2 Image Optimization Tools and Image Display

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3D Image Optimization [1, 2]

The first step regardless of mode of 3D acquisition is to obtain the highest quality 2D image possible of the region of interest (ROI; Fig. 2.1). Next the 3D counterpart of the 2D image is obtained by pressing the desired 3D mode button (Fig. 2.1).

Regardless of mode of acquisition, 3D image size can be optimized using the Lateral Size/Width and Elevation Width (Philips Healthcare) or Volume Size/Volume Shape (GE Healthcare) function controls (Figs. 2.2, 2.3, and 2.4).

As expected, there is a progressive decrease in the 3D volume rate or frame rate as the 3D volumetric data set gets larger. On the Philips 3D platforms, the initial 3D Full Volume image obtained represents only the posterior half of the entire 3D volume because the anatomic crop plane used to obtain the image is a coronal plane that bisects the heart into two equal anterior and posterior halves. The missing anterior half is restored by pressing a Reset Crop button (Fig. 2.5).

After appropriate image display (discussed later), the 3D image/video clip is initially optimized by using the lowest compression settings possible (Fig. 2.6). Lower compression produces a high contrast image with better fine image details.

Persistent noise and other echo artifacts can be removed through a process known as tissue cropping. Tissue cropping is also very useful to highlight or view the ROI within the 3D volumetric data set and therefore, is crucial for image optimization. The different vendors offer several methods to achieve adequate tissue cropping. These include use of tomographic crop planes that can be advanced into the 3D volumetric data set in parallel to the primary planes of the heart [coronal, sagittal, or transverse which are perpendicular to the elevation or z-axis, azimuthal or x-axis, and axial depth or y-axis respectively [Crop Adjust Box (Philips Healthcare); Crop Tool (GE Healthcare), Box Edit (Siemens Healthineers) Fig. 2.7] or from any angle [Translate (GE Healthcare; Fig. 2.8), Crop Adjust Plane or Plane Crop (Philips Healthcare) a freely adjustable arbitrary cropping plane that has a purple color when in front the 3D volumetric data set (Fig. 2.9)], or alternatively, crop lines or boxes [iCrop , Face Crop, or Quick Vue (Philips Healthcare), 2 Click Crop (GE Healthcare); D'art (Siemens Healthineers)] that determine the ROI within the 3D volumetric data set to be viewed (Figs. 2.10 and 2.11).

Care should be taken to avoid over cropping and thus creation of artefactual defects. The effects of excessive gain or too low a gain setting are illustrated in Fig. 2.12.

Smoothing is the process by which the texture of a rough surface is evened out. Too much smoothing masks fine image details (Fig. 2.13).

3D Image Display

Appropriate image display is important. For the enface left atrial view of the mitral valve, the 3D image is rotated so that the anterior aortic valve is at the top of the image with the medial atrial septum to the right and the anterolateral left atrial appendage to the left of the image (Figs. 2.6 and 2.14).

This view is referred to as the surgeon's view because it closely resembles how the cardiac surgeon sees the mitral valve upon opening up the left atrium. *Current 3D imaging platforms offer the option of automatic display of the mitral valve in a surgeon's view format.* By simply rotating the 3D

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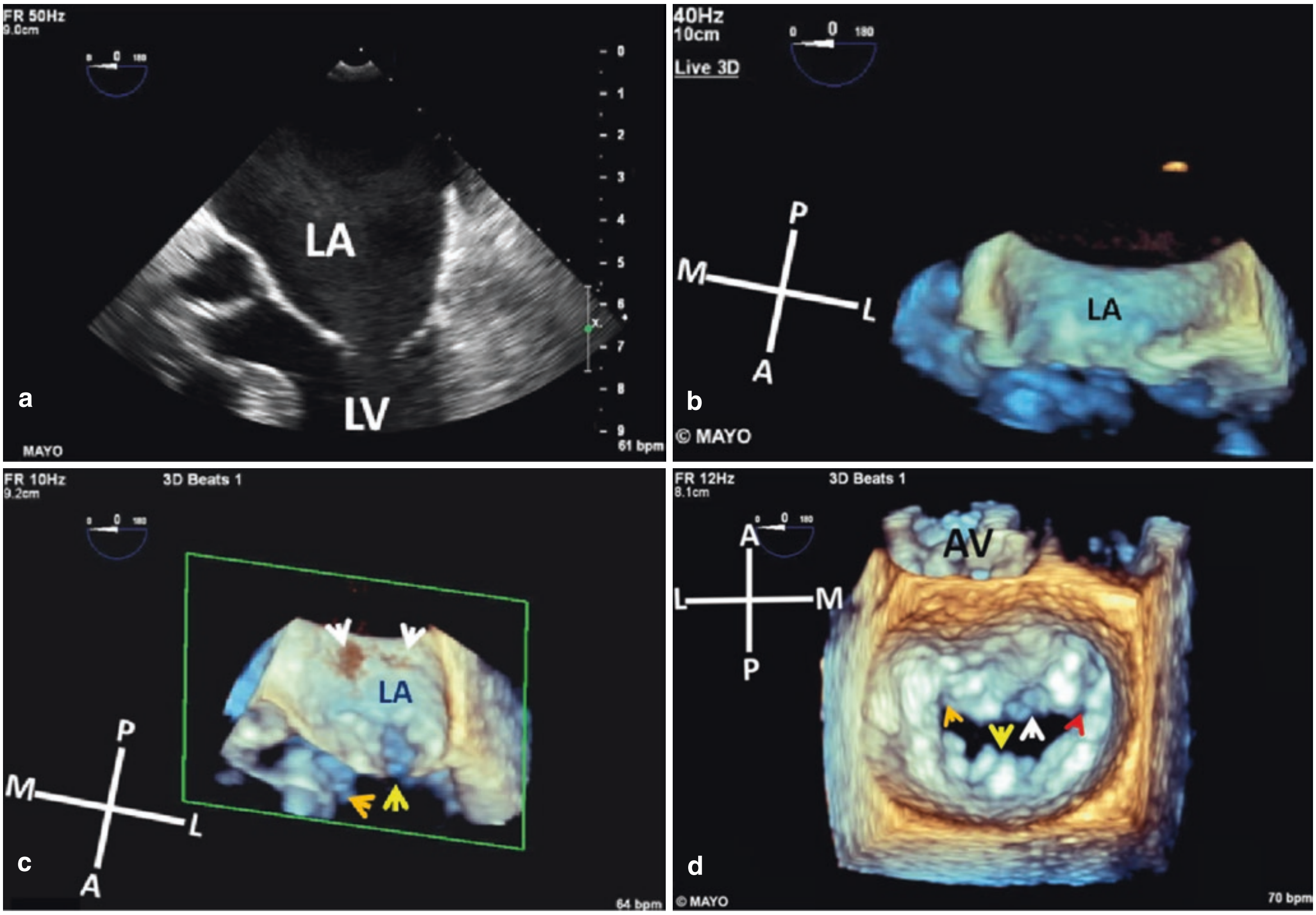

Fig. 2.1 **Top panel**: 2D TEE (**a**) and corresponding live 3D (**b**). Note the small 3D volume acquisition and high FR (40) also referred to as VR. **Bottom panel**: Live single beat FV and 3D zoom of the same 2D TEE. (**c**) FV acquisition . Note the larger 3D image data set compared with live 3D and consequently marked drop in FR to 10 despite the slightly lower image depth. White arrows point to posterior mitral annulus, yellow arrow points to MV and orange arrow points to LVOT. Green box indicates that the FV is autocropped with only the posterior half of the image being displayed. (**d**) 3D zoom acquisition at an even shallower depth . The entire MV including AML (white arrow), PML (yellow arrow), medial and lateral commissures (red and orange arrows respectively) is seen at an adequate FR. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. A, anterior; AML, anterior mitral leaflet; AV, aortic valve; FR, frame rate; FV, full volume; L, lateral; LA, left atrium; LV, left ventricle; LVOT, left ventricular outflow tract; M, medial; MV, mitral valve; P, posterior; PML, posterior mitral leaflet; VR, volume rate

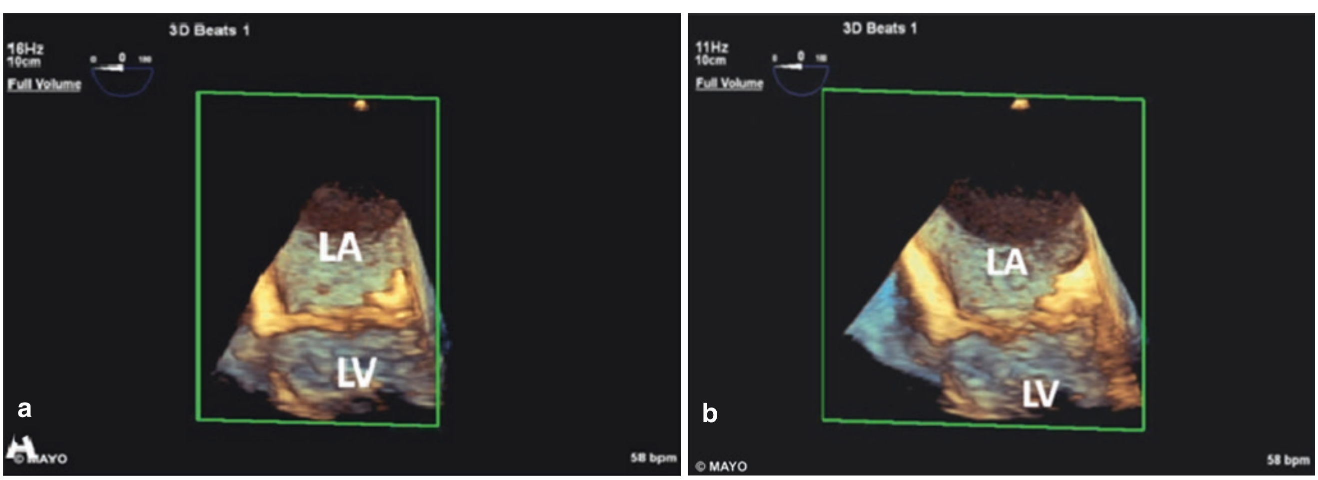

Fig. 2.2 Optimizing live single beat FV size using Lateral Size function. As expected, the FR decreases from **a** to **b** with increase in lateral width. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. FR, frame rate; FV, Full Volume; LA, left atrium; LV, left ventricle

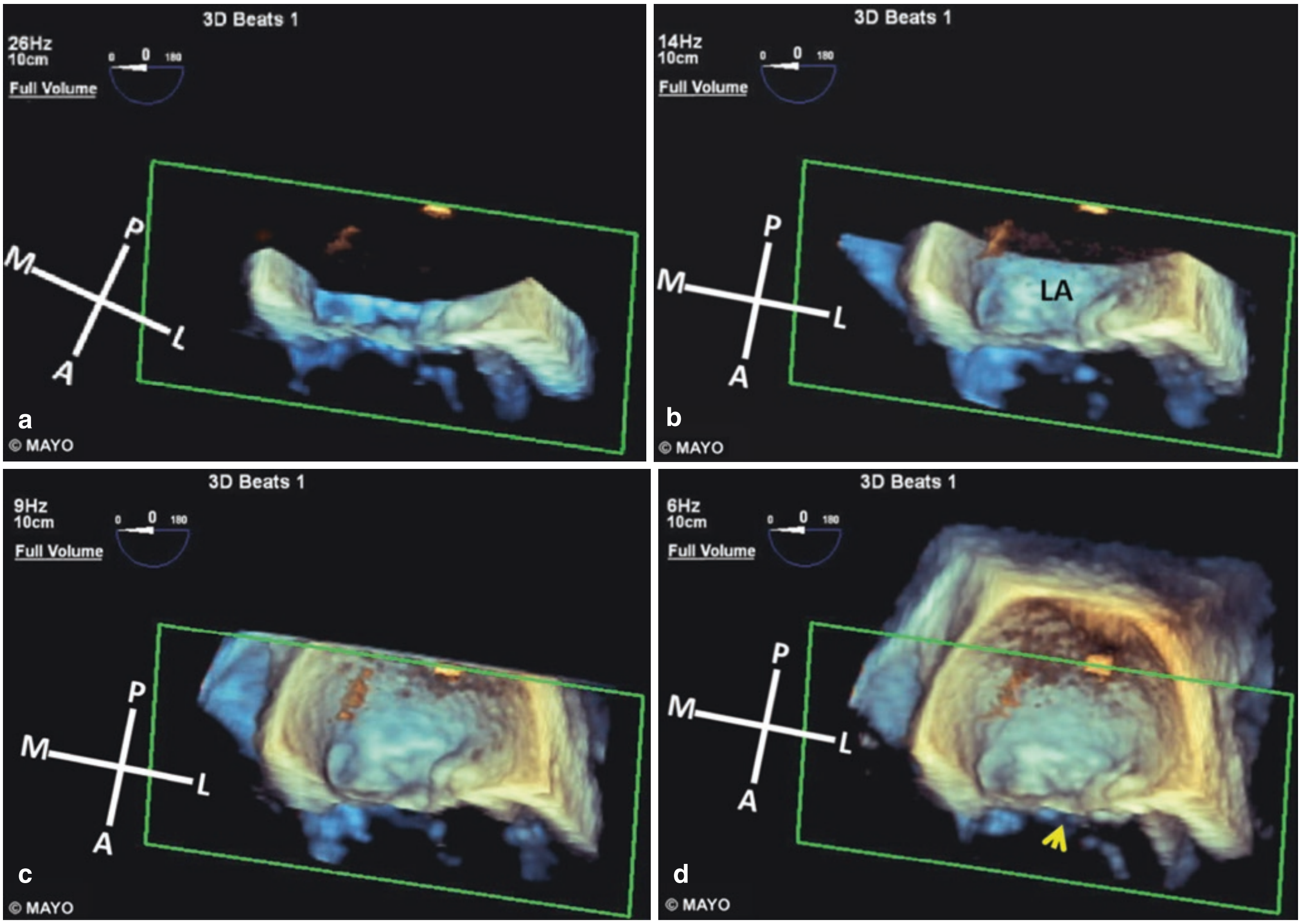

Fig. 2.3 (**a**–**d**) Adjusting elevation in a live FV acquisition while keeping the lateral width the same. Note the progressive increase in posterior image depth and corresponding decrease in FR with increase in size of 3D data set. Because the FV is autocropped, the progressive increase in anterior image dimensions can only be appreciated after crop reset (see Fig. 2.5). Arrow points to MV. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. A, anterior; FR, frame rate; FV, Full Volume; L, lateral; LA, left atrium; M, medial; MV, mitral valve; P, posterior

