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Evaluation of Carotid Artery Plaques with B-Flow Sonography and Comparing the Results with Color, Power Doppler US and DSA

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Abstract: To evaluate carotid artery lesions with B-flow sonography and compare the findings with color, power Doppler sonography and digital subtraction angiography (DSA). Forty-Four patients (30 males, 14 females; mean age 64±9; age range: 42-81) with 61 carotid artery lesions were involved in the prospective study. The lesions were evaluated with color, power Doppler and B-flow sonography. All images were reviewed and graded independently by two radiologists for surface delineation, plaque morphology and overall image quality. The grades for each technique were compared with Friedman and Wilcoxon tests. Simple regression analysis was used to compare the percentage of stenosis calculated with different sonographic techniques and DSA for lesions causing more than 60% stenosis. Statistical analysis with Friedman test revealed that B-flow is superior to other sonographic techniques for all three parameters (plaque surface delineation, plaque morphology and overall image quality). Wilcoxon test also showed B-flow is superior to other methods for the evaluation of plaque surface delineation and plaque morphology (p=0.000); while no significant difference was found between B-flow and power Doppler imaging for the evaluation of overall image quality (p=0.09). Kappa scores reflected moderate to good interobserver correlation (0.297-0.659). The percentage of stenosis calculated with both B-flow and power Doppler sonography correlated with DSA significantly (p=0.000). B-flow sonography is a technique that provides visualization of the blood flow and the morphology of the surrounding vessel wall simultaneously. This technique maintains more efficient evaluation of carotid artery lesions by eliminating artifacts such as aliasing and overwriting.

Keywords: Ultrsonography, B-Flow, Doppler, Atherosclerosis, Carotid Artery, Stenosis.

1. Introduction

In westernized societies, atherosclerosis is one of the leading causes of ischemic stroke (1). Especially atherosclerosis of internal carotid artery (ICA) is one of the major causes of stroke. The stroke risk can be reduced with early diagnosis and appropriate treatment (2, 3). Large multicenter trials such as North American

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Symptomatic Carotid Endarterectomy Trial (NASCET) and European Surgery Trial (ECST) have demonstrated that the stenosis grade of ICA is particularly important in therapy planning. Recent studies showed that surface characteristics and morphology of atheroma plaques are also among predictors of stroke risk (4-6).

Digital subtraction angiography (DSA) has been accepted as the “gold standard” in the evaluation of ICA-stenoses with a sensitivity, specificity, and accuracy of 95%, 99%, and 97%, respectively (7). On the other hand, DSA has shortcomings such as high cost, invasiveness, ionizing radiation, risk of nephrotoxicity, and neurologic complications which initiates the search for alternative diagnostic methods for evaluation of ICA-stenosis.

Computerized tomography (CT) is one of the modalities frequently used in the evaluation of ICA-stenosis. Main disadvantages are the use of ionizing radiation, risk of nephrotoxicity, suboptimal stenosis grading especially in calcified plaques (8).

Magnetic resonance imaging (MRI) without the need for ionizing radiation and good sensitivity particularly for the evaluation high-grade stenosis is an alternative method for carotid stenosis detection. However relatively high costs, long examination duration, unable to perform in patients who have a pacemaker or claustrophobia limits its usage (8, 9).

Color Doppler sonography (with many advantages e.g., wide accessibility, noninvasive nature, application without ionizing radiation exposure) is one of the most used methods in evaluating carotid arteries. On the other side color doppler sonography has its own limitations; B-flow sonography is a relatively new method that may overcome the shortcomings of color Doppler ultrasonography. With B-flow ultrasound, it is possible to image blood flow and vessel wall simultaneously without the limitations of Doppler imaging such as loss of signal at some detection angles, limitations of wall filter and aliasing. In this study, we aimed to evaluate carotid artery lesions with B-flow sonography and compare the findings with color, power Doppler sonography and digital subtraction angiography (DSA).

2. Material and Methods

2.1. Data collection and Patients

This is a single-center study performed at Gazi University Hospital. The study was approved by the Ethics Committee of Gazi University, and all the patients signed informed consent forms.

From March to December 2004, 44 consecutive patients (14 females, 30 males) who had atherosclerosis in ICA were prospectively included. The mean patient age was 64±9 (range, 42-81 years). Patients who have ICA stenosis>60% were evaluated with DSA.

