

# Transesophageal echocardiography in NeoChord procedure

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## ABSTRACT

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**Background:** Transapical off-pump mitral valve intervention with neochord implantation for degenerative mitral valve disease have been recently introduced in the surgical practice. The procedure is performed under 2D-3D transesophageal echocardiography guidance. **Methods:** The use of 3D real-time transesophageal echocardiography provides more accurate information than 2D echocardiography only in all the steps of the procedure. In particular 3D echocardiography is mandatory for preoperative assessment of the morphology of the valve, for correct positioning of the neochord on the diseased segment, for the final tensioning of the chordae and for the final evaluation of the surgical result. **Result and Conclusion:** This article is to outline the technical aspects of the transesophageal echocardiography guidance of the NeoChord procedure showing that the procedure can be performed only with a close and continuous interaction between the anesthesiologist and the cardiac surgeon.

**Key words:** Mitral valve prolapse; NeoChord delivery system; three-dimensional transesophageal echocardiography

## INTRODUCTION

Over the past decade, minimally invasive approaches to mitral valve (MV) surgery have been commonly used at many centers around the world with excellent short- and long-term outcomes.<sup>[1-4]</sup> There has been great enthusiasm about their performance because they have proven to be at least as good and safe as the standard sternotomy approach, even in elderly patients. A variety of approaches<sup>[5,6]</sup> have been reported, aimed at reducing surgical trauma and postoperative morbidity while remaining safe and effective. In this way, transcatheter procedures for treatment of diseased MV in selected patients are of increasing importance.<sup>[7]</sup> Recently, a new transapical approach has been presented to treat degenerative MV disease using the innovative NeoChord device (NeoChord DS1000 system, NeoChord, Inc., Minneapolis, Minnesota).<sup>[8-13]</sup> The NeoChord system [Figure 1] is designed to

deliver artificial chordae tendineae under beating-heart conditions with transesophageal echocardiography (TEE) used to guide the device to the target leaflet for deployment of the NeoChords. The technology is based on two principles: (1) The very broad and excellent experience with surgical implantation of NeoChords using expanded polytetrafluoroethylene sutures (Gore-Tex suture W. L. Gore and Associates, Inc., Flagstaff, Ariz);<sup>[14,15]</sup> and (2) the secure and standardized transapical left ventricular (LV) access. The DS1000 device includes potential advantages over conventional open MV repair. The technology enables resuspension of a prolapsed leaflet of MV under physiological conditions on the beating heart without the use of cardiopulmonary bypass with inherent risks of morbidity and mortality low despite the very early stage of development and clinical application. In this work, we describe the role of TEE in this new approach during NeoChord procedure.

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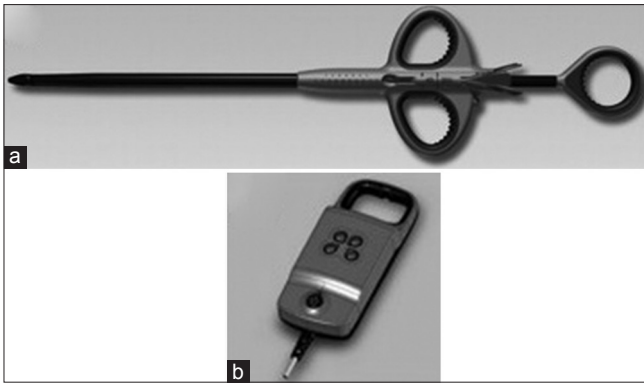
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**Figure 1:** NeoChord device for the transapical implantation of neochord. The NeoChord DS1000 device which contains a handle for steering purpose, the needle, which is advanced through the mitral valve leaflet tissue, and a long shaft with the grasping mechanism on the tip (a). The associated device monitor, which contains four fiber optic monitor lights changing from red to white when the effective leaflet is captured (b)

