

CASE REPORT

INTERMEDIATE

DAVINCI CORNER

Insights Into Interaction Between Clip Device and the Mitral Valve Apparatus in the Human Heart



Takanori Sato, MD, PhD,^a Issam D. Moussa, MD, MBA,^b Peter Hanna, MD, PhD,^a Kalyanam Shivkumar, MD, PhD,^a Shumpei Mori, MD, PhD^a

ABSTRACT

Precise appreciation of the 3-dimensional relationship between the edge-to-edge clips and mitral valve apparatus remains clinically challenging. We demonstrate the images of clips observed in situ 4 years after implantation. Detailed observation from this case helps improve our understanding of 3-dimensional clinical cardiac anatomy related to transcatheter edge-to-edge mitral valve repair. (**Level of Difficulty: Intermediate.**) (J Am Coll Cardiol Case Rep 2023;22:101999)
© 2023 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Intraprocedural transesophageal echocardiography is the gold standard for guidance of transcatheter edge-to-edge mitral valve repair.^{1,2} Transesophageal echocardiography, however, provides very limited understanding of the location and interaction of the mitral chordae tendineae with the mitral leaflets. Thus, manipulation of the

transcatheter edge-to-edge mitral valve repair device in the left ventricle is essentially blind to the chordae tendineae. We herein share the images of edge-to-edge clip device (MitraClip, Abbott Laboratories) observed in situ 4 years after implantation.

CASE REPORT

We received the heart of a 58-year-old man that was rejected for transplantation. Medical history included an old myocardial infarction, atrial fibrillation, coronary artery bypass graft surgery (11 years ago), and transcatheter edge-to-edge mitral valve repair (4 years ago). This patient died as a result of nonoperative extensive bilateral frontal and temporal parenchymal hemorrhage. Before dissection, the heart was pressure-perfused and fixed to maintain the pathophysiological morphology.³ Two clips, central and medial, had been implanted at the A2-P2 scallops of

LEARNING OBJECTIVES

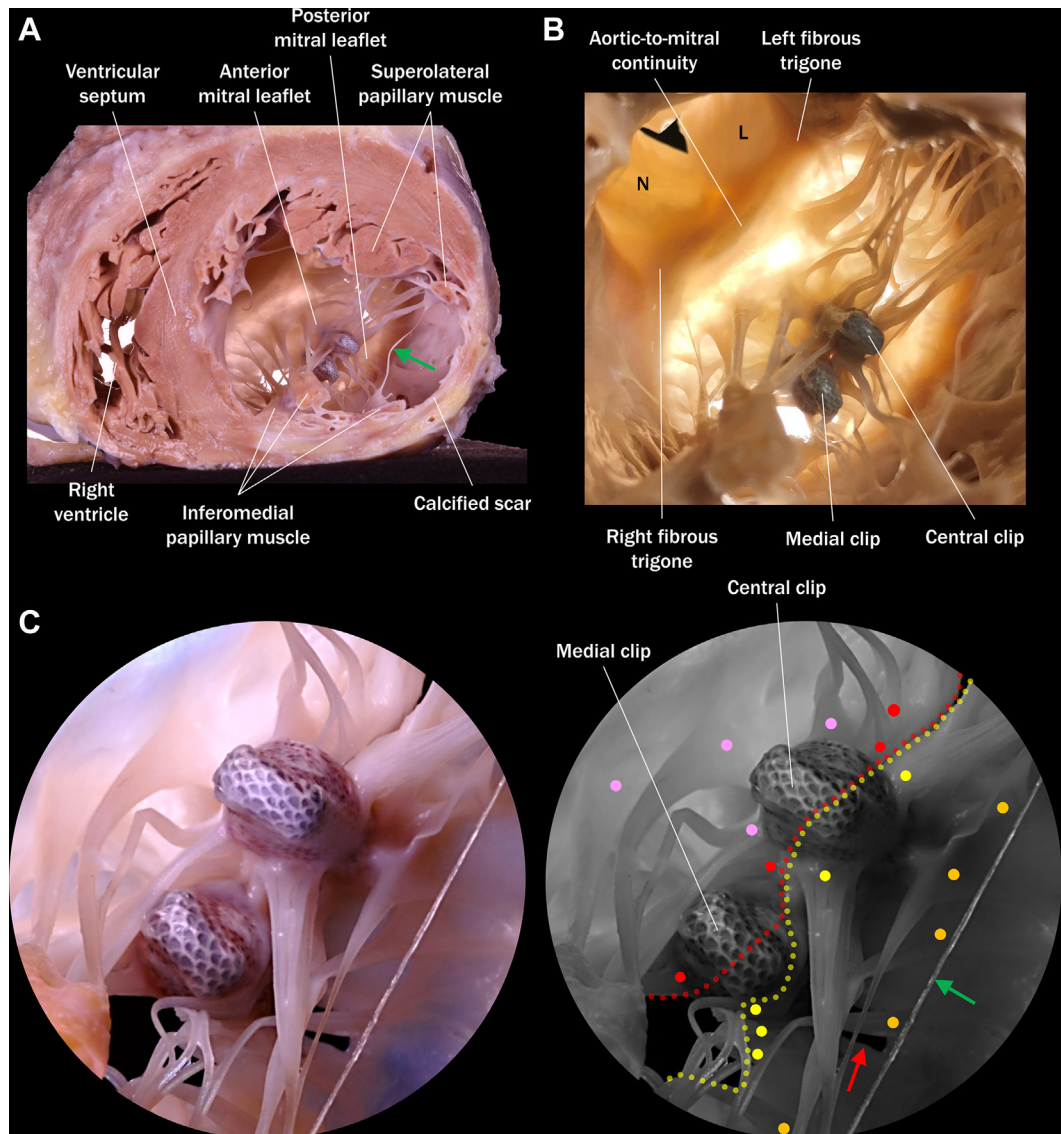
- To appreciate the undistorted anatomy of clip device-mitral valve apparatus interactions.
- To visualize the 3-dimensional anatomy of the chordae tendineae connections to the mitral leaflets.
- To recognize that the distance between the clip arms is reduced in the setting of a single-leaflet capture.

