Hybrid approaches to aortic arch lesions were developed with the goal of treating patients at high risk for traditional open operations. These procedures were assumed to be safer because they avoided or limited the use of cardiopulmonary bypass (CPB) and hypothermic circulatory arrest (HCA). Extra-anatomic bypasses of the supra-aortic vessels were combined with endovascular techniques and early reports described the feasibility of such an approach with similar outcomes to conventional open repairs.\(^1,2\) As more experience has accumulated with these integrated procedures, the risk of neurovascular events, spinal cord injury, retrograde aortic dissections and endoleaks brings their value into question. Technical success has been reported to be 86\%, with the most common cause of failure being type 1 endoleak (9\%). Perioperative stroke and death averages approximately 16\%.\(^3\)

As early as 2005, we performed these procedures at our institution with some excellent success in the highest risk patients, but we also encountered issues with stroke and retrograde dissection that have given us pause. We rarely perform a simple debbranching procedure combined with landing thoracic endografts into zone 0 of the aorta at the Cleveland Clinic Aortic Center. Instead, we tailor the operation to the patient’s anatomy and disease. We believe it is more effective to employ all of the tools at our disposal including the use of stent-graft devices and the use of CPB and cardiac arrest with or without HCA. When possible, we avoid landing a stent-graft into native proximal aorta. As long term follow-up of stent-grafts continues, it is not surprising to see that many patients require additional interventions at a later date, because other segments of their aorta frequently develop disease. Rather than simply providing a less invasive approach for higher risk patients, the hybrid approach to the aorta facilitates a more effective and potentially more durable repair for the complex aortic patient. It also allows for a scaled approach to the patient while maintaining quality with the potential for increased safety. The objective of this article is to review the current hybrid options to address lesions of the aortic arch and describe how we apply them in our practice.

**Conventional total arch repair**

Advances in cannulation techniques, hypothermic circulatory arrest, cerebral perfusion monitoring and anesthesia have been revolutionary in the treatment of aortic arch pathologies. Outcomes continue to improve, and the procedures are becoming safer.\(^4,6\) The traditional open approach utilizes of CPB, cardiac arrest and HCA with selective antegrade brain perfusion to a core temperature of approximately 20 °C. A branched polyester graft is then anastomosed to the proximal descending thoracic aorta with separate grafts to the left subclavian artery (LSA), the left com-
mon carotid artery (LCCA) and the innominate artery. After a process of de-airing the graft and aorta, the cross-clamp is applied to the proximal graft, flow is restored and the patient is rewarmed while the proximal anastomosis is performed, with or without addressing any issues with the aortic valve.

Results for the open technique of total arch repair procedures are the gold standard and have yet to be improved upon by more complex but potentially less invasive hybrid techniques. At the same time, patients who were previously denied surgery because of comorbidities and prohibitive risk often being treated with a hybrid approach with similar results to conventional repair. Recent comparisons of hybrid versus open traditional repairs reveal no difference in outcomes despite the higher risk population that lends itself to the less invasive techniques, but these comparisons are generally underpowered and biased by the heterogeneity of the population.\cite{1,2,7,8}

## Hybrid arch repair classification

Hybrid arch repair in the literature has taken on a wide range of meanings. In many series hybrid arch repair includes procedures such as thoracic endovascular aortic repair (TEVAR) with coverage of the left subclavian artery before or after a carotid to subclavian artery bypass.

They can also include patients with multisegment disease who have undergone sternotomy, CPB, HCA with total ascending and arch replacement with placement of traditional elephant trunk (ET) completed with TEVAR to address the distal arch and descending aorta. To simplify a discussion of hybrid arch repair, we use a classification system that focuses on the intensity of mechanical circulatory support to differentiate the various repair. Additionally, procedures can each be subdivided into single (S) or dual staged (D) repairs. The common element, is that both open and endovascular techniques are employed to repair the entire arch, resulting in a “hybrid” procedure. We do not include the simpler combination of left subclavian artery coverage and revascularization in our classification of hybrid arch repair since this is essentially a descending aorta repair. The specific approach for each patient is dictated by the surgeon’s preference, the patient’s particular anatomy and comorbidities. This classification scheme is illustrated in Figure 1.1.

Type I hybrid repairs are performed on a beating heart (with or without CPB) and utilize a side-biting clamp on the ascending aorta to facilitate debranching of the supra-aortic vessels to create a landing zone in the ascending aorta for a thoracic endograft, placed in a single (S) or dual (D) staged procedure, via an antegrade or retrograde approach, respectively.

Type II hybrid repairs are performed using CPB with cardiac arrest, but without HCA. These repairs include replacement of the ascending aorta with a surgical graft and debranching of the supra-aortic vessels, and landing a thoracic endograft in the replaced ascending aorta via a retrograde or antegrade approach in a single (S) or dual (D) staged repair.

Type III repairs require HCA and are typically performed in patients without a suitable proximal aortic landing zone even after debranching due to multi-segment disease. These repairs include the replacement of both the ascending aorta and the arch using a surgical graft and the creation of an elephant trunk. The elephant trunk may be stented- or frozen- and completed in a single (S) stage or completed endovascularly as a dual (D) staged repair.

## Patient selection

Indications for aortic arch replacement include acute or chronic aortic dissection extending into the aortic arch, aortic arch aneurysm either in isolation or involving multi-segment thoracic disease, and congenital arch disease including aortic coarctation or Kommerel’s diverticulum.
Also, for young patients with known connective tissue disorders and patients with thoracic aortitis requiring root and ascending repair, we have a low threshold to extend repair through the aortic arch knowing that they are at high risk for later complications. We have shown that patients with connective tissue disorders can benefit from a hybrid strategy to repair the aorta beyond the root, with an estimated survival at 1, 5, and 10 years of 91%, 79% and 62%, respectively.\textsuperscript{9} Considering the chronic and progressive nature of aortic disease, operative planning must anticipate the need for later intervention for a majority of patients.\textsuperscript{6}

The concept of what defines a thoracic aortic disease patient as high-risk is often discussed but not clearly defined and warrants further study. Much of this is operator dependent based on experience. Frequently, the bedside assessment is the most relied upon factor in patient selection.

Although multiple studies have shown comparable outcomes between conventional and hybrid approaches it is difficult to appreciate a fair comparison of the groups. Hybrid repairs are often utilized in the emergency or utilized urgently in patients felt to be too high-risk for a traditional open repair.\textsuperscript{2,8,10}

### Imaging and perioperative considerations

There is great variability in arch anatomy and morphology. When selecting patients for a hybrid arch procedure a clear understanding of the aortic anatomy is crucial to planning the operation. Preoperative contrast enhanced computed tomography (CT) of the chest, abdomen and pelvis with three dimensional reconstructions provides the necessary information. For type 1 and 2 repairs where the device is placed into the highly elastic ascending aorta, endograft selection is typically performed with oversizing around 20% to optimize sealing. For a type 3S repair, or frozen elephant trunk, the endograft device is fixated directly into the aorta with suturing so no oversizing is used to optimize fit and minimize wrinkling of the graft material. Measurements of the aortic diameter are made at the point of fixation within the arch and at the distal landing zone, perpendicular to the axis of blood flow using 3-dimensional multiplanar reconstructions.\textsuperscript{11} When there is any doubt about the landing zone measurements, intravascular ultrasound (IVUS) is a reasonable adjunct but will not necessarily provide a true center line measurement.\textsuperscript{12}