### UTILITY OF TRANSESOPHAGEAL ECHOCARDIOGRAPHY

Echocardiography is an important diagnostic tool for the evaluation of MV in patients undergoing MV repair. Conventional two-dimensional echocardiography with Doppler capability is one of the most useful methods for assessing mitral regurgitation (MR) and is a widely accepted diagnostic tool for the assessment of MV disease where a high level of expertise is also required for the accurate interpretation of two-dimensional images. However, the complex anatomy of the MV apparatus exposes the limitations of two-dimensional in particular during the NeoChord procedure where more detailed quantification of MV prolapse is being required. For these reasons real-time three-dimensional TEE recently introduced have increasing value compared with that of two-dimensional TEE, providing higher quality visualization of MV anatomy<sup>[16]</sup> with more accurate geometric information on the MV. Three-dimensional TEE depicts the MV in the “en face” view, allows detailed detection of MV pathology with particular emphasis on prolapse. Earlier studies have reported the feasibility and accuracy of three-dimensional TEE for identifying the locations of MV prolapse<sup>[16,17]</sup> and in this sense we used it for the treatment of MV prolapse with NeoChord device. The accuracy and feasibility of three-dimensional echo and the enlargement of the potential value of three-dimensional TEE as a complement to two-dimensional TEE lead to successful repairs of the MV. However, three-dimensional TEE has limitations that need to be considered. This modality is strongly dependent on spatial resolution and frame rate, and a good three-dimensional image is always the result of good two-dimensional image quality. In our experience, all patients who underwent NeoChord procedure required

both complete two-dimensional TEE and three-dimensional TEE exam. TEE has performed using an iE33 ultrasound imaging system (Philips Medical Systems, Andover, Massachusetts) equipped with a fully sampled matrix-array TEE transducer (X7-2t, Philips Healthcare DA Best, The Netherlands) that can display two-dimensional and three-dimensional images.

### PATIENT SELECTION, ANESTHESIA, AND APPROACH

Patients were treated with NeoChord procedure if presented Carpentier type II MV disease (MV prolapse or flail with no annular dilatation and central regurgitant jet). Key exclusion criteria include secondary MR, severe LV dysfunction (LV end-diastolic diameter >6.5 cm) and concomitant cardiac disease with an indication for surgical treatment. The anesthesia during the NeoChord procedure was performed with the patient under general anesthesia in ordinary cardiac surgery operating room with a fast-track anesthesia protocol. Patients received a premedication dose of 2 mg of oral flunitrazepam 1-h before anesthesia induction. Standard monitoring included pulse oximetry, electrocardiography, end-tidal CO<sub>2</sub>, invasive blood pressure, diuresis, bispectral index, and core body temperature. Anesthesia was induced with thiopental (1.5 mg/kg), fentanyl (5 mcg/kg), and rocuronium (0.6 mg/kg). Patients were intubated with a single tracheal lumen and ventilated with a mixture of air and oxygen (60%), and the end-tidal CO<sub>2</sub> was maintained between 35 and 40 mmHg. After the induction of anesthesia, a central venous catheter (three lumens) and a high flow dual lumen catheter was inserted separately in the left internal jugular vein. We used the high flow catheter to give rapidly blood lost during operation using intra-operative blood salvage. Anesthesia was maintained with continuous infusion of propofol (3–5 mg/kg/h) and remifentanyl (0, 1–0, 2 mcg/hg/min). During the procedure, a complete heparinization was necessary administering 300 U/kg of heparin to reach ACT more than 400 s, that was completely reversed at the end of the procedure by protamine. At the end of surgery, before to stop propofol and remifentanyl, 3 mcg/kg of fentanyl was administered and started an elastomeric infusion pump with tramadol and ketoprofen for postoperative pain management. The patients at the end of the operation were extubated in the operating room.

The approach to the patient for transapical access to the LV is achieved through a left lateral thoracotomy in the fifth intercostal space (4–5 cm incision). A safe LV

access site, placed 2-4 cm posterolateral from the apex, is obtained by probing the LV with finger and viewing with the echo the proximity of the potential site to the papillary muscle.

