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## Evaluation of Pretreatment and Follow-up Examination with Color Doppler Flow Imaging in Arterial Occlusive Diseases in the Pelvis and Lower Extremity

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### 骨盤下肢閉塞性動脈疾患の PTA 術前術後 検査法としてのカラードプラ法の評価

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PTA の適応となった骨盤下肢閉塞性動脈疾患 55 症例 72 病巣を対象として、骨盤下肢閉塞性動脈疾患に対する PTA の術前検査および経過観察法としてのカラードプラ法 (CDFI) の有用性を血管造影と対比検討した。(1) PTA 前に CDFI を施行した 57 病巣中 51 病巣 (89.3%) が血管造影などの情報無しに検出可能であった。(2) 血管造影で完全閉塞と診断した 31 病巣中 29 病巣 (93.5%) は CDFI でも完全閉塞と診断された。他の 2 病巣は CDFI で高度狭窄と診断された。狭窄程度の診断は 24 病巣中 19 病巣 (79.0%) で血管造影と CDFI が一致し、2 病巣で CDFI の方

が、3 病巣で血管造影の方が高度狭窄と診断された。(3) CDFI と血管造影の両方で閉塞と診断された 29 病巣中 28 病巣 (96.6%) において閉塞範囲の診断が一致した。(4) PTA 前後に CDFI を施行した 15 病巣は全例で病巣部での血流の改善がみられた。PTA 後 metallic stent を挿入した 11 例全例に stent 内の血流が良好にカラー表示された。PTA 直後の血管造影と PTA 後 3 日以内に CDFI を施行した 32 病巣を比較すると、CDFI で good とした 14 病巣、irregular と判定した 6 病巣については血管造影でも同様の所見であった。しかし、狭窄残存と CDFI で判定した 12 病

巢のうち7病巣は血管造影でも狭窄残存と判定されたが3病巣は irregular, 2病巣は good と判定された。(5)PTA後にCDFIを施行した39病巣について、合併症の有無の診断, intimal flap, A-V fistula, pseudoaneurysm の診断能が血管造

影と一致した。

CDFIはPTA前に病変部の正確な同定と、範囲や狭窄の程度が把握でき、PTA後の血流状態の改善の評価、合併症の有無の判定が可能で、PTA術前術後検査法として有用であった。

## Introduction

The routine pre- and post-treatment evaluation of percutaneous transluminal angioplasty (PTA) is limited to arteriography, although this method delineates only the state of the vessel lumen, while providing little information about the vessel wall or occluded areas. Moreover, because of its invasive nature, arteriography is not suited for the serial examinations needed to follow-up. Color Doppler flow imaging (CDFI), on the other hand, is a non-invasive method making possible real-time observation of blood flow patterns in affected regions, in addition to providing information from B-mode images about the presence or absence of calcification and atheromatous plaque on the vessel wall<sup>1)</sup>.

CDFI is already being applied clinically in the region of the carotid artery, with results comparable to those obtained by digital subtraction angiography (DSA) reported<sup>2),3),4)</sup>. However, few reports have appeared in the literature regarding the usefulness of CDFI in the evaluation of arterial occlusive disease in the pelvis and lower extremity, and in particular, in the evaluation of effect of PTA performed in these lesions<sup>5),6),7)</sup>. Thus, we carried out this study to investigate the diagnostic capability of CDFI, as compared to arteriography, and its usefulness as a pretreatment and follow-up examinations.

## Subjects and Methods

Seventy-two arterial occlusive lesions in 55 patients in the pelvis and lower extremity in whom indications for PTA were present were investigated. Fifty-seven of these lesions were studied by CDFI at pretreatment, and 39 lesions at post PTA. Fifteen of these lesions were studied by CDFI at pre and post PTA. All of the patients had arteriosclerotic occlusive disease. Twenty-nine lesions were located in the common iliac artery, 18 in external iliac artery, 5 in common femoral artery, 17 in superficial femoral artery, 3 in popliteal artery. PTA using a balloon catheter was performed for stenotic lesions, while the occluded lesions were first treated with high-dose intraarterial urokinase infusion followed by PTA for the residual stenosis. Stents were inserted in 11 cases to prevent recurrence (Z-stents and Wallstents in 9 and 2 cases respectively).

The sonography units used were Yokogawa RT 8000 and Toshiba SSA 270 A models with 3.5, 3.75, 5, 7.5 MHz linear and convex transducers. The minimum possible pulse-repetition frequency not causing aliasing errors was fixed with reference to systolic peak flow velocity in areas considered normal, with gain set at the maximum possible value at which artifacts did not appear. Filtering was performed at 50-100 Hz. Each examination was completed within 30-40 minutes. All CDFI were performed by one of the authors. The angiographic units used were Shimazu ER 1000 and DAR-2400. Arteriography was performed by using an anteroposterior station cut film technique and DSA. When completed, the arteriograms were evaluated blindly by consensus opinion of two

angiographers.

The following items were investigated;

1. On the basis of only the clinical symptoms and physical findings, 57 lesions before PTA were studied by CDFI from the abdominal aortic bifurcation to the bilateral popliteal arteries to assess the detectability of lesions with this method. Arteriography was performed within 10 days of the CDFI, and when discrepancies in the results obtained by the 2 methods were found, CDFI was repeated to confirm the initial results.

