



GE HealthCare

Vivid™ Magazine

Interventional



Edition 6



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Reader,

From the most demanding structural heart procedures to navigating complex congenital heart disease, in this edition of Vivid Magazine, we're exploring the next wave of innovations and innovators that are helping to transform care in the cath lab.

With a mission to deliver complementary technologies for real-time guidance, and AI-enabled tools to reduce burdens on clinicians, combined with advancements in miniaturization, innovations like the 4D ICE NUVISION™ catheter and the mini 4D TEE probe are now available on the recently introduced Vivid Pioneer. However, progress in interventional cardiology is driven not only by technology but by the collaboration and shared commitment of clinicians, institutions, and innovators worldwide.

In this issue, we feature innovators like Dr. Bassem Chehab of Ascension Via Christi St. Francis in Kansas who leads a globally recognized Structural Heart team that has been opening new pathways for treating fragile patients with tricuspid regurgitation. And Professor Alex Lee in Hong Kong who is part of a high-volume team that performs numerous mitral and tricuspid transcatheter edge-to-edge repair (TEER) procedures annually, with deep experience in overcoming the limitations of TEE. Dr. Konstatinos Papadopoulos of Interbalkan Medical Center in Greece and his team perform up to three hundred procedures yearly and are using the mini 4D TEE to help reduce esophageal trauma. And in France, Prof. Philippe Acar and his team at Toulouse University Hospital are helping to expand access to advanced, real-time imaging for delicate pediatric patients.

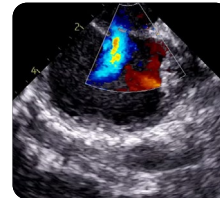
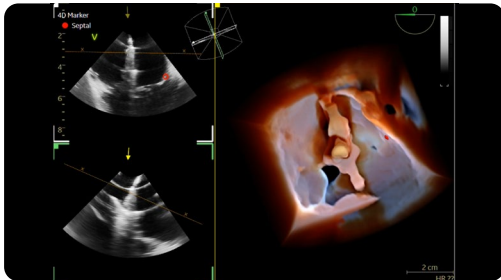
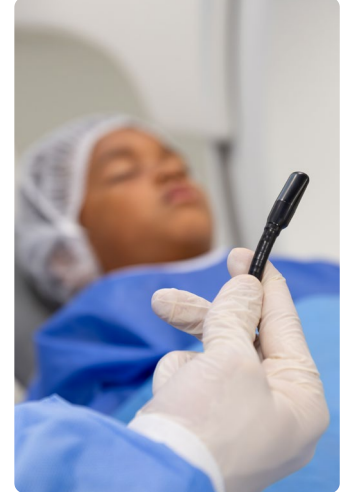
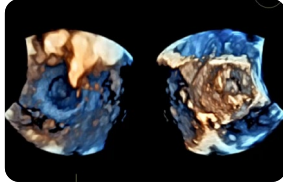
As these leaders in interventional techniques share their findings, insights, and perspectives, we look forward to 2026 being a year of setting new standards in interventional care through continued inspiration and collaboration as we shape the future of cardiovascular care, together.

Dagfinn Saetre

A handwritten signature in black ink, appearing to read 'D. Saetre', written in a cursive style.

P.S. – Stay tuned for our next exclusive issue focusing on Vivid Pioneer clinical case studies from around the world.

Vivid Magazine



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Transforming the interventional toolbox

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Guiding the future of transcatheter tricuspid interventions

How 4D ICE NUVISION™ could provide new hope to fragile patients running out of time and options

Next-generation intracardiac echocardiography is providing a new perspective on transcatheter tricuspid interventions. The prevalence of severe tricuspid regurgitation (TR) and poor prognosis have fueled breakthrough innovations in valve repair and replacement, with advances in intraprocedural imaging driving more progress.



Up until recently, patients with moderate to severe TR had limited treatment options, leading to heart failure, hospitalizations, and a diminished quality of life.¹ Multiple studies have called attention to high mortality rates associated with medical therapy and current surgical options² — highlighting the need for alternative solutions. While emerging transcatheter technologies have shown promising results in safety and efficacy, success is heavily dependent on the quality of procedural imaging.^{3,4}

The Structural Heart team at Ascension Via Christi St. Francis in Kansas is part of that progress. The globally-recognized program, which is led by Bassem Chehab, MD, is participating in several pivotal studies to develop new therapeutic options for patients with failing tricuspid valves. Dr. Chehab was also an

early adopter of the 4D ICE NUVISION™ ultrasound catheter by Biosense Webster, Inc. part of Johnson & Johnson MedTech,* which has opened the door to more minimally invasive procedures.

With real-time, volumetric imaging, a 90° x 90° field of view, and an independent rotating tip, the 4D ICE NUVISION catheter has become Ascension Via Christi's preferred tool while treating tricuspid regurgitation. The sophisticated technology, powered by GE HealthCare's Vivid™ ultrasound system, is designed to allow multiplanar and real-time 4D volume imaging of target structures with minimal manipulation. The Structural Heart program is also leveraging the catheter to guide mitral valve repairs and treat congenital heart disease.

We recently asked Dr. Chehab to share his insights on the latest advancements in tricuspid interventions and the value of 4D ICE in clinical practice.

Can you describe the evolution of your structural heart program at Ascension Via Christi?

Dr. Chehab: *From day one, we were heavily focused on quality, excellence, and good academics. We treated a wide range of structural heart patients, and our program grew tremendously. We went from performing 50 TAVR procedures a year to 350 or 400. We also increased TEER or tricuspid/mitral valve repairs from 30 procedures to more than 100 annually. In 2015, we*

initiated our research program and were involved in numerous IDE clinical trials which included multiple sponsors and technologies. Our team hit high marks. We were top enrollers in both national and global trials. Today our program is one of the top TEER programs in the U.S. primarily because of our multi-disciplinary approach in imaging and ensuring that we are always on the cutting edge with technology.

What has been your experience in using 2D ICE in the structural heart arena?

Dr. Chehab: I've been using what I will call "standard" ICE since 2009. It was always an excellent technology and tool, but it was lacking from a technical or software standpoint. There was never a good marriage between software and hardware, and this was always the limiting factor with 2D ICE.

As we started our program, the value of 2D ICE was largely confined to congenital heart disease conditions, like ASD (Atrial Septal Defect) and PFO (Patent Foramen Ovale). At that time, it wasn't sufficient from a structural

perspective compared to what we have today. We tried to push the envelope many times within our structural heart interventions, but it didn't work well for us.

Also, TEE has progressed so much in the last decades that it's been hard for ICE to catch up. TEE allows for 4D technologies, 4D reconstructions, and all volumetric studies. And when combined with FlexiSlice MPR (Multi-planar Reconstruction) and the biplane options offered with GE HealthCare's system, 2D ICE was really behind.

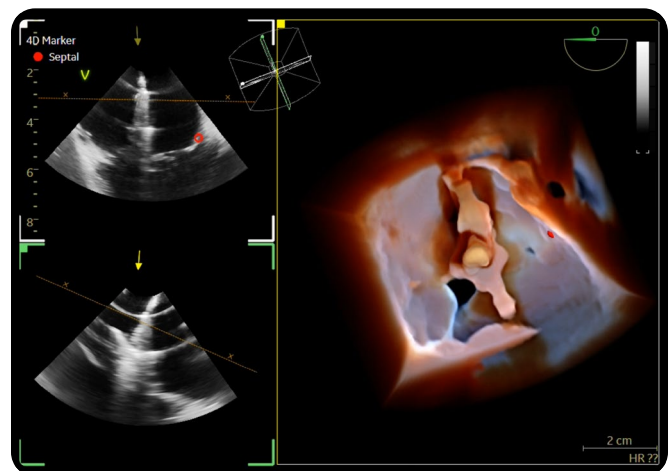
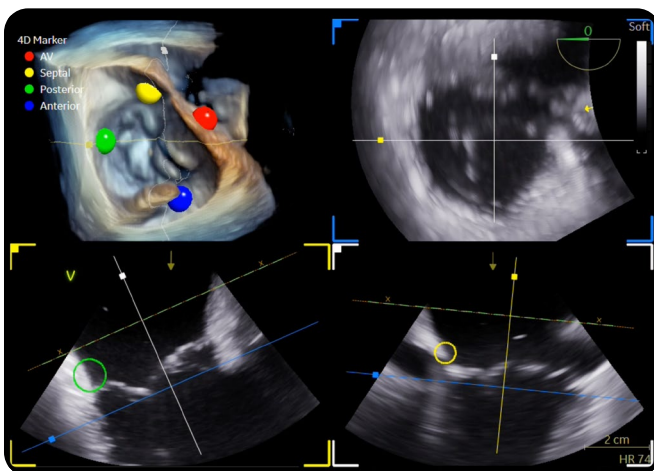
Tricuspid disease has been largely undertreated, but we're now seeing a lot of growth. What's contributed to this growth, and what does this mean for your patients?

Dr. Chehab: The tricuspid space is ready to blow up as the advancement in imaging technologies has significantly increased treatment options. Previously, in our tricuspid interventions, we would struggle with clear imaging. Believe it or not, one of the main screen failures in tricuspid trials is imaging — not anatomical or clinical screen failures. You'd insert the

“ It adds value. If you have sites with heavy volume and they're comfortable with their imaging cardiologist, then adding a 4D ICE catheter is like gold. It's only going to make them better and improve and excel even more. I love having options — and this is an amazing option.”

TEE probe into the patient, and you just couldn't see anything. You couldn't see the tricuspid well enough to fix, repair, or replace it. We tried imaging with 2D ICE as well, and it didn't bring much to the table either.

We now have imaging that enables clear visualization of structural anatomy. What does this mean for our patients? Many people may no longer need to medically manage their TR symptoms. High-quality imaging expands valve repair or replacement options which can drastically improve quality of life for patients.



You were among the first in the U.S. to use the 4D ICE NUVISION catheter. What were your initial impressions and why was it appealing for tricuspid interventions?

Dr. Chehab: *I was skeptical in the beginning. I started with congenital cases, PFO and ASD. The first cases worked well, and I believed there was more potential. Then as I was imaging the septum for congenital cases, I glanced at images of the tricuspid and it was like a crystal-clear picture. The quality, the details, the high definition of the tricuspid leaflet blew my mind. That was my first step.*

At that time, many people in the U.S. were also starting to see the need to do more tricuspid cases with 4D ICE. So we started using the 4D ICE NUVISION catheter in the tricuspid space and this is where it really blew my mind. It's unbelievable.

How has the 4D ICE NUVISION catheter's unique design been beneficial in procedures?

Dr. Chehab: *When the right atrium is large, the imaging catheter can get lost in space. For example, with 2D ICE it can take 8 to 10 moves to get to the position you want. This is a lot of movement. As I started to use 4D ICE NUVISION catheter for imaging the tricuspid, I noticed that it took me a third of the time and effort. That is a significant reduction in time for imaging during interventions.*

The beauty of the 4D ICE NUVISION catheter is that the tip allows for 360°

rotation and the system includes a knob that allows you to scan the space around the crystal tip. This is a key feature, and I don't think it's available on any other system. It minimizes the sensation of being disoriented in the right atrium so you're consistently confident of where and what you are imaging.

“ *I performed two very challenging cases with edge-to-edge repair for the tricuspid valve. If I was just using TEE, I would have stopped. I added the 4D ICE NUVISION catheter and it took less than an hour to complete both cases, and we had excellent results. It was smooth, streamlined, and we felt confident and relaxed.”*

The feature also makes a big difference if there's any shaking or movement after you've already found the ideal spot for imaging. All you have to do is adjust the 360° rotation knob and you're right back in place. No need to go through large movements or feel lost in space.

With other systems, you need to flex or rotate your hand in multiple directions to find the right location. Every time you flex the crystals on the tip, you lose your image and then need to re-orient yourself.

Has stability ever been an issue with the 4D ICE NUVISION catheter in patients with severe or torrential tricuspid regurgitation or when imaging tricuspid valves in patients with large atriums?

Dr. Chehab: *We've had no stability problems with the 4D ICE NUVISION catheter. Although we did have stability issues with 2D ICE. If you're too high with 2D ICE, you lose the image quality and if you're too low, it's not stable and you won't see anything. You are just too close to the valve.*

The NUVISION design is very smart and user-friendly. One of the key features is the ability to manipulate the position of the catheter and it stays in place. It doesn't change and it doesn't move. The device is very stable and it stays exactly where you want it. That's what makes it so much easier for us. There's a noticeable change from 2D to 4D ICE.

How has the 4D ICE NUVISION catheter impacted your overall workflow?

Dr. Chehab: *The catheter design is very user-friendly and allows a single operator to do both the imaging and the tricuspid valve repair or replacement. Before we needed a dedicated operator with 2D ICE and someone to do the actual intervention. Right now, I'm the only operator.*

In our program, there are scheduling issues with imaging, so the 4D ICE NUVISION catheter has helped us a lot. It's adaptable to patient volume but doesn't replace an imaging

sonographer or imaging cardiologist. It adds value. If you have sites with heavy volume and they're comfortable with their imaging cardiologist, then adding a 4D ICE catheter is like gold. It's only going to make them better and improve and excel even more. I love having options — and this is an amazing option.

In addition to easing scheduling issues, how has the high-resolution, real-time catheter made a difference in exam time?

Dr. Chehab: *It used to take hours to complete a case and now we can do it in less than an hour. And that's even with a difficult case. A few weeks ago, I performed two very challenging cases with edge-to-edge repair for the tricuspid valve. If I was just using TEE, I would have stopped. I added the 4D*

ICE NUVISION catheter and it took less than an hour to complete both cases, and we had excellent results. It was smooth, streamlined, and we felt confident and relaxed.

“ *There is no way I will do any tricuspid without 4D ICE NUVISION.”*

Many structural heart programs are using GA (general anesthesia) for most of their procedures. Do you think 4D ICE could reduce the use of GA in the future?

Dr. Chehab: *In my opinion, one of the reasons why we do general anesthesia with tricuspid is that no one is going to*

tolerate a TEE probe for 3 to 4 hours while awake. No matter what you do — monitored anesthesia care or light sedation — there's no clinical reason to put someone to sleep if you're repairing or replacing a tricuspid valve. It's an imaging issue and a TEE issue. The second you take away the need for TEE, you take away the need for anesthesia. There's a direct link.

A few years ago when we were still learning with the 4D ICE NUVISION catheter, we always did TEE and 4D ICE. But as the comfort level and the learning curve changed, we started turning off the TEE probe and doing 4D ICE with the TEE probe as a backup. As you become more confident, you determine that you can do it all with 4D ICE and you don't need to put the patient to sleep. And that's the game changer.



“ 4D ICE NUVISION catheter is a major breakthrough. The accuracy and confidence we have in repairing or replacing a tricuspid valve is equal or on par with replacing an aortic valve with a TAVR or doing a mitral edge-to-edge repair. It has also given us better outcomes.”

You described your progression utilizing the 4D ICE NUVISION catheter. How are you incorporating it into tricuspid valve procedures today?

Dr. Chehab: *There is no way I will do any tricuspid without 4D ICE NUVISION. It's in our protocol right now. Any operator who does not use it in our program is going to get a review from me that says, 'Why are you putting the patient at risk and why are you doing something that is going to take four hours versus one hour?' It's a must.*

How would you describe the value of the 4D ICE NUVISION catheter and the potential impact on tricuspid interventions?

