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SPECIAL ARTICLE

Standard method for ultrasound evaluation of carotid artery lesions

Terminology and Diagnostic Criteria Committee, Japan Society of Ultrasonics in Medicine

Objectives

This report is aimed at providing standard methods for ultrasound evaluation of carotid artery lesions which will help the diagnosis and treatment of lifestyle- related diseases (diabetes mellitus, dyslipidemia, hypertension, smoking, obesity, etc.) and atherosclerotic arterial diseases (cerebrovascular disease, ischemic heart disease, arteriosclerosis obliterans, etc.).

Indications

Carotid artery ultrasonography is indicated in the following cases: (1) patients having diseases that are more likely to be associated with stenosis or obstructive lesions of the carotid artery (cerebrovascular disease, disturbed perfusion through the vertebral and basilar arteries, Takayasu disease, etc.) or patients having clinical signs suggestive of such diseases (hemiplegia, arterial bruit, pulse weakness, etc.) or (2) patients requiring risk evaluation of invasive treatment for atherosclerotic lesions of other organs (coronary artery disease, arteriosclerosis obliterans, aortic aneurysm, etc.).

In addition, this examination may be indicated also in (3) patients who have risk factors for atherosclerosis (diabetes mellitus, dyslipidemia, hypertension, smoking, obesity, etc.) and in whom the possibility of progression in atherosclerosis cannot be ruled out.

Examination procedure

Posture of the patient

Usually, the patient is examined in a supine (or sitting) position. The posture needs to be modified to allow an extensive area of the patient's body to be observed (Fig. 1). Observation is expected to be easier if the area to be observed is extended and the head is inclined by about 30° (Fig. 1, left). Depending on the patient's physique, insertion of a pillow, towel tion of the origin of the common carotid artery (Fig. 1, upper right). The distal part of the internal carotid artery may be observed effectively if observation is made from behind the neck of the patient with lateral decubitus position (Fig. 1, lower right).

Selection of a probe

Usually, a high-frequency linear array probe is used for carotid artery ultrasonography because of the morphological features and location (depth) of the carotid artery. The center frequency of the probe needs to be 7 MHz or higher

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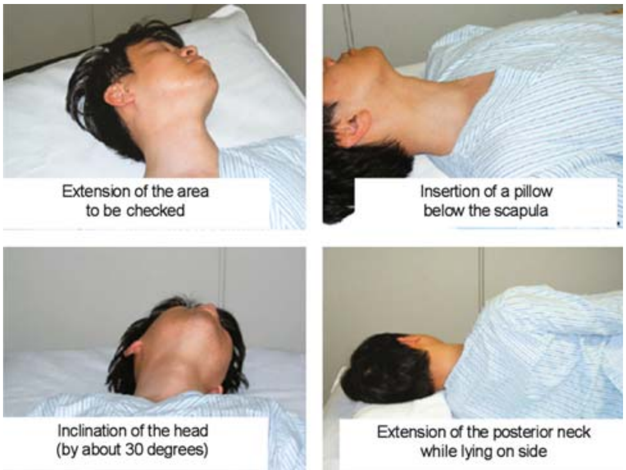


Fig. 1 Position of patient (*left*: ordinary posture for test of the right carotid artery, *right*: a posture using a pillow)

if the accuracy of measurement for the intima-media complex (IMC) is taken into account.

For observation of blood vessels located deeply (e.g., the distal segment of the internal carotid artery), a convex probe or a sector probe with the center frequency of about 5 MHz is sometimes useful.

Method of imaging

Two-dimensional ultrasonography

When taking short-axis view of blood vessels (transverse image), the patient is observed from the caudal side (the foot side), and the patient's right side is presented on the left side of the image obtained as one faces it. When taking longaxis view of blood vessels (longitudinal image), the direction is presented on the image obtained.

Color Doppler method

The color used for color Doppler method is red (warm color) for the blood flow approaching the probe and blue (cold color) for the blood flow leaving the probe (Fig. 2). This decision does not apply if a color bar is shown in the image.

