ASE CONSENSUS STATEMENT

# Use of Carotid Ultrasound to Identify Subclinical Vascular Disease and Evaluate Cardiovascular Disease Risk: A Consensus Statement from the American Society of Echocardiography Carotid Intima-Media Thickness Task Force *Endorsed by the Society for Vascular Medicine*

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Continuing Medical Education Course for "Use of Carotid Ultrasound to Identify Subclinical Vascular Disease and Evaluate Cardiovascular Disease Risk: A Consensus Statement for the American Society of Echocardiography Carotid Intima-Media Thickness Task Force"

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***Target Audience:***

1. Physicians, physicians' assistants, and nurses with an interest in cardiac and vascular imaging, preventive cardiology, and cardiovascular disease risk assessment. 2. Ultrasonographers with interest in vascular imaging and cardiovascular disease risk assessment.

***Objectives:***

Upon completing this activity, participants will be able to: 1. Describe the rationale for using carotid ultrasound to identify subclinical vascular disease and to evaluate cardiovascular disease risk. 2. Explain the application of carotid ultrasound to cardiovascular disease risk assessment. 3. Describe the scanning technique for identifying subclinical vascular disease using carotid ultrasound. 4. Explain the key components of interpreting carotid ultrasound studies for cardiovascular disease risk assessment.

***Authors Disclosures:***

James H. Stein, MD, FASE:
Research grants: Siemens Medical Solutions, Sonosite
Intellectual property: listed as the inventor of Patent #US 6,730,0235 "Ultrasonic Apparatus and Method for Providing Quantitative Indication of Risk of Coronary Heart Disease." It has been assigned to the Wisconsin Alumni Research Foundation.
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Speakers bureau for Merck, BMS-Sanofi and AstraZeneca; Research grant support from BMS-Sanofi, Pfizer and GSK.
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## SUMMARY

There is great interest in identifying asymptomatic patients at high risk who might be candidates for more intensive, evidence-based medical interventions that reduce cardiovascular disease (CVD) risk. Measurement of carotid intima-media thickness (CIMT) with B-mode ultrasound is a noninvasive, sensitive, and reproducible technique for identifying and quantifying subclinical vascular disease and for evaluating CVD risk. To address issues of standardization and help improve the availability of experienced clinical laboratories that can perform high-quality CIMT studies, this consensus document provides recommendations for the use of carotid ultrasound for identifying and quantifying subclinical vascular disease and for evaluating CVD risk in clinical practice. Nine published prospective studies that included at least 1000 asymptomatic participants have examined CIMT and CVD risk. Each study demonstrated that CIMT was significantly associated with risk for myocardial infarction, stroke, death from coronary heart disease, or a combination of these events. In most of these studies, the ability of CIMT to predict future CVD events was independent of traditional risk factors. Furthermore, 9 large studies have demonstrated similar or greater predictive power for carotid plaque and CVD.

Measuring CIMT and identifying carotid plaque can be useful for refining CVD risk assessment in patients at intermediate CVD risk (ie, patients with a 6%-20% 10-year risk of myocardial infarction or coronary heart disease death who do not have established coronary heart disease or coronary disease risk equivalent conditions). Patients with the following clinical circumstances also might be considered for testing: (1) family history of premature CVD in a first-degree relative; (2) individuals younger than 60 years old with severe abnormalities in a single risk factor who otherwise would not be candidates for pharmacotherapy; or (3) women younger than 60 years old with at least two CVD risk factors. This test can be considered if the level of aggressiveness of therapy is uncertain and additional information about the burden of subclinical vascular disease or future CVD risk is needed. Imaging should not be performed unless the results would be expected to alter therapy. CIMT testing can reclassify patients at intermediate risk, discriminate between patients with and without prevalent CVD, and predict major adverse CVD events. Outcome data regarding the ability of a management strategy that includes CIMT or plaque screening tests to improve cardiovascular outcomes are limited to changes in patient or physician behavior that would be expected to reduce CVD risk. Consensus recommendations are highlighted in **bold** and are also presented in tables. Because a randomized, controlled trial studying the effectiveness of carotid ultrasound imaging as a tool to modify preventive therapies and improve CVD outcomes has not yet been performed, the clinical practice recommendations in this document are based on the best available observational data. For CVD risk assessment, carotid ultrasound imaging and measurement should follow the protocol from a large epidemiologic study that reported CIMT values in percentiles by age, sex, and race/ethnicity (eg, the Atherosclerosis Risk in Communities Study). The recommended carotid ultrasound scanning protocol is described in detail. CIMT measurements should be limited to the far wall of the common carotid artery and should be supplemented by a thorough scan of the extracranial carotid arteries for the presence of carotid plaque, to increase sensitivity for identifying subclinical vascular disease. Carotid plaque is defined as the presence of focal wall thickening that is at least 50% greater than that of the surrounding vessel wall or as a focal region with CIMT greater than 1.5 mm that protrudes into the lumen that is distinct from the adjacent boundary. The presence of carotid plaque or CIMT greater than or equal to 75th percentile for the patient's age, sex, and race/ethnicity are indicative of increased CVD risk and may signify the need for more aggressive risk-reduction interventions. Serial studies of CIMT to address progression or regression are not recommended.

## INTRODUCTION

Atherosclerotic vascular disease begins in childhood and progresses over decades.[1] Symptomatic, clinical cardiovascular disease (CVD) events generally occur when atherosclerosis progresses to flow-limiting disease that causes ischemia, or when a thrombus forms on an existing plaque as a result of rupture or erosion.[2] Although not everyone with underlying atherosclerotic plaque will experience a clinical CVD event, the greater the degree of subclinical atherosclerosis, the greater the risk for future cardiovascular events.[3-7] To prevent death and morbidity from CVD, there is great interest in identifying asymptomatic patients at high risk who would be candidates for more intensive, evidence-based medical interventions that reduce CVD risk.[3,4] Imaging of arteries to identify and quantify the presence of subclinical vascular disease has been suggested to further refine CVD risk assessment.[3,4] As a screening test, imaging must be safe, be sensitive, be affordable, and lead to interventions that can favorably alter the natural history of CVD. Measurement of carotid intima-media thickness (CIMT) with B-mode ultrasound is a noninvasive, sensitive, and reproducible technique for identifying and quantifying atherosclerotic burden and CVD risk. It is a well-validated research tool that has been translated increasingly into clinical practice.[8-13] The United States Centers for Medicare and Medicaid has established a *Current Procedural Terminology* code (0126T) for "Common CIMT study for evaluation of atherosclerotic burden or coronary heart disease risk factor assessment."

