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Tricuspid regurgitation diagnosed by intravenous digital subtraction angiography

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Summary

In spite of numerous available diagnostic methods, controversies concerning the precise diagnosis of tricuspid regurgitation (TR) still remain. In right ventriculography, catheter placement may modify tricuspid valvular function. Though noninvasive Doppler echocardiography is a useful method, it is sometimes too sensitive for clinical use. Furthermore, it is not applicable to cases in which ultrasound penetration is limited. In this study, we evaluated TR using intravenous digital subtraction angiography (DSA), which can provide good images even in cases with poorly recorded echocardiograms. For this study, we placed a catheter in the superior vena cava.

Cardiac DSA examinations were performed in one hundred and one patients with heart disease. We injected 35 m*l* of contrast medium at a speed of 18 m*l*/sec via a catheter introduced in the superior vena cava. DSA images by continous mode were obtained in the RAO projection for 15–20 sec. Sequential DSA images were observed and analyzed by time-density curves of the regions of interest (ROI) which were placed in the right ventricle (RV) and inferior vena cava (IVC). Doppler echocardiography was performed for 16 cases in which TR was suspected. Of these, phonocardiography with jugular pulse tracing was recorded for 14 and contrast echocardiography were performed for six, respectively.

In cases without evidence of TR, regurgitation of contrast medium into the IVC during RV systole was not recorded by the DSA method. In cases of clinically-proven TR, regurgitation into the IVC during RV systole was observed. Thus, this was considered a diagnostic feature of positive TR using the DSA method, and 13 of the 16 cases undergoing Doppler echocardiography were diagnosed as having

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TR using the DSA method. The severity of TR was categorized as mild, moderate and severe according to analyses of time-density curves. The severity established by the DSA method showed a close correlation with the clinical severity of TR. Doppler echocardiography was negative for TR in two of the 13 cases, but positive for TR in two of the 16 suspected cases only by the Doppler method. In cases of moderate to severe TR diagnosed by the DSA method, jugular pulse tracings showed a regurgitant wave. By contrast echocardiography, TR was evident only in cases of severe TR diagnosed by the DSA method.

In conclusion, the DSA method proved useful for diagnosing TR.

Key words

Tricuspid regurgitation Digital subtraction angiography Doppler echocardiography Jugular pulse Contrast echocardiography

Introduction

Accurate diagnosis of tricuspid regurgitation (TR) is difficult. Among many diagnostic methods now available, none provides an absolute evaluation of the presence and severity of TR[1,2]. A classical triad of TR is not always observed on physical examination even in severe TR cases, and silent TR is not uncommon. Evaluation of TR using right ventriculography is difficult, because regurgitation might be modified by a catheter introduced into the right ventricle via the tricuspid valve[3]. Noninvasive Doppler echocardiography is promising, but it is too sensitive for clinical use[4].

Digital subtraction angiography (DSA) is a relatively new angiographic method[5], which can be used in many parts of the body with excellent spatial and temporal resolutions[6]. Using DSA, we imaged the heart by intravenous injection of contrast medium, less invasively than by conventional angiography, and avoided catheter-induced valvular regurgitation.

In the present study, we used intravenous DSA to diagnose the presences or absence and the severity of TR.

Subjects and Methods

Study population

The study population consisted of one hundred and one patients with heart disease who were admitted to the University of Tsukuba Hospital and who received the cardiac DSA examination between November, 1984 and January, 1987. There were 67 men and 34 women whose mean age was 51.4±13.2 years. Diseases included angina pectoris in 28; old myocardial infarction in 24; chest pain syndrome in 12; valvular heart disease in 12; congenital heart disease in 13; myocardial disease in five; bradyarrhythmia in three, and four others including pericardial disease.

Digital subtraction angiography (DSA)

A commercially available DSA system (Digiformer–X, Toshiba) was used for the examination. A catheter (Mallinckrodt 5F) introduced from the antecubital vein was placed in the superior vena cava. For five patients, a catheter (Cordis 7F) was introduced via the femoral vein, when their antecubital veins were too small for catheterization or when cardiac catheterization was performed at the same time. For two patients in whom it was difficult to introduce a catheter into the superior vena cava via the basilar vein, a short catheter was placed in the antecubital vein. Thirty-five m*l* of contrast medium (Urografin ® 76%) were injected at a speed of 18 m*l*/sec. DSA images were obtained in a right anterior oblique (30 degrees) projection while the patients suspended respiration in inspiration. DSA images were recorded for 15–20 sec during each examination. X-ray TV images were logarithmically amplified and digitized using a 10 bit A/D converter into a 512×512 pixel matrix with an 8 bit depth at standard TV rates (30 frames/sec). Prior to injection of contrast medium, an initial image was obtained during one sec (30 frames) and stored in the computer memory, as a digital mask image. Immediately thereafter, contrast medium was injected, and sequentially