From the ^aUniversity of California Los Angeles (UCLA) Cardiac Arrhythmia Center, Cardiovascular & Interventional Programs, UCLA Health System, David Geffen School of Medicine at UCLA, Los Angeles, California, USA; and the ^bCarle Illinois College of Medicine, University of Illinois, Carle Heart and Vascular Institute, Champaign, Illinois, USA.

Bartosz Hudzik, MD, PHD, served as the Guest Associate Editor for this paper. James L. Januzzi, Jr, MD, served as the Guest Editor-in-Chief for this paper.

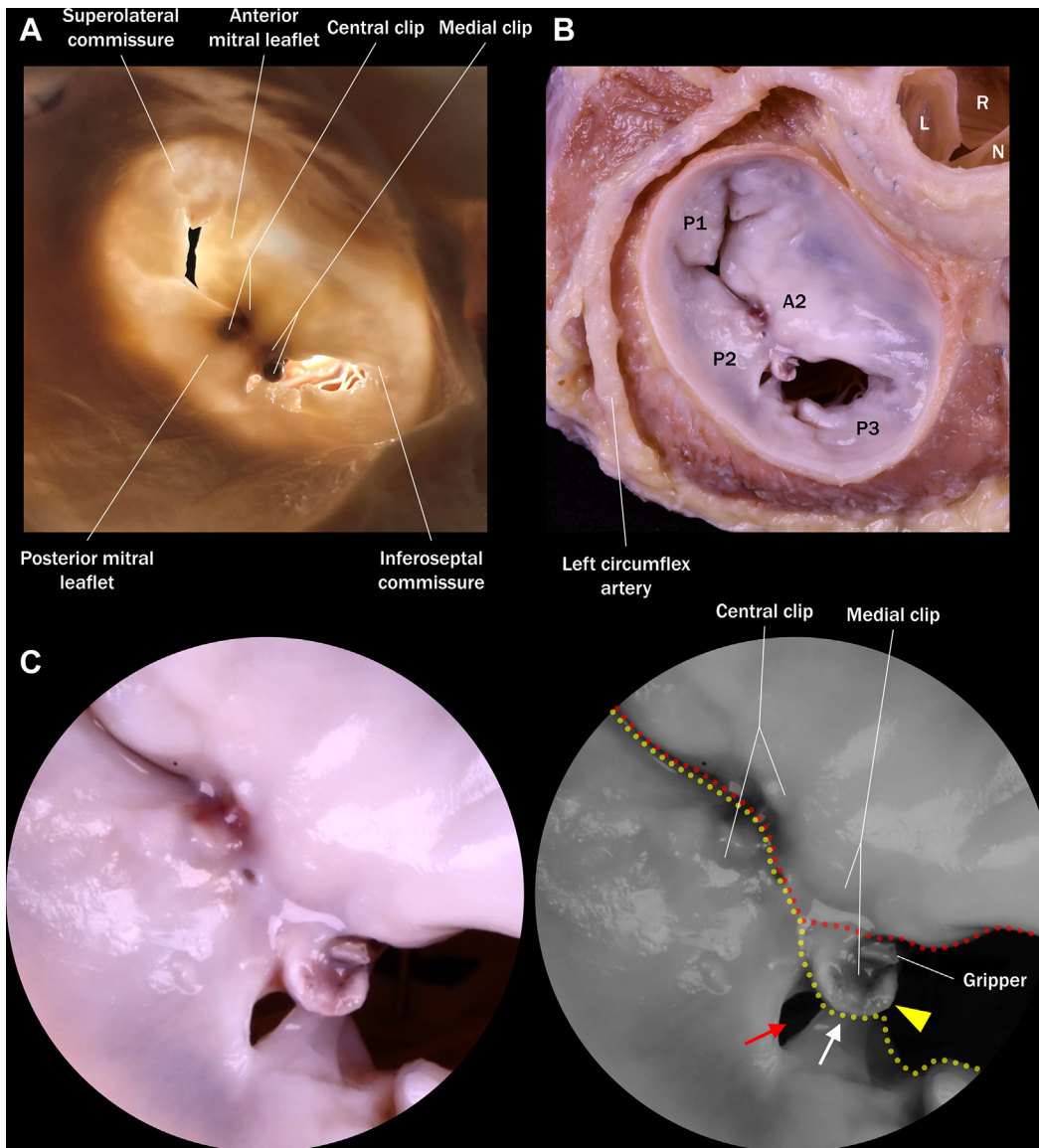
The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the [Author Center](#).

Manuscript received January 16, 2023; revised manuscript received May 3, 2023, accepted June 6, 2023.

FIGURE 1 Mitral Valve Viewed From the Left Ventricle

Extensive calcified infarction scar is noted at the inferolateral left ventricular wall (**A**). The inferomedial papillary muscle and part of the superolateral papillary muscle are also involved, suggesting ischemic mitral regurgitation as the potential mechanism (**A**). Magnified image with transillumination (**B, C**) shows that the chordae-free zone is very narrow in both mitral leaflets, where it is appropriately grasped by the central clip. Both clips apparently grasp multiple first-generation chordae (rough zone chordae) attaching to the edge of the leaflets (**red and yellow circles**), together with the leaflets. Partial endothelialization and/or fibrous adhesion around the clips are also evident. Multiple second-generation chordae (strut chordae) attaching to the ventricular surface of the leaflets (**pink and orange circles**) are not affected by the clips. The medial clip is surrounded by numerous chordae tendinae originating from the inferomedial papillary muscle (**B, C**), suggesting the limited working space and increased risk of clip entanglement. A tiny tear in the posterior mitral leaflet (**red arrow**) and thin single chordal connection between the papillary muscles (**green arrows**) are noted. **Red and yellow dotted lines** denote the free margin of the anterior and posterior mitral leaflets, respectively (**C**). Although it is difficult to appreciate from this direction, the posterior mitral leaflet is not grasped by the medial clip, but shows the adhesion on its inferior surface. L = left coronary aortic leaflet; N = noncoronary aortic leaflet.

