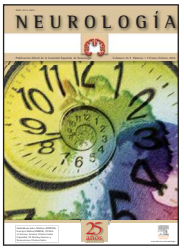
Neurología. 2010;**25(6)**:357-363

NEUROLOGÍA

www.elsevier.es/neurologia



ORIGINAL ARTICLE

Validation of supra-aortic trunks ultrasound in the diagnosis of atherosclerotic disease of the internal carotid artery. Comparison of the results with angiography

J.C. Portilla Cuenca[a,*], J.M. Ramírez-Moreno[a], L. Fernández de Alarcón[b], I. García Castañón[a], M. Caballero Muñoz[a], A. Serrano Cabrera[a], A. Falcón García[a], M. Gómez Gutierrez[a] and I. Casado Naranjo[a,c]

[a] *Sección de Neurología, Hospital San Pedro de Alcántara, Cáceres, Spain*
[b] *Servicio de Radiología, Hospital Infanta Cristina, Badajoz, Spain*
[c] *Departamento de Ciencias Biomédicas, Facultad de Medicina, Universidad de Extremadura, Spain*

Received on 10th July 2009; accepted on 15th February 2010

KEYWORDS
Cerebral angiography;
Carotid atherosclerosis carotidea;
Doppler;
Extracraneal stenosis;
Ultrasound study

Abstract
Introduction: Arteriosclerosis of the extra-cranial arteries is believed to be responsible for almost one-third of all ischaemic strokes. The sound diagnosis of the degree of stenosis is essential in deciding the best therapeutic strategy. Although cerebral angiography is considered the reference technique, ultrasound study (UST) is a more readily available, non-invasive and well-established procedure for quantifying carotid stenosis. However, on being a dependent exploratory technique, it is recommended that each laboratory validates its results against angiography.
Objectives: To establish the validity of the neuro-ultrasound study in our laboratory for use in the diagnosis of extracranial atheromatous disease, and determine its capacity to quantify the degree of stenosis in the internal carotid artery.
Material and methods: A retrospective study of patients with extracranial carotid atheromatous disease, in whom the diagnostic process was carried out with carotid ultrasound as well as supra-aortic trunk digital-subtraction angiography.
Results: A total of 254 carotids were evaluated and the degree of stenosis being classified into >50%, 70-99% and 100%. The UST for the first group had a sensitivity (Se) of 97%, a

* Corresponding author.
E-mail: portilla7819@yahoo.es (J.C. Portilla Cuenca).

specificity (Sp) of 90%, a positive predictive value (PPV) of 94.6%and a negative predictive value (NPV) of 94.2%. The second group had a Se of 96.4%, Sp 93%, PPV 94.4%and NPV 95.4%. The respective values for carotid occlusion were, 85%, 96.8%, 80%and 97.8%.
Conclusions: Our data validates the ability of UST performed in our Laboratory to diagnose the degree of carotid stenosis.

PALABRAS CLAVE
Angiografía cerebral;
Aterosclerosis carotidea;
Doppler;
Estenosis extracraneal;
Estudio ultrasonográfico

Validación del estudio ultrasonológico de troncos supraaórticos en el diagnóstico de la enfermedad aterosclerótica de la arteria carótida interna. Comparación de los resultados con los de angiografía

Resumen
Introducción: Se considera que la arteriosclerosis de las arterias extracraneales causa casi un tercio de los ictus isquémicos. El diagnóstico certero del grado de estenosis es fundamental para indicar la mejor estrategia terapéutica. Si bien la angiografía cerebral se considera la técnica de referencia, el estudio ultrasonográfico (EUS) es un procedimiento más disponible, no invasivo y bien establecido en la cuantificación de la estenosis carotídea. Sin embargo, al ser una técnica dependiente del explorador, se recomienda que cada laboratorio valide sus resultados frente a la angiografía.
Objetivos: Establecer, en nuestro laboratorio, la validez del estudio neurosonológico en el diagnóstico de la enfermedad ateromatosa extracraneal y determinar su capacidad para cuantificar el grado de estenosis de la arteria carótida interna.
Material y métodos: Estudio retrospectivo de los pacientes con enfermedad ateromatosa carotídea extracraneal en cuyo proceso diagnóstico se realizó tanto ultrasonografía carotídea como angiografía por sustracción digital de troncos supraaórticos.
Resultados: Se evaluaron 254 carótidas clasificando el grado de estenosis en > 50%, 70-99%y 100%. Para el primer grupo el EUS obtuvo una sensibilidad del 97%, una especificidad del 90%, un valor predictivo positivo (VPP) del 94,6%y un VP negativo (VPN) del 94,2%. En el segundo grupo, se obtuvo: sensibilidad, 96,4%; especificidad, 93%; VPP, 94,4%; y VPN, 95,4%. Para la oclusión carotídea los valores respectivos fueron del 85, el 96,8, el 80 y el 97,8%.
Conclusiones: Nuestros datos validan la capacidad del EUS realizado en nuestro laboratorio para el diagnóstico del grado de estenosis carotídea.

