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# Development of Real-time Two-dimensional Doppler Echocardiography and its Clinical Significance*

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## 1. Introduction

Recently, we [1,2,3] have developed "two-dimensional doppler echocardiography" (2-D doppler), which allows us to obtain non-invasively intra-cardiac blood-flow imagings in real time. First of all, I would like to point out briefly the steps of research to "real-time 2-D doppler blood-flow imagings".

In 1975, Fish reported on "multi-channel doppler"to have blood flow profile along a beam direction.

In 1978, Matsuo, Kitabatake and Chihara reported on blood-flow mapping "so-call doppler angiography"with off-line technique.

In 1982, Brandestini described color-coded doppler in M-mode display. Bommer reported on real-time 2-D dopp ler, in which enhancement by contrast material was required. Namekawa, Kasai and Koyano, coauthors of this paper, described on real-time 2-D doppler system available for practical use.

In 1983, Omoto, Namekawa and others first reported on clinical application of "real-time 2-D doppler" at the Annual Meeting of Japanese Circulation Society.

The main purpose of this paper is to reveal the clinical usefulness of 2-D doppler in cardiology.

## 2. Method

The device combines a conventional pulsed doppler system and a newly developed autocorrelator, in which bloodflow imagings within a given cross section of a beating heart are displayed in real time. The direction of blood flow is expressed by a red color for blood flow approaching the transducer and a blue color for away from it. With regard to turbulance of blood flow a green color is added in proportion to the extent of turbulence. Therefore, the three kinds of information concerning the blood flow, such as the direction, velocity, and the state of turbulence are recognized by differences in color.

In this series, 215 patients whose diagnoses are confirmed by angiogram and/or surgery have been surveyed(152 : acquired valvular, 54 : congenital, 15 : dissecting aneurysms).

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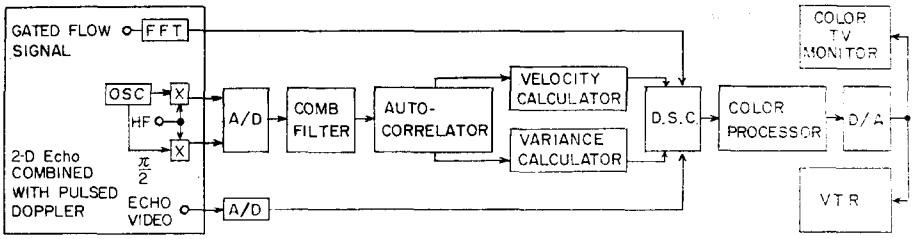


**Fig. 1.** Block diagram of newly-developed 2-D dopplr system Comb filter functions for the cancellation of wall motion

Study on diagnostic usefulness with the new system has been performed so far in acquired valvular diseases, congenital heart diseases and dissecting aortic aneurysms. The comparative study has been carried out between the findings in 2-D doppler and conventional X-ray angiography or surgery.

### 3. Results

#### (1) Normal heart

First, to show the basic functions of this new system, Aloka-880, 2-D Doppler images of a normal heart are shown. When the transducer is placed in the lower parasternal position, blood-flow images of the inflow tract (diastole in red) and outflow tract (systole in blue) of the leftventricle are displayed. In the flow-mapping M-mode, the blood flow images above the anterior mitral leaflet are clearly color-distinguished from the blood-flow images below the anterior mitral leaflet. Spectral analysis is also possible. The flow-mapping M-mode scan, which allows precise analysis of blood-flow dynamics in the left ventricle and evaluation of the left ventricular function is highly useful as it enables better time resolution.

#### (2) Acquired valvular diseases

**Case 1** : MS·MR (Sellers' 2 grade)

Using the lower parasternal view, inflow blood of the left ventricle forcefully passes through the stenotic mitral orifice, The mosaic flame pattern is turbulent blood flow through the stenotic orifice in diastole.

**Table 1.** Characteristics of 2-D Doppler system

| | |
|---|---|
| Ultrasound frequency | 2.5 MHz |
| Pulsed repetition rate | KHz |
| Scanning angle for 2-D Doppler | 40, 50 degrees |
| for 2-D Echo | 90 degrees |
| Frame rate | 10~30 frams/sec |
| Display | B-mode, M-mode, FFT |
| Transducer | phased array |
| *Mamimum detectable flow velocity | **120cm/sec |
| *Minimum detectable flow velocity | 23cm/sec (B-mode)<br>6cm/sec (M-mode) |
| Recording | VTR, 35mm film, instant photo. |

(*Assuming that beam angle to blood flow is 60 degrees)
(**Images of the blood flow with high velocity exeeding the range result in a wrap around of the top portion of Doppler frequencies)

**Table 2.** Comparison of the grade of aortic regurgitation (AR) assessed by angiocardiography (Angio) and 2-D Doppler (54 aortic regurgitations). A significant correlation is noted

| 2-D Angio \ Doppler | 0° | I° | II° | III° | IV° |
|---|---|---|---|---|---|
| 0° | | | | | |
| I° | 3 | 8 | 3 | | |
| II° | 1 | 2 | 17 | 4 | |
| III° | | | | 13 | |
| IV° | | | | | 3 |