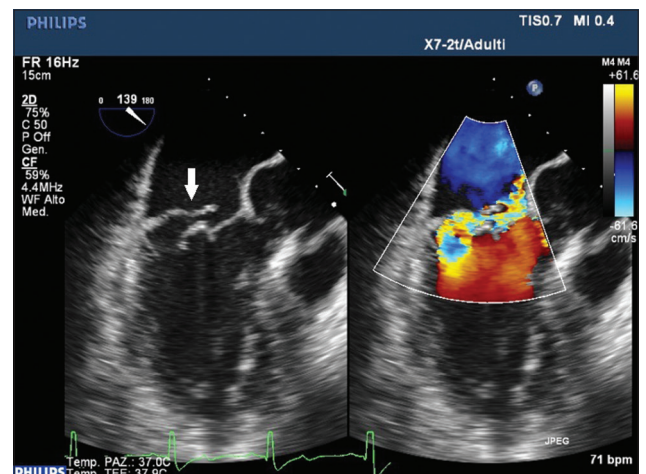
### TRANSESOPHAGEAL ECHOCARDIOGRAPHY IN NEOCHORD PROCEDURE

The NeoChord procedure is performed under two-dimensional and three-dimensional TEE guidance through a standard transapical access as previously described. TEE guidance is necessary to implement the phases of the procedure as follows: MV evaluation, insertion of the device, leaflet grasping and assessment of leaflet capture, tension of NeoChords, and evaluation of results. These are the steps for the procedure:

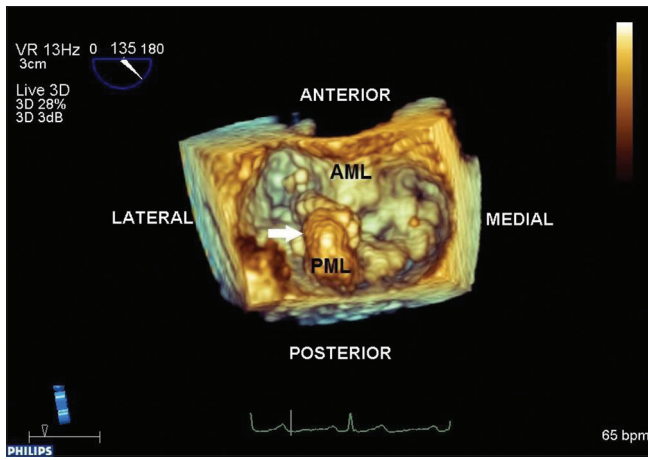
#### Mitral valve evaluation

Complete two-dimensional, color, pulsed-wave, and continuous-wave Doppler images are obtained for assessing MV. Multiplane two-dimensional TEE evaluation includes the complete standard protocol for the evaluation of the MV, allowing complete description of all segments of the valve. The Carpentier nomenclature is applied to the locations of MV prolapse. Two-dimensional prolapse gaps is measured in each patient using two-dimensional TEE with and without color flow Doppler to identify the primary mechanism and etiology of MV prolapse from the 4-chamber, the transcommissural and the 2-chamber view obtained at the midesophageal level with 0°, 60°, 90° and from the long-axis view obtained at the midesophageal level with 120°. Prolapse gap and width are quantified in the end-systolic frame [Figure 2]. In addition from the same last position, we use three-dimensional TEE for scanning three-dimensional images, that is particularly useful for assessing the complex commissural and lateral and/or medial lesions of MV prolapse. Three-dimensional TEE can provide high image quality with high-resolution although it requires particular attention for acquisition of the complete data set and reconstruction of the images. Zoomed three-dimensional TEE images of the entire MV is choose and gain settings is optimized using narrow-angle acquisition mode. It must be noted that enlarging the region of interest excessively will result in a further detrimental decrease of the spatial and temporal resolution relative to real-time three-dimensional. A zoomed acquisition permits a focused, wide sector view of MV (allowing the highest temporal and spatial resolution) and is best suited to detail MV leaflet anatomy and motion. After capturing the three-dimensional close-up MV image, we rotate

it to obtain a surgical view from the atrium with the aorta in the foreground and the appendage on the left. To avoid misidentification of the individual MV segments owing to the foreshortening effect, image quality is optimized on-line with a modifiable cutting plane to remove artifacts, adjusted segment-by-segment for the commissural landmarks and obtain detailed visualization of MV segments. During the end-systolic frame, we identify the posterior leaflet segments using the commissures and clefts as referral points. The so-called posterior leaflet scallops are classified as lateral (P1), middle (P2), and medial (P3) starting from the anterolateral commissure to the first cleft, then the second cleft, and finally the posteromedial commissure, respectively. The anterior leaflet segments is classified as lateral (A1), middle (A2), and medial (A3) using the facing segment of the posterior leaflet as the referral points. Prolapsing segments is carefully identified in every patient and is recognized when the tip of one or more valvular segments extended 2 mm relative to the leaflet-annular hinge points using a modifiable cutting plane to perform a multiplanar reconstruction long-axis view with a segment-by-segment analysis perpendicular to the intercommissural line [Figure 3]. Prolapse localization is classified as one or more segment monoleaflet, bileaflet, commissural, or combined (leaflet and commissure). Furthermore, bileaflet prolapse is labeled as symmetric (facing segments) or asymmetric (nonfacing segments). The multiple middle scallops observed between P1 and P3 and the presence of ruptured chordae tendineae (flail) are annotated. Alternatively to the zoom mode we can use live three-dimensional. With this modality, the acquisition and display of three-dimensional images



