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REVIEW

Echocardiographic-fluoroscopic fusion imaging for transcatheter mitral valve repair guidance

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The echocardiographic-fluoroscopic fusion imaging is a new imaging system which has recently become available, with the proposal to facilitate catheters and device navigation during catheter-based structural heart disease interventions. Several reports have described the early developments and the first clinical experiences, but literature focusing on the practical applications of fusion imaging technology to mitral valve transcatheter interventions, and on its potential advantages and current limitations, is still limited. In this review, we, therefore, describe the role of this novel imaging system during Mitraclip, Cardioband, and paravalvular leak closure interventions. The technical principles and the fluoroscopic anatomy of the interatrial septum and mitral valve are also described.

Keywords transoesophageal echocardiography • fluoroscopy • mitral valve repair • fusion images

Introduction

Over the past 10 years, percutaneous mitral valve (MV) therapies have emerged as alternatives to open heart surgery in high-risk patients with mitral regurgitation (MR).[1–4] The principles lying behind two of these percutaneous approaches have been developed from well-established surgical techniques: edge-to-edge MV repair with the Mitraclip system (Abbott Vascular, Santa Rosa, CA, USA) and transfemoral direct annuloplasty with the Cardioband system (Edwards Lifesciences, Irvine, CA, USA). Similarly, transcatheter closure of mitral paravalvular leak (PVL) is nowadays a feasible alternative to surgical repair especially in patients who, for clinical reasons are poor candidates to redo-surgery.[5] Two-dimensional (2D) and three-dimensional (3D) transoesophageal echocardiography (TOE) are crucial tools in the guidance these procedures, and they are considered to have the same relevance as fluoroscopy in term of efficacy and frequency of use.[6–9]

However, the 'dual imaging-based approach' (i.e. fluoroscopy and TOE) suffers from a lack of precise spatial and temporal integration. While catheters and devices are best visualized through fluoroscopy on one screen, MV leaflets and the mitral annulus can be exclusively visualized with 2D/3D TOE on a second screen. Interventional cardiologists are therefore obliged to consult repetitively and sequentially the two screens during each catheter manipulation. Moreover, echocardiography and fluoroscopy have their own tridimensional spatial co-ordinates and display cardiac structures in different orientations, thus requiring an interpretative effort to the operators to integrate ultrasound and fluoroscopic data. Because of the technical complexity of transcatheter MV procedures, a better integration between echocardiographic and fluoroscopic imaging data has become mandatory.

A novel imaging technique (Echo-Navigator, Philips Medical System, Best, the Netherlands) is able to acquire patient-specific imaging data from both fluoroscopic projections and bi-dimensional and 3D TOE volumetric data set. These two real-time imaging techniques are then 3-dimensionally overlapped. Co-registration is a term that describes this spatial and temporal alignment process. The result is a sort of 'hybrid image' which has the unquestionable advantage of providing an easy to interpret and reliable interface to interventional cardiologists, since soft tissues are displayed within the standard fluoroscopic projections. These echocardiographic-fluoroscopic hybrid images (the so-called 'fusion images') have been designed with the purpose to facilitate catheters' and devices' manipulation during catheter-based structural heart disease (SHD) interventions. Several

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reports have described the early developments and the first clinical experiences[10–15] with this approach, but literature focusing on the practical applications of this fusion imaging technology to MV transcatheter interventions, and on its potential advantages and current limitations, is still limited. In this review, we describe the technical principles regarding this novel imaging modality, the fluoroscopic anatomy of the important structures involved in these procedures, the novel echocardiographic 2D/3D TOE perspectives, and its potential role in each step of the main percutaneous interventions, such as Mitraclip, Cardioband, and PVL closure. The review is based on the experience gained in more than 100 percutaneous MV procedures performed in the departments of Cardiology of Cardiocentro Ticino in Lugano, of the University Heart Center in Zurich and of the Scientific Institute San Raffaele in Milan (*Table 1*).

Basic principles of fusion imaging

The method is based on the localization of the 3D TOE probe into the fluoroscopic space as described by Gao *et al.*[12] Their hypothesis was that using an efficient and robust image-based TOE probe-tracking algorithm and one or more fluoroscopic images, the position and orientation of the TOE probe could be automatically determined from the fluoroscopic data. The image-based TOE probe-tracking algorithm is based on an ultra-high resolution tomographic data set of a 3D model of a 3D TOE probe (nano-PET TM/CT, Mediso Ltd, Budapest, Hungary), previously calibrated on fluoroscopic images. The algorithm compares the reconstructed projections of the model (digitally reconstructed radiograph [DRR]) with the actual fluoroscopic image. At each comparison, the system calculates the similarity between fluoroscopic images and DRR and iteratively adjusts its estimation of the position and orientation of the TOE probe. The process continues until the best match between the TOE probe model and the actual fluoroscopic image of the TOE probe is identified. Two fluoroscopic projections [usually 30°left anterior oblique (LAO) projection and 30°right anterior oblique (RAO) projection at the time of TOE probe co-registration] minimize potential registration errors which may occur in the 3D space in the direction of the fluoroscopic beam or when the area of interest moves from the near field to the far field. A digitized, green-coloured, 3D model overlaying the fluoroscopic image, confirms that the probe is correctly coordinated with the intervention table and with the angulation of the C-arm.

Table 1 Number of percutaneous MV procedures

Procedures	Fondazione Cardiocentro Lugano	University Heart Center Zurich	Istituto Scientifico S. Raffaele Milan
Mitral clip	32	19	68
Cardioband	2	4	3
Paravalvular leak	3	2	9
Complications	2[a]	0	2[b]

[a]Vascular complications.
[b]Valve damage requiring surgery.

When fluoroscopy is activated, the system immediately overlaps the 2D or 3D echo image with the fluoroscopic silhouette and every time C-arm angulation is changed, the system recognizes and registers it and automatically updates the 2D/3D TOE image orientation on the screen. Additional hardware system permits to reconstruct the probe head model projection and registration to the X-ray plane by transferring the echo machine's live 3D imaging data to the X-ray system and by showing the rendering in the proper orientation and fusion with X-ray. However, since the additional hardware system is coupled with the X-ray system (Philips Allura Xper FD20/10 fluoroscopic system) and to the echo-machine hardware system (Philips CX50 or IE33 or Philips EPIC 7) which is provided by the same vendor (Philips Medical system), implementation of this system in the context of a hybrid room is straightforward. A wireless mouse, controlled either by interventional cardiologist or by the echocardiographer, regulates the different options, and tools of the fusion imaging system. Both 2D and 3D images may be displayed in a large fluoroscopic screen that can be split in separate panels (up to four) as they are visualized in the echo-machine (2D echo planes and 3D echo perspectives) or as they appear when they are aligned to the fluoroscopic projection. A dedicated panel shows the fused images.