**Table 3.** Comparison of the grade of mitral regurgitation (MR) assessed by angiocardiography (Angio) and 2-D Doppler (42 mitral regurgitations)

| 2-D Angio \ Doppler | 0° | I° | II° | III° | IV° |
|---|---|---|---|---|---|
| 0° | | | | | |
| I° | 1 | 7 | | | |
| II° | | | 15 | 3 | |
| III° | | | 1 | 12 | |
| IV° | | | | | 3 |

**Table 4.** Comparison of the grade of tricuspid regurgitation(TR) assessed by operative findings(Ope) and 2-D Doppler (28 tricuspid regurgitation). Although a significant correlation is noted, 2-D

| 2-D Ope. \ Doppler | 0° | I° | II° | III° |
|---|---|---|---|---|
| 0° | | 4 | 1 | |
| I° | | 5 | 3 | |
| II° | | | 6 | 3 |
| III° | | | | 6 |

Imaged is also associated moderate mitral regurgitation in systole.

**Case 2** : MR (Sellers' 4 grade).

This is the case of severe mitral regurgitation. The extremely enlarged left atrium and stenotic mitral orifice is seen. 2-D Doppler is very useful in detecting aortic, mitral and tricuspid regurgitations. Also, it facilitates correlation with angiography or surgical findings for quantitative evaluation of valvular regurgitation[4]. Regurgitant jet, characterized by turbulent blood flow during systole, is clearly observed in the leftatrium. For this patient, 2-D Doppler findings alone determined cardiac suegery without cardiac catheterization The direction of regurgitant jet can be changed during one cardiac cycle. This is not gassible with the conventional pulsed-doppler method as it has only a small sample volume. In the flow-mapping M-mode, disturbed regurgitant flow is demonstrated in the left atrium in systole. In spectral analysis, regurgitant blood flow is characterized by wide-banded and bi-directional frequency signals.

**Case 3** : Multivalvular disease ; MS·MR (Sellers'3 grade)+TR(severe). Acquired valvular diseases often coexist with two or more valvular lesions. Clinical experience has shown that 2-D Doppler is very effective in diagnosing multivalvular diseases. In the apical four-chamber view, mitral stenosis associated with mitral regurgitation and tricuspid regurgitation are demonstrated. In this case, tricuspid regurgitation is very severe. Regurgitant flow images are present in the entire right atrium in systole. In marked tricuspid regurgitation, it is common to find regurgitant flow to the hepatic vein in systole. M-mode fidings and ECG timing confirm that flow into the hepatic vein shown in red, is indicative of advanced tricuspid regurgitation.

**Case 4** : APR+IE (postoperative case of MVR)

Aortic regurgitation is induced by infective endocarditis. In the mitral position,

a St. Jude medical valve is inserted. With 2-D Doppler, direct observation of aortic regurgitation and evaluation of its severity is possible. In the long-axis view, blood flow toward the ventricular septum through the St. Jude valve is imaged in red, as it is crossed by the bluish aortic regurgitant flow toward the apex. In the short-axis view, blood flow imaged in red is surrounded by aortic regurgitant flow in blue. In lower parasternal view a better image of blood flow passing through the St. Jude valveis shown. In the higher parasternal view, aortic regurgitant flow is clearly seen. In apical view, movement of the mechanical valve leaflets and blood flow through the mechanical valve are shown. By freely changing the 2-D Doppler's cross-sectional view, three-dimensional conception of intracardiac blood-flow dynamics is obtained.

### (3) Congenital heart diseases

**Case 5** : ASD

Shown is a case of atrial septal defect. The defect of the atrial septum is suspected in the apical four chamber view of the 2-D Echocardiography. The shunt flow through ASD can be recognized as a flow toward the tranasducer, and the extension of the shunt flow area considered to be related to the severity of the disease.

**Case 6** : VSD(type Ⅱ)

This is the case of ventricular septal defect type II. A ventricular septal defect is recognized at the membraneous portion of the interventricular septum. The VSD shunt flow is displayed as a mosaic turbulent flow in the ventricular systolic phase.

### (4) Dissecting aortic aneurysms

**Case 7** : DeBakey type-I dissecting aneurysm

As shown in the chest X-ray, the mediastinum is dilated and the trachea deviates to the right. 2-D echocardiogram shows an intimal flap in the dilated ascending aorta. As seen in 2-D Doppler imageing, blood flow leaves the aortic root, passes through the true lumen and then enters the false lumen in a swirling motion. Thus, with 2-D Doppler, it is easy to determine the site of entry and to ascertain the true and false lumens.

## 4. Conclusion

The results are summarized as follows: (1) In acquired valvular diseases, valvular regurgitations in aortic, mitral and tricuspid positions have been visualiled quantiatively. (2) In congenital heart diseases, significant intra-cardiac shunts have been visualized. (3) In dissecting aortic aneurysms, the sites of entries have been clearly visualized in patients with DeBakey type-I dissections. (4) It is suggested that 2-D Doppler may replace the conventional X-ray angiography in some situations.

In conclusion, the new divice, 2-D Doppler, has been found to offer non-invasively new diagnostic informations on intra-cardiac blood flow.