Doppler Mirror Image Artifacts Mimicking Mitral Regurgitation in Patients with Mechanical Bileaflet Mitral Valve Prostheses

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Aims: To characterize the origin and mechanisms of generation of Doppler mirror images in the left atrium observed in patients with mechanical bileaflet mitral valve prosthesis. We hypothesized that these systolic colour Doppler images are artifactual and generated by reflection of the left ventricular outflow tract flow at the leaflet of the mitral valve prosthesis.

Methods and Results: Fifty patients with mechanical bileaflet mitral valves were prospectively examined by means of transthoracic Doppler-echocardiography. From different apical views, the left atrium was carefully interrogated for systolic colour flow signals, which were further analysed by pulsed wave Doppler.

In all patients, a systolic colour Doppler signal was detected in the left atrium. Pulsed wave Doppler analysis revealed a low velocity signal (=mirror image) corresponding to the shape and duration of the left ventricular outflow tract signal. The peak velocities of these mirror images, however, were consistently lower than the velocities obtained from the left ventricular outflow tract. In addition, if paravalvular mitral valve leakage was present, a high velocity signal identical to the duration of mitral regurgitation time was detected outside the ring of the prosthesis.

Conclusions: Mirror image artifacts mimicking mitral regurgitation occur in patients with mechanical mitral valve prostheses. As mirror image artifacts can specifically be identified by analysis of shape, velocity, and duration of pulsed wave Doppler spectra, their identification will help to avoid misinterpretation of both spectral and colour Doppler signals in patients with prosthetic mitral valves.

Key Words: Doppler echocardiography; mirror image artifact; mechanical valve prosthesis; paravalvular leak.

Introduction

Doppler echocardiography has been established as the method of choice for the postoperative examination and follow-up of patients with prosthetic heart valves. Although it may often be difficult to detect paravalvular leakage by means of transthoracic colour Doppler echocardiography, the detection of such leaks can be of clinical relevance. Doppler echocardiography may be complicated by imaging artifacts which, if unrecognized or wrongly interpreted, can result in false diagnosis[1–6]. Colour Doppler mirror image artifacts occur adjacent to highly reflecting acoustic interfaces such as the wall of great arteries[1,2,4] and metallic surfaces[6]. In patients with bileaflet prosthetic mitral valves, we have observed a low-velocity systolic colour flow region in the left atrium, suggesting mitral regurgitation using apical views (Fig. 1A). If this colour flow signal would correspond to mitral regurgitation, however, a high velocity signal would be expected.

We hypothesized that this systolic colour flow signal is artifactual and caused by acoustic mirroring due to ultrasound reflected by the prosthesis. Using transthoracic Doppler echocardiography, we prospectively investigated whether: (i) mirror image artifacts are present in patients with bileaflet mechanical mitral valve prosthesis and if so, (ii) whether these artifacts may mimic mitral regurgitation and can be unmasked by pulsed wave Doppler.
Methods

Patients and Methodology

A total of 50 patients (mean age = 61 ± 10 years) who had received isolated bileaflet mitral valve replacement (6/50 were St. Jude Medical, St. Paul, MN, U.S.A. size 27–31 mm and 44/50 were Carbomedics, Sulzer Carbomedics, Austin, TX, U.S.A., size 27–31 mm) referred for regular follow-up >3 months after surgery were examined prospectively using a commercially available Doppler-echocardiographic system (Sequoia C256, Acuson Corp, Mountain View, CA, U.S.A.) with harmonic imaging (1.75/3.5 MHz). Power output of the

Figure 1. (A). Apical four-chamber view recording of colour Doppler mirror images in the left atrium of a patient with a bileaflet prosthetic mitral valve. During mid-systole, a colour Doppler signal is detected behind the mitral valve prosthesis suggesting mitral regurgitation (arrow). Note the shadowing ($) caused by the mitral valve prosthesis (MV) in the left atrium (LA).

(B) Pulsed wave Doppler signal obtained from the colour Doppler image depicted in (A) (arrow). The systolic low velocity Doppler signal begins simultaneously with aortic valve opening (AO) and ends with its closure (AC). Shape and duration of this signal are identical to the Doppler signal obtained from the left ventricular outflow tract (*). Pulsed wave Doppler analysis reveals a high frequency, aliased signal (*) which begins with mitral valve closure (MC) and ends with mitral valve opening (MO), including isovolumetric relaxation period as well as isovolumetric contraction time. As this signal is identical with duration of mitral regurgitation time (MC–MO), it reflects mitral regurgitation.

