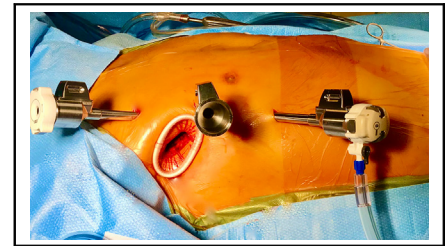


## Two decades of experience with robotic mitral valve repair: What have we learned?



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▶ Video clip is available online.



Robotic mitral valve repair is the less-invasive and most-precise surgical approach.

### CENTRAL MESSAGE

Robotics-enhanced vision allows for precise and comprehensive mitral valve analysis. Better understanding of the pathologic details enables performing individualized/tailored repairs.

What challenges come with repairing the degenerative mitral valve (MV)? What insight into this condition have we gained from our dedicated robotic practice? When performing robotic MV repair, optimal visualization of the entire MV apparatus allows for a more precise and comprehensive valve analysis compared with any other surgical approaches or imaging modalities. Enhanced visualization has made us aware of some pathologic features that we find important to address for perfecting MV repair strategies and outcomes. The purpose of this editorial is to discuss the most common ones.

SAM (systolic anterior motion) was the first serious adverse effect of MV repair to be recognized.<sup>1,2</sup> A ratio of [posterior leaflet height] to [anteroposterior orifice diameter] greater than 1 to 3 after annuloplasty was found to be the main risk factor. Therefore, it was advised to decrease the height of the posterior leaflet (PL) and avoid excessive reduction annuloplasty to maintain the normal 1:4 ratio.<sup>3</sup> This has been one of the core principles in MV repair. In the last 2 decades, earlier indications for MV repair have given rise to operating on patients with smaller and hyperdynamic LVs (left ventricles), which has been recognized as a new risk factor for postoperative SAM.<sup>4,5</sup> This led us to think more globally and 3 dimensionally about LV topology. We have become more attentive to preserving the balance between the LV inflow and outflow spaces. Inflow and outflow must be understood as 2 virtual spaces obtained by dividing the LV cavity according to a plane passing through the 2 trigones and the LV apex point. On the arrested heart, the dividing plane corresponds to the anatomic continuity

formed by the anterior leaflet (AL), its marginal chordae, and the PMs (papillary muscle). Via conventional sternotomy, the LV inflow is visualized through the MV orifice and the outflow through the aortic orifice. Alternatively, robotics allows for complete access and exploration of both the inflow and outflow through the mitral orifice just by lifting the AL margin with dynamic retraction. A septal myomectomy can be done through the mitral orifice without detaching the AL (Video 1 @14min 35sec). We are performing septal myomectomy routinely in case of prominent sigmoid septum, particularly when the angle between the aortic and mitral orifice plane nears 90°. <sup>6</sup> Likewise, we commonly remove all structural anomalies present in the LV outflow that predispose to SAM. These include muscle bands originating from the LV apex that attach directly to the AL without chordal intermediary, large accessory PM supporting a short AL secondary chorda, large trabeculations located between the septal knuckle and LV apex, and anteriorly displaced PM bases obliterating the LV apex. These different configurations tend to restrict AL motion into the outflow during early systole and initiate SAM. <sup>7</sup> Robotics makes all these contributory anatomic features accessible to complete or partial excision through the mitral orifice. We have found these outflow enlargement techniques very efficient in preventing the occurrence of

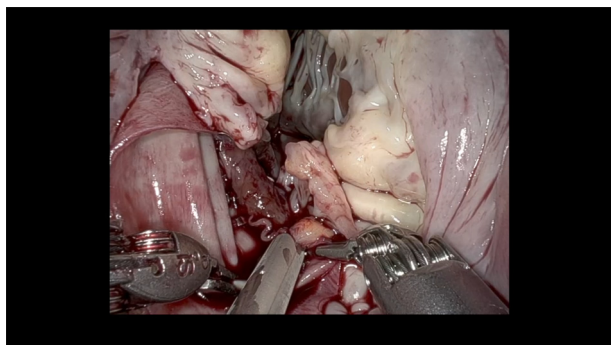
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Received for publication Oct 24, 2023; revisions received Jan 5, 2024; accepted for publication Jan 18, 2024; available ahead of print Jan 23, 2024.