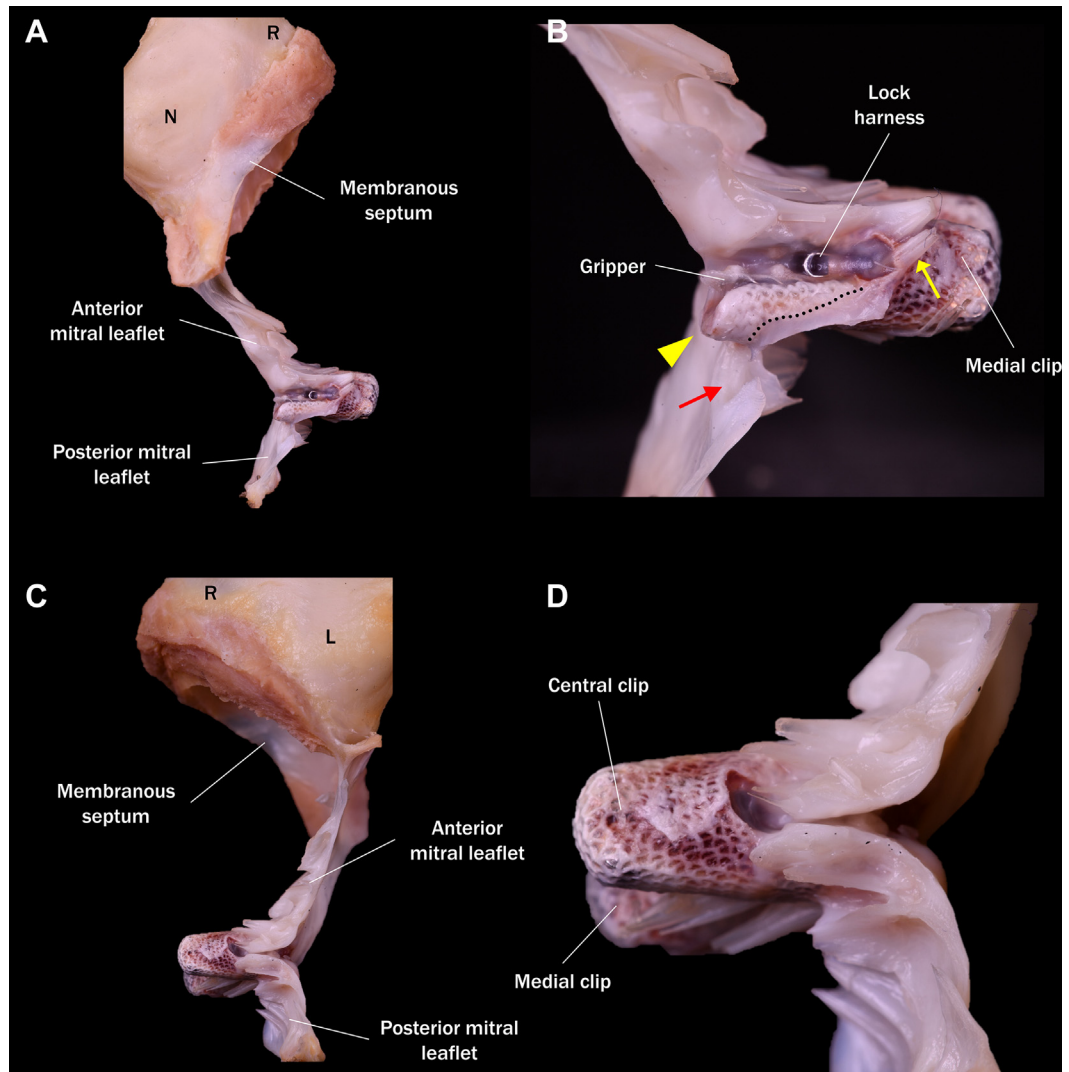
FIGURE 2 Mitral Valve Viewed From the Left Atrium



Surgical view with transillumination (A) shows that the inferior arm of the medial clip looks bare without coverage by the posterior mitral leaflet. Image after removal of the left atrium (B) and magnified image of the middle scallops (C) confirm the bare inferior arm of the medial clip (yellow arrowhead), failing to grasp the posterior mitral leaflet. Both arms of the central clip and the superior arm of the medial clip are covered by the leaflets, indicating the successful capture of the leaflet. A tiny tear in the posterior mitral leaflet (red arrow) and adhesion of the posterior mitral leaflet to the inferior surface of the inferior arm of the medial clip (white arrow) are noted. Red and yellow dotted lines denote the free margin of the anterior and posterior mitral leaflets, respectively (C). R = right coronary aortic leaflet; other abbreviations as in Figure 1.

