Carotid Evaluation by Doppler Echoflow Scan, Frequency Analysis and Duplex Scan

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Introduction

Carotid disease causes anatomical change at the common carotid bifurcation as well as pathophysiological change at the bifurcation and in distal circulation beds.

In recent years several important studies have been carried out in the field of ultrasound in order to display both the anatomical structures and the blood circulating through the vessels (1, 4, 5, 6, 7, 10, 12, 15).

It is important to distinguish between Doppler and B-mode imaging. They differ in the features outlined in Tables 1 and 2. Firstly and most important, Doppler devices image the blood flow and thus reveal only the vessel lumen, which in most instances is approximately displayed. B-mode sonography images the vessel wall with precise detail including deposited plaque. Secondly, Doppler instruments in general provide physiological information about blood flow, while B-mode devices principally supply anatomical information. Finally, Doppler images are produced by repeatedly moving the transducer across the vessel to «build up» an image on the display screen, whereas in B-mode imaging the sound beam is rapidly swept across the vessel by electronic means to produce an instantaneous view of an entire segment of vessel.

Table 1: Different features of Doppler imaging device

Doppler
Registers echoes that are related to velocity of flow in a moving column of blood
Highlights vessel lumen
Provides static images, constructed over 10–20 minutes

Table 2: Different features of high resolution B-mode sonography

B-scan
Registers echoes that are related to variations in acoustical impedance
Highlights vessel wall
Provides instantaneous real-time images of the pulsating bifurcation in transverse and longitudinal sections

Doppler signals possess five features used in diagnostic cerebrovascular disease: source, amplitude, frequency, direction, and pulsatility (10). All of the diagnostic features, other than source of signal, reside in the time – varying frequency – amplitude spectrum, which can be presented in an audible and/or visual format. Although visual presentations of Doppler signals assist the interpreter, the trained human ear is also of great value. But the human ear lacks somewhat in objectivity and quantitation, qualities provided by visual spectral displays.

With these thoughts in mind, it can be easily appreciated that the combination of Doppler carotid imaging, frequency spectrum analysis, and B-mode imaging represent an ideal ultrasound approach by providing both pathophysiological and anatomical information.

In the neurosonological laboratory at the University Hospital, Innsbruck, the Dopplerechoflow-scan II (Diagnostic Electronics Corporation) as well as the Duplexscan (Diasonic) have been used in over 1,200 patients.

Doppler Echoflow-Scan With Spectrum Analysis

White (1978) has used the Doppler echoflow scan to develop image analysis of carotid velocity data. This device employs a continuous wave Doppler directed at the carotid bifurcation with computer analysis of the velocity information displaying the image in one color. This instrument appears to be very accurate in the detection of hemodynamically significant stenoses, in particular if combined with frequency analysis (8, 13). During the past six months 414 carotid vessels on which the Doppler imaging had been performed were compared with subsequent angiography (Table 3).

Table 3: Comparison of Doppler echoflow scan and angiographic findings.
N = 414 vessels

Angiography	N	Dopplerechoflow-scan			
		Red 0–39%	Yellow 40–69%	Blue 70–99%	Occlusion
Normal	273	264	9		
1–35%	40	35	5		
35–65%	24	1	12	11	
66–99%	31		1	27	3
Occlusion	20				20
Plaque	26	25	1		

The following pitfalls could be observed and can be overcome by using frequency analysis.

1) When a mild stenosis was present, there was no way of confirming whether the increased frequencies were abnormal and indicative of a stenosis, or increased but normal, as may occur in young persons or in those cases with contralateral stenosis and a compensatory increase in flow.
2) A further source of difficulty in carotid Doppler imaging is the detection of more than two vessels at the carotid bifurcation. It is relatively simple to map

the anatomy by noting which vessel exhibits high or low resistance flow characteristics.