The system provides several options to display and to process fused images:

a. Redundant extraneous tissues may be cropped directly on fluoroscopy, thus revealing soft tissue anatomy that is relevant to the procedure.
b. 2D TOE slices derived by 3D data set can be moved from the near to the far field in the direction of the fluoroscopic beam.
c. A specific tool that increases translucency of 3D TOE images relative to fluoroscopy makes catheters and devices well visible through the partially translucent soft tissues.
d. A dedicated software allows to place fiducial reference markers on 2D/3D images. When deemed accurate, reference markers are then accepted and immediately transferred and superimposed to the fluoroscopic image.

Fluoroscopic anatomy of interatrial septum and MV

In patients lying in the supine position [antero-posterior (AP) fluoroscopic projection], the right atrial (RA) cavity is right and anterior, whereas the left atrial (LA) cavity is left and posterior. As a result, the fossa ovalis (FO) is oriented left-to-right with an angle of about 65° with respect to the sagittal plane of the body. Owing to this obliquity, in the AP projection the FO is partially overlapped with the aortic root (Ao), which lies anterior and left to the FO. In the standard 30°RAO view the FO is 'en face' and Ao lies on the left with no overlapping, whilst in the 30°LAO view the FO is projected tangentially, thus precisely dividing the left from the RA cavity, with an almost complete overlap with the Ao (*Figure 1*).

For this reason, a RAO 20–30° is the ideal projection to confirm that the tip of the needle is positioned in the precise site within the FO, whilst in the LAO 20–30° the curvature of the FO (tenting) pointing towards the LA cavity appears maximal. Although most interventional cardiologists use pre-defined fluoroscopic angulations in order to perform trans-septal puncture (TSP), no specific angle in

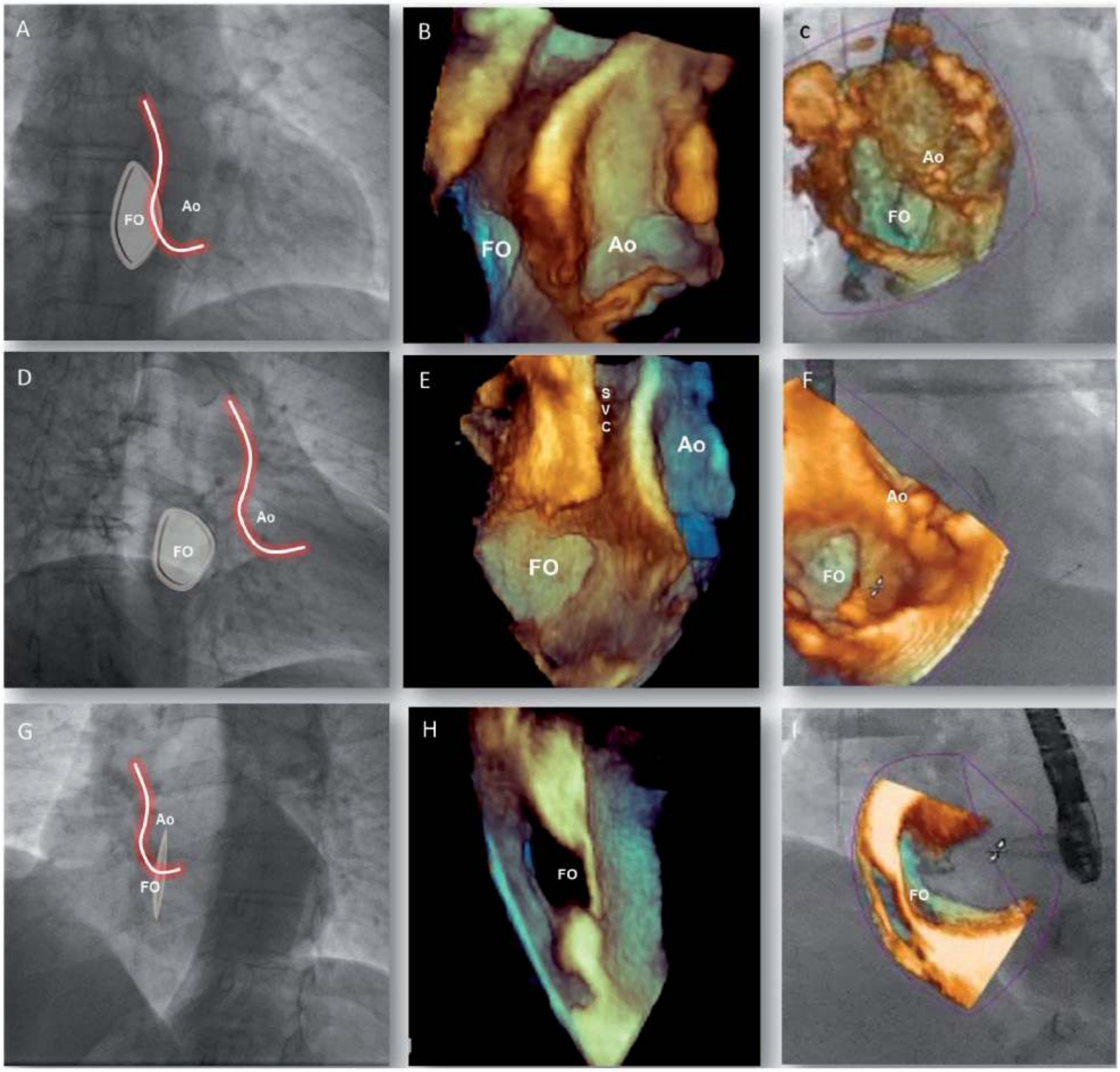

Figure 1 Fluoroscopic, 3D TOE and fusion image: (*A–C*) AP projection, the white/red line marks the right profile of the Ao, partially overlapping the FO; (*D–F*) RAO 30° projection, the FO is displayed 'en face' and the Ao does not overlap the FO; (*G–I*) LAO 30° projection, the Ao nearly completely overlaps the FO, thus both in 3D TOE and in fusion imaging the aorta has been removed for visualizing the FO in cross section. SVC, superior vena cava.

the RAO or LAO projections is anatomically consistent in all patients. Indeed, the position of the FO and its spatial relationship with surrounding structures may significantly change either physiological conditions (due to individual anatomical variations) or in pathological states.[16,17] For example, both dilatation of the LA and of the Ao tend to displace the FO more posteriorly. Moreover, the size of the FO may vary considerably from heart to heart, ranging from a large and round FO, frequently found in LA dilatation, to a very small and oval FO seen in patients with a lipomatous septum. One of the potential advantages of hybrid imaging is that when echocardiographic and angiographic images are overlapped, the FO becomes visible on the fluoroscopic screen and, consequently, C-arm angulation can gradually be adjusted until the FO appears in the correct perspective, allowing a perfect patient-tailored fluoroscopic view.