Pulse Doppler method

When presenting the direction of blood flow relative to the baseline of the Doppler flow, the blood flow approaching the probe is depicted above the baseline (the positive side) while the blood flow leaving the probe (Fig. 3) is depicted below the baseline (the negative side). This decision does not apply if the orientation of blood flow is specified on the image. Simultaneous ECG is advisable if distinction of arteries from veins or evaluation of blood flow patterns is required.

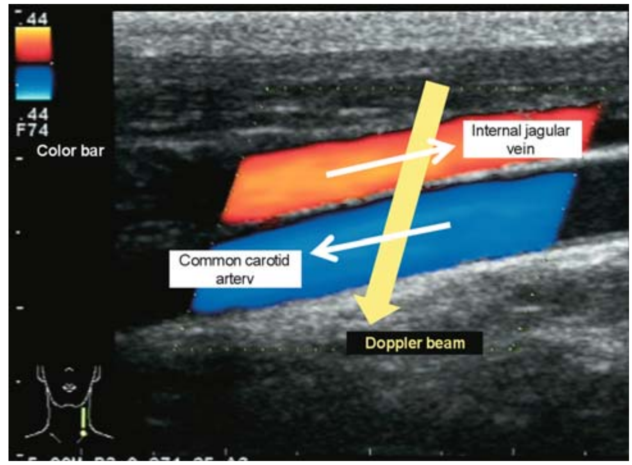


Fig. 2 Representation by color Doppler method

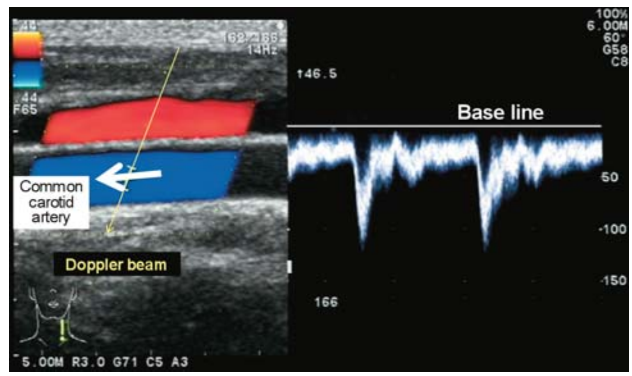


Fig. 3 Representation by pulse Doppler method

Approach

Setting the cross-section to be observed

Two-dimensional observation of the carotid artery involves two directions (short-axis view and long-axis view). Short-axis view is particularly useful to check for vascular lesions. However, short-axis scanning needs to be made in at least two directions, i.e., anterior and lateral (posterior) directions, so that inadequate depiction in one direction may be made up for by depiction in another direction (Fig. 4).

Scope of observation

Carotid artery ultrasonography covers the observation-possible areas of the common carotid artery (CCA), bulbus (Bul or bifurcation; Bif), internal carotid artery (ICA) and vertebral artery (VA) on both the right and left side. As needed, the external carotid artery (ECA), sub-clavian artery (SCA), and their branch arteries may also be covered. Observation of the CCA, bulbus and ICA is indispensable when evaluation of IMC thickness (IMT: intima-media thickness) and plaques is needed.

