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CORRELATION OF CAROTID COLOR DOPPLER AND ANGIOGRAPHIC FINDINGS IN PATIENTS WITH SYMPTOMATIC CAROTID ARTERY STENOSIS

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SUMMARY – In order to validate ultrasonographic criteria for various degrees of carotid stenosis, patients who underwent digital subtraction angiography (DSA) of carotid arteries were retrospectively analyzed. Data on 91 patients with symptomatic carotid disease who first underwent ultrasonography followed by DSA were evaluated. Color Doppler criteria were previously set for four categories of internal carotid artery (ICA) stenosis: mild, moderate, severe, and occlusion. DSA classified ICA stenosis into the same categories. Spearman's Rank Correlation Coefficient was calculated. Spearman's Rank Correlation Coefficient between ultrasound and angiography in detecting various degrees of carotid stenosis was 0.86. Ultrasonographic criteria for detection of severe ICA stenosis showed a sensitivity of 75%, specificity of 98%, false positive ratio of 20%, false negative ratio of 25%, positive predictive value of 95%, negative predictive value of 85%, and accurate diagnosis of 88%. Ultrasonographic criteria for ICA occlusion showed a sensitivity of 82%, specificity of 98%, false positive ratio of 10%, false negative ratio of 18%, positive predictive value of 94%, negative predictive value of 95%, and accurate diagnosis of 95%. Our combination of various ultrasonographic parameters was sensitive for detection of various degrees of carotid stenosis, with a very high specificity, thus providing highly positive predictive values for such a classification. A lower sensitivity was obtained due to the lower sensitivity of angiography in detecting minimal flow in near-occluded ICAs.

Key words: *Carotid stenosis, radiography; Carotid stenosis, ultrasonography; Cerebral angiography*

Introduction

Since the publications of the European Carotid Surgery Trial (ECST)[1,2] and North American Symptomatic Carotid Endarterectomy Trial (NASCET)[3], which demonstrated a significant benefit of surgery for patients with symptomatic advanced carotid artery stenosis, an ongoing discussion about the different angiographic methods of measuring internal carotid artery (ICA) stenosis has emerged[4]. Because these two methods provide different results, the patient's management depends on the method used for evaluation of angiograms. Due to limitations of angiography, three methods have been proposed for the measurement of carotid stenosis, which produce different measurements for the same stenosis (Fig. 1). Besides, an-

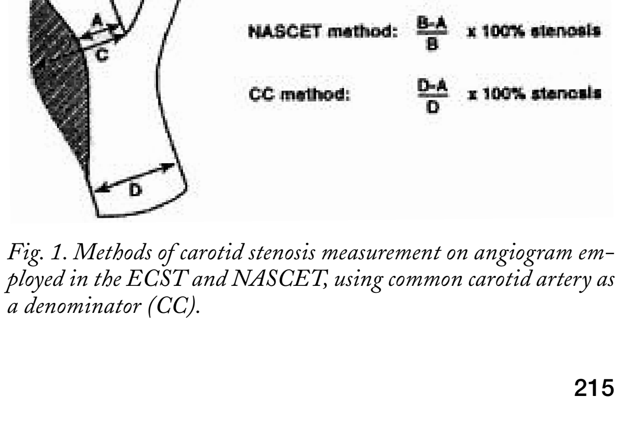

Fig. 1. Methods of carotid stenosis measurement on angiogram employed in the ECST and NASCET, using common carotid artery as a denominator (CC).

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giography is associated with a relative risk of stroke and systemic complications. Therefore, the need of an accurate and safe noninvasive assessment of carotid artery disease is obvious.