the mitral leaflets (Figures 1 and 2). Subsequent progressive dissection of the heart was then performed focusing on the relationship between the clips and the mitral valve apparatus. Direct observation of the left ventricular wall and the interaction between the clips and the mitral valve apparatus (particularly the

chordae tendineae) revealed insightful anatomical nuances that would be impossible to visualize using clinical imaging modalities. These observations include the partially infarcted papillary muscles (Figure 1), the topographic relationship between each clip and the chordae tendineae/mitral leaflets

FIGURE 3 Magnified Image of the Clips

Close-up images of the medial clip viewed from the medial side (**A, B**) and central clip viewed from the lateral side (**C, D**) in similar fashion with **Figure 4** revealed that the inferior arm of the medial clip fails to capture the posterior mitral leaflet. Thus, the inferior arm looks bare (**yellow arrowhead**) without coverage by the leaflet, and the leaflet is not sandwiched between the gripper and the inferior arm (**B**). A tiny tear in the posterior mitral leaflet (**red arrow**) and adhesion of the posterior mitral leaflet to the inferior surface of the inferior arm of the medial clip (**black dotted line**) are confirmed. **Yellow arrow** denotes the first-generation chorda tendineae of the anterior mitral leaflet captured by the medial clip. On the other hand, the central clip clearly shows dual-leaflet capture (**D**). Note a physiological angulation between the aortic and mitral valvar orifice (**A, C**). Abbreviations as in **Figures 1 and 2**.

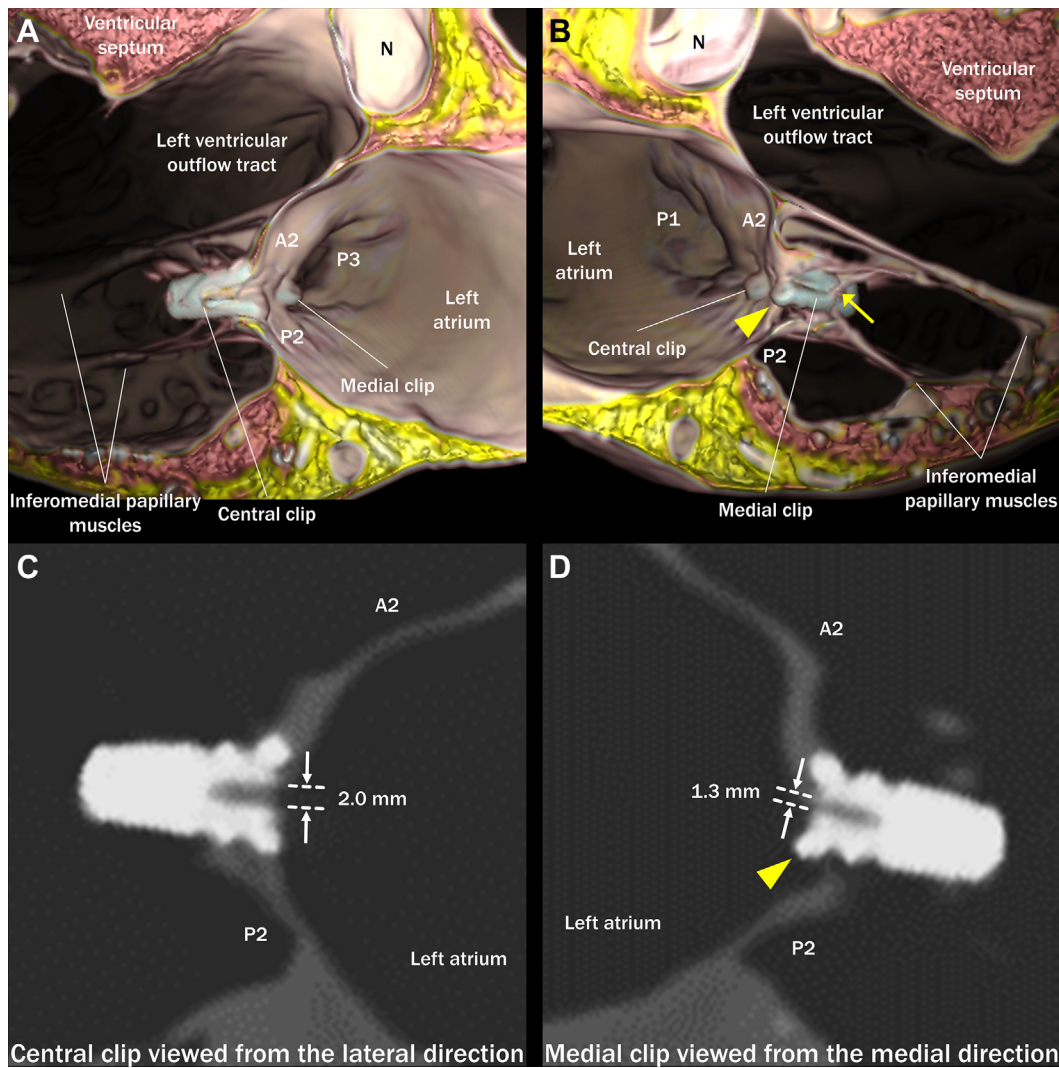
(**Figures 1 to 4**), the tiny tear at the posterior mitral leaflet (**Figures 1 and 2**), the adhesion of the posterior mitral leaflet to the medial clip surface (**Figures 2 and 3**), the capture of the first-generation chordae tendineae by the clips (**Figures 3 and 4**), the chordal connection between both papillary muscles (**Figure 1**), the 3-dimensional relationship between the mitral and aortic valves (**Figures 1 and 3**), and the single-

