybrid therapy. Such patients include those with significant preexisting comorbidity, a need for a redo sternotomy, recent history of myocardial infarction, or severe atherosclerotic aortic disease.

Two-Staged Versus One-Staged Procedure

A 2-staged procedure is defined as a PCI and CABG performed in 2 different operative suites, with the 2 procedures separated by hours or days but typically during the same hospital stay. One-staged HCR is defined as CABG and PCI performed in a hybrid suite in 1 operative setting, staged by minutes. Because most centers lack a hybrid operating room, 2-staged procedures are most commonly performed. PCI can be performed first followed by CABG surgery. This allows aggressive multivessel stenting but requires performing the surgery under the effect of clopidogrel. If CABG is performed first followed by PCI, this allows PCI under the protection of the LIMA-to-LAD graft and the ability to verify the patency of the LIMA-to-LAD graft while avoiding the risk of bleeding due to the use of clopidogrel. For these reasons, the surgery-first strategy for staged HCR seems preferable.

Antiplatelet Strategies

The best antiplatelet regimen for patients undergoing HCR still remains a controversial issue, and no standardized
guidelines are currently available. Although the objective is to ensure stent patency, this has to be carefully balanced with minimizing the risk of bleeding. Different authors have reported various different antiplatelet strategies. Kon et al\textsuperscript{16} described their results in 15 patients who underwent surgery using MIDCAB and immediate PCI afterward. In their series, heparin was not reversed at the end of the surgery, and the patients were loaded with a 300-mg dose of clopidogrel on arrival to the intensive care unit, which was then followed by 75 mg daily. No reexplanation for bleeding or acute stent thrombosis occurred in their series. At 1-year follow-up, there was 1 (6.6\%) event of stent failure. Bonatti et al\textsuperscript{18} reported on their results in 5 patients who underwent totally endoscopic CAGB followed by immediate PCI. Their strategy involved administering 300 mg of clopidogrel and 100 mg aspirin 12 hours preoperatively. Postoperatively, 75 mg of clopidogrel was taken daily for at least 6 months. There were no bleeding complications and no stent restenosis or thrombosis at 6-month follow-up. Gilard et al\textsuperscript{15} published their findings in 70 patients who underwent PCI followed by MIDCAB within 16 hours of PCI. In this series, 250 mg of ticlopidine was given at the completion of PCI, and an additional 500-mg dose was given at the end of the surgery followed by 75 mg of clopidogrel daily for 1 month. Ticlopidine has delayed onset of antiplatelet action; thus, it may potentially minimize the risk of perioperative bleeding. Although there was no reexplanation for bleeding reported, 1 patient had a bleeding episode after starting clopidogrel and was treated with platelet transfusion. This led to discontinuation of clopidogrel in this patient, which resulted in subacute stent thrombosis requiring a repeat PCI on day 7. Another patient developed subacute stent thrombosis on day 6 after PCI because of failure to take ticlopidine and required a repeat PCI. At an average follow-up of 33 months, there were no adverse cardiac events reported. In our series\textsuperscript{20} of 112 patients who underwent CAGB with concomitant PCI, a 300-mg loading dose of clopidogrel was administered immediately before surgery in the holding area for electively planned hybrid procedures. For unplanned hybrid procedures, those procedures determined intraoperatively, clopidogrel was given through a nasogastric tube at the time the decision was made to perform PCI. We used a 300-mg loading dose of clopidogrel rather than the standard 600-mg dose used for standard PCI to balance the risks of bleeding with intrastent thrombosis. Only 3 (3\%) patients required reoperation for bleeding, and only 1 (1\%) patient developed intrastent thrombosis during the hospital stay.

Hence, although a standardized regimen for antiplatelet strategies has yet to be implemented, different institutions have used various protocols. Further follow-up studies and data will be helpful to determine what standards of care can be established.