Dr. Chehab: *4D ICE NUVISION catheter is a major breakthrough. The accuracy and confidence we have in repairing or replacing a tricuspid valve is equal or on par with replacing an aortic valve with a TAVR or doing a mitral edge-to-edge repair. It has also given us better outcomes.*

There's no way to even start to describe where 4D ICE is going to go in the tricuspid space. Alone, the use of the 4D ICE NUVISION catheter has significantly improved the reduction of tricuspid regurgitation. I think this technology is really a game changer and the key to expanding care for more patients. So we don't have to tell patients, 'we can't treat you because we cannot see very well, or you will have to wait for different technologies.' With 4D ICE NUVISION catheter, it's here today, it's ready, and available. There is no reason for anyone to delay the care of any tricuspid patient because of bad or suboptimal imaging. You just have to start using it.

Ascension Via Christi was also one of the early adopters of the world's first mini 4D TEE probe. Can you describe your experience?

Dr. Chehab: *My first reaction was, 'What in the heck is this? Is this real? It's not going to work and we already have a TEE.' But I was wrong. It makes sense that the mini probe may help to reduce complications for people who have esophageal strictures, but the value goes way beyond that. I didn't understand it until I started using it.*

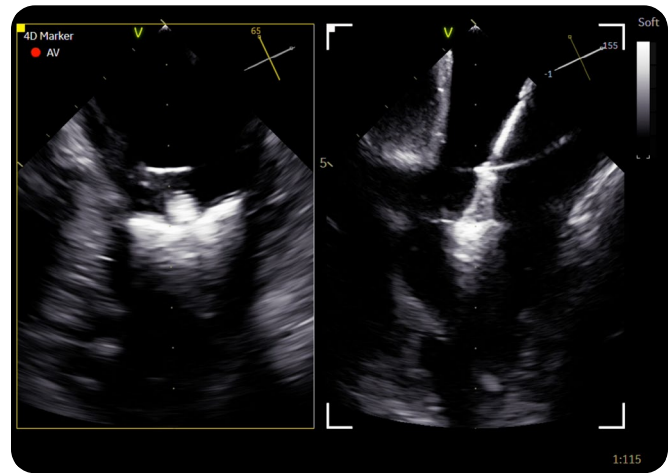
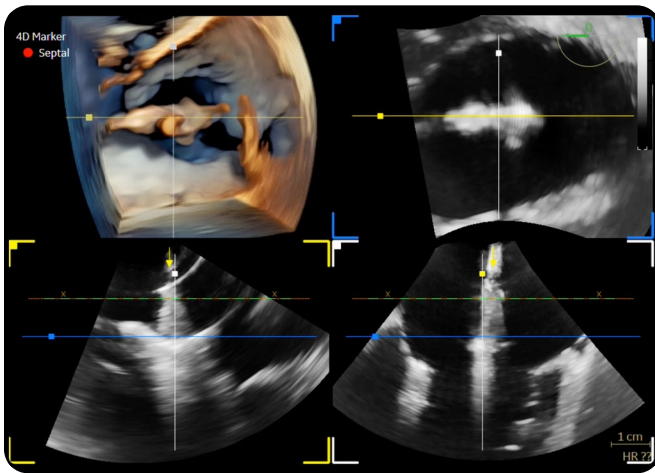
With a mini, the question is: can you compensate and have the same image quality as regular 4D ICE? I thought that there was no way, and I was very wrong. It's only slightly less quality than what we have with the adult 4D TEE from GE HealthCare, but really a negligible change.

I am comfortable using the mini 4D TEE for a lot of things I do with 4D TEE. It again helped me shift from general anesthesia to conscious sedation. For example, when I'm doing an appendage closure, sometimes I have a challenging transeptal puncture and the patient is awake and I don't want to pass the TEE probe. I will pass the mini probe and the patient tolerates very easily and it takes me two minutes. I'm done with my transeptal puncture, take the probe out, and I finish the rest with the 4D ICE NUVISION catheter. It really allows us in certain challenging cases to mix and match the technology and has complemented our program.

“ Alone, the use of the 4D ICE NUVISION catheter has significantly improved the reduction of tricuspid regurgitation. I think this technology is really a game changer and the key to expanding care for more patients.”

How can the 4D ICE NUVISION catheter and mini 4D TEE probe be expanded to more structural heart interventions?

Dr. Chehab: *4D ICE NUVISION is essential for tricuspid imaging or you're done. It's definitely a must. For our aortic program, we do a lot of TAVR cases and use conscious sedation. When we started doing TTE and TEE ages ago,*



general anesthesia was used, but now we've gone to conscious sedation.

With transthoracic cases, we're sometimes not sure how much PVL is on the aortic side. And you know these patients are fully heparinized, so the last thing you want to do is use a big TEE probe. While they're awake, I just pass the mini 4D TEE probe and it's atraumatic — it's an easy insertion. Then I can assess the aortic valve with hyper-accuracy to make sure that I'm comfortable, so this is the value of the mini 4D TEE probe.

Today's structural heart programs include aortic valves, TAVR, LAAC, the mitral valve, and now the tricuspid valve. The Vivid ultrasound portfolio includes 4D TTE, 4D TEE, mini 4D TEE and the 4D ICE NUVISION catheter. What are the benefits of these tools?

Dr. Chehab: The value of the GE HealthCare imaging portfolio is its versatility. It takes away a lot of the thinking and frustration from these structural procedures. The patient is not getting the best outcome without a

plethora of options. That includes a cutting-edge 4D TEE integrated with innovative software like you have with GE HealthCare, a mini 4D TEE probe, and 4D ICE NUVISION catheter.

Whether it be related to the tricuspid, mitral, atrial appendage, aortic, congenital, etc., anything from a structural heart standpoint, I feel confident in my imaging. That's the beauty of having a portfolio in your hand.

“ There is no reason for anyone to delay the care of any tricuspid patient because of bad or suboptimal imaging. You just have to start using it.”

What surprises you most about GE HealthCare cardiovascular ultrasound and the Vivid portfolio?

Dr. Chehab: Nothing surprises me anymore because I've been surprised so many times. What surprises me is

the dedication GE HealthCare has for structural. That's changed the game and that has put us at a different level. It's very rare for an imaging company to understand the interventional world because historically the culture has been 'we sell you the machine and we're done.' That's how it's been done with many other companies in the past and continues with some today. With GE HealthCare, the Vivid product, and cardiovascular imaging department, they're dedicated to case coverage and have excellent clinical support. I've had cases where GE HealthCare clinical specialists have shared ideas from other programs, so they're very experienced, dedicated, and passionate about what they do.

I'm not buying a machine. I'm also buying all the clinical experience and the clinical specialists that come with the machine. And I think that's my biggest asset — more than just having 4D ICE or having Vivid software. I'm getting the whole package and getting the whole deal, and that's what I like. ■



Dr. Chehab, MD, FACP, FACC, FSACI is an Associate Professor of Medicine at University of Kansas and Director of the Structural Heart Program at Ascension Via Christi. He specializes in complex coronary and structural cardiology interventions, with a deep focus on clinical trials and new cardiovascular drug and device research. Dr. Chehab is also the author of multiple peer-reviewed journal articles and has received several awards for his research.

- 1 Arnold, S, Goates, S, Sorajja, P, et al. Health Status After Transcatheter Tricuspid-Valve Repair in Patients With Severe Tricuspid Regurgitation. *JACC*. 2024 Jan, 83 (1) 1–13. <https://doi.org/10.1016/j.jacc.2023.10.008>.
- 2 Dreyfus J, Flagiello M, Bazire B, et al. Isolated tricuspid valve surgery: Impact of aetiology and clinical presentation on outcomes. *Eur Heart J* 2020;41:4304-17.
- 3 Wang, X., Petrossian, G., Robinson, N. B., Chung, W., Khan, J. M., Shin, D., Mihalatos, D., Cohen, D. J., Ali, Z. A., & Khalique, O. K. (2024). Early Experience of 3-Dimensional Intracardiac Echocardiography in Transcatheter Tricuspid Interventions. <https://doi.org/10.1016/j.jscai.2024.102168>.
- 4 Hahn R.T., Nabauer M., Zuber M., et al. Intraprocedural imaging of transcatheter tricuspid valve interventions. *JACC Cardiovasc Imaging*. 2019;12(3):532–553. [PubMed] [Google Scholar].

*4D ICE NUVISION catheter is not available in all markets. The 4D ICE NUVISION Catheter is not CE-marked. 4D ICE NUVISION is distributed by Biosense Webster, Inc., part of Johnson & Johnson MedTech.

Dr. Chehab is a paid consultant for GE HealthCare and was compensated for participation in this article. The statements by Dr. Chehab described here are based on his own opinions and on results that were achieved in his unique setting. Since there is no “typical” hospital/clinical setting and many variables exist, i.e. hospital size, case mix, staff expertise, etc. there can be no guarantee that others will achieve the same results.

JB30930XX

Sealing the risk: a case of left atrial appendage closure

Recorded clinical case in collaboration with PCROnline, featuring Allia™ IGS 7 with Valve ASSIST II¹ and Vivid™ E95 with the 9VT-D probe.

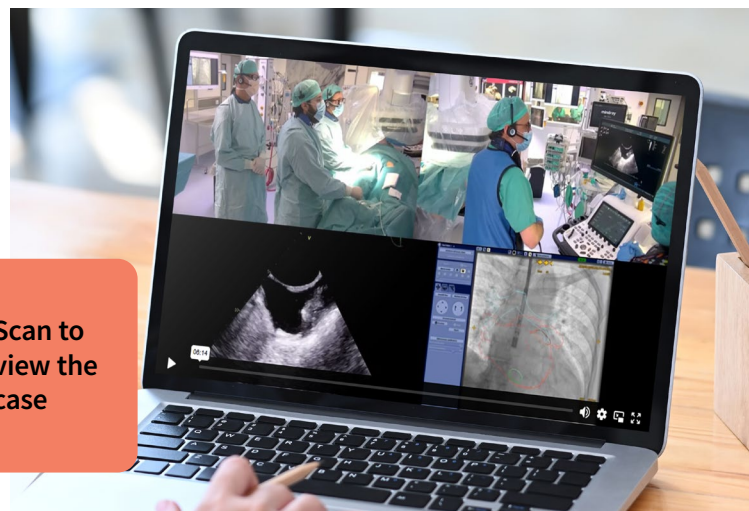
A 76-year-old woman with permanent atrial fibrillation, a history of breast cancer, and a recent diagnosis of an intestinal stromal tumour presents with a high thromboembolic and bleeding risk, making long-term anticoagulation unsafe.

Cardiac CT reveals a challenging left atrial appendage anatomy.

How would you treat this patient?



Scan to view the case



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The invited expert's opinion



“The concept of LAAC performed under conscious sedation, supported by advanced imaging techniques, is poised to expand access to this important intervention. By reducing procedural complexity and anesthesia-related risks, this approach may significantly increase the number of eligible patients, and ultimately help reduce the burden of stroke in AF populations. Consequently, interest in and research on minimalistic LAAC strategies continues to grow rapidly for the benefit of patients worldwide.”

– **Dr. Philippe Garot***
Interventional cardiologist
Cardiovascular Institute Paris Sud (ICPS) – Massy, France

*The statements by Dr. Garot described here are based on his own opinions and on results that were achieved in his unique setting. Since there is no “typical” hospital/clinical setting and many variables exist, i.e., hospital size, case mix, staff expertise, etc. there can be no guarantee that others will achieve the same results.

1. Valve ASSIST II solution includes TAVI Analysis, HeartVision 2 and requires AW workstation with Volume Viewer, Volume Viewer Innova. These applications are sold separately.

JB36210XX





Precious hearts. Precise imaging.

The tiny solution expanding the reach of 4D imaging to more pediatric congenital heart disease patients

Real-time 3D echocardiography is rapidly transforming the diagnosis and management of congenital heart disease (CHD). While it's not yet the standard in pediatric cardiology, the technology is playing a crucial role in patient assessment, pre-surgical planning, and interventional guidance. The world's first mini 4D TEE probe is leading the evolution — unlocking a new dimension of imaging for some of the smallest hearts.



For physicians like Prof. Philippe Acar, who has spent three decades developing 3D imaging technology, the innovation is a long time coming. Dr. Acar, a Professor of Pediatric and Congenital Cardiology at Toulouse University Hospital in southwestern France, was among the first to experience the 9VT-D miniaturized probe. The compact transducer, powered by the Vivid™ ultrasound system, enables real-time multiplane and 3D imaging in patients as small as 5 kg. Dr. Acar also contributed to growing research that supports the probe's feasibility, handling, and image quality in daily practice.

Congenital heart disease is the most common birth defect worldwide¹ and makes up a large portion of the cardiac caseload at Toulouse

University Hospital. The team performs approximately 200 to 250 surgeries annually, with a similar volume of catheterization procedures. It also conducts 10,000 consultations a year for children, adolescents, and adults with a range of congenital heart defects.

Precise assessment of CHD is essential because each patient's anatomy is unique. Clinicians need the right images for a thorough understanding of cardiac anatomy and hemodynamics to select the best treatment strategy. Unfortunately, 10% of pediatric echo diagnostics are driven by misleading anatomy or physiology.²

We recently met with Prof. Acar and three of his colleagues from Toulouse University Hospital: Dr. Clément Karsenty, Head of the Pediatric Cardiology Department; Dr. Khaled Hadeed, pediatric cardiologist; and Dr. Najeeb Bina, pediatric & congenital heart surgeon, to learn more about how the mini 4D TEE probe is impacting care for CHD patients.

What are the main challenges in treating patients with congenital heart disease and why is imaging precision, especially in echocardiography, so crucial?

Dr. Hadeed: *Each heart defect is unique. There are always specific anatomical peculiarities, highlighting the importance of precise evaluation to offer personalized treatment. Congenital heart disease primarily affects young children, including newborns, who are physically fragile, further complicating care. The timing of treatment is also crucial and often stressful for parents. Therefore, it's essential to reassure parents and conduct a precise evaluation to propose the best therapeutic strategy, minimizing medium- and long-term risks.*

Echocardiography is a routine, non-invasive, low-cost, and non-irradiating examination that provides a typically comprehensive anatomical and hemodynamic assessment of the defect, helping to determine the most suitable treatment.

Dr. Karsenty: *Advances in imaging over recent years and decades have revolutionized diagnosis and patient management. 4D imaging, in particular, allows us to refine and enhance how we care for our patients.*

Can you describe the probes you used before the introduction of GE HealthCare's mini 4D TEE probe, and what were their inherent limitations?

Dr. Hadeed: *For transesophageal echocardiography, we used pediatric 2D mini probes, which allowed for*

conventional 2D evaluation of congenital heart defects in children weighing between 5 kg and 25 kg. We also had an adult 3D matrix probe for larger children over 25 kg. However, we were limited for children under 25 kg as we didn't have a 3D matrix probe for this population.

“ Today, having access to a 4D mini TEE probe is indescribable in terms of ease and comfort.”

Dr. Bina: *The 2D probes had many limitations. I've worked in various contexts outside of Europe, for example, in Africa or Asia, where we had to use transthoracic probes for transpericardial use. These required sterile conditions and gel application, which were cumbersome. Today, having access to a 4D mini TEE probe is indescribable in terms of ease and comfort. It's extraordinary what can be achieved with 4D imaging.*

How has the mini 4D TEE probe allowed you to extend the use of 4D echocardiography to a broader patient population?

Prof. Acar: *The real revolution with this new pediatric probe is the ability to perform 4D imaging in children and even small infants, which was previously impossible due to the need to use adult probes. For children weighing less than 25–30 kg, 3D transesophageal echocardiography was simply not feasible.*

Dr. Hadeed: *The pediatric mini 4D TEE probe is a revolutionary tool for managing congenital heart disease as it brings 4D technology to small children, which wasn't available before. This probe can be used for newborns, infants, and young children weighing as little as 5 kg — providing detailed, dynamic 3D imaging to propose the best-tailored care.*

What is the added value of 4D echocardiography compared to 2D echocardiography in managing congenital heart defects?