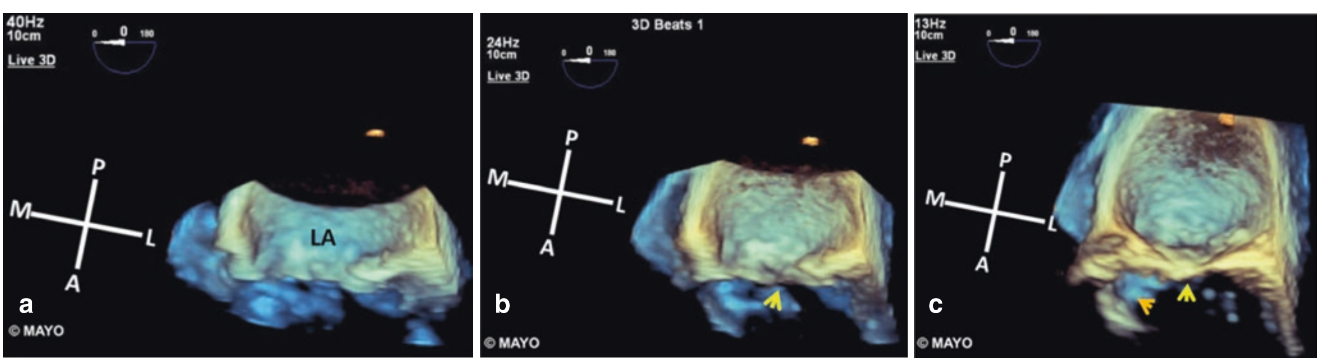

Fig. 2.4 (**a**–**c**) Adjusting elevation in a Live 3D acquisition of the MV. Note the progressive increase in posterior dimensions of the 3D data set accompanied by progressive decrease in the FR. Yellow arrow points to MV and orange arrow points to LVOT. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. A, anterior; FR, frame rate; L, lateral; LA, left atrium; LVOT, left ventricular outflow tract; M, medial; MV, mitral valve; P, posterior

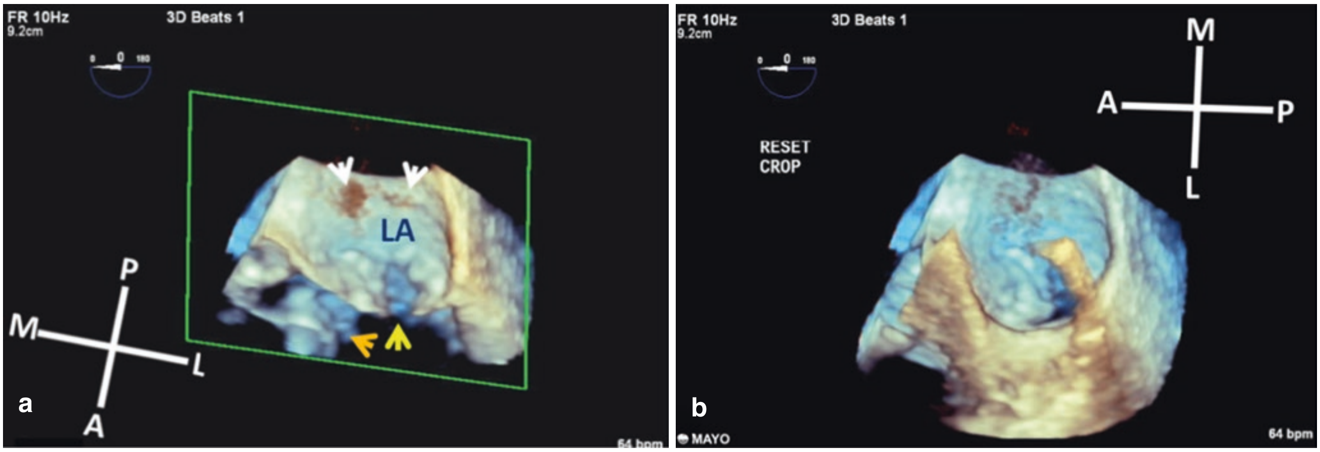

Fig. 2.5 (**a**) Auto cropped live FV image of MV. Only the posterior half of the 3D data set can be seen. White arrows point to posterior MV annulus. (**b**) FV after restoring the anterior half of the 3D data set (Reset Crop). Note that the FR remains the same. Yellow arrow points to MV and orange arrow points to LVOT. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. A, anterior; FR, frame rate; FV, Full Volume; L, lateral; LA, left atrium; LVOT, left ventricular outflow tract; M, medial; MV, mitral valve; P, posterior

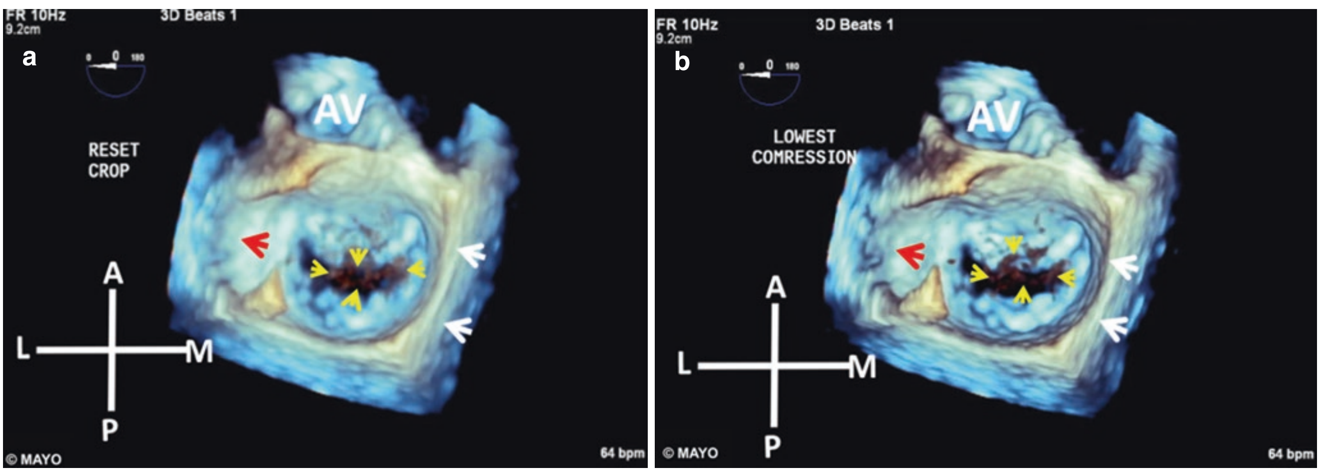

Fig. 2.6 (**a**) Fully restored FV image in Fig. 2.5 rotated such that the AV is at top of the image (surgeon's view). (**b**) Same view after dialing down the compression to the lowest possible without creating artifactual defects. White arrows point to atrial septum and red arrows point to LAA. Note the noise artifacts in both images (yellow arrows). Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. A, anterior; AV, aortic valve; FV, Full Volume; L, lateral; LAA, left atrial appendage; M, medial; P, posterior

"surgeon's view" of the mitral valve, enface views from the left ventricular apex can be obtained, and provide an excellent perspective of the left ventricular outflow tract after appropriate image optimization (Fig. 2.15). The enface left ventricular view of the mitral valve closely resembles the interventional cardiologist's fluoroscopic view.

3D/4D Zoom Dual layout (Philips and GE platforms) and 4D Dual view (Siemens) provide simultaneous enface views of *both* surfaces of the structure of interest (e.g. left atrial and left ventricular views of the mitral valve and left and right atrial views of the atrial septum) (Fig. 2.16). Dual Layout is also feasible with Full Volume acquisition including CFD

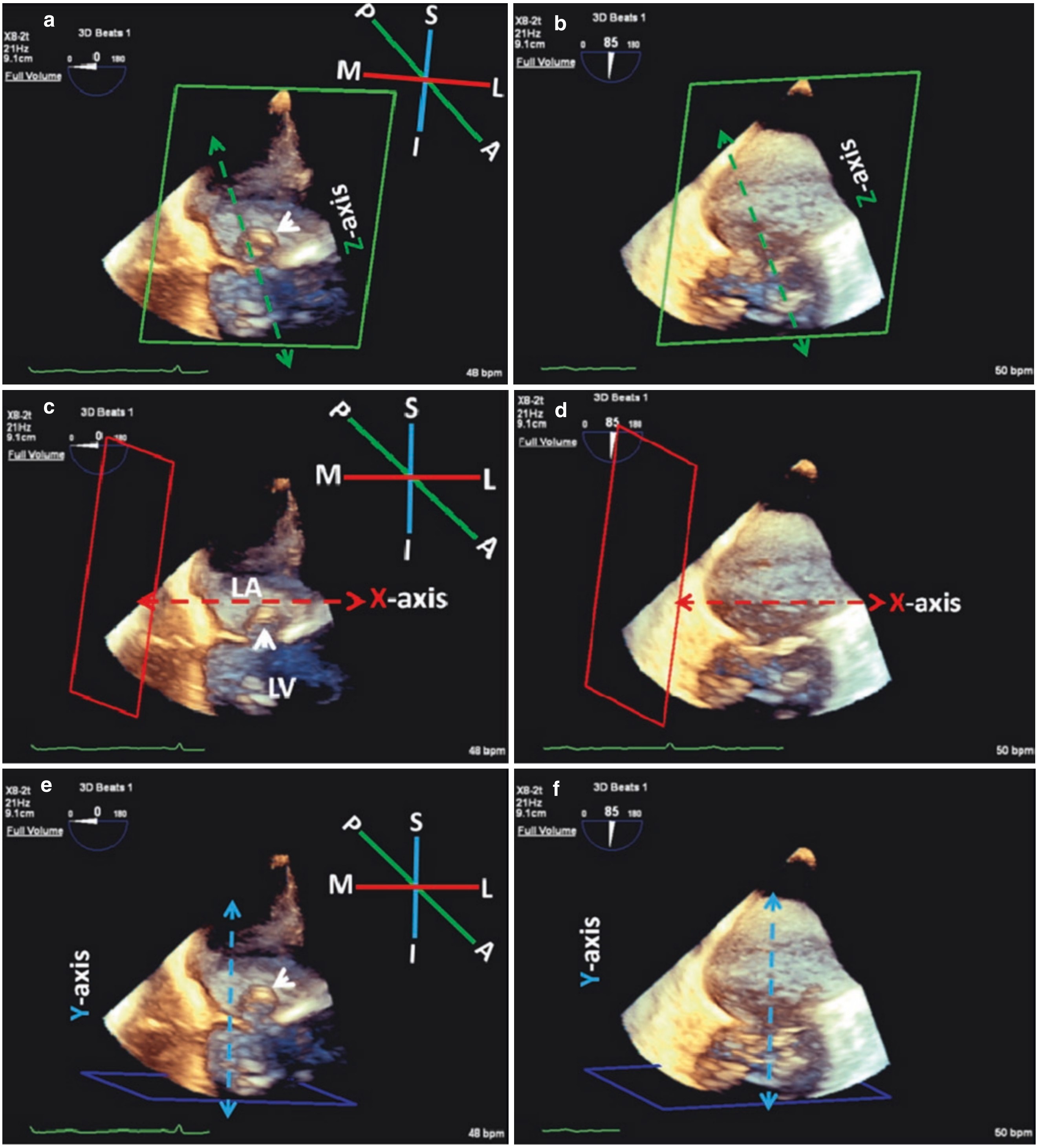

Fig. 2.7 Crop Adjust Box (Philips Healthcare) using color coded planes. Cropping of 3D TEE volumetric data set using the three primary planes of the heart. **Top panel**: (**a**, **b**) Green for coronal or frontal plane divides the heart into anterior and posterior portions and is perpendicular to the elevation or z-axis. **Middle panel**: (**c**, **d**) Red for sagittal or vertical plane divides the heart into right and left portions and is perpendicular to the azimuthal or x-axis. **Bottom panel**: (**e**, **f**) Blue for transverse short-axis plane divides the heart into superior and inferior portions and is perpendicular to the axial or *y*-axis. Note that although the 3D data sets were obtained from 2D images that are nearly orthogonal to each other (0 and 85° left and right column respectively), cropping direction remains the same. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. A, anterior; I, inferior; L, lateral; LA, left atrium; LV, left ventricle; M, medial; P, posterior; S, superior. Arrows point to P2 prolapse