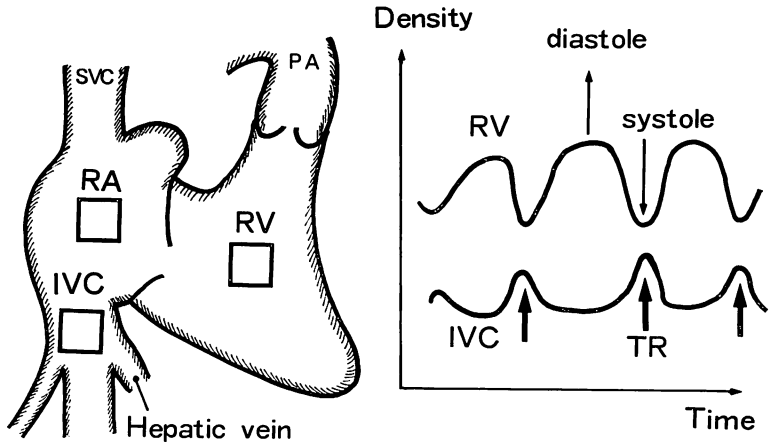


Fig. 1. Schematic representation of the method.

DSA images are obtained in a right anterior oblique projection. Regions of interest (ROI) are placed in the right ventricle (RV), right atrium (RA), and inferior vena cava (IVC). The density of the RV increases during diastole and decreases during systole. In the case of tricuspid regurgitation (TR), the density of the IVC increases during RV systole.

SVC=superior vena cava; PA=pulmonary artery.

subtracted images were obtained using a continuous mode. Successive frames of TV images were subtracted from the mask image in real time. These subtracted images were stored on an analog video disc recorder.

After sequential images were observed, time-densitometry was performed in the regions of interest (ROI), and regional time-density curves were obtained. The ROIs were the right ventricle (RV), the right atrium (RA) and the inferior vena cava (IVC). The presence and severity of TR were assessed (**Fig. 1**).

Doppler echocardiography

Doppler echocardiography (pulsed and/or color flow mapping) was performed in all cases of suspected TR. TR and its severity were evaluated by Doppler echocardiography according to a modified criteria reported by Miyatake et al[7]. Using the maximal distance from the tricuspid orifice attained by a regurgitant signal, the severity of the TR was classified by a three-point scale: 1+=less than 1.5 cm; 2+=1.5 cm or more and less than 3.0 cm; 3+=3.0 cm or more. Doppler echocardiographic units (SSH-65A and SSH-40A, Toshiba) were used for this examination.

Contrast echocardiography

Contrast echocardiography was performed according to the method of Amano et al[8] in six of 16 patients with suspected TR. Indocyanine green (ICG) dissolved in saline was injected via a 19-gauge butterfly needle placed in the left antecubital vein and was followed by injection of 15 m*l* of cold saline. TR was assessed at the IVC level in the supine position. An echocardiography unit (SSH-11A, Toshiba) was used for this examination.

Phonocardiography and jugular pulse tracing

Phonocardiography with jugular pulse tracing was performed for 14 of 16 cases with suspected TR. Recordings were obtained while the patients suspended respiration in expiration in the supine position.

Results

Since the volume of the RV increases during diastole and decreases during systole, the density of the ROI placed in the RV changed cor-