2. The presence or absence of occlusions and the degree of stenosis were determined by CDFI, and compared with the results of arteriography performed within 10 days of the CDFI. Occlusion or stenosis was judged to be present by CDFI based on the following findings. Occlusion was judged to be present when at the time of systolic peak flow velocity, color display of turbulent flow or flow

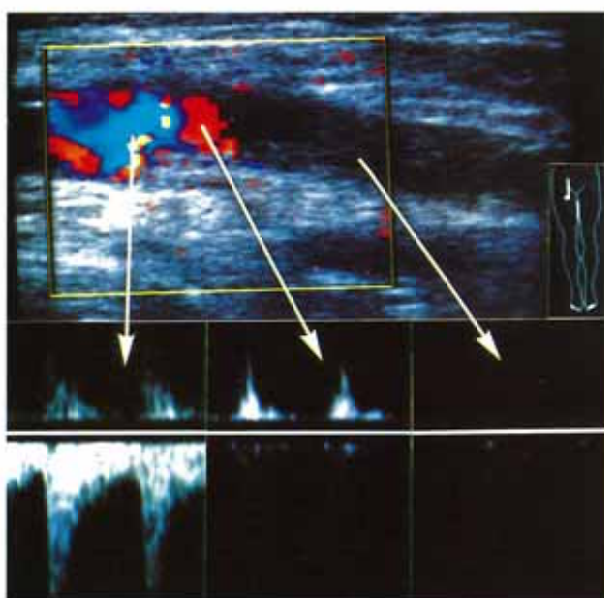
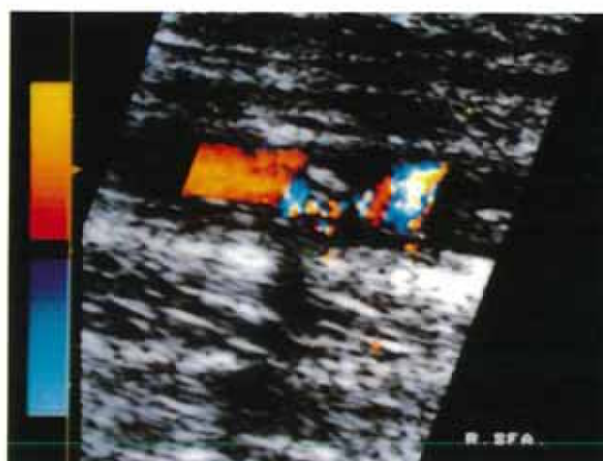
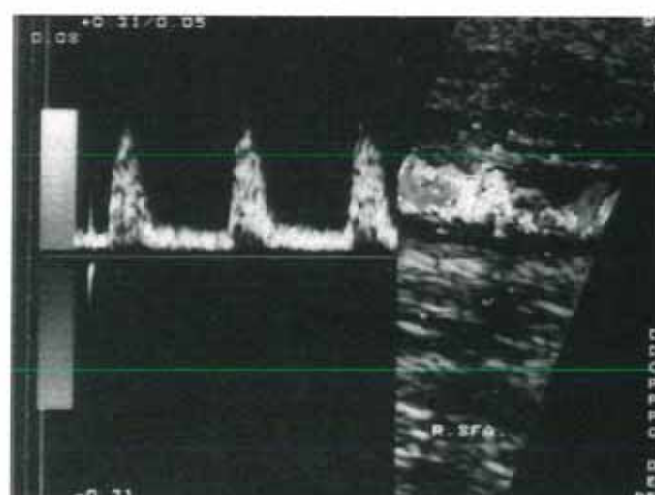


Fig. 1 Occlusion is judged to be present when at the time of systolic peak flow velocity, color display of turbulent flow or flow reversal was obtained proximal to the lesion, with no color display seen distal to it (A). Turbulent flow (B) and flow reversal (C) were obtained at the proximal end also by pulsed Doppler. And disappearance of pulsed Doppler waveforms at the occluded portion (C) were confirmed by pulsed Doppler.

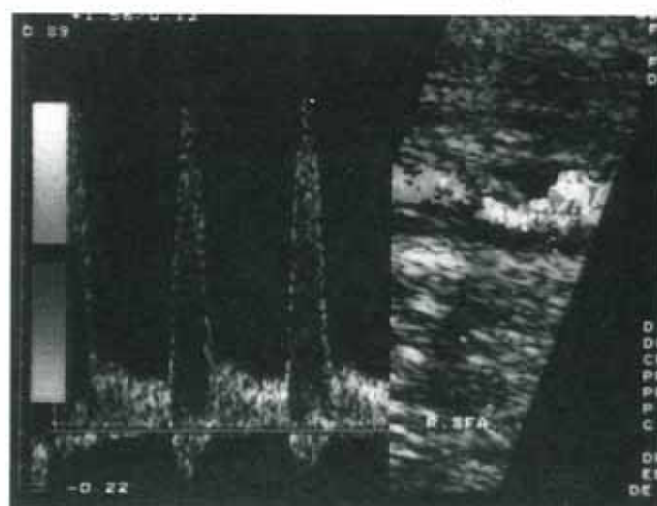
reversal was obtained proximal to the lesion, with no color display seen distal to it. When turbulent flow at the proximal end and disappearance of pulsed Doppler waveforms at the occluded portion were confirmed by pulsed Doppler, the tip of the color display was considered to be the proximal end of the occlusion, and total occlusion was diagnosed (Fig. 1). Stenosis was judged to be present when color display was obtained of only a portion of the vessel lumen, with aliasing or mosaic-like color display, which reflect high velocity or turbulent flow, depicted at this site at the time of systolic peak flow velocity. Pulsed Doppler was used simultaneously to confirm that the systolic peak flow velocity at the stenotic site exceeded by 2-fold or more that at the proximal side of the