Understanding position and orientation of mitral leaflets and mitral annulus in different fluoroscopic projections is essential to guide transcatheter MV interventions. Two echocardiographic-fluoroscopic fusion projections are particularly relevant in transcatheter MV repair: the RAO projection 20–30° and the LAO projection 20–30°[16] (*Figure 2*). In the RAO (20–30°) cranial (10–20°) projection leaflets are displayed inside the cardiac silhouette in a cross section which roughly corresponds to the commissural view of 2D TOE. In this view, the maximal mitral annulus diameter is projected. This projection clearly separates segments of leaflets, but as in 2D TOE, it overlaps A1, A2,

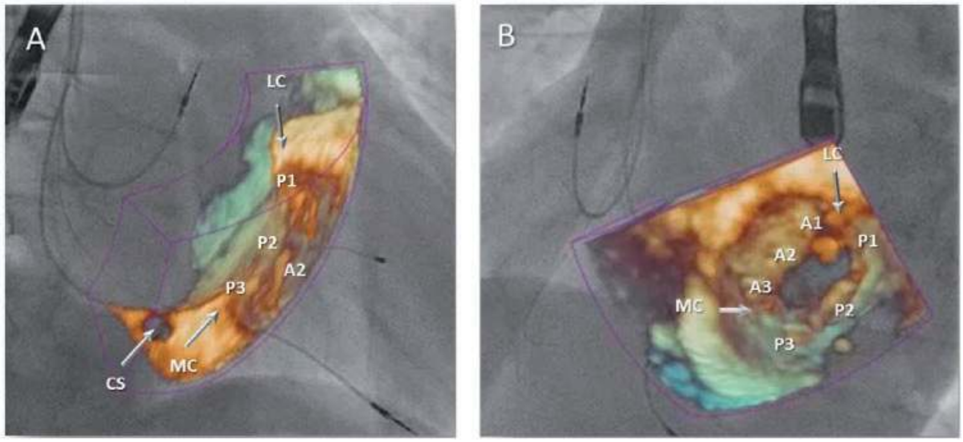

Figure 2 (*A*) Fused image of mitral valve in RAO projection. This projection separate segments of leaflets, but overlaps A1, A2, and A3 and P1, P2, and P3. The medial commissure (MC) is right-inferior, while the lateral commissure (LC) is left-superior. (*B*) Fused image of mitral valve in LAO projection. The image of mitral valve is seen from a ventricular perspective. This projection clearly separates segments of anterior from segments of posterior leaflet.

and A3 and P1, P2, and P3. Since the annular plane has an oblique direction from right-inferior to left-superior, this projection appears extremely useful during Mitraclip procedures for the visualization of the supero-inferior clip trajectory which must be perfectly perpendicular to the annular plane. Moreover, 2D TOE colour Doppler nicely shows the site of the regurgitant jet on fluoroscopy, thus greatly facilitating the steering manoeuvre towards the regurgitant orifice (see below). The origin of the regurgitant jet is particularly important after the first (or second) clip deployment in order to decide if the implantation of an additional clip is necessary. The position of trigones and commissures, relevant during the Cardioband procedure, are easily detected with the antero-lateral commissure superior and leftward, and posterior-medial commissure inferior and rightward. To clearly separate anterior from posterior MV leaflets the C-arm is rotated up to RAO 70° and tilted caudally up to 30–40°. In this fluoroscopic projection, the 2D/3D TOE image within the fluoroscopic silhouette is analogous to the 2D TOE long axis view 120° in which the minimum MV annular diameter is projected. This extreme RAO can be useful in the Mitraclip procedure for the grasping of A2–P2. However, the latter is rarely used by interventional cardiologists. In LAO (20–50°) with a slight caudal inclination (20–30°), the fluoroscopic projection is perpendicular to the mitral annulus, thus showing the en face view of the MV from the left ventricle perspective (analogous to 3D TOE ventricular perspectives of MV). In this view, the perimeter of the mitral annulus is entirely projected on the fluoroscopic plane. The fusion image allows to safely navigate into the LA around the perimeter of the valve. The same projection appears also useful after Mitraclip(s) deployment to appreciate the two orifices and the amount of leaflet tissue that has been grasped.

The role of fusion imaging during Mitraclip

Nowadays, percutaneous edge-to-edge MV repair with Mitraclip system is the only commercially available option for transcatheter treatment of both functional and degenerative MR. After its initial introduction in clinical practice, thousands of Mitraclip procedures have been performed worldwide. Although the implant is effectively guided by 2D/3D TOE echocardiography, there are several steps of the procedure where echocardiographic-fluoroscopic fusion imaging proves more useful and reliable than separate imaging. In particular, we found fusion imaging very helpful in (i) guiding the search of TSP site, (ii) navigating in the left atrium (to avoid impinging on the lateral wall or left lateral ridge), (iii) establishing the exact distance between the tip of the guiding catheter and the interatrial septum (for a safer withdrawing of the delivery system when needed), (iv) in assessing superior-inferior clip trajectory and, finally, and (v) in localizing the origin of the regurgitant jet on fluoroscopy (particularly useful after the implant of one or two clips).

Site-specific TSP

In general, the procedure requires a TSP near the superior and posterior margin of FO in order to obtain a good steerability of the delivery system within the LA.[6] This 'site-specific' TSP using 2D TOE requires two planes: a mid-oesophageal aortic valve short-axis view to determine the AP position and a bi-caval view to determine the supero-inferior position. An adjunctive cross section (usually the four chamber view) is necessary to measure the distance between the tip of leaflets and the annular plane. Using fused imaging in RAO projection the FO is projected in 'en face' view making it easier to determine the site-specific point. The addition of fiducial markers on standard fluoroscopic images, may further facilitate the correct positioning of the tip of the needle during the withdrawal and torqueing of the trans-septal needle. When the catheter approaches the desired point, the interventional cardiologist should be asked to rotate the C-arm in the LAO 30° projection. This projection displays the FO in sagittal view, clearly demonstrating the tenting of the FO and, following a further pressure the crossing of the needle which appears in the LA[17] (*Figure 3A–C* and Supplementary data online, *Movie S1*).

LA navigation with bulky and stiff delivery system might constitute a difficult and potentially dangerous manoeuvre. Advancing and withdrawing the guidewire and guiding catheter into the LA or steering the delivery system towards the MV may prove safer, if soft tissues of the atrial wall and FO are visible on fluoroscopy (*Figure 3D–F*).