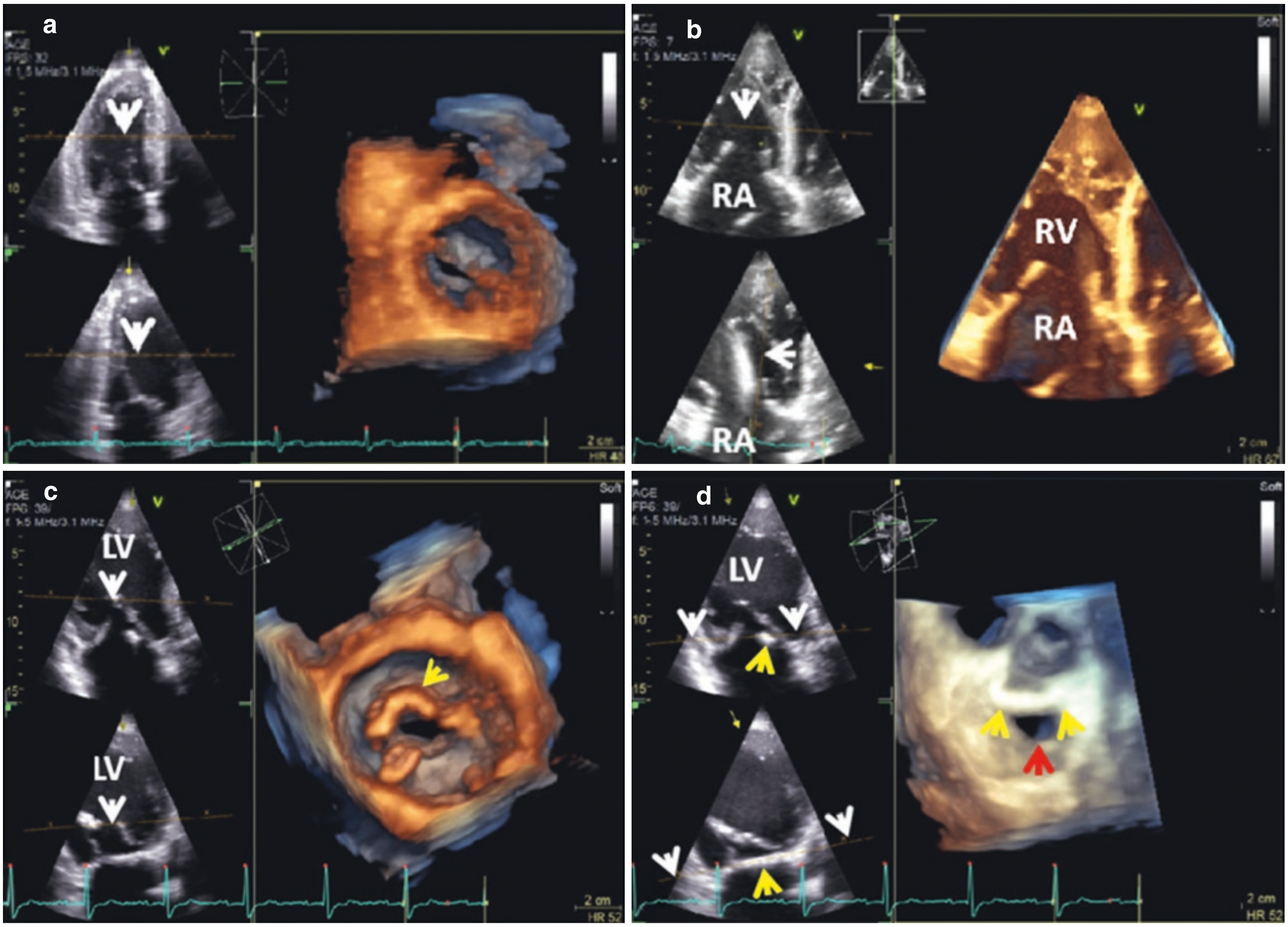

Fig. 2.8 3D TTE cropping using Translate function (moves crop plane within the 3D volume). **Top panel**: (**a**) cropping of MV from LV side (white arrows). (**b**) Cropping of TV from RV side. Note that the Translate crop plane can be repositioned in any direction by the track ball (white arrow bottom of image). **Bottom panel**: Use of Translate crop plane to view posterior annuloplasty ring dehiscence post MV repair. (**c**) Translate crop plane at tips of MV leaflets viewed from LV perspective (white arrows). Yellow arrow points to AML. (**d**) Translate crop plane moved towards the LA (white arrows) to be at level of annuloplasty ring (yellow arrows). Red arrow points to defect caused by the annuloplasty ring dehiscence. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. AML, anterior mitral leaflet; LA, left atrium; LV, left ventricle; MV, mitral valve; RA, right atrium; RV, right ventricle; TV, tricuspid valve

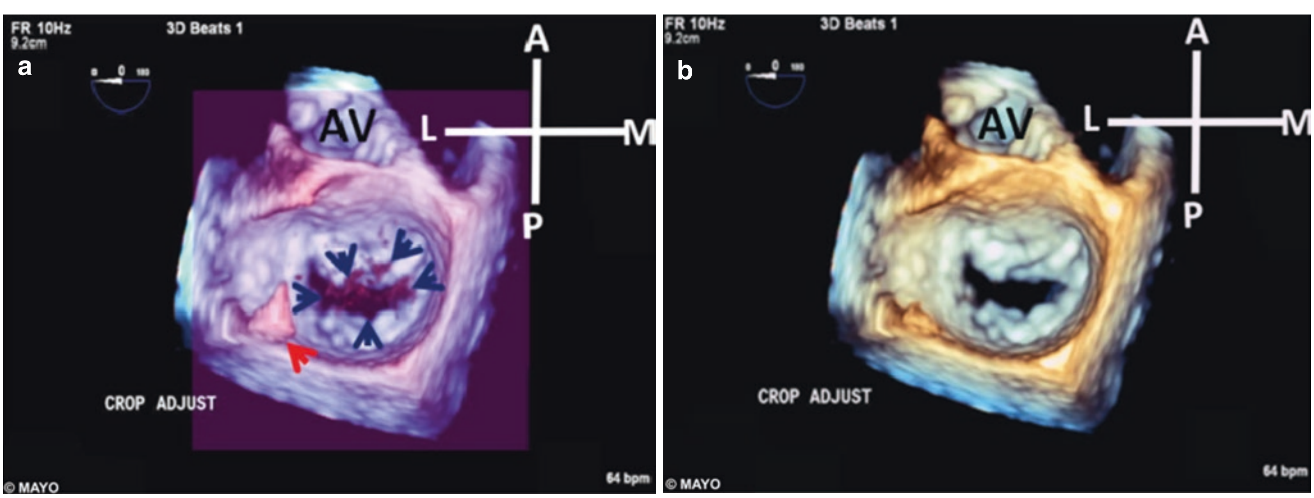

Fig. 2.9 Use of freely adjustable arbitrary "purple" plane to crop out artifacts. (**a**) Crop plane above plane of MV aligned parallel to transverse plane of the heart. Note the noise (dark blue arrows) and tissue (red arrow) artifacts that need to be cropped out. (**b**) Same image after tissue cropping. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. A, anterior; AV, aortic valve; L, lateral; M, medial; MV, mitral valve; P, posterior

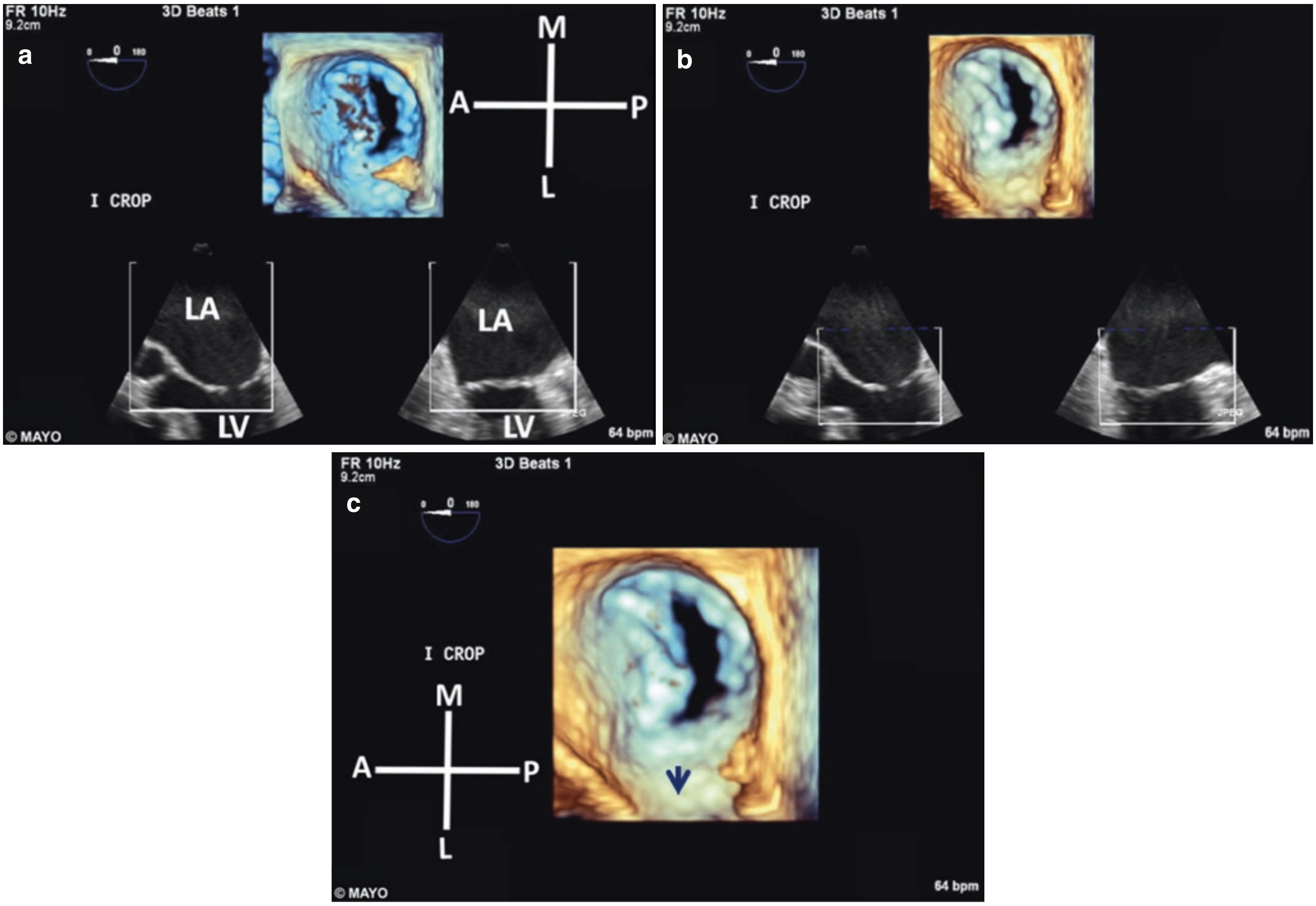

Fig. 2.10 iCrop of MV 3D data set. Selection of the ROI on two orthogonal MPR reference images within the 3D data set (**a**) and image optimization (**b**). The 3D image of the MV can then be viewed from either the LA or LV perspective. (**c**) Final iCrop 3D image as viewed sideways from LA perspective. Arrow points to ostium of LAA. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. A, anterior; L, lateral; LA, left atrium; LAA, left atrial appendage; LV, left ventricle; M, medial; MPR, multiplanar reconstruction; MV, mitral valve; P, posterior; ROI, region of interest

(Fig. 2.16) on the Epic Philips 3D platforms. TrueVue (Philips Healthcare) provides a different perspective of the 3D image tissue characteristics by adjusting the position of a light source within the 3D volumetric data set (Figs. 2.17 and 2.18b). GlassVue (Philips Healthcare) with its internal light source provides more transparent 3D visualization of anatomy of interest thus allowing shapes and boundaries of intracardiac structures including soft tissues to be more easily seen (Fig. 2.18).

3DE Multiplanar Reconstruction

Multiplanar reconstruction (MPR) of 3D volume rendered data sets, analogous to its use in other imaging modalities such as CT and MRI, allows for viewing cardiac structures from any perspective, assessing cardiac pathology simultaneously in multiple planes, quantifying complex geometric lesions and flow, and obtaining measurements needed prior to structural heart interventions. Three crop planes color coded blue, red, and green (Philips Healthcare and Siemens Healthineers) and green, white, and yellow (GE Healthcare) form the basis for MPR. They can be orthogonal to each other in the default setting (3DQ Philips Healthcare) aligned parallel to one of the three primary planes of the heart (Fig. 2.7) analogous to Crop Box, and therefore, perpendicular to one of the three axes [elevation (z-axis), azimuthal (x-axis) or axial (y-axis)] in which the matrix transducer transmits and receives acoustic data. Accordingly, in 3DQ MPR, the coronal or frontal plane divides the heart into anterior and posterior portions and is color coded green, the sagittal or vertical plane divides the heart into right and left portions and is color coded red, and the transverse short-axis or depth plane divides the heart into superior and inferior portions and is color coded blue. The green, red and blue planes are perpendicular to the elevation or z-axis, the azimuthal or x-axis, and axial or y-axis respectively (Figs. 2.19, 2.20, and 2.21).