(A)



(B)

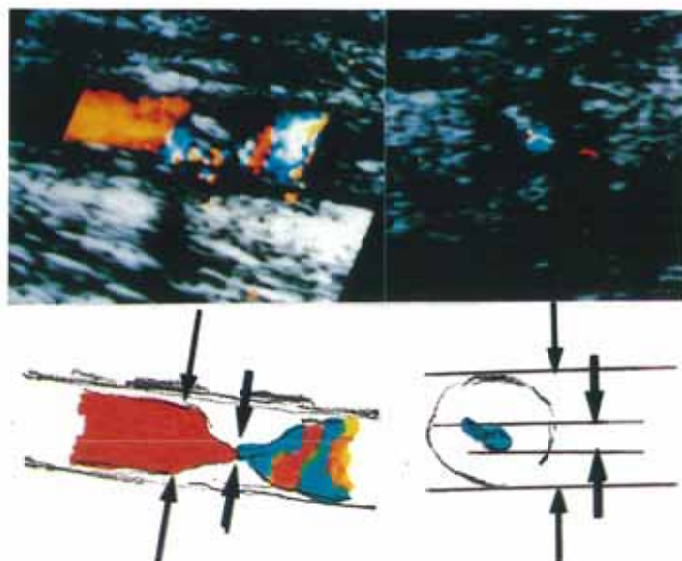


(C)

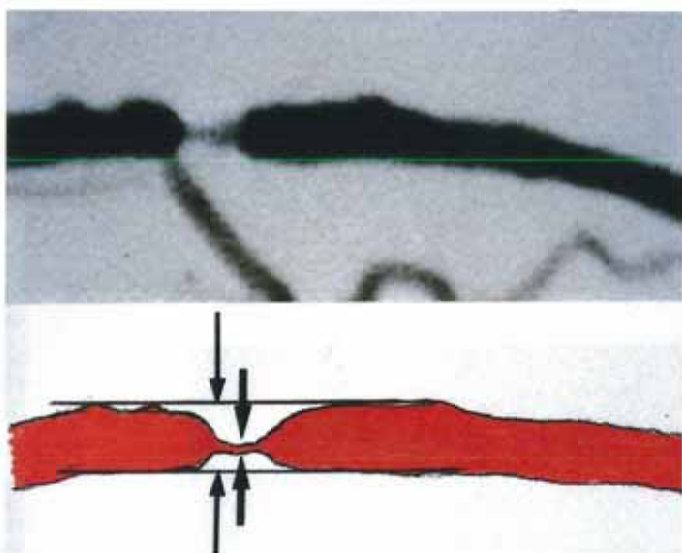
Fig. 2 Stenosis is judged to be present when color display was obtained of only a portion of the vessel lumen, with aliasing or mosaic-like color display (A).

The systolic peak flow velocity at the stenotic site (C) exceeded by 2-fold or more that at the proximal side (B) of the lesion by pulsed Doppler.





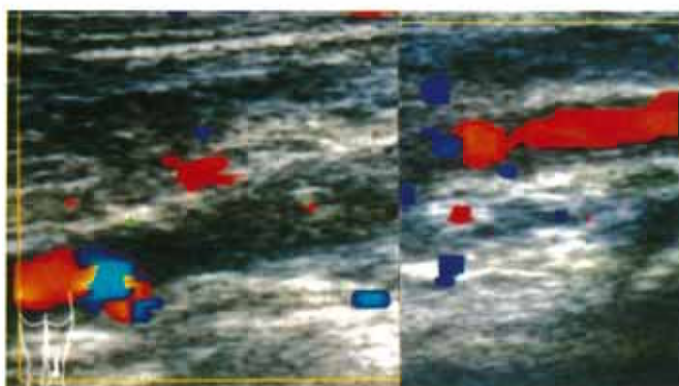
(A) The area showing the most severe stenosis was determined by both longitudinal and transverse scanning, and the stenosis ratio was calculated from the normal vessel diameter in that part and the diameter of the colored portion.



(B) Arteriogram was judged solely on the basis of anteroposterior views.

Fig. 3 Degree of Stenosis by CDFI and Arteriography

lesion (Fig. 2). The area showing the most severe stenosis was determined by both longitudinal and transverse scanning, and the stenosis ratio was calculated from the normal vessel diameter in that part and the diameter of the colored portion. Arteriogram was evaluated solely on the basis of anteroposterior views (Fig. 3). Moderate and severe stenoses were defined as lesions showing  $>50$  -  $<70\%$  and  $>70\%$  stenosis respectively.



(A) On CDFI, the entire length of the occlusion is displayed in one image. The length is 2 cm on the monitor (arrows).



(B) On arteriogram, the length of occlusion measured on the film is similarly 2 cm (arrows).