**Figure 2:** Two-dimensional transesophageal echocardiography long-axis view of mitral valve. On the left side showed prolapse of posterior leaflet (arrow). On the right side with color flow Doppler the mitral regurgitation

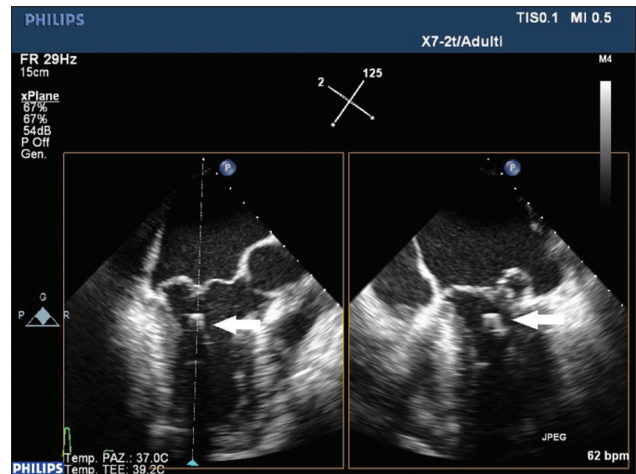


**Figure 3:** Zoomed three-dimensional transesophageal echocardiographic image for the assessment of mitral valve prolapse in P2 segment (arrow). AML: Anterior mitral leaflet, PML: Posterior mitral leaflet

occur instantaneously (on-line) using the matrix array probe, “live” over a single heart beat or gated over multiple heartbeats. During “live” acquisition, the displayed three-dimensional TEE image can change on-screen but only with physical probe movement (turning or advancing) and not by adjusting the multiplane angle. All three-dimensional TEE data are digitally stored for off-line analysis (QLAB Cardiac 3DQ; Philips Medical Systems, Netherlands).

#### Insertion of the device

After the acquisition with three-dimensional TEE of prolapse, we use simultaneous multi-plane imaging (X-plane), unique to the matrix array transducer that permits the use of a dual screen to simultaneously display two real-time images. At the beginning, it is useful to evaluate at 0° and 90° the apex of the left ventricle to identify exactly in 2 planes the point of puncture of the left ventricle placed 2–4 cm posterolateral from the apex. After which the probe is rotated at 120–130° to obtain a long-axis view of the left ventricle. This mode allows the MV to be seen in two planes in real-time. The first image is typically a reference view of MV at 120–130°, while the second image, that is inverted right-left (anterior in the right side and posterior in the left side), or “lateral plane” represents a plane rotated at 90° from the reference plane. This mode allows the MV to be seen in two planes in real-time and to visualize the position the catheter during the insertion. After ventriculotomy, the device is inserted in the LV and the X-plane imaging used to navigate the instrument to the flailing segment of the prolapse MV leaflet [Figure 4]. Although the advancement of the distal tip could be impeded by the



**Figure 4:** Multi-plane imaging (X-plane) of mitral valve (MV). The use of a dual screen is useful to simultaneously display two real-time images. In the left side the image is typically a reference view of MV at 120–130°, while on the right side the image that is inverted right-left (anterior in the right side and posterior in the left side), or “lateral plane” represents a plane rotated at 90° from the reference plane. This plane allows the MV to be seen in two planes in real-time and to visualize the position of the device during the insertion (arrow)