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JTCVS Techniques 2024;24:76-81  
2666-2507

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<https://doi.org/10.1016/j.jtc.2024.01.014>



**VIDEO 1.** Robotic mitral valve repair in a case with MAC and a high risk of postoperative SAM. Video available at: [https://www.jtcvs.org/article/S2666-2507\(24\)00043-9/fulltext](https://www.jtcvs.org/article/S2666-2507(24)00043-9/fulltext).

postoperative SAM in the setting of smaller and hyperdynamic LVs.

MAC (mitral annular calcification) is a common degenerative finding evolving along PL hinge; it will become more frequent with our aging population. MV repair complexity rises significantly when MAC involves more than one annular segment. MAC recognition on preoperative imaging is inconsistent. There are no imaging modalities that can precisely and unfailingly render MAC location, shape, and extension. Ultrasound scans have low sensitivity and specificity in detecting annular calcifications. Ultrasound scans are only useful for evaluating MAC extension to the PL—the length of residual leaflet determines the possibility of MV repair. Radiographs are more sensitive in detecting calcifications. MAC can be seen on regular radiographs of the chest, cardiac catheterization, or computed tomography. Gated computed tomography angiography with 3-dimensional reconstruction gives the most informative MAC representation; it is used more commonly as part of our preoperative robotic MV repair workup. However, no preoperative imaging technique will reach the precision of valve analysis obtained with robotic vision. MAC is intuitively misconceived as a bent cylinder with regular edges evolving along the mitral annulus. It seems innately possible to safely cast needle bites around it as it were a solid anchor to fix annuloplasty devices or artificial valves. Some authors still recommend leaving it in place and working around it, although this approach has shown substandard results in past reports.<sup>8</sup> Monobloc excision with enhanced visualization has made us more knowledgeable about MAC frequency, location, shape, and extension.<sup>9</sup> Experience has shown us that MAC can develop haphazardly into wildly diverging configurations like a rhizome. Its parts have different consistency owing to variable degree in mineralization or core liquefaction. Overall, MAC is an unpredictable heterogeneous structure upon which we cannot rely as a tissue for suturing either around or through it. Therefore, our practice has evolved towards removing it

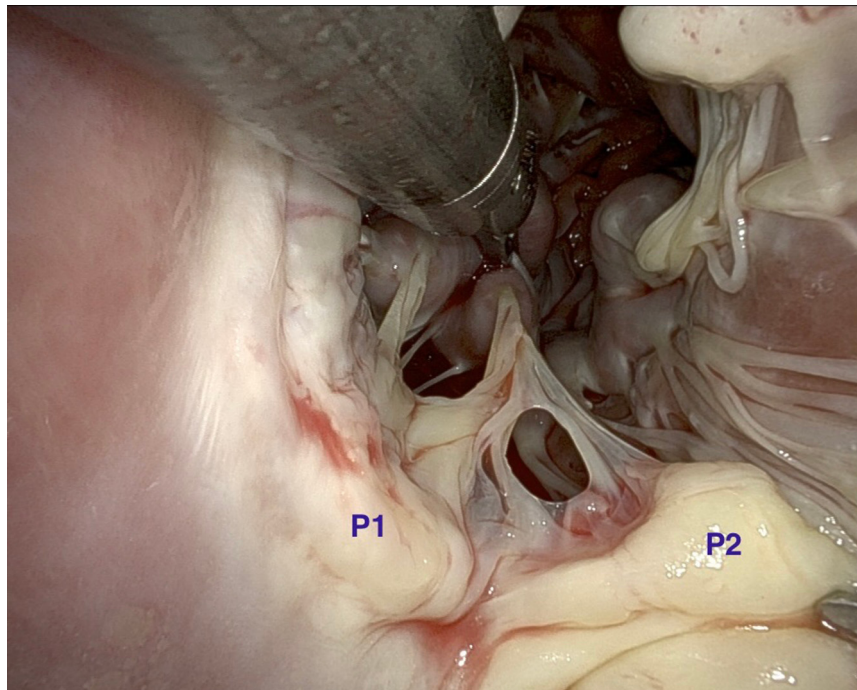
entirely and reconstructing the MV annulus whenever possible (Video 1 @3min).