Dr. Hadeed: *Traditionally, examining congenital heart defects has relied on 2D echocardiography, which involves taking multiple slices to explore the defect. The operator must mentally reconstruct these slices into a 3D image to understand the complexity of the defect. The main limitation of this approach is that the interpretation of 2D echocardiography is operator-dependent and may not always reflect reality.*

“ The pediatric mini 4D TEE probe is a revolutionary tool for managing congenital heart disease as it brings 4D technology to small children, which wasn't available before. This probe can be used for newborns, infants, and young children weighing as little as 5 kg — providing detailed, dynamic 3D imaging to propose the best-tailored care.”

4D echocardiography provides a volumetric, real-time view of the defect, offering a direct visualization of the geometry of the cardiac anomaly and its spatial relationships with other structures. This enables a better spatial understanding of the anomaly and the development of the optimal surgical strategy.

Dr. Karsenty: With 2D echocardiography, we view the heart in specific slices but only within a single plane. Thanks to 4D imaging, we can be completely immersed in the heart, enabling us to understand malformations at a glance. This immediate comprehension allows us to choose the best treatment strategy for our patients.

Prof. Acar: 4D imaging provides a superior advantage by allowing us to visualize not just a single slice but the entire intracardiac view. For many malformations, it delivers critical anatomical insights.

Dr. Bina: As a pediatric & congenital heart surgeon at the University Hospital of Toulouse, I must emphasize how much easier things are today with the introduction of 4D probes compared to a few years ago. As you know, pediatric cardiac surgery is about anatomical heart repair. This means we need a wealth of information — not only about anatomy but also about the histopathology and internal structures of the heart.

Today, with 4D probes, we can gather information not just on the heart's anatomical structure but also on tissue quality. This is particularly useful in valve repairs, such as for

atrioventricular canal defects, ventricular septal defects, or Ebstein's anomaly. These insights significantly enhance our ability to assess tissue quality and aid in making better surgical decisions.

What were your first impressions when you discovered the mini 4D TEE probe?

Dr. Karsenty: The first time we used the mini 4D TEE probe, we were genuinely impressed. The image quality was exceptional, both in small children and older ones, whether using 2D or 4D imaging. The image quality of this probe was truly astonishing from the first use.

Prof. Acar: Having been involved in pediatric probe development, where adult probes are often adapted for pediatric use, earlier models were not always optimal for children. With this probe, we immediately recognized its high quality in 2D imaging. The 4D volumetric imaging, which we had previously explored with transthoracic approaches, provided excellent volumetric rendering with smooth frame rates, offering valuable information.

Dr. Bina: Firstly, the ease of insertion and the compact size of the probe impressed me. Once anesthesia is administered, we can gather all the necessary information within two minutes, collaborating with the cardiology and anesthesia teams. Before making the incision, we conduct a 5- to 10-minute debrief based on the echocardiographic images obtained in the operating room. This provides us

with a wealth of information. The images are fresh in our memory, allowing us to save valuable time assessing anatomical structures. This is particularly helpful as we can view not only the surgical field but also anatomical structures through the TEE probe — such as transventricular and transatrial views.

“ The first time we used the mini 4D TEE probe, we were genuinely impressed. The image quality was exceptional, both in small children and older ones, whether using 2D or 4D imaging. The image quality of this probe was truly astonishing from the first use.”

Your team published a prospective study on the mini 4D TEE probe: 'Advancing paediatric cardiac imaging: a comprehensive analysis of the feasibility and accuracy of a novel 3D paediatric transesophageal probe'²³ in 2023. Can you share the key results?

Dr. Karsenty: We published a study on the first 4D TEE procedures performed with this mini 4D TEE probe at the University Hospital of Toulouse. The results align with our daily practice, demonstrating excellent outcomes.

“The image quality is outstanding, regardless of the patient’s size, from newborns to larger children of adult size. Both 2D and 4D imaging provide nearly perfect resolution. In our study, we also showed that for two patients, the probe enabled us to revise the diagnosis, leading to better patient management.”

The probe is easy to insert, even in patients as small as 5 kg and as large as 75 kg. The image quality is outstanding, regardless of the patient’s size, from newborns to larger children of adult size. Both 2D and 4D imaging provide nearly perfect resolution. In our study, we also showed that for two patients, the probe enabled us to revise the diagnosis, leading to better patient management.

Can you explain in more detail how you are currently utilizing the 4D mini probe in practice and what is the main benefit?

Dr. Karsenty: We use the 4D probe in two main pediatric situations: in the operating room, before and especially after cardiac surgery, to confirm successful outcomes and check for residual lesions. We also use the probe in the catheterization lab, which is of particular interest to me, to guide the

procedure throughout the intervention. The primary advantage of this 4D probe, especially in interventional catheterization, is the ability to guide the procedure with precision across all planes simultaneously.

Prof. Acar: Each professional, whether a catheterization specialist, surgeon, or imager, has their own perspective. From my standpoint, as someone more experienced in cardiac imaging, I find the technology astonishing. To fit this matrix into a tiny, flexible probe and make it usable in children as small as 5 kg is remarkable, all while maintaining excellent 2D image quality.

Has the mini 4D TEE probe changed how surgeons and interventional cardiologists approach procedures?

Dr. Karsenty: The transition from 2D to 4D imaging has significantly improved communication between echocardiographers, surgeons, and interventionalists. A single image now provides all the necessary information to cardiologists or surgeons. Additionally, the ability to place 4D markers on different areas of interest simplifies discussions and communication among team members.

Dr. Bina: Communication is essential, particularly in cardiac surgery. Using these 4D markers allows us to achieve the desired anatomical position and function. It facilitates debriefing for each patient and significantly improves communication within the heart team.



“ I find the technology astonishing. To fit this matrix into a tiny, flexible probe and make it usable in children as small as 5 kg is remarkable, all while maintaining excellent 2D image quality.”

Besides 4D Markers, what other features available on the Vivid ultrasound system are beneficial for your team?

Dr. Hadeed: 4D Markers and FlexiSlice allow us to navigate 2D views within the 4D volume and create slices focused on areas of interest. These features help guide percutaneous interventions more effectively, enabling the most precise procedures.

Dr. Karsenty: The 4D probe enables bi-plane, tri-plane, and FlexiSlice imaging. These features are particularly useful, for instance, in bi-plane mode to confirm the exact position of an atrial or ventricular septal defect. FlexiSlice allows us to ensure that we are in the correct plane, perpendicular to a structure, and to take very precise measurements. These features are extremely helpful.

During catheterization, an interesting mode is dual cropping, which allows us to view both sides of the 4D image simultaneously. For example, when closing an atrial septal defect, we can see the left and right discs being positioned simultaneously in a single view. For complex procedures, 4D

imaging is highly valuable. In the case of a challenging ventricular septal defect, 4D imaging can precisely define its anatomy and size, enabling the selection of the most suitable device.

Dr. Bina: The advantages of these tools are immense. They allow us to make decisions immediately, reducing clamp time and extracorporeal circulation (ECC) time. Post-declamping, when evaluating the surgery, we find that in 90% of cases, the correction aligns with what we aimed to achieve, thanks to our collaboration with colleagues. This is incredible.

What additional advantages do you see with the mini 4D TEE probe in percutaneous procedures?

Dr. Hadeed: For guiding percutaneous interventions, 4D echocardiography allows detailed visualization of septal defects, the geometry of interatrial or interventricular communications, their precise location, and spatial relationships with other structures. This enables better guidance for choosing and positioning the device most appropriately. It likely reduces procedure time, radiation exposure, and the use of contrast agents, making it an essential tool for interventions.

“ The advantages of these tools are immense. They allow us to make decisions immediately, reducing clamp time and extracorporeal circulation (ECC) time.”

Did you encounter a learning curve with the mini 4D TEE probe?

Dr. Karsenty: The Mini 4D probe is very easy to insert and use, so there is no real learning curve.

Dr. Hadeed: Using the mini 4D TEE probe is straightforward and similar to using any transesophageal probe in terms of insertion and manipulation. There is no significant learning curve. It's the same technique but with the added advantage of a third dimension, providing a more detailed view of congenital heart defects.

“ It likely reduces procedure time, radiation exposure, and the use of contrast agents, making it an essential tool for interventions.”

Dr. Bina: There is a learning curve for the surgical team. In our workflow, decisions are primarily based on the surgeon's view. With the mini 4D TEE probe, we have additional perspectives, such as transatrial and transventricular views, both left and right. Initially, finding landmarks can be challenging. The learning curve typically lasts 1 to 2 months. However, reviewing many images with cardiologists helps immensely, and soon after, everything becomes much faster.



3D Glasses make CHD clearer for pediatric patients

Picture this: 3D glasses at the pediatric cardiologist's office — not the cinema. Physicians at University Hospital Toulouse are using the glasses to help families better understand CHD and what's happening inside their child's heart.

“Look, this is your heart in 3D. Focus mainly on the right, where it's orange. This is the mitral valve,” Prof. Philippe Acar directs 10 year-old Cylian to look at his latest scans. “You look really stylish in the glasses.”

Cylian was born with an arterial trunk and has undergone one Blalock surgery and an open-heart surgery with extracorporeal circulation over the last decade. The third grader has spent a lot of time in doctors' offices. His mother acknowledges there have been many long days.

Prof. Acar recognizes the emotional weight that comes with a CHD diagnosis and how it often turns a joyful time into one of fear and uncertainty. The glasses are just one part of the team's plan to ensure families are supported at every step. “You need to approach a diagnosis with pedagogy, humanity, and over multiple consultations. The entire diagnosis cannot be delivered abruptly or in one go, especially when the congenital heart disease is complex.”

Engaging young patients and parents is also important to Prof. Acar. The 3D glasses transform the clinical consultation into an interactive learning experience that's more meaningful for families. “It's a moment of sharing and exchange. You can't just stay in front of the screen. You have to share something using an image, in a face-to-face interaction.”

While some might dismiss the glasses as simple and fun, Cylian's family believes they point to something far more significant. The real importance lies in the 3D imaging they support — offering crucial, detailed views of Cylian's heart. “As parents of a child with congenital heart disease, we've learned a lot. The 3D technology is impressive,” his mother says. “For me, it's essential to know the facts clearly, without sugar-coating. It's important that the University Hospital of Toulouse remains at the forefront of innovation — otherwise, it complicates things for families like ours.”



4D echocardiography is not yet standard in pediatric care. We understand that you are actively involved in global projects aimed at raising awareness and training medical teams on the advantages of this technology. What is at issue?

Prof. Acar: *It ultimately comes down to the discretion of each team to decide whether or not to use 4D. It should be noted that most transthoracic probes today, and increasingly transesophageal probes as well, are now three-dimensional. So, the question is more about whether pediatric cardiology teams are adopting this new mode and engaging with them to promote this technique in all its facets — both the anatomical visualization aspect and the quantification aspect.*

How do you envision the future of echocardiography in pediatric cardiology, and what impact do you think it will have on patient care in the coming years?

Prof. Acar: *Regarding care, it's a bit challenging to define, as it remains ultrasound imaging — it's neither surgery nor catheterization. However, in all cases, it aids surgeons in better understanding and helps interventionalists guide their procedures. Ultimately, it's an operative and interventional support tool.*

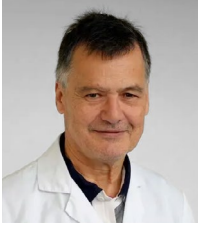
In my opinion, the applications are numerous. Certainly, they pertain to care, but they also extend to the realm of communication and education. For instance, with students and trainees,

we use it to explain intracardiac anatomy through 3D imaging — similar to what is done with CT scans, but here it's done with 3D ultrasound. Similarly, it enhances communication with patients and families, helping to explain concepts like an atrial septal defect using a 3D model.

We also have new systems that allow us to export 3D imaging for 3D printing. With these small 3D-printed models, we can represent and even touch the anatomy. Additionally, we have virtual reality systems with headsets that enable us to better visualize and understand intracardiac anatomy. ■



**Scan to
see the video**



Philippe Acar, M.D., Ph.D., is a Professor of Pediatric Cardiology at Toulouse Children Hospital at Toulouse University. Prof. Acar has been an expert in 3D echocardiography for more than 20 years and was instrumental in developing the echo lab in 3D pediatric cardiac imaging at Toulouse. He's published more than 150 peer reviewed articles, mostly focused on 3D echocardiography. Prof Acar is Associate Editor of the Archive of Cardiovascular Diseases Journal and former president of the French Pediatric and Congenital Cardiology Association.



Clément Karsenty, M.D., Ph.D., is a pediatric and interventional cardiologist. He currently leads the pediatric cardiology department at the Children's Hospital in Toulouse, part of the Toulouse University Hospital. He has been actively involved in research on cardiac diseases, publishing numerous peer-reviewed articles that primarily focus on interventional catheterization, echocardiography, and congenital heart defects.



Khaled Hadeed, M.D., is a pediatric cardiologist specializing in both diagnostic and interventional echocardiography. He is a hospital practitioner in pediatric cardiology at Toulouse University Hospital. Dr. Hadeed has published numerous scientific publications and is actively involved in research and teaching. His expertise focuses on advanced imaging of congenital heart diseases, with a particular interest in 3D echocardiography, percutaneous interventions in children, and 3D modeling and printing, which he uses for preoperative planning, education, and interventional guidance.



Najeebullah Bina, M.D., Ph.D., is a senior pediatric and congenital cardiac surgeon at Toulouse Teaching Hospital. His expertise lies in leading cardiac surgery teams across various regions of the world and in establishing and developing cardiac surgery centers in Asia, as well as East and West Africa. Dr. Bina is the member of French and German Societies of Cardio-thoracic Surgery and an active member of the "Académie Nationale de Chirurgie" in France.

1 Bouma BJ, Mulder BJ. Changing landscape of congenital heart disease. *Circ Res* 2017;120:908–22.

2 Oscar J. Benavidez et.al. | Diagnostic Errors in Pediatric Echocardiography Development of Taxonomy and Identification of Risk Factors | <https://www.ahajournals.org/doi/full/10.1161/CIRCULATIONAHA.107.758532>

3 Karsenty C, Hadeed K, Pyra P, Guitarte A, Djedjai C, Vincent R, Dulac Y, Silagdze I, Gobin J, Combes N, Ratsimandresy M, Berthomieu L, Calvaruso D, Acar P. Advancing paediatric cardiac imaging: a comprehensive analysis of the feasibility and accuracy of a novel 3D paediatric transoesophageal probe. *Front Cardiovasc Med*. 2023 Dec 5;10:1294109. doi: 10.3389/fcvm.2023.1294109. PMID: 38116539; PMCID: PMC10728472.

9VT-D was introduced with the Ultra Edition release in August 2022 and is exclusively available on some Vivid systems. Please consult your local representative to confirm compatibility.

The statements by Prof. Acar, Dr Karsenty, Dr. Hadeed and Dr. Bina are based on their own opinions and on results that were achieved in their unique setting. Since there is no "typical" hospital/clinical setting and many variables exist, i.e., hospital size, case mix, staff expertise, etc. there can be no guarantee that others will achieve the same results.

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ASD closure in a 6-year-old patient using the 4D mini TEE probe

Courtesy of Dr. Khaleed Hadeed, Toulouse Children Hospital, France

Patient history/pathology

A 6-year-old child weighing 16 kg was referred for the management of an atrial septal defect (ASD) of the ostium secundum type. The transthoracic echocardiography (TTE) revealed a significant left-to-right shunt via an ASD measuring 12 mm.