**Limitations of HCR**

The limitations that apply to PCI as the sole treatment modality apply to HCR. Although DES have shown excellent results in clinical trials, their effectiveness in clinical practice with more complex patients and complex lesions (high Syntax score, totally occluded coronary vessels, bifurcated lesions, small vessels, long lesions requiring multiple stents, ostial stenosis, calcified vessels) remains to be seen. Patients with diabetes, who comprise $\approx$30\% of the surgical population, have higher restenosis rates with DES.\textsuperscript{22} Late stent restenosis and thrombosis is another concern. Incomplete revascularization is also higher in PCI than in CAGB surgery.\textsuperscript{4} In the New York state registry, in which 11 294 patients with multivessel disease were treated with DES, the rate of incomplete revascularization was 69\% with increased risk of death.\textsuperscript{23} Furthermore, it is important to emphasize that the clinical consequences are much more serious for patients who experience stent thrombosis than for patients whose graft occluded.

Minimally invasive surgical approaches are not without procedure-related morbidity. Because of the limited access, the patency rates of LIMA-to-LAD grafts may be inferior to those performed through a midline sternotomy with increased rate of graft occlusion and late adverse events. Hence, it is our opinion that all grafts performed through a minimally invasive approach should be imaged at the time of or immediately after the surgery to confirm graft patency at the end of the procedure.\textsuperscript{20} Other procedure-specific complications are the increased rate of wound complications, increased late pain and occurrence of lung herniation because of longer operative times, and excessive rib and skin retraction.

**Hybrid Valve Surgery/PCI**

Hybrid valve surgery/PCI typically involves minimally invasive valve surgery combined with PCI to treat concomitant CAD.\textsuperscript{14,24} Traditional treatment involves combined valve and CAGB surgery using a median sternotomy. However, this combined surgical approach may prove to have a prohibitively high risk in some patients. For instance, in patients with valve disease and either acute coronary syndrome, poor conduit quality, or poor target-vessel quality, as well as low ejection fraction, and in patients undergoing reoperative cardiac surgery, the risks of such a combined surgical procedure may outweigh the benefits.\textsuperscript{14,24} A hybrid approach using a minimally invasive incision to perform valve surgery combined with PCI can prove to have a distinct advantage in high-risk patients with complex CAD and valve disease because it simplifies the operation into 2 lower-risk procedures. Patients requiring valve re-replacement or native valve surgery after prior CAGB surgery also can benefit from this approach because it can prevent the requirement for and dangers associated with a redo sternotomy, dissection of pericardial adhesions, and injury to patent bypass grafts.\textsuperscript{24,25} Furthermore, mitral valve exposure after previous aortic valve surgery can be challenging using the standard approach, whereas minimally invasive right thoracotomy offers superior exposure.

Patients with combined valve and CAD with acute coronary syndrome are particularly suitable for this approach. In this approach, PCI is performed to the “culprit lesion” followed by valve surgery.\textsuperscript{25} In a series of 26 high-risk patients with CAD and cardiac valve disease,\textsuperscript{25} the operative mortality was 3.8\% (1 of 26), which was dramatically lower than the Society of Thoracic Surgeons predicted mortality of 22\%. In another series of 18 high-risk patients with combined
coronary and aortic valve disease. PCI performed first followed by minimally invasive aortic valve surgery resulted in low (0.5%) operative mortality. We have adopted this technique and now have updated data on 39 high-risk patients who underwent PCI and minimally invasive mitral valve surgery through a small (5-cm) anterolateral right thoracotomy between March 2006 and June 2009 (unpublished data). Of the 39 patients, 5 (13%) presented with acute coronary syndrome, 19 (49%) were in congestive heart failure, 16 (41%) underwent urgent or emergent surgery, and 16 (41%) had prior heart surgery. Thirty (77%) patients underwent a 1-staged procedure with initial PCI followed by valve surgery in the hybrid operating room. Nine (23%) patients underwent a 2-staged procedure. Patients undergoing a 2-staged procedure underwent PCI 1 to 4 days before mitral valve surgery. Operative mortality was only 2.6% (1 of 39), which was substantially lower than the Society of Thoracic Surgeons predicted mortality of 14% for combined CABG and valve surgery.