3) Severe stenosis can be mistaken for occlusion. The flow velocity is apparently not sufficient to produce a detectable Doppler shift resulting in an error of clinical importance (3). B-mode imaging does not seem to be helpful, since it is very unlikely that the tiny lumen present in the severely stenosed vessel will be identified.
4) Strongly attenuating atheromatous plaque can result in weak or absent Doppler signals over a segment and lead to considerable difficulty in mapping the vessels. It is important in such cases to scrutinize the *resistance* index (RI = A – A/B) and using periorbital or posterior orbital studies for evidence supporting or refuting occlusive disease. The RI, described by Planilo and Pourcelot, is a quantitative and sensitive method of measuring common carotid flow characteristics.
5) Superimposition of the external and internal carotid arteries can create a false impression of carotid occlusion. The internal carotid artery is usually assumed to be obstructed. This error can be eliminated if one finds normal flow resistance in the ipsilateral common carotid artery and absence of external carotid collateral flow. The elusive vessel can usually then be imaged by putting the patient's head into an oblique position to one side or another and rescanning the bifurcation.
6) Significant error can occur when the internal carotid is occluded and external carotid branches are mistaken for normal bifurcation. The principal means of preventing this mistake is to closely examine the pulse-velocity characteristics of the Doppler signals heard in each of the bifurcation branch vessel. These characteristics can be detected aurally in the Doppler audio output or visually by frequency spectral analysis (2, 8).

The Doppler spectrum is a name given to the band of frequencies which are present in the output of the Doppler receiver. A number of different frequencies are present because the red cells are moving at different velocities resulting in different flow profiles. In the echoflow scan II device Doppler shifted frequency is shown on the vertical axis, time (on heart cycle) is shown on the horizontal axis, and amplitude is color coded.

The following frequency spectral abnormalities associated with stenotic lesions could be observed: 1) elevation of peak systolic and diastolic frequencies; 2) poor definition of the upper margin of the spectrum during systole as a result of disturbed flow; 3) spectral broadening in systole and diastole due to disturbed flow; 4) loss of the «triple peak» of the normal sonogram, and 5) poststenotic spectral broadening resulting from turbulence. The advantages of frequency spectral analysis are exemplified by our current reliance on frequency analysis (Fig. 1 and 2).

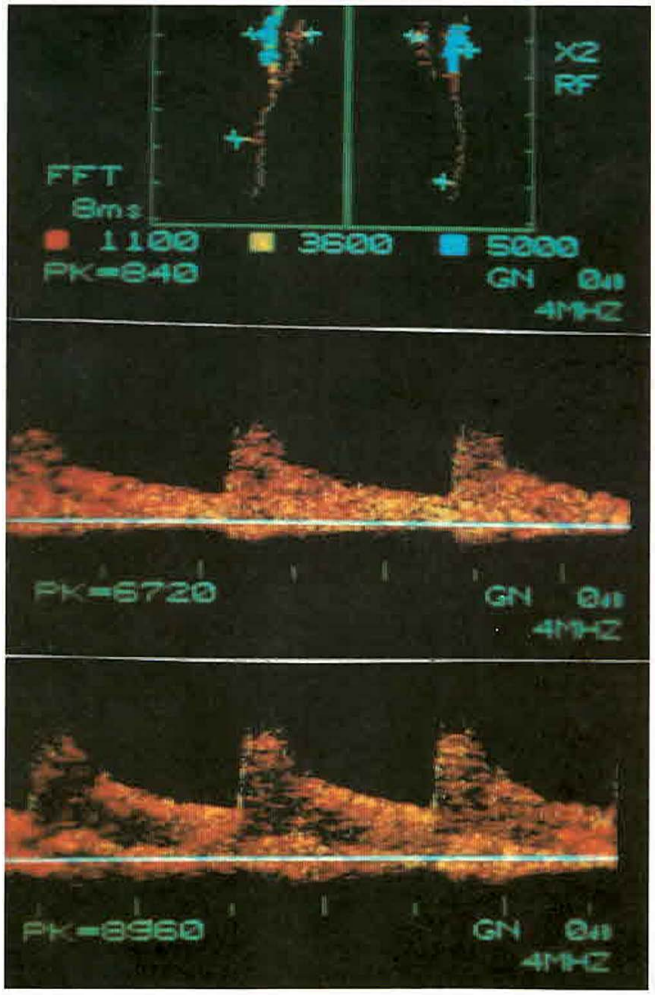

Fig. 1: Study of carotid artery performed with 4 MHz transducer. Blue region on map indicates severe stenosis of the right and left internal carotid artery. Spectrum analysis of both pathological arteries shows an increased peak frequency to 6.7 and 8.9 KHz with high diastolic frequency.