In 2000, the American Heart Association Prevention Conference V concluded that CIMT "can now be considered for further clarification of coronary heart disease (CHD) risk assessment at the request of a physician," provided that it is performed by an experienced laboratory.[3] In 2001, the National Cholesterol Education Program (NCEP) Adult Treatment Panel III stated that CIMT "could be used as an adjunct in CHD risk assessment . . . the finding of an elevated CIMT (eg, ≥75th percentile for age and sex) could elevate a person with multiple risk factors to a higher risk category," while noting that "expense, lack of availability, and difficulties with standardization preclude a current recommendation for its use in routine risk assessment."[14] This expert panel concluded that "if carried out under proper conditions, CIMT could be used to identify persons at higher risk than that revealed by the major risk factors alone."[14] The clinical application of CIMT methodology recently was reviewed in a report from the American Society of Echocardiography (ASE) and the Society of Vascular Medicine and Biology.[15] To address issues of standardization and help improve the availability of experienced clinical laboratories that can perform high-quality CIMT studies, this consensus statement provides recommendations for the use of carotid ultrasound to assess subclinical vascular disease and CVD risk.

## RATIONALE FOR USING CAROTID ULTRASOUND TO IDENTIFY SUBCLINICAL VASCULAR DISEASE AND EVALUATE CVD RISK: EVIDENCE FROM CLINICAL RESEARCH STUDIES

Standard clinical carotid duplex ultrasound studies primarily are indicated to identify occlusive carotid plaques (ie, carotid artery

**Table 1** Prospective studies of carotid intima-media thickness and risk for cardiovascular disease events in individuals without known cardiovascular disease (N >1000 participants each)

| Study | N | Age (y); F | Follow-up (y) | Measurement; site | Event | ΔCIMT (mm); adjusted RR (95% CI)* | CIMT cut point; adjusted RR (95% CI)*† |
|---|---|---|---|---|---|---|---|
| ARIC[5] | 12,841 | 45-64; 57% | 5.2 | Mean of mean; CCA/bulb/ICA | MI, CHD death | 0.19;<br>F: 1.38 (1.21-1.58)<br>M: 1.17 (1.04-1.31) | Highest tertile;<br>F: 2.53 (1.02-6.26)<br>M: 2.02 (1.32-3.09) |
| | | | | Mean; CCA | MI, CHD death | 0.19;<br>F: 1.46 (1.22-1.74)<br>M: 1.08 (0.91-1.1.27) | — |
| ARIC[19] | 14,214 | 45-64; 55% | 7.2 | Mean of mean; CCA/bulb/ICA | Stroke | 0.19;<br>F: 1.36 (1.16-1.59)<br>M: 1.21 (1.05-1.39) | Highest tertile;<br>F: 2.32 (1.09-4.94)<br>M: 2.24 (1.26-4.00) |
| | | | | Mean; CCA | Stroke | 0.18;<br>F: 1.32 (1.10-1.58)<br>M: 1.38 (1.16-1.65) | Highest tertile;<br>F: 1.65 (0.85-3.19)<br>M: 2.69 (1.49-4.87) |
| CAPS[20] | 5056 | 19-90; 50% | 4.2 | Mean; far wall CCA | MI | 0.16;<br>1.16 (1.05-1.27) | Highest quartile<br>1.83 (0.97-3.45) |
| | | | | Mean; far wall CCA | Stroke | 0.16;<br>1.11 (0.97-1.28) | Highest quartile<br>1.82 (0.64-5.16) |
| | | | | Mean; far wall CCA | MI, stroke, death | 0.16;<br>1.17 (1.08-1.26) | Highest quartile<br>1.85 (1.09-3.15) |
| CHS[6] | 4476 | >65; 39% | 6.2 | Mean of maximum; near + far CCA/ICA | MI | 1 SD;<br>1.36 (1.23-1.52) | Highest quintile;<br>3.61(2.13-6.11) |
| | | | | Maximum; near + far CCA | MI | 0.20;<br>1.24 (1.12-1.38) | Highest quintile;<br>2.46 (1.51-4.01) |
| | | | | Mean of maximum; near + far CCA/ICA | Stroke | 1 SD;<br>1.33 (1.20-1.47) | Highest quintile;<br>2.57 (1.64-4.02) |
| | | | | Maximum; near + far CCA | Stroke | 0.20;<br>1.28 (1.16-1.42) | Highest quintile;<br>2.13 (1.38-3.28) |
| KIHD[21] | 1257 | 42-60; 0% | 3 | Maximum; far wall CCA | MI | 0.11;<br>1.11 (1.06-1.16) | >1.0 mm;<br>2.1 (0.8-5.2) |
| Yao City[22] | 1289 | 60-74; 0% | 4.5 | Mean of maximum; near + far CCA/ICA | Stroke | — | Highest quartile;<br>4.9 (1.9-12.0) |
| | | | | Maximum; near + far CCA | Stroke | — | Highest quartile;<br>4.9 (1.9-12.0) |
| MDCS[23] | 5163 | 46-68; 60% | 7 | Maximum; far wall CCA | MI, CHD death | 0.15;<br>1.23 (1.07-1.41) | Highest tertile;<br>1.50 (0.81-2.59) |
| Rotterdam[24] | 6389 | >55; 62% | 7-10 | Maximum; near + far CCA | MI | 0.21;<br>1.28 (1.14-1.44) | Highest quartile;<br>1.95 (1.19-3.19) |

*CCA*, Common carotid artery; *CHD*, coronary heart disease; *CI*, confidence interval; *CIMT*, carotid intima-media thickness; *F*, female; *ICA*, internal carotid artery; *M*, male; *MI*, myocardial infarction; *RR*, relative risk. ARIC, Atherosclerosis Risk in Communities Study; CAPS, Carotid Atherosclerosis Progression Study; CHS, Cardiovascular Health Study; KIHD, Kuopio Ischemic Heart Disease Study; MDCS, Malmö Diet and Cancer Study.
*Adjusted for age, sex, and traditional risk factors.
†Highest tertile quartile or quintile compared with lowest.

stenosis), a manifestation of advanced atherosclerosis. For assessment of CVD risk, the carotid artery wall, rather than the degree of luminal narrowing, is examined to identify areas of increased thickness and nonocclusive atherosclerotic plaque, which represent early stages of arterial injury and atherosclerosis. Ultrasound imaging of the far wall of the carotid artery produces two echogenic lines. In situ anatomic and in vitro histologic studies have validated these lines as the lumen-intima interface and the media-adventitia interface.[16-18] The combined thickness of the intimal and medial layers of the arterial wall constitute the CIMT. Current ultrasound technology is not sufficiently sensitive to measure the thickness of the intima alone.