Fig. 4 Occlusion of the right popliteal artery

3. The length of the occlusion as determined by CDFI and arteriography was compared in the cases in which occlusion was shown to be present by both methods. By arteriography, the length of the occlusion was measured on the films. On CDFI, in cases in which the proximal end of occlusion and reopened portion were contained in one image, the image was frozen so that the entire length of the occluded portion of the vessel was depicted and measured on the monitor (Fig. 4). Also, in cases in which the proximal end of the occlusion or reopened portion was depicted with a bifurcation (e. g. aortic bifurcation, bifurcation of internal iliac artery and external iliac artery, bifurcation of superficial femoral artery and deep femoral artery) on one image, the distance from the bifurcation was measured on the monitor. In the remaining cases, while observing the proximal end of the occlusion and reopened portion on the monitor, marks were placed on the skin surface and the distance between these marks determined. Differences of 1 cm or less in values determined respectively by the two methods were considered to be attributable to standard measurement error.

4. The 32 lesions for which CDFI was performed within 3 days of PTA were classified into "good", "persistent irregular lumen" and ">20% residual stenosis", and compared with the results obtained

by arteriography. When the treated vessel wall was smooth and residual stenosis was absent, the effect of PTA was judged "good". When the treated vessel wall was irregular and residual stenosis was less than 20%, it was judged "persistent irregular lumen". When the residual stenosis was more than 20%, it was judged ">20% residual stenosis".

5. In 39 lesions for which CDFI was performed posttreatment, the presence or absence of complications due to PTA was evaluated by CDFI.

## Results

### 1. Detectability of lesions by CDFI

Lesions were detected by CDFI in the absence of other information in 51 of the 57 lesions (89.3%) in which CDFI was performed before PTA (Table 1). When CDFI was repeated with the information of the arteriographic findings, 55 of the 57 lesions (96.4%) were detected, the only exceptions being 2 stenotic lesions in the highly tortuous external iliac artery. The lesions not detected by the initial CDFI were found in cases with multiple stenoses, with the overlooked lesions located distal to severe stenoses. All of the initially overlooked lesions were stenoses, with all of the occlusions detected. Three and 1 of these stenoses were located in the external iliac artery and common femoral artery respectively. All of the lesions located in the superficial femoral and popliteal arteries were detected.

Table 1 Detectability of Lesions by Color Doppler Imaging

Location	Stenosis	Occlusion	Total
Com. Iliac A.	11/13	8/8	19/21
Ext. Iliac A.	6/9	6/6	12/15
Com. Fem. A.	0/1	2/2	2/3
Superficial Fem. A.	2/2	14/14	16/16
Popliteal A.	1/1	1/1	2/2
Total	20/26	31/31	51/57

### 2. Presence or absence of occlusion and degree of stenosis determined by CDFI

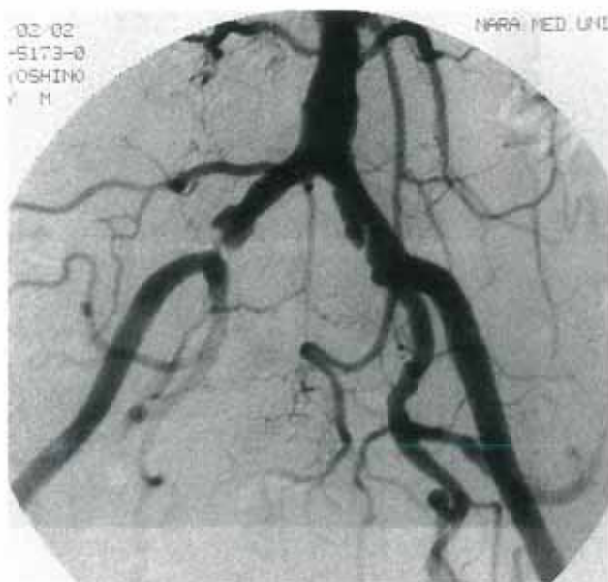
Twenty-nine of the 31 lesions (93.5%) showing total occlusion on arteriography were similarly diagnosed by CDFI. In the remaining 2 lesions, a slight color display was obtained by CDFI in the

Table 2 Correlation of Color Doppler Imaging and Angiogram

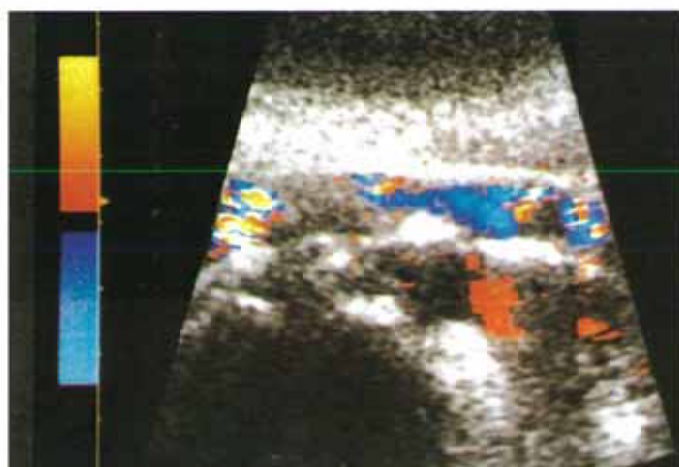
Color Doppler Imaging	Angiogram		
	Moderate Stenosis	Severe Stenosis	Occlusion
Moderate Stenosis	3	3	0
Severe Stenosis	2	16	2
Occlusion	0	0	29

Moderate stenosis: 50-70% ; Severe stenosis: 70-99%





(A) Arteriogram shows two stenotic lesions, the proximal lesion is judged moderate stenosis (arrow), and distal lesion is severe stenosis (arrow head).