Duplex scanning has been well accepted as a reliable diagnostic tool for detection and classification of ICA stenosis[5-12]. The results of NASCET and ECST trials on the degree of carotid stenosis in the prevention of stroke are based on angiographic findings[1-3]. If noninvasive imaging is to replace angiography, the exact relationship between the degree of stenosis measured by ultrasonographic technique and that measured by angiography must be accurately defined. The previously reported studies[5-12] evaluated sensitivity and specificity of different criteria used for assessment of the degree of carotid stenosis. While in some investigations the peak systolic velocity (PSV) in ICA was found to be the best single velocity parameter for quantifying a >70% stenosis[6,13], in others it was the PSV ratio in ICA and common carotid artery (CCA)[5]. The more so, color Doppler flow imaging (CDFI) enabled visualization of pseudo-occlusion, thus being superior to angiography[14,15]. The application of the same ultrasonographic diagnostic criterion of PSV at two ultrasonographic laboratories using similar equipment showed different sensitivity and specificity in grading of carotid stenosis[16]. Higher sensitivity of ultrasound screening was achieved by use of diagnostic criteria specific to each laboratory. Neither laboratory had formerly published their combination of criteria. Therefore, extrapolation of duplex criteria from one center to another is inappropriate, and the criteria are laboratory specific[8]. Due to these differences and limitations of CDFI, we have set a combination of different criteria for defining various degrees of carotid stenosis.

The aim of the investigation was to validate this combination of ultrasonographic criteria for each group of carotid stenosis in comparison to angiography.

Patients and Methods

We compared carotid angiographic findings with CDFI findings obtained in 91 consecutive patients undergoing angiography from January 1, 1997 to December 31, 1998. All patients had either previous amaurosis fugax, transient ischemic attacks (TIA) or stroke. Digital subtraction angiography (DSA) was performed within two weeks from ultrasonographic examination. Angiography was performed by the intra-arterial digital subtraction technique *via* femoral route using selective catheterization of extracranial arteries. Biplanar images were obtained for each ICA. All measurements were assessed in a blind manner. The stenoses were categorized as mild, moderate, severe or occlusion[4]. We used these four categories of carotid stenosis because of different clinical management of each category.

CDFI and power Doppler imaging (PDI) of carotid arteries and vertebral arteries were performed on an Acuson 128XP (Mountain View, California). The probe contained to a 7.5 MHz linear array transducer for morphologic investigation and 5 MHz pulsed Doppler for hemodynamic investigations with the possibility of angle-corrected velocity measurements. The sample volume was 1.5 mm. The sensitivity of the system for detecting motion was set for each subject slightly above the level of color noise. The CCA and ICA were evaluated. The stenosis of carotid arteries was classified as mild, moderate, severe or occlusion.

Mild stenosis was determined by at least two of the following criteria (Fig. 2): diameter reduction during systole in longitudinal plane by ≤50%, angle corrected ICA PSV 1.2-1.7 m/s, PSV ICA/PSV CCA ≤1.8. The criteria for moderate stenosis (Fig. 3) were at least two of the following: diameter reduction during systole in longitudinal plane by 51%-75%, angle corrected ICA PSV 1.71-2.99 m/s, PSV ICA/PSV CCA 2.8-3.9. The criteria for severe stenosis (Fig.4) were at least two of the following: diameter reduction during systole in longitudinal plane by >75%, angle corrected systolic blood flow velocities ≥3 m/s, PSV ICA/PSV CCA ≥4, ipsilateral PSV in the ophthalmic artery <0.1m/s, or inverse flow direction in the ophthalmic artery. The criteria for pseudo-occlusion were: stenosis of more than 95%, angle corrected ICA PSV <0.5 m/s, absent diastolic flow (Fig. 5). The patients with pseudo-occlusion were classified into the category of severe stenosis. The criteria for occlusion were: lumen filled with plaques, absent CDFI and PDI flow. The criteria for distal occlusion were: color filling of the entire lumen, ICA PSV <0.5 m/s, absent diastolic flow (Fig. 7). The patients with distal occlusion were classified into the category of occlusion.

All ICAs were classified into four categories according to angiography and color Doppler. All data were entered in a personal computer, and a decision matrix was generated for calculation of the sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV). Spearman's Rank Correlation Coefficient was calculated.