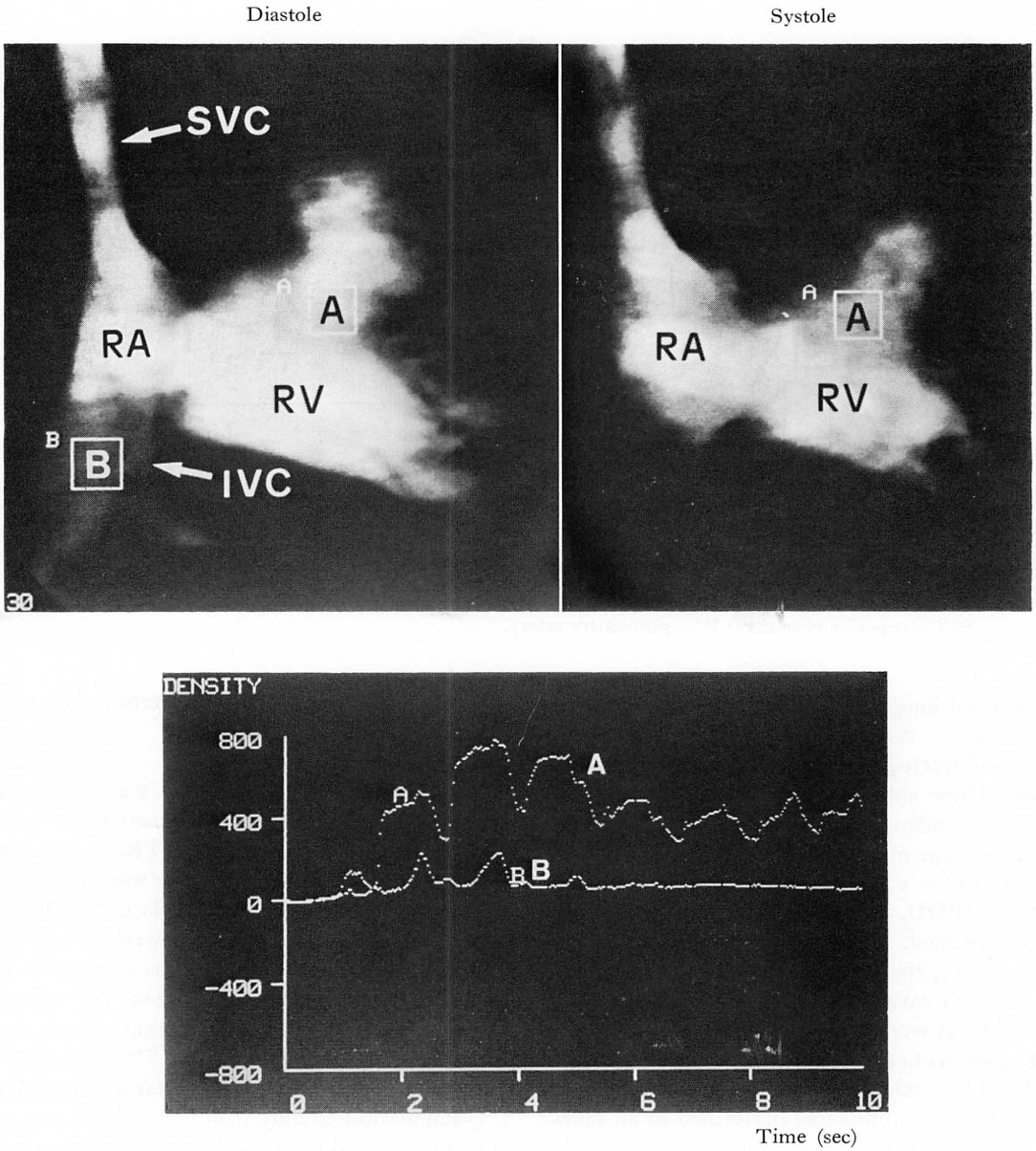


Fig. 2. DSA images and time-densitometry curve of a case without TR (a 49-year-old woman with chest pain syndrome).

Top: There is no reflux of contrast medium into the inferior vena cava (IVC) during right ventricular (RV) systole, though reflux by right atrial contraction is demonstrated.

Bottom: The density of the ROI placed in the RV (A) increases during RV diastole and decreases during RV systole. The density of the IVC (B) increases in the RV end-diastolic phase by RA contraction, but does not increase by RV contraction.

SVC=superior vena cava; RA=right atrium; RV=right ventricle; A, B; regions of interest placed in the RV and IVC, respectively.