(C) Apical four-chamber view recording of a patient with a bileaflet mitral valve prosthesis demonstrating both paravalvular leakage and mirror image artifact: a mosaic colour Doppler signal is present laterally in the left atrium (arrow). Pulsed wave Doppler analysis reveals a high frequency, aliased signal (*) which begins with mitral valve closure (MC) and ends with mitral valve opening (MO), including isovolumetric relaxation period as well as isovolumetric contraction time. As this signal is identical with duration of mitral regurgitation time (MC–MO), it reflects mitral regurgitation.

(D) Pulsed wave Doppler signal (arrow) obtained from the same patient as shown in (C). Again, the sample volume is placed in the left atrium behind the mitral valve prosthesis more medially than in (C). Note that shape, duration, and timing of this signal (*) are completely different from the pulsed wave Doppler signal depicted in (C). This signal begins with aortic valve opening (AO) and ends with aortic valve closure (AC), thus it is identical to the left ventricular outflow tract signal and represents a mirror image artifact (*).

LA=left atrium; LV=left ventricle; MV=mitral valve prosthesis; AO=aortic valve opening; AC=aortic valve closure; MC=mitral valve closure; MO=mitral valve opening. *=pulsed wave Doppler signal, $=$ acoustic shadowing.
The system was set to the maximum for both two-dimensional (2D) and Doppler imaging (0 dB). Built-in fundamental velocity colour Doppler (2 MHz) with a red/blue colour map and variance was used. Sampling rate was set at maximum depending on the sampling depth, resulting in frame rates >15 Hz and velocities >0.6 m s⁻¹. High pulse repetition frequencies (HPRF Doppler) were not utilized in order to avoid range ambiguities. To avoid mirroring artifacts and background noise without loss of signal, the initial high Doppler gain was gradually reduced to the point where the signal was optimally displayed. To confirm that the occurrence of mirror images do not depend on a specific echocardiography system, 10 patients were also studied using two other systems (Sonos 5500, Hewlett Packard, Andover, USA and SSD-5500, Aloka, Tokyo, Japan).

Doppler Echocardiographic Examination

First, routine Doppler echocardiographic examination was performed. In order to detect regurgitant flow and to minimize the problem of acoustic shadowing multiple apical, parasternal, and substernal views were used. Starting from an apical four-chamber view, the left atrium was carefully examined for the presence of a systolic colour Doppler flow signal. The ultrasound probe was then carefully rotated to obtain the optimal Doppler signal. In order to investigate whether mirror image artifacts occur in other apical planes, the examination was repeated in the apical long-axis view and the apical two-chamber view. The gate of the pulsed-wave Doppler was placed in the region of the colour Doppler signal in the left atrium and then interrogated by pulsed-wave Doppler. The left ventricular outflow tract was also examined by pulsed wave Doppler. Mitral regurgitation was defined as paravalvular if a high velocity regurgitant colour Doppler signal was located outside the ring of the mitral valve prosthesis. During colour flow examination of the paraprosthetic regurgitation, special attention was paid to the presence of a proximal flow acceleration zone on the ventricular side of the mitral prosthesis. Because all bileaflet mitral valve prostheses are designed to have some degree of normal or physiologic regurgitation, the sole presence of a
high velocity continuous wave Doppler signal from the apical view did not suffice for the diagnosis of a paravalvular leak.

**Results**

Using the four-chamber view, a low-velocity colour Doppler signal was detected in all patients behind the mitral valve prosthesis in the left atrium. Figure 1A (arrow) depicts a representative sample of a systolic colour Doppler signal. The shape of the signal is longish in the axial direction and the width measures up to 1 cm. A gap can be observed between the colour signal and the mitral valve prosthesis. We found that the best way to obtain the colour signal is to begin imaging from the apical four-chamber view and to slightly rotate the transducer clockwise and, if necessary, to angulate it somewhat cranially (modified four-chamber or long axis view). Mirror image artifacts could be also detected in different apical views such as apical two-chamber and apical long-axis views. In parasternal views, however, no mirror images could be detected.