(B) By CDFI, two lesions are judged severe stenosis (arrow, arrow head).

Fig. 5 Multiple Stenoses of the Right Common Iliac Artery

areas shown by arteriography to be occlusions, and were judged to be severe stenoses. Conversely, no cases were found in which arteriography showed severe stenosis and CDFI occlusion. Nineteen of 24 lesions (79.0%) were judged by both methods to show same degree of stenosis, with the remaining 2 lesions diagnosed as severe stenoses by CDFI (Fig. 5). In contrast, 3 other lesions were diagnosed as severe stenoses by arteriography (Table 2).

### 3. Length of occlusion diagnosed by CDFI

The length of occlusion of the 29 lesions judged by both methods to show occlusion was compared.

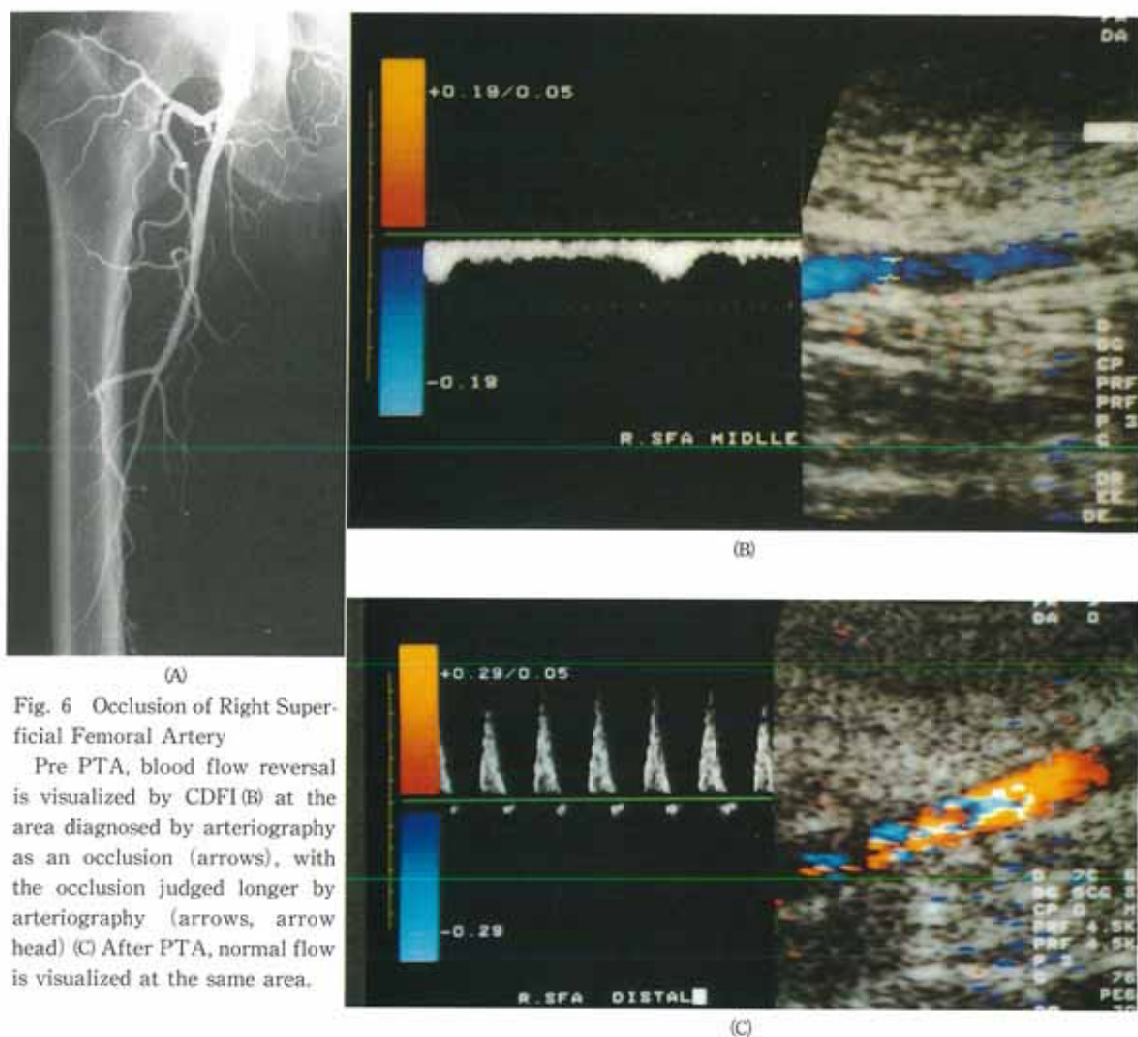


Fig. 6 Occlusion of Right Superficial Femoral Artery

Pre PTA, blood flow reversal is visualized by CDFI (B) at the area diagnosed by arteriography as an occlusion (arrows), with the occlusion judged longer by arteriography (arrows, arrow head) (C) After PTA, normal flow is visualized at the same area.



Fig. 7 (A)

Fig. 7 Stenosis of the Right Common Iliac Artery  
Pre-PTA; (A) Arteriogram shows severe stenosis (arrow)

(B) CDFI shows severe stenosis (arrows).

Post-PTA and stenting; (C) arteriogram shows good effect of treatment. (D) Blood flow within the stent is clearly color displayed by CDFI.