Introduction

Extracranial carotid atherosclerotic disease is considered to cause about 20% of all ischemic strokes.[1,2] Its optimal management includes an early diagnosis and subsequent protocolized monitoring,[3] as both medical and surgical treatments have proven effective in preventing recurrence; the benefit of one or the other depends on the characteristics of the disease itself. Surgical or endovascular treatment is therefore indicated in cases where there is an atheromatous plaque that narrows the arterial lumen by more than 70%, whereas, in general, medical treatment is recommended for stenoses that are less than 70%, although stenoses between 60 and 69%could be the subject of revascularisation in terms of other variables conditioning the risk/benefit ratio.[4] Therefore, the detection and quantification of the degree of carotid stenosis are essential in the indication of the most appropriate preventive treatment.

Even today, angiography still remains the gold standard in the diagnosis of extracranial atherosclerotic disease, despite being a relatively complex and invasive technique. These limitations favour its replacement by other more accessible, less risky procedures, such as neurosonological studies and neuroimaging techniques (MR and CT angiography).[5-9]

The use of carotid ultrasonography, through continuous pulsed Doppler associated with B-mode (duplex) images and colour Doppler, thanks to its high reliability, accessibility and reproducibility, has been established as the test of choice in the initial and follow-up studies of cerebrovascular disease with an atherothrombotic origin. However, it is considered appropriate to validate the reliability of the exploration results in each laboratory, since this is a technique that depends on both the instrument and the operator.

The aim of this study is to establish in our laboratory the validity of ultrasonography studies of the supra-aortic trunks in the diagnosis of extracranial atherosclerotic disease and to determine their ability to quantify the degree of stenosis of the internal carotid artery.

Table 1 Percentage of stenosis calculated for the internal carotid artery (ICA) according to findings from the neurosonological study

Stenosis in ICA	MSV in ICA	EDV in ICA	ICA / CCA ratio	Reduction of diameter in B mode
< 50%	< 4 kHz; < 120 cm/seg	< 1.3 kHz; < 40 cm/seg	< 1.5	< 50%
50-69%	> 4 kHz; > 120 cm/seg	> 1.3 kHz; > 40 cm/seg	> 1.8	> 50%
70-90%	> 8 kHz; > 250 cm/seg	> 3.3 kHz; > 100 cm/seg	> 3.5	> 50%
90-99%	Very elevated or very low	Very elevated or very low	> 4 or normal	Minimal or residual
100%	Not obtained	Not obtained	Not applicable	No residual lumen

CCA: common carotid artery, EDV: end diastolic velocity; MSV: maximum systolic velocity.

Material and methods

To establish our validation, we performed a retrospective study of patients with extracranial carotid atherosclerotic disease, both symptomatic and asymptomatic, in whose diagnostic process carotid ultrasonography or digital subtraction angiography of supra-aortic trunks was employed.

The neurosonological study was performed with a Logiq 400 CL PRO Series ultrasound model. The percentage of stenosis in the internal carotid artery was calculated according to the findings obtained with the ultrasound in B mode and colour mode (with which the size and morphology of the plate was determined) and on the basis of the results of the duplex in pulsed mode (with which the haemodynamic repercussion of the atheromatous plaque in the vessel lumen was established through the quantification of systolic, diastolic and average velocities). This was also done by placing the sample volume at the point of maximum stenosis and in upstream and downstream points to the stenosis (table 1). These measurements were obtained for both the axial and longitudinal planes of the internal carotid artery.

The angiographic study was performed with a Philips digital angiograph (model Integris Allura), with the selective study of supra-aortic trunks being performed in three projections. The percentage of stenosis was determined following the NASCET criteria.[10]

Sonographic studies were performed by 4 neurologists, 3 of them accredited by the Spanish Society of Neurology (JMRM, IGC, MCM and ICN), working in the Neurology Section at Hospital San Pedro de Alcantara in Caceres. Three radiologists from the Radiology Service at Hospital Infanta Cristina in Badajoz were involved in the performance of the angiographies. No kind of masking was employed on the operators who participated in both tests.