Interrogation of the colour Doppler signal with pulsed wave Doppler revealed a low velocity signal occurring simultaneously with the aortic ejection period (Fig. 1B and Fig. 2). This low velocity signal, although less intense, was identical to the duration and timing of the pulsed wave Doppler signal of the left ventricular outflow tract, consistent with a mirror image artifact. The ejection times obtained from the left ventricular outflow tract and from the mirror image signal were identical. Velocity profiles of a representative patient are depicted in Figure 2. Also shown are the pulsed wave Doppler spectra from the left ventricular outflow tract (Fig. 2A) and from the mirror images (Fig. 2C and 2D). The shapes of the three velocity profiles are identical, but the peak velocities and the intensities of the mirror images are consistently lower, a phenomenon found in all patients.

In a subset of patients (6/50), paravalvular mitral regurgitation was detected. This proportion, however, does not reflect the incidence of paravalvular leaks at our institution due to different referral clinics. Figure 1 (C, D) depicts pulsed wave and colour Doppler spectra obtained from a patient with both paravalvular leakage (Fig. 1 C) and mirror image artifact (Fig. 1 D). Patients with paravalvular leakage demonstrated a high-velocity, mosaic colour Doppler signal within the left atrium. The additional presence of a flow convergent zone on the left ventricular portion of the mitral valve was a strong predictor of a paravalvular leak. This colour Doppler signal was located outside the sewing ring, or it was separated from the confines of the forward flow stream in cases where the origin could not be clearly seen. Interrogation of the regurgitant colour Doppler signal behind the mitral valve by pulsed wave Doppler revealed a high velocity aliased signal, which occurred simultaneously with the closure of the mitral valve prosthesis and lasted until its opening (Fig. 1C). The duration of this signal includes
the isovolumetric relaxation and isovolumetric contraction time, thus corresponding to the duration of mitral regurgitation time.

Discussion

This study demonstrates the occurrence of mirror image artifacts in the left atrium of patients with bileaflet mechanical mitral valve prostheses. These mirror images can be detected by transthoracic colour Doppler echocardiography from different apical windows. They can be misdiagnosed as mitral regurgitation due to the systolic colour Doppler signal behind the mitral valve (Fig. 1A). However, these signals can be reliably distinguished from true paravalvular leaks by analysis of the pulse-waved Doppler spectra which demonstrate low velocities and a duration and shape identical to the ones obtained from left ventricular outflow tract. The knowledge of the presence of these artifacts may help facilitate the further evaluation of patients in whom leakage after mechanical mitral valve replacement is suggested.

The generation of mirror image artifacts is caused by reflection of transmitted ultrasound at the leaflet of the mitral valve prosthesis (Fig. 3). The angle of reflection equals the incident angle of the acoustic pulse. The reflected sound is backscattered by circulating red blood cells in the left ventricular outflow tract to the leaflet of the prosthesis, and is then reflected to the transducer. The transducer will detect this echo signal generated by the red blood cells in the left ventricular outflow tract. As this signal takes longer to be transmitted to the transducer, the echo system will detect these signals as if they arose from a position deeper in the field of the view. The ultrasound system determines target depth on the basis of time-of-flight measurements, assuming a straight line of propagation from the transducer of the received sound (Fig. 3) and displays a mirror image of the velocity profile of the left ventricular outflow tract appearing beyond the mitral valve prosthesis, explaining why the colour Doppler signal occurs behind the mitral valve. Furthermore, the finding that the pulsed wave Doppler signals from the left ventricular outflow tract and those detected behind the valve are identical in shape and duration can be explained by this mechanism. Both the observation that the mirrored image in the left atrium has a lower velocity than the signal from the left ventricular outflow tract and the finding of the longish shape of the mirrored colour Doppler signal in the left atrium (Fig. 1A) strongly favour the accuracy of our theory, depicted in Figure 4 as a diagram.

The prerequisite for the generation of mirror images is fulfilled if the ultrasound beam is reflected at the mitral valve prosthesis into the left ventricular outflow tract.

![Figure 4](left). Mechanisms underlying the difference in peak velocities between actual signal and the mirror image shown in the Doppler study depicted in Figure 2 (Panels A, C, and D).