There are 8 published prospective studies of CIMT and CVD risk that included at least 1000 participants, and presented odds ratios or relative risks adjusted for CVD risk factors (Table 1).[5,6,19-24] These studies recently have been reviewed in detail.[25] All 8 studies demonstrated that CIMT was significantly associated with risk for myocardial infarction, stroke, CHD death, or a combination of these.[5,6,19-24] An additional study with 10,000 participants had similar results.[26] In several studies, the adjusted relative risks associated with the greatest degrees of wall thickness (see cut points in Table 1) were sufficiently high (>2.0) that they would be expected to improve clinical risk prediction in appropriately selected patients.[5,6,19,21,22] CIMT values add additional information beyond traditional risk factors for classifying patients in regard to the likelihood of presence of significant angiographic coronary artery disease.[27] In two studies, CIMT values modestly increased the area

**Table 2** Prospective studies of carotid plaque presence and risk for cardiovascular disease events in individuals without known cardiovascular disease (N >1000 participants each)

| Study | N | Age (y); F | Follow-up (y) | Event | Plaque presence adjusted HR (95% CI)* |
|---|---|---|---|---|---|
| ARIC[38] | 12,375 | 45-64; 54% | 7 | MI, CHD death | With AS; 2.96 (1.54-3.30)<br>Without AS: 2.02 (1.42-2.41) |
| KIHD[39] | 1288 | 42-60; 0% | ≤2 y | MI | 4.15 (1.50-11.47) |
| Yao City[22] | 1289 | 60-74; 0% | 4.5 | Stroke | 3.2 (1.4-7.1)† |
| MDCS[23] | 5163 | 46-68; 60% | 7 | MI, CHD death | 1.81 (1.14-2.87) |
| Northern Manhattan[40] | 1939 | >40; 59% | 6.2 | Stroke | 3.1 (1.1-8.5) |
| Rotterdam[24] | 6389 | >55; 62% | 7-10 | MI | Severe; 1.83 (1.27-2.62) |

*AS*, Acoustic shadowing; *CHD*, coronary heart disease; *CI*, confidence interval; *F*, female; *HR*, hazard ratio; *MI*, myocardial infarction. ARIC, Atherosclerosis Risk in Communities Study; KIHD, Kuopio Ischemic Heart Disease Study; MDCS, Malmö Diet and Cancer Study.
*Adjusted for age, sex, and traditional risk factors.
†Relative risk.

under the receiver operator characteristic curve for predicting cardiovascular events.[28,29] The relationship between increasing CIMT and incident CVD events has been established across a wide age range; however, the strongest data are for individuals between 42 and 74 years of age, because several studies of individuals in this age range show similar results (Table 1). For younger adults (18-42 years old), consistent, strong relationships between increasing risk factor burden, emerging risk factors, and CIMT have been demonstrated.[30-37] In the Carotid Atherosclerosis Progression Study (CAPS), CIMT predicted cardiovascular events even among the 2436 individuals younger than 50 years old (mean 38.7 years).[20] In that study, the relative risk associated with increased CIMT appeared to be higher among younger than older adults.[20]

Similarly, 6 observational studies that included at least 1000 participants and presented relative risks or hazard ratios adjusted for CVD risk factors have demonstrated the predictive power of the presence of carotid plaque (Table 2).[22-24,38-40] In these studies, the relative risks associated with plaque were similar to or slightly higher than those observed with increased CIMT. Three additional large studies had similar results.[26,41,42] In one study, the presence of carotid plaque significantly improved the area under the receiver operator characteristic curve for prediction of all-cause mortality even after considering risk factors and use of medications.[41] There was not a uniform definition of carotid plaque in these studies.[43] Most studies identified plaque as focal widening relative to adjacent segments with protrusion into the lumen and/or had a minimum wall thickness.[43] A previous ASE report defined nonobstructive plaque "as the presence of focal thickening at least 50% greater than that of the surrounding vessel wall.[15] The Mannheim CIMT Consensus Report suggested that plaque should be defined as "a focal structure that encroaches into the arterial lumen of at least 0.5 mm or 50% of the surrounding intima-media thickness or demonstrated a thickness of greater than or equal to 1.5 mm."[44,45] These definitions are similar to those used in the Atherosclerosis Risk in Communities (ARIC) Study, the largest prospective cohort study that demonstrated the predictive value of plaque in CVD risk assessment.[38]

## THE RELATIONSHIP BETWEEN CIMT AND SUBCLINICAL VASCULAR DISEASE

CIMT is associated with CVD risk factors, prevalent CVD, incident CVD, and the degree of atherosclerosis in several different arterial beds.[3,4,15,46,47] Progression of CIMT may be attenuated or reversed with risk factor interventions, in association with a reduced risk of future CVD events.[48,49] These findings provide support to the concept that CIMT measurements can be used as a surrogate marker of atherosclerosis. Increased CIMT may be related to intimal or medial hypertrophy or both, and may be an adaptive response to changes in flow, wall tension, or lumen diameter.[50,51] It is well-established that CIMT increases with advancing age, even in the absence of overt or occult atherosclerosis, as a result of thickening of both the intimal and medial layers. In human beings, CIMT increases nearly 3-fold between the ages of 20 and 90 years.[52] Postmortem studies indicate that age-associated increases in carotid wall thickening mainly are caused by an increase in intimal thickening.[53] In rodent and nonhuman primate models of aging, age-associated arterial changes are observed with advancing age, even though these animals tend not to develop atherosclerosis.[54,55] These alterations encompass many factors that have been implicated in the pathogenesis and progression of atherosclerotic plaques, such as endothelial dysfunction; increased endothelial cell adhesiveness and permeability; increases in procoagulant, vasoconstrictive, and inflammatory molecules; increases in cytokines and chemokines; increased oxidative stress; and proliferation and migration of smooth muscle cells.[54,55] Thus, intimal-medial thickening is a feature of arterial wall aging that is not synonymous with subclinical atherosclerosis, but is related to it because the cellular and molecular alterations that underlie intimal-medial thickening have been implicated in the development, progression, or both of atherosclerosis. Accordingly, carotid wall thickening is not synonymous with atherosclerosis, particularly in the absence of plaque. It represents subclinical vascular disease, the pathophysiologic substrate that explains why CIMT is a risk factor and a marker of CVD risk.[56,57]

## APPLICATION OF CAROTID ULTRASOUND TO CVD RISK ASSESSMENT

The traditional approach to CVD risk assessment involves identifying and quantifying the presence or absence of CVD risk factors. The NCEP recommends estimating the 10-year risk for CHD death or myocardial infarction using the Framingham risk score (FRS) model.[14] Patients at intermediate risk may benefit most from measurement of subclinical vascular disease to further refine their CVD risk estimates, as decision-making about preventive therapies in this group may be uncertain.[3,4,15,58,59] Although the FRS accurately discriminates short-term CVD risk, it has some potential limitations. Because