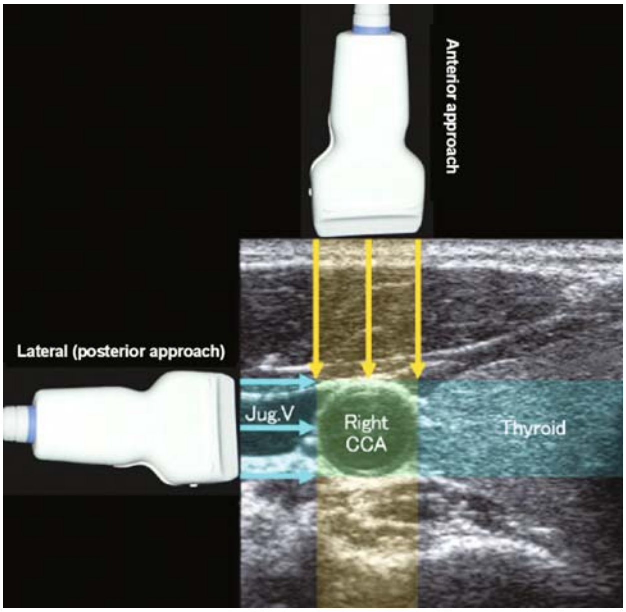


Fig. 4 Short-axis view: anterior and lateral approach

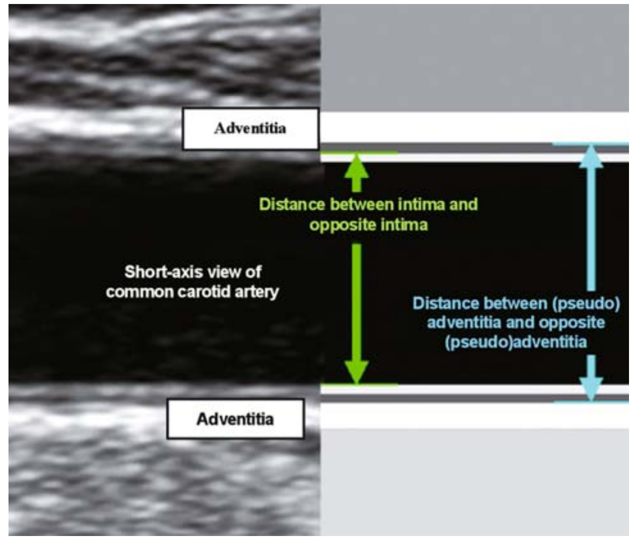


Fig. 5 Sampling points for vascular diameter measurement

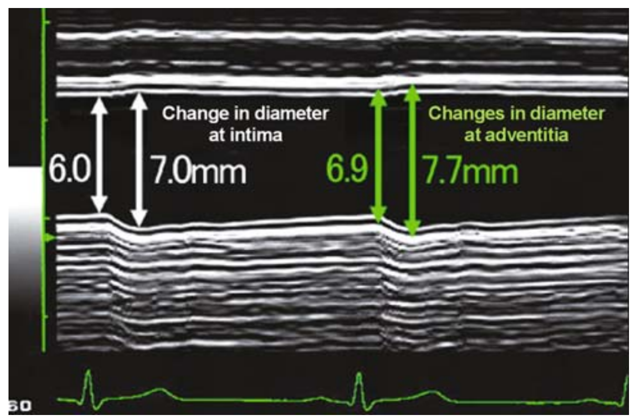


Fig. 6 Phase of vascular diameter measurement (associated with QRS on ECG)

Parameters

IMT

When checking for atherosclerotic lesions, maximum intima-media thickness (max IMT) of the common carotid artery, bulbus and internal carotid artery on the right and left side is an indispensable parameter, and mean intima-media thickness (mean IMT) of the common carotid artery may be measured as an optional parameter.

Percent stenosis

Percent stenosis of area of the common carotid artery is measured as an indispensable parameter, and percent stenosis of diameter is additionally measured as needed. When checking for lesions of the internal carotid artery, percent stenosis according to the criteria of the North American Symptomatic Carotid Endarterectomy Trial (NASCET) is measured as a primary parameter, accompanied as needed by measurement of percent diameter narrowing and percent stenosis of diameter according to the criteria of the European Carotid Surgery Trial (ECST). In addition, blood flow (maximum velocity, etc.) through the stenotic lesion is also measured.