Fig. 7 (B)



Fig. 7 (C)

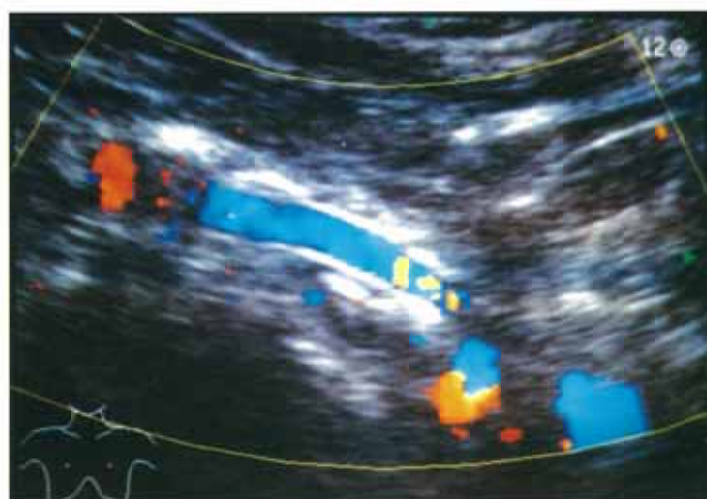


Fig. 7 (D)



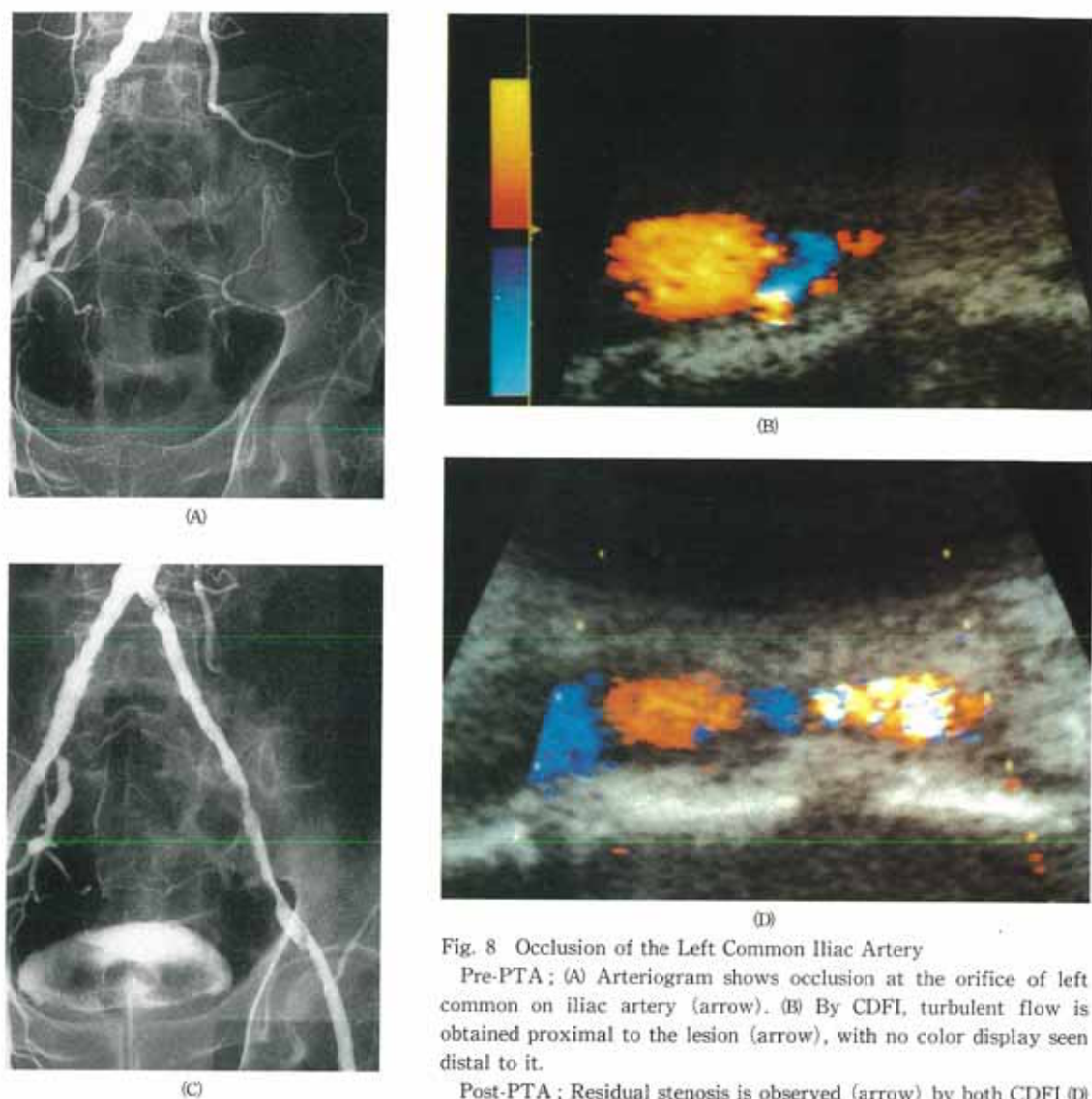


Fig. 8 Occlusion of the Left Common Iliac Artery

Pre-PTA; (A) Arteriogram shows occlusion at the orifice of left common on iliac artery (arrow). (B) By CDFI, turbulent flow is obtained proximal to the lesion (arrow), with no color display seen distal to it.