2.2. Image assessment

All color doppler, power doppler, and B-flow examinations were performed with LOGIQ sonography system (GE Medical Systems, Milwaukee, WI, USA) with the aid of a 4-10 MHz linear transducer. During the color and power doppler examinations related parameters (color gain, wall filter, and velocity scale) were optimized to minimize artifacts. During B-flow imaging “sensitivity” was set to 8, “background: on”, and focus was adjusted posterior to vessel. In all three methods, gain was set to obtain the best possible image quality. Images and movies were recorded via “Logiqworks” archiving system (GE Medical Systems, Milwaukee, WI, USA).

Plaque surface delineation, morphology of plaques and overall image quality were independently assessed by two experienced radiologists using a three-point scale (1=the plaque was vaguely characterized/image quality: poor, 2=the plaque was moderately characterized/ image quality: average, and 3=the plaque was clearly characterized/image quality: excellent).

20 patients who had ICA-stenosis>60% were also evaluated with DSA. DSA was performed via a 5F catheter. Left and right carotid arteries were visualized at least in two projections. For each projection 6 ml, 320 mg/ml non-ionic iodinated contrast media was used.

The ICA-stenosis grades from the images of ultrasonography and DSA were independently measured by two radiologists.

2.3. Statistical Analysis

Statistical analysis was performed with the aid of SPSS for Windows (SPSS, IBM, USA). Values are presented as means ± standard deviations and ranges. The comparisons of quantitative data were evaluated using Friedman and Wilcoxon tests. Correlation between stenosis grades measured with Color Doppler, power Doppler, B-flow and DSA were analyzed with simple regression analysis. Interobserver agreement was analyzed via Kappa score. p-value<0.05 was considered to indicate a statistically significant difference.

3. Results

Of the total 61 atheromatous plaques; 32 (54.2%) were at right ICA, 21 (35.6%) plaques were at left ICA, 3 (5.1%) were at left external carotid artery (ECA) and 1 (1.7%) was at right ECA.

There was a statistically significant difference among the three parameters between B-flow, color, and power Doppler sonography (p=0.000) (Table 1).

Table 1: Friedman test results.

	Surface delineation	**Plaque morphology**	**Overall image quality**
Color Doppler	1.43	1.67	1.48
Power Doppler	1.81	1.80	2.15
B-Flow	2.75	2.52	2.37

Lowest value 1 represents poor image quality, where highest value 3 represents excellent image quality.

Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p<0.017$. In comparison to power and color doppler sonography B-flow sonography found to be superior in the assessment of plaque surface and morphology ($p=0.000$). In terms of overall image quality B-flow and power Doppler sonography were found to be superior to color Doppler sonography ($p=0.000$). However, in terms of overall image quality, there was no significant difference between B-flow sonography and power Doppler sonography ($p=0.09$) (Table 2).

Table 2: Wilcoxon test results.

Surface delineation	**Plaque morphology**	**Overall image quality**
PD>CD (p=0.000)	PD>CD (p=0.000)	PD>CD (p=0.000)
BF>CD (p=0.000)	BF>CD (p=0.000)	BF>CD (p=0.000)
BF>PD (p=0.000)	BF>PD (p=0.000)	BF=PD (p=0.009)

CD: Color Doppler; PD: Power Doppler; BF: B-flow.

Kappa score showed moderate to good interobserver agreement (0.297-0.659) (Table 3).

Table 3: Interobserver agreement (Kappa score).

	Surface delineation	**Plaque morphology**	**Overall image quality**
Color Doppler	0.576	0.319	0.659
Power Doppler	0.350	0.297	0.316
B-flow	0.400	0.435	0.374

In patients who had stenosis greater than 60% were also compared in terms of stenosis grade with B-flow, power/color Doppler sonography and DSA. Figure 1 summarizes the stenosis grade of 20 patients who were evaluated with DSA.

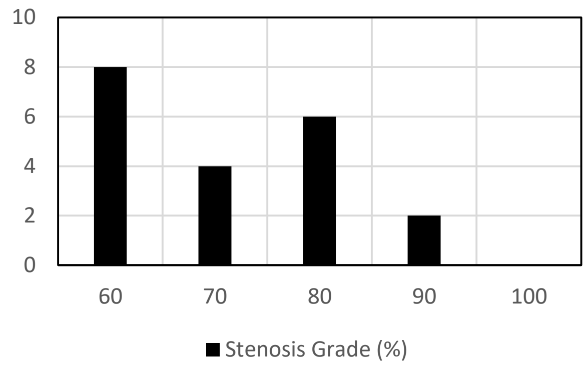

Figure 1: Distribution of stenosis grade of patients who were evaluated with DSA.