MPR crop planes and lines may be arbitrary however, with the crop direction of a color coded line/plane depending

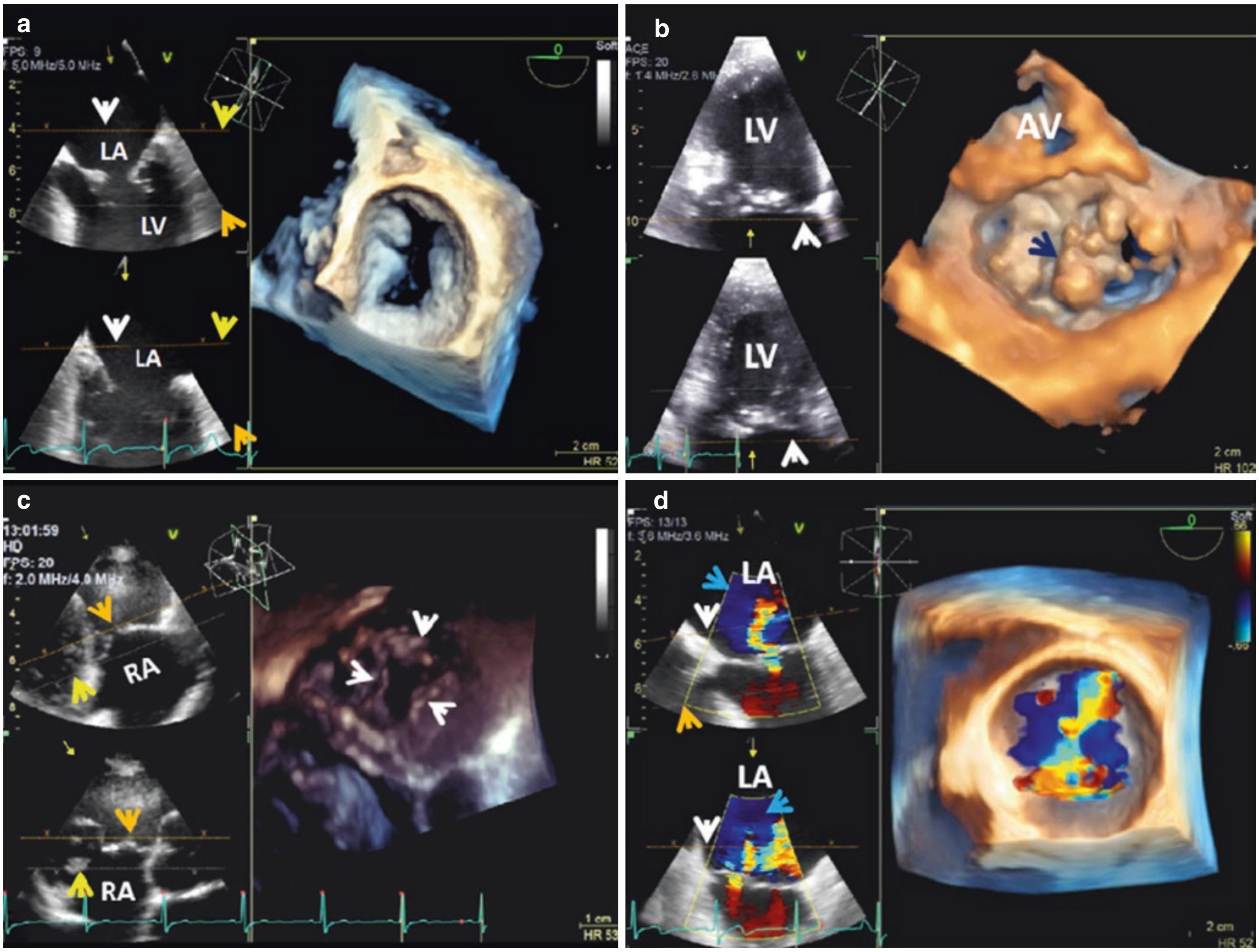

Fig. 2.11 2 Click Crop **Top panel**: MV 3D TEE (**a**) and 3D TTE (**b**) viewed from LA (white arrows). Yellow and orange arrows point to position of the LA and LV crop planes respectively. Dark blue arrow points to flail P2 segment. **Bottom panel**: (**c**) 3D TTE of TV leaflets in late diastole viewed from RV perspective (white arrows). Yellow and orange arrows point to position of RA and RV crop planes respectively. (**d**) 3DTEE MR viewed from LA side (white arrows). Orange arrow points to LV side of the cropped image. Note low velocity flow (blue arrows) that can be cropped out. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. AV, aortic valve; LA, left atrium; LV, left ventricle; MR, mitral regurgitation; MV, mitral valve; RA, right atrium; RV, right ventricle; TV, tricuspid valve

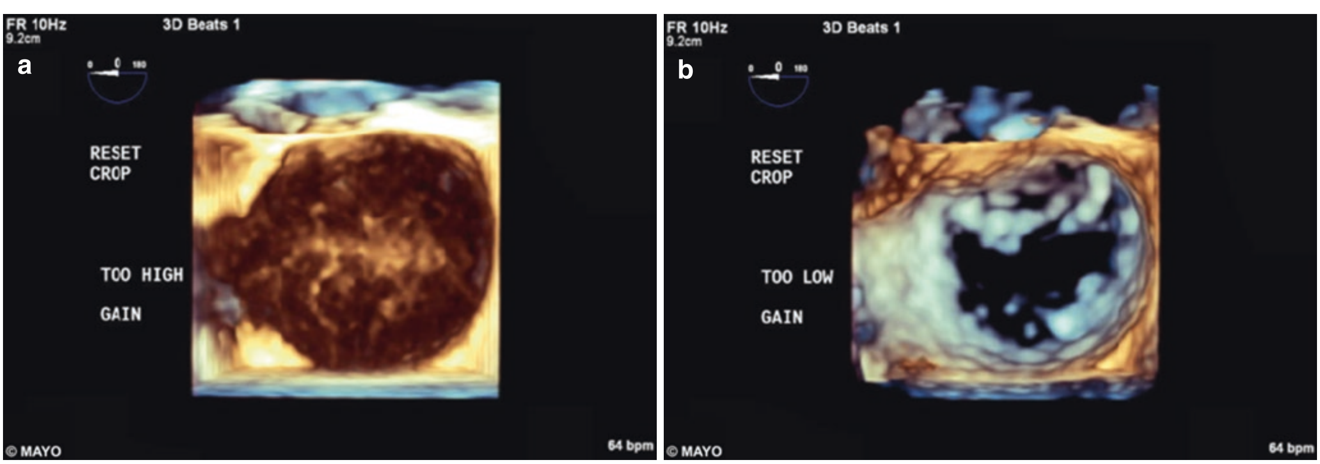

Fig. 2.12 (**a**) Too high a gain setting shows marked noise that resembles dense SEC. (**b**) Too low a gain setting creates drop out MV leaflet artifacts. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. MV, mitral valve; SEC, spontaneous echo contrast

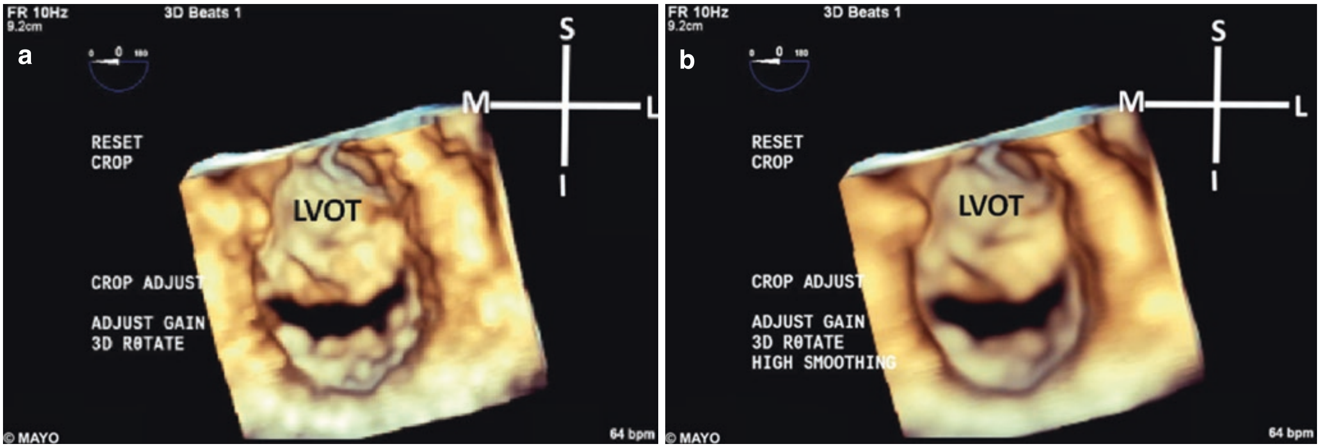

Fig. 2.13 3D TEE enface LV view of MV. (**a**) Optimal image view. (**b**) Too much smoothing. Note the loss of fine image details. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. I, inferior; L, lateral; LVOT, left ventricular outflow tract; LV, left ventricle; M, medial; MV, mitral valve; S, superior

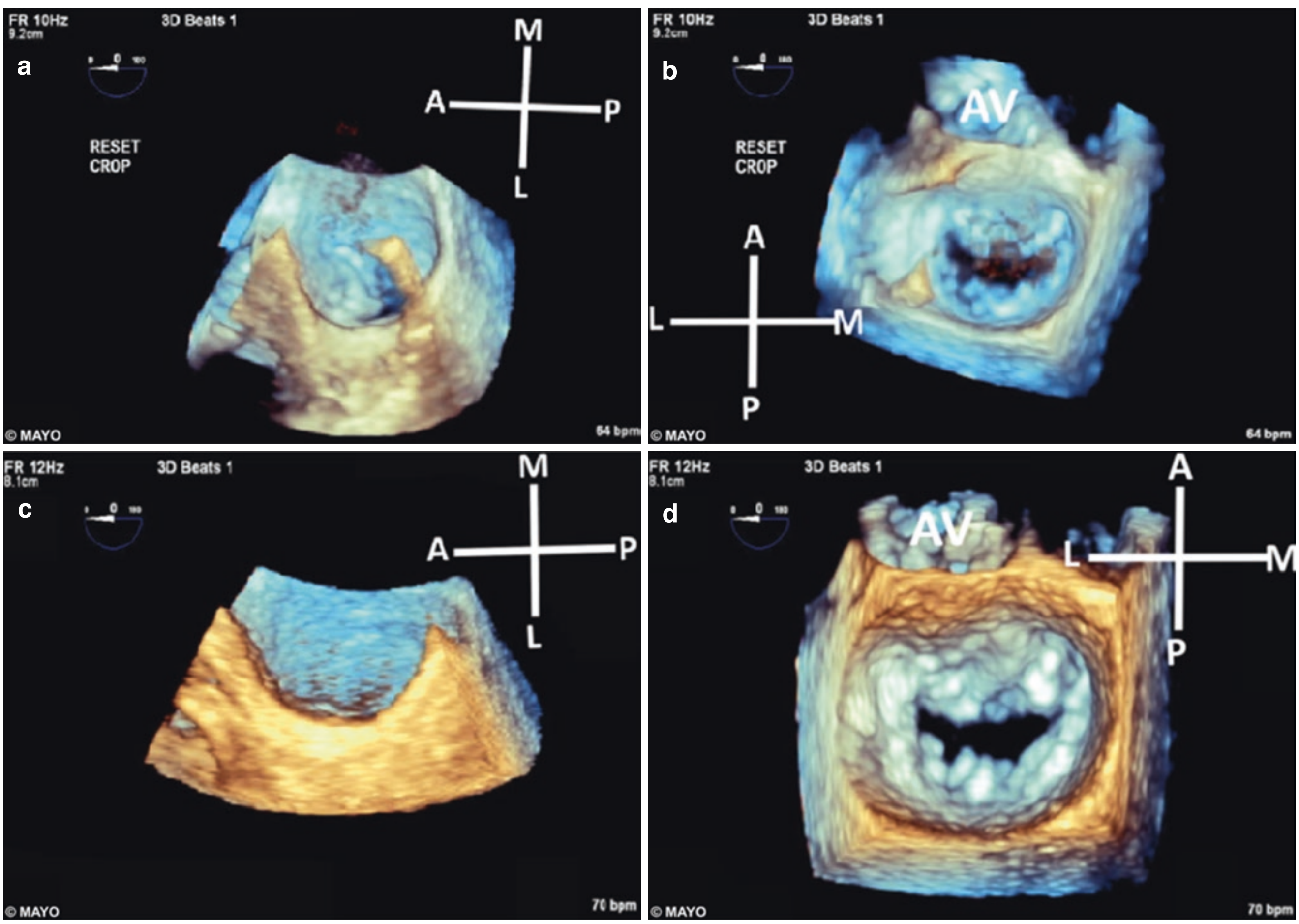

Fig. 2.14 3D TEE enface LA views of the MV. Appropriate image display for a FV (top panel-**b**) and 3D Zoom clip (bottom panel-**d**). Note that the acquired 3D data set for either FV (**a**) or 3D Zoom (**c**) needs to be rotated such that the AV is displayed on top of the image (surgeon's view). Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. A, anterior; AV, aortic valve; FV, Full Volume; L, lateral; LA, left atrium; LV, left ventricle; M, medial; MV, mitral valve; P, posterior