After localizing the regurgitant jet (target lesion), the delivery system is advanced towards the target lesion and its trajectory should be exactly perpendicular to the valvular plane. Perpendicularity is of utmost importance to prevent oblique implantation of the clip with eventual ineffective grasping and distortion of the coaptation line. By the aid of fusion imaging, using either the 2D biplane or the 3D modality, the correct trajectory and alignment of the delivery system can be easily obtained. During this step, we usually prefer the dual panel display which simultaneously shows the perpendicularity of the clip arms to the coaptation line (*Figure 4A*) and the perpendicularity of the delivery system to the valvular plane (*Figure 4B* and Supplementary data online, *Movie S2*).

Localizing the site(s) of MR with 2D TOE colour Doppler on the fluoroscopic screen rather than using the 2D/3D TOE monitor alone, may greatly facilitate the advancement of the Mitraclip delivery system towards the origin of the jet by just coupling hand's manipulation with fluoroscopic advancement of the system towards a well-visible regurgitant jet. Notably, to further facilitate navigation, the regurgitant jet can be labelled with a fiducial marker positioned on its origin. In the common scenario of multiple clips implantation, the localization of the origin of any significant residual regurgitant jet may result of great usefulness to effectively direct the mitral clip delivery system towards the residual regurgitant orifice (*Figure 5* and Supplementary data online, *Movie S3*).

The role of fusion imaging during Cardioband procedure

Cardioband (Edwards Lifesciences, Irvine, CA, USA) is a percutaneous surgical-like direct annuloplasty device that is implanted in the beating heart on the posterior annulus. A polyester sleeve with radiopaque markers is fixed through multiple anchors inserted into annular tissue from the antero-lateral to the postero-medial commissure. At the end of implantation, the device size is adjusted, by assessing adequate reduction of MR severity under TOE guidance. Preliminary results appear promising.[4] The main steps of the Cardioband procedure are TSP, system insertion and navigation within the LA, implant deployment and implant size adjustment.

A patient-tailored TSP allows a good steerability of the delivery system around the entire perimeter of the annulus. The site-specific

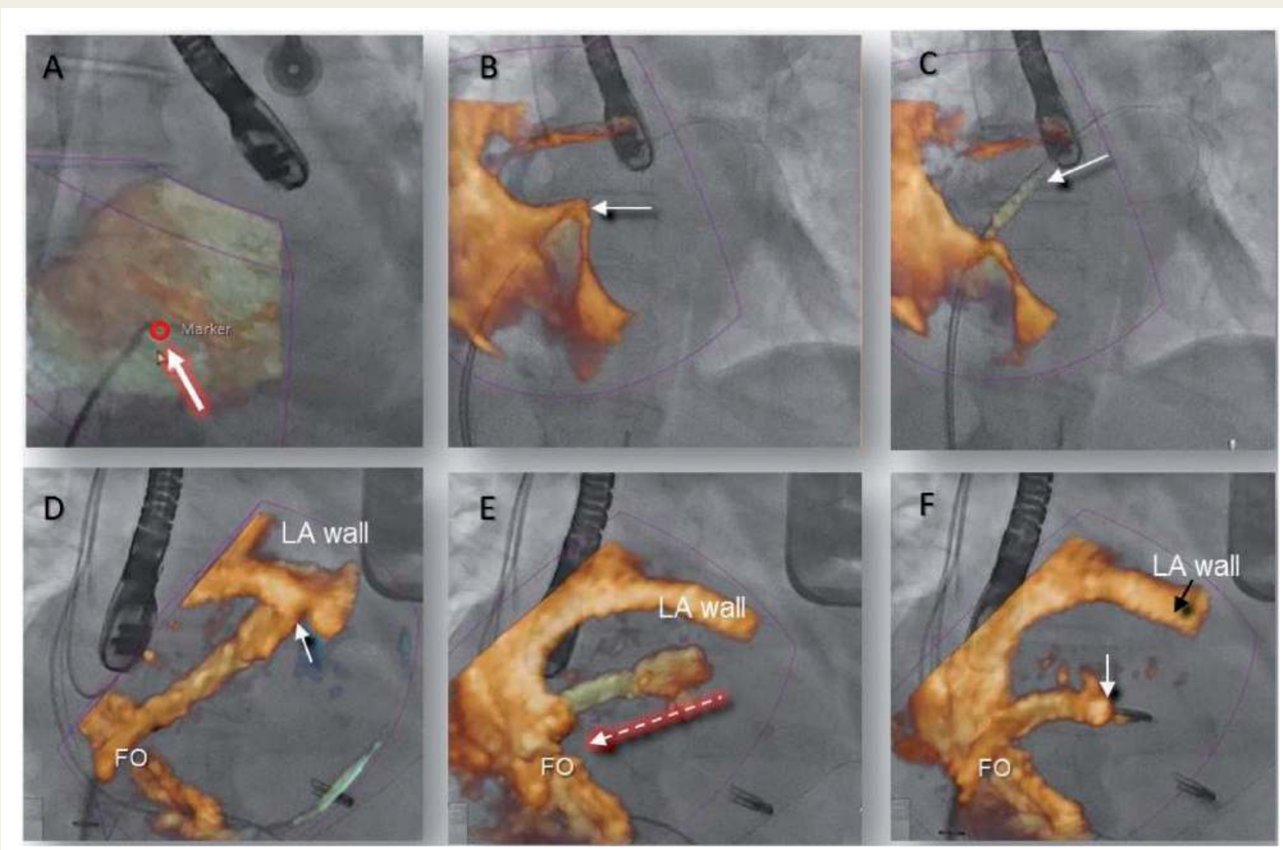

Figure 3 (*A*) Site-specific transseptal puncture. The site of the puncture is best localized in RAO 30° where the FO is seen 'en face'. The fiducial marker (circle and arrow) facilitates the manoeuvre. (*B*) The 'tenting' seen in LAO 30°. (*C*) The guide wire is seen crossing the FO (arrow). (*D–F*) Navigation within the atrium. (*D*) The delivery system is blocked on the lateral wall of the left atrium (LA) (arrow). (*E* and *F*) The system is safely pulled back and steering since the soft tissue of the lateral wall and FO are clearly visible on fluoroscopic image.