Arterial diameter

Vascular diameters used for evaluation of stenosis and aneurysmal dilatation are measured at the affected point of the blood vessels concerned. In screening tests, arterial diameter is measured on two-dimensional ultrasound images taken during the contracting phase (diastolic phase). The diameter measured is basically the distance between the intimal layer and the opposite intimal layer or between the (pseudo) adventitial layer and the opposite (pseudo) adventitial layer (Fig. 5). In M-mode ultrasonography or ECG-gated ultrasonography, vascular diameter is measured during the late phase of vascular contraction (end diastolic phase: QRS phase on ECG) (Fig. 6). It is necessary for both the point and the value of measurement to be described in the report. For example, diameter of common carotid artery (minimal distance between the internal layers) = 6. 0 mm.

Measurement of IMT

Measurement of max IMT IMC is composed of two layers, i.e., the hyperechoic layer closer to the vascular lumen

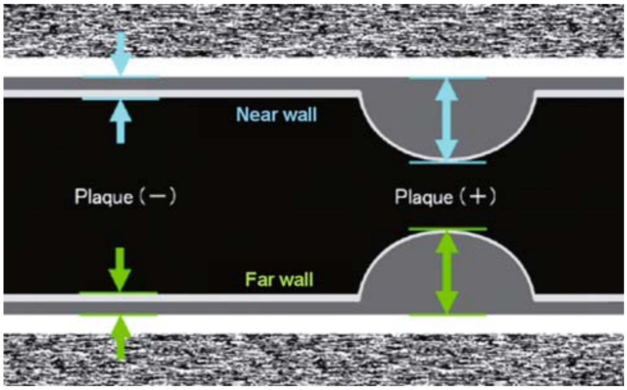


Fig. 7 Sampling points for IMT measurement

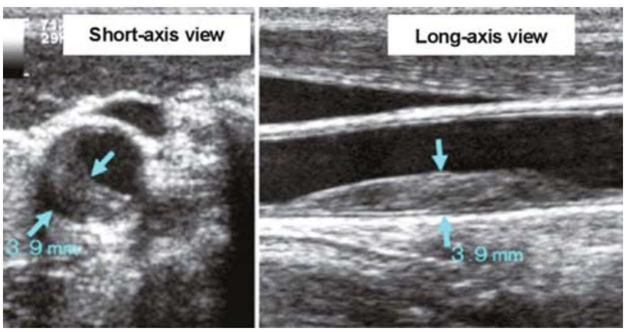


Fig. 8 Evaluation of lesions on short-axis and longaxis view

and the hypoechoic layer. It is known that an increase in its thickness, IMT, correlates with atherosclerotic diseases such as cerebral infarction and myocardial infarction and lifestyle-related diseases, which are risks for atherosclerotic diseases (Fig. 7). On both the right and left sides, max IMT is measured in the observation-possible areas of the CCA, bulbus (Bul or Bif) and ICA, excepting the ECA. In cases where the artery has obstruction or calcification, "not evaluable" should be described in the report. Because of the characteristics of ultrasound, depiction of IMC along the anterior wall is sometimes difficult. If such difficulty forces observation to be confined to the posterior wall, the report should specify that max IMT has been obtained only for the posterior wall (far wall). The minimum unit of IMT measurement should be 0.1 mm. It is desirable to magnify the image for this measurement so that the error in measurement may be minimized. Either the short-axis view or the long-axis view of the blood vessel may be used for measurement of IMT. However, it is desirable to adopt IMT based on measurement in both directions and comparison between the both views (Fig. 8).

Mean IMT Measurement of mean IMT is performed on the right and left common carotid artery, excluding the

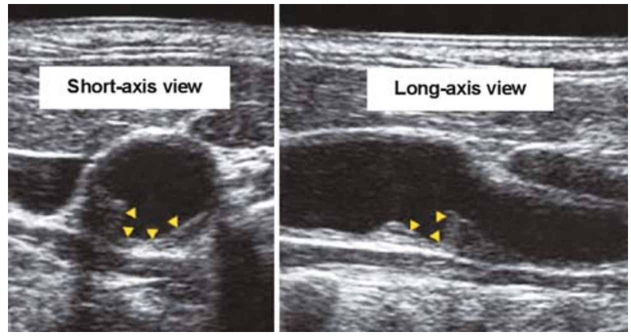


Fig. 9 Plaques accompanied by ulcer

bulbus (Bul or Bif). Mean IMT is an average of readings at two or more points of measurement. Reported methods for measurement of mean IMT include automatic measurement using IMT software, calculation of a mean of 3 points (including max IMT) after measurement of IMT at the point of max IMT and two surrounding points on both side (each 1 cm distant from the point of max IMT), and so on.