Table 3 Study setup

| Sonographer | Patient |
|---|---|
| Position at head of patient, with enough space to rest elbow on bed | Position supine on scan bed with head resting comfortably |
| Adjust height and location of ultrasound system keyboard and monitor, examination bed, and chair to avoid ergonomic injuries | Slightly hyperextend and rotate neck in direction opposite to probe |
| | Use 45-degree angle wedge pillow to help standardize lateral rotation |
| | During scan, sonographer may adjust neck position to optimize images, especially in anterior scanning planes |
| | Use rolled towels under neck and pillows under legs for comfort |
| | Use external landmarks such as the Meijer arc (Figure 1)[91] or similar devices can help standardize transducer angle |

the FRS only predicts 10-year risk rather than lifetime risk[60] and women tend to develop CVD at older ages, women with significant subclinical vascular disease can be misclassified as being at lower risk based on the 10-year FRS alone, and therefore, may not receive appropriate preventive measures.[61-63] In addition, patients with extremely high levels of a single risk factor, such as genetic forms of dyslipidemia, may not be adequately classified based solely on their FRS.[14,58,64] In addition, the FRS does not account for family history of premature CVD, and some risk factors such as smoking and diabetes mellitus are considered only as present or absent, although epidemiologic data support a continuous relationship between CVD risk and tobacco exposure and glucose levels, respectively.[64] Finally, chronologic age is the overriding determinant of the FRS, ignoring great interindividual variation in atherosclerotic burden at older ages.[65]

The clinical usefulness of CIMT measurement and plaque detection is related to the patient's pretest CVD risk, which is altered by the relative risk based on the test results, as in Tables 1 and 2. **Measuring CIMT and identifying carotid plaque by ultrasound are most useful for refining CVD risk assessment in patients at intermediate CVD risk (FRS 6%-20% without established CHD, peripheral arterial disease, cerebrovascular disease, diabetes mellitus, or abdominal aortic aneurysm). Patients with the following clinical circumstances also might be considered for CIMT measurement and carotid plaque detection: (1) family history of premature CVD in a first-degree relative (men < 55 years old, women < 65 years old); (2) individuals younger than 60 years old with severe abnormalities in a single risk factor (eg, genetic dyslipidemia) who otherwise would not be candidates for pharmacotherapy; or (3) women younger than 60 years old with at least two CVD risk factors.** This test can be considered if the level of aggressiveness of preventive therapies is uncertain and additional information about the burden of subclinical vascular disease or future CVD risk is needed. **Imaging should not be performed in patients with established atherosclerotic vascular disease or if the results would not be expected to alter therapy. Serial studies of CIMT to address progression or regression are not recommended for use in clinical practice.**

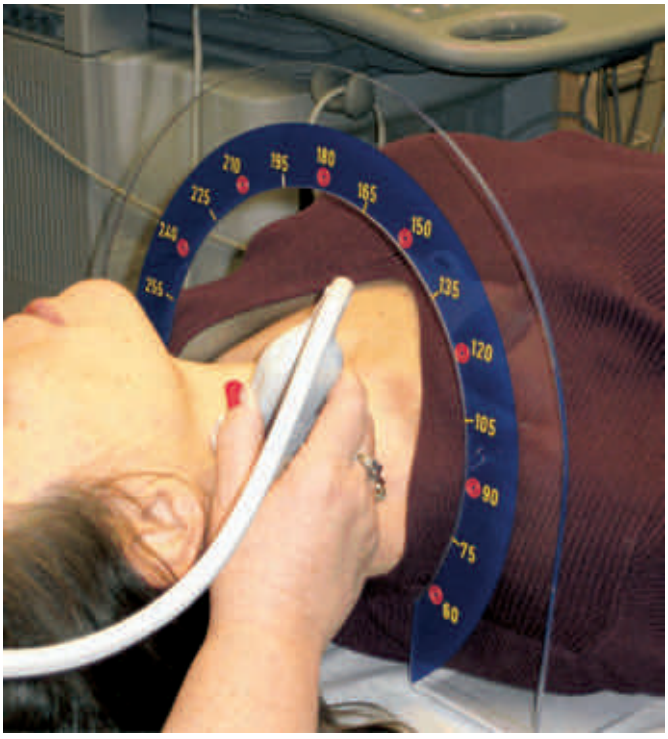


**Figure 1** Patient position for carotid ultrasound study.

Fast computed tomography to measure coronary artery calcium also evaluates subclinical vascular disease[66]; however, carotid ultrasound has some potential advantages compared with this test. Carotid ultrasound does not involve exposure to ionizing radiation, an important consideration when imaging healthy young and middle-aged adults.[67] In addition, CIMT has the advantage of being a continuous measure that could be used to stratify risk in women and younger men, and in African American individuals, where coronary artery calcium scoring may have limited discriminatory power because of a high prevalence of a zero calcium score.[68]

Table 4 Instrumentation and display

| |
|---|
| State-of-the-art ultrasound system |
| Digital image acquisition and storage, preferably DICOM |
| Phantom scans every 6 months and after any system changes |
| Semiannual routine preventive maintenance |
| Transducer |
| Linear array |
| Minimal compression (<10:1) |
| Fundamental frequency ≥ 7 MHz |
| Footprint ≥ 3 cm |
| Display |
| Depth 4 cm |
| Single focal zone |
| Frame rate ≥ 25 Hz |
| High dynamic range |
| Clear 3-lead electrocardiographic signal |
| Annotate images to describe segments, angles, and other findings |
| Carefully adhere to predefined scanning protocol |

*DICOM*, Digital Imaging and Communications in Medicine.

**Table 5** Recommend scanning protocol for evaluation of common carotid artery carotid intima-media thickness and detection of carotid plaques

| Step | View | Area of interest | Technique | Use |
|---|---|---|---|---|
| 1 | Transverse B-mode scan (3-5 beat cine-loop in each segment) | From proximal CCA through middle of the internal carotid artery | Notch of transducer oriented to right of patient<br>Slowly advance probe, keep vessel in center of screen, show double lines on near and far walls | Overview of vessel orientation, wall thickness, plaques, and surrounding structures |
| 2 | Internal and external carotid artery Doppler recordings (one frame of each) | Pulsed wave Doppler of proximal 1 cm of each branch | Sample volume parallel to flow by beam steering and angle correction of ≤60 degrees<br>If narrowing is seen, obtain pre- and post-velocities to document severity | Verifies anatomic orientation and may identify significant stenosis if present |
| 3 | Longitudinal plaque screen scan (3-5 beat cine-loop from at least 3 different angles in each segment) | Near and far walls of CCA, bulb, and internal carotid artery segments | Rotate 90 degrees from transverse plane with notch of transducer oriented toward head of patient<br>Circumferential plaque screen scan from anterior, lateral, and posterior imaging planes<br>Return to transverse plane to corroborate maximum plaque size in orthogonal plane<br>Document location and angle that plaque has greatest encroachment into lumen | Identification and description of plaques |
| 4 | CIMT imaging (3-5 beat cine-loop and optimized R-wave gated still frames at each angle) | Distal 1 cm of each CCA | Longitudinal images from 3 imaging planes: optimal angle of incidence and two complementary angles (anterior, lateral, and posterior) (Figure 2)<br>Use cursor to mark location of bifurcation<br>Display clear images of distal CCA perfectly horizontal with double lines on near and far walls, indicating true perpendicular scanning plane (Figure 3)<br>Optimize transducer depth (usually 4 cm) to avoid slice thickness artifacts | Segments for CIMT measurement |

*CCA*, Common carotid artery; *CIMT*, carotid intima-media thickness.
By convention, the right carotid artery is imaged first.