### SEMANTICS

Let's examine another important finding consequent to enhanced visualization. The anatomic region separating the PL scallops is commonly called the “cleft” (eg, the P1-P2 or P2-P3 cleft). Originally, the word “cleft” was used in valve pathology to describe the AL slit found in AV canal malformations. In AV canal, an AL cleft can be complete (from the margin to the hinge) or partial and does not have any specific chordal system other than some secondary chordae. “Cleft,” a pathologic connotation, makes it an erroneous term to name the normal segmentation area between the PL scallops. Robotic visualization of a normal PL shows a continuity between PL scallops consisting of a leaflet pleat supported by an organized chordal system, whose configuration recapitulates those of the anterior or posterior commissure (Figure 1). A commissure is a complex and highly differentiated structure, therefore prone to developmental defects. Failure to differentiate into a proper commissural configuration generates a spectrum of various anomalies: (1) partial or complete chordal fusion (Figure 2); (2) calcified band linking the MV annulus to a PM head and supporting some commissural chordae (Figure 3); and (3) complete failure of commissural delamination resulting in a fibrous or calcified band plastered to the LV wall (Figure 4). Such conditions most often cause leaflet tethering by restricting commissural motion. Occasionally, a prolapse can result from a laterally bound PM slewing towards the mitral orifice. In our experience with degenerative MV diseases, the commissures (either between the AL and PL or between the PL scallops) are often subject to these malformations. A triangular or quadrangular excision of the pathologic commissure followed by suturing the corresponding segments together is our preferred approach to restore normal leaflet motion and prevent calcification in these cases.

### PLASTY OR PLASTIC?

There are radically different ways of performing a MV repair today. Differences are reflected in sharp divides between the adherents and defectors of the classic excision techniques.<sup>10,11</sup> The long-term results of MV repair were established with the classic excision and reconstruction techniques.<sup>12</sup> Excisions are justified by Barlow's most distinctive macroscopic features, namely, excessive leaflet tissue. Excision concerns the most prolapsed and dystrophic leaflets segments, which may include leaflet ulcerations, fibrotic and myxoid thickening, cartilaginous and calcific transformations, calcification liquefaction. Reconstruction consists in detaching, relocating, and suturing some of the remaining segments with the aim of obtaining a configuration that conforms to the native MV structure and function.



**FIGURE 1.** A normal P1-P2 commissure.

From an execution standpoint, the classic excision-reconstruction techniques present special challenges. A need for simplification was fostered by the emergence of the less invasive approaches in the mid-1990s. Reduced access and visualization led some surgeons to avoid excising. The use of artificial chordae became an alternative technique accepted by less invasive as well as conventional surgeons. Nevertheless, the classic excisional techniques have remained our preferred way for repairing the MV notably in younger patients for following reasons. First, as opposed to the less-invasive approaches, robotics allows for complete thoracoscopic MV repair without any compromise in access or visualization. Robotics facilitates MV repair execution whether using excisional or nonexcisional techniques. Second, we believe excising advance degenerative lesions stabilizes the degenerative process as shown by the low incidence of long-term failure caused by disease progression after excisional repair.<sup>13</sup> Third, as a reminder, artificial chordae are made of Gore-Tex sutures (W. L. Gore & Associates, Inc), a material mainly composed of air (70%). Gore-Tex material is porous, stretchable, and vulnerable to calcification as observed during reoperations by their transformation into rigid twigs. Gore-Tex sutures were not engineered or tested for flexing every second and staying pliable for a lifetime. Last, the use of artificial chordae requires the proper selection of stable implantation sites to provide durable leaflet coaptation. The frequency of subvalvar anatomic variations makes this difficult. “The MV

apparatus, including the PMs, is as unique to each individual as one’s own fingerprints” as stated by the late great MV anatomist Dr Solomon Victor.<sup>14</sup> Robotic vision has shown us that PMs are inconsistent in length, texture, elasticity, trunklets arrangement, and quality of attachment to the LV wall. At the end of the spectrum, PM noncompaction can result into multiple small myocardial stems instead of well-structured PM trunks. If not fully appreciated, these common anatomic variants may derail an apparently standardized and deceptively simple technique.