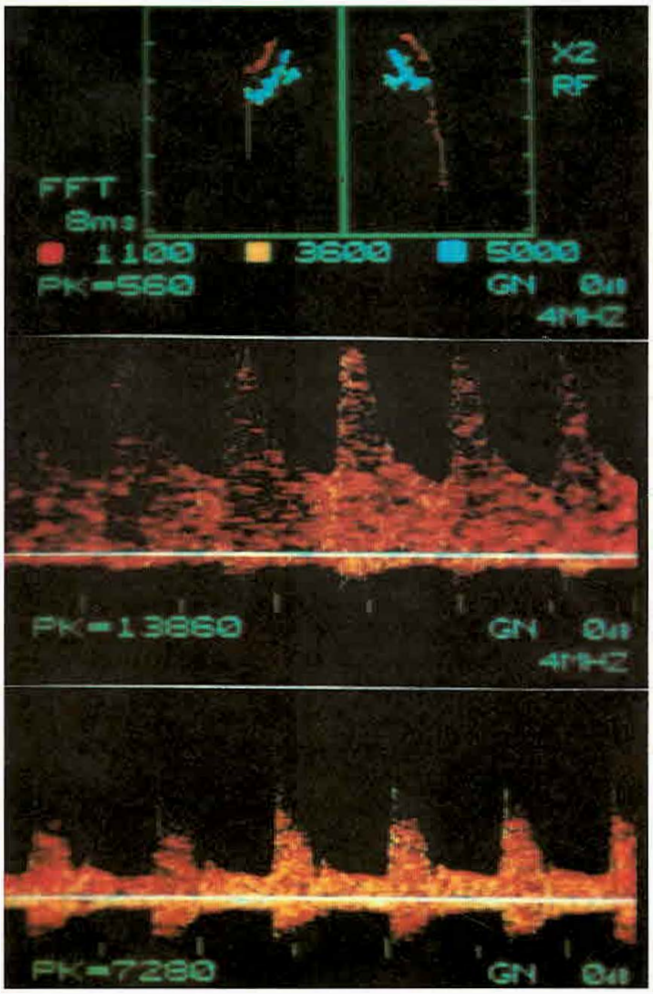

Fig. 2: Study of carotid artery performed with the Dopplerechoflow-scan. Standard color coding for carotid scanning indicates severe stenosis of the right and left external carotid artery. A frequency analyzer is helpful in distinguishing between the internal and external carotid arteries.

Duplex

High resolution B-mode carotid imaging represents a major advance in ultrasound cerebrovascular diagnosis because it directly examines the arterial wall. The definition of high resolution sonography includes axial and lateral resolution of at least 1 mm. Plaque can be detected and evaluated (Fig. 3). B-mode sonography should always be used in conjunction with Doppler techniques. As of today, we have performed over 1,000 high resolution carotid examinations, most of all in conjunction with Doppler using a Duplex scan (Table 4 and Fig. 4).