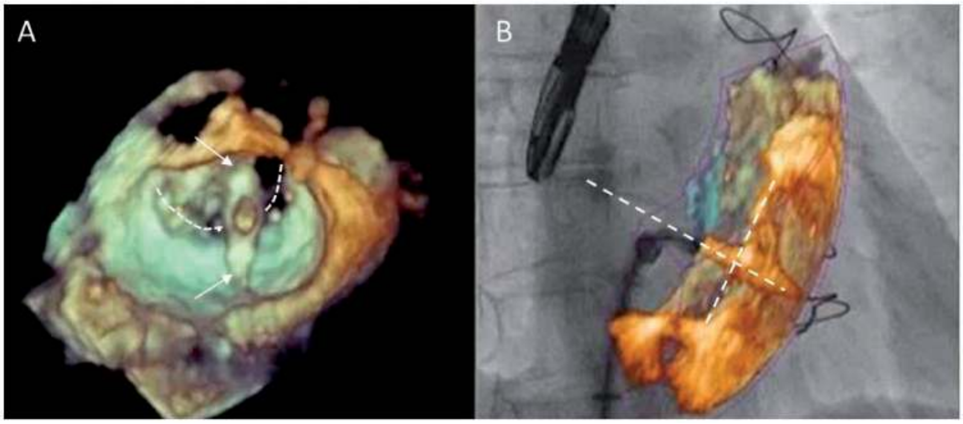

Figure 4 The dual panel display showing (*A*) the correct orientation of the arms of the clip perpendicular (arrows) to the coaptation line (dotted line) and (*B*) the trajectory of the clip delivery system perpendicular to the valvular plane (dotted lines).

TSP is pre-defined through a computed tomography scan performed before the procedure. However, as a general rule, it should take place at the level of the postero-medial commissure with a distance that is equal to or higher than 3.5 cm from the annular plane. As for the Mitraclip procedure, fusion imaging may greatly facilitate TSP. Following TSP, the implant delivery system (IDS) is advanced into the LA. The IDS comprises a steerable guide catheter and an implant catheter (IC) with the Cardioband implant loaded on its distal end. The delivery system is steered until the tip of the IC is placed over the anterior commissure where the first anchors are deployed as close to the aorta as possible (*Figure 6A–C*). The site of the first implant is displayed on 3D TOE imaging on the left of the screen while on fluoroscopy the same point is displayed on the right upper corner.

Fusion imaging offers a more familiar vision where the 'soft' echo image of the lateral commissure is oriented according to the fluoroscopic projection (*Figure 6C* and Supplementary data online, *Movie S4*).

The IC tip is then driven to the next anchoring point along the posterior annulus. These actions are repeated until the IC tip reaches the last anchoring site on the posterior commissure. Navigation within the LA is usually monitored using a 3D overhead perspective of the LA (*Figure 6* and Supplementary data online, *Movies S5* and *S6*). During Cardioband implant, fusion imaging may help to obtain the correct orientation of the catheter with respect to the annular plane and its correct positioning in relation to the leaflets' hinge line, well visible within the fluoroscopic silhouette (*Figure 5C*). Moreover, we noticed that in some steps shadowing artefacts might reduce the quality of echocardiographic imaging. In such a cases, fusion imaging improves the visualization of all the components (catheter, anchors, and annulus). Finally, each anchor site may be labelled with fiducial markers which, once displayed on the fluoroscopic screen, may facilitate device implantation.

The role of fusion imaging during MV PVL closure

Paravalvular leak (PVL) occurs in 5–17% of patients after prosthetic valve replacement.[18–20] For symptomatic patients, repeat surgery has been the traditional treatment, but it is associated with high operative mortality.[18,19] PVL percutaneous repair has therefore, emerged as an alternative therapy especially in high-risk patients.[20–22] However, successful PVL closure relies on a good understanding of PVL anatomy. Number, location, severity, and shape of PVL defects are currently assessed with transthoracic and transoesophageal 2D and 3D echocardiography, which is performed before the procedure. Mitral percutaneous PVL closure can be performed using the anterograde (venous, trans-septal), retrograde (arterial, transfemoral), or transapical access. The access-site selection depends on the location of the PVL, operator experience and preference, and the anatomical peculiarities of the individual patient.

In PVL closure fusion imaging is, to our experience, extremely helpful. *Figure 7* shows two PVLs identified and labelled on 3D TOE image (*Figure 7A*). The fiducial markers appear on the fluoroscopic image (*Figure 7B*) precisely indicating the fluoroscopic position of the leaks. Overlapping the regurgitant jet on the fluoroscopic screen, the operator may select the best fluoroscopic orientation that displays the largest 'vena contracta' which roughly corresponds to the largest diameter of the leak (*Figure 8A* and *B*). Both fiducial markers and the vena contracta greatly facilitate leak crossing (*Figures 7 and 8* and Supplementary data online, *Movies S7* and *S8*). Finally, the reduction (or abolition) of regurgitation after the deployment of the plug is directly detected on fluoroscopy to avoid the use of contrast.

Discussion

The aim of this review is to illustrate the potential advantages of this novel technology specifically tailored to guide MV procedures. Despite previous papers reporting single initial experiences, to the best of our knowledge this is the first review that specifically describes the potential advantages and limitations of this fusion imaging in the context of MV procedures on the basis of more than 100 cases performed in three different Institutions.

Echocardiography-fluoroscopy fusion technique has undoubtedly opened a new perspective in the field of percutaneous structural