The results of hybrid valve surgery/PCI are from isolated single-center experiences. The results of published series are summarized in Table 2. In reviewing the data, it is important to note that several of the patients who underwent this technique were high-risk elderly patients who had already undergone prior cardiac surgery. Hence, this approach is beneficial in such selected patients. Minimally invasive valve surgery poses new challenges to the surgeon because of the need to work through smaller incisions with endoscopic or longer instruments and because the institution of cardio-pulmonary bypass requires specially designated cannulae and techniques. Moreover, there is concern regarding the risk of bleeding if the surgery is performed after the PCI and the possibility of stent thrombosis with protamine reversal.

### Hybrid Atrial Fibrillation Procedures

The treatment options for atrial fibrillation (AF) have been expanding as our understanding of the mechanisms causing AF in different patient cohorts increases and the knowledge of pharmacological and nonpharmacologic therapies continues to grow. Because medical therapy is not always adequate for the treatment of AF, there has been an increasing interest in surgical and interventional treatment options. The development of minimally invasive surgical techniques has refined the current surgical options that exist for AF. Cardiologists also are developing more-complex ablation techniques that are able to generate therapeutic linear lesions similar to that of surgical intervention.

Although surgical ablation approaches have the advantages of being quicker than catheter-based interventions and provide access to the entire atrial epicardium of a beating heart, certain lesions, such as a lesion to the mitral annulus, are more easily created by a percutaneous approach. A hybrid technique in which minimally invasive endoscopic surgical therapy is combined with catheter-based therapy to produce epicardial and endocardial therapeutic lesions forms the basis of the concept of the “hybrid maze” procedure. Many patients with AF refractory to medical therapy are candidates for the procedure. The surgical portion of the procedure involves using bilateral thoracoscopic techniques and manipulation of the left atrial appendage off pump. Once the radiofrequency ablation on the epicardium and the left atrial appendage ligation are performed through this surgical incision, the endocardial ablation is performed by the interventional cardiologist or electrophysiologist using percutaneous vascular access. The hypothesis is that in using such a hybrid approach, the combination of both therapeutic techniques will result in an improved and more-permanent freedom from recurrent AF. Another advantage with this technique is that the electrophysiologist will be able to perform endocardial mapping for lesion effectiveness, which could potentially improve the overall outcomes. Possible complications include longer operating room times, anesthesia risks, and trauma to adjacent organs that may require further intervention. Because this procedure is still relatively new, long-term follow-up studies will still need to be performed.

### Hybrid Therapy for Combined Coronary Artery and Carotid Artery Disease

The best treatment option for patients with concomitant coronary artery and carotid artery disease is not clearly delineated. Combined as well as staged carotid endarterectomy (CEA) and CABG have been reported to have higher rates of morbidity and mortality. In an attempt to minimize the perioperative morbidity and mortality, hybrid carotid artery stenting (CAS) and CABG has emerged as an alternative form of therapy for such high-risk patients. Versaci et al reported on their experience with this technique in 101 high-risk patients with severe coronary
artery and carotid artery disease who underwent CAS followed by CABG. Twenty-six (26%) patients presented with unstable angina, 16 (16%) had previous strokes, 55 (55%) had significant bilateral carotid artery stenosis, and 79 (78%) had 3-vessel coronary artery disease. Procedural success was achieved in 98 (98%) patients. The 30-day mortality rate was 2% (2 of 101). The 30-day rates of myocardial infarction and nonfatal stroke were 0% and 2% (2 of 101), respectively.