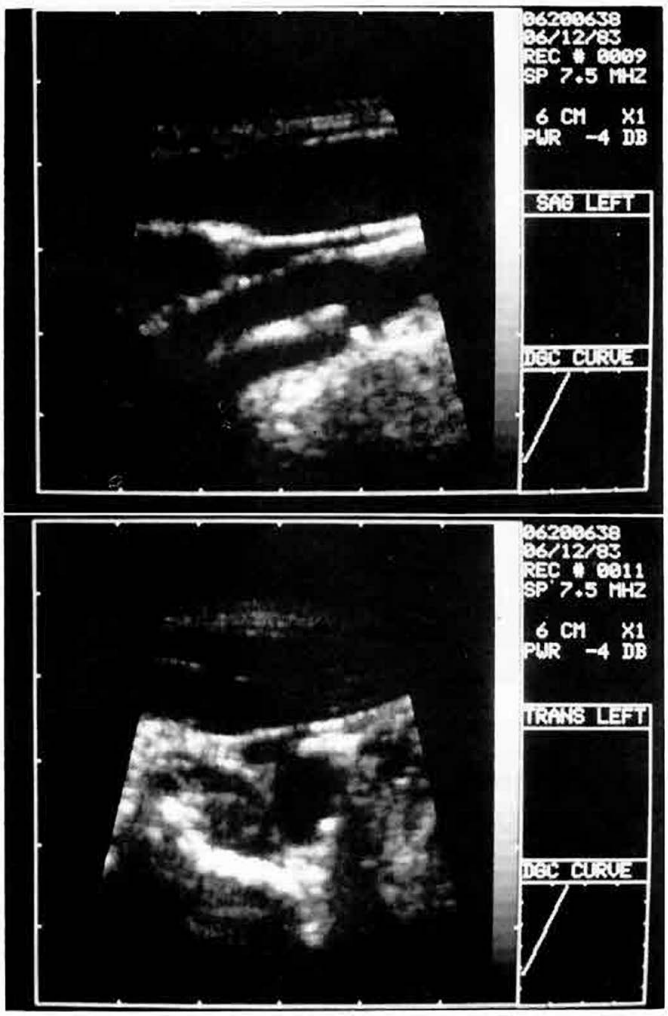

Fig. 3: Sagittal and transverse 7.5MHz ultrasound image of the left carotid artery bifurcation with duplex pulsed Doppler ultrasound display showing an atherosclerotic plaque.

Table 4: Comparison of the results of Duplex sonography and arteriography.
N = 240 vessels

Arteriography	N	Duplex sonography					
		Normal	1–35%	35–65%	66–99%	Occlusion	Plaque
Normal	171	167					4
1–35%	22	5	11	1			5
36–65%	11		3	6			2
66–99%	13		1	3	7	2	
Occlusion	12	7				5	
Plaques	11						11

We examined 240 vessels by Duplex scan and subsequently angiographically. We routinely attempt to image the cervical carotid bifurcation in three longitudinal transducer positions (axial view, anterolateral and posterolateral position) as well as in the transverse view. Good quality transverse scan can almost always be obtained in the common carotid and bulb, but it is frequently impossible to obtain satisfactory transverse scans of the internal and external carotids.

Using B-sonography the following considerations have to be taken into account:

1) The appearance of plaque protruding into the vessel lumen can vary greatly as the image phone is moved. Successful sonographic carotid diagnosis clearly requires an ability to «think» threedimensionally.
2) A part of the regions of the vessel may not be imaged with B-sonography.
3) The dilemma of diagnosing a nearly occluded vessel is frequently not resolved by use of Doppler in conjunction with B-sonography, since flow may be too sluggish to result in a detectable Doppler shift, but this can be overcome by using frequency analysis.
4) A significant limitation of B-sonography imaging is the failure to visualize a thrombus. The failure to image a thrombus resulted in significant error in our study (15).

None of the devices is perfect at present. We have to compensate the imperfection of each device by using a row of instruments and tests (8, 9, 14). The comparison of Doppler echoflow-scan and Duplex scan underline the complementary role of these devices (Table 5). Such a series of tests does provide 100% sensitivity, but to a certain degree it also yields false positives. We believe that the sensitivity or ability to detect every positive lesion is the most important function of any noninvasive detection system.