Post-PTA; Residual stenosis is observed (arrow) by both CDFI (D) and arteriography (C).

The extent of occlusion as determined by the 2 methods was consistent in 28 of the 29 lesions (96.6%) (Fig. 4). In the 1 exception, blood flow reversal was visualized by CDFI at the area diagnosed by arteriography as an occlusion, with the occlusion judged longer on arteriography (Fig. 6).

#### 4. Evaluation of the effect of PTA

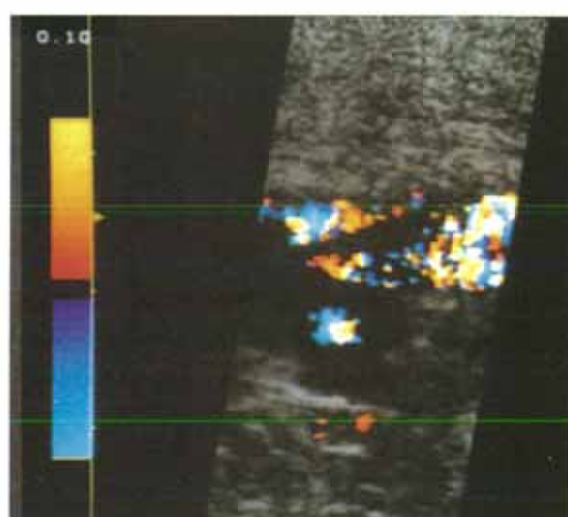
All of the 15 cases in which CDFI was performed both before and after PTA showed improved blood flow after the procedure. All of the 11 cases in which stents were inserted after PTA showed good color display of blood flow within the stent (Fig. 7). In the 32 lesions undergoing arteriography immediately after and CDFI within 3 days after PTA, the 14 lesions respectively judged "good" by CDFI and 6 lesions "irregular" showed similar findings on arteriography (Fig. 7). However, of

Table 3 Evaluation of the effect of PTA (n=32)

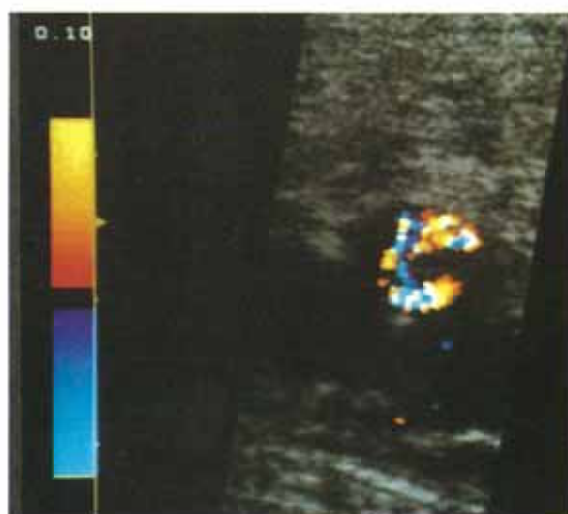
Color Doppler Imaging	Angiogram		
	good	persistent irregular lumen	$\geq 20\%$ residual stenosis
good	14	0	0
persistent irregular lumen	0	6	0
$\geq 20\%$ residual stenosis	2	3	7



(A)



(B)



(C)

Fig. 9 Intimal Flap of the Femoral Artery

The intimal flap is demonstrated as a defect on the color display.

(A) Left femoral arteriogram

(B) CDFI (longitudinal scan)

(C) CDFI (transverse scan)



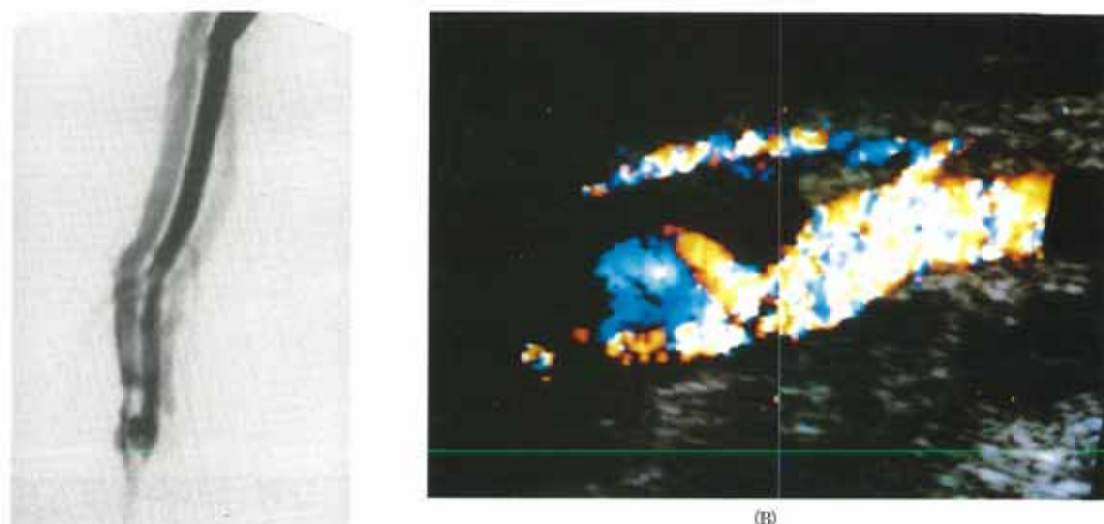


Fig. 10 Pseudoaneurysm and A-V Fistula of the Popliteal Artery  
 (A) Arteriogram shows pseudoaneurysm (arrow) and A-V fistula (arrow head) at the popliteal artery. A : popliteal artery V : vein  
 (B) By CDFI, turbulent flow is visualized within the pseudoaneurysm (x) and the A-V fistula is clearly observed at the distal portion (arrow).

the 12 cases judged to show residual stenosis by CDFI, only 7 showed similar findings on arteriography (Fig. 8), with the remaining 3 lesions judged "irregular" and 2 lesions judged "good" respectively (Table 3). In two cases, even when the effect of PTA was evaluated as good by arteriography, residual stenosis was detected by CDFI, with intraarterial urokinase infusion then added.