Challenges

The procedure is typically guided by two-dimensional (2D) transesophageal echocardiography (TEE), which requires multiple imaging planes to assess the morphology and measure the defect. This approach often underestimates the true dimensions of the defect.

This procedure is realized under a detailed imaging guidance throughout the procedure to avoid complications, and to ensure the proper positioning of the device.

System, probe & device used

Three-dimensional 3D-TEE guidance was possible in this small child using the 9VT-D mini 4D TEE probe during the procedure.

Step-by-step procedure

The procedure was performed under general anesthesia to ensure the child's comfort and immobilization. The pediatric 4D TEE probe was positioned without any difficulty.

TEE imaging identified the defect's initial dimensions from 8 to 12 mm according to the angle cut from 0° to 120°. 3D-TEE acquisition provided detailed visualization of the defect, and revealed an ovoid shape with the largest diameter in the superior-inferior axis, measuring 10x4 mm.

A sizing balloon was used to measure the stretched diameter of the defect, which was determined to be 14 mm. A 14-mm Amplatzer occluder device was chosen to match the measured stretched diameter with exactly corresponding to the maximal diameter by 3D imaging.

Under continuous 4D TEE guidance, the device was carefully deployed, ensuring proper positioning and stability without interference with adjacent cardiac structures.

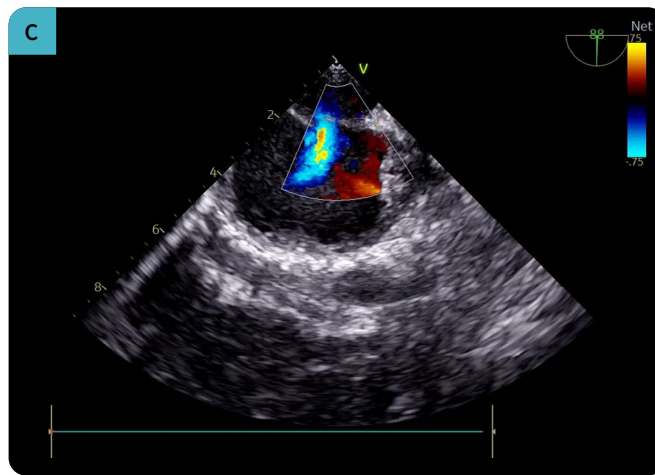
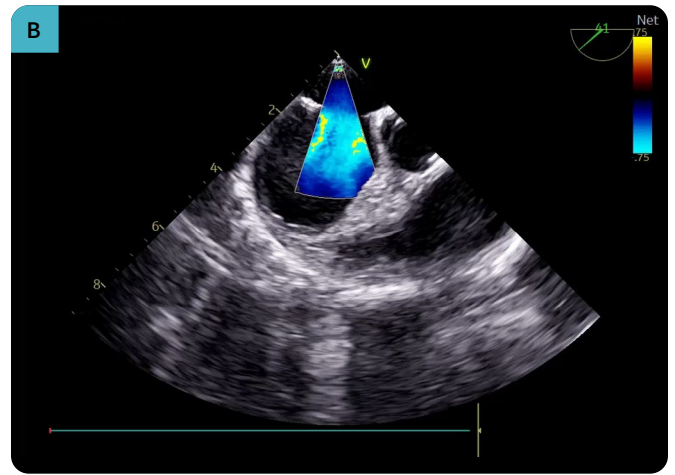
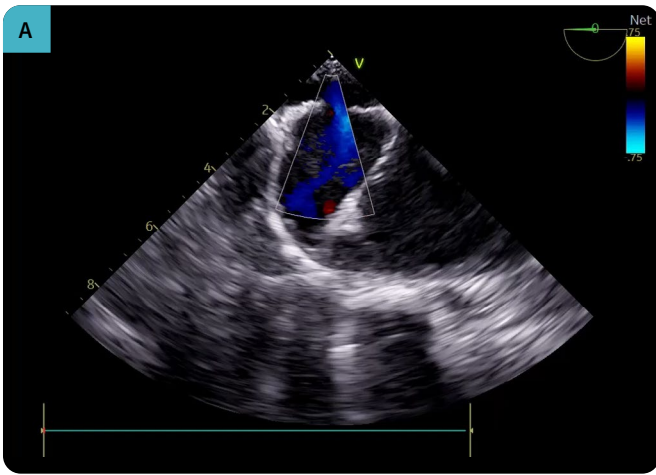
Post-Deployment Assessment confirmed the complete closure of the defect with no residual shunt. The device was well seated, with no obstruction to the pulmonary veins, atrioventricular valves, or other nearby structures.

Conclusion

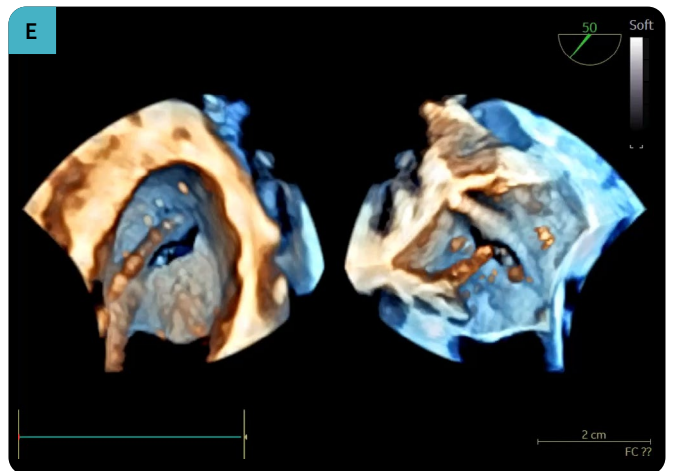
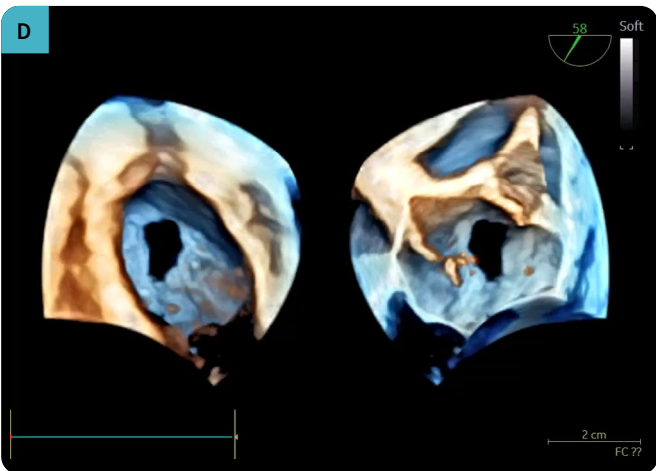
This case highlights the important role of pediatric 4D transesophageal echocardiography in the percutaneous closure of ASD. The enhanced imaging capabilities allowed for precise defect assessment, accurate device sizing, and safe deployment. The procedure was successful, with no complications, demonstrating the value of this advanced imaging technology in pediatric interventional cardiology.

Imaging follow-up

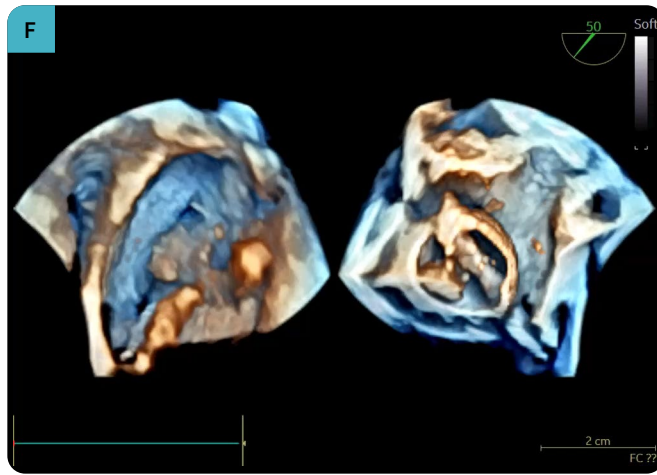
Follow-up imaging was performed using TTE and showed the occluder device in place with no evidence of residual shunting and no interference with surrounding structures, including the pulmonary veins or atrioventricular valves. The child's clinical course was uneventful, with resolution of the left-to-right shunt and no reported complications.



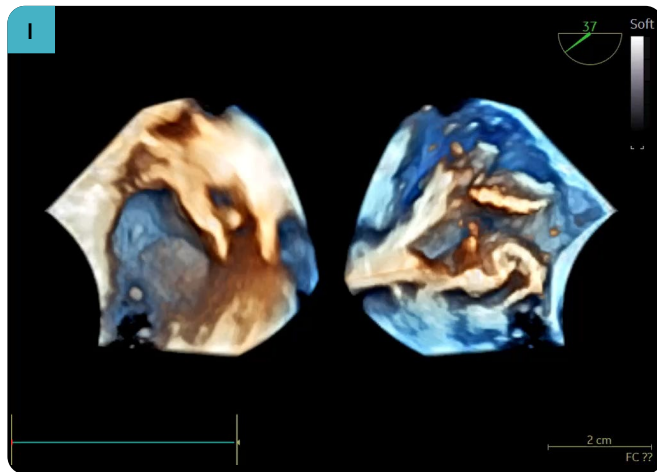
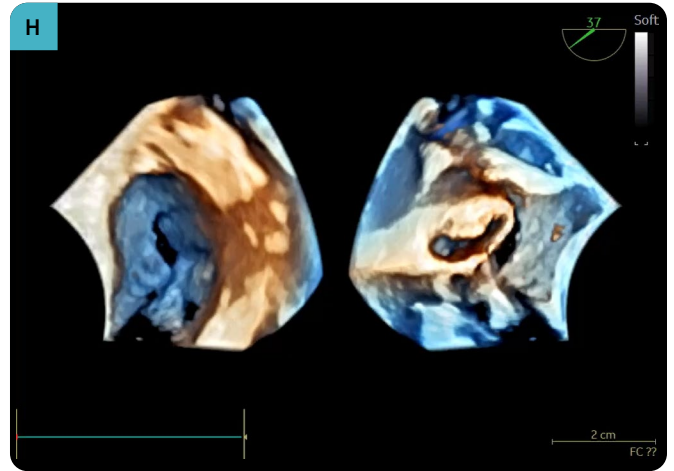
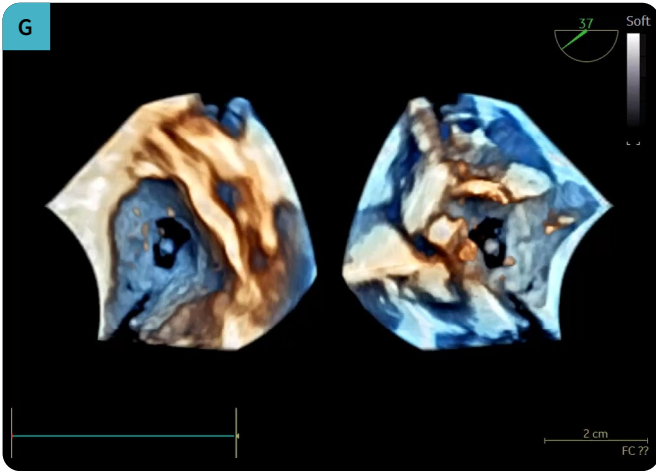
A-C) 2D TEE demonstrating ASD L to R shunt at 0°, 45°, and 120°



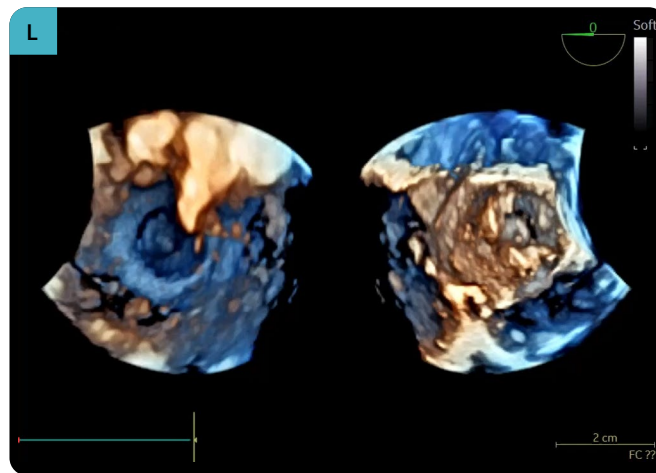
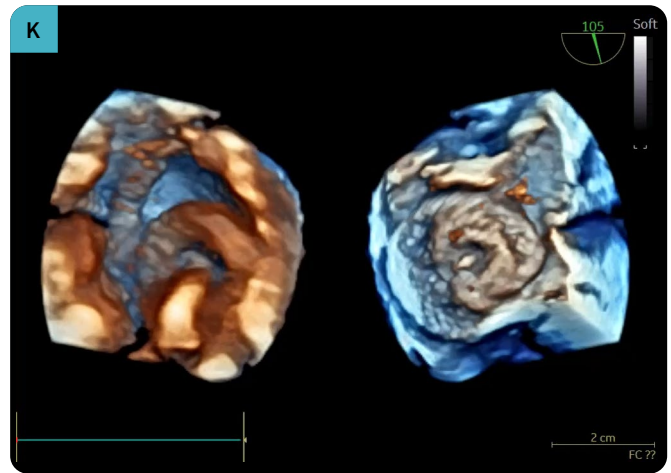
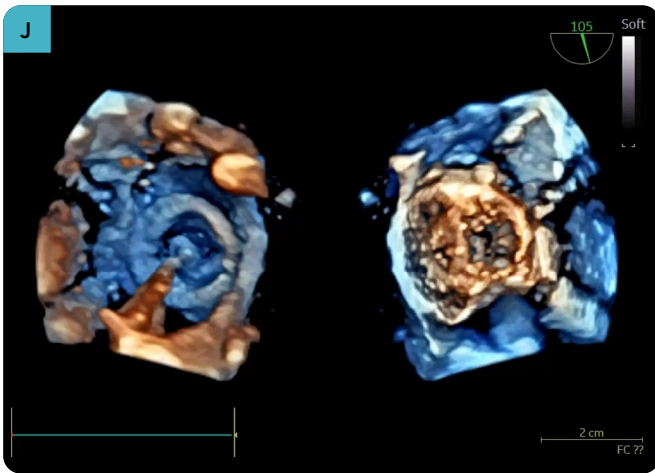
D-E) ASD viewed by 3D TEE from left and right side perspective



F) Sizing balloon viewed from left and right side



G-I) Device deployment under 3D-TEE live monitoring




J-L) ASD device before release, during Minnesota maneuver, and after release with final position

The statements by Dr. Khaled Hadeed described here are based on his own opinions and on results that were achieved in his unique setting. Since there is no "typical" hospital/clinical setting and many variables exist, i.e., hospital size, case mix, staff expertise, etc. there can be no guarantee that others will achieve the same results.

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Could the mini 4D TEE probe help enable faster structural heart procedures?

How the miniaturized probe can deliver precise imaging without the risks of general anesthesia

TEE is an indispensable tool for structural heart disease diagnostics and transcatheter interventions, but associated risks have spurred interest in alternatives that could reduce esophageal injury and the need for general anesthesia. The challenge is finding a secure option that doesn't sacrifice image quality. A transformative solution is emerging in the 9VT-D mini 4D TEE probe. It's not only gaining attention for its clinical utility and patient benefits, but also for enhancing workflow efficiencies and the potential to reduce healthcare costs.



While traditional adult TEE has a favorable safety profile, it's been linked to complications, including oropharyngeal trauma, esophageal lesions, and chest pain. A 2020 study¹ involving 50 patients undergoing TEE-guided interventions found 86% had some degree of esophageal or gastric injury, with 40% experiencing complex lesions. Longer procedural time and poor or suboptimal image quality were associated with an increased risk.