Another study was recently conducted by Timaran et al29 to assess the nationwide outcomes of patients who underwent CAS followed by CABG versus combined CEA and CABG. A total of 27,084 patients discharged after concurrent carotid artery and coronary artery revascularization procedures between 2000 and 2004 were identified using the Nationwide Inpatient Sample. Only 3.3% of these patients underwent CAS followed by CABG, whereas the remaining 96.7% had undergone combined CEA and CABG. Patients who underwent CAS followed by CABG had a lower incidence of postoperative stroke (2.4% versus 3.9%; P<0.001) and combined stroke and death (6.9% versus 8.6%; P<0.001) than the combined CEA and CABG group. After risk stratification, the combined CEA and CABG group had a 62% increased risk of postoperative stroke compared with patients undergoing CAS followed by CABG. Thus, from the previously mentioned reports, patients who undergo CAS followed by CABG have significantly reduced in-hospital stroke rates compared with patients undergoing combined CEA and CABG, despite similar in-hospital mortality. Therefore, CAS may be a safer method of cerebral revascularization for some patients who require CABG.

Further studies are needed to adequately assess the long-term benefits of CAS followed by CABG compared to traditional combined CEA and CABG. However, the initial clinical outcomes appear encouraging.

Hybrid Therapy for Congenital Heart Disease

Although surgical therapy continues to play a major role in the treatment of congenital heart disease, interventional treatment modalities also have become increasingly promising. Percutaneous interventional techniques can be difficult to perform as a result of small patient size and difficulties with vascular access and the presence of congenital anatomic variations, such as transposition of the great vessels, double-outlet right ventricle, or tortuous pulmonary artery anatomy associated with the tetralogy of Fallot. Such constraints may limit or complicate the performance of percutaneous interventional techniques. However, surgical intervention also can have its limits in scenarios such as closure of multiple apical muscular ventricular septal defects, management of a previously deployed stentotic stent, or maintenance of adequate long-term relief of peripheral pulmonic stenosis. Thus, an integrated hybrid approach where surgical and interventional techniques are combined could offer the benefits of both modes of therapy and help to overcome such limitations.

The more common hybrid congenital procedures that have been performed include hybrid ventricular septal defect closure or atrial septal defect closure, hybrid therapy for pulmonary artery stenoses, and hybrid palliation for hypoplastic left heart syndrome and other single-ventricle anomalies.

In one of the largest congenital hybrid series, Bacha et al31 reported on 24 pediatric patients (mean age, 4 months; range, 2 weeks to 4 years) who underwent hybrid congenital therapy. In this series, 16 patients underwent treatment of ventricular septal defects, and 8 underwent treatment of pulmonary artery stenoses. Nine of the patients with ventricular septal defects underwent sequential Amplatz device closure in the catheterization laboratory followed by surgical completion. The remaining patients underwent 1-staged intraoperative off-pump device closure through a periventricular approach, with 5 of these patients also undergoing subsequent repair of concomitant heart lesions. Cardioplegic arrest was either avoided or shortened in all these patients treated for muscular ventricular septal defects. The remaining 8 patients presented with branch pulmonary artery stenoses and underwent intraoperative pulmonary artery stenting or stent balloon dilation as well as a right ventricular outflow procedure or Fontan completion. Observed complications included tricuspid regurgitation in 2 patients, embolization of the device into the aorta in 1 patient, a residual ventricular septal defect in 1 patient, and pulmonary artery rupture from stent overinflation in 1 patient. All patients survived their hospital stays.

The benefits of such hybrid procedures may include reduced operative and cardiopulmonary bypass times. Pitfalls include a steep learning curve, which may be especially challenging in neonatal patients. Although the hybrid approach to congenital cardiac surgery has been shown to be a feasible procedure, further advances and long-term follow-up will determine the full extent of its benefits.