Measurement of plaques

Definition of plaques Localized elevated lesions with maximum thickness of more than 1 mm, having a point of inflection on the surface of IMC, are defined as "plaques". In cases of vascular remodeling, the term "plaques" may be used, irrespective of the presence/absence of elevation of the lesion into the vascular lumen. Plaques are included when measuring max IMT (Fig. 7).

Imaging of plaques Usually, images of the plaque are taken in two directions (short axis and long axis views) of the blood vessel where the maximum thickness may be depicted. However, when imaging is designed to characterize the surface or inside, appropriate cross-sections to be imaged may be selected without a limit.

Parameters and properties of plaques On each plaque, the following parameters and properties are measured or evaluated: (a) size including the maximally thick area and the elevated area, (b) surface morphology, (c) internal properties, (d) mobility, and so on. These parameters and properties are important for evaluation, treatment and follow-up of atherosclerotic lesions.

(a) Measurement of plaques

Like measurement of IMT, plaque thickness is measured at the maximally thick point at the border with the vascular lumen and the adventitial layer (Fig. 7). Usually, plaque size is expressed as plaque thickness. It is sometimes expressed as plaque area, percent occupied area, etc., along the major axis of the blood vessels or on short-axis view.

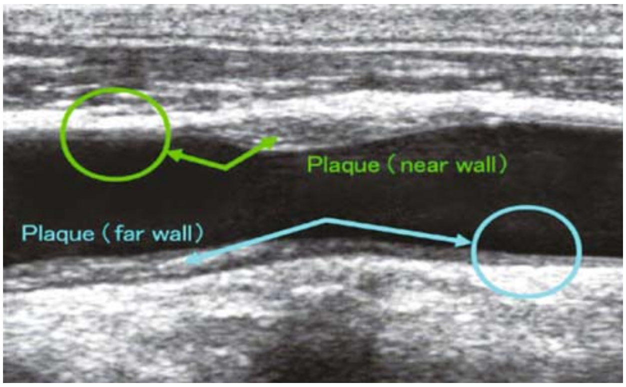


Fig. 10 Structure serving as a control for evaluation of plaque echogenicity

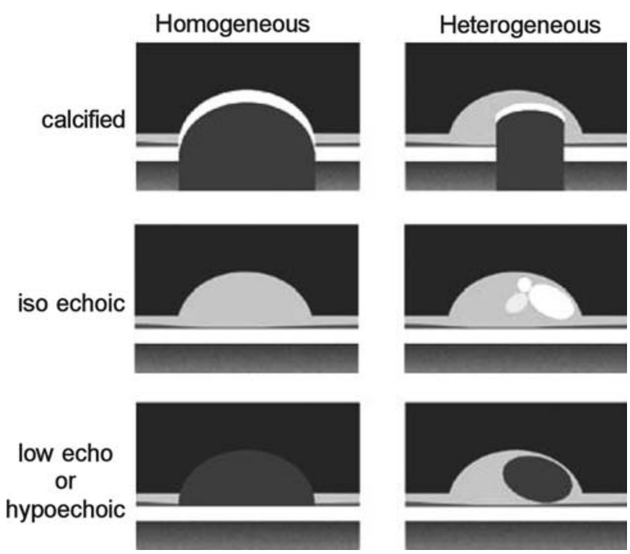


Fig. 11 Plaques classified by echogenicity and texture

(b) Plaque surface morphology

Plaque surface morphology is expressed using terms such as smooth, irregular, and ulcerated (accompanied by marked depression, as shown in Fig. 9).