## PUBLISHED EXPERIENCE OF CAROTID ULTRASOUND FOR CVD RISK PREDICTION IN CLINICAL PRACTICE

Several clinical CVD risk assessment programs have used carotid ultrasound to measure CIMT.[8-13,69,70] In clinical practice, CIMT values can help reclassify patients at intermediate risk,[8-10] discriminate between patients with and without prevalent CVD,[69] and predict major adverse cardiovascular events.[12] Most of these studies incorporated the patient's age and sex by using normative percentile values.[8,9,11-13] Outcome data describing the ability of a management strategy that includes CIMT or plaque screening tests to improve CVD outcomes are limited to changes in patient or physician behavior that would be expected to lead to reduced CVD risk. In a small (N = 50) interventional study, physicians were more likely to prescribe aspirin and lipid-lowering therapy to patients who were found to have carotid plaque during an office screening examination.[71] In a small (n = 74) randomized study, smokers shown images of their carotid plaques were more likely to stop smoking at 6 months.[72] In a study of 210 individuals described in a review article, patients were more likely to adhere to recommendations regarding diet, exercise, and smoking cessation 12 months after seeing pictures of their CIMT examination.[73] **More research is needed to determine whether improved risk prediction observed with CIMT or carotid plaque imaging translates into improved patient outcomes. Because a randomized, controlled trial studying the effectiveness of carotid ultrasound imaging as a tool to modify preventive therapies and improve CVD outcomes has not yet been performed, the clinical practice recommendations in this document are based on the best available observational data.** The Measuring Effects on Intima-Media Thickness: An Evaluation of Rosuvastatin (METEOR) Study demonstrated that middle-aged adults at apparently low to intermediate CVD risk but with increased CIMT (N = 984) benefited from statin therapy that they otherwise would not have qualified for based on current treatment guidelines.[14,74] In this prospective, randomized multicenter clinical trial, the magnitude of the difference in CIMT progression rates (−0.145 mm/y) was similar to that observed in secondary prevention trials that were associated with a reduction in cardiovascular events.[48,74] Although not definitive, this study suggests that using CIMT to modify preventive treatment strategies is feasible and associated with a delay in the progression of vascular injury. **Appropriately designed prospective studies to investigate the effectiveness of carotid ultrasound imaging as a strategy to help improve CVD outcomes are recommended.**

## CAROTID ULTRASOUND SCANNING TECHNIQUE

### Patient and Sonographer Preparation (Table 3, Figure 1)

Both the sonographer and patient should be positioned properly to facilitate high-quality, reproducible images. Allow sufficient time for the scan to facilitate positioning and to avoid rushing.[75]

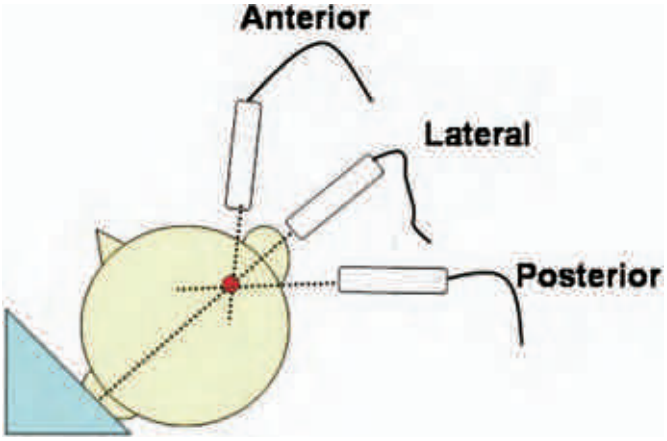


Figure 2 Head position and probe orientation for carotid ultrasound scanning, right-side example.

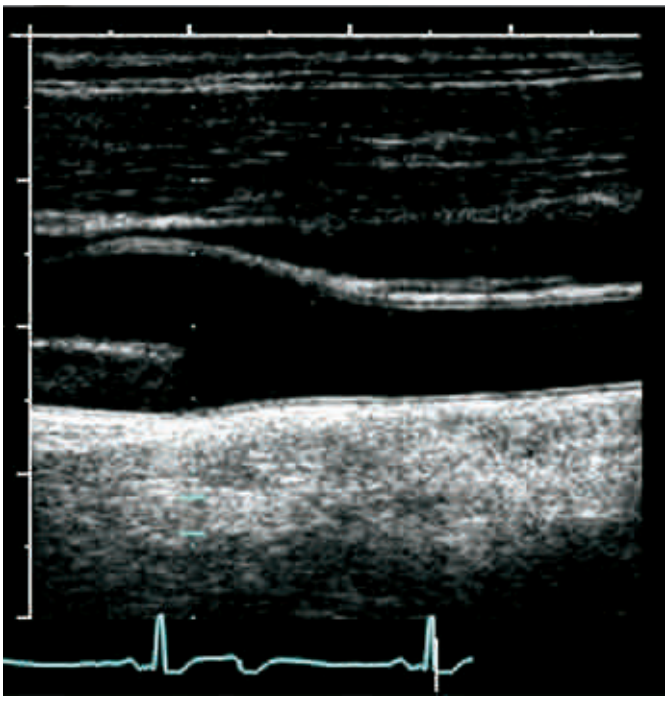

Figure 3 True longitudinal plane simultaneously demonstrating double lines on the near and far walls of the common carotid artery ("double-line" sign).

### Instrumentation and Image Display

**The carotid arteries should be interrogated using a state-of-the-art ultrasound system with a linear-array transducer operating at a fundamental frequency of at least 7 MHz.** Use of nonfundamental frequencies can increase wall thickness. Use of ultrasound contrast is a research technique that is not recommended for clinical assessment of CIMT at this time. Most patients can be scanned at a standard depth of 4 cm, however, increased depth may be necessary in some patients with larger necks or deeper vessels. Resolution decreases with increasing imaging depth. The typical pixel size when imaging at a 4-cm depth is approximately 0.11 mm. Because CIMT measurements are extremely small, differences of 1 digital pixel can classify patients in different risk categories, so close attention to instrumentation and standardized imaging and reading protocols are critical. Use of the zoom function is discouraged because most studies relating CIMT to CVD events did not use zoomed images. The zoom function on some commercial ultrasound systems increase the pixel size, rather than increasing resolution. When viewing zoomed images, the location of external landmarks for standardized image acquisition may be lost and it is easier for the probe to drift off the optimal image and location. If used, zoom functions should be relegated to very standardized protocols, where internal and external landmarks are kept constant. These considerations require a very experienced operator who can avoid subtle drifting. Protocol deviations from those published require validation, including evaluation of reproducibility.