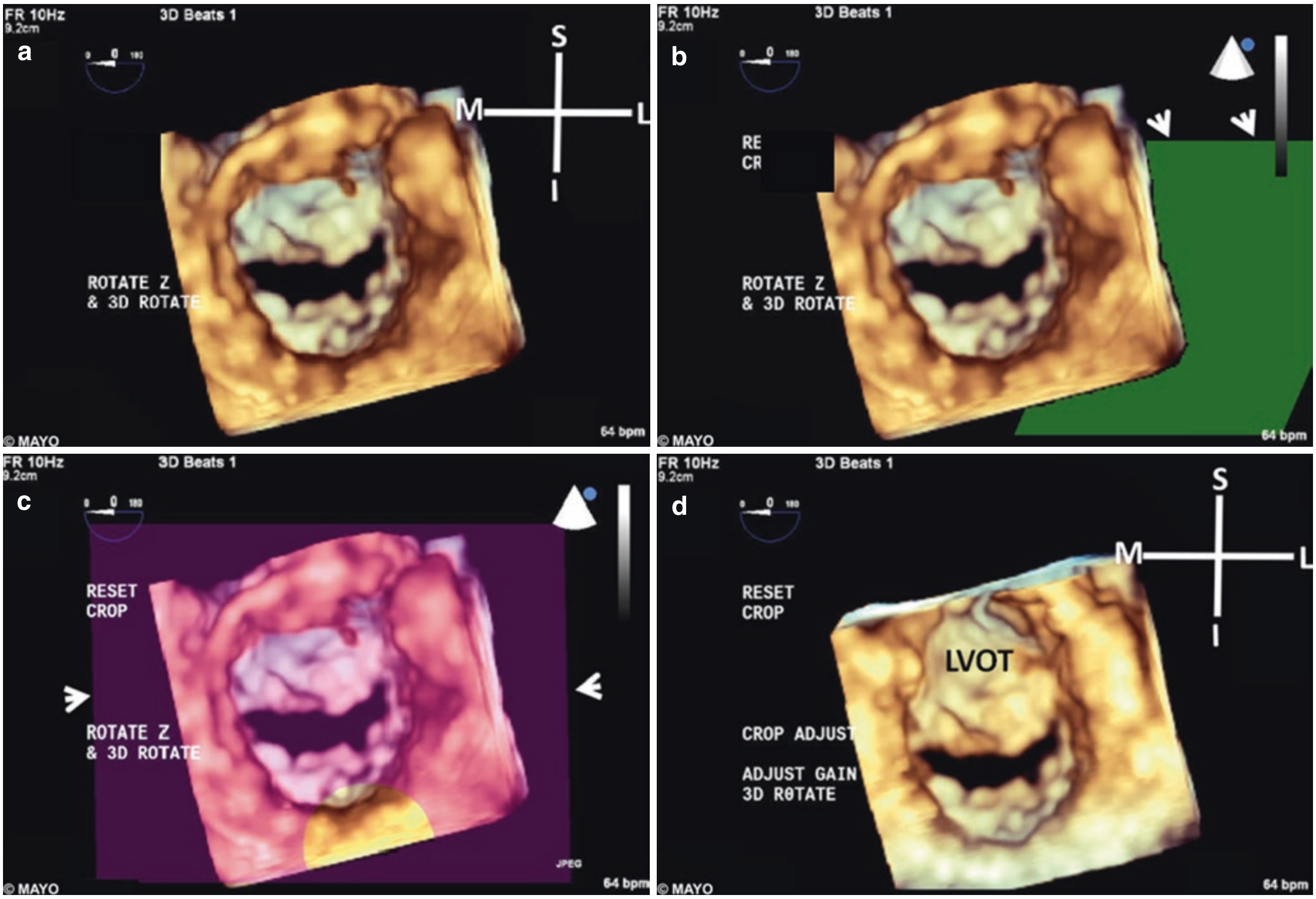

Fig. 2.15 (**a**–**d**) 3D TEE enface LV views of the MV: Image optimization is achieved using the freely adjustable "purple" plane (white arrows) and by adjusting both gain and compression settings to obtain the final image **d** at bottom right. Note that cropping using the freely adjustable plane is only possible when the plane is purple. This is achieved by simply rotating this crop plane from green (**b**) to enface purple (**c**). Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. I, inferior; L, lateral; LVOT, left ventricular outflow tract; LV, left ventricle; M, medial; MV, mitral valve; S, superior

on the 2D image view from which the 3D volumetric data set is generated [MultiVue (Philips Healthcare) and FlexiSlice (GE Healthcare)] (Figs. 2.22, 2.23, and 2.24). MPR can be used in any 3D acquisition mode.

The availability of the MPR software on the machine allows for timely analysis of the 3D data set either in real time [MultiVue (Philips Healthcare) and Flexi-Slice (GE Health Care)] or after 3D data acquisition [post processing (Figs. 2.25 and 2.26)]. Real time Flexi-Slice or MultiVue can be very helpful during transcatheter interventions (see Chap. 33). iSlice (Philips Healthcare) or Multi-Slice (GE Healthcare and Philips Healthcare) enable simultaneous display of equidistant short axis views generated from a 3D volume acquisition, and are very useful for quantitation of left ventricular ejection fraction and regional wall motion analysis (Fig. 2.26).

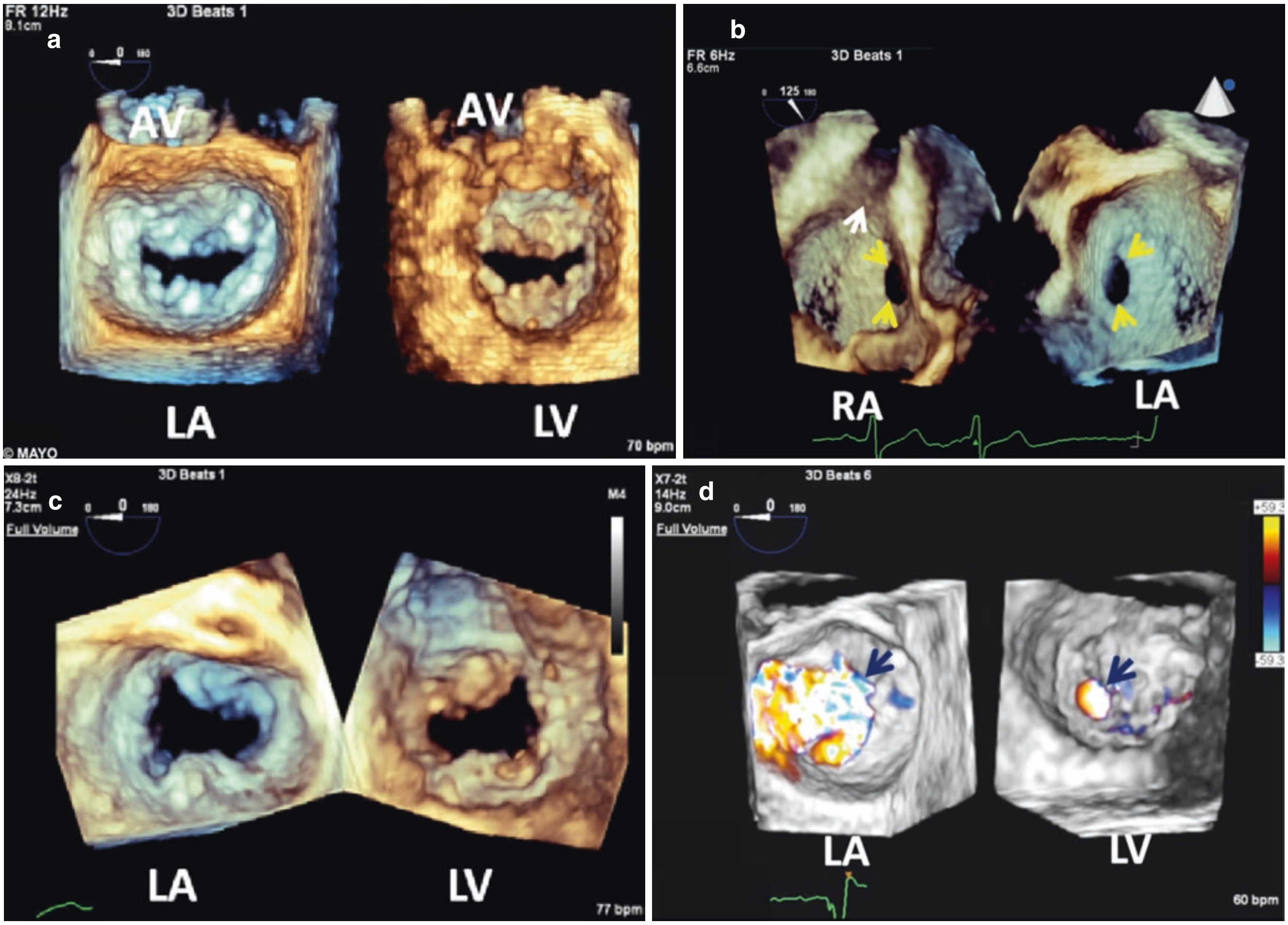

Fig. 2.16 **Top panel**: 3D zoom dual layout of MV (**a**) and ASD (yellow arrows, **b**). White arrow points to SVC. **Bottom panel**: (**c**) Dual layout FV acquisition of MV. (**d**) Dual layout FV MR CFD (arrows). Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. ASD, atrial septal defect; AV, aortic valve; CFD, color flow Doppler; FV, Full Volume; LA, left atrium; LV, left ventricle; MR, mitral regurgitation; MV, mitral valve; RA, right atrium; SVC, superior vena cava

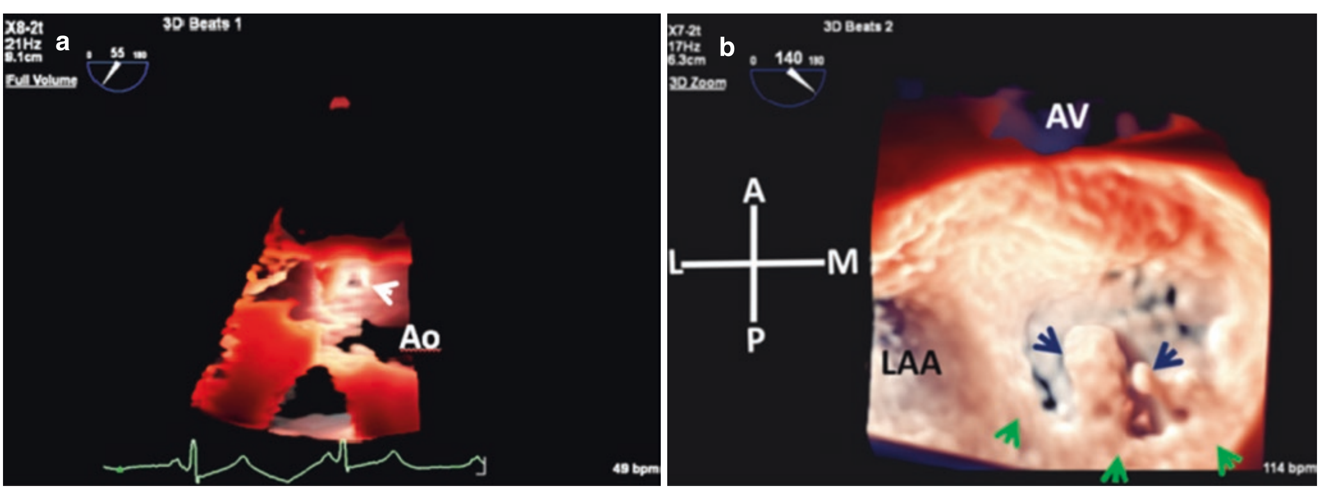

Fig. 2.17 TrueVue (Philips Healthcare) 3D TEE. (**a**) Coronary artery ostium (arrow). (**b**) Thrombus (dark blue arrows) on SR (green arrows). Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. A, anterior; Ao, ascending aorta; AV, aortic valve; L, lateral; LAA, left atrial appendage; M, medial; P, posterior; SR, sewing ring