(c) Echogenicity classification and texture of plaques

Plaques are divided into three major types by the echogenicity inside the plaques. They are further subdivided into six types according to the texture of internal echo. Evaluation of echogenicity of plaques requires a structure for comparison. "The IMC around the plaque" is adopted as this structure (control), and its echogenicity is compared with that within the plaque. Because echogenicity can vary depending on the depth of observation or conditions of recording, the IMC on the same side as the plaque (i.e., the IMC facing the anterior wall or the posterior wall) is selected as the control (Fig. 10). Echogenicity is rated on a three-category scale: (a) calcified (hyperechoic; calcified lesions accompanied by acoustic shadow), (b) low echo (hypoechoic or echolucent) (areas with low echogenciity as compared to the control structure), and (c) is echoic (echogenicity comparable to that of the control structure). Plaques with partially low echogenicity are preferentially rated as low echo (hy-poechoic) even when they include some hyperechoic or iso echoic areas. Each type is subdivided into homogenous type (uniform echogenicity inside the plaque) and heterogenous type (non-uniform echogenicity). In total, there are six types (homogenous hyperechoic type, heterogenous hyperechoic type, homogenous is-echoic type, heterogenous iso-echoic type, homogenous hypoechoic type and heterogenous hypoechoic type), as shown in Fig. 11. If adequate depiction is not possible even with imaging in multiple directions and it is difficult to evaluate echogenicity inside the plaque, the entry should be "difficult to distinguish" instead of attempting distinction based on inadequate findings.

(d) Mobility

Mobile plaques are sometimes found. Pedunculated substances, fibrous capsules covering hypoechoic substances and entire or partial plaques may be mobile. These represent thrombi or vulnerable plaques to which attention should be drawn as plaques prone to cause embolism.

Plaque score Plaque scoring is useful as a means of semiquantitative analysis of the degree of atherosclerosis. The simplest way of scoring plaques, reported to date, is to total the plaque thickness for three segments (internal carotid artery, bulbus and common carotid artery) on each of right and left sides. 3.6 Pulse Doppler test of blood flow.

(1) Sampling point

In cases of stenosis, sampling points are set at the stenotic points. In cases free of stenosis, sampling points may be set freely at points which will allow good depiction. However, the points showing a change in diameter, points near bifurcation and tortuous points are not suitable as sampling points because of unstable flow rate and possible blood flow turbulence. Each sampling point usually should have a size equivalent to 1/2 or more of the vascular diameter and within the size of the vascular lumen. It is set at the center of the blood vessel. In cases of stenosis, the extent of stenosis is taken into account when setting the size of the sampling point. The Doppler incident angle should be within 60° (with error of measurement taken into account). It is advisable to set this angle as small as possible (Fig. 12).

(2) Measurement of blood flow patterns

In cases free of stenosis, blood flow through the carotid artery is measured at points of bilateral CCA and ICA