The serum MPO levels of MS patients (median=9192.30) were lower than the MPO levels of the healthy control group (median=1076.91) and this decrease was statistically significant (p=0.034) (Table 1). No significant correlation was found between MS patients' serum MPO levels and age, EDDS score, disease duration, ARR (p>0.05) (Table 2). There was no significant difference between the serum MPO levels of MS patients, and the DMT groups used (p=0.558) (Table 2).

When MS patients were classified by disease types, the disease duration and EDSS score of SPMS patients were significantly higher compared to RRMS patients, but there was no significant difference between these two groups in terms of age, ARR and MPO levels (Table 3).

All three sonography methods showed statistically significant correlation with DSA in terms of stenosis measurement ($p<0.0001$). Correlation coefficient between B-flow sonography and catheter angiography ($p_{BF}=0.969$) was higher than power and color doppler sonography ($r_{PD}=0.894$, $r_{CD}=0.886$, respectively). Figure 2 shows linear regression analysis results of color Doppler and B-flow sonography.

In stenosis grading, the difference between B-flow sonography and DSA was -6% to +5%, whereas the difference between power Doppler and DSA was -16% to +8%. DSA and B-flow sonography showed among 15 (75%) patients the highest correlation (Figure 3). On the other hand, DSA and power Doppler sonography showed among 3 (15%) patients, DSA and Doppler sonography showed among 2 (10%) patients the highest correlation.

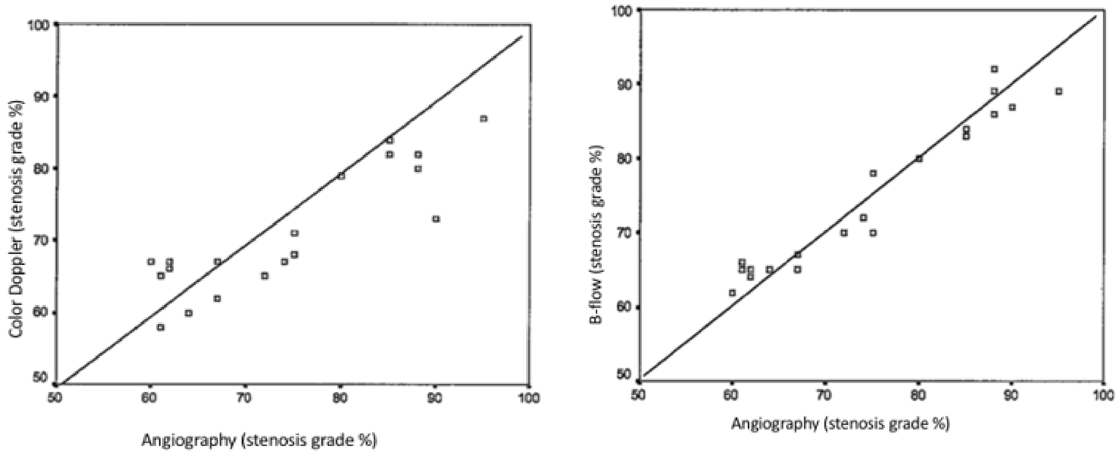

Figure 2: Linear regression analysis results.

