optic nerve sheath and at the lamina cribrosa. In both instances, the pressure in the distal retinal vessels becomes greatly reduced or unmeasurable, producing abnormality on ophthalmodynamometry. However, the medial and lateral posterior ciliary arteries, which supply approximately 90% of the total ocular blood, have origins in the ophthalmic artery that are separate from the central retinal artery. Consequently, these vessels remain intact in central retinal artery occlusion, allowing normal eye pulsation and normal ocular pneumoplethysmographic results. Thus, abnormal ophthalmodynamometric results (particularly when the values are 0) in the presence of ipsilateral normal ocular pneumoplethysmographic results are strongly suggestive of central retinal artery occlusive disease. Conversely, when both ophthalmodynamometric and ocular pneumoplethysmographic results are normal, the diagnosis of complete central retinal artery occlusion should be seriously questioned. If the clinical setting is typical for central retinal artery occlusion and both ocular pneumoplethysmographic and ophthalmodynamometric results are abnormal, a separate pressure-significant lesion of the internal carotid system probably exists proximal to the central retinal artery and may have served as an embolic source.

Acknowledgments
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References

Pattern Difference of Reversed Ophthalmic Blood Flow Between Occlusion and Stenosis of the Internal Carotid Artery
An Ultrasonic Doppler Study

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SUMMARY Reversed ophthalmic blood flow in the occlusions (33 patients) and stenoses (11 patients) of the internal carotid artery (ICA) was examined using the ultrasonic Doppler technique. The Doppler shift frequencies of the blood flow signal were analyzed to obtain their sound spectrogram. In stenosis of the ICA, "presystolic notch" was more frequently observed and "d/S" value (S, d; maximum blood flow velocity at systolic and diastolic) was smaller than in occlusion.

These two characteristics of stenosis distinguish it from occlusion with 89% accuracy although this method is applicable only for the patients with reversed ophthalmic blood flow.

REVERSED BLOOD FLOW in the ophthalmic artery is frequently detected by the ultrasonic Doppler flowmeter in patients with occlusion or stenosis of the internal carotid artery (ICA).

Reports suggest that obstructive lesions of the ICA may be diagnosed noninvasively by detection of the reversed ophthalmic collateral flow.

A few authors have reported the possibility of the differential diagnosis between occlusion and stenosis of the ICA with the use of the Doppler techniques. No author has discussed the differences in patterns blood flow in the ophthalmic artery itself as a distinguishing feature. The purpose of this report is to clarify the rheological differences of reversed blood flow in the ophthalmic artery per se between the occlusion and the stenosis using an ultrasonic Doppler method and then to describe the possibility of the differential diagnosis.

Subjects and Methods
Consecutive patients with 54 occlusions and 62 stenoses of the ICA admitted from June 1976 to October 1979 were all examined both by cerebral angiography and ultrasonic Doppler studies. The ultrasonic Doppler examination was performed after angiography except for 15 patients. Among them, 33 patients with carotid occlusion (21 were men, and 12 were women, the average age was 63.6 years old) and 11 patients with stenoses of the ICA (9 were men, and 2 were women, with an average age of 69.3 years old.) were
found to have the reversed ophthalmic blood flow and were selected as the subjects for the present study. The ultrasonic Doppler findings of the pattern of reversed ophthalmic blood flow was compared with findings on angiograms.

A directional ultrasonic Doppler flowmeter of dual filter type (EUD-3B, Hitachi Medico, Tokyo) was used. Ophthalmic artery blood flow was detected by lightly placing the ultrasonic probe on the eye lid about 5 to 10 mm above and lateral to the corneal midpoint. The ultrasonic beam was directed to the optic canal. Ophthalmic artery blood flow could be detected from this point.\(^5\) Supratrochlear artery blood flow was also detected but this flow was not used in the results. The Doppler shift frequencies of blood flow signal from the ophthalmic artery were analyzed with a sound spectrograph (SG-07, Rion, Tokyo) to obtain a sonogram of spectral display. The blood flow patterns of the sonograms were compared to clarify the difference between occlusions and the stenoses of the ICA; especially observing "presystolic notch" (Fig. 1) which indicates a very short period of low velocity of reversed ophthalmic blood flow and the values of the maximal blood flow velocity at systolic (S, KHz) and at diastolic (d, KHz).

Angiography was performed to obtain fifteen serial films from 0 to 10 sec of an A-P view and 20 films from 0 to 11 sec of a lateral view. Slowed distal flow was carefully sought and if contrast medium was found in the delayed films, the case was diagnosed as stenosis. All patients with reversed ophthalmic blood flow had stenotic lesions of more than 60% or complete occlusion on angiograms.