#### **VISUALIZATION, FOCUS, AND TECHNICAL POSSIBILITIES**

The figure-ground principle of Gestalt theory states that people instinctively perceive objects as either being in the foreground or the background. Visual objects stand out prominently in the front (the figure) or recede into the back (the ground). Figure-ground lets us know what we should be focusing on and what we can safely ignore in a representation. The focal point principle states that whatever stands out visually will capture and hold the viewer’s attention first. In traditional surgery, surgeons’ eyes are distant from the MV. The MV orifice and leaflets become the foreground while the subvalvar region the background. Surgeons focus on the most visible part missing some important aspects of the sub-valvar apparatus. Valve analysis is often reduced to hydrostatic testing. Valve reconstruction turns into a simple dichotomy: what is found

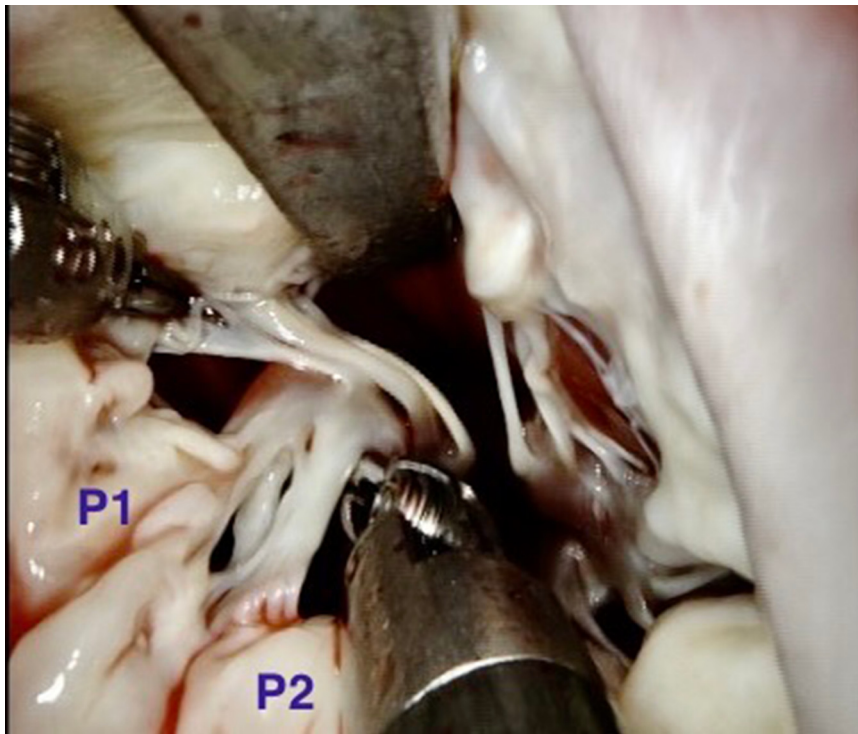


FIGURE 2. A P1-P2 commissure with chordal fusion.

prolapsing above the MV orifice plane is either removed using some basic excision-suture technique or tethered into the LV with artificial chordae. Conversely, in robotic

surgery the visual sensor can be moved near the MV orifice and further into the LV. Remote sensing permits the delocalization of the point of view of the observer at the center of

