The art of aortic valve repair

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In cardiac surgery, as with many endeavors, there is a point to which science can take you, and then art—namely observation, hands-on skill, craft, imagination, and mental impu-
tation—must take over. And so it is with aortic valve repairs. Certainly, there are some important physics principles to note: (1) the greater the contact area of leaflet to
leaflet apposition, the less leakage; (2) according to Pois-
euille equation, small changes in the diameter of an orifice
lead to large gradient increases by radius to the fourth po-
wer; (3) the longer the leaflets, the greater likelihood of tur-
bulence and gradients (ie, increased shear over a longer
distance at the boundary layer disrupting laminar flow);
(4) tension and the risk of leaflet tear or perforation are
increased with less apposition of leaflets to relieve linear
edge stress; (5) greater leaflet height increases the contact
area of apposition without sacrificing orifice area; and (6)
there is increased stasis and likelihood of clot formation
(Virchow’s triad) with sinuses that are too deep, particularly
with added pericardium.

Based on these principles, usually with aortic valve
repair, regurgitation is less with increasing pressure load
on the leaflets when coming off pump compared with mitral
valve repair, in which case worsening of regurgitation
occurs.

There is no shortcut to successful aortic valve repairs. It is
a matter of observation, experience, and time “spent” on the
learning curve to understand what a normal tricuspid leaflet
valve should look like, and for bicuspid valves, what works.
After performing well over 1000 aortic valve repairs, reim-
plantations, and remodelings, I am convinced that achieving
a competent and nonstenotic aortic valve is more art than
science.1-6 Measurements are of little value when, for
example, the tying suture sequence during reimplantation
changes the geometry of the leaflets.

Critical to a successful repair is considering the aortic
valve, the root, and its components as a unit to obtain early
and late competence. Thus, all components of the CLASS
schema (commissures, leaflets, anulus, sinuses, and sinu-
tubular junction) need to function in concert for a successful
repair (Table 1). This helps determine the appropriate tech-
nique to use (Table 2).

There are some basic leaflet repair techniques that can be
used in 90% of cases with great success (Figures 1 and 2,A
and B), some of which a historic innovations, including
Cabrol sutures, commissure apposition stitches, Trussler
stitches, and running polytetrafluoroethylene (PTFE) su-
tures on the leading cusp edge, a technique that may reduce
late leaflet prolapse.7 Cabrol described placing stitches at
the base of the commissure to increase apposition of leaf-
lets.8 This typically works well for bicuspid valves, but

TABLE 1. CLASS schema

|   | Commissures | Leaflets | Anulus | Sinuses | Sinutubular junction |
|---|-------------|----------|--------|---------|----------------------|
| C |             |          |        |         |                      |
| L |             |          |        |         |                      |
| A |             |          |        |         |                      |
| S |             |          |        |         |                      |

CENTRAL MESSAGE

Surgeons must understand principles of aortic root repair;
consider the aortic valve, root, and components as a unit; and
observe many repairs to learn the art of successful repair.

See Commentaries on pages 126 and 128.
not for trileaflet valves; however, the surgeon must be careful not to place the stitches too low and thereby create stenosis or turbulence. Furthermore, in the long term, these sutures can result in clot deposition, fibrous formation, stenosis, and calcification. During remodeling, the beveled graft can be sewn to these sutures to brace the anulus instead of placing a circumferential brace, such as with PTFE sutures, felt, or one of the newer materials/devices. I find that use of the PTFE suture as a left ventricular outflow tract (LVOT) circumferential suture increases the risk of pacemakers; the only late failure that I have experienced with this suture resulted in a LVOT membrane and stenosis.

The Trussler stitch is used to shorten the edge of a leaflet at a commissure. A suture is woven through the leaflet edge near the commissure and then tied to shorten the length. It is an alternative to mid-leaflet plication, but I rarely use it, because I find that the tension on the sutures sometimes results in leading-edge tears at the commissures. Plication of the leaflet has better durability if leaflets are prolapsing or for an incomplete fusion. In addition, resection and suture leaflets carries a greater risk of leakage through the suture line and of late failure. If after placing figure-of-8 sutures, trileaflet valve prolapse remains, I use a mid-leaflet plication stitch. For prolapse, a 1-mm plication with a horizontal mattress suture is often all that is needed (see below). As with mitral valve repairs, the less done the better in many cases. For incomplete fusions, I first do a running 2-layer polyester stitch for strength to get the approximate symmetrical orientation for a bicuspid valve and then finish the repair with a horizontal mattress suture to get the best possible symmetry without any prolapse when testing with 2 forceps (Figure 2, B). This is further improved by figure-of-8 adjusting sutures. Running PTFE sutures along the leaflet edge should be used with care but may improve long-term durability of particularly long bicuspid valve leaflets. Usually, the leaflet edge in bicuspid valves is a little