Hybrid Aortic Debranching Procedures Combined With Endovascular Grafting for Complex Aortic Arch Pathology

Endovascular repair of aortic aneurysms using stent grafts has become a practical alternative to open repair, with superior survival. This approach has been used increasingly for thoracic aneurysms and has been used in combination with operative repair for aortic arch and distal ascending aorta pathologies. Traditional operative repair of aortic arch aneurysms still entails a relatively invasive procedure, requiring both cardiopulmonary bypass and deep hypothermic circulatory arrest, and may be associated with high postoperative morbidity and mortality. Hence, this less-invasive approach is a feasible alternative. However, proper endovascular stent-graft deployment and stabilization both require a satisfactory proximal landing zone length. To obtain this, a hybrid approach combining surgical debranching and endovascular techniques has been developed. This hybrid approach involves debranching of the head vessels by first placing an aorto-innominate graft and then reimplanting the head vessels to this graft to provide surgical revascularization. After the surgical revascularization is performed, stent-graft implantation into the transverse aortic arch is completed. Morbidity and mortality rates after such procedures are reported to be much lower than after traditional open arch surgery. Some investigators
have reported higher rates of endovascular leaks with such techniques,\textsuperscript{14,34–36} although there has been good (90\%) resolution at 6-month follow-up.

Endovascular repair combined with an operative approach also has been used as an alternative to conventional open repair of thoracoabdominal aneurysms. In this case, creation of an adequate distal landing zone for stent-graft implantation requires bypass of mesenteric and renal arteries. The bypasses can originate from the supraceliac aorta, infrarenal aorta, common iliac artery, or external iliac artery. Such debranching techniques have reported success rates of 90\%, with mortality rates between 3\% and 24\%.\textsuperscript{14,34–36} Long-term patency rates of visceral and renal grafts will need to be assessed with long-term studies. Until the long-term safety and durability of such techniques are determined, hybrid thoracoabdominal aneurysm repair should be reserved only for selected patients at high risk for traditional surgical intervention.

**Transcatheter Valve Procedures**

Transcatheter valve therapy is a treatment modality that has accrued popularity since its initial introduction by Cribier et al\textsuperscript{37} in 2002. Transcatheter aortic valve replacement (AVR) can prove to be beneficial in select scenarios where standard AVR has prohibitively high risk. For instance, in patients with multiple medical comorbidities, extensive aortic calcification, prior sternotomies, depressed left ventricular function, advanced pulmonary disease, and advanced age, a surgical AVR can have a mortality rate as high as 50\%.\textsuperscript{38} In such patients, transcatheter AVR may prove to be a viable alternative. The 2 most common currently used percutaneous aortic valves are the Edwards Sapien valve (Edwards Lifesciences; Irvine, Calif) and the CoreValve ReValving System (Medtronic; Minneapolis, Minn).\textsuperscript{14} The Edwards Sapien valve\textsuperscript{14} is a trileaflet bovine prosthesis placed on a stainless steel balloon-expandable stent, which is deployed in the subcoronary position using a 23-French (F) or 26-F sheath. The stent has a polyethylene terephthalate fabric skirt designed to decrease the incidence of perivalvular leaks. The CoreValve ReValving System\textsuperscript{14} is a trileaflet porcine pericardial prosthesis mounted in a self-expanding nitinol frame. It is deployed across the left ventricular outflow tract using an 18-F or 22-F sheath and extends into the aortic root. The frame has 3 distinct functional levels with different radial and hoop strengths.

**Techniques for Transcatheter Valve Procedures on a Beating Heart**

**Antegrade Approach**

In this approach, access and valve delivery are performed through a femoral vein with advancement of the catheter through the interatrial septum into the left atrium and then to the aorta under fluoroscopy. Transversing the interatrial septum requires transseptal puncture. This approach was used in most early transcatheter procedures. It can be technically demanding and prone to complications due to the requirement for transseptal puncture. These challenges have led to a diffusion of this approach.

**Retrograde Approach**

For the retrograde approach, access is obtained through a femoral artery, and the device is advanced toward the aortic annulus using fluoroscopy. A catheter with a manually activated deflectable tip is used for valve delivery to avoid trauma to the aortic arch. This approach is difficult to perform if the aorta is calcified or bulky arteromas exist.