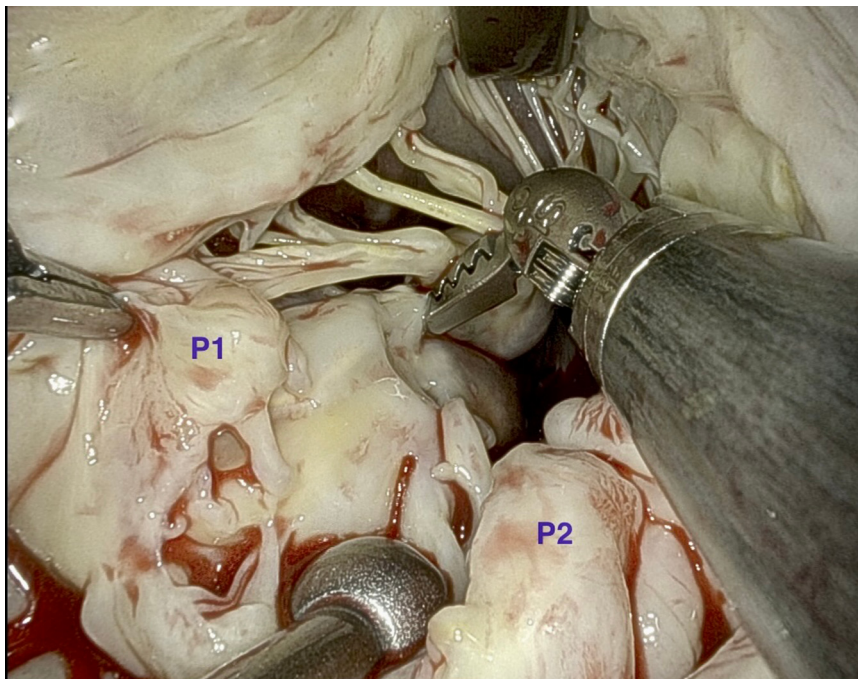
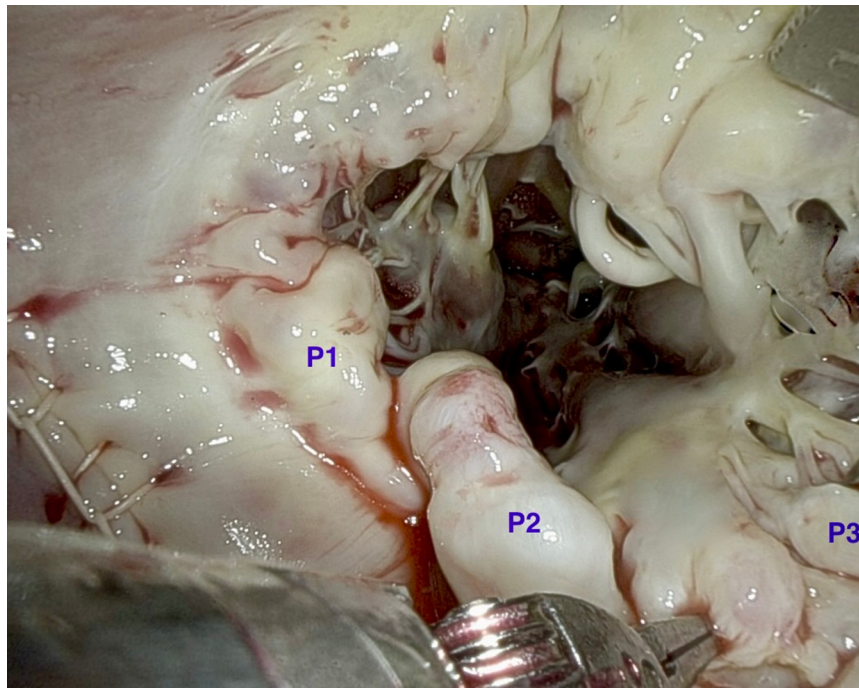


FIGURE 3. A P1-P2 commissure with a calcified band.



**FIGURE 4.** A P2-P3 commissure plastered to LV wall. R, Right; L, left; LV, left ventricle.

the heart cavities. The MV structure can be comprehended in its entirety and more 3-dimensional reality. A deeper sense of perception and immersion helps repair accuracy by allowing recognition of a variety of pathologic conditions that would have otherwise been deemed uniform. It inspires specific correction of each lesion with a corresponding technique without any limitation.<sup>15</sup>

### SYNERGISM

“There is no greater solitude than that of the samurai unless it is that of the tiger in the jungle... Perhaps...” (from the Code of Bushido and quoted in Jean-Pierre Melville’s movie “The Samurai”). The comparison could be extended to the present-day cardiac surgeon. It is sometimes dispiriting to experience the solitude of a MV repair surgeon while hybrid rooms are not large enough to accommodate the crowds required to replace a valve. MV reconstruction is unique, as it demands conceptualizing the potential effect of a combination of techniques on a complex structure with the aim of restoring functional normality. It requires judgment and experience. More than traditional surgery, robotics requires the cooperative efforts of several people working closely together. The surgical field has become visible and accessible by more than one experienced surgeon enabling collaborative decision-making and techniques execution. A surgical team approach provides balance in the operating room. We have found the resulting synergy a great antidote to the otherwise increasing cardiac surgeon lonesomeness.

### ENLIGHTENMENT

It has been commented before that the median sternotomy approach for MV repair has the mindset of being the “gold standard” status, as well as its tolerated complications such as bleeding, transfusions, rib fractures, or sternal infections and dehiscence. Centers with expertise in robotic MV repair have obtained equal results (quality) with less morbidity (cost), and therefore more value (value = quality/cost) for their patients.<sup>16-22</sup> However, as illuminated by the aforementioned points, there are more subtle benefits from robotics fostering a more enlightened approach to MV reconstruction.<sup>23</sup>

### Conflict of Interest Statement

The authors 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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**Key Words:** mitral repair, robotics