#### 5. Diagnosis of complications due to PTA.

The presence or absence of complication due to PTA were similarly diagnosed by both methods. Three intimal flaps (Fig. 9), 1 A-V fistula (Fig. 10), 2 pseudoaneurysm (Fig. 10), and 1 distal thrombus which were diagnosed by arteriography were detected also by CDFI. Even in the case in which B-mode images entirely failed to depict an intimal flap, the flap portion was demonstrated as a defect in the color display.

### Discussion

CDFI in addition to providing B-mode findings such as atheromatous plaque, permits observation of the state of blood flow at real-time and easily identifies both occlusions and stenoses. Moreover, lesions not appreciated on B-mode images are depicted as defects on the color display, facilitating diagnosis of the length of the lesion, presence or absence of occlusions, and degree of stenosis. Regarding the usefulness of US in the detection of arteriosclerotic lesions in the carotid arteries, numerous studies have already demonstrated that the diagnostic ability of CDFI is approximately equal to that of DSA<sup>(1,2,3,4)</sup>. However, few reports are available on the usefulness of this method to diagnosis of similar arteriosclerotic lesions in the pelvis and lower extremity<sup>(5,6)</sup>. This may be attributable to deep location of the arteries and the presence of the loops of intestine between the transducer and arteries. Despite this problem, the entire length of the vessels from the aortic

bifurcation to the femoral artery can be depicted when a convex transducer is used and intestinal gas removed by pressing the abdomen. However, when convex transducers are used, the angle formed by the direction of the beam and vessel changes according to the site of the field of vision, mandating that the angle between the target vessel and the beam be kept to a minimum. Also, it is necessary to optimize the conditions of the color display according to the angle between the vessel and beam direction, and the pattern of blood flow. Namely, because of the properties of CDFI, in some cases no color display is obtained when the flow speed and direction of the target vessel are not consistent with the set conditions. In contrast, the pulsed Doppler method provides excellent grasp of the state of blood flow at certain sampling points and is a highly accurate testing method. Accordingly, the combined use of pulsed Doppler together with CDFI is required for the detection of occlusive lesions. Combining these two methods in this way, identification of the affected sites was feasible in the large majority of cases with the exception of stenotic lesions located in markedly tortuous vessels.

With regard to the evaluation of the presence or absence of occlusion, the results of the 2 methods did not agree in some cases. It is thought that in the 2 cases in which arteriography showed total occlusion and CDFI severe stenosis, the stenosis may have developed in the interval between the 2 examinations. All of the lesions judged by CDFI to be total occlusions were similarly judged by arteriography suggesting that CDFI is an extremely useful method to diagnose the presence or absence of occlusion.

With regard to the diagnosis of the degree of stenosis, this parameter is judged by arteriography solely on the basis of anteroposterior views, and the true vessel diameter is not measured. In contrast, With CDFI, because the evaluation is based on a combination of both longitudinal and transverse images, the extent of the stenosis can be judged more precisely. However, with CDFI errors in the color display are present on mechanically, with in fact color encoding to be displayed to a larger extent than the portion with blood flow<sup>8)</sup>. Accordingly, when cases diagnosed as having severe stenosis by arteriography but moderate stenosis by CDFI are identified, the possible role of errors in the color display should be considered. One case was seen in which the 2 methods gave inconsistent results about the length of occlusion. In this case, in the area diagnosed by arteriography to be an occlusion, a color image of low velocity reversal was displayed by CDFI, suggesting that this method may be able to detect abnormal flows not recognized on routine arteriography.

The evaluation of the effect of PTA and the diagnosis of complications are also simple with CDFI<sup>7),9),10),11)</sup>. In two cases, even when the effect of PTA was evaluated as good by arteriography, residual stenosis was detected by CDFI, with intraarterial urokinase infusion then added. This experience suggests that CDFI may also be useful as a monitor at the time of PTA. CDFI may also be particularly helpful in the recognition of complications. For example, when an uncalcified flap is resented, the detection of dissection is difficult relying on B-mode images alone. CDFI, however, easily identifies such dissections by displaying differences in flow velocity and direction between the true and false lumens, with the intimal flap portion seen as a defect on the color display. Blood flow within both Z-stents and Wallstents was well displayed. The use of stents is expected to increase, and CDFI may prove to be of especial benefit in the long-term follow-up of cases in which they are used. In conclusion, CDFI accurately identifies lesions prior to PTA, well defines the extent and

degree of stenosis, is useful in the evaluation of blood flow patterns after PTA, and establishes the presence or absence of complications, suggesting that it will become indispensable in the evaluation of cases receiving PTA.

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