1. **Left ventricular outflow tract.** The angle between the incident sound beam and the direction of motion of the red blood cells in the left ventricular outflow tract (a) is about zero. Because the cosine of 0 is 1, there is no velocity error and the peak velocity of the Doppler spectrum is maximal (see Fig. 2, panel A).
2. **Left atrium.** Ultrasound is transmitted by the transducer (b) and reflected at the leaflet of the MV. The angle (β) between the reflected ultrasound beam and the forward moving red blood cells is less than 1. Therefore, the peak velocities of the mirrored spectra have to be lower than the ones obtained from the left ventricular outflow tract (see Fig. 2, panel C).
3. **Left atrium (slightly different transducer position).** Again, ultrasound is transmitted by the transducer (b') and reflected at the leaflet of the MV. The angle (β') between the reflected signal (b') and a is greater than β. Accordingly, the peak velocity of b' will be lower than b (see Fig. 2, panel D). Theoretically, it is possible to have positive mirror images provided that the angle β between a and b is >90°.
4. **Distance of the displayed and mirrored colour Doppler beam is identical (b=b, and b'=b') therefore the mirror image has to be confined to a distinct region within the left atrium.**

- a=Doppler beam in the left ventricular outflow tract; b and b'=mirrored Doppler beam at the mitral valve prosthesis; b_r and b'_r=display of the mirror image from b and b' in the left atrium; β and β' angle between mirrored and left ventricular outflow tract; AO=ascending aorta; LA=left atrium; LV=left ventricle; MV=mitral valve prosthesis; RBC=red blood cells in the left ventricular outflow tract; RBC_r=reflected red blood cells from the left ventricular outflow tract.
and vice versa. This explains why mirror images were only detected from apical but not from short-axis views, and why the individual transducer position and the exact location and maximum of the Doppler signal could not be predicted in an individual patient. Mirror images were detected most successfully from a modified four-chamber view (slight clockwise rotation and upward angular motion) or from a modified long-axis view. Because mirror images are a reflection of the left ventricular outflow tract flow, neither the presence nor the extent or location of paravalvular leaks has any impact on the presence and extent of mirror images. The fact that the mirror images could be consistently reproduced using three ultrasound systems has ruled out the possibility of a system-related phenomenon.

With this study, we have extended the use of an established method for the evaluation of bileaflet mitral valve prostheses by utilizing pulsed wave Doppler spectra information. Thus the ‘pulsed wave Doppler method’ allows the clear differentiation of artifacts from an actual velocity signal. Patients with both a systolic colour Doppler and a low-velocity pulsed wave Doppler signal in the left atrium and no evidence of malfunctioning of the mitral valve prosthesis do not need further evaluation. However, if the signal in the left atrium has a high-velocity spectrum with a duration which is identical to mitral valve closure time, two different aetiologies have to be taken into consideration: (i) normal or physiological transvalvular regurgitation (design of bileaflet mitral valve prosthesis) and (ii) paravalvular regurgitation. Thus, the sole presence of a high-velocity signal does not suffice for the diagnosis of a paravalvular leak. As previously mentioned, evidence that the high-velocity jet originates outside the sewing ring is required.

Doppler echocardiography is commonly used for the assessment of prosthetic heart valves and enables the diagnosis of prosthetic valve dysfunction. Detection of a paravalvular leak may have further diagnostic and therapeutic consequences. If there is no or low probability for infective endocarditis based on the clinical presentation, there should be no need to perform further diagnostic or therapeutic procedures in the presence of a systolic Doppler signal behind the mitral valve, if such a signal can be identified as a mirror image artifact by pulsed wave Doppler.

The additional diagnostic value of parasternal views for detecting regurgitant jets in prosthetic mitral valves is often limited due to acoustic shadowing. In contrast, transoesophageal echocardiography is a good tool to detect paravalvular regurgitation due to better resolution and unobstructed views of the left atrial side of the mitral valve prosthesis. This method should be used if the diagnostic information obtained by transthoracic echocardiography is not sufficient. For the application of transthoracic echocardiography, however, the knowledge of the existence of mirror image artifacts and the ability to differentiate these artifacts from transvalvular or paravalvular mitral regurgitation will help to avoid the unnecessary use of further timely diagnostic procedures.

Conclusions

This study demonstrates the occurrence of mirror image artifacts in patients with mechanical mitral valves prosthesis which can mimic mitral regurgitation. As mirror image artifacts can be specifically identified by analysis of shape and duration of pulsed wave Doppler spectra, the knowledge of this phenomenon will facilitate the correct diagnosis and avoid misinterpretation of both spectral and colour Doppler imaging signals in patients with prosthetic mitral valves.

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