To analyse the validity of the methodology we have followed previous studies;[11] patients were stratified according to the percentage of stenosis. The cut-off points for different intervals were:

- For 50% stenoses below this interval produced a slight increase of speeds and frequency in the pulsed duplex study. In addition, stenoses below this value did not usually have an impact on decision-making for medical treatment indication.
- For 70% established as the cut-off point for its importance in the therapeutic decision, being the degree of stenosis at which the indication for revascularisation was established as a treatment of choice to prevent further recurrences.
- For 100% patients who presented extracranial carotid obstruction did not benefit from surgical treatment.

Patients were grouped into four groups according to the percentage of stenosis obtained by both techniques: *a*) those with stenosis less than 50%; *b*) those who presented stenosis between 50 and 69%; *c*) between 70 and 99%; and *d*) those with complete occlusion (100%). Subsequently, we elaborated 2 × 2 tables for each group and calculated the statistical values for sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and the kappa index.

The analysis of the results was performed blind by a neurologist (JCPC) who did not participate in the performance of any of the techniques.

Results

During the period between January 2001 and December 2007, both techniques were performed for the diagnosis of extracranial atherosclerotic disease in 128 patients. One of the patients was excluded from final analysis because it was not possible to determine the exact degree of stenosis in the angiographic study, so the study finally included 127 patients, representing 254 internal carotid arteries for analysis. In all the cases, the neurosonological study was carried out first and then the angiographic study was performed over a period of between 4 and 25 days. Some neurosonological studies were performed in the acute stage of ischemic cerebrovascular disease, while others were performed on an outpatient basis. Angiographic studies were not performed in the acute phase of ischemic cerebrovascular disease (less than a week).

Table 2 presents the final distribution of patients into groups, based on the percentage of stenosis obtained with both techniques.

The values distributed on the diagonal of the table correspond to cases that match the percentages of stenosis obtained with both diagnostic techniques, which occurred in 85% of patients (220 arteries), while those grouped above the diagonal are those in which the outcome of the

Table 2 Distribution of patients according to the percentage of stenosis determined by each examination technique

Percentage of stenosis according to neurosonological study	Percentage of stenosis according to angiographic study				
	0-49%	50-69%	70-99%	100%	Total
0-49%	81	3	2	0	86
50-69%	6	15	3	0	24
70-99%	3	5	96	5	109
100%	0	0	7	28	35
Total	90	22	109	33	254

The diagonal of the table represents cases in which there is concordance between both techniques.

Table 3 Non-correlated cases in which the neurosonological study underestimated the angiographic results (*)

	Right internal carotid artery		Left internal carotid artery	
	Neurosonology	Angiography	Neurosonology	Angiography
Case 1	Normal*	70%*	75%	80%
Case 2	Normal	Normal	40%*	75%*
Case 3	55%	60%	65-70%*	Filiform*
Case 4	65-70%*	90%*	90%	90%
Case 5	60%*	80%*	90%	85%
Case 6	< 50%*	55%*	70%	75%
Case 7	< 50%*	55%*	80%	< 50%
Case 8	< 50%*	64%*	70%	79%
Case 9	Filiform*	100%*	70%	79%
Case 10	Filiform*	100%*	40%	< 50%
Case 11	Filiform*	100%*	90%	95%
Case 12	Filiform*	100%*	60%	55%
Case 13	Filiform*	100%*	50-60%	60%

neurosonological study underestimated that obtained with the angiography study, representing 4.5% of the total (13 arteries). Finally, the cases represented under the diagonal are those in which the outcome of the neurosonological study overestimated the angiographic technique, which occurred in 8.25% of cases (21 arteries).

When we analyse the cases where the outcome of the neurosonological study underestimated that of the

Table 4 Non-correlated cases in which the neurosonological study overestimated the angiographic results (*)

	Right internal carotid artery		Left internal carotid artery	
	Neurosonology	Angiography	Neurosonology	Angiography
Case 1	60%*	Normal*	90%	90%
Case 2	70%	75%	50-60%*	40%*
Case 3	60-70%*	Normal*	Filiform	Filiform
Case 4	60%*	40%*	100%	100%
Case 5	100%	100%	60%*	< 50%*
Case 6	< 50%	< 50%	60%-70%*	< 50%*
Case 7	70%*	Normal*	50-60%	55%-60%
Case 8	< 50%	< 50%	90%*	< 50%*
Case 9	80%*	< 50%*	90-95%	Filiform
Case 10	Filiform	Filiform	Filiform*	60%*
Case 11	100%	100%	75-80%*	50%*
Case 12	Normal	Normal	70%*	56%*
Case 13	Normal	Normal	70%*	50%*
Case 14	70%*	66%*	50-60%	60%

*False positives for carotid occlusion are not included.