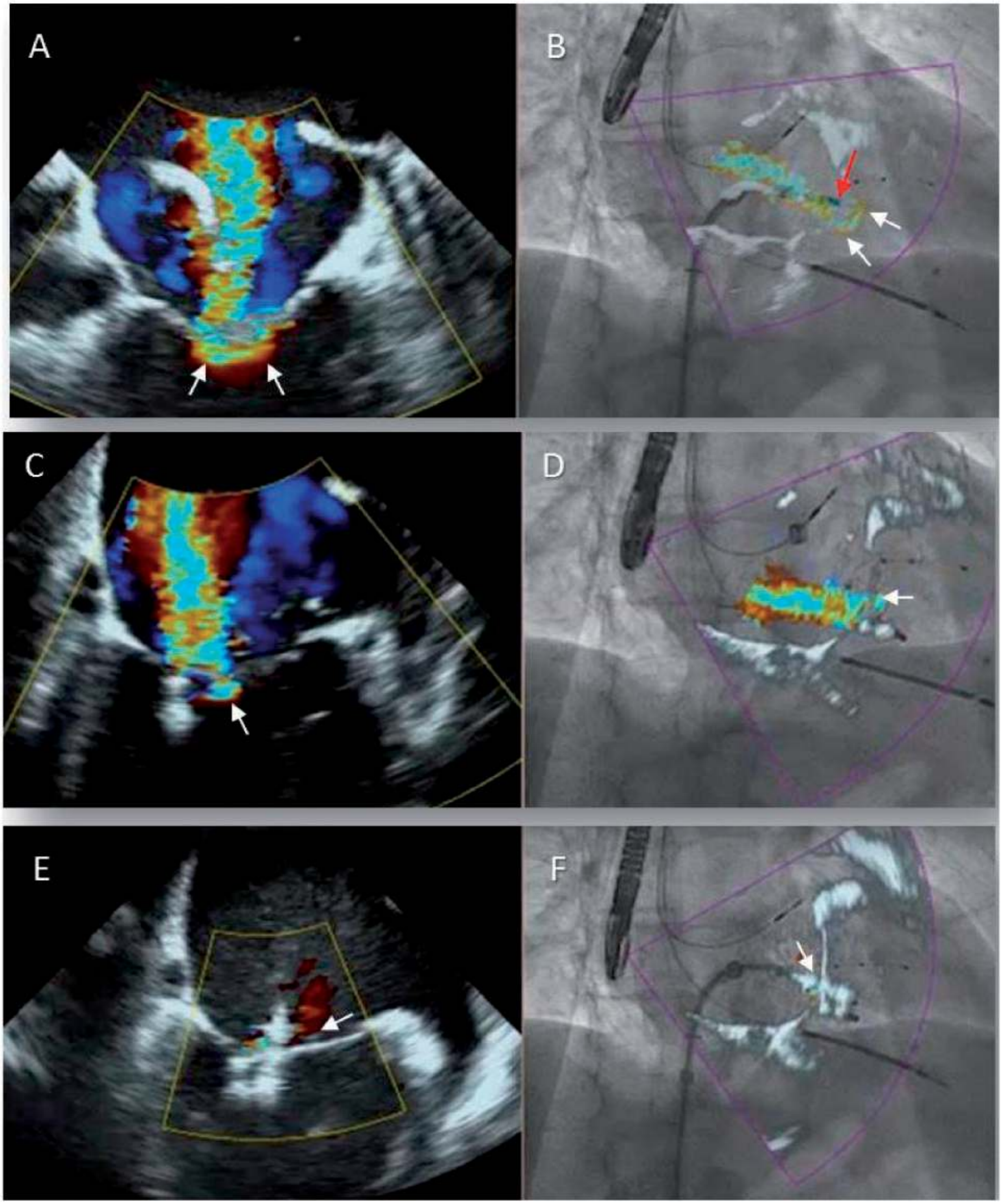

Figure 5 (*A* and *B*) The dual panel display showing a large mitral regurgitation (arrows). In fused image is clearly visible the clip delivery system approaching towards the origin of the jet (red arrow). (*C* and *D*) After a first clip, there is a residual regurgitant jet lateral to the first clip (arrow). (*E* and *F*) A second clip is then implanted on the origin of this residual jet.

interventions and has the potential to influence the catheterization laboratory structure in terms of medical devices' design and the skills required. In fact, while fusion imaging certainly facilitates the communication between the echocardiographist and the interventional cardiologist, proper and effective use of this novel technique requires a learning curve. From the echocardiographist point of view, such learning curve consists of a thorough understanding of the new 2D/3D TOE projections that characterize fusion images (which differ

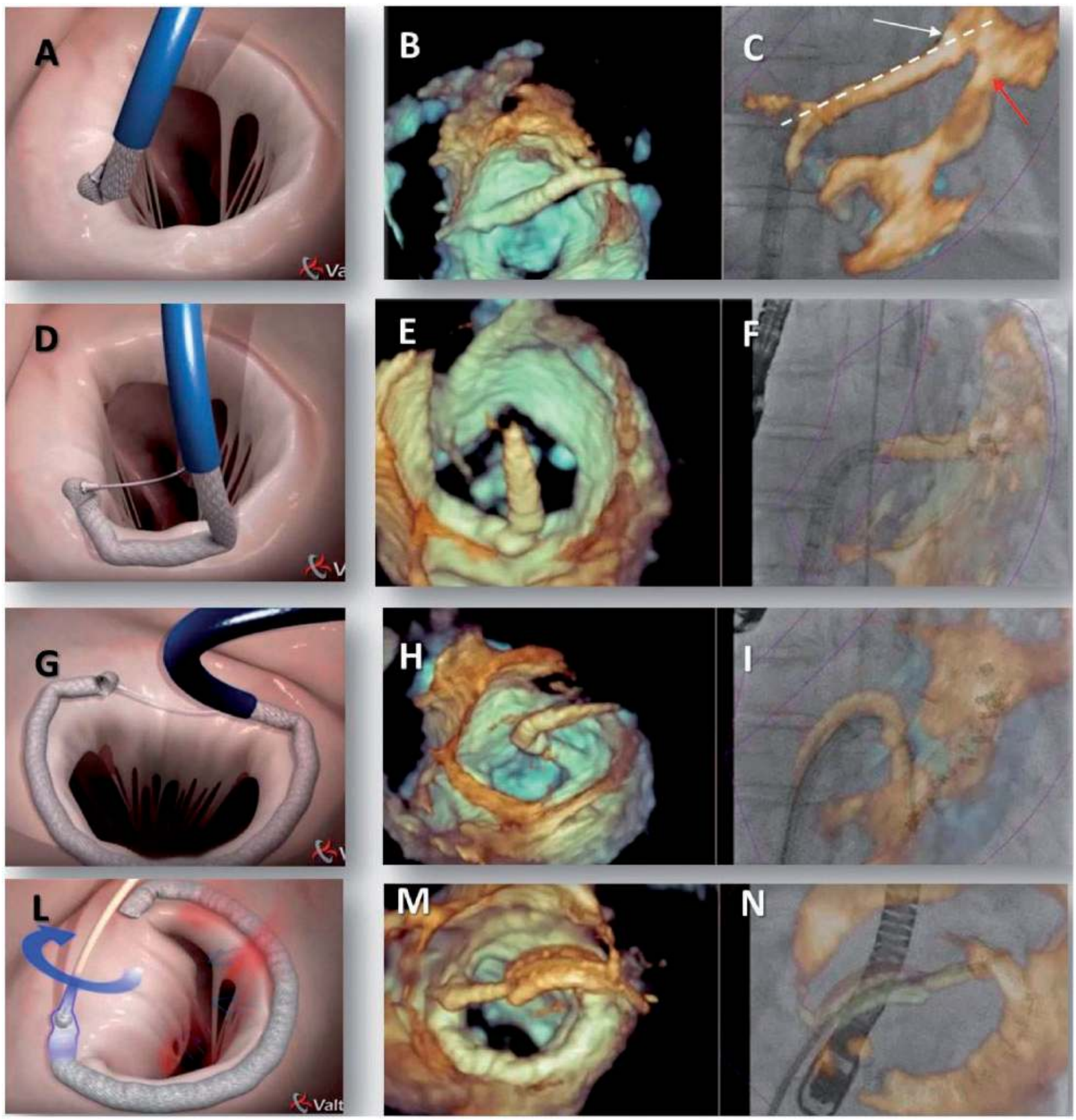

Figure 6 Steps of the procedure visualized by a cartoon (*A*, *D*, *G*, *L*) provided by the vendor, 3D TOE (*B*, *E*, *H*, *M*) from an overhead perspective, and fusion imaging (*C*, *F*, *I*, *N*). (*C*) The orientation of the catheter is marked by the dotted line, the white arrow points at the tip of catheter on the annulus while the red arrow at the hinge line.

from typical 2D/3D TOE images) and of the proper use of the available tools (i.e. adequate cropping to visualize target lesions, knowing when to apply 2D rather than 3D images and vice versa and increasing or reducing transparency of soft tissues according the procedure's ongoing step).