Table 5: Comparison of findings received by Dopplerechoflow-scan and Duplex sonography.
N = 280 vessels

Doppler-echoflow-scan	N	Duplex sonography					
		Normal	Plaque	1–35%	36–65%	66–99%	Occlusion
Red 0–39%	223	188	29	4	2	–	–
Yellow 40–70%	19	1	9	2	7	–	–
Blue 71–99%	27	0	1	1	10	13	2
Occlusion	11	7	–	–	–	–	4

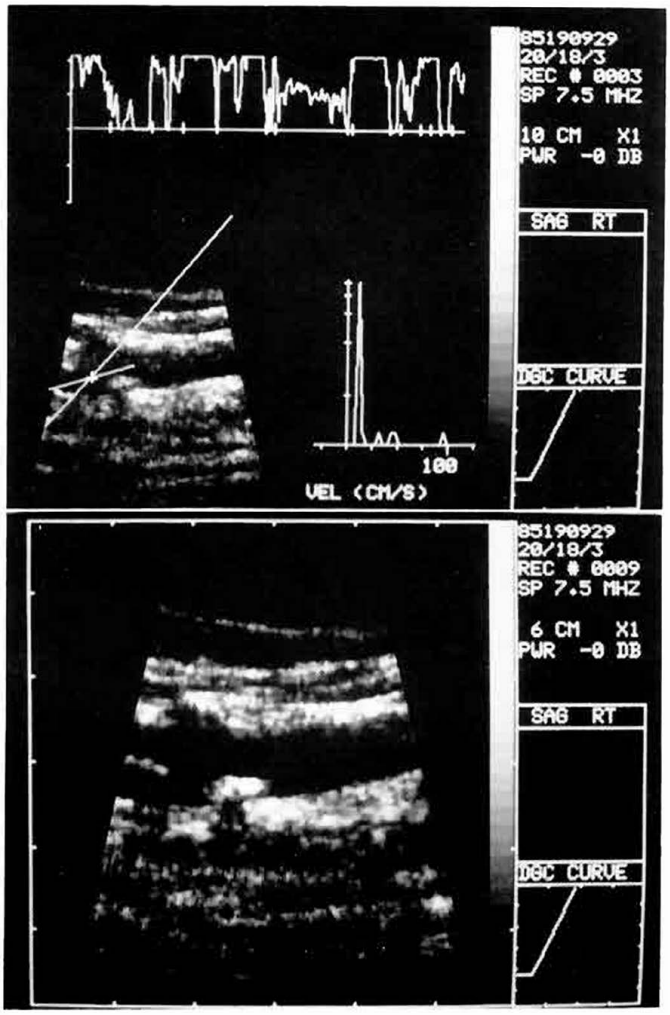

Fig. 4: A duplex mixed mode display shows Doppler analysis proximal to the plaque of right carotid bifurcation. The display allows simultaneous B-scan imaging and Doppler spectral analysis from a known location in the stenotic area. Turbulent flow is easily identified by the irregular Doppler wave forms. The quantitive histogram displays the average velocity of blood flow.

Summary

In the evaluation of the extracranial carotid disease Doppler-echoflow-scan combined with frequency analysis and Duplex sonography were used routinely to determine the accuracy of these methods.
In carotid disease, where high resolution imaging and Doppler spectral analysis complement each other for diagnosis of all stages of disease, the techniques described reveal an overall sensitivity of approximately 100% with the angiographic findings. Since angiographic findings show some disadvantages in estimating the morphology and hemodynamics of the carotid artery disease, the surgical findings rather than the X-ray findings must be the standard for evaluation of the ultrasonic results.

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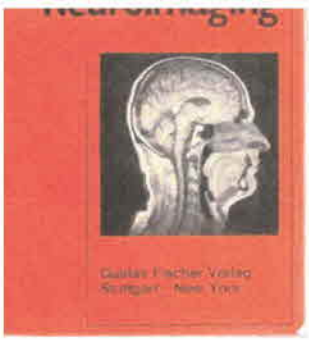

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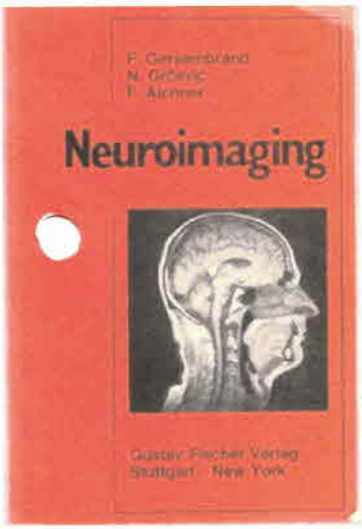

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