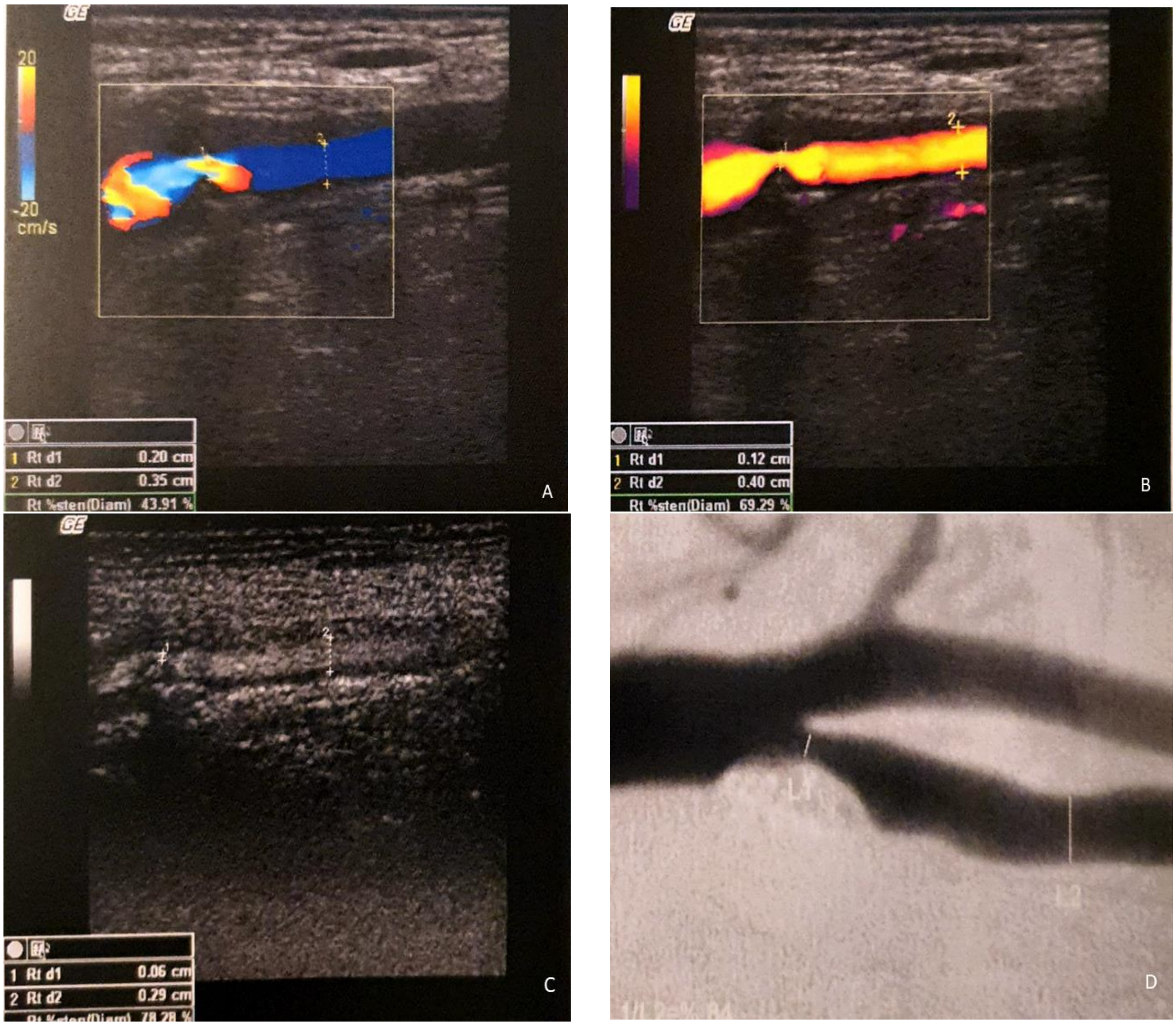

Figure 3: 70-year-old male patient with stenosis in left internal carotid artery graded as 44 % in color Doppler **(A)**, 69% in power Doppler **(B)**, and 78% in B-flow **(C)**. Here B-flow imaging correlated well with DSA **(D)** which graded the stenosis as 84%.