**B-mode imaging is preferred over M-mode imaging.** Although M-mode has superior temporal resolution, it provides measurement of only a single point of thickness, rather than a segmental value. Carotid wall thickening is not uniform, so a single value without considering a wider region is difficult to reproduce and may not accurately represent arterial changes. Perpendicular imaging also is challenging using M-mode. Because M-mode measurements or point-to-point measurements of B-mode images are limited multiples of the pixel size, measurement precision is reduced unless multiple (several hundred) points are measured. Multiple measurements of several extended segment lengths permit expression of CIMT values with higher precision (subpixelar level) instead of simple multiples of the pixel size. All reported observational studies relating CIMT values to cardiovascular events used B-mode measurements, usually averaged over at least a 1-cm segment.

**A small parts ultrasound phantom should be used to determine whether the ultrasound system is calibrated**

Table 6 Frequently observed carotid ultrasound imaging pitfalls and potential solutions

| Pitfall/problem | Potential solutions |
|---|---|
| Lack of "double-line" sign | Place vessel horizontal on screen, move transducer perpendicular to vessel, adjust focus and gain |
| Tortuous vessel | Further extend and slightly rotate neck to elongate segment |
| Image too deep, blurry posterior angles | Adjust focus, add gel, press sternocleidomastoid muscle and slowly decrease pressure until ideal acoustic impedance is achieved, showing clear double lines |
| Image too shallow, slice thickness artifact | Increase distance of vessel from near field, add more gel, use less pressure, stack over jugular vein |
| Under-gained images | Adjust time-gain compensators and overall gain, ensure proper monitor settings |
| Over-gained images (falsely thick) | Adjust time-gain compensators and overall gain, ensure proper monitor settings |
| Translation artifact from pulsatile jugular vein | Have patient hold breath at midinspiration to stabilize image |

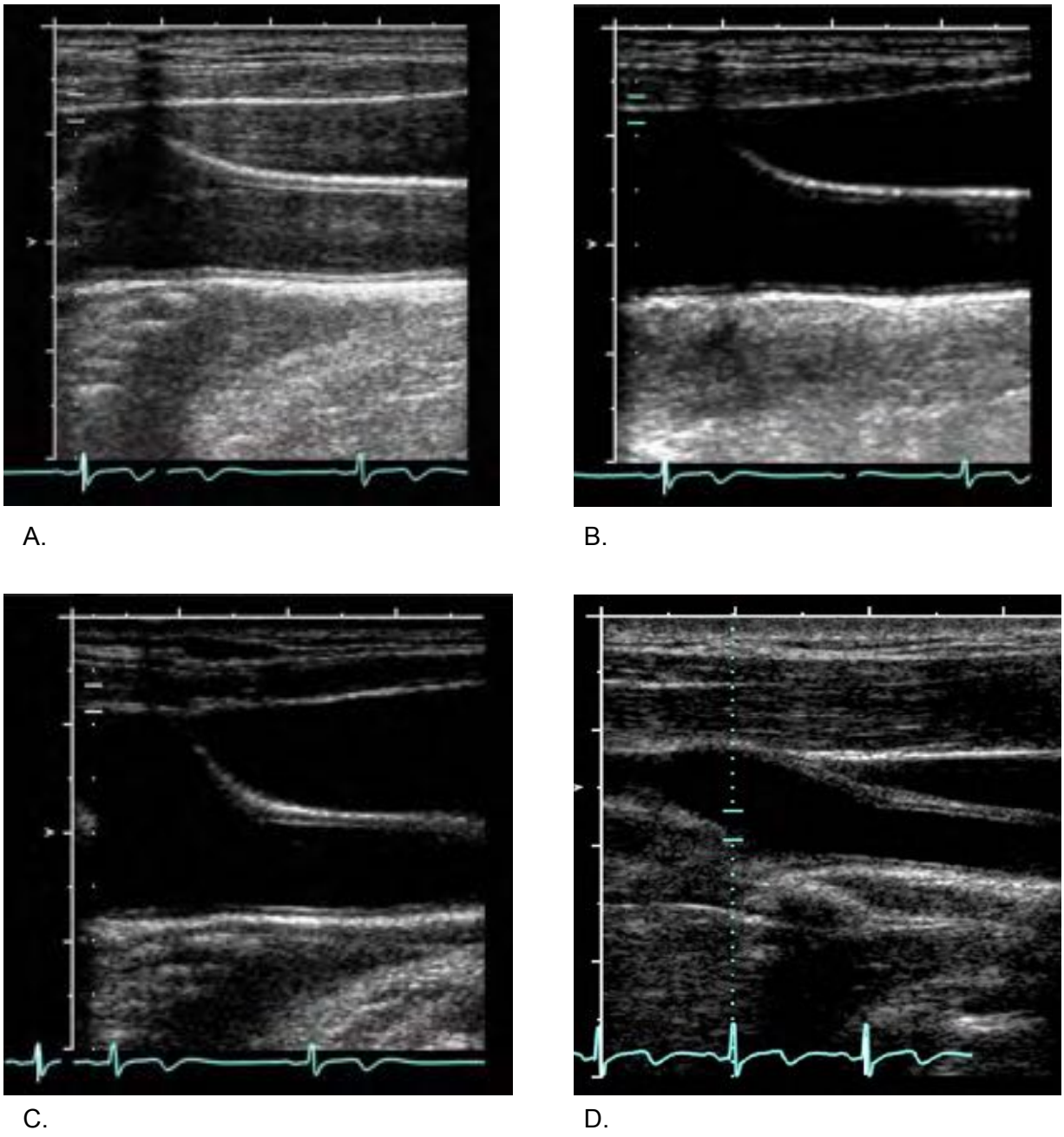


**Figure 4** Common carotid artery intima-media thickness imaging pitfalls and potential solutions. (**A**), Image is over-gained. Reduce overall gain. (**B**), Persistence is too high. Turn down persistence. (**C**), Image not well aligned; double lines lost at right of common carotid artery segment. Re-align transducer with vessel. (**D**), Image not horizontal. Use heel-toe motion of transducer to re-align.