leaflet capture by the medial clip (**Figures 1 to 5**) with the observed difference in the extent of opening distances of the clips (**Figures 4 and 5**).

DISCUSSION

Typically, the superolateral and inferomedial left ventricular papillary muscles project chordae

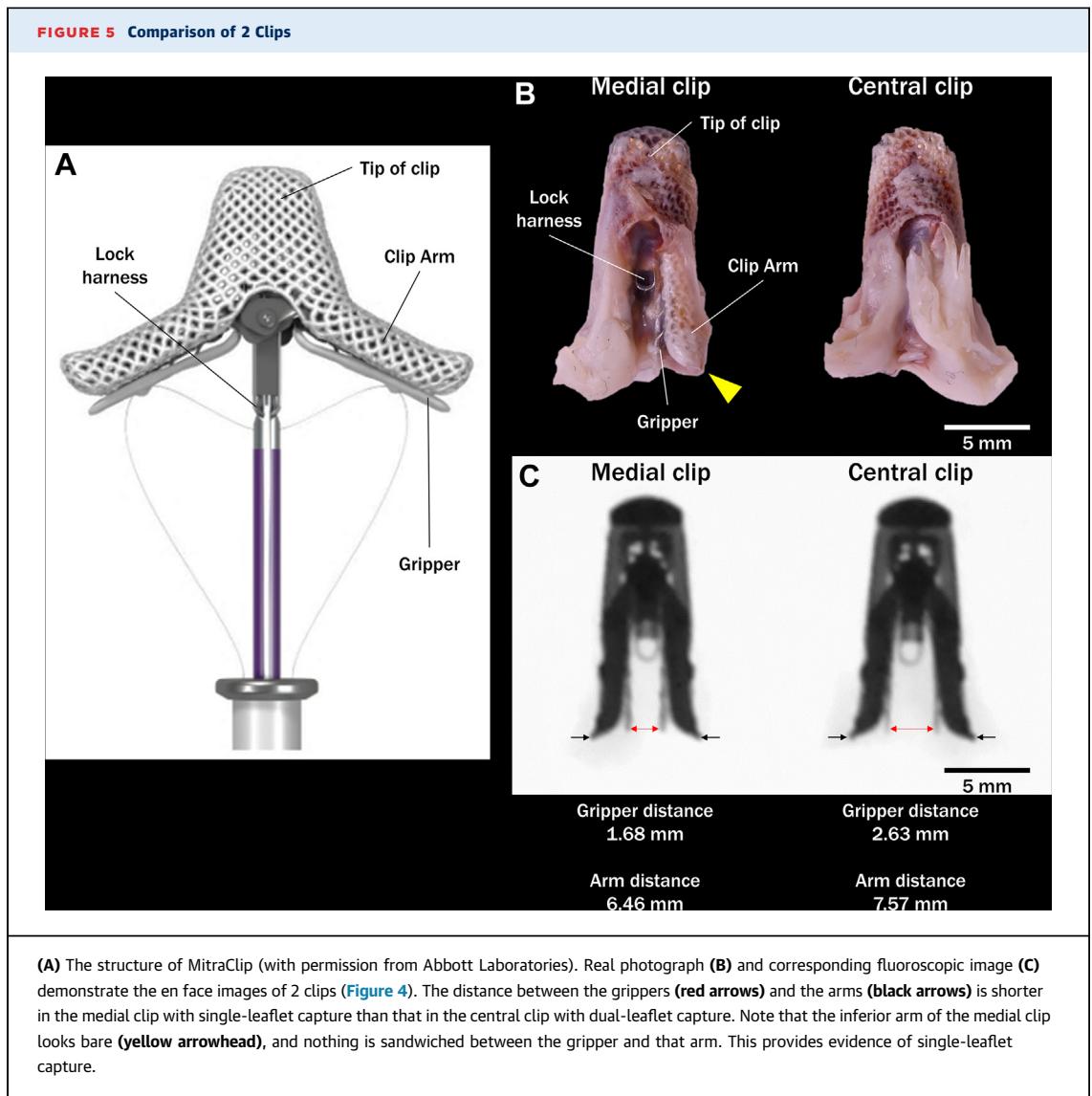
FIGURE 4 Virtual Dissection of the Clip and Mitral Valve Apparatus