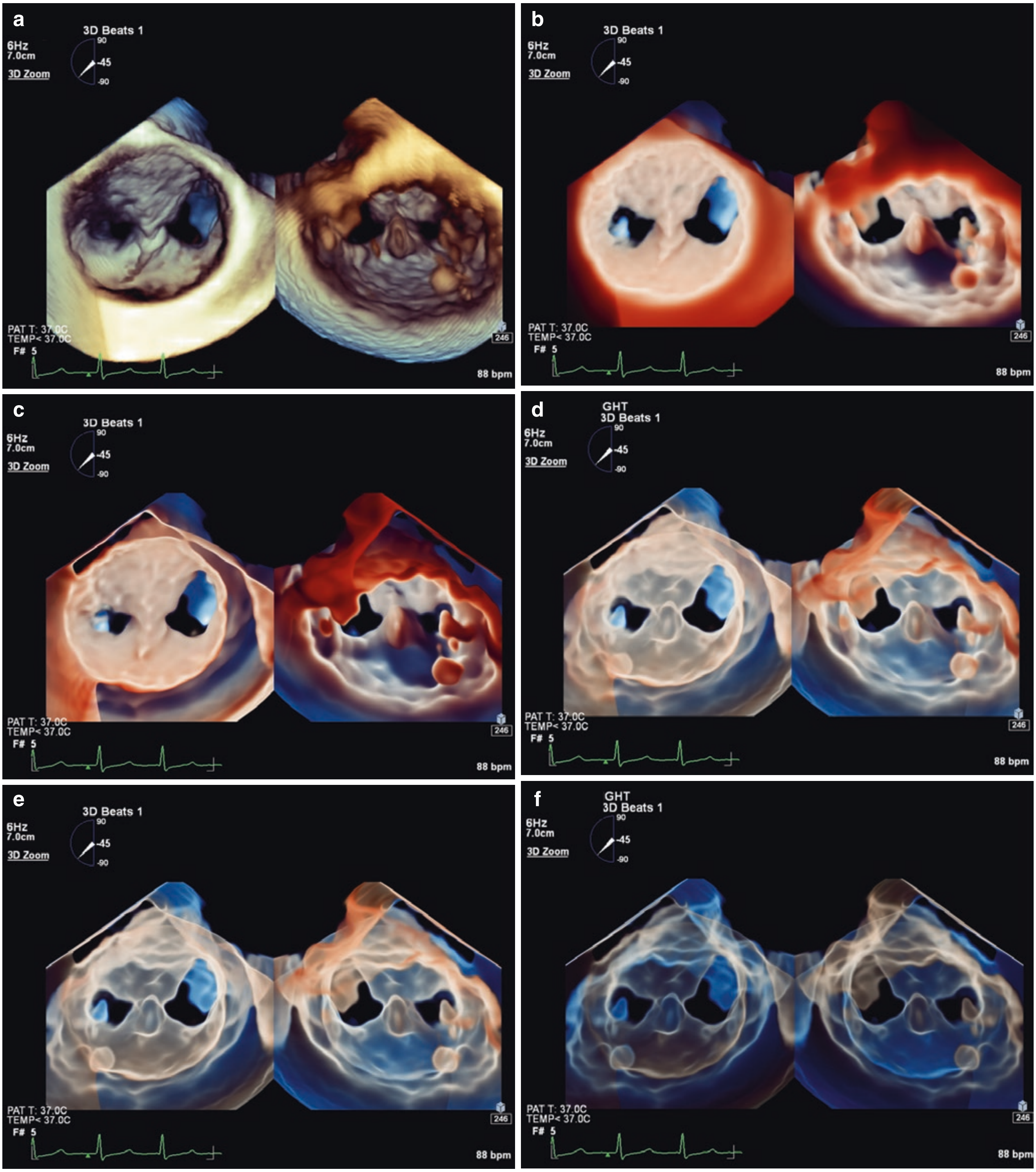

Fig. 2.18 3D Zoom Dual layout collage of double orifice MV post MitraClip deployment with focus on GlassVue (Philips Healthcare). **Panels a and b:** Default 3D Zoom (**a**) and same image in TrueVue format (**b**) after optimizing compression and smoothing options. **Panels c–f:** GlassVue of same TrueVue image in panel b using progressively higher transparency settings [0(**c**),10(**d**),15(**e**), and 20(**f**)]. Images courtesy of Dr. Sari Padang. Used with permission of Mayo Foundation for Medical Education and Research.

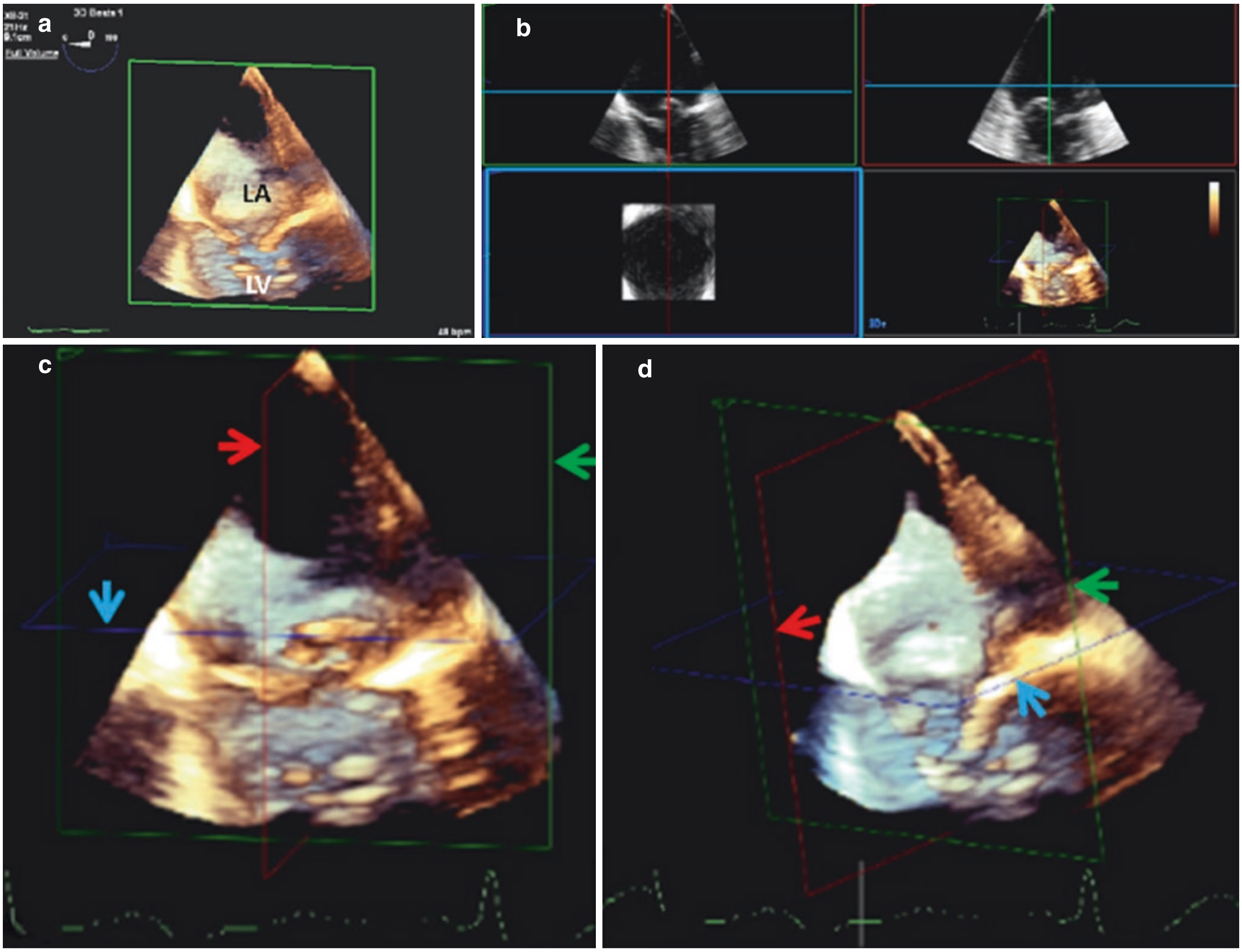

Fig. 2.19 **Top panel**: Default MPR; Philips Healthcare 3DQ (**b**) of volumetric 3D TEE data set (**a**) obtained from 2D 4 chamber (0°) mid-esophageal view. Blue lines and rectangle, Red line and rectangle, and Green line and rectangle refer to the transverse, sagittal, and coronal planes respectively as in Crop Box. The 2D TEE 4 chamber view is in the coronal plane (green rectangle) **Bottom panel**: Enlarged images of the default 3D data set (**c**) with tilted 3D volume to better show the crop planes (**d**). The same crop planes in MPR can be seen with the arrows color coded accordingly. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. LA, left atrium; LV, left ventricle; MPR, multiplanar reconstruction

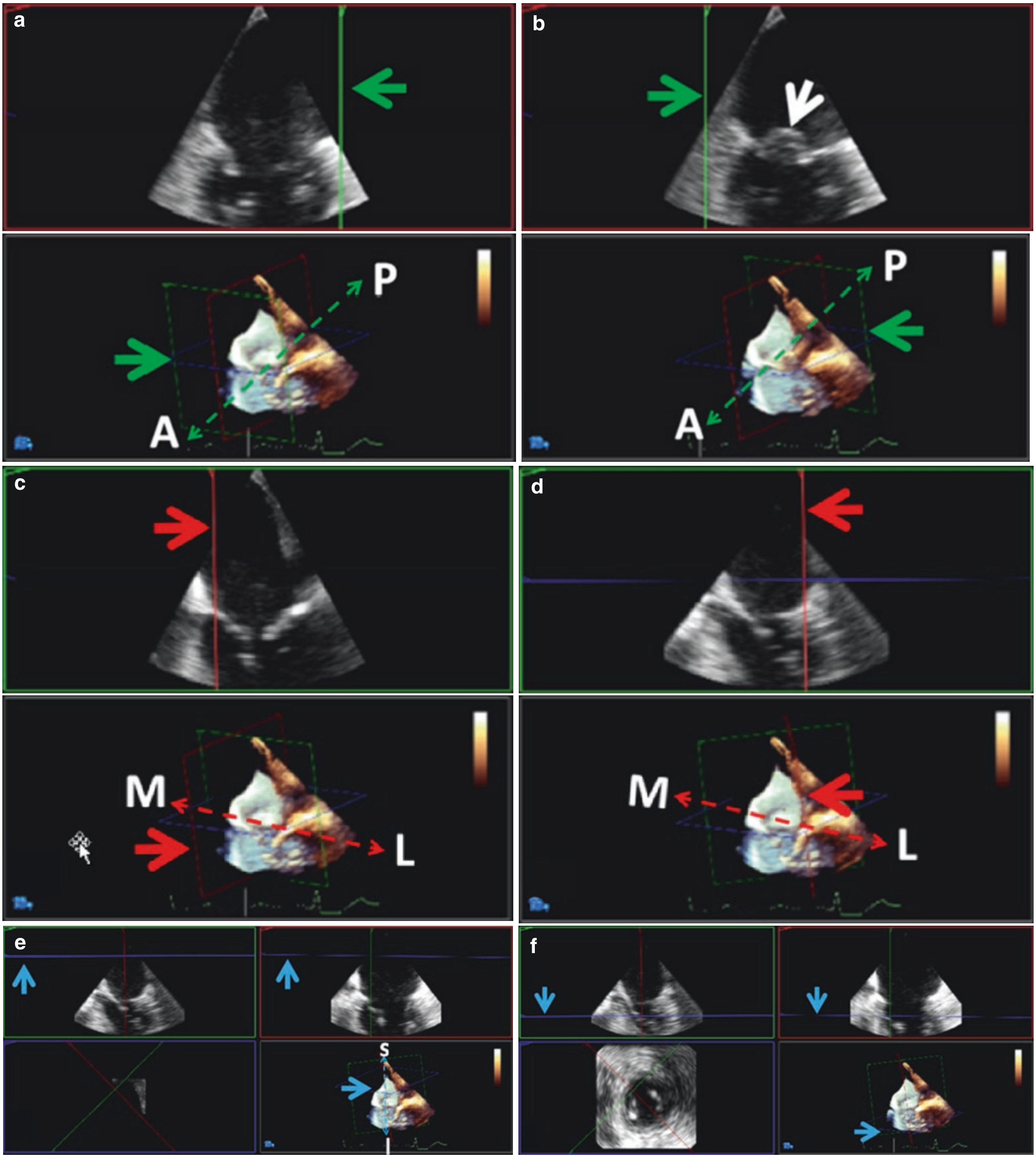

Fig. 2.20 Same MPR as in Fig. 2.19. (**a**, **b**) Green line/plane (green arrows) moved anteriorly (**a**) and posteriorly (**b**) in the tomographic 2D space with corresponding movements of the coronal plane (green arrows) in the 3D space. Note the P2 prolapse (white arrow) when the crop line/plane is posterior. (**c**, **d**) Red line (red arrows) moved from medial (**c**) to lateral (**d**) in the tomographic 2D space with corresponding movements of the sagittal plane in the 3D space (red arrows). (**e**, **f**) Blue line/plane moved in a superior (**e**, blue arrows) to inferior (**f**, blue arrows) direction. Used with permission of Mayo Foundation for Medical Education and Research. A, anterior; I, inferior; L, lateral; M, medial; P, posterior; S, superior