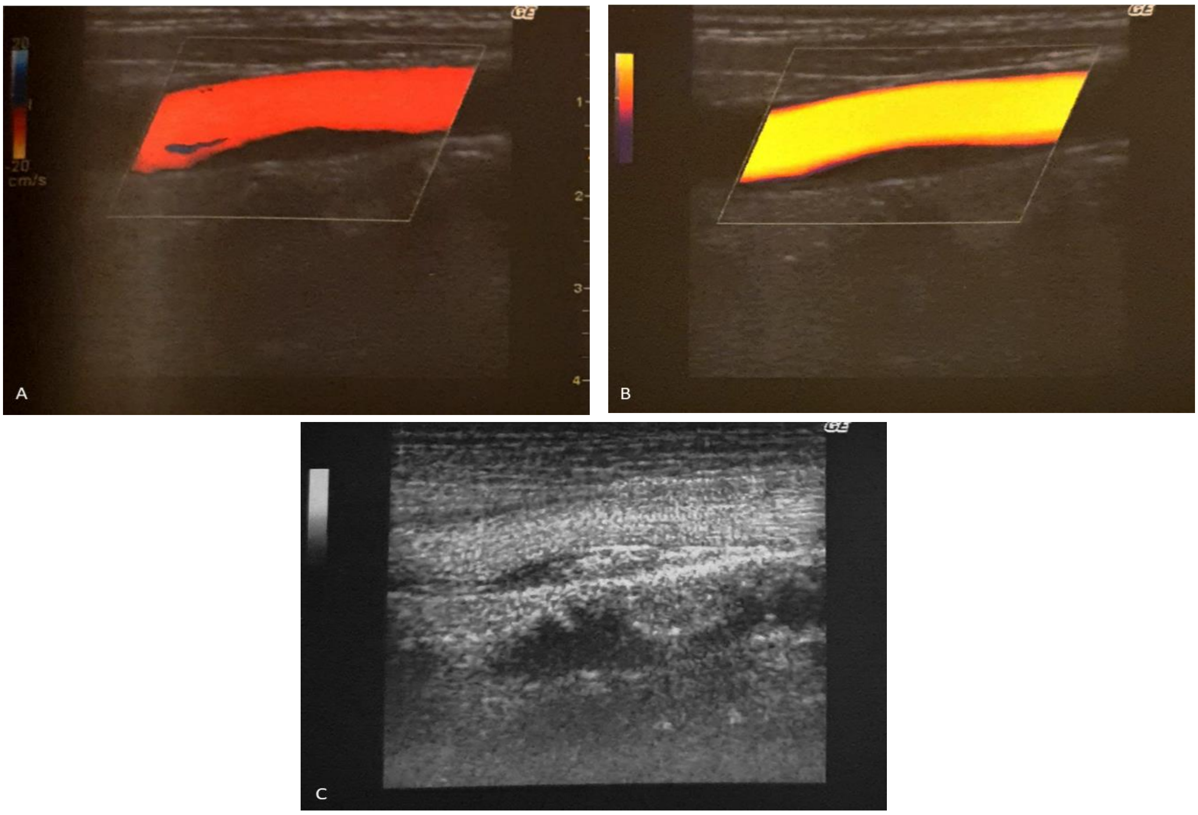

Figure 4: 59-year-old male patient with a fibrofatty plaque in the right common carotid artery. Plaque surface delineation and morphology cannot be optimally visualized with color **(A)** and power Doppler **(B)** imaging. With B-flow imaging **(C)** the heterogeneous structure of the plaque and the surface delineation can be visualized.