Table 5 Cases in which the neurosonological study estimated stenosis above 50%

	Angiographic study		
Neurosonology	Yes	No	Total
Yes	159	9	168
No	5	81	86
Total	164	90	254

Compared with the findings obtained by the angiography study (considered as the gold standard) for the same group of cases. The values of sensitivity, specificity, positive predictive value and negative predictive value were calculated with reference to this table.

Table 6 Cases in which the neurosonological study estimated stenosis above 70%

	Angiographic study		
Neurosonology	Yes	No	Total
Yes	136	8	144
No	5	105	110
Total	141	113	254

Compared with the findings obtained by the angiography study (considered as the gold standard) for the same group of cases. The values of sensitivity, specificity, positive predictive value and negative predictive value were calculated with reference to this table.

angiographic study (table 3), we can observe that in 3 of them (Cases 6, 7 and 8) the results obtained with both techniques were close to the 50%cut-off point. This means that they were grouped into different stenosis intervals, but without having a practical impact on clinical management. Similarly, we can see that in 6 cases (5, 9, 10, 11, 12 and 13), the percentages of stenosis in the neurosonological study were close to those of the angiographic. The main limitation of this analysis is the time delay in the completion of the angiography, which could influence the underestimation of stenosis by ultrasonography.

Table 4 also includes cases in which the outcome of the neurosonological study overestimated the angiographic. False positives for carotid occlusion were not represented, and were analysed later. It was noted that in 5 cases (2, 4, 5, 12 and 14), the values were close to the cut-off point for each subgroup, so they had no impact on clinical practice. In another 5 cases (1, 3, 9, 10 and 11), the contralateral artery presented high-grade atheromatous affectation; this could influence the results obtained in the neurosonological study by producing compensatory haemodynamic changes in the non-stenotic artery with an increase in blood flow speed, which would be detected in the pulsed duplex study as a false sign of stenosis in the arterial lumen.

Table 7 Cases in which the neurosonological study estimated occlusion

	Angiographic study		
Neurosonology	Yes	No	Total
Yes	28	7 (false +)	35
No	5 (false —)	214	219
Total	33	221	254

Compared with the findings obtained by the angiography study (considered as the gold standard) for the same group of cases. The values of sensitivity, specificity, positive predictive value and negative predictive value were calculated with reference to this table.

For the statistical analysis of the results, we performed 2 × 2 tables for each patient subgroup. Table 5 presents the analysis of the cases in which the neurosonological study estimated stenosis greater than 50%, compared with the results obtained by angiography. We obtained sensitivity values of 97% (95% confidence interval [CI], 94.3%99.6%) and specificity values of 90%(95%CI, 83.8%96.20%), PPV of 94.6% (95% CI, 91.24%98.05%) and NPV of 94.2% (95% CI, 89.24%99.13%), which means that the accuracy was 94.5%

Table 8 Non-correlated cases in which the neurosonological study overestimated the angiographic results in the diagnosis of carotid occlusion

	Left internal carotid artery		Right internal carotid artery	
	Neurosonology	Angiography	Neurosonology	Angiography
Case 1	Occlusion*	85%*	70-79%	75%
Case 2	Occlusion*	Filiform*	Occlusion	Occlusion
Case 3	Normal	< 50%	Occlusion*	70-80%*
Case 4	Normal	Normal	Occlusion*	Filiform*
Case 5	Normal	Normal	Occlusion*	Filiform*
Case 6	70-80%	72%	Occlusion*	Filiform*
Case 7	Filiform	Filiform	Occlusion*	Filiform*

*False positives in the diagnosis of internal carotid artery occlusion obtained by the neurosonological study.

and the kappa index was 0.88. Table 6 represents cases where stenosis was diagnosed over 70% with the neurosonological study and their comparison with the findings of digital angiography. The statistical values obtained for this patient group were: sensitivity, 96.4%(95% CI, 93.5%99.5%), specificity 93%(95% CI, 88.19%97.65%), PPV, 94.4%(95%CI, 90.70%98.19%) and NPV, 95.4%(95%CI, 91.56%99, 35%), with an accuracy of 94.8% and a kappa index of 0.89.