### Results

**"Presystolic notch"**

Two typical sonograms of reversed ophthalmic blood flow are shown in figure 1. In the blood flow sonograms with stenosis, a notch (see arrows), which indicates a very short period of low velocity of reversed ophthalmic blood flow, can be observed immediately before the systolic period. This is called a "presystolic notch", and was observed in 7 of 11 stenotic arteries and 1 of 33 occlusions. The difference in prevalence of the "presystolic notch" was statistically significant ($\chi^2$-test, $p < 0.01$).

**Maximal blood flow velocity during systole (S), diastole (d) and their ratio (d/S)**

As shown in figure 2, the mean value of "S" was 2.63 ± 0.90 (S.D.) KHz for stenotic arteries, and 3.04 ± 1.80 (S.D.) KHz for occlusions of the ICA. The difference in these two values was not statistically significant. But the mean value of "d" for stenotic (0.53 ± 0.32 KHz) was smaller than that found with occlusions (1.34 ± 1.06 KHz). The difference was statistically significant (Student, t-test, $p < 0.05$).

The value of "S" and "d" is generally influenced by the angle between artery and the ultrasonic beam, and the diameter of the artery. In order to eliminate such factors as well as to clarify the characteristics of the blood flow pattern, the ratio of "d/S" was introduced. The mean value of "d/S" for stenotic arteries (0.23 ± 0.14) was lower and statistically different than that found with occlusions (0.42 ± 0.15) (t-test, $p < 0.01$) (Fig. 2). The critical point of the "d/S" value which most differentiates between occlusions and stenoses was found to be 0.3. A "d/S" value was larger than 0.3 in 24 of 33 occlusions (72.7%) and smaller than 0.3 in 9 of 11 stenoses (81.8%).

### Differential diagnosis

Based on the flow pattern characteristics of the reversed ophthalmic collateral flow, diagnostic criteria for the stenosis of the ICA were introduced as follows:

- i) The existence of "presystolic notch"
- ii) The value of "d/S" is smaller than 0.3.

Only when both of these conditions are satisfied, should stenosis be diagnosed. According to these criteria, 63.6% (7/11) of stenoses were positively diagnosed and 97.0% (32/33) of occlusions of the ICA.

### Discussion

It has been reported that an obstructive lesion of the ICA could be diagnosed noninvasively by utilizing ultrasonic Doppler techniques. Detection of reversed ophthalmic artery blood flow by Doppler ultrasound provides informative data such as a semiquantitative evaluation of ophthalmic collateral flow.\(^1\) The value of the flow pattern differences of reversed ophthalmic flow between stenosis and occlusion of the ICA has not been reported.

Analysis of reversed blood flow in the supratrochlear artery and the flow pattern differences between occlusion and stenosis was less useful, i.e. "presystolic notch" and was recognized in 4 of 11 stenoses and in one of 33 occlusions. The mean value of "d/S" of stenoses (0.33 ± 0.12) was lower than that of occlusions (0.42 ± 0.12) but this difference was not statistically significant. We believe that the detection of reversed blood flow in the ophthalmic artery is more reliable than flow changes in the supratrochlear artery for the differentiation of stenosis and occlusion of the ICA.

Reversed ophthalmic collateral flow with stenosis had two characteristics different from that with occlusion; one is the "presystolic notch" and the other is "diastolic low flow velocity". The pathophysiological reasons for the existence of the "presystolic notch" in stenosis of the ICA were considered. In figure 3, the upper and lower sonograms show respectively reversed and physiological flow component of the right ophthalmic artery per se which are obtained from a

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FIGURE 1. Two typical sonograms of the stenosis (left upper) and the occlusion (left lower) of the internal carotid artery. Each angiogram is represented on the right side respectively.

Patient with stenosis of the right ICA. The lower sonogram was recorded just after the upper one by switching a channel of the ultrasonic Doppler flowmeter from away-from-probe flow direction to toward-probe flow direction holding the ultrasonic probe unchanged. With physiological flow (lower sonogram), acute angled waves are observed at the initial systolic period as shown by the small arrows which is temporally comparable with the presystolic notch of the reversed flow (upper sonogram). Low physiological flow component following the acute angled wave of the lower sonogram might reflect some physiological blood flow in

FIGURE 2. The distribution of $S$ (KHz), $d$ (KHz) and $d/S$ in the occlusions and the stenoses of the internal carotid artery.
some small arteries near the ophthalmic artery but not the ophthalmic artery itself. With stenosis, blood flow via the ICA must reach the ophthalmic artery a bit earlier (about 10–40 msec) than that via the external carotid artery. Therefore, reversed flow is suppressed at its end-diastolic phase by this acute angled wave of physiological flow, then the presystolic notch of reversed flow is produced. This hypothesis can explain the predominance of the presystolic notch in stenoses of the ICA.