With the growing prevalence of valvular heart disease² and trend for less invasive therapies, Dr. Konstantinos Papadopoulos of Interbalkan Medical Center in Greece is focused on strategies that minimize the need for general anesthesia and avoid intubation. It's particularly important given that a majority of his patients are elderly, frail, and have multiple comorbidities — leading to increasingly complex cases.

Interbalkan Medical Center is one of the leading cardiology centers in Greece. Dr. Papadopoulos is the Director of the Echo Lab, which utilizes advanced echocardiographic techniques, including 2D/4D transthoracic and transesophageal echocardiography, strain imaging, and stress echocardiography. The Interbalkan Medical Center performs 150-200 TAVI, 50 Mitral-TEER, 10-15 Tricuspid-TEER procedures, and more than 50 occluder device implantations annually for PFO, LAA, and ASD closure.

Dr. Papadopoulos and his team contributed to research supporting the use of the mini 4D TEE probe in everyday practice and for guiding transcatheter interventions. Their study published in 2024³ involved a direct comparison with a standard adult TEE probe.

We recently asked Dr. Papadopoulos to share the experience, key findings from his research, and the potential impact of the probe on providers and patients.

What are the main challenges you face during structural heart procedures? What steps have you taken to overcome these challenges?

Dr. Papadopoulos: *The primary challenges include achieving optimal TEE imaging quality, which is crucial for procedural success, and ensuring seamless communication between the imaging specialist and the interventionist. To address these challenges, we conduct extensive heart team discussions on patient management and provide specialized*

training in cardiac imaging for interventionists to enhance intra-procedural communication. Our hospital also supports our imaging efforts by equipping us with state-of-the-art echocardiography machines and 4D probes, ensuring the highest imaging quality.

You are among the first physicians to use the mini 4D TEE probe in adult structural heart procedures. What were your initial impressions of the probe?

Dr. Papadopoulos: *I was impressed by the probe's exceptional image quality, despite its compact size and its original design for pediatric use. Regardless of the patient's weight, it consistently delivered excellent images, both in routine echo lab examinations and during cath lab interventions.*

TEE is a vital tool in transcatheter interventions where it aids in preoperative planning and intraoperative guidance. Can you expand on the mini 4D TEE probe's imaging capabilities?

“ *I was impressed by the probe's exceptional image quality, despite its compact size and its original design for pediatric use. Regardless of the patient's weight, it consistently delivered excellent images, both in routine echo lab examinations and during cath lab interventions.* **”**

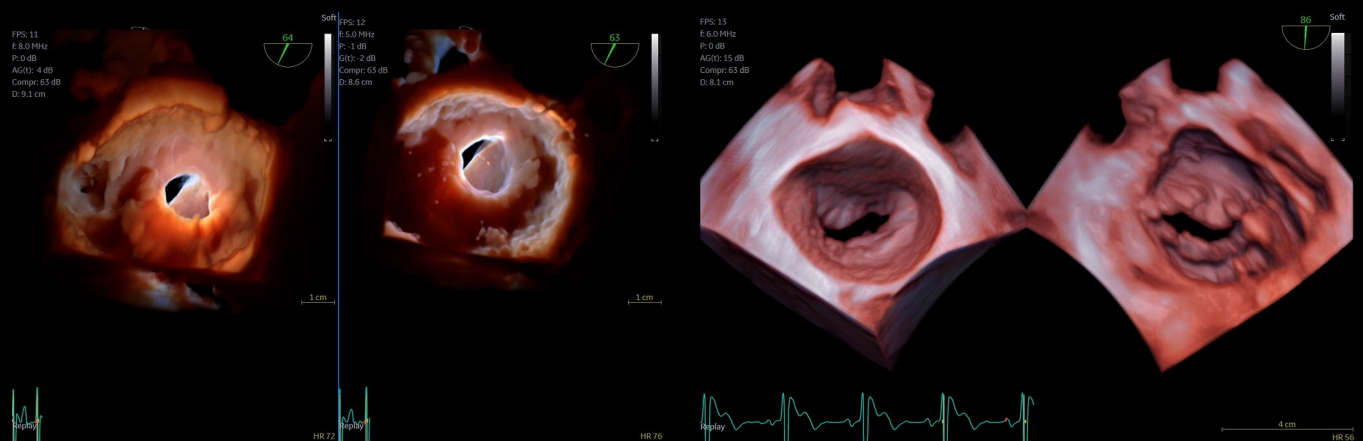
Dr. Papadopoulos: *Preprocedural planning and intraoperative guidance are essential for successful interventions. The mini 4D TEE probe offers outstanding 2D and 4D image quality with high frame rates. Compared to the standard adult TEE probe, there were no significant compromises in imaging resolution, which contributes to procedural effectiveness.*

What surprised you the most about the mini 4D TEE probe?

Dr. Papadopoulos: *The fact that such a small and flexible probe could deliver imaging quality comparable to a standard adult probe, especially in terms of 4D spatial resolution.*

You conducted a retrospective study, 'Initial Experience with the 4D Mini TEE Probe in the Adult Population,' which involved 30 patients at Interbalkan Medical Center and Rennes University in France. What were your key findings?

Dr. Papadopoulos: *We found direct comparison with the adult TEE probe showed equivalent imaging quality. TEE examinations using the mini 4D TEE probe could be performed without sedation, using only local lidocaine, and transcatheter interventions could be conducted without general anesthesia or intubation.*



Flexilight/“photorealistic method” of en face views of a dysfunctional metallic mitral valve. Direct comparison of images acquired with 9VT-D probe (left) and 6VT-D probe (right image)

Dual crop image of 3D en face view of normal mitral valve. Image enhanced with anatomic 1 map

“The mini 4D TEE probe offers outstanding 2D and 4D image quality with high frame rates. Compared to the standard adult TEE probe, there were no significant compromises in imaging resolution, ensuring procedural safety and effectiveness.”

Your study also concluded that the mini 4D TEE probe could reduce esophageal trauma. This is particularly important, given that past research has demonstrated 86% of patients undergoing structural cardiac interventions experienced TEE-related injuries. With the potential to reduce injury, how might this innovation impact the patient population?

Dr. Papadopoulos: Our standard practice involves mild sedation for TEE procedures to enhance patient tolerance.

Patients are often apprehensive about anesthesia and intubation. The ability to perform interventions without intubation is highly appealing, and the mini 4D TEE probe will definitely reduce complications. It reduces the risk of esophageal trauma from the TEE probe and tracheal trauma from intubation, as well as damage to the patient’s teeth in the oral cavity of the trachea. Additionally, some patients experience adverse reactions to anesthetic agents, which may be avoided using the mini 4D TEE probe without general anesthesia.

What type of patients could benefit from using a mini 4D TEE probe?

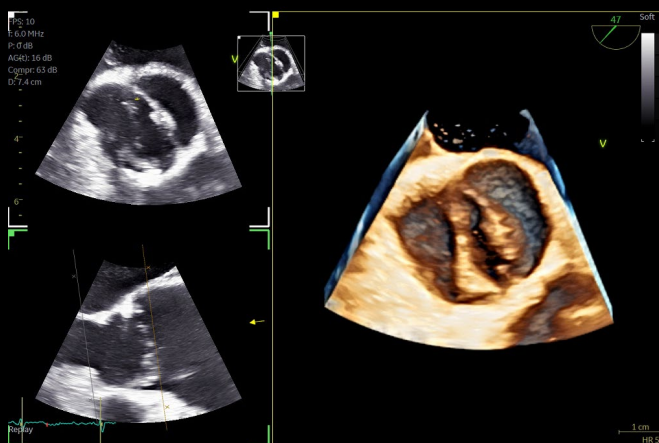
Dr. Papadopoulos: In my opinion, the mini 4D TEE is attractive for all patients and preferable for the very young and the very old.

PFO interventions are usually for people under 55 years old with cryptogenic stroke. Most of the ASD cases are young adult patients: 18, 19, 20-years-old. If you can perform it with just mild sedation and a very small probe, it’s better for them.

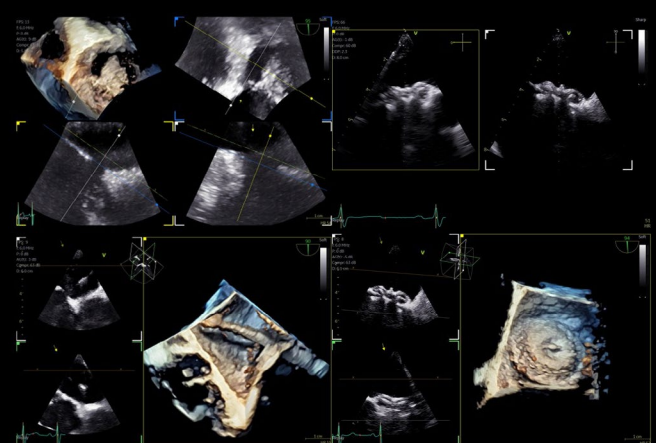
Some patients, particularly younger individuals, struggle with the standard adult probe due to oropharyngeal sensitivity, necessitating anesthesiologist involvement. The mini 4D TEE probe was well tolerated by nearly all patients without sedation, allowing them to drive home independently post-exam, with no complaints of odynophagia, chest discomfort, or hoarseness.

“The ability to perform TEE without the need for an anesthesiologist has streamlined our workflow.”

In older, frail patients, even mild sedation can cause a drop in blood pressure. We’ve had incidents where we have had to call anesthesia to help stabilize blood pressure, and there have been instances of respiratory arrest. So in really frail patients, we try to avoid intubation to really minimize risk.



3D en face view a “2-sinus of Valsalva” true bicuspid aortic valve



“ASD closure case.” 3D evaluation of an “oval-shaped” secundum ASD with flexislice method and echocardiographic guidance for Amplatzer occluder implantation

How did the mini 4D TEE probe affect your workflow?

Dr. Papadopoulos: *The ability to perform TEE without the need for an anesthesiologist has streamlined our workflow. By avoiding intubation, you don't need to wait for the patient to wake up and be extubated, so you gain a lot of time. In high volume centers, where they need to perform back-to-back interventions, they can increase numbers and decrease hospitalizations. I've received feedback that if we don't intubate, we can safely discharge patients on the same day.*

“TEE examinations using the mini 4D TEE probe could be performed without sedation, using only local lidocaine, and transcatheter interventions could be conducted without general anesthesia or intubation.”

Did you experience any learning curve with the mini 4D TEE probe?

Dr. Papadopoulos: *No, no learning curve was required. The only main difference was the feeling of the probe, which was flexible.*

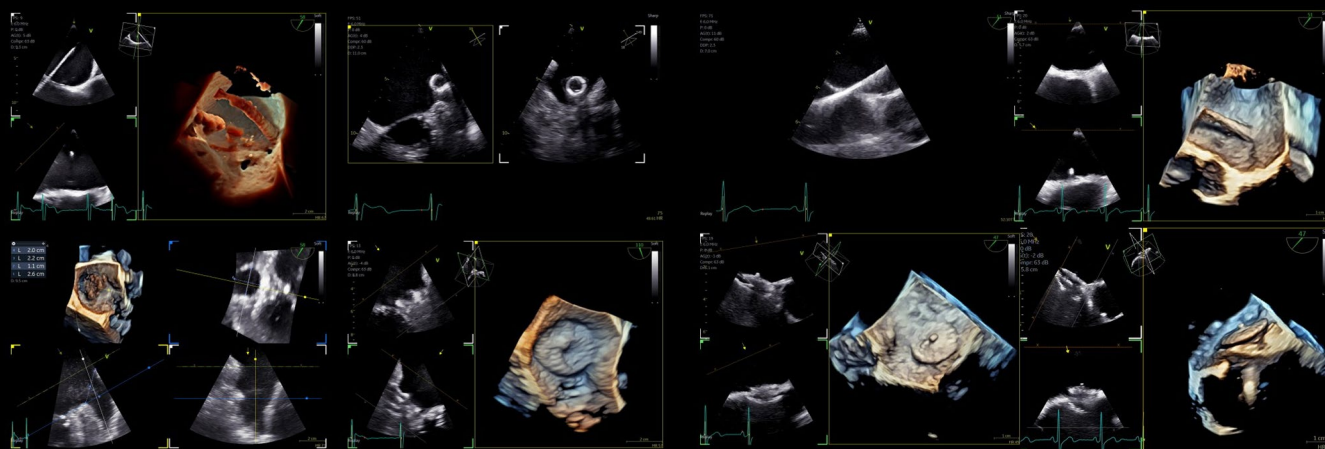
With the advantages you've outlined, how are you currently utilizing the mini 4D TEE probe in your center?

Dr. Papadopoulos: *We primarily use the mini 4D TEE probe in two scenarios: for patients who can't tolerate the adult probe or prefer to avoid sedation. We also use it for shorter interventions, such as PFO or ASD, that can be completed with mild sedation, rather than intubation. However, procedures such as Mitral-TEER can extend beyond an hour, requiring careful sedation management.*

For echocardiologists, one common challenge is navigating the devices and communicating with the interventional cardiologist during the procedure. How do you address this challenge?

“In my opinion, the mini 4D TEE is attractive for all patients and preferable for the very young and the very old.”

Dr. Papadopoulos: *The close collaboration between the echocardiologist and interventionalist is very, very important. We emphasize meticulous pre-procedural planning as a team, ensuring proper device sizing and positioning. Our interventionalists learn how to appreciate echo images. While they may not know how to acquire the images, they understand how to read whatever is on the screen. During procedures, continuous transitions between 2D and 4D imaging provide excellent spatial orientation, facilitating precise navigation. Mastering this approach takes extensive training and experience.*



“LAA closure case.” 3D evaluation of left atrial appendage with flexislice method and echocardiographic guidance for Amulet device implantation

“PFO closure case.” 2D/3D echocardiographic guidance for PFO Amplatzer implantation

What do you see as the future of echocardiography and how will you and your team play a role?

Dr. Papadopoulos: *My ideal scenario would be to avoid intubation for all interventions by using smaller probes with full 4D capabilities. If future technology could provide an even smaller TEE probe without sacrificing imaging quality, it would further improve procedural efficiency and patient comfort.*

How do I see my role in the future? Echocardiography will remain the

first-line imaging modality for patient evaluation, as it seamlessly integrates imaging with clinical information. My primary goal is to contribute to the training of colleagues, sharing advanced echocardiographic skills to ensure high standards across all cardiology departments. Additionally, through research and clinical experience, I aim to collaborate with the industry to enhance the quality of future generations of echocardiographic machines, optimizing their performance and expanding their capabilities. ■

“ We primarily use the mini 4D TEE probe in two scenarios: for patients who can't tolerate the adult probe or prefer to avoid sedation. We also use it for shorter interventions, such as PFO or ASD, that can be completed with mild sedation, rather than intubation.”



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- 2 Helmut Baumgartner, Bernard Lung, David Messika-Zeitoun, Catherine M. Otto, The year in cardiovascular medicine 2021: valvular heart disease, *European Heart Journal*, Volume 43, Issue 7, 14 February 2022, Pages 633–640, <https://doi.org/10.1093/eurheartj/ehab885>
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9VT-D was introduced with the Ultra Edition release in August 2022 and is exclusively available on some Vivid systems. Please consult your local representative to confirm compatibility.