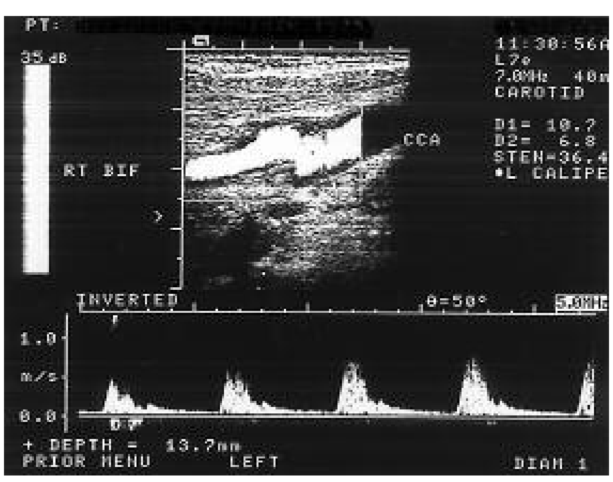

Fig. 2. Mild ICA stenosis: diameter reduced by 36.4%, systolic blood velocity below 0.62 m/s.

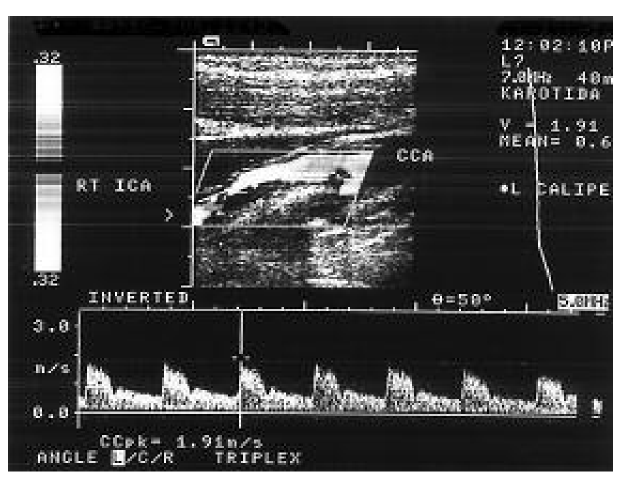

Fig. 3. Moderate ICA stenosis: diameter reduced by 61.2%, systolic blood velocity 1.91 m/s.

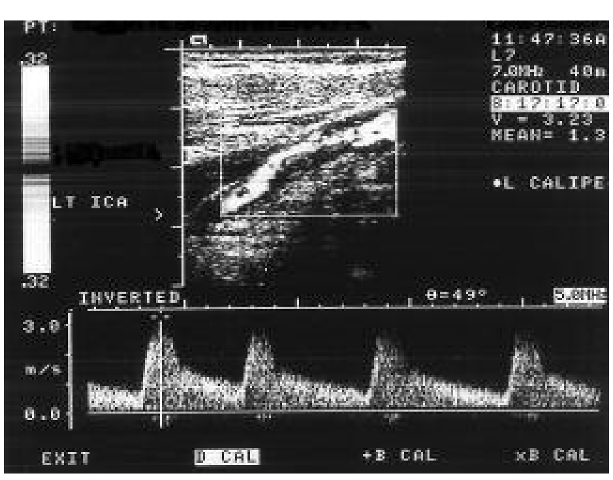

Fig. 4. Severe ICA stenosis: diameter reduced by 80%, systolic blood velocity 3.23 m/s.

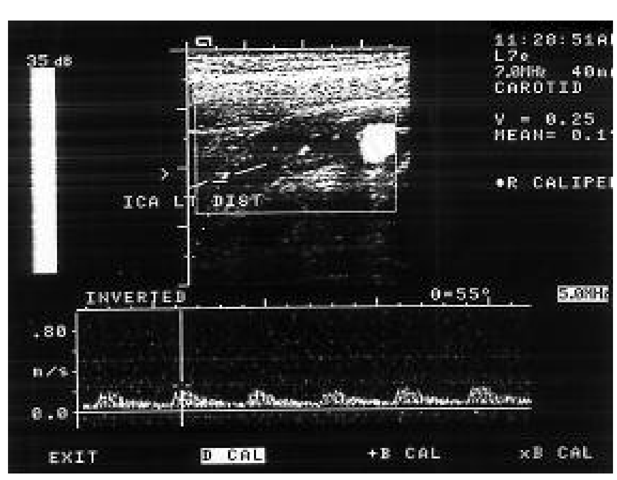

Fig. 5. Pseudo-occlusion of ICA: tinny color coded flow, systolic blood flow velocity 0.25 m/s.