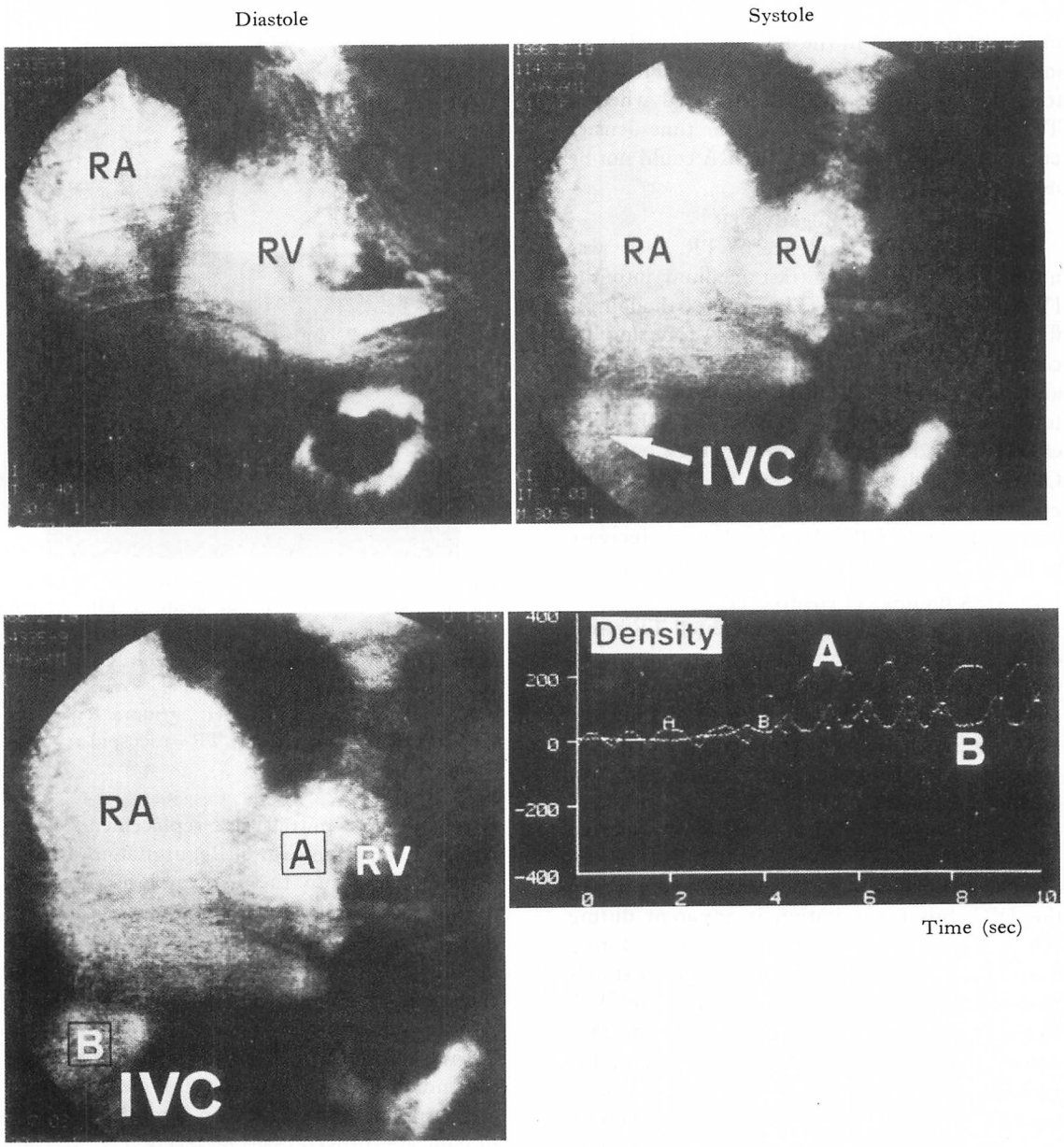


Fig. 3. DSA images and time-densitometry curve of a case with TR (Case No. 1; 60-year-old woman).

Reflux of contrast medium into the IVC during RV systole is demonstrated. There is no reflux during RV diastole.

An increase in density of the ROI (B) placed in the IVC occurs during RV systole.

RA=right atrium; RV=right ventricle; IVC=inferior vena cava; A, B: regions of interest placed in the RV and IVC, respectively.

respondingly. Therefore, the time-density curve of the ROI placed in the RV can be used as an indicator of the cardiac cycle. During RV systole, the volume of the RA increased whether TR was present or not. Thus, the time-density curve of the ROI placed in the RA could not be used for evaluating TR.

1. DSA findings of negative TR

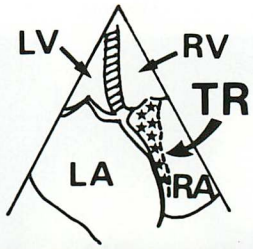
In cases without evidence of TR, there was no regurgitation of contrast medium into the IVC during RV systole (**Fig. 2** top), though reflux of contrast medium into the IVC during RA contraction was common. The density of the RV also increased during atrial contraction. Simultaneous densitometry of the RV and the IVC clearly showed this relationship (**Fig. 2** bottom). On the time-density curve of the IVC, an increase in density was observed by RA contraction at the end of RV diastole, but no increase in density was recorded by RV contraction.

2. DSA findings of positive TR

In cases with clinically documented TR based on physical examination, phonocardiography with a jugular pulse tracing, Doppler echocardiography and/or cardiac catheterization, the DSA examination demonstrated apparent regurgitation of contrast medium into the IVC during RV systole.

Fig. 3 (top) shows a case of TR complicated with mitral stenosis (Case No. 1). There is no diastolic regurgitation of contrast medium into the IVC, but regurgitation is apparent during RV systole. The RA volume increased during this regurgitation. **Fig. 3** (bottom) shows simultaneous densitometry curve at the RV and IVC. Regurgitation of contrast medium into the IVC demonstrated by an increase in density of the time-density curve B was obvious by RV contraction, which was demonstrated by a decrease in density of the time-density curve A. Doppler echocardiography (color flow mapping) demonstrated severe (grade 3) TR (**Fig. 4**). By contrast echocardiography, severe TR was also evident (**Fig. 5**). Phonocardiograpy with a jugular pulse tracing showed a TR murmur (Levine 2/6) and a prominent regurgitant wave.