Compared with the findings obtained by the angiography study (considered as the gold standard) for the same group of cases. The values of sensitivity, specificity, positive predictive value and negative predictive value were calculated with reference to this table.

Finally, table 7 shows the statistical analysis for occlusions observed through the neurosonological study; the values obtained were: sensitivity, 85% (95% CI, 72.62%97.08%), specificity 96.8%(95%CI, 94.52%99.14%), PPV, 80%(95%CI, 66.75%93.25%) and NPV, 97.8% (95% CI, 95.74%99.70%), with an accuracy of 97.7%and a kappa index of 0.80. Of the total occlusions detected in the neurosonological study, 7 (20%) were false positives, that is, the percentage of stenosis observed on digital angiography was overestimated; in table 8 we can see that in 5 cases (71.5% of false positives), the true stenosis estimated by the angiographic study was greater than 95%, and this occurred irrespectively of the condition of the contralateral artery.

Compared with the findings obtained by the angiography study (considered as the gold standard) for the same group of cases. The values of sensitivity, specificity, positive predictive value and negative predictive value were calculated with reference to this table.

Discussion

The need to establish the degree of extracranial carotid stenosis in ischemic cerebrovascular disease is determined by the different therapeutic options according to the percentage of luminal stenosis. Angiography remains as the standard technique, but because it is invasive, costly and in some ways, scarcely accessible, it is necessary to establish other alternative diagnostic procedures that have high sensitivity and specificity in the detection of this disease. In this sense, the neurosonological study is particularly important, but according to the recommendations in the literature, it would be necessary to validate the results obtained in each laboratory.

In the analysis of the results of our series, we noted that there was general agreement between both techniques in 85%of cases, and we found that the neurosonological study overestimated angiographic findings more frequently than it underestimated them. It is possible that these results were due to the fact that the neurosonological study during the acute phase of ischemic stroke detected haemodynamic changes in the arteries studied that may have increased the velocities obtained in the pulsed duplex study and that this increase was considered secondary to stenosis of the arterial lumen. It was thus found that the largest number of overestimations took place in cases where the neurosonological study detected occlusion of the arterial lumen, although the angiographic study revealed a high grade stenosis. Consequently, we consider that, when faced with a possible neurosonological diagnosis of complete obstruction of the extracranial carotid artery during the acute phase of stroke, it is advisable to use echo-contrasts (which were not used in all cases in our series due to the lack thereof). It is likewise advisable to complete the study using transcranial Doppler techniques and other non-invasive imaging tests (CT/MR angiogram) to confirm the findings before performing digital subtraction angiography. The correct diagnosis in this group of patients has important therapeutic implications; in our series, we confirmed that in all cases except one (Case 4 in table 8), when we obtained erroneous results of arterial occlusion in the neurosonological study, revascularisation treatment was conducted after the angiographic findings.

When we performed the statistical analysis of sensitivity, specificity, PPV and NPV, we obtained high values for all percentages of stenosis. These were consistent with those of other published series.[12-17]

The main limitations of our analysis stem from the methodology used: as a retrospective study, there is a potential selection bias because the arteries analysed had a documented symptomatic carotid atherosclerotic disease in most cases, although in a small group the reason for the neurosonological study was an asymptomatic carotid bruit.

There may also be a verification bias, given that in our study angiography was performed more frequently in the most pathological neurosonological studies; this may have increased the sensitivity by increasing the prevalence of disease in the test. The existence of cut-off points to divide cases into subgroups may have caused the values obtained with both diagnostic techniques near these cut-off points to be framed within different groups, thus changing the statistical results obtained without having an impact on the clinical practice. Another limitation to note is the delay in carrying out both tests, since the atheromatous disease could progress in that period and cause an underestimation of the findings obtained previously by neurosonology. Neither were the anatomical characteristics of individual patients taken into account, which may have hindered the performance of the ultrasonography technique and, therefore, of its findings. The possible bias in the review of the results was reduced by carrying out the analysis of angiographic studies blindly to the ultrasonography study that had motivated them; moreover, the analysis was conducted by a neurologist who did not actively participate in the completion of any additional studies.

We believe that both the concordance values and the statistical analyses show the great reliability of our neurosonology laboratory in the diagnosis of extracranial carotid atheromatous disease. Despite this, we believe that the results can be improved if we reduce the time delay between duplex and arteriography and complete the study with complementary techniques, particularly transcranial Doppler, which will provide useful information on the haemodynamic status through the study of collateral circulation and cerebral vasoreactivity tests and will help us in making treatment decisions. In addition, echo-contrast techniques should be used and the results should be confirmed once the acute phase of ischemic disease has passed.