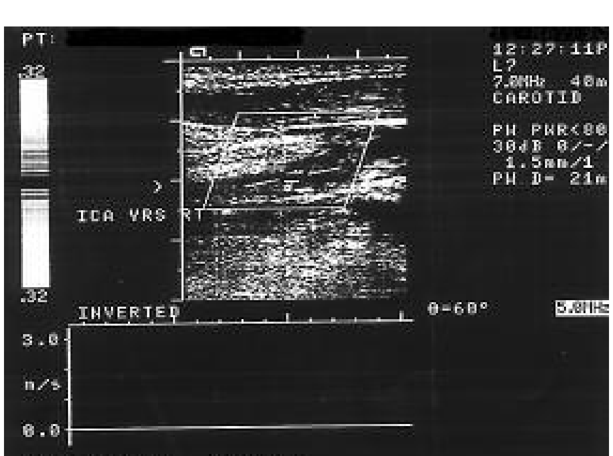

Fig. 6. Pseudo-occlusion of ICA: lumen filled with plaque, absent color coded flow.

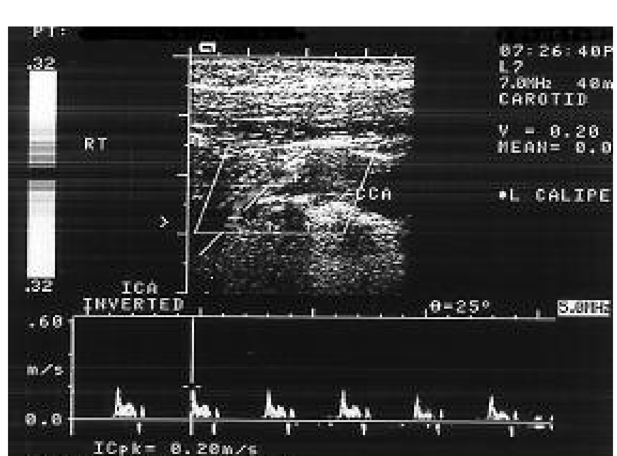

Fig. 7. Distal occlusion of ICA: color filling the entire lumen, ICA peak systolic velocity 0.20 cm/s, absent diastolic flow, minimal diastolic reverse flow.

Results

Data on 91 patients (61 males and 30 females), including 130 ultrasonograms and 127 angiograms of stenotic carotid bifurcations were evaluated. Table 1 shows the number of ICAs in each group of carotid stenosis according to color Doppler and angiography findings. Figure 8 illustrates the correlation between angiography and color

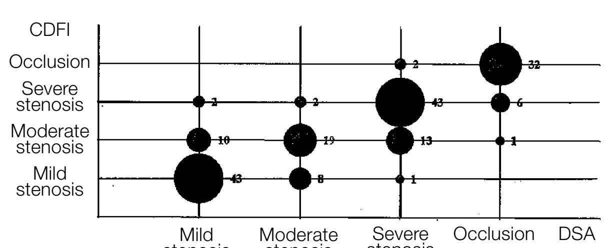

Fig. 8. Correlation of digital subtraction angiography (DSA) and color Doppler flow imaging (CDFI) in four groups of carotid stenosis at 182 carotid bifurcations; Spearman's correlation coefficient = 0.86.

Doppler of various groups of carotid stenosis. Spearman's Rank Correlation Coefficient was 0.86. While DSA showed 39 ICA occlusions, Doppler examination revealed 32 occlusions, 6 severe stenoses and one moderate stenosis in the same group. In the group of severe ICA stenosis according to DSA (59 cases), ultrasound revealed 2 occlusions, 43 severe stenoses, 13 moderate stenoses and one mild stenosis. DSA showed 29 moderate ICA stenoses, while in the same group CDFI showed 8 mild, 19 moderate and 2 severe stenoses. In the group of mild stenosis, DSA and CDFI correlated in 43 out of 55 cases of mild stenosis shown by DSA; the rest of 12 cases were by CDFI classified as moderate (10 cases) or severe stenosis (2 cases). With these data, a decision matrix was formed.