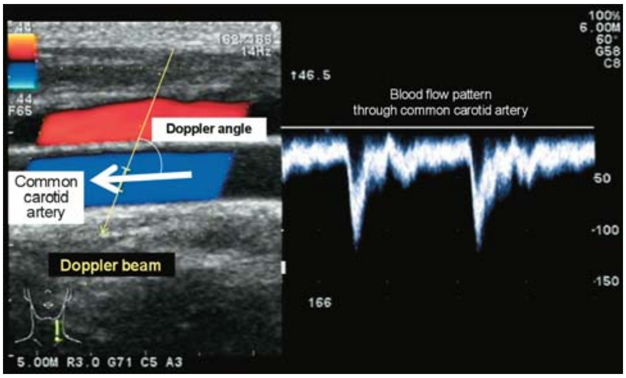


Fig. 12 Correction of angle for pulse Doppler blood flow patterns

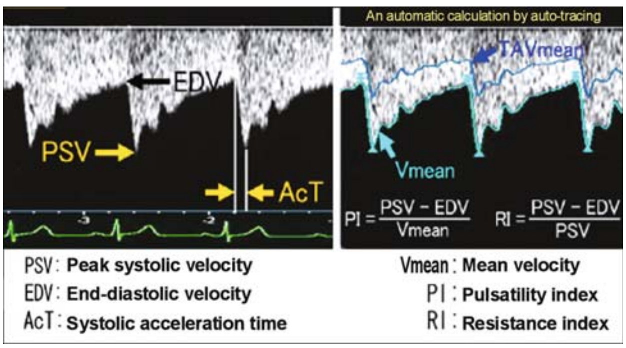


Fig. 13 Parameters for Doppler evaluation of blood flow patterns

where good depiction and incident angle are expected. In cases of stenosis, this measurement should be done at and around the stenosis. Parameters measured are peak systolic velocity (PSV) and end-diastolic velocity (EDV) (Fig. 13). As needed, measurement is also made of acceleration time (AcT), peak systolic velocity/end-diastole velocity (SD ratio), resistance index (RI), pulsatility index (PI, based on mean blood flow velocity Vmean) (Fig. 13). The laterality of end-diastolic velocity (EDV) (ratio of higher velocity/lower velocity; ED ratio) is also useful, and individuals with this ratio of CCA over 1.4 are likely to have distal obstruction or intense stenosis on the lower EDV side (ICA obstruction suggested in cases where this ratio is over 4).[1]

[1] Mean blood flow velocity can be calculated in two ways. One is TAV mean, the average of time-averaged velocity, which is used for calculation of blood flow and can be calculated by tracing TAV by automatic tracing function of the device. The other is Vmean, a synonym of time-averaged maximum velocity, which is the time average of maximum velocity calculated by tracing the maximum velocity per second and is used for calculation of pulsatility index (PI).