Presentations

Partially presented at the LX Annual Meeting of SEN.

Conflict of interests

The authors declare no conflict of interests.

Acknowledgements

Juan Zapata and Rosa Moro. Radiology Department, Hospital Infanta Cristina.

References

1. Feigin VL, Lawes CMM, Bennett DA, Anderson CS. Stroke epidemiology: A review of population-based studies of incidence, prevalence, and case-fatality in the late 20th century. Lancet Neurol. 2003;2:43-53.
2. King IJM, Young V, Gillard J. Carotid-artery imaging in the diagnosis and management of patients at risk of stroke. Lancet Neurol. 2009;8:569-80.
3. Álvarez Sabin J, Rovira Cañellas A, Molina C, Serena J, Moltó M. por el comité ad hoc del Grupo de Estudio de Enfermedades Cerebrovasculares de la SEN, Guía para la utilización de métodos y técnicas diagnósticas en el ictus. In: Díez Tejedor E, editors. Guía para el diagnóstico y tratamiento del ictus. Barcelona: Prous Science; 2004. p. 25-63.
4. Harold A, Del Zopo G, Mark A, Deepak L, Brass L, Furlan A, et al. Guidelines for the early management of adults with ischemic stroke. Stroke. 2007;38:1655-711.
5. Debrey SM, Yu H, Lynch JK, Lövblad KO, Wright VL, Janket SJ, et al. Diagnostic accuracy of magnetic resonance angiography for internal carotid disease: a systematic review and meta-analysis. Stroke. 2008;39:2237-48.
6. Yuan C, Mitsumori LM, Beach KW. Carotid atherosclerotic plaque: nonivasive MR characterization and identification of vulnerable lesions. Radiology. 2001;221:285-99.
7. DeMarco JK, Huston J, Nash AK. Extracranial carotid MR imaging at 3T. Magn Reson Imaging Clin N Am. 2006;14:109-21.
8. Saloner D, Acevedo-Bolton G, Wintermark M, Rapp JH. MRI og geometric and compositional features of vulnerable carotid plaque. Stroke. 2007;38(Suppl 2):637-41.
9. Gil Peralta A, Martínez Fernández E. Estudio neurosonológico de los troncos supraaórticos. In: Arboix A, editor. Métodos diagnósticos en las enfermedades vasculares cerebrales. Madrid: Ergon; 2006. p. 215-31.
10. North American Symptomatic Carotid Endarterectomy Trialists' Collaborative Group. N Engl J Med. 1998;339:1415-25.
11. Garzón F, Gil-Peralta A, Otero A, Crespo P, Salinas E. Estudio de validez del Doppler continuo. Rev Neurol. 1999;29:980-4.
12 Blakeley DD, Oddone EZ, Hasselblad V, et al. Noninvasive carotid artery testing. A meta-analytic review. Ann Intern Med. 1995;122:360-7.
13. Leonardo G, Crescenzi B, Cotrufo R, et al. Improvement in accuracy of diagnosis of carotid artery stenosis with duplex ultrasound scanning with combined use of linear array 7.5MHz and convex array 3.5MHz probes: validation versus 489 arteriographic procedures. J Vasc Surg. 2003;37:1240-7.
14. Hwang CS, Liao KM, Lee JH, Tegeler CH. Measurement of carotid stenosis: comparisons between duplex and different angiographic grading methods. J Neurimaging. 2003;13:133-9.
15. Fortea Cabo G, Fages Caravaca EM, Tembl JI, Boscá Blasco I, Lago Martin A. Control de calidad del diagnóstico mediante Doppler en neurología vascular. Rev Neurol. 2003;37:627-31.
16. Fernández V, Bellmunt S, Escribano JM, Juan J, Allegue N, Álvarez-Sabin J, et al. Indicaciones de endoarterectomia carotidea sin arteriografía. Estudio de validación mediante eco-Doppler. Rev Neurol. 2000;31:412-6.
17. Wardlaw JM, Chappell FM, Best JJK, Wartolowska K, Berry E, on behalf of the NHS Research and Development Health Technology Assessment Carotid Stenosis Imaging Group. Non-invasive imaging compared with intra-arterial angiography in the diagnosis of symptomatic carotid stenosis: a meta-analysis. Lancet. 2006;367:1503-12.