Another case of severe TR which persisted after aortic and mitral valve replacements (Case No. 3) is shown in **Fig. 6.** Regurgitation of contrast medium into the IVC and hepatic vein during RV systole is demonstrated. The time-density curve shows an increase in the density of the IVC during RV contraction. Doppler echocardiography showed severe TR (grade 3). A heart murmur (Levine 2/6) compatible with TR was also recorded. Both a jugular pulse tracing and an RA pressure recording demonstrated a regurgitant wave. Based on the DSA findings of clinically-proven cases of severe TR, we considered that DSA is diagnostic of TR when the density of the IVC increases during RV systole for more than three beats. This is because premature beats such as ventricular premature contractions can cause regurgitation of contrast medium. Thirteen cases of TR were diagnosed using this DSA method.



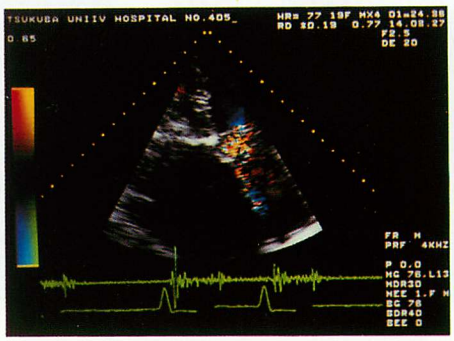


Fig. 4. Doppler echocardiogram (Case No. 1).
Color flow mapping shows grade 3 TR. At the bottom of the image, phonocardiogram and electrocardiogram are recorded simultaneously. Doppler image is obtained during RV systole.
LV=left ventricle; LA=left atrium; RV=right ventricle; RA=right atrium; TR=tricuspid regurgitation.

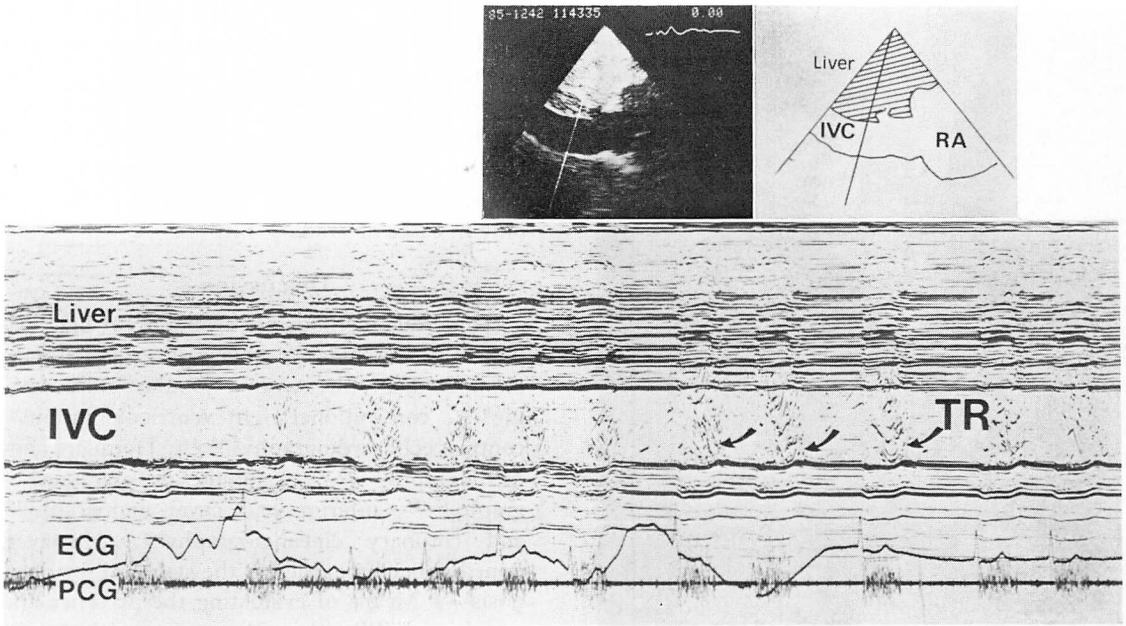


Fig. 5. Contrast echocardiogram (Case No. 1).
The contrast echocardiogram shows severe tricuspid regurgitation (TR). The electrocardiogram (ECG) and phonocardiogram (PCG) showing a holosystolic murmur are recorded simultaneously. Reflux of contrast medium during RV systole is apparent.
RA=right atrium.