Virtual dissection images (A, B) and multiplanar reconstruction images (C, D) of the central clip (A, C) and medial clip (B, D) corresponding to Figure 3 are reconstructed with computed tomographic scanning (SOMATOM Definition AS, Siemens Healthcare). The medial clip does not grasp the posterior mitral leaflet (D). Thus, the inferior arm looks bare (yellow arrowheads) without coverage by the leaflet, and the posterior mitral leaflet is not sandwiched by the medial clip (D). Distance between the arms of the clip is shorter in the medial clip (C, D) than in the central clip. Yellow arrow denotes the first-generation chorda tendineae of the anterior mitral leaflet captured by the medial clip as shown in Figure 3. Abbreviation as in Figure 1.

tendineae to the superolateral and inferomedial aspects of the mitral leaflets,^{3,4} respectively, sparing the central leaflets edges. Thus, the central segments of the anterior and posterior mitral leaflets are considered chordae-free zone.⁵ The presence and extent of chordae-free zone is highly variable in both normal hearts and hearts with mitral valve prolapse.^{6,7} In the current case, chordae-free zones were very narrow in both mitral leaflets, which were

appropriately grasped by the central clip (Figure 1). Even when the noncentral zone outside the chordae-free zone is targeted, transcatheter edge-to-edge mitral valve repair has been reported to be a safe and effective treatment for mitral regurgitation.⁵ However, complications during the procedure may occur, such as clip entanglement/entrapment in the chordae tendineae, resulting in chordal rupture.⁸ The dense chordae network surrounding the medial clip



(Figure 1) can complicate device manipulation, and potentially lead to chordae tendineae capture, which can increase the risk of shallow leaflet capture, single-leaflet capture, or capture failure of both leaflets.

Single-leaflet capture is reported in 1.5% of transcatheter edge-to-edge mitral valve repair.⁹ It can be clinically silent and may be overlooked if the chordae tendineae is captured close to its attachment to the noncaptured leaflet. A detailed observation of clip morphology using fluoroscopy, computed tomography, and direct macroscopic examination revealed that the distance between the 2 arms of the clip with single-leaflet capture is shorter than that of the dual-leaflet capture (Figures 4 and 5). This observation is clinically relevant because it may assist operators in diagnosing a

potential single-leaflet capture before release of the clip. Further investigation in the clinical setting is needed to evaluate the relationship between the distance between the clip arms and single-leaflet capture using intraoperative and postoperative transesophageal echocardiography (3-chamber view), intraoperative fluoroscopy (deep right anterior oblique and caudal angulation), and postoperative cardiac computed tomography.