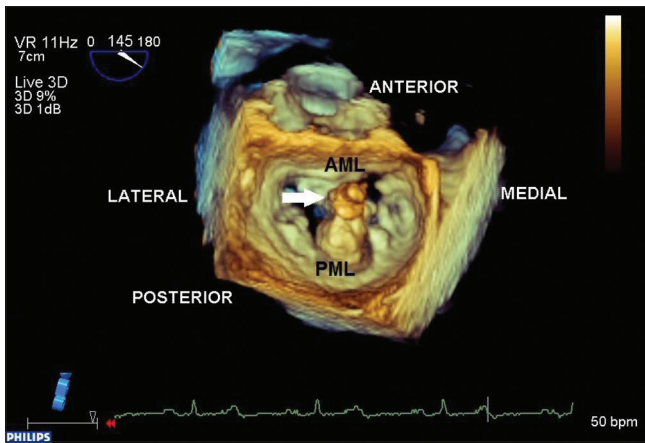
native chordae, this is resolved with simple retraction of the device. Contact with the native chordae is minimized by slowly advancing the device while frequently observing the trajectory of the device in 2 planes. This phase is successfully completed when the device is inserted through the MV into the left atrium.

#### Leaflet grasping and assessment of leaflet capture

At this point, capturing the MV in the zoom mode permits visualization of the catheter and the correct position to the level of the leaflets were necessary to attach the NeoChords. The jaws of the device are opened, and the flailing segment is captured [Figure 5]. Effective leaflet capture is confirmed by the four fiber-optic monitor lights changing from red to white. Piercing and fixation with subsequent retraction of the NeoChords are realized using a special needle inserted in the device. Once a NeoChord is deployed, the device is removed from the heart. Optimal placement of each NeoChord is evaluated by placing the NeoChord under tension and observing significant contribution to MR reduction. If the placement is deemed inappropriate, a retrieval suture is used to remove the deployed suture.

#### Tension of NeoChords and evaluation of results

At the end of the procedure, we evaluate with two-dimensional and three-dimensional the results of the procedure. If MR is effectively reduced under

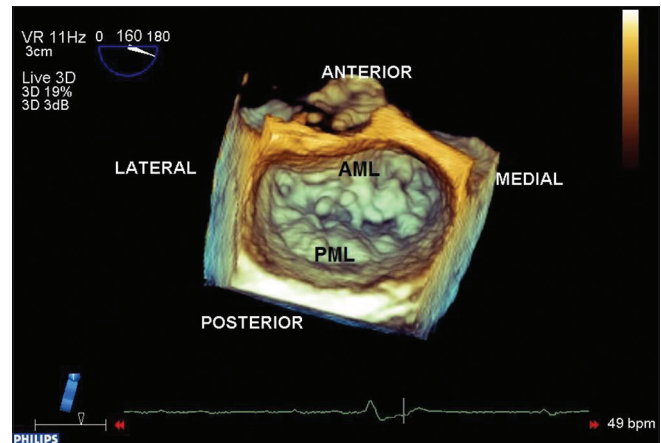


**Figure 5:** Three-dimensional transesophageal echocardiography of mitral valve (MV) with the NeoChord device (arrow) within the MV orifice. The grasping mechanism, which can be identified as the accentuation on the tip, is facing the P2 segment where there is the prolapse. Three-dimensional echocardiography imaging is especially valuable for identification of the prolapsing segment of the MV as well as for intraoperative navigation of the device. AML: Anterior mitral leaflet, PML: Posterior mitral leaflet

light tension of the suture, the neochordal position is considered to be good, and the NeoChord left in MV leaflet. In addition, a short-axis view is used to visualize the deployed NeoChords to determine desired position. At the end deployed NeoChords are anchored to the epicardium by passing the sutures back through the LV wall and then suturing to the epicardium over a pledget adjacent to the ventriculotomy with a standard surgical knot. Tension and securing of NeoChords are controlled by TEE to achieve maximal competence of the MV [Figures 6 and 7].

