CLINICAL APPLICATION OF COLOR ANGIOCARDIOGRAM

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SUMMARY

In order to assess angiocardiographic findings more precisely, a new method was developed for color display of conventional monochromatic angiogram. The principles of the method are as follows: different light intensities which compose the angiographic findings of a monochromatic film are converted into the corresponding 12 different colors through a video camera connected to a computer, and are projected on a cathode ray tube as a "color angiogram". Thus, the difference in the density of the monochromatic silhouette was expressed as the difference in color. Angiograms of 25 patients with various heart diseases were analyzed with the above method. Normal laminar flow of contrast medium in the aorta as well as turbulent blood flow in the patients with aortic valvular diseases were revealed satisfactorily with this method. The grade of regurgitation (e.g. mitral regurgitation) and intracardiac shunt (e.g. ventricular septal defect) were evaluated semi-quantitatively, according to the color description of the distribution density of contrast medium. The method was also applied to coronary angiogram. The distribution of contrast medium in the ventricular muscle was analyzed, and abnormal distribution of contrast medium or defects due to the preceding myocardial infarction could be shown up. We conclude that "color angiogram" is an useful diagnostic method for cardiovascular diseases.

Angiography is an essential procedure for the diagnosis of cardiovascular diseases. However, the interpretations of the silhouettes on the conventional monochromatic angiograms have a certain limitation. Color additive subtraction techniques were developed to obtain more informations from angiography than can be obtained with conventional viewing, and have been applied mainly for use in medical illustrative material and teaching^{1,2}. Eber and his associates³ used a special color-coded, triple emulsion cine film (magenta, cyan, and yellow) for the clear separation of the ventricular wall

and lung to calculate left ventricular free wall thickness accurately. The purpose of the present study is to develop a new method which can be applied easily to clinical cases and to offer more detailed informations on angiograms than the previously introduced methods.

METHODS AND MATERIALS

The principles of the method are as follows; the different densities of the angiocardiograms on a monochromatic film are converted into the corresponding 12 different colors through a video camera, and are displayed on a cathode ray tube as "color angiocardiogram", which, in turn, is photographed on the usual 35 mm color films. The densities of every parts of the angiocardiographic silhouette are changed to analog signals through a video camera, amplified, and are converted to the digital numbers of 1 to 12 with an analog-digital converter. The 12 digital numbers are distributed to 12 different colors through a digital-analog converter with the combination of three primary colors (red, green, and blue) and are displayed on the cathode ray tube (Fig. 1)*. Thus, a certain range of the light intensities on a monochromatic angiocardiographic silhouette is expressed as a certain color composing an isoconcentric band. The arrangement of the colors is listed in (Table 1). The portions of the angiogram with the highest density correspond to white, and the lowest ones to black, giving 10 more different

Fig. 1 The block diagram of the color data system.

Table 1

White—Light blue—Dark blue—Light green—Orange—Yellow—Brown—Dark
green—Red—Violet—Magenta—Black.
Light intensity (Density)————→

* The system for the analysis was supplied by nac Co. Ltd., Tokyo, Japan (nac color data system 1200): and Ohsawa Shokai Co. Tokyo, Japan (Spatial Data System).

colors for inbetween densities (Table 1). (The hues on the cathode ray tube were adjusted with a gray mark attached to the angiographic film to violet-color calibration). These gray marks are seen as violet square bands in Fig. 2, 5, 6, 8.

In the present study, left heart catheterization was performed with percutaneous method via the femoral artery. Elema-Schönander 14"×14" cut-film changer was used at the speed of 6 frames per second for left cardiac ventriculogram as well as aortogram, and 3 frames per second for coronary angiogram. The developed 14"×14" films were used for the analysis with the above method. The angiocardiograms of a total of 25 patients were studied: 5 left ventriculograms (of 2 patients with ventricular septal defect, 2 patients without any significant cardiac abnormalities, and 1 patient with mitral regurgitation): 3 aortograms (of 2 patients with aortic stenosis, and 1 patient with aortic regurgitation): 17 coronary angiograms (of 6 patients with well documented histories of myocardial infarction, 7 patients with significant stenosis in at least one of the main branches of the coronary arteries, and 4 patients with completely normal coronary angiographic findings)⁴.

RESULTS

Two coronary angiograms were poorly conditioned, i.e., the original films were too dark, and the color display of them showed exceedingly low density areas and were unreadable. The color description of the ventriculogram of a patient with a ventricular septal defect (right ventricular pressure-115/10 mmHg, left ventricular pressure-116/15 mmHg) revealed markedly enlarged ventricles with homogeneous density (single color description) and did not offer any informations more than those obtained from the original monochromatic film. Satisfactory color displays of the original monochromatic angiocardiograms were obtained in other 22 patients. Some illustrative cases are shown in the following.

Patient 1, a 49-year-old woman with a systolic murmur of short duration at the apex. No other significant findings were noted on physical and laboratory examinations including electrocardiograms. Left ventricular angiography was undertaken to exclude the possibilities of intracardiac abnormalities. Left ventricular pressure was 150/5 mmHg and left ventricular angiogram revealed no abnormal findings. Fig. 2 is the color description of the left ventricular angiogram of the patient (antero-posterior projection). The contrast medium was injected into the left ventricle, and the contrast medium is diluted from the center of the left ventricle toward the aorta (white-light blue-dark blue-light green-orange-yellow). The right ventricle is not revealed and the pulmonic area is expressed with violet. Note a violet square band for color calibration, which is originally

gray. We can realize that the isoconcentric bands are progressing apparently as a laminar flow toward the peripheral direction of the aorta.

Patient 2, a 20-year-old woman with aortic stenosis. The patient was noted to have heart murmur at the age of 3 for the first time. She had had no limitation in daily life until the time of this study. A systolic crescendo-decrescendo murmur of grade 4 was heard over the aortic ostium, which radiated to the apex and to the carotid arteries. There was no sign of congestive heart failure and the electrocardiogram showed marked left ventricular hypertrophy with associated ST-T segment changes. The conventional monochromatic angiogram revealed valvular aortic stenosis with dilated aortic root, and the systolic pressure gradient across the aortic valve was 70 mmHg. Fig. 3 is the "color aortogram" of the patient (lateral projection). Isoconcentric bands are irregular and turbulent nature of the blood flow is estimated. In this color display, any intrathoracic structures that have lower densities than those corresponding to red were erased by means of electronic technique.

Patient 3, 27-year-old woman with ventricular septal defect. She was noticed to have heart disease at her birth, and had a history of bacterial endocarditis at the age of 19. She was admitted to our hospital for the evaluation of low grade fever of 2 months duration. Right heart catheterization revealed right ventricular pressure of 24/2 mmHg, pulmonary arterial pressure of 22/10 mmHg, and left to right shunt of 60%. Fig. 4 is the "color ventriculogram" of the patient. The catheter tip was located at the center of the left ventricle, where the contrast medium was injected under pressure. The density of the contrast medium is maximal at the center of the left ventricle (blue-yellow) and thinner at the marginal areas (brown-dark green). This low density part penetrates into the right ventricle and disclosed the interventricular septal defect of mild degree. In this picture, any structure which has the density lower than that corresponding to red was expressed uniformly with black for the sake of simplicity. The patient had a successful surgical repair thereafter for the prevention of recurrent bacterial endocarditis, and was found to have 0.5×0.5 cm ventricular septal defect at the membranous septum.

Patient 4, a 33-year-old man with mitral regurgitation. The patient had been doing well until 4 years ago, when he was noticed to have heart murmur. He had had an episode of ankle edema and shortness of breath 2 years before the present admission. This time he was admitted to our hospital for the evaluation of the cardiac status. At the time of admission, the heart rate was 88 regular, systemic blood pressure was 124/60 mmHg, there was no ankle edema or jugular venous dilatation, but the liver was enlarged 3 cm below the right costal margin. A holosystolic murmur of grade 4 and S3 were audible at the apex. Cardiac

catheterization was performed; left ventricular pressure was 120/6 mmHg, LV max dp/dt was 2200 mmHg/sec, and left ventriculography revealed mitral regurgitation. Fig. 5 is the color display of the angiographic film. The contours of the left ventricular and atrial chambers are delineated. The density of the contrast medium in the left atrium (mostly orange-yellow) is lower than that in the left ventricle (light blue-light green, partly orange-yellow). The findings are compatible with mitral regurgitation of grade 3.⁵

Coronary angiograms were analyzed with the same method. The angiograms taken 1-3 seconds after the completion of the injection of contrast medium (meglumine diatrizoate 76%, 6 ml) into the left coronary arterial ostium were used for the analysis. In this period the contrast medium is presumed to be distributed throughout the cardiac muscles which are under the perfusion of the coronary artery.

Patient 5, a 59-year-old woman with the chief complaint of anterior chest pain of 6 months duration. The findings on physical examinations stayed within normal limits. The electrocardiograms including post-exercise ones were also normal. The coronary angiograms revealed no significant stenosis in either right or left coronary arteries. Fig. 6 is the color analysis of the late phase (2 seconds after completion of injecting contrast medium) of the coronary angiogram. Most of the left ventricular wall is displayed in orange-yellow, and the marginal area in brown-dark green. The retrosternal area, which is anatomically occupied by the right ventricle is tinged with red. Thus, the above findings are presumed to show an example of a normal left ventricular wall including the interventricular septum.

Patient 6, a 43-year-old man with a history of myocardial infarction. The patient had a well documented history of acute myocardial infarction 2 years ago. Since then he had not noticed any sorts of cardiac problems except the continuation of abnormal electrocardiographic findings (QS pattern associated with ST segment elevation in V1-V3. On physical examinations, there were no signs of congestive heart failure, and left heart catheterization revealed left ventricular pressure of 108/12, and max dp/dt of 1330 mmHg/sec. Left ventricular angiogram disclosed a localized ventricular aneurysm at the anterior wall of the left ventricle near the apex (Fig. 7b). Coronary angiogram disclosed complete occlusion of the left anterior descending artery (Fig. 7a). Fig. 8 is the color analysis of the angiogram. The monochromatic angiographic film taken one second after the completion of contrast medium injection was used for the analysis. There is a defect at the anteroseptal area near the apex of the left ventricle (black arrow). The area which is stained with orange-yellow is rather limited and the dark green area is more extensive compared to that shown in Fig. 6. The defect and dark

green area (low density area) correspond with the area of the ventricular aneurysm and coronary occlusion which are shown in Fig. 8.

DISCUSSION

In the present study, color display of angiocardiograms was attempted in order to analyze the angiographic findings more precisely. Fig. 9 and 10 are the original monochromatic angiograms of the color angiograms shown in Fig. 2 and 3, respectively. Fig. 9 is the antero-posterior projection of the normal ventriculogram. The vertebral silhouette in the lower center of the picture partly disturbs the density analysis of the cardiac shadow. This problem can be avoided in the lateral projection as in Fig. 10. However, the elevated diaphragm might disturb the analysis of the left ventricular cavity or wall in this projection. The rib silhouettes in Fig. 10 are also possible contaminations, though these are not disturbing in Fig. 3. For these reasons, proper projection should be selected in applying this method. Another important problem is the minimal requirement in the size of a silhouette which can be delineated in the color display. In our experience, a silhouette which has the size larger than 5 mm in diameter on 14"×14" film is duplicated in color with satisfactory accuracy. Thus, the catheters which have the external diameter of 3 mm show vague configurations in the color angiograms.

One of the possible clinical applications of the method is for rheological study as shown in Fig. 2 and 3. With the color display of the angiograms of great vessels, the nature of the blood flow including turbulence or flow speed can be evaluated. Another possibility is the semi-quantitative estimation of regurgitation across the semilunar or atrio-ventricular valves and the interventricular shunting as shown in Fig. 4 and 5. As seen in Fig. 2, 4, and 5, the configuration of the left ventricle was made clear with color display, and this might be useful for volume study of the ventricle³. The cut-film changers were used in the present study, however, cineangiographic findings can be treated with the same method and "color cineangiocardiogram" will be obtained if it is preferable.

At the present time, radioisotope methods using ^{131}I ⁶, ^{43}K ⁷, or ^{129}Cs ⁸ are applied for myocardial scintigraphy. In our study, color display of the left ventricular wall was tried as a new approach. The basic concept of our study is that the left ventricular muscle under the perfusion of the left (or right) coronary artery will be delineated with the contrast medium which has distributed throughout the cardiac muscles at a certain interval after the injection. Ross and his associates⁹ injected ^{133}Xe into the left coronary artery of the patient and observed that radioactivity disappears as a single exponential for 60 and 90 seconds. In

our study, the color displays of the ventricular wall were performed at the average of 1.9 ± 0.3 sec after the completion of the contrast medium injection into the coronary arteries, at which time the left ventricular wall was most clearly displayed with this method. In our study six patients with significant stenosis of the coronary arteries showed essentially same left ventricular wall findings as 4 patients without any abnormal coronary findings: a demonstrative case was shown in Fig. 6. On the other hand, among 5 patients with well documented histories of myocardial infarction, 3 had anteroseptal infarction proved with electrocardiograms, coronary angiograms, and ventriculograms. All of the 3 patients with anteroseptal infarction showed the same configuration as shown in Fig. 8, and none of the patients without anteroseptal wall infarction had this sort of abnormal finding. However, in 2 patients with inferior wall infarction, the infarction area could not be displayed clearly. Both of them had stenosis of 75% and 90% in the posterior descending arteries, either of which were from left circumflex arteries and there was no significant stenosis in the right coronary arteries. The development of the collateral circulation might be the reason, though there were no significant collaterals demonstrated in either of 2 patients. There is also a possibility that the infarction areas were concealed under the diaphragm silhouette. This warrants further studies.

From the experiences mentioned above, we conclude that "color angiogram" is an useful additional diagnostic method for cardiovascular diseases.

(The authors chanced to see Dr. Rashkin's paper in which they had applied the same method to pulmonary roentgenography, during the process of revision of this report).¹⁰

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Fig. 2 Color display of a normal left ventricular angiogram (48 year-old-woman, antero-posterior projection). VL: left ventricle, Ao: Aorta

Fig. 3 Color aortogram of a 20-year-old patient with aortic stenosis (lateral projection). Ao: Aorta, LV: left ventricle. Note that any intrathoracic structures which have lower densities than those corresponding to red are erased out with electronic technique

Fig. 4 A 27-year-old woman with ventricular septal defect (lateral projection). The contrast medium was injected into the left ventricle. LV: left ventricle, RV: right ventricle, Ao: Aorta, S: Sternum. The existence of an interventricular septal defect of membranous type (0.5x0.5cm) was confirmed at operation. Note that any structures which have lower densities than those corresponding to red are expressed in black for simplicity

Fig. 5 Color display of mitral regurgitation (a 33-year-old-man, lateral projection). LV: left ventricle, LA: left atrium

Fig. 6 Color description of the late phase of coronary angiogram of a 59-year-old-woman with normal coronary angiographic findings (lateral projection). LVW: left ventricular wall

Fig. 7 The coronary angiogram (a), and ventriculogram (b) of patient 6 (old antero-septal infarction, lateral projection).

Fig. 8 Color display of the left ventricular wall (LVW) of the patient 6

Fig. 9 The original monochromatic angiogram of the color angiogram shown in Fig. 2 (patient 1)

Fig. 10 The original monochromatic aortogram of the color aortogram shown in Fig. 3 (patient 2)