**Transapical Approach**

This newer technique uses a small left thoracotomy incision and entails direct puncture and sheath insertion into the left ventricle and is performed in the hybrid operating room. A guidewire is used to cross the aortic valve, and the transcatheter valve is deployed. Fast cardiac pacing is used while the valve is delivered. This technique requires close teamwork between the surgeon and interventionalist.

**Potential Risks and Clinical Outcomes**

As with any new technology, transcatheter procedures require a steep learning curve and close teamwork among all the teams involved and have their respective risks. Transcatheter AVR procedures may carry the risk of developing paravalvular regurgitation and potential aortic insufficiency after valve replacement.\textsuperscript{14,37,38} Hence, it is important to carefully measure the annulus and select a valve that is 10% to 20% larger in order to minimize perivalvular leak. Also in general with any transcatheter valve procedure, there is always the risk of trauma or injury to vessels and adjacent tissue, device migration, and stroke.\textsuperscript{14,37,38} Transcatheter aortic valve therapy is still a relatively new and advancing technology, and randomized trials are currently under way to confirm procedural safety. Data on the Edwards Sapien valve are available from the European Registry.\textsuperscript{39} These data show a 95\% procedural success, a 30-day mortality of 6.4\%, and presence of 2/4 aortic regurgitation in 26\% of the patients. Bleiziffer et al\textsuperscript{40} published the results from their series of 137 high-risk patients who underwent transcatheter AVR using the CoreValve (114 patients) or Edwards Sapien valve (23 patients). Thirty-day mortality was 12.4\% in this series. The stroke rate was 5.1\%. New York Heart Association class had significantly improved from an average class III to an average class II at 1-month follow-up. Eighty percent of the patients were alive, and there was good hemodynamic function of the prostheses at 6-month follow-up.

The transapical approach usually is reserved for patients with poor peripheral vascular access, severe carotid artery disease, and porcelain aorta and constitutes a much sicker population than those undergoing a retrograde approach. In a study on 53 patients, Walther et al\textsuperscript{41} reported a 13.6\% 30-day mortality with a 93\% periprocedural success. Although some of the outcomes of transcatheter valve therapy appear encouraging, it is important to note that these techniques are still in their relative infancy, and future long-term follow-up studies are still required.

**Conclusions**

As the complexity of patients referred to cardiac surgery increases, integrated hybrid therapy is becoming an increasingly popular treatment option for patients with cardiovascular dis-
ease. This stems from the fact that this therapeutic strategy entails less-extensive surgical trauma and has the capacity to curtail the magnitude of the surgery involved. By doing so, it has the potential to decrease operative risk while not compromising the long-term outcomes. Furthermore, hybrid strategy combines the tools available to the surgeon with those available to the cardiologist to treat any set of lesions. Hybrid procedures currently play a clinical role in selected high-risk patients requiring a tailored combined approach. Future trials are needed to better delineate the patient population who may benefit the most from hybrid therapy. The National Heart, Lung, and Blood Institute-sponsored study on hybrid coronary intervention is the first step to try to answer this question.

**Sources of Funding**

Vanderbilt Heart and Vascular Institute, Nashville, Tenn.

**Disclosures**

None.

**References**


39. Lefèvre T. The SOURCE Registry. Paper presented at: Transcatheter Cardiovascular Therapeutics; October 13, 2008; Washington, DC.


Key Words: thoracic surgery ■ disease management ■ coronary artery bypass
Surgical Update: Hybrid Procedures, Do They Have a Role?
Marzia Leacche, Ramanan Umakanthan, David X. Zhao and John G. Byrne

Circ Cardiovasc Interv. 2010;3:511-518
doi: 10.1161/CIRCINTERVENTIONS.110.957951
Circulation: Cardiovascular Interventions is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2010 American Heart Association, Inc. All rights reserved.
Print ISSN: 1941-7640. Online ISSN: 1941-7632

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circinterventions.ahajournals.org/content/3/5/511

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation: Cardiovascular Interventions can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation: Cardiovascular Interventions is online at:
http://circinterventions.ahajournals.org//subscriptions/