3. Evaluation of the severity of TR

By DSA, the number of heart beats with contrast regurgitation into the IVC were assessed during RV systole after completion of contrast injection. The extent of regurgitation and washout of injected contrast medium from the right heart were also evaluated. The cases of clinically-proven severe TR showed more than 10 beats of contrast regurgitation, thus 10 beats was adopted as a criterion for severe TR. Cases which exhibited less than 10 beats of contrast regurgitation were categorized in two grades, above five and below four beats. The severity of TR was thus classified in three grades (**Table 1**).

All subjects with known or suspected TR are shown in **Table 2.** According to our criteria, five cases (No. 1～5) had grade 3 TR; 2 (No. 6, 7), grade 2 TR; 6 (No. 8～13), grade 1 TR; and 3 (No. 14～16) had no TR.

4. Comparison with other methods (**Table 2**)

Among 13 patients diagnosed as having TR by DSA method, 11 were diagnosed as having TR by Doppler echocardiography. In all five cases diagnosed as having grade 3 TR by DSA, Doppler echocardiographic diagnosis was also grade 3. Among eight cases of grade 2 or 1 TR by DSA, Doppler echocardiographic diagnosis was grade 2 or 1 in six cases, and negative in two. Two cases had no TR by DSA in spite of apparently positive findings of TR by Doppler echocardiography.

Jugular pulse tracings showed "regurgitant wave"[9] in all cases diagnosed as having grade 3 or 2 TR by DSA, except for one case with a technically poor jugular pulse tracing. "Regurgitant waves" were not recorded in cases of grade 1 TR.

Contrast echocardiography was performed in three cases with grade 3 TR by the DSA method

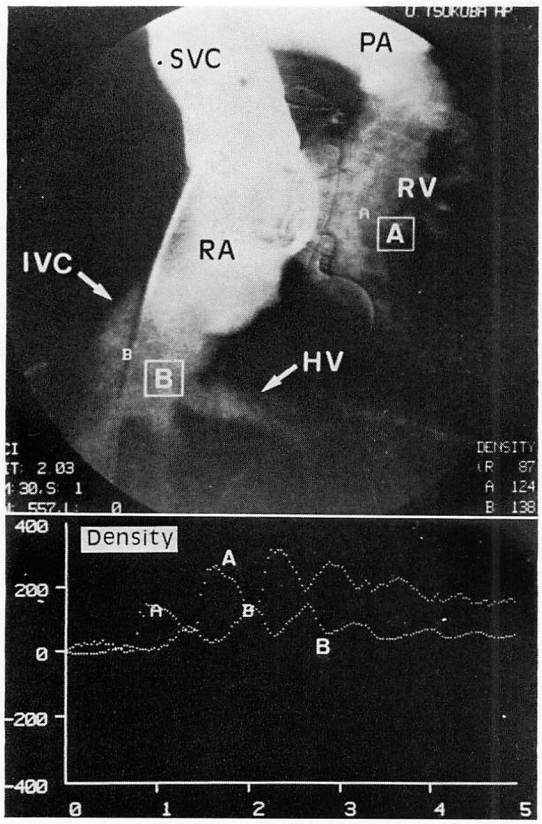


Fig. 6. DSA findings of positive TR (Case No. 3).
Reflux of contrast medium into the inferior vena cava (IVC) and hepatic vein (HV) during RV systole is demonstrated. The time-density curve shows an increase in density of the IVC during RV contraction.
RV=right ventricle; RA=right atrium; SVC=superior vena cava; PA=pulmonary artery; A, B=regions of interest placed in the RV and IVC, respectively.

and in three cases with grade 1 TR. In all grade 3 TR cases, contrast echocardiography revealed severe TR. In grade 1 TR cases, only mild TR or no TR was demonstrated.

The clinical signs of TR including dilated jugular veins with positive pulsation, TR murmurs, hepatomegaly and/or edema, were evident only in cases of grade 3 TR.

Discussion

Numerous methods are available for diagnosing TR, including physical examination[3], phonocardiography with a jugular pulse tracing[9,11], conventional right ventriculography[10], contrast echocardiography[2,12~14], Doppler echocardiography[1,7,15,16], radionuclide angiocardiography[17,18], inferior vena caval angiography[19] and coronary cineangiography[20]. However, none has been regarded as the standard for diagnosis[1,2]. Means of evaluating the presence and severity of TR are still controversial despite much effort having been made and the development of new approaches.

On physical examination, the classical triad, consisting of a prominent jugular pulse, Carvallo's sign and a pulsatile liver, is not always detectable, even in cases of severe TR. In some cases of severe TR, a heart murmur of TR is not audible. In our study, a TR murmur was inaudible in one case (No. 5) of extreme TR. Carvallo's sign may be absent in patients with advanced TR, and the enlarged liver may have cirrhosis, preventing systolic pulsation[3].