CONCLUSIONS

In this case report, we demonstrate rare images of a mitral valve clip device in a postmortem heart 4 years after implantation. The insights provided with regard to the interaction between the clips and the chordae

tendineae and the morphologic features of single-leaflet capture can improve the interventionalist's understanding of 3-dimensional interaction between the clip device and the mitral valve apparatus.

ACKNOWLEDGMENTS The authors are thankful to those individuals who have donated their bodies and tissues for the advancement of education and research. They thank the OneLegacy Foundation and the NIH SPARC Program, which formed the basis for obtaining donor hearts for research and for funding this effort, respectively. They are also grateful to Anthony A. Smithson and Arvin Roque-Verdeflor of the UCLA Translational Research Imaging Center (Department of Radiology) for their support in computed tomographic data acquisition. They

appreciate our Research Operations Manager, Amiksha S. Gandhi for her dedication to support our projects.

FUNDING SUPPORT AND AUTHOR DISCLOSURES

This work was made possible by support from National Institutes of Health grants OT2OD023848 to Dr Shivkumar and from the UCLA Amara-Yad Project. All authors have reported that they have no relationships relevant to the contents of this paper to disclose.

ADDRESS FOR CORRESPONDENCE: Dr Shumpei Mori, UCLA Cardiac Arrhythmia Center, UCLA Health System, David Geffen School of Medicine at UCLA, Center of Health Sciences, Suite 46-119C, 650 Charles E. Young Dr South, Los Angeles, California 90095, USA. E-mail: smori@mednet.ucla.edu.

REFERENCES

1. Silvestry FE, Rodriguez LL, Herrmann HC, et al. Echocardiographic guidance and assessment of percutaneous repair for mitral regurgitation with the Evalve MitraClip: lessons learned from EVEREST I. *J Am Soc Echocardiogr*. 2007;20:1131-1140.
2. Beigel R, Wunderlich NC, Kar S, Siegel RJ. The evolution of percutaneous mitral valve repair therapy: lessons learned and implications for patient selection. *J Am Coll Cardiol*. 2014;64:2688-2700.
3. McAlpine WA. Heart and Coronary Arteries: An Anatomical Atlas for Clinical Diagnosis, Radiological Investigation, and Surgical Treatment. New York, NY: Springer-Verlag; 1975.
4. Mori S, Shivkumar K. Anatomical basis of cardiac interventions. In: Shivkumar K, ed. Atlas of Cardiac Anatomy. Vol 1. Cardiotext Publishing; 2022.
5. Estévez-Loureiro R, Franzen O, Winter R, et al. Echocardiographic and clinical outcomes of central versus noncentral percutaneous edge-to-edge repair of degenerative mitral regurgitation. *J Am Coll Cardiol*. 2013;62:2370-2377.
6. Virmani R, Atkinson JB, Byrd BF 3rd, Robinowitz M, Forman MB. Abnormal chordal insertion: a cause of mitral valve prolapse. *Am Heart J*. 1987;113:851-858.
7. Sato T, Moussa ID, Hanna P, Shivkumar K, Mori S. The intermediate accessory papillary muscle: an anatomic variant of interest for transcatheter edge-to-edge mitral valve repair. *Circ Cardiovasc Imaging*. 2023. In press.
8. Benito-González T, Estévez-Loureiro R, Gualis J. Chordal rupture following MitraClip implantation resulting in massive mitral regurgitation. *J Invasive Cardiol*. 2015;27:E224-E225.
9. Sorajja P, Vemulapalli S, Feldman T, et al. Outcomes with transcatheter mitral valve repair in the United States: an STS/ACC TVT Registry Report. *J Am Coll Cardiol*. 2017;70:2315-2327.

KEY WORDS anatomy, chordae tendineae, MitraClip, mitral regurgitation, transcatheter edge-to-edge repair