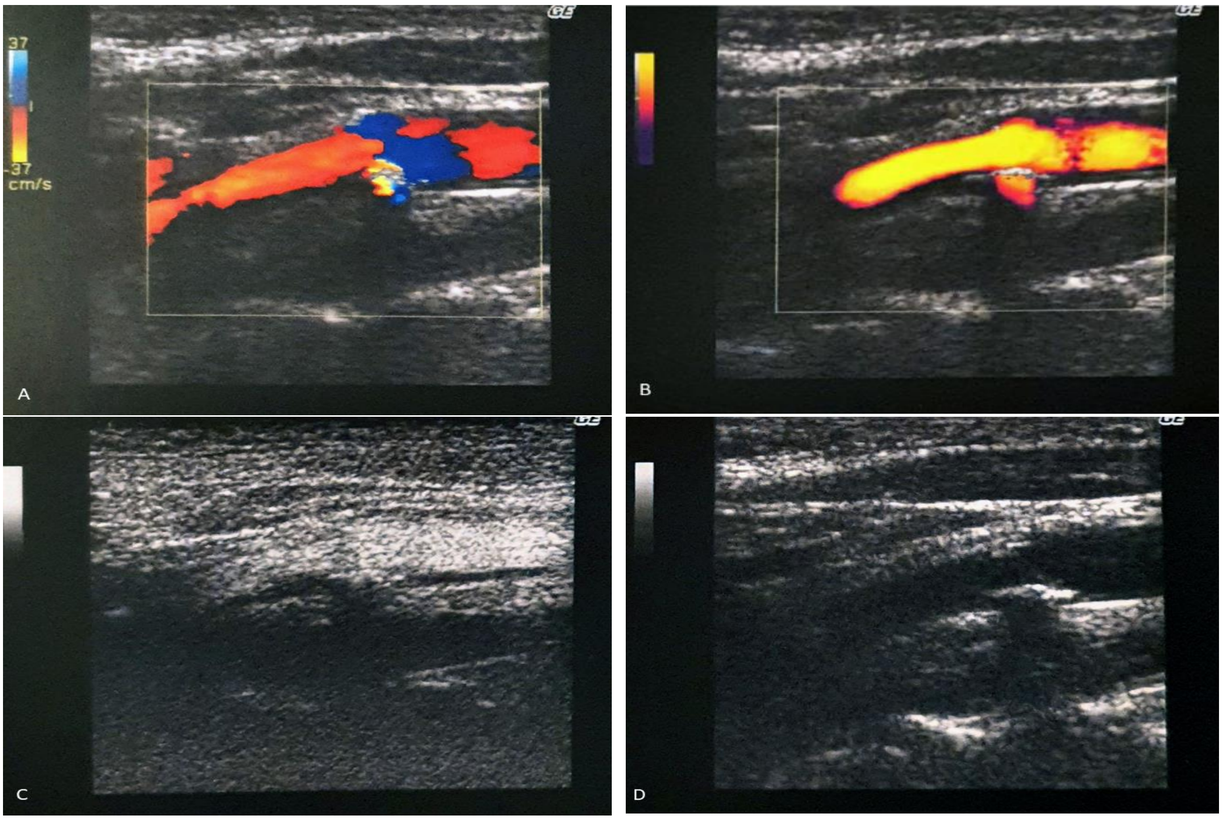

Figure 5: 74-year-old male patient color with a calcified plaque in the carotid artery. Color **(A)** and power Doppler **(B)** suffer from “twinkling artifact” seen posterior to the calcified atheroma plaque. B-flow **(C)** demonstrates the plaque and flow without artifacts. Characteristics of plaque in B-mod **(D)**.

4. Discussion

Atherosclerosis of carotid arteries is a common disease which causes high mortality and morbidity. Defining the nature of atheroma plaque, as well grading the stenosis plays an important role in determining the appropriate treatment. Although DSA is the traditional method in carotid artery stenosis measurement, because of high costs, ionizing radiation and complication potential there is a search for alternative noninvasive methods (10-12).

Large population trials like NASCET and ECST showed that in high-grade carotid artery stenosis, patients get more benefit from carotid endarterectomy in comparison to medical treatment. It is shown that symptomatic patients have a larger intraplaque hemorrhage in comparison to asymptomatic patients (13, 14). Another study confirmed that patients who have type 1 and 2 plaques encounter more transient ischemic attacks (15, 16). These studies showed that the assessment of plaque morphology may be as important as grading stenosis.

Color and power Doppler sonography have some technical limitations in plaque morphology imaging. In color and power Doppler sonography, grayscale and flow images were generated separately with different techniques. Color codes generated with Doppler sonography technique are overwritten over gray-scale images. The gray-scale information of the vessel wall and plaques were partially covered by color codes of Doppler imaging. Aliasing artifact which is seen in high grade stenosis also limits the evaluation of plaque morphology. Separately generating grayscale and Doppler images demands high computational power which causes a drop in frame rate and spatial resolution. Angle dependent nature of Doppler sonography may also limit assessment of carotid artery stenosis. Increased flow velocity is a good predictor of high-grade stenosis. However, in patients with arrhythmias or aortic insufficiency estimation of stenosis grade with of carotid arteries, arteriovenous malformations, carotid body tumors or high-grade stenosis/occlusion in the contralateral carotid artery may cause a false increase in flow velocities (17). B-flow sonography uses digitally coded ultrasound waves which enhance the weak signal derived from streaming blood, simultaneously suppresses the signals from the surrounding stationary tissues. This allows displaying the flow and surrounding tissues in the same spatial plane with the same, high frame rate. With B-flow imaging some limitations of color and power Doppler are overcome, so that blood flow, vessel wall and neighboring tissues can be real-time visualized.