Table 1. Number of carotid arteries according to stenosis degree as detected by color Doppler flow imaging (CDFI) and digital subtraction angiography (DSA)

Stenosis degree	CDFI	DSA
Mild	52	55
Moderate	43	29
Severe	53	59
Occlusion	34	39

Table 2 presents decision matrix for severe ICA stenosis. The sensitivity was 75%, specificity 98%, false positive ratio 0.2, false negative ratio 0.25, positive predictive value 95%, negative predictive value 85%, and accurate diagnosis 88%.

Table 2. Decision matrix presenting ratio between CDFI and DSA findings of severe carotid stenosis

CDFI/DSA	Severe stenosis +	Severe stenosis –
Severe stenosis +	43	14
Severe stenosis –	2	82

Table 3 presents decision matrix for ICA occlusion. The sensitivity was 82%, specificity 98%, false positive ratio 0.1, false negative ratio 0.18, positive predictive value 94%, negative predictive value 95%, and accurate diagnosis 95%.

Table 3. Decision matrix presenting ratio between CDFI and DSA findings of carotid occlusion

CDFI/DSA	Occlusion +	Occlusion –
Occlusion +	32	7
Occlusion -	2	141

Discussion

Our results showed high correlation between angiography and ultrasonography in detecting various degrees of carotid stenosis (Spearman's Rank Correlation coefficient, 0.86). Ultrasound was more sensitive in detecting the category of severe stenosis (near occlusion, pseudo-occlusion), as already demonstrated elsewhere[8,14,15]. This is the reason for 82% ultrasound sensitivity in detecting ICA occlusion and 18% rate of false negative results, which is consistent to the results reported by Curley et al.[8] on 79% sensitivity, 99.5% specificity, 96% PPV and 96% NPV. Due to the higher CDFI sensitivity, 6 ICAs ultrasonographically classified as severe and one as moderate stenosis were angiographically designated as ICA occlusion. This led to lower sensitivity of ultrasound in detecting severe ICA stenosis. In comparison to others[5,6,11], the sensitivity for severe ICA stenosis was lower, however, it was accompanied by a gain in the specificity (95% for severe ICA stenosis and 98% for ICA occlusion). Even in the study of Curley et al.[8], the specificity was similar (96%), but the sensitivity was much lower (37%). Besides, some investigations had some errors, e.g., no angle corrected velocimetry[5], vascular surgeon evaluating the angiograms[5], different classification of stenosis degree[6], and absent ROC analysis[11]. A meta-analytical review[10] pointed to some important limitations: the information obtained only from published series report only on positive studies, which leads to overestimation of the true sensitivity and specificity. Inappropriate use of ultrasound was obvious in some reports[17]. On the other hand, ultrasound provides some additional information such as plaque characteristics, content, and surface[12,18,19]. Even the degree of stenosis as assessed by angiography was much higher than that detected on operation[9].

We compared different categories rather than the sensitivity of different ultrasonographic criteria with the exact percentage of stenosis (diameter or area). These categories were used because of different clinical management required for each of them[20-22]. Mild stenosis should be controlled at longer, and moderate stenosis at shorter intervals. In moderate stenosis, plaque characteristic is important (e.g., soft plaque or irregular surface suggesting ulceration on the symptomatic side). Differentiation between pseudo-occlusion and occlusion is essential for the need of intervention in the former. In these cases, ultrasound proved superior to angiography and, according to operative findings, accurate.

On category defining (mild, moderate or severe stenosis, occlusion), we were mostly guided by Zwiebel's criteria[23] and report by Arbeille et al.[24]. For years of ultrasound use, we were frustrated by the method limitations. Some limitations, such as the vessel masking by a calcified plaque or very low velocities in pseudo-occlusion, could be overwhelmed by the additional use of PDI[7,19,25]. Despite this, in some patients, the masking from a calcified plaque completely prevented visualization of the underlying plaque, however, we observed hemodynamic changes in the area after the stenosis. Some patients had large, sometimes elongated, soft plaques (Fig. 9), in which the degree of stenosis was not accompanied by hemodynamic changes. This was the reason for introducing the degree of diameter stenosis or unilaterally diminished or reversed flow in the ophthalmic artery[26] as additional criteria for advanced stenosis. To avoid subdiagnosing of the stenosis degree in impaired cardiac output or damped flow due to proximal advanced stenosis, the PSV ICA/PSV CCA ratio was also introduced, which even showed higher sensitivity for detecting advanced stenosis in some investigations[5].