Phonocardiography with a jugular pulse tracing may reveal no TR murmur, even in cases of severe TR, and a shallow x descent is frequently observed in atrial fibrillation without TR[4,11,21].

Since penetration of ultrasound may be

Table 1. Grading of TR by DSA

Grade 1 (mild):	3~5 beats with regurgitation into the IVC
Grade 2 (moderate):	6~10 beats with regurgitation into the IVC and hepatic vein
Grade 3 (severe):	more than 10 beats with regurgitation into the IVC and hepatic vein, and marked retention of contrast medium in the right side of the heart

IVC=inferior vena cava.

Table 2. Data of the cases with documented or suspected TR

No.	Case	Age & sex	Diagnosis & rhythm	DSA	Doppler	Contrast echo	Jugular pulse	PAP (mmHg)	Clinical TR
1	KN	60 F	MS, TR, Af	##	##	severe	RW (+)	60/30 (48)	+
2	MH	77 M	MR, TR, Af	##	##	severe	RW (+)	—	+
3	TI	34 F	AVR, MVR, TR, Af	##	##	—	RW (+)	54/19 (35)	+
4	YT	42 F	MR, TR, Af	##	##	severe	poor	32/15 (20)	+
5	SK	33 M	TOF, CP, TR, Af	##	##	—	RW (+)	29/15 (20)	+
6	SS	55 F	PAS, JR	#	+	—	RW (+)	28/ 8 (16)	−
7	SO	62 M	MS, MR, Af	#	+	—	RW (+)	—	−
8	KI	65 F	MS, MR, Af	+	#	mild	N	30/10 (18)	−
9	TY	31 M	MR, Af	+	#	N	poor	45/10 (25)	−
10	HO	45 M	MS, Af	+	+	mild	poor	36/20 (26)	−
11	SO	58 F	MS, Af	+	+	—	SX (+)	21/ 8 (14)	−
12	SN	71 M	OMI, SR	+	−	—	—	—	−
13	TK	48 M	SSS, RV-pacing	+	−	—	N	—	−
14	TH	61 F	SSS, RV-pacing	−	#	—	RW (+)	—	−
15	YK	58 F	MS, Af	−	+	N	N	23/10 (16)	−
16	FM	51 M	AS, AR, MS, Af	−	−	—	—	44/24 (32)	−

Contrast echo=contrast echocardiography; PAP=pulmonary arterial pressure [systolic/diastolic (mean)]; MS=mitral stenosis; TR=tricuspid regurgitation; Af=atrial fibrillation; RW=regurgitant wave; MR=mitral regurgitation; AVR=aortic valve replacement; MVR=mitral valve replacement; TOF=postoperative tetralogy of Fallot; CP=constrictive pericarditis; PAS=persistent atrial standstill; JR=junctional rhythm; N=negative finding; SX=shallow x descent; OMI=old myocardial infarction; SR=sinus rhythm; SSS=sick sinus syndrome; RV-pacing=right ventricular pacing; AS=aortic stenosis; AR=aortic regurgitation.

limited, the echocardiogram may be technically poor and inconclusive, as in postoperative patients, elderly patients, those with chronic obstructive pulmonary disease, and those with endocardial pacing leads.

TR is more evident in deep inspiration[3], but suspended inspiration is not suitable for any ultrasonic echocardiographic examinations. The two-dimensional echocardiography coupled with Doppler techniques images limited planes. It may underestimate or fail to detect regurgitant signal if the direction of regurgitation is not in the plane investigated. However, the DSA method can provide clear images in such cases. In two cases (No. 12 and No. 13) diagnosed as having no TR by the Doppler method, the recording of echocardiograms were technically unsatisfactory. Two cases (No. 10 and No. 11) were negative for TR on initial Doppler echocardiography, but detailed reexamination revealed TR.

Contrast echocardiography is apt to yield false negative results at the IVC level in cases of mild TR[1], and ambiguous findings at the tricuspid level[14]. However, Doppler echocardiography is extremely sensitive if the penetration of ultrasound is sufficient. TR is not infrequently detected by Doppler echocardiography, even in normal subjects; therefore, this is sometimes too sensitive for clinical use[4].

In right ventriculography, catheter placement through the tricuspid valve may distort valve movement and may result in false positive examination[1,3]. Ventricular premature contractions induced by this method frequently inhibit the assessment of TR[1]. Use of a preshaped catheter does not always resolve these problems.