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Initial experience with the 4D mini-TEE probe in the adult population

Konstantinos Papadopoulos,^{1*} Ignatios Ikonomidis,² Augustin Coisne,^{3,4} Özge Özden Kayhan,⁵ Apostolos Tzikas,^{6,7} Nikolaos Fragakis,⁷ Antonios P. Antoniadis,⁷ Mani A Vannan⁸ and Erwan Donal⁹

Abstract

Background: Transesophageal echocardiography (TEE) is a vital diagnostic tool in clinical practice, particularly in transcatheter interventions where it aids in both pre-operative planning and intra-operative guidance. Traditional TEE probes often require general anesthesia due to patient discomfort. However, the development of miniaturized TEE probes presents a promising alternative, enabling routine examinations and interventions with minimal sedation. This study evaluates the feasibility of performing a complete 2D/4D TEE protocol with the new 4D mini-TEE probe in the echocardiography department and its application in transcatheter interventions.

Methods: This is a retrospective study that included 30 consecutive patients from two high-volume European hospitals (Interbalkan Medical Center, Thessaloniki, Greece, and Rennes University, France) that underwent TEE or transcatheter interventions. The new 4D mini-TEE 9VT-D probe (GE Healthcare) was utilized. The quality of the images and the tolerance of the probe were assessed in the cath lab during interventions and in the echocardiography department during routine TEE examinations.

Results: Direct comparison of the 4D mini-TEE probe with the standard 6VT-D probe confirmed the excellent image quality of this new pediatric probe. Most of the patients required minimal sedation or local oropharyngeal anesthesia, with satisfactory tolerance reported. Most of the transcatheter procedures did not require general anesthesia and intubation, resulting in shorter procedural time. Both 2D and 4D imaging modalities offered adequate intra-operative guidance for transcatheter procedures.

Conclusions: The 4D mini-TEE probe delivers exceptional imaging capabilities for routine examinations and transcatheter interventions without needing sedation. Its use reduces esophageal trauma and the need for general anesthesia, enhancing patient comfort and safety.

Keywords: transesophageal echocardiography; mini-TEE probe; three-dimensional echocardiography; transcatheter interventions

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1. Introduction

Transesophageal echocardiography (TEE) is an invaluable diagnostic tool for structural heart diseases, offering high-quality images suitable for routine echocardiographic examinations.¹⁻³ Its significance extends to transcatheter interventions, where it plays a pivotal role from pre-operative planning to intra-operative guidance and final result assessment.⁴⁻⁷ Effective collaboration between the imager and interventionist is crucial, with real-time demonstration of procedural steps facilitated by two- and three-dimensional (3D) echocardiographic images.^{8,9} Notably, 3D echocardiography enables precise device sizing, exhibiting a strong correlation with other imaging modalities such as cardiac computed tomography (CT).¹⁰

Despite the generally favorable safety profile of adult TEE probes, they may cause minimal complications, including oropharyngeal trauma, esophageal lesions, and postexamination symptoms such as throat hoarseness or chest pain.¹¹⁻¹³ These complications are related to the thickness of the adult TEE probe, the manipulations of the probe during the examination, and probe-generated heat. The standard adult TEE probes are often poorly tolerated in non-sedated patients, limiting their prolonged use. While routine TEE examinations typically last 10–15 min and do not necessitate deep sedation, transcatheter interventions last longer, necessitating general anesthesia (GA) as standard practice in order to mitigate patient discomfort. However, GA requires the presence of an anesthesiologist and results in extended procedural and hospitalization times, along with an increased risk of anesthesia-related complications.

Intra-cardiac echocardiography (ICE) is as a potential solution to the limitations of adult TEE probes.¹⁴ However, ICE is an invasive tool requiring additional venous access and has additional substantial costs. Another alternative, the micro-TEE probe (10T-D GE HealthCare), lacks support for three-dimensional imaging, which is imperative for most transcatheter procedures.¹⁵⁻¹⁷

The objective of this study is to assess the feasibility of employing the new 4D mini-TEE probe for both routine examinations and guidance of transcatheter procedures, while evaluating the quality of the obtained images.

2. Materials and methods

This is a multi-center retrospective analysis that assessed the feasibility of (1) using the 4D mini-TEE probe in everyday practice and (2) guiding transcatheter interventions. Our cohort consisted of 30 consecutive patients who either visited the echocardiography department or were scheduled for a transcatheter procedure. Interbalkan Medical Center and the University Hospital of Rennes participated in the study and the registry was approved by their local ethics and scientific committees. All TEE examinations were conducted by experienced imaging specialists with the new 9VT-D, 4D mini-TEE probe that has recently been made commercially available. All examinations were performed with the Vivid™ ultrasound machine and were stored and post-processed in EchoPAC workstations. Standard 2D/4D examination protocols^{3,7} were acquired for complete assessment of the patients, for pre-operative planning and intra-operative guidance. For qualitative assessment of

the images, a 5-point score was used (1: non-interpretable images, 2: poor quality but interpretable, 3: average quality, 4: good quality, 5: excellent quality) that was answered immediately after the end of the TEE and was internally reviewed by three experienced echocardiographers (K.P., I.I., E.D.).

2.1. Comparison between mini-TEE and standard adult TEE probe

To assess the image quality of the mini-TEE probe and ensure the accuracy of findings, a limited number of patients were selected for examination using both the adult 6VT-D and pediatric mini-TEE 9VT-D probes. Prior to the examination, patients were duly informed about the procedure and provided their consent. The protocol dictated the initial examination with the adult probe followed by the insertion and utilization of the pediatric probe to capture identical images. To increase patient comfort during probe insertion, mild sedation with midazolam and local application of lidocaine to the oropharynx were administered.

2.2. Echocardiography department transesophageal echocardiography

For routine TEE examinations, the anesthesia protocol comprised the local application of lidocaine at the posterior oropharynx, coupled, for some, with minimal sedation using 1–2 mg of midazolam to ensure patients remained calm yet awake throughout the procedure. In instances where patients exhibited intolerance to the probe, higher doses of midazolam (5–10 mg) were administered based on individual response levels.

Probe insertion into the esophagus involved the utilization of an endocavity probe cover coated with lubricant gel at the tip, aiming at preventing artifacts from

partial attachment of the mini probe to the esophageal wall. To assess probe tolerance, a 5-point scoring system was employed, with patients completing a questionnaire following the examination. Scores ranged from 1 (indicating probe intolerance necessitating termination of the examination) to 5 (signifying no discomfort experienced during or after the TEE procedure) (1: non-tolerable probe/termination of examination, 2: major discomfort during TEE, 3: major discomfort immediately after TEE with chest pain/bleeding, 4: minor discomfort, 5: no discomfort during or post-TEE).

2.3. Intra-Procedural transesophageal echocardiography

For transcatheter procedures, the preferred approach involved sedation without the need for general anesthesia or intubation. This decision was contingent upon factors such as the duration of the procedure, patient tolerance of the probe, and their ability to remain still during the operation, thereby assisting the interventionist in completing the procedure effectively. During the insertion of the probe into the esophagus for

transcatheter procedures, an endocavity probe-cover coated with lubricant gel was once again utilized. Unlike routine TEE examinations where patients typically lie in the decubitus position, for transcatheter procedures, all patients were positioned supinely to facilitate probe insertion. Probe tolerance was assessed at the conclusion of the procedure through a straightforward inquiry regarding the patient's level of cooperation or necessity for intubation.

3. Results

3.1. Comparison between mini-TEE and standard adult TEE probe

The quality of images obtained with the 9VT-D pediatric probe and the accuracy of findings were assessed through examination of the first three patients. Each patient underwent a comprehensive TEE protocol using both the pediatric 9VT-D and adult 6VTD probes, allowing for direct comparison of findings and image quality. Throughout the procedure, patients received local oropharyngeal lidocaine and mild sedation with midazolam to ensure tolerance.

The adult probe was initially inserted for complete 2D/4D image acquisition, followed by the insertion of the pediatric probe while the patient remained under sedation. Remarkably, insertion of the pediatric probe was effortless in all cases, requiring no additional sedation. Despite encountering challenging diagnostic scenarios in all three cases (1st patient: combined severe aortic stenosis and severe mitral regurgitation (MR) due to P1 scallop prolapse, 2nd patient: malfunction of metallic mitral valve prosthesis with an occluded disk, 3rd patient: bioprosthetic aortic valve with paravalvular leak and significant MR in previously MV repair with a complete ring), the pediatric probe consistently provided high-quality images comparable to those obtained with the standard adult probe (Figures 1 and 2, video S4). Notably, there was no compromise in 2D and 4D spatial and temporal resolution, with only minor differences observed compared to the adult 6VT-D probe (Table 1). Evaluation using the 5-point scoring system consistently yielded an average score close to 5 for all three cases, indicating excellent image quality (Table 1).

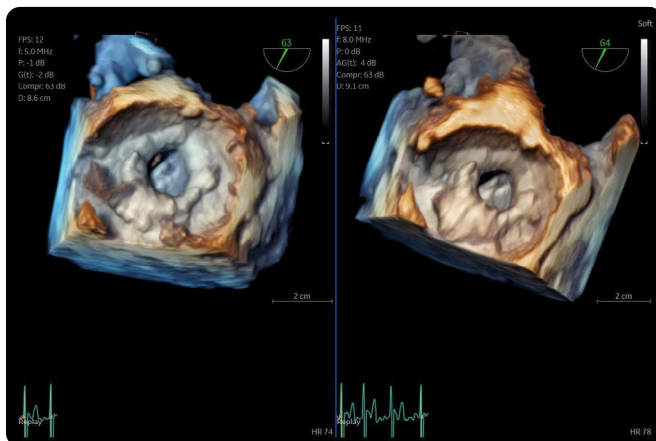


Figure 1: Direct comparison of 3D volume-rendered “en face” images of a metallic prosthetic mitral valve with occluded disk. Left image corresponds to 6VT-D adult probe and right image corresponds to 9VT-D pediatric probe.

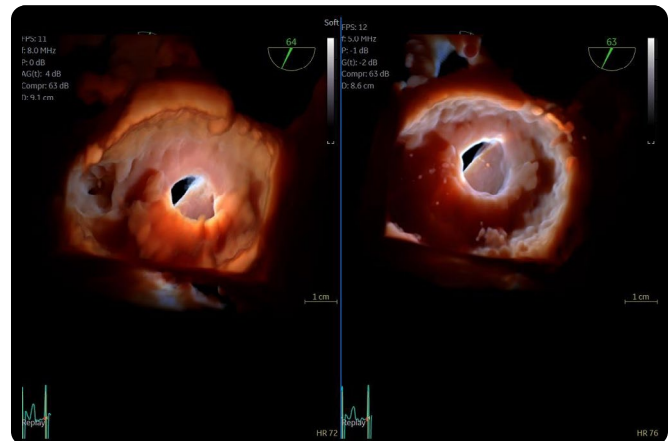


Figure 2: Direct comparison of 3D volume-rendered “en face” images of a metallic prosthetic mitral valve with occluded disk. Images enhanced with “photorealistic method” with Flexilight application (GE HealthCare). Left image corresponds to 6VT-D adult probe and right image corresponds to 9VT-D pediatric probe.

Probe Used	6VT-D						9VT-D					
Method for Scoring	2D	2D Color	PWD	CWD	3D	Average Score	2D	2D Color	PWD	CWD	3D	Average Score
1 st patient	5	5	5	5	5	5	5	5	5	5	4	4.8
2 nd patient	5	5	5	5	5	5	5	5	5	5	5	5
3 rd patient	5	5	5	5	5	5	4	5	5	5	4	4.6

Table 1: Direct comparison of imaging quality in patients examined with both 6VT-D and 9VT-D probe. Scoring system: 1: non-interpretable images, 2: poor quality but interpretable, 3: average quality, 4: good quality, 5: excellent quality. 2D, two-dimensional; PWD, pulsed-wave Doppler; CWD, continuous-wave Doppler; 3D, three-dimensional.

3.2. Echocardiography department transesophageal echocardiography

Following the initial comparison between the pediatric and adult probes, where confidence in the accuracy of the 9VT-D probe was established, the rest of the consecutive patients underwent the TEE protocol solely with the pediatric probe. Most patients received local anesthesia of the posterior pharynx with lidocaine but only four (4) of them required minimal doses of midazolam (1–2 mg) due to slight discomfort in order to ensure they remained cooperative throughout the procedure. With the exception of one patient who experienced intense pharyngeal reflex and required sedation with 5 mg of midazolam, all other patients tolerated the mini-TEE probe well (Table 2).

Our initial experience further showed that in a small number of patients and especially the younger ones with pharyngeal reflex, left lateral decubitus position was suboptimal for the introduction of the probe. The introduction in these patients was much easier in the sitting position and they were asked to swallow the probe by themselves with a very limited involvement of the physician or the nurse. Local anesthesia could also be unnecessary for a significant number of patients in the future after we have obtained experience of introducing this new mini probe.

Regarding imaging quality, almost all patients exhibited excellent images without any compromise in resolution,

obviating the need to confirm findings using the standard TEE probe (Figures 3 and 4, video S5). Despite the one patient requiring additional sedation due to intense pharyngeal reflex, the quality of images obtained remained consistent across all cases. In 22 cases out of 30 included in this study, the 2D and 3D imaging quality received a score of 5 suggesting excellent imaging totally equal to the one acquired with the adult probe. In four cases, 2D and 3D images were commented as good with a score of 4 and in another four cases, while the 2D images were excellent, 3D images were again mentioned to be good, almost equal to the standard probe but not exceptional enough to receive a grade of 5 (Table 3).

Score	Probe Tolerance (Number of Patients) Total Number of Patients = 19
1	0
2	1
3	0
4	4
5	14

Table 2: Tolerance of probe during examinations in the echocardiography department. Five-point scoring system. 1: non-tolerable probe/termination of examination, 2: major discomfort during TEE, 3: major discomfort immediately after TEE with chest pain/bleeding, 4: minor discomfort, 5: no discomfort during or post-TEE.

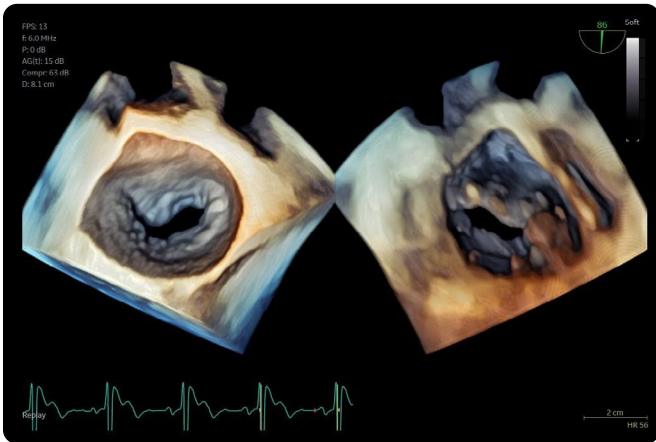


Figure 3: Dual crop 3D volume-rendered atrial (left) and ventricular (right) views of normal mitral valve.

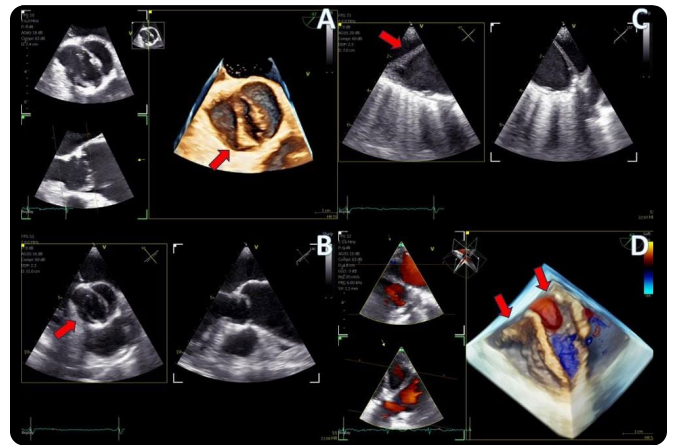


Figure 4: (A) 4D demonstration of a true-bicuspid aortic valve (red arrow), (B) Biplane 2D demonstration of a true-bicuspid aortic valve (red arrow), (C) Chronic dissection of descending aorta (red arrow showing the wall of the true lumen), (D) 3D volume-rendered color Doppler image showing the true (right arrow) and the false lumen (left arrow).