Interventional cardiologists could more easily familiarize with hybrid images, since they are basically fluoroscopic images enriched with soft tissue data. On the other hand, they would have to change their 'eye-hand co-ordination' gained in years in the SHD field using fluoroscopic and TOE imaging separately; for this reason, not all Interventional cardiologists are willing to accept this new imaging modality in the absence of scientific evidence. Additionally, this huge amount of visual data may be distractive ('fusion or confusion?'), and it will likely require time and training to be fully appreciated. Thus, it is not surprising that experienced cardiologists consider the clinical usefulness of this new technology questionable. However, in our

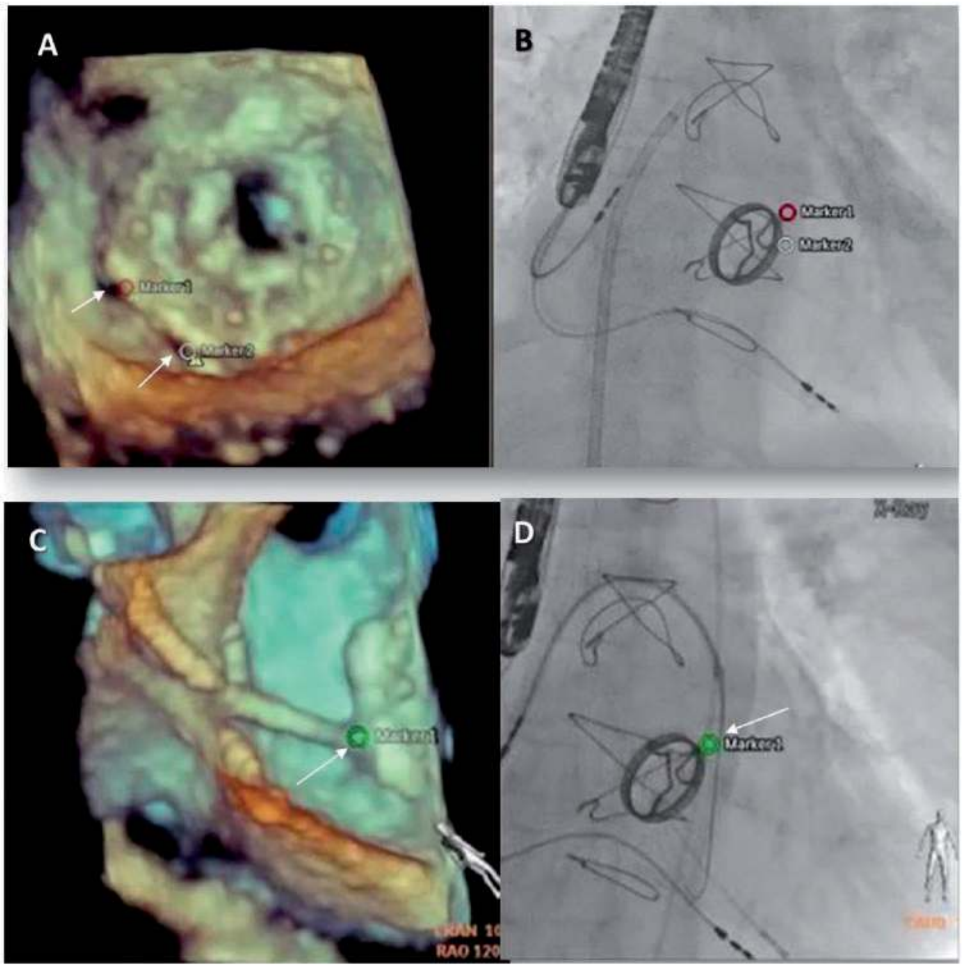

Figure 7 (*A*) 3D TOE image showing two paravalvular leaks (arrows). Locations marked with fiducial markers on the 3D images, immediately appear on the fluoroscopic screen (*B*) allowing an easier identification of the site. (*C*) 3D TOE image showing the catheter crossing one paravalvular leak (arrow) marked by marker. (*D*) Fluoroscopic image of the same step of procedure.

experience less experienced interventional cardiologists and trainees in invasive cardiology might benefit from this more intuitive imaging technique and as a result their learning curve might be shortened.

The exponential clinical advantages that may be gained from this new technology is not yet established. In the absence of comparative data, it is difficult to evaluate the impact of this imaging modality in terms of reduction of procedural times, radiation exposure, incidence and seriousness of complications, and operator confidence improvement, when compared with traditional 2D/3D TOE guidance. On the other hand, obtaining comparative data remains challenging. Multiple determinants such as experience of the operator, difficulties related to the single procedure, quality of echocardiographic imaging might make comparative data rather unreliable. Currently, there is a very limited experience worldwide, and the collection of adequate case series is difficult to obtain. Sündermann *et al.*[15] demonstrated a trend towards a reduction in terms of both radiation dose and procedural times in patients undergoing percutaneous edge-to-edge MV repair in which more than one clip was required. In a subgroup of patients from Zurich University (unpublished data), a comparison between MV procedures performed with and without the aid of fusion imaging, did not reveal differences in terms of procedural length, fluoroscopy time, and radiation dose (*Table 2*). Finally, future advances in spatial and temporal resolution of 3D TOE and new computational techniques in valves' modelling will be essential to develop a more effective guidance of complex SHD interventions.