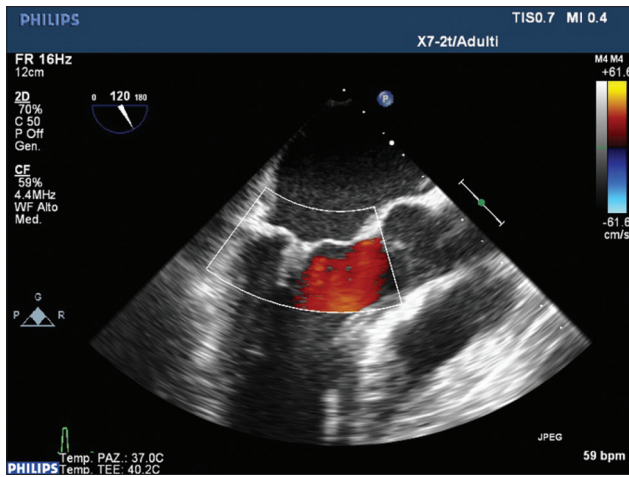
## DISCUSSION

The number of surgeries performed using less-invasive techniques has increased dramatically over the last two decades. While the minimally invasive approach has become the standard of care for many surgical procedures, this shift was initially slower in cardiac surgery, since most heart operations are very complex, requiring not only cardiopulmonary circulation but also outstanding precision to achieve successful results. Advancements in diagnostic tools, development of specific cardiac instruments, the introduction of peripheral cardiopulmonary bypass circuit systems and novel surgical techniques have enabled cardiac surgeons to start operating on the heart through a minimally invasive approach. Among the different areas of cardiac surgery, this approach has gained particular popularity in the field of MV treatment. In this context,



**Figure 6:** Three-dimensional transesophageal echocardiography of mitral valve (MV) at the end of the procedure. The prolapse of the posterior leaflet as we have seen previously disappeared. Tension and securing of NeoChords is controlled by three-dimensional transesophageal echocardiography and two-dimensional to achieve maximal competence of the MV. AML: Anterior mitral leaflet; PML: Posterior mitral leaflet

transapical beating-heart implantation of NeoChord represents a novel surgical procedure for performing MV repair in patients with MV prolapse and severe MR.<sup>[8-12]</sup> The goal of the procedure is to decrease the invasiveness of MV repair procedures, to avoid the risks of cardiopulmonary bypass and aortic cross-clamping, providing the option of a small incision with favorable cosmetic effect without the disadvantage of inferior durability. The use of real-time three-dimensional TEE is mandatory to perform the NeoChord procedure, TEE plays a key role in the procedure and real-time three-dimensional TEE provides more accurate information than two-dimensional TEE to guide the device to the target leaflet for deployment of the NeoChords. Three-dimensional TEE allows for complete visualization of the MV apparatus by providing images from both the atrial and the ventricular perspective<sup>[17-19]</sup> with the feasibility and accuracy for identifying the locations of MV prolapse and in addition contributes to performance adequacy and to evaluating the individual steps of NeoChord implantation. The three-dimensional views of the intracardiac devices' position with respect to the heart structures help the operator to guide the delivery system through the MV and to capture the flailing segment. Therefore, TEE guidance is necessary to implement all the phases of the procedure. In addition, clinical experience and evidence from the literature suggest that real-time three-dimensional TEE improves visualization of the MV through the display of the whole valve from a single image. This means that consulting off-line sources or relying on one's



**Figure 7:** Two-dimensional transesophageal echocardiography showed no residual regurgitation after NeoChord implantation

memory is not needed and that even physicians who are not expert in ultrasound imaging, such as surgeons and interventional cardiologists, can easily interpret the echo view. As a consequence, three-dimensional TEE ameliorates communication between operator and echocardiographer.

Additional questions remain regarding this promising repair technique. What's long-term durability of the NeoChord procedure? What's target population for use of this device? Further investigation is needed to answer these questions, in particular to assess durability and long-term outcome.

## CONCLUSIONS

The NeoChord approach with its promising initial results, is a treatment option in patients with isolated MV leaflet prolapse, where the physiological approach, the low invasiveness, and the effective reduction of MR at a very low operative risk may be used in primary MR. The determination of the exact positioning, length adjustment, and NeoChords tensioning depends exclusively on the ability and training of the operator and echocardiographer where the TEE has a key role. In our experience, transapical NeoChord implantation under beating-heart conditions is feasible, can be performed safely, and results in a relatively short procedure time. In this context TEE not only plays a major role but also is an indispensable tool and real-time three-dimensional TEE rather than two-dimensional TEE provides more accurate information to guide the device to the target leaflet for deployment of the NeoChords. Cardiac anesthesiologists, who combine expertise in intraoperative echocardiography with skill

in hemodynamic management, play a fundamental role in this new procedure being guiding eyes for the surgeon.

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