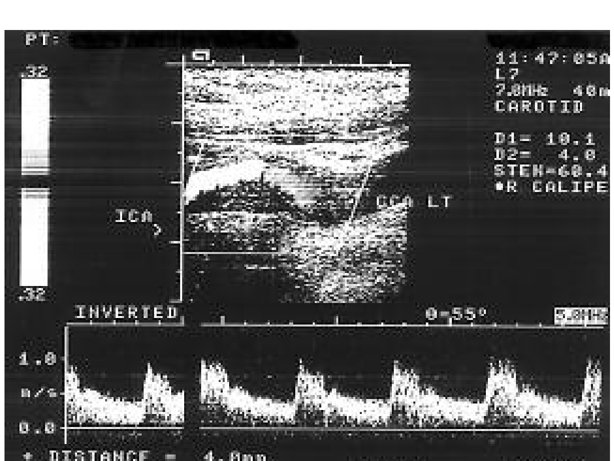

Fig. 9. Moderate ICA stenosis with soft plaque: diameter reduction by 60.4%, without changes in hemodynamic spectra.

In conclusion, our combination of various ultrasonographic parameters proved sensitive for the detection of various degrees of carotid stenosis, with a very high specificity and yielding high positive predictive values for such classification. A lower sensitivity compared to other studies was obtained due to the lower sensitivity of angiography in detecting minimal flow in near-occluded ICAs (pseudo-occlusion). The question for further discussion is: does angiography still need to be considered a 'gold standard'?

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Sažetak

KORELACIJA OBOJENOG DOPPLERA I ANGIOGRAFSKIH KAROTIDNIH NALAZA U BOLESNIKA SA SIMPTOMATSKOM STENOZOM KAROTIDNIH ARTERIJA

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Podaci bolesnika u kojih je učinjena digitalna subtrakcijska angiografija (DSA) karotidnih arterija analizirani su kako bi se postavili ultrazvučni kriteriji za određivanje različitih stupnjeva karotidne stenoze. Procijenjeni su podaci za 91 bolesnika sa simptomatskom karotidnom bolešću u kojih je najprije učinjen obojeni dopler karotidnih arterija, a nakon toga DSA. Karotidne stenoze su svrstane prema ultrazvučnim kriterijima u četiri kategorije: blaga, umjerena, uznapredovala stenoza i okluzija. Prema DSA karotidne stenoze svrstane su u iste četiri kategorije. Stupanj korelacije testiran je pomoću Spearmanovog koeficijenta korelacije. Spearmanov koeficijent korelacije kategorija stenoze ultrazvuka i DSA bio je 0,86. Kombinacija ultrazvučnih kriterija za otkrivanje uznapredovale karotidne stenoze pokazala je osjetljivost od 75%, specifičnost od 98%, odnos lažno pozitivnih od 20%, odnos lažno negativnih od 25%, pozitivnu prediktivnu vrijednost od 95%, negativnu prediktivnu vrijednost od 85%, te točnost dijagnostičkog testa od 88%. Kombinacija ultrazvučnih kriterija za otkrivanje okluzije unutarnje karotidne arterije pokazala je osjetljivost od 82%, specifičnost od 98%, odnos lažno pozitivnih od 10%, odnos lažno negativnih od 18%, pozitivnu prediktivnu vrijednost od 94%, negativnu prediktivnu vrijednost od 95% i točnost dijagnostičkog testa od 95%. Naša kombinacija različitih ultazvučnih parametara pokazala se vrlo osjetljivom u otkrivanju različitih stupnjeva karotidne stenoze, s vrlo visokom specifičnošću i pozitivnom prediktivnom vrijednošću. Niža osjetljivost ultrazvuka dobivena je zbog slabije osjetljivosti angiografije u prikazu minimalnog protoka.

Ključne riječi: *Karotidna stenoza, radiografija; Karotidna stenoza, ultrasonografija; Cerebralna angiografija*