Limitations

Current existing limitations which may prevent an extensive use of this fusion imaging technique must be mentioned. One is the restricted rotation of the C-arm, which impedes the appropriate overlap of some very useful 3D TOE perspectives with the fluoroscopic background. For example, in the setting of Mitraclip procedure, interventional cardiologists consider the 3D TOE view of the left atrium to be the most appropriate to place the clip's arms as perpendicular as possible to the leaflets' coaptation line. Such perspective

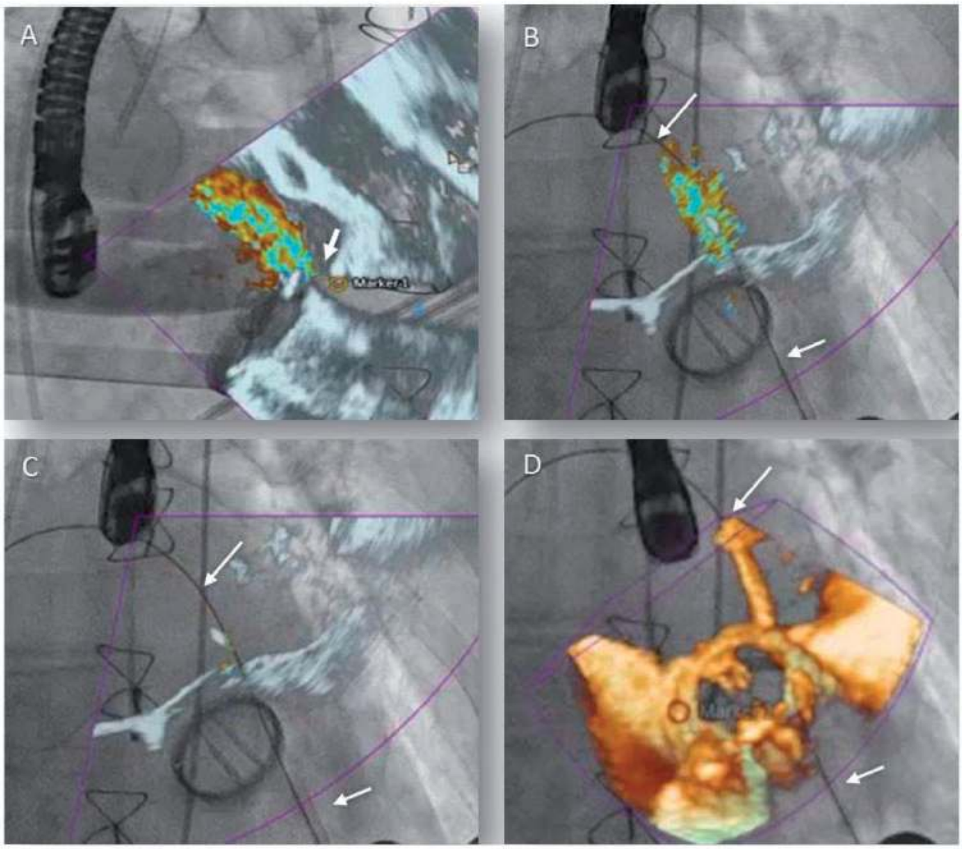

Figure 8 (*A*) 2D colour Doppler fused image showing the regurgitant jet originating from the paravalvular leak (arrow). (*B*) Colour Doppler (as well as fiducial markers) may facilitate the interventionalist in crossing the leak. The arrows point the guide wire across the leak. (*C* and *D*) Same step in 2D and 3D image.

cannot be merged with fluoroscopy. This can be overcome by splitting the screen in two (or more) panels showing the 3D TOE overhead perspective and the fused image, respectively.

A second limitation is the fact that, once positioned, fiducial markers remain fixed on the screen and do not follow soft tissue motion. This limitation is particularly relevant when the fiducial markers are positioned to localize PVLs. Because of heart motion, location indicated by markers may be correct in one frame of the cardiac cycle and incorrect in another. Malalignment between fiducial markers and structure could lead to operator misperception and errors during the procedure.

Another limitation is the inconsistency of co-registration when the probe is placed in the stomach, where the position and orientation of the probe cannot be easily tracked by the image-processing algorithm; as consequence fusion images from the trans-gastric view are difficult to obtain. Since trans-gastric views are currently the most used views to guide percutaneous clipping of the tricuspid valve, this procedure can hardly be guided by fusion imaging.

Last but not least, in our opinion the main limitation is linked to the fact that in the current fusion system both the fluoroscopy apparatus and the echo-machine at present are provided by the same vendor; such a restriction limits the application of this technique in those institutions where the echo-machine and/or the fluoroscopic system are provided by different vendors. Other manufacturers will shortly commercialize their own 'fusion imaging technique' and their more widespread use will allow to clarify its clinical role.

Conclusion

Echocardiograpy-fluoroscopic fusion imaging couples two 'real-time' imaging techniques showing in the same screen a sort of 'hybrid image' where soft tissues appear onto the fluoroscopic cardiac silhouette. This new imaging modality has the potential to become the main imaging technique in catheter-based SHD interventions. However, the absence of data showing a reduction in terms of procedural and fluoroscopic times, radiation exposure and improved outcomes, hampers its clinical applicability. Though new approach to fusion imaging from different manufactures are likely to emerge in the near future, the fact that this imaging modality is currently provided by a single vendor limits its more widespread use, experience and data collection.

Table 2 Unpublished data from University Heart Center Zurich on procedural length, fluoroscopic time, and radiation dose with a without fusion

Mitral clip	With fusion	Without fusion	*P*-value
Degenerative/functional	11/8	11/8	
1, 2, and 3 clips	9/9/1	9/9/1	
Procedural length (min ± ds)			
1 clip	56 ± 20	61 ± 15	0.25 ns
2 clips	65 ± 16	75 ± 21	0.12 ns
3 clips	99 ± 35	108 ± 43	0.51 ns
Fluoroscopy time (min ± ds)			
1 clip	18 ± 7	17 ± 7	0.7 ns
2 clips	22 ± 6	23 ± 10	0.41 ns
3 clips	31 ± 15	33 ± 19	0.93 ns
Radiation dose (Gy/cm^2 ± ds)			
1 clip	25 ± 12	24 ± 15	0.61 ns
2 clip	31 ± 15	32 ± 19	0.73 ns
3 clip	66 ± 21	70 ± 19	0.71 ns
Cardioband	**With fusion**	**Without fusion**	***P*-value**
Procedural length (min ± ds)	143 ± 36	125 ± 21	0.41 ns
Fluoroscopy time (min ± ds)	47 ± 12	52 ± 9	0.61 ns
Radiation dose (Gy/cm^2 ± ds)	36 ± 28	40 ± 31	0.85 ns
Paravalvular leak	**With EchoNav (2)**	**Without EchoNav (2)**	***P*-value**
	2	2	1 ns
Procedural length (min ± ds)	128 ± 11	115 ± 35	0.65 ns
Fluoroscopy time (min ± ds)	83 ± 27	86 ± 36	0.9 ns

Supplementary data

Supplementary data are available at *European Heart Journal - Cardiovascular Imaging* online.

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