**accurately and to help determine the axial and lateral resolutions of the transducer.** Phantoms also provide information on gray-scale ranges, help the sonographer select postprocessing maps, and provide an objective tool to compare different systems and transducers. **Routine ultrasound system preventive maintenance should be performed at least biannually.**

Early carotid ultrasound images were recorded on videocassette tapes for subsequent offline image capture and digitization. Although this approach yielded reproducible measurements in highly specialized laboratories, image degradation was inevitable. Current ultrasound technology enables direct storage of digital images on digital media. **Digital images should be stored directly from the ultrasound system, rather than digitized video captures.** Most current ultrasound systems store images in a Digital Imaging and Communication in Medicine (DICOM) format or one that maintains study organization and internal image calibration, thus eliminating errors caused by manual calibration (Table 4).

### Imaging Protocol

**Carotid ultrasound imaging should follow a scanning protocol from a large epidemiologic study that reported CIMT values in percentiles by age, sex, and race/ethnicity (eg,**

**Table 7** Interpretation of carotid ultrasound studies for cardiovascular disease risk assessment

| Step | Action | Rationale |
|---|---|---|
| 1 | Review images on high-quality monitor (resolution ≥ 1024 × 768 pixels) | Preserve image quality<br>Accurate display of boundaries |
| 2 | Review study images for overall image quality, wall thickness, plaque presence | Corroborate settings<br>Identify incidental findings |
| 3 | Evaluate for presence of carotid plaques<br>-Use transverse and longitudinal views to distinguish between plaque presence and imaging artifacts<br>-Report location of plaques (near or far wall, segment, side) | Describing plaque presence improves description of extent of subclinical vascular injury<br>Carotid plaque presence predicts future CVD events |
| 4 | Select best images of distal 1 cm of CCA far wall from each of 3 angles; review loops, then measure from R-wave gated still frames | Complementary angles better represent overall wall thickness |
| 5 | Measure images in triplicate by tracing far wall blood-intima and media-adventitia interfaces using leading edge–to–leading edge method (Figure 5)<br>-Measure 1-cm length<br>-Assure that measurements from each angle are within 0.05 mm of others<br>-Plaques should be traced as part of CIMT | Triplicate measurements insure consistency, averaging increases precision<br>If more variation is identified, critically review images; only trace images with clear boundaries that are over-gained and are imaged perpendicular to artery |
| 6 | Measurement data should automatically enter report<br>-Measured images should be saved digitally to document tracing for later review<br>-Images and measurements should be stored in database<br>-Report mean CIMT values from far walls of right and left CCAs (mean-mean) | Avoids manual entry errors<br>Permits later review and facilitates quality assurance<br>Mean CIMT values are reproducible and predict future CVD events |

*CCA*, Common carotid artery; *CIMT*, carotid intima-media thickness; *CVD*, cardiovascular disease.

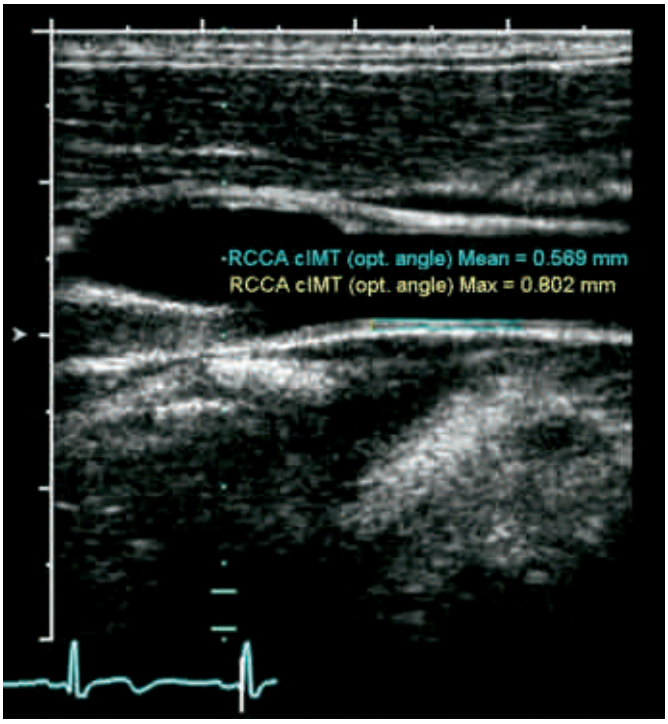


**Figure 5** Example measurement of far wall common carotid artery (*CCA*) carotid intima-media thickness (*cIMT*).

**ARIC Study or others listed in Table 1 and Appendices 1 and 2).** The 4 studies described in Appendix 1 were selected because they are large, cross-sectional, high-quality studies that reported common carotid artery (CCA) CIMT values by age, sex, and race/ethnicity and were conducted in North America (Alice M. Arnold, PhD, personal communication, December 2006; and Robyn L. McClelland, PhD, personal communication, January 2007).[6,76,77] The 50th percentile mean far wall CCA CIMT values for white and black men and women between 45 and 64 years of age in ARIC and Multi-Ethnic Study of Atherosclerosis (MESA) are remarkably similar given the differences between the studies (Robyn L. McClelland, PhD, personal communication, January 2007).[76] For older patients, the 50th percentile maximum CCA CIMT values in the Cardiovascular Health Study (CHS) Study tended to be higher than in MESA, likely because individuals with known CVD were excluded from MESA, but not CHS (Alice M. Arnold, PhD, personal communication, December 2006; Robyn L. McClelland, PhD, personal communication, January 2007).[6,78] Four additional large studies from Europe that reported CCA CIMT values are described in Appendix 2 (Matthias W. Lorenz, MD, personal communication, December 2006; F. Gerald R. Fowkes, MBChB, PhD, personal communication, November 2006; Maria Rosvall, MD, PhD, Bo Hedblad, MD, PhD, and Goran Berglund, MD, PhD, personal communication, December 2006).[20,23,79-81] These studies did not provide information about race/ethnicity, but were conducted mostly in white individuals. In general, CIMT values in studies such as the Carotid Atherosclerosis Progression Study (CAPS) and Malmö Diet and Cancer Study (MDCS) tended to be higher than in the North American studies, so

**Table 8** Components of the carotid ultrasound study for cardiovascular disease risk assessment report

| |
|---|
| Patient information |
| Name, date of birth, medical record/identification number |
| Sex |
| Race/ethnicity |
| Ordering health care provider |
| Indication |
| Statements |
| This is a screening carotid ultrasound study for CVD risk assessment |
| This study is not a replacement for a clinically indicated carotid duplex ultrasound |
| This study measures the thickness of the walls of the carotid arteries and identifies the presence of carotid plaques |
| Percentile values do represent percent stenosis |
| Summary of scanning protocol and reference database (ie, ARIC Study, right and left CCA) |
| Data reporting |
| Describe carotid plaques |
| Presence/absence |
| Location (ie, side, segment, near/far wall) |
| Acoustic shadowing (optional) |
| State mean CIMT values for each side (a composite value is optional)* |
| State percentile range for each CIMT value, relative to the patient's age, sex, and race/ethnicity (Appendices 1 and 2) |
| Describe other clinically relevant findings (eg, possible obstructive carotid artery disease, thyroid abnormalities, lymphadenopathy) |
| Interpretation |
| Level of CVD risk (ie, increased, unchanged, lower) |
| Relative risk associated with findings (optional) |
| Recommendations (optional) |