Echocardiographic Modality	Number of Patients	1 Non-Interpretable	2 Poor	3 Average	4 Good	5 Excellent	Average Score
2D	30	0	0	0	4	26	4.87
2D color	30	0	0	0	0	30	5
PWD	30	0	0	0	0	30	5
CWD	30	0	0	0	0	30	5
3D	30	0	0	0	8	22	4.73
3D color	30	0	0	0	8	22	4.73

Table 3: Scoring of imaging quality of the new 4D mini-TEE probe according to different echocardiographic modalities: 1: non-interpretable images, 2: poor quality but interpretable, 3: average quality, 4: good quality, 5: excellent quality. 2D, two-dimensional; PWD, pulsed-wave Doppler; CWD, continuous-wave Doppler; 3D, three-dimensional.

3.3. Intra-Procedural Transesophageal Echocardiography

The new 4D mini-TEE probe was utilized in eight consecutive patients undergoing transcatheter procedures at our clinic. Among them, four patients underwent cry-ablation for atrial fibrillation, two underwent patent foramen ovale (PFO) closure, one underwent atrial septal defect (ASD ostium secundum) closure, and one underwent left atrial appendage (LAA) closure.

Despite the protocol recommending minimal sedation and avoidance of intubation, two of the “ablation” patients were unable to tolerate the probe, necessitating intubation and administration of general anesthesia. Additionally, the patient scheduled for LAA closure required general anesthesia due to the detection of thrombus formation at the distal part of the appendage at the onset of the procedure, posing safety concerns for the interventionist. The

decision to proceed under general anesthesia was made to minimize risk and ensure patient safety. Conversely, the remaining “ablation” patients, as well as those undergoing ASD and PFO closure, tolerated the mini-TEE probe well and completed the intervention with mild sedation only. The average duration of probe insertion into the esophagus for all procedures was 29 min (range 20–32 min). None of the patients reported post-operative discomfort, and no esophageal

trauma was observed. The anesthesiologist noted that while it was easier to awaken patients who did not receive general anesthesia, maintaining sufficient sedation for the duration of the procedure was more demanding. Despite the challenges encountered, there were no anesthesia-related complications, and all patients adhered to the standard 24 h post-procedural hospitalization protocol. However, same-day discharge can be considered for patients who do not require intubation, offering an attractive and cost-effective option.

The imaging capabilities of the 4D mini-TEE probe were consistently excellent across all procedures (Figures 5–9). Trans-septal puncture in ablation cases was facilitated by biplane imaging (Figure 5), demonstrating a nice tending of the septum. For the guidance of wires to the pulmonary veins, both 2D and 4D volume-rendered images were utilized (Figures 5 and 6), expediting the procedure. The TEE probe was removed after the insertion of the cryo-ablation catheter into the LA.

In the case of LAA closure (Figure 8, video S3), 3D tools (MPR-flexislice) aided in accurate sizing of the ostium and the landing zone (important for AMULET device), particularly in the presence of distal thrombus where contrast infusion was contraindicated. The final result was satisfactory, with no leakage observed and a stable device placement was confirmed with a tug test.

PFO closure cases (Figure 9, video S2) benefited from the probe's excellent imaging, enabling precise wire insertion and providing anatomical criteria for device sizing. A bubble contrast study was performed at the beginning and at the end of the procedure for any remaining shunt. The stability of the device was confirmed with a wiggle test. Similarly, in the ASD case (Figure 7, video S1), the probe facilitated visualization of all defect rims and accurate sizing of the oval-shaped defect (with MPR) confirmed with balloon sizing and stop-flow technique and ensured a successful outcome with no residual shunt observed.

Overall, the 4D mini-TEE probe demonstrated exceptional imaging capabilities and played a pivotal role in guiding transcatheter interventions with precision and efficacy.

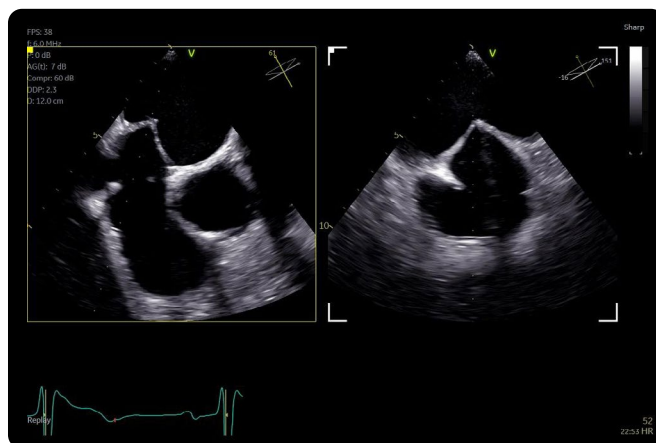


Figure 5: Biplane images of tending of the atrial septum during trans-septal puncture for atrial fibrillation cryo-ablation.

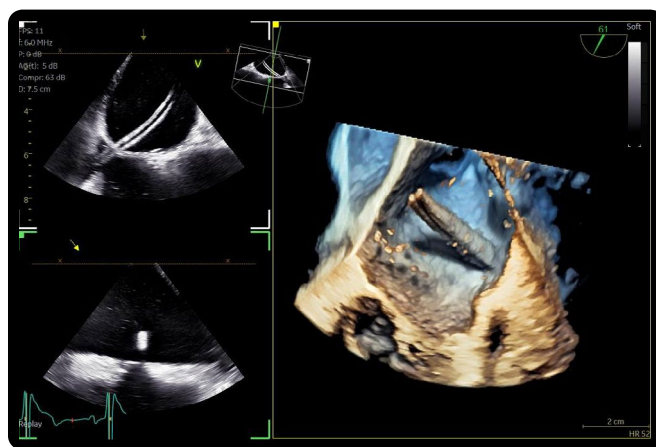


Figure 6: Azimuth level (top left), elevation level (bottom left), and 3D volume-rendered image (right) of an SLO catheter for the guidance of cryo-ablation procedure.

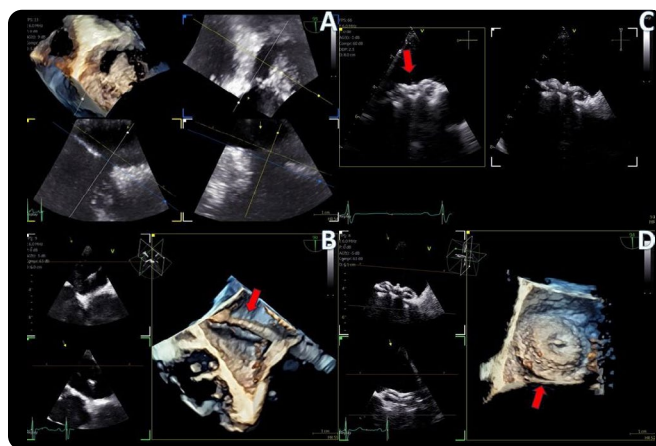


Figure 7: Secundum ASD closure case; (A) Flexislice method for measurements with both 2D and 4D images, (B) guide catheter through the defect (red arrow), (C) biplane 2D images showing the implanted ASD occluder, (D) 3D volume-rendered image showing the final result with an ASD occluder.

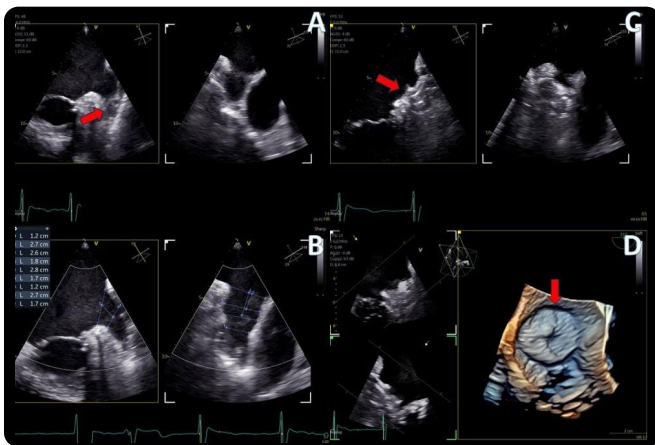


Figure 8: LAA closure case; (A) biplane images of the LAA showing the presence of distal thrombus (red arrow), (B) measurements of the ostium and the landing zone with biplane imaging, (C) Biplane images of the implanted AMULET device (red arrow), (D) 3D volume-rendered image showing a view of the implanted AMULET device (red arrow).

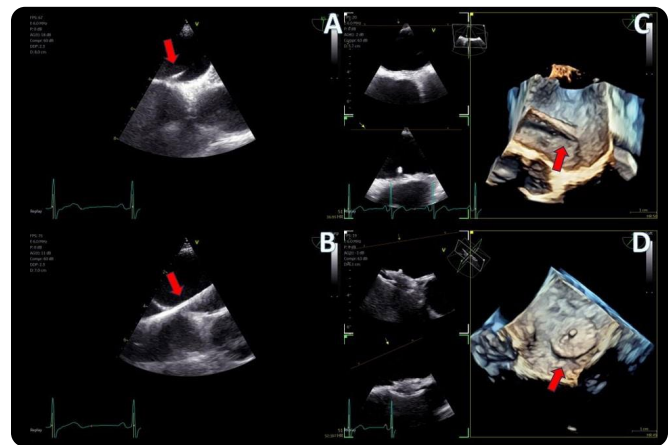


Figure 9: PFO closure case; (A) J wire through the PFO tunnel (red arrow), (B) stiff wire for guidance through the PFO tunnel (red arrow), (C) 3D volume-rendered view of the guide catheter through the PFO tunnel (red arrow), (D) final result with left atrial view of the PFO Amplatzer occluder (red arrow).

4. Discussion

Our study represents a pioneering effort in evaluating the new 4D mini-TEE probe (9VT-D GE HealthCare) across diverse adult patient populations, encompassing both routine TEE examinations and transcatheter procedures. Dr. Sanchis et al. have recently published their experience with this particular probe in a small number of LAA occlusion cases with excellent feedback in terms of patient's tolerance and imaging quality.¹⁸ Dr Karcenty et al. have also published data from the use of this particular probe in a pediatric population, showing superior quality of images compared with other 2D pediatric probes.¹⁹ While previous studies have included procedures using miniaturized TEE probes,^{15–17,20,21} ours is unique by the fact that this is the first commercially available probe boasting full 3D options and capable of supporting all TEE examinations and transcatheter procedures in adults. The added value of 3D echocardiography lies in its capacity for precise device sizing and

improved comprehension of cardiac anatomy. Notably, biplane imaging facilitates trans-septal puncture, thereby reducing procedural time. Multi-planar reconstruction (Flexislice method) serves as a vital tool for sizing in cases such as secundum ASDs and LAAs, where precise structural dimensions are imperative.⁴

Our study demonstrates that the new 4D mini-TEE 9VT-D probe effectively addresses the limitations of the adult TEE probe. The introduction of the probe requires less effort, especially in non-sedated patients that are asked to swallow it, under the physician's supervision. The role of the physician continues with the manipulation of the probe with the patient lying down in a left decubitus position. Direct comparison of images between the pediatric and adult probes confirmed the exceptional imaging quality achieved with the mini probe. The inclusion of 3D tools facilitates both routine examinations and transcatheter interventions, rendering this probe superior to previous mini-TEE/micro-TEE 2D probes and intra-cardiac echocardiography (ICE).

While ICE may emerge as an attractive alternative option in the future, its current limitations in terms of cost and image resolution preclude it from matching the 3D imaging capabilities of the 9VT-D probe.¹⁴

Moreover, the thin and flexible nature of the 9VT-D probe ensures good tolerability during the examination even in non-sedated patients. Our study analyzed thirty patients but only nineteen were included in the scoring system for the tolerance of the probe since the first three patients received sedation in order to complete the protocol with comparison of both probes, and another eight patients underwent transcatheter interventions with the presence of an anesthesiologist. Of these nineteen patients that completed the TEE examination without sedation, only one mentioned major discomfort and did not tolerate the probe, while four others reported minor discomfort. The remaining 14 patients tolerated this mini probe well and graded their experience with a score of 5.

This new probe is probably a tool that will become necessary for large tertiary centers where frail patients are often referred for diagnosis that could be suitable for percutaneous treatment. The greatest benefit is observed in transcatheter procedures, where the full array of 3D options can be leveraged without requiring intubation and general anesthesia. This results in reduced procedural time, avoidance of anesthesia-related complications, and the potential for same-day discharge, particularly advantageous for high-surgical-risk patients undergoing transcatheter procedures. Notably, our study revealed no complications from the esophagus or the administered anesthesia.

In summary, our study underscores the remarkable clinical utility and patient benefits afforded by the 4D mini-TEE 9VT-D probe, positioning it as a valuable tool in contemporary echocardiography practice, particularly in the era of transcatheter interventions.

Limitations

While our experience with the mini-TEE probe in routine practice has generally been favorable, there are certain issues that warrant mention. Unlike the standard adult probe, which is thick and rigid, facilitating its advancement past the tongue and posterior pharynx, the mini-TEE probe is thin and flexible. This can result in instances where the probe curls into the oral cavity, resembling a naso-gastric Levin tube. In one intubated patient, the anesthesiologist had to utilize a laryngoscope to aid in probe insertion

into the esophagus. Additionally, in one awake patient who exhibited poor tolerance to the probe, standard doses of sedation were necessary to complete the examination.

Another limitation is the current cost of the mini-TEE probe which is 1.5 times higher than that of the standard adult 4D probe (6VT-D). Our pilot experience provides convincing evidence in favor of the use of the mini-TEE despite its higher cost. Future studies will have to further investigate the clinical advantages and the long-term benefits of this adult probe by targeting a larger population. A randomized control trial using the standard adult probe could further assess the tolerance of the new probe by using the same scoring scale. Finally, this new probe could be further evaluated in a direct comparison with other pediatric 2D-TEE probes that are already established in standard practice.

5. Conclusions

The introduction of the new 4D mini-TEE probe represents a significant advancement in echocardiography, offering excellent imaging capabilities and encompassing all the essential 2D/4D options required for a comprehensive TEE protocol and guidance of transcatheter interventions. Notably, the utilization of this probe might lead to a reduction in esophageal and anesthesia-related complications. However, further validations are needed.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/jcm13216450/s1>, Video S1: Atrial septal defect closure case, Video S2: Patent foramen ovale closure case, Video S3: Left atrial appendage closure case, Video S4: Metallic mitral valve assessment, Video S5: Bicuspid aortic valve with chronic descending aortic dissection.

Author Contributions: Conceptualization, K.P., I.I. and E.D.; methodology, K.P., I.I., Ö.Ö.K., M.A.V. and E.D.; formal analysis, K.P., I.I., A.T. and E.D.; investigation, K.P., A.C., A.T., N.F. and A.P.A.; writing — original draft preparation, K.P., A.C., Ö.Ö.K., A.T., N.F., A.P.A., M.A.V. and E.D.; writing — review and editing, K.P., I.I., A.C., Ö.Ö.K., A.T., N.F., M.A.V. and E.D.; supervision, K.P. and E.D. All authors have read and agreed to the published version of the manuscript.