With stenosis of the ICA, the mean value of “d” with reversed ophthalmic blood flow on sonogram was less than that for occlusions. Two reasons for this can be considered; one is that the presystolic notch which is observed more frequently in stenoses of the ICA, and the other is due to “low flow velocity” during diastole. We measure the end-diastolic flow velocities immediately before the presystolic notch (“d’”) and these results were compared for stenosis and occlusion of the ICA. The mean value of “d’” with stenosis [0.77 ± 0.35 (S.D.) KHz] was still statistically smaller than that with occlusion [1.42 ± 1.07 (S.D.) KHz] (p < 0.05, t-test). The smaller value of “d’” with stenosis was determined not only from the presystolic notch but also from “low flow velocity during diastole”. Some possible causes of the “low diastolic flow velocity” were pointed out; 1) Non-Newtonian fluid nature of blood; its kinetic viscosity in the stenotic lumen of the artery decreases during after blood flow velocity or systolic period and increases during slower blood flow velocity or diastolic period. Consequently, resistance to blood flow in the stenotic lumen becomes larger during diastolic period than systolic period. This hypothesis cannot explain the “low flow velocity during diastole” of the reversed ophthalmic artery blood flow. 2) Changes of the arterial lumen of the stenotic portion by pulsation; residual lumen of the stenotic portion may be wider during systole than during diastole because of arterial wall pulsation usually observed in normal artery. As a result, the resistance of stenotic lumen increases during diastole than during systole. This also cannot explain smaller “d’” value of the reversed ophthalmic blood flow. 3) Turbulent flow in the stenotic lumen of the ICA. This hypothesis best describes the probable cause. During cardiac diastole, resistance to blood flow in the stenotic lumen decreases relatively because of reduction of turbulent flow at that site. Then, local blood pressure in the syphonous portion of the ICA increases during diastole with stenosis as compared with that for occlusion. As a result, the velocity of reversed ophthalmic blood flow during diastole becomes smaller with stenoses of the ICA.

We used to diagnostic criteria using the two characteristics; the “presystolic notch” and the “d/S” ratio. However, accuracy of the differential diagnosis between stenosis and occlusion was the same when we used only the finding of a presystolic notch. We do not know which is better criteria from this study, but we use these two flow characteristics as criteria in the differential diagnosis for patients.

We could not obtain a reasonable correlation between the degree of stenosis and the “d/S” ratio, as the number of patients with stenosis was too small number and some patients had well developed collaterals other than the ophthalmic artery and concomitant stenosis of the external carotid artery.

The pattern analysis of reversed ophthalmic blood flow has another clinical advantage. This occurs in noninvasive follow up estimations of obstructive lesions of the ICA. One patient who was followed up with this method is reported here.
A 67-year-old male who had a left hemiplegia 21 years previously and fully recovered to social life in a few days. He awoke one morning to find himself affected with a left hemiparesis which was progressing stepwise. On admission, the Doppler examination suggested stenosis of the ICA because of the existence of reversed ophthalmic blood flow on the right, which had both of a “presystolic notch” (see arrows) and “d/S” smaller than 0.30 on the sonogram (fig. 4, upper). Stenosis of the ICA was confirmed by angiography. Three days later, a follow-up Doppler study was conducted, which showed the disappearance of “presystolic notch” on the reversed ophthalmic blood flow sonogram (fig. 4, bottom). This finding suggested that the stenotic lesion had progressed to be complete occlusion. The complete occlusion of the ICA was confirmed at surgery for carotid end-arterectomy.

We could not diagnose accurately 4 of 11 stenoses and one of 33 occlusions of the ICA. Therefore, these techniques seemed to have a higher yield for occlusion of the ICA. A false positive diagnosis of the 4 stenoses was as follows; 2 cases with very severe stenotic lesion of the ICA (more than 90%), one case with the concomitance of stenotic lesion of the external carotid and one case in which no appropriate reason was found. One patient with occlusion of the ICA had a presystolic notch on reversed ophthalmic flow and was misdiagnosed. His well developed collateral flow via the circle of Willis and the middle meningeal artery may produce a presystolic notch. This method does not require either complex calculation as that of R.B. Rutherford et al. nor a complicated procedure to distinguish external from internal carotid artery as that of von Reutern et al. We believe our method is clinically useful, although it will not obviate the need for the angiogram and it has a limitation; the method cannot be applied to those without reversed ophthalmic blood flow.

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