*ARIC*, Atherosclerosis Risk in Communities; *CCA*, common carotid artery; *CIMT*, carotid intima-media thickness; *CVD*, cardiovascular disease.
*Clearly state if a different scanning protocol is used or maximum values are reported.

they are reported separately (Matthias W. Lorenz, MD, personal communication, December 2006; and Maria Rosvall, MD, PhD, Bo Hedblad, MD, PhD, and Goran Berglund, MD, PhD, personal communication, December 2006).[20,23] Reasons for the thicker CIMT values observed in these studies include different population characteristics, instrumentation, imaging and recording standards, and measurement techniques, including whether segments with plaque were included in the measurement protocol. Nevertheless, the relative risks associated with increasing CIMT were similar across the studies in Table 1, so the studies in Appendix 2 may provide more appropriate reference values for clinical sites in Europe.

**Within the context of the protocols and nomograms from large epidemiologic studies, the task force recommends that ultrasound images of the distal 1 cm of the far wall of each CCA should be obtained and compared with values from a normative data set.** Because of its size, superficial location, ease of accessibility, and limited movement, the far wall of the CCA provides a convenient window to study arterial structure using B-mode ultrasound. The distal CCA is easy to image, as it is straight and relatively superficial. With current ultrasound technology, it is difficult to reliably discern the intima-media interface of the near wall of the CCA, however, far wall CCA CIMT measurements predict future cardiovascular events (Table 1). Although near wall measurements and those from other segments also have been used in some studies, they are more challenging technically, less reproducible, and do not appreciably improve risk prediction.[15] In addition, near wall CIMT is less accurate because the ultrasound beam is traveling from more echogenic to less echogenic layers at the adventitia-media and intima-lumen interfaces of the near wall. In one study, the ultrasound measurement of the near wall CIMT was 20% lower than the corresponding histologic measurement.[18] Although atherosclerosis and CIMT progress more rapidly in the bulb and internal carotid segments, **limiting CIMT measurements to the far wall of the CCA is the preferred strategy for clinical testing; however, it should be supplemented by a thorough scan of the extracranial carotid arteries for the presence of carotid plaques, to increase sensitivity for identifying subclinical vascular disease.** A circumferential scan of both carotid arteries to identify plaque can compensate for reduced sensitivity that may result from only measuring CCA CIMT.[15,70,82]

**The CIMT and carotid plaque scanning protocol recommended for most adults (40-70 years old) is in Table 5.** The CIMT portion of the recommended scanning protocol is based on the ARIC Study protocol because it was a large study with published nomograms for CIMT values in the age range that usually is most appropriate for screening (Appendix 1).[76] Furthermore, in the ARIC Study, both increasing CIMT and carotid plaque presence independently predicted CVD events (Tables 1 and 2), and the scanning methods are reproducible in most clinical laboratories.[5,19,38,76,83] **Scanning protocols from observational studies with published nomograms may be used if they are more germane to the age, sex, and race/ethnicity of the clinical population being investigated, however, the clinical laboratory must have sufficient expertise to perform them accurately and reproducibly.** Decisions as to which segments of the carotid artery are interrogated, at which angles, and which measurements are obtained must match those in the normative data set of the representative epidemiologic study (Appendices 1 and 2). For example, the CIMT measurements in the Bogalusa Heart Study have not yet been related to future CVD events; however, they are the only normative CIMT values in young adults from North America.[77] Similarly, the CIMT measurements in the MESA Study have not yet been related to future CVD events; however, they are the only normative values for CIMT in Chinese and Hispanic Americans (Robyn L. McLelland, PhD, personal communication, January 2007). Based on the similar relative risk associated with increasing CIMT across the age ranges described in Table 1, it can be inferred that increased CIMT in these patient groups (as determined by comparison with these data sets) is associated with increased CVD risk. **Use of values from clinically referred populations are discouraged, because of the high likelihood of referral bias and inaccurate risk estimates.**

### Tips for Carotid Plaque Screening

Because of the eccentric nature of plaques, a circumferential scan ranging from anterior to posterior angles, and imaging the near or far walls of the CCA, bulb, and internal carotid artery segments is required (Table 5, Figure 2). During the plaque screen, the bulb and internal carotid arterial segments are carefully interrogated because plaque typically develops earliest in these segments. In some cases, plaques are present in the proximal or middle segments of the CCA or further than the proximal 1-cm segment of the internal carotid artery, so the full extracranial carotid arterial bed should be interrogated. Small plaques can be missed if images are obtained too quickly

**Table 9** Requirements for training and certification of sonographers and readers

| | Sonographers | Readers |
|---|---|---|
| Ultrasound background | Registered diagnostic cardiac sonographer, medical sonographer, or vascular technician<br>Certification in cardiopulmonary resuscitation and institutional emergency procedures | Appropriate credentials and institutional privileges to interpret cardiac and/or vascular ultrasound studies |
| Content areas (minimum 8 h of didactic or online training) | Pathophysiology of atherosclerosis, histopathologic correlations between ultrasound and healthy and diseased arteries, carotid artery anatomy<br>CVD risk assessment and rationale for noninvasive testing with carotid ultrasound<br>Clinical use of carotid ultrasound to identify subclinical vascular injury and predict CVD risk, including evidence base from epidemiologic and clinical trials and advantages and limitations of testing<br>Scanning technique, instrumentation, protocol selection, and imaging pitfalls, including limited hemodynamic evaluation of stenotic lesions, recognition of common cardiac arrhythmias, and blood pressure monitoring<br>Ultrasound principles and quality assurance<br>Measurement and reporting<br>Training standards for readers and sonographers | |
| Initial hands-on, supervised training | Scanning (minimum 8 h, in-person)<br>-Protocol, image acquisition, best image<br>-Demonstrate knowledge of content areas above<br>Reading (minimum 2 h, in-person)–demonstrate proficiency with reading program | Scanning (minimum 2 h, in-person)<br>-Understand image generation and pitfalls<br>-Familiarity with scanning protocol<br>Reading (minimum 2 h, in-person)–demonstrate proficiency with reading program |
| Follow-up of initial training | Submit at least 3 paired mock studies for review by an experienced sonographer<br>2 sets of images obtained at least 1 day apart, from 3 