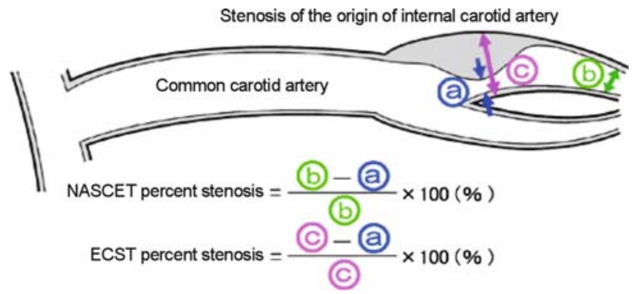


Fig. 14 Methods for calculating percent stenosis

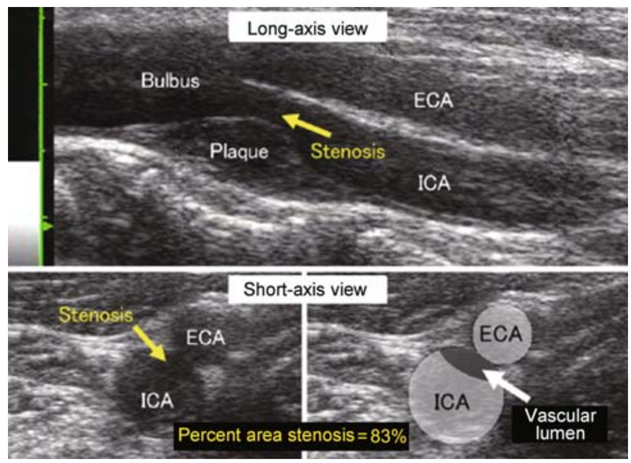


Fig. 15 Methods for calculating percent area stenosis

Evaluation of stenosed lesions

Method for calculation of percent stenosis

Like angiographic evaluation of stenosis, ultrasound evaluation of stenosis involves quantitative evaluation on the basis of calculation of percent stenosis. Because ultrasonography allows simultaneous observation of vascular lumen and wall, unlike angiography, the past method of measuring percent stenosis was based on the diameter stenosis rate (ECST method, Fig. 14) and the area stenosis rate. However, NASCET method (Fig. 14) is recommended for evaluation of stenosis of the origin of the internal carotid artery, which is more likely to develop stenosis, because this area is elevated adjacently to the bulbus, it has larger vascular diameter than the distal side, and thus ECST method overestimates percent stenosis compared to angiography. With NASCET method, the criterion vascular diameter is the diameter of the intact area of the internal carotid artery distal to the stenosed area where the diameter is stable (Fig. 14b). Because different methods are available for calculation of percent stenosis, the method adopted needs to be specified in each report.

For measurement of the vascular internal diameter to calculate percent stenosis, B-mode ultrasound image is used, as far as possible. In cases where B-mode image is difficult to obtain and the blood flow depicted by the color Doppler method is used as a guide for calculation of percent stenosis, the data should be labeled as "reference data."

Method for calculation of percent stenosis on irregularly stenotic area

The stenotic lumen of peripheral blood vessels often assumes irregular forms (e.g., oval or half moon forms), making it difficult to make appropriate evaluation of percent stenosis on long axis view. For this reason, when evaluating stenotic area on two-dimensional ultrasound images, measurement is based on short-axis view, whenever possible, and area stenosis rate is also calculated simultaneously (Fig. 15).

Estimation of percent stenosis by Doppler method

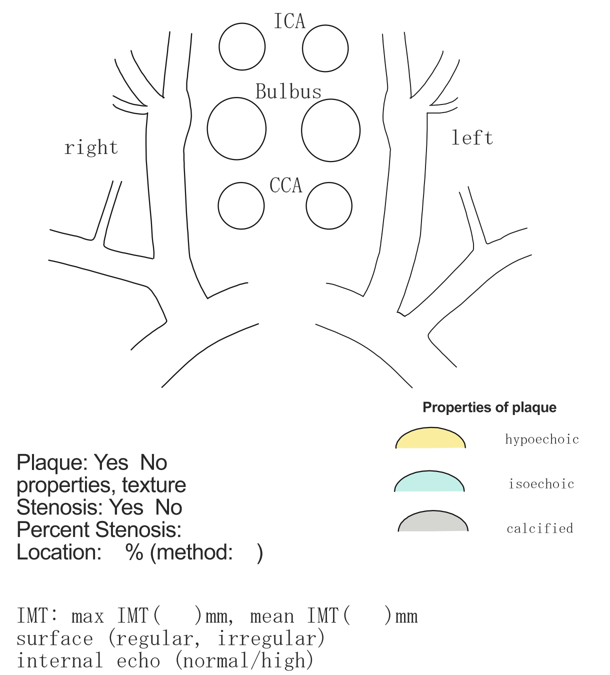
In cases where two-dimensional ultrasound images of the stenotic area are difficult to take because of calcification or other reasons, percent stenosis may be estimated on the basis of peak systolic velocity (PSV), end-diastolic velocity (EVD), etc., by taking records of blood flow through the common carotid artery, stenotic area and post-stenotic part of internal carotid artery with pulse Doppler or continuous wave Doppler method. If PSV of the stenotic area exceeds 1.5 m/s, NASCET percent stenosis is estimated to be 50% or higher. If PSV is over 2.0 m/s, NASCET percent stenosis is estimated to be 70% or higher. In cases of severe stenosis, the blood flow distal to the stenotic area may show acceleration time (AcT) prolongation or turbulent flow.

Remarks

This standard evaluation method is based on the reports and clinical practice as of 2008. The standard may require modification based on forthcoming research findings and reports in the future.

Reference: Reporting the results of ultrasound evaluation of carotid artery

When reporting the results of ultrasound evaluation of the carotid artery, it is advisable to attach graphic representation (figure or reference)



of presence/absence and properties of lesions to ensure correct and easily understandable reporting to the physician who order imaging or to the attending physician.

Appendix

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