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Transforming the interventional toolbox

The impact of 4D ICE NUVISION ultrasound catheter in structural heart procedures

For years, transesophageal echocardiography (TEE) has been the standard imaging modality for structural heart interventions, but not without tradeoffs. Acoustic shadowing, limited views of certain structures, and the frequent need for general anesthesia have pushed the field to explore alternatives. Now, 4D ICE is becoming an essential element of the modern interventional toolbox — with the 4D ICE NUVISION™¹ ultrasound catheter by Biosense Webster, Inc., part of Johnson & Johnson MedTech, helping to drive the shift.

A leader in advancing echocardiography, Professor Alex Lee was among the first physicians in the Asia-Pacific region to embrace 4D ICE. He also championed the early use of the first mini 4D TEE probe. Prof. Lee is a Cardiologist and serves as the Chair of the Education and Research Committee for the Asian Pacific Association of Echocardiography. He holds a position at a leading cardiovascular intervention centre in Hong Kong, which serves a population exceeding one million and provides advanced diagnosis and treatment for complex cardiac conditions.

As an early adopter, Prof. Lee has integrated the 4D ICE NUVISION catheter into routine practice, where it's already making an impact —

shaping procedural strategies and broadening therapeutic options for patients. The advanced imaging tool, which can be used under conscious sedation, supports real-time, volumetric imaging and multiplanar visualization. It also features a 360° independent rotating tip, which enables crucial views of targeted anatomy and device-leaflet interactions with minimal manipulation.

Prof. Lee is part of a high-volume team that performs numerous mitral and tricuspid transcatheter edge-to-edge repair (TEER) procedures annually. The team also conducts a wide range of other structural heart interventions, including TAVI, TTVR, LAA closure, and septal defect closure.

We asked Professor Lee to share his thoughts on the addition of the 4D ICE NUVISION catheter — and how it, alongside the mini 4D TEE probe, is enhancing imaging capabilities in his practice.

What are the main challenges you encounter during structural heart procedures and how are you addressing the issues?

Prof. Lee: *In our experience, acoustic shadowing artifacts in the midesophageal TEE view may obscure right heart structures, particularly in*



“In my practice, overall, 4D ICE NUVISION represents a true game changer. One of the most notable is its independent rotating tip. This feature is particularly useful in procedures such as LAAC, where the tip can be rotated 180° without moving the entire catheter. It simplifies maneuvering, making the process easier and more efficient.”

the presence of mechanical mitral or aortic valve prostheses, septal occluders, mitral TEER devices, or hiatal hernias. Since TEE transmits ultrasound posteriorly through the left atrium and aorta, these implanted structures can create significant shielding artifacts, impairing visualization of critical procedural steps, most notably, leaflet grasping during tricuspid edge-to-edge repair.

To overcome these challenges, we utilized the transgastric view (2D ± 4D MPR) to mitigate acoustic shadowing and optimize leaflet grasping monitoring. In this view, leaflet grasping could be assessed in the tricuspid valve short axis, or with the addition of a reconstructed long-axis view. However, a limitation of this approach is the potential uncertainty in determining the final depth of leaflet insertion.

You were among the first in Asia Pacific to adopt 4D ICE. What initially drew you to this technology, and what aspects have had the greatest impact on your procedures?

Prof. Lee: We have long anticipated the arrival of 4D ICE because of its potential to revolutionize structural heart imaging. Since the implanted devices reside in the left heart — often obstructing ultrasound signals from TEE due to esophageal placement — it stands to reason that an alternative ultrasound source in the right atrium, adjacent to the tricuspid valve and free of intervening structures, would offer superior imaging.

Moreover, proximity enhances resolution, further optimizing visualization. The value of 4D imaging cannot be overstated. Critical aspects like leaflet grasping and other dynamic interactions are best assessed in real-time 4D or reconstructed multiplanar views derived from 4D datasets. Undoubtedly, 4D ICE is a transformative advancement in the field. It's an indispensable tool for precision and success in complex interventions.

From your perspective, what are the biggest benefits of the 4D ICE NUVISION catheter?

Prof. Lee: In my practice, overall, 4D ICE NUVISION represents a true game changer. One of the most notable is its independent rotating tip. This feature is particularly useful in procedures such as LAAC, where the tip can be rotated 180° without moving the entire catheter. It simplifies maneuvering, making the process easier and more efficient.

Another major benefit is image quality. It's excellent. Because the probe is positioned close to the target — whether a clip or the tricuspid leaflet — it provides highly detailed images. The ultrasound beam crosses the tricuspid valve perpendicularly rather than obliquely, which greatly enhances clarity and minimizes interference from artifacts caused by the aorta or prosthetic materials.

Using the 4D ICE NUVISION catheter can also extend some procedures to patients who are unsuitable for general anesthesia due to high risk, allowing them to undergo the intervention under alternative forms of anesthesia.

“Using the 4D ICE NUVISION catheter can also extend some procedures to patients who are unsuitable for general anesthesia due to high risk, allowing them to undergo the intervention under alternative forms of anesthesia.”

I've also talked about efficiency for some procedures like tricuspid. When you're using ICE to perform the procedure, we save time because we don't need to manipulate the TEE so many times to look at the leaflet capture and insertion, which can sometimes be difficult to see. With 4D ICE NUVISION catheter, we can see the leaflet so clearly that one attempt is often enough so the procedure time may be even shorter.

You mentioned the 4D ICE NUVISION catheter's unique design, including the independent rotating tip. Can you walk us through how you're incorporating these features into your imaging workflow during procedures?

Prof. Lee: *My standard imaging protocol begins with the home view on ICE, which I then adjust to 30–45 degrees to obtain the RV inflow-outflow view. Next, I activate biplane imaging, displaying the leaflet grasping view on the right panel, which typically provides excellent 2D visualization of the TEER device, with clips fully opened and optimally positioned for leaflet capture.*

If further refinement is needed, I switch to 4D ICE with the anatomic marker placed at the aortic valve and use FlexiSlice to dynamically assess leaflet grasping and clip deployment in real time — rotating the aortic valve to the 5 o'clock position on 4D imaging for standard display.

What types of procedures have benefited most from using the 4D ICE NUVISION catheter, and how has it changed your approach?

Prof. Lee: *The 4D ICE NUVISION catheter is a game changer — reducing reliance on TEE and providing unprecedented visualization for tricuspid valve interventions. It delivers superior image resolution by positioning the probe close to the tricuspid valve, eliminating interference from surrounding structures. Its 4D capability ensures stable image orientation and enables*

“With 4D ICE NUVISION catheter, we can see the leaflet so clearly that one attempt is often enough so the procedure time may be even shorter.”

real-time adjustments for optimal views, so the visualization of the leaflet and leaflet insertion, leaflet capture, is something unprecedented for ICE.

For procedures like tricuspid TEER, where precise visualization of leaflet grasping is critical, I have moved from TEE-only guidance to a hybrid approach, supplementing TEE with 4D ICE. Unlike 2D ICE, which cannot consistently provide the necessary imaging planes or rotational adjustments, 4D ICE reliably overcomes these limitations.

In the past, we only used 4D TEE to guide LAA closure. But now, we try to use 4D ICE to guide LAA procedures so patients don't have to undergo general anesthesia. So it's a transformative technology.

Can you elaborate on your hybrid approach and the value of each tool in tricuspid TEER procedures?

Prof. Lee: *I use both ICE and TEE simultaneously because each has distinct advantages for different aspects of the procedure. ICE is particularly useful for leaflet grasping. TEE, on the other hand, excels in clip steering and positioning due to its wider field of view. For now, this is*

how I integrate both imaging modalities, but I anticipate that future advancements in ICE technology may reduce the reliance on TEE.

What advice would you offer to other centers considering the adoption of 4D ICE NUVISION catheter for structural heart interventions?

Prof. Lee: *Good teamwork between the imager and interventionalist is key to get the best results. The interventionalist should direct where to place the ICE probe, while the imager handles the imaging — adjusting settings, optimizing the images, and deciding when to use tools like 4D, FlexiSlice, or 4D Markers. Working together smoothly leads to clearer pictures and a more efficient procedure.*

“The 4D ICE NUVISION catheter is a game changer — reducing reliance on TEE and providing unprecedented visualization for tricuspid valve interventions. It delivers superior image resolution by positioning the probe close to the tricuspid valve, eliminating interference from surrounding structures. Its 4D capability ensures stable image orientation and enables real-time adjustments for optimal views, so the visualization of the leaflet and leaflet insertion, leaflet capture, is something unprecedented for ICE.”



You are also an early adopter of the 9VT-D miniaturized probe. How has this technology enhanced imaging capabilities and patient comfort in interventional procedures?

Prof. Lee: *The mini 4D TEE probe offers a compelling balance of advanced imaging and enhanced patient comfort. With a 57% reduction in tip volume compared to conventional probes, it maintains full functionality — including real-time 4D (90° × 90°), diagnostic 2D, comprehensive Doppler (Color, PW, CW, TDI), and FlexiSlice reconstruction while preserving the familiar 180° manual array rotation. Clinically, the smaller profile improves tolerability during procedures such as LAA occlusion and valvular interventions — reducing the need for*

sedation in both pediatric and adult patients. The imaging quality remains robust, making it a practical option for cases where maneuverability and patient comfort are priorities.

“Clinically, the smaller profile improves tolerability during procedures such as LAA occlusion and valvular interventions — reducing the need for sedation in both pediatric and adult patients. The imaging quality remains robust, making it a practical option for cases where maneuverability and patient comfort are priorities.”

From a clinical perspective, what do you see as the most significant benefits of adopting the mini 4D TEE probe?

Prof. Lee: *Looking ahead, this innovation brings us closer to the long-term goal of performing more interventions under local anesthesia, gradually reducing the reliance on general anesthesia. Another key benefit is cost-effectiveness. Unlike ICE catheters, which are single-use, the mini 4D TEE probe can be reused across many procedures. For patients and healthcare systems where cost is a concern, this makes the mini 4D TEE probe a practical and sustainable alternative while still delivering high-quality imaging.*

“The mini 4D TEE probe offers a compelling balance of advanced imaging and enhanced patient comfort.”

Have you discovered any unexpected advantages or clinical insights from using the mini 4D TEE probe in real-world clinical scenarios?

Prof. Lee: *The 4D imaging capacity has improved significantly. Just last week, we treated a patient with osteogenesis imperfecta, a condition that causes severe bone deformities. Because of spinal abnormalities and a narrowed esophagus, a standard TEE probe could not be used. Instead, we were able to complete the procedure with the mini 4D TEE probe. In this case, the MitraClip also had to be delivered via the jugular vein rather than the femoral vein, since abdominal deformities prevented femoral access. Situations like this highlight the*

importance of having the mini 4D TEE probe available, as it gives us the ability to successfully treat patients who otherwise could not undergo the procedure.

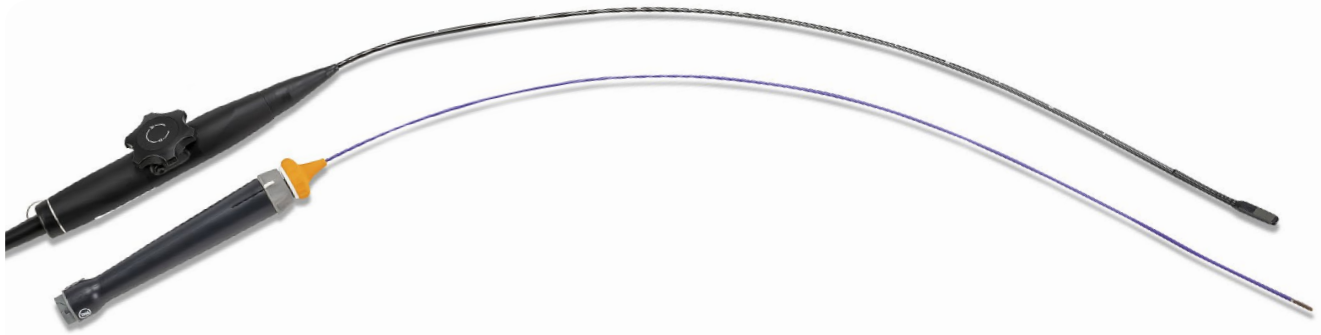
With a toolbox that includes both the 4D ICE NUVISION catheter and the mini 4D TEE probe, will it enable more structural heart procedures to be performed under conscious sedation?

Prof. Lee: *Yes, both interventionalists and imagers aim to perform these procedures under conscious sedation, as it reduces procedural time and lowers risks for certain high-risk patients. Currently, the need for standard TEE is the primary reason general anesthesia is required. However, for 4D ICE or the mini 4D TEE probe to fully replace TEE, they must offer superior imaging capabilities — including a wider field of view, higher resolution, and real-time 4D visualization. Advances in 4D ICE and the mini 4D TEE probe are progressing precisely toward these goals.*

Currently, LAA occlusion is one procedure where 4D ICE offers sufficient imaging quality while avoiding the need for general anesthesia, making it well-suited for conscious sedation. As a result, I have encountered a growing trend toward performing LAA occlusion under conscious sedation.

“By minimizing general anesthesia requirements, they enable shorter postoperative recovery times and reduced complications, thereby accelerating rehabilitation. Importantly, these innovations demonstrate significant potential to enhance procedural success rates while maintaining cost-effectiveness — a crucial consideration in contemporary healthcare systems.”





What impact do you think 4D ICE NUVISION and the mini 4D TEE probe have on patient outcomes and the broader field of structural heart interventions?

Prof. Lee: *The 4D ICE NUVISION catheter and the mini 4D TEE probe represent transformative advancements in structural heart interventions, offering superior imaging quality and improved patient tolerability. These technologies are particularly valuable for high-risk patients considered ineligible for conventional surgery due to general anesthesia concerns. By minimizing general anesthesia requirements, they enable shorter postoperative recovery times and reduced complications,*

thereby accelerating rehabilitation. Importantly, these innovations demonstrate significant potential to enhance procedural success rates while maintaining cost-effectiveness – a crucial consideration in contemporary healthcare systems.

What emerging technologies or innovations do you believe will have the greatest impact on the future of echocardiography?

Prof. Lee: *The most transformative advancements on the horizon include next-generation real-time 3D imaging systems with enhanced spatial resolution and multi-modal fusion capabilities for structural heart interventions, and sophisticated*

“ *The 4D ICE NUVISION catheter and the mini 4D TEE probe represent transformative advancements in structural heart interventions, offering superior imaging quality and improved patient tolerability.* **”**

AI-driven platforms capable of automating complex quantitative analyses. These innovations promise to revolutionize procedural planning, intraoperative guidance, and long-term patient management in structural heart disease. ■



Alex Lee, M.D., is a Cardiologist and serves as the Chair of the Education and Research Committee at the Asian Pacific Association of Echocardiography. Prof. Lee specializes in echocardiographic and his research covers heart valve disease, heart failure, and the use of advanced echocardiographic techniques such as 3D imaging, strain imaging and contrast echocardiography to guide structural interventions. Prof. Lee has made significant contributions to understanding the mechanisms of functional mitral regurgitation and mitral annular disjunction in degenerative and mitral regurgitation. He’s published over 300 peer-reviewed articles.

¹ 4D ICE NUVISION catheter is not available in all markets. The 4D ICE NUVISION Catheter is not CE-marked. 4D ICE NUVISION is distributed by Biosense Webster, Inc., part of Johnson & Johnson MedTech.

Prof. Lee is a paid consultant for GE HealthCare. The statements by Prof. Lee described here are based on his own opinions and on results that were achieved in his unique setting. Since there is no “typical” hospital/clinical setting and many variables exist, i.e., hospital size, case mix, staff expertise, etc. there can be no guarantee that others will achieve the same results.



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