Frame rate, spatial and contrast resolution are higher in B-flow imaging than Doppler methods. High frame rate and spatial resolution of B-flow gives the opportunity for a real-time demonstration of complicated hemodynamic flow patterns. Simultaneously evaluation of surface characteristics of plaque and altered flow dynamics may help to better grade cerebrovascular event risk. Additionally, high contrast and spatial resolution help to image the vessel wall and soft tissue planes simultaneously with blood flow. B-flow imaging is user friendly with fewer settings (sensitivity, background (on/off), focus position).

There are many studies about B-flow imaging of carotid arteries. However, most of the studies were focused on stenosis grading, there is a limited number of studies about plaque structure assessment (18-22). Most of these studies were focused on comparing B-flow imaging with power Doppler and DSA. These studies revealed that B-flow imaging showed a higher correlation with DSA than power Doppler imaging. Mikami T et all. studied pathological flow patterns in carotid stenosis with B-flow imaging. In some patients, a prestenosis reverse flow was observed which may cause embolus (23). In another study in post stenotic flow changes of gray-scale intensity was analyzed, which showed no correlation with systolic flow velocity (19).

Distinctly in our study, we evaluated the surface and structural characteristics of plaques with B-flow imaging and compared it with color and power Doppler sonography. We found that in imaging plaque surface and structural characteristics B-flow imaging was superior to color and power Doppler imaging. Lower contrast and spatial resolution in color and power Doppler imaging makes imaging the plaque characteristics difficult (Figure 4).

Additionally, “overwriting” and “aliasing” artifacts covers the plaque surface making it impossible to evaluate. B-flow imaging with high contrast and spatial resolution and without the above-mentioned artifacts has great advantages.

The twinkling artifact is caused by structures causing high reflection such as calcified plaques. This artifact generates blue and red color codes posterior to calcified plaques which causes difficulties in plaque and flow analysis. In our study we did not observe any twinkling artifacts in B-flow imaging, which helped in analyzing calcified plaques (Figure 5).

In our study power Doppler and B-flow imaging showed high correlation with DSA in grading ICA-stenosis. The correlation coefficient between B-flow imaging and DSA was higher than the doppler methods. B-flow imaging without the “overwriting” artifact enables a more accurate measurement of stenosis. In some cases, with tortuous vessels -because of angle dependent nature of color Doppler imaging-true plane stenosis analysis is exceedingly difficult. In moderate stenosis even with optimal PRF and Doppler gain settings vessel lumen is not filled completely with Doppler color codes, which causes undegrading the stenosis. Our findings showed that B-flow imaging correlates well with the gold standard DSA in carotid artery stenosis grading. Another important result is that in B-flow imaging the plaque morphology can be evaluated simultaneously with flow information.

NASCET and ECST recommend endarterectomy in high-grade ICA-stenosis. When stenosis over 70% is taken as cut off point, in color Doppler imaging 3 patients were undegraded, whereas with B-flow imaging none of the patients were undegraded.

Compared to our study Umemura et all. showed a higher correlation between B-flow imaging and DSA (r=0.977 vs r=0.969) (21). On the other hand, in a similar study, Yurdakul et all showed a lesser correlation between B-flow imaging and DSA compared to our study (22). However, in all studies correlation coefficients are extremely close. These results encourage the use of B-flow imaging in carotid artery stenosis grading.

Posterior acoustic shadowing caused by calcified plaques and insufficient signal obtained from deeply coursing vessels are the major limitations of B-flow imaging. Most patients have superficial carotid arteries, as well when necessary deeply coursing vessels can be better evaluated with low-frequency probes.

5. Conclusions

As a result, B-flow imaging with real-time flow information on gray-scale images, with less susceptibility to artifacts is a complementary method to Doppler imaging in carotid stenosis grading and plaque structure analysis.

Conflict of Interests

The authors declare that there is no conflict of interest.

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Author Contributions

Gümüş T, Yücel C, Oktar S and Ilgıt ET had the idea for and designed the study and drafted the original manuscript. Gümüş T, Oktar S, Özdemir H and Önal B collected the data. Özdemir H, Önal B and Ilgıt ET contributed to literature search and checked the data. Gümüş T, Yücel C, Önal B and Oktar S contributed to the statistical analysis. Yücel C, Özdemir H and Ilgıt ET contributed to critical revision of the manuscript. All authors read and approved the final manuscript.

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