![Figure 1. Use of different types of repair methods on aortic valves.](image-url)
FIGURE 2. A. Newer techniques for aortic valve repair, the first of which involves placing figure-of-8 suspension sutures at the leading edge of the cusps. Cabrol commissuroplasty showing 2 commissural stitches (pledgeted and commissural approximation) and central plication (Reproduced with permission from Zeeshan and colleagues.1). B. Intraoperative photographs of bicuspid repairs with Cabrol, plication, leaflet edge, and figure-of-8 sutures. Note the use of a Hegar dilator to ensure that no stenosis is created.

FIGURE 3. Suturing commissures at a higher level. A. Mobilizing commissure for a large root. B. Closing gaps in aortic root incisions. C. Reattachment of commissures resuspended in a tube graft at a higher level. (Reproduced with permission from Svensson and colleagues.9)
thickened and will hold sutures; however, if the leaflet tissue is thin and reliance is placed on this suture to "suspend" the leaflet edge, it may tear out. I tie the suture outside the aorta, do both leaflets, and use it in combination with figure-of-8 sutures tied down around a Hegar dilator of at least 21 mm (Figure 2, B).

Having been of the conviction that placing commissures at a higher level would correct and compensate for prolapse, I initially went through a period where I cut the commissures free, closed the gap outside of the freed commissures, and then reimplanted the commissures in a tube graft at a higher level (Figure 3). In approximately 10 patients, this worked very well in obtaining a competent valve without stenosis; however, as this was often for thinned dilated roots, with tension on suture lines, bleeding from the suture lines had to be carefully controlled. Nevertheless, I am not aware of any patient requiring reoperation.

For patients who do not need their valves lifted as much, the alternative is to place a PTFE stitch over and over at the leading edge of the leaflets near the commissures. This better opposes them and provides more strength in terms of leaflet tearing compared with the Trussler stitch. I then suspend the sutures 3 to 4 mm higher and tie them on the outside, about 3 to 4 mm apart (Figure 2). The PTFE may provide some elasticity in absorbing the pressure load of the returning diastolic pressure wave. I use this routinely for bicuspid valve repairs (Figure 2) and trileaflet repairs (Figure 4, arrows), isolated repairs with an ascending tube graft, remodeling, and reimplantation of trileaflet or bicuspid valves if there is asymmetry with prolapse. Apart from raising the level of the commissures, this technique can be used to move a commissure in an opposite direction to a prolapsing leaflet and increase tension of the prolapsing leading edge. Of note, these sutures rarely need more than 1 to 3 mm of adjustment of the leaflet edge. Initially, in my early experience with the modification of the David reimplantation operation (Figure 5), using pledgets in the LVOT tract and a Hegar dilator to reduce the anulus to a normalized valve for body surface area diameter, roughly 1 in 4 patients needed additional leaflet repairs, mostly with figure-of-8 sutures. However, as our experience has continued, having performed 1113 reimplantations as of December 2020, I rarely need to place figure-of-8 sutures or do plications.

Leaflet prolapse, particularly of the right cusp, usually can be adjusted by moving the commissure away from the prolapsing leaflet to improve suspension of the leaflet.

In 2014, we reported on 728 bicuspid aortic valve repairs with 91% freedom from reoperation at 10 years, but recent repairs using more modern techniques appeared to be holding up better. Similarly, in the large series of >1000 recent...
aortic valve repairs, bracing the root and using figure-of-8 sutures were associated with long-term durability. Note the many repair techniques used in attempts to achieve a durable repair (Figure 1). Nevertheless, a word of caution is needed. With appropriate selection of patients based on age and clinical findings, one should be “conservative” in doing repairs. Namely, the patient should be a good candidate for successful repair, with no calcification of the leaflets, no major perforations, and not more than 2 prolapsed leaflets. Furthermore, freedom from reoperation at 10 years after reimplantation with the techniques described has been 97% (Figure 6). The risk of death for elective reimplantation surgery is 0.17%. As of the end of 2020, we had completed a total of 4680 aortic valve repairs, of which 1430 were for bicuspid, unicuspid, or quadricuspid valve repairs performed at Cleveland Clinic.

Although aortic valve repair can be tricky, by adhering to the principles and techniques described herein and observing the operation being done by seasoned experts, with experience, the art of aortic valve repair can be learned.

Conflict of Interest Statement
The author reported no conflicts of interest.

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

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