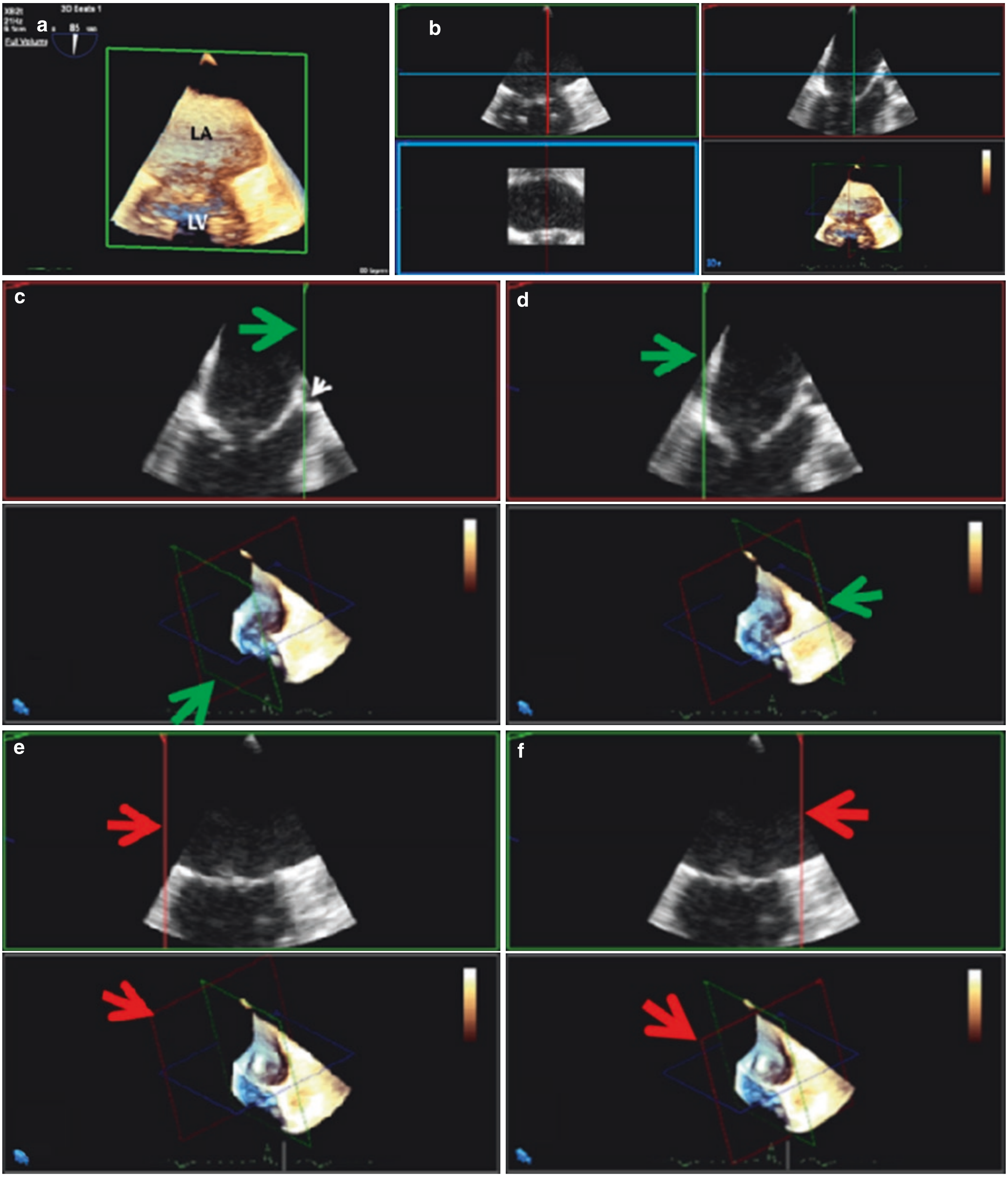

Fig. 2.21 **Top panel**: Default MPR; 3DQ Philips Healthcare (**b**) of volumetric 3D TEE data set (**a**) obtained in same patient in Figs. 2.19 and 2.20, from a nearly orthogonal mid-esophageal 2D view (85°). The 2D two chamber view is now in the coronal plane (green rectangle). (**c**, **d**) Green line/plane (green arrows) moved anteriorly (**c**) in direction of aortic valve (white arrow) and posteriorly (**d**) in the tomographic 2D space with corresponding coronal plane movement in the 3D space (green arrows). (**e**, **f**) Red or sagittal line/plane (red arrows) moved from medial (**e**) to lateral (**f**) in the two chamber tomographic 2D space with corresponding sagittal plane movements in the 3D space (red arrows). Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. LA, left atrium; LV, left ventricle; MPR, multiplanar reconstruction

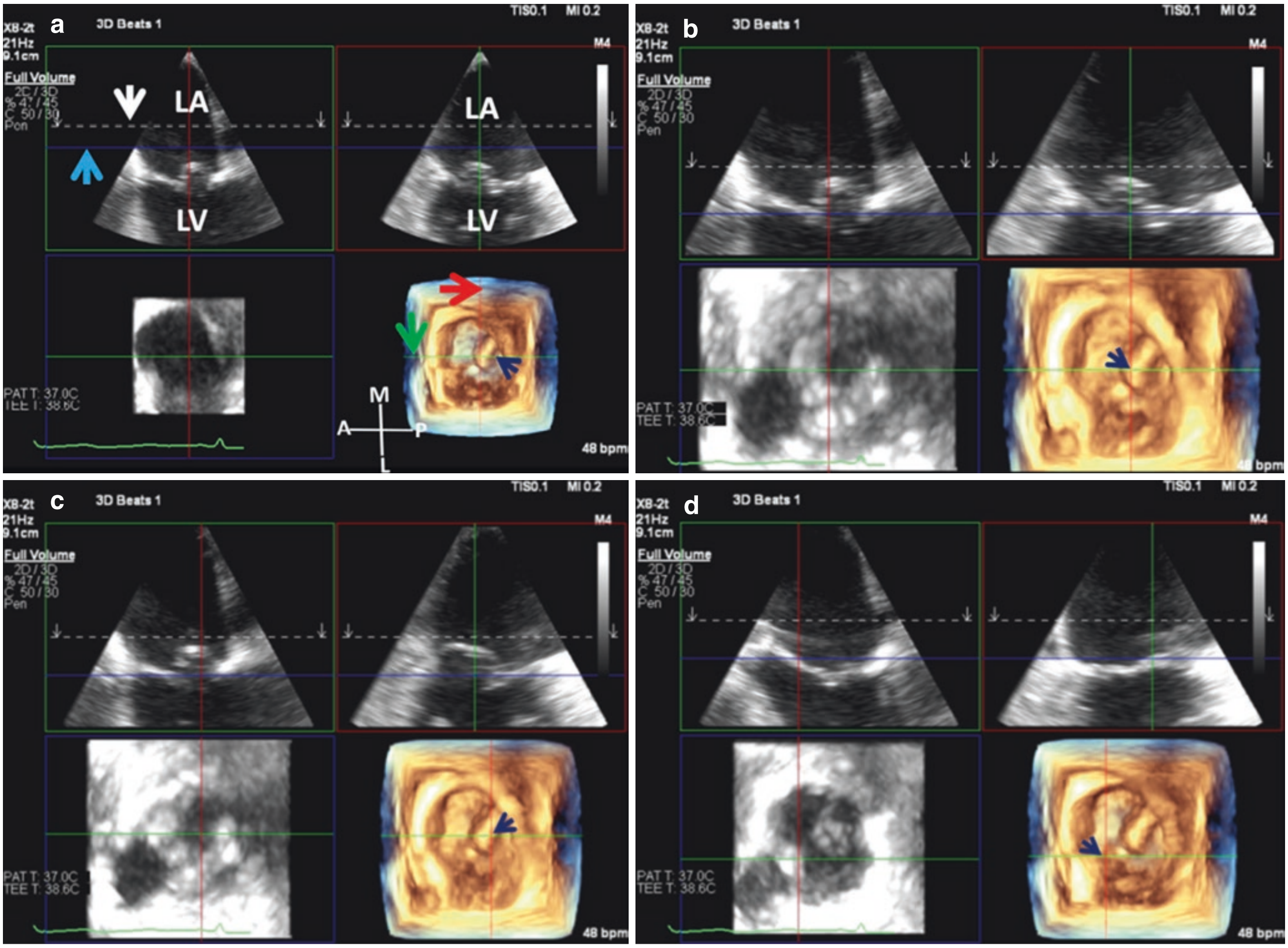

Fig. 2.22 RT FV MultiVue (Philips Healthcare). 3D TEE volumetric data set obtained from a midesophageal 2D four-chamber view (horizontal 0°) in a patient with a large prolapsing posterior mitral leaflet P2 segment. **Top panel**: (**a**) Default MPR. Crop planes are represented by lines or rectangles that are color coded green, red or blue. Direction of crop view is provided by the interrupted white line (white arrow). Light blue arrow points to blue line that represents the tail end of the crop plane reflected in the blue rectangle in left lower quadrant and the corresponding cropped 3D image. Dark blue arrow points to prolapsing P2 segment. Note the cross-hair intersection of the red line (red arrow) and green line (green arrow) in the blue rectangle tomographic 2D space and in the adjacent 3D space. (**b**) MPR enlarged by using zoom control after optimizing the image by adjusting position and size of the crop plane. **Bottom panel**: The cross-hair intersection of the red and green lines placed over the prolapsing P2 segment (**c**) and AML (**d**) and the corresponding changes in the MPR 2D tomographic space. Used with permission of Mayo Foundation for Medical Education and Research. A, anterior; AML, anterior mitral leaflet; FV, Full Volume; M, medial; L, lateral; LA, left atrium; LV, left ventricle; MPR, multiplanar reconstruction; P, posterior; RT, real time

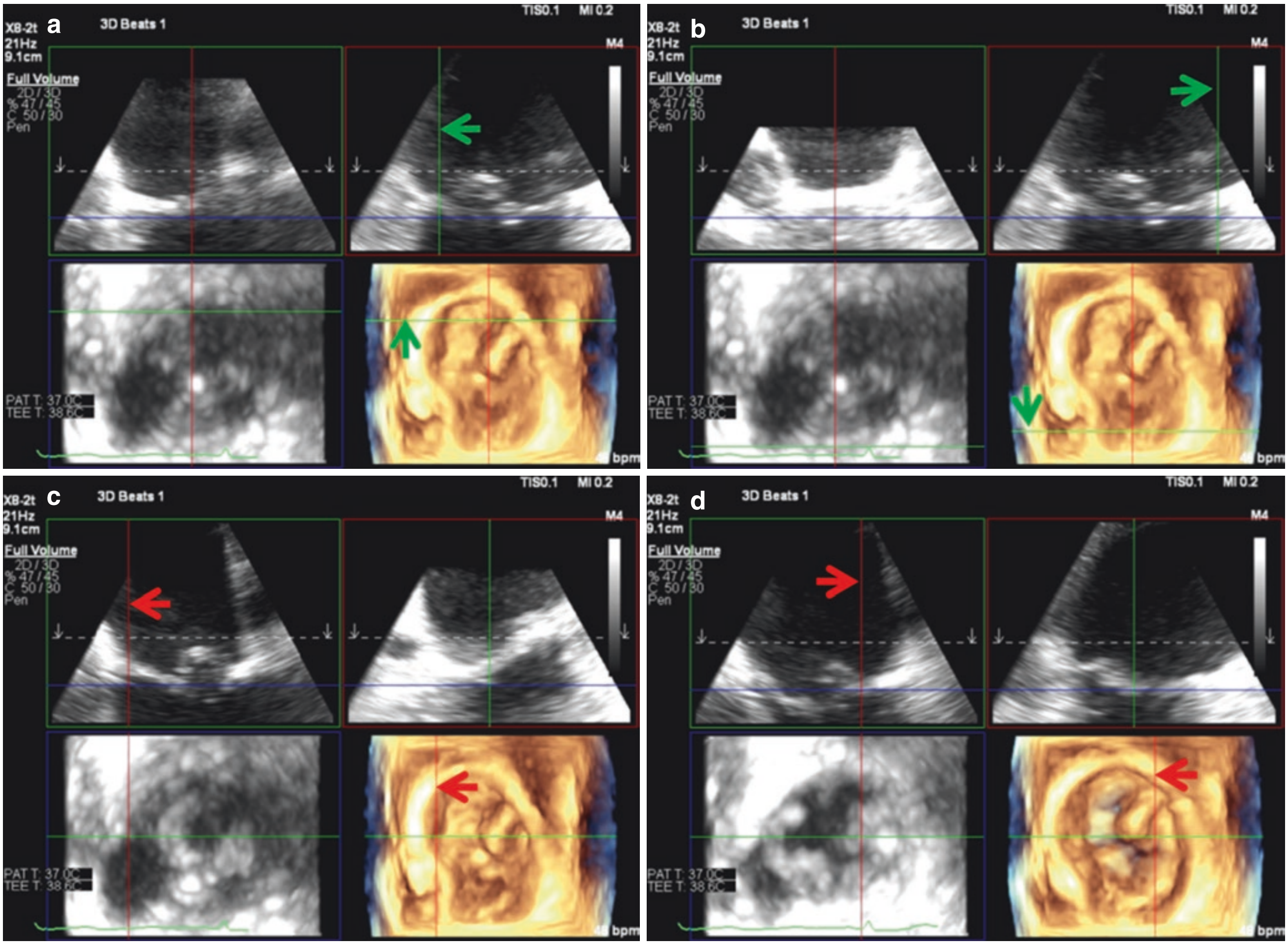

Fig. 2.23 Same MultiVue MPR of Fig. 2.22 to illustrate crop direction of the green and red lines that is clearly appreciated when viewed in the 3D space. Refer to 3D spatial coordinates legend in Fig. 2.21. **Top panel**: Green line (green arrows) moves in a medial (**a**) to lateral (**b**) direction in both the 2D tomographic and 3D space. **Bottom panel**: Red line (red arrows) moves in an anterior (**c**) to posterior (**d**) direction in both the 2D tomographic and 3D space. Used with permission of Mayo Foundation for Medical Education and Research.

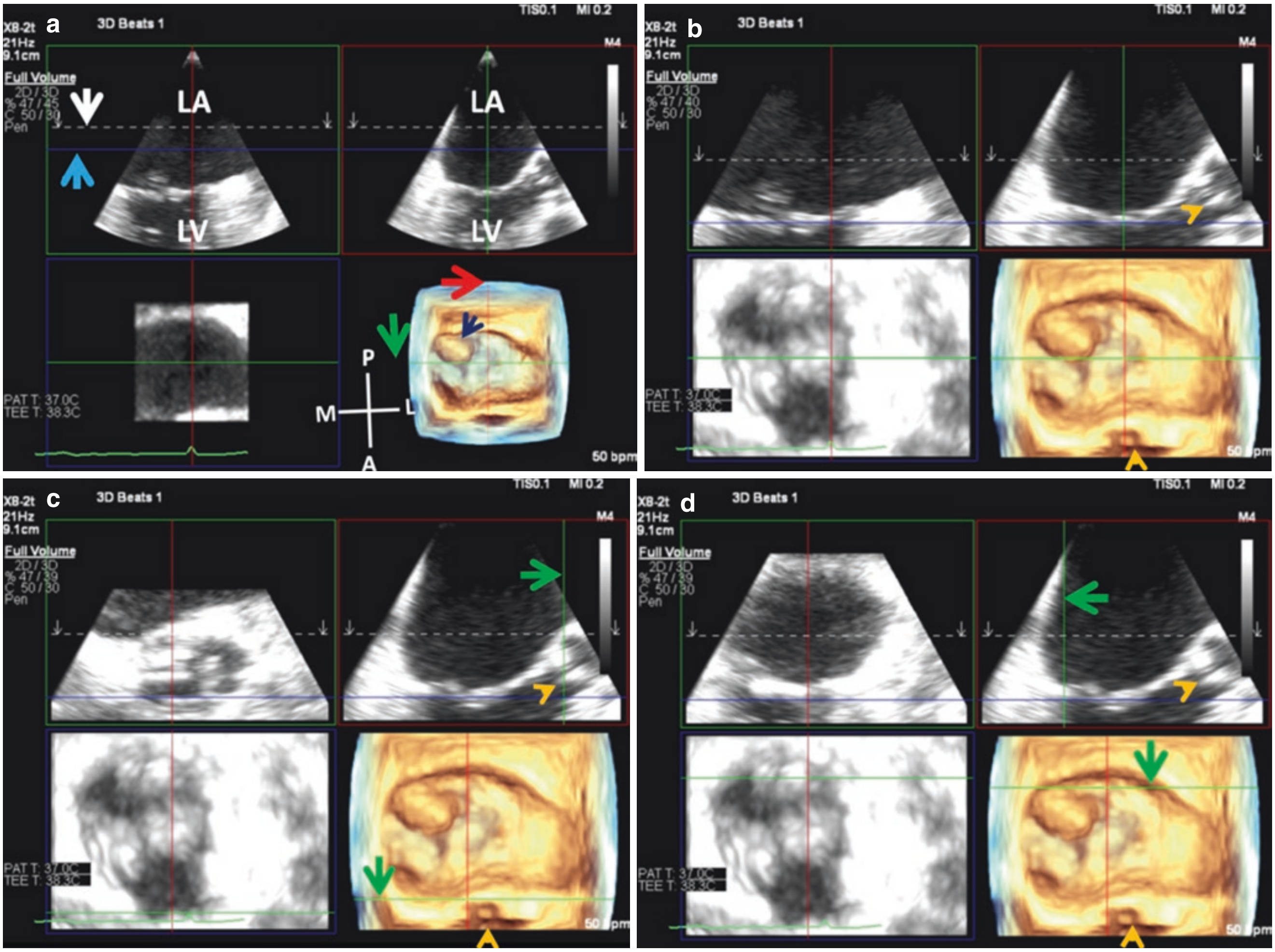

Fig. 2.24 **Top panel**: (**a**, **b**) 3D TEE MultiVue MPR from same patient but with 3D volumetric data set obtained from an orthogonal 2Chamber view. Legend same as for Fig. 2.22. Orange arrow heads point to aortic valve. **Second panel**: Green line (green arrows) moves in an anterior (**c**) to posterior (**d**) direction in both the 2D tomographic and 3D space. **Third panel**: Red line (red arrows) moves in a medial (**e**) to lateral (**f**) direction in both the 2D tomographic and 3D space. **Bottom panel**: (**g**, **h**) Tilting the green or red line provides a non-linear view of region of interest. Used with permission of Mayo Foundation for Medical Education and Research.

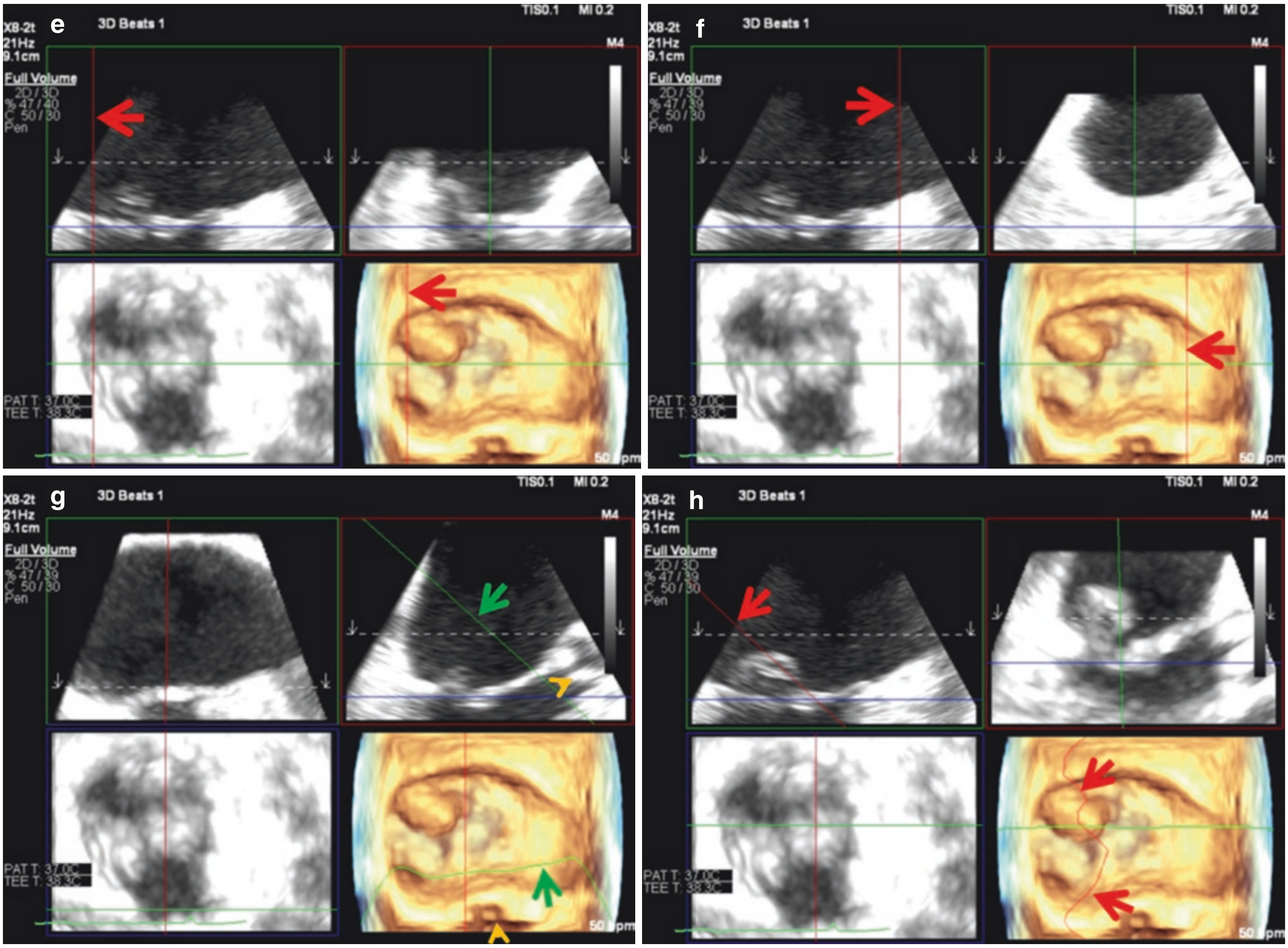

Fig. 2.24 (continued)

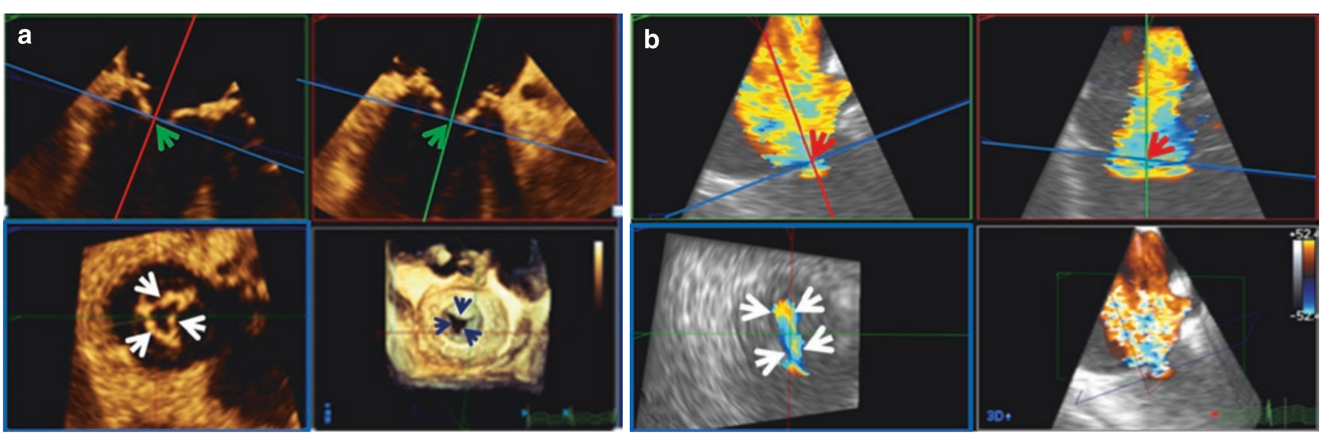

Fig. 2.25 Quantitative MPR of volumetric 3D data sets (3DQ, Philips Healthcare). Assessment of severity of mitral bioprosthesis stenosis (**a**, dark blue arrows), and MR severity (**b**). In both MPRs the intersection of two orthogonal crop planes (blue and red lines top left, and blue and green lines top right in each MPR) at LV tips of MV bioprosthesis leaflets (green arrows) and MR VC (red arrows) is displayed in the blue plane (blue box) at bottom left of each image (white arrows). Bioprosthesis stenosis severity and MR VC area can thus be quantified using the measurement software. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. EROA, effective regurgitant orifice area; LV, left ventricle; MPR, muliplanar reconstruction; MR, mitral regurgitation; MV, mitral valve; VC, vena contracta

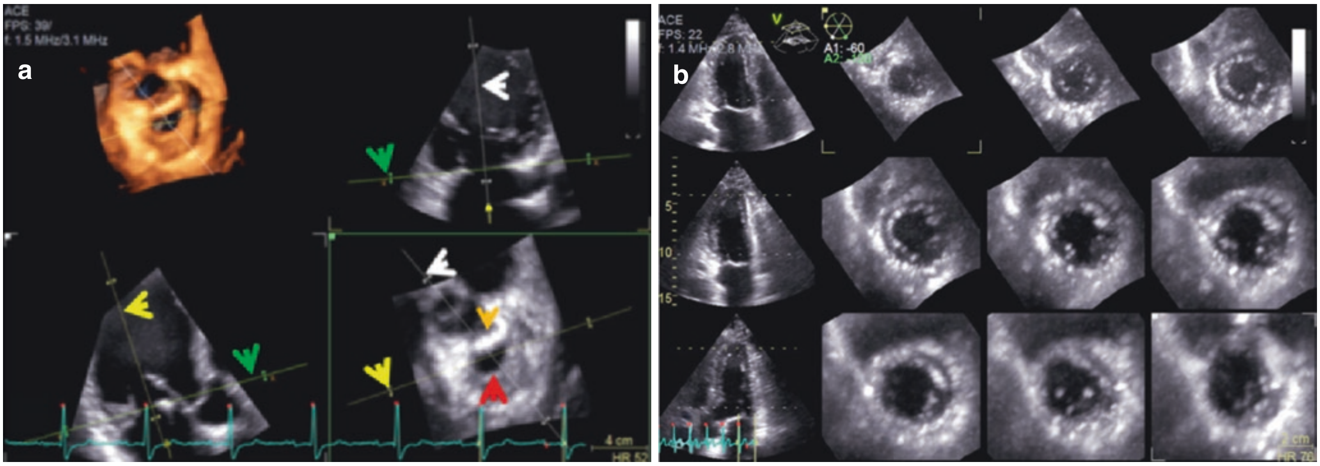

Fig. 2.26 (**a**) Post MV repair annuloplasty dehiscence quantitative MPR using **Flexi Slice** (GE Healthcare). The site and extent of dehiscence is clearly defined (red arrow) by the intersection of three arbitrary orthogonal planes (white, green, and yellow arrows). Orange arrow points to annuloplasty ring. (**b**) 3D TTE LV **Multi-Slice** acquisition (GE Healthcare) used for LV EF measurement and for regional wall motion analysis. Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved. EF, ejection fraction; LV, left ventricle; MPR, multiplanar reconstruction; MV, mitral valve

References

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2. Vegas A. Three-dimensional transesophageal echocardiography: principles and clinical applications. Ann Card Anaesth. 2016;19(Suppl 1):S35–43.