Mishkin et al[17] and Gould et al[18] attempted to diagnose TR by intravenous radionuclide angiocardiography. They injected radionuclide into the peripheral vein to avoid catheter-induced tricuspid regurgitation, and they documented reflux of the radionuclide into the IVC. However, temporal and spatial resolutions are not as excellent as those of DSA. The radionuclide reflux into the IVC may be caused only by atrial contraction, a common phenomenon reported by many observers[12,16].

Okumachi et al[19] also tried to avoid catheter interference by inferior vena caval angiography to evaluate TR. They injected a small amount of contrast medium into the IVC, and observed turbulence and a negative jet in the RA using a cineangiography system. We injected contrast medium into the superior vena cava, and also observed turbulence and a negative jet in the RA using the DSA system, which seems to provide better images with low doses of contrast medium. In our experience, however, the RA was easily filled with contrast medium during only 1～2 cardiac cycles, and evaluation of a negative jet or turbulence was rather ambiguous and inconsistent. We were unable to clearly evaluate such turbulence or a negative jet, except in one case (No. 5). However, we could detect positive reflux into the IVC clearly and consistently, and we were able to evaluate its severity by densitometry, which is not possible in conventional cineangiography.

Though the DSA method is a sort of angiography of the heart, we do not require the catheter to be placed in the RV through the tricuspid valve. This method is less invasive compared to classical right ventriculography.

Radionuclide angiocardiography does not provide sufficient spatial and temporal resolutions. With our DSA method, better quality of images were provided, and densitometry clearly differentiated reflux caused by RV contraction from that caused by RA contraction.

The DSA method facilitated evaluating the severity of TR by observing sequential images and by time-densitometry. Evaluation of the severity of TR by the DSA method closely correlated with clinical evaluations of its severity (**Table 2**), though the effect of closure of the tricuspid valve on the regurgitation is still an unsolved problem.

The DSA method seems superior to conventional right ventriculography, radionuclide angiocardiography and inferior vena caval angiography for diagnosing TR. It can be a useful alternative to echocardiographic techniques such as contrast echocardiography and Doppler echo-

cardiography, when the latter are not appropriate.

Limitation of the method

Though DSA is less invasive than conventional right ventriculography, catheter insertion and injection of contrast medium are necessary. Like other angiographic methods, this method is not applicable to cases of severe renal dysfunction. It is also unsuitable for patients who cannot suspend respirations for intervals of at least 10 sec to obtain DSA images.

Conclusion

We have presented a new DSA method for diagnosing TR. Though further evaluation is necessary, this method seems useful for the accurate clinical diagnosis of TR.

要　約

経静脈性 digital subtraction angiography を用いた三尖弁閉鎖不全症の診断

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三尖弁閉鎖不全症 (TR) の診断には絶対的な方法はなく，問題点が多い．右室造影法ではカテーテルによる三尖弁機能への影響があり，ドップラー心エコー図法は，臨床的には鋭敏すぎたり，また超音波が入りにくい症例では十分な検査が実施できない．我々は，経静脈性 DSA 法を用いると，心エコー図がよく記録できない症例においても良好な画像が得られることに着眼し，DSA による TR の評価を試みた．

心疾患 101 例に心臓 DSA 検査を行った．三尖弁機能を障害しないよう，カテーテルを上大静脈に留置し，35 m*l* の造影剤を 18 m*l*/秒 の速度で注入した．Continuous mode による差分画像を右前斜位 30 度で 15～20 秒間記録した．一連の差分画像の視覚的観察に加えて，右室ならびに下大静脈に設定した関心領域における時間 - 濃度曲線を作成し，検討を行った．ドップラー心エコー図検査を，TR が疑われた 16 例で実施した．頸静脈波記録を含む心音図検査，ならびにコントラスト心エコー図検査を，それぞれ，14 例，6 例で実施した．

DSA 法では，右室収縮期に造影剤が下大静脈へ逆流する現象が，TR の症候のない症例では認められなかったが，明らかに TR と考えられる症例で認められ，診断的所見と考えられた．16 例中 13 例で DSA 法上の TR が陽性であった．時間-濃度曲線の検討に基き，TR の重症度を 3 段階 (軽症，中等症，重症) に分けた．DSA 法による重症度評価は，臨床的にみた重症度と密接な関連を示した．ドップラー心エコー図法では，DSA 法で TR 陽性とされた 13 例のうち 2 例で TR 陰性であったが，16 例中の 2 例はドップラー心エコー図法でのみ TR 陽性であった．DSA 法で中等症もしくは重症の TR と診断された例では頸静脈波が逆流波を示した．コントラスト心エコー図法では，DSA 法で重症 TR と診断された症例が TR 陽性と診断された．

TR の診断において，DSA 法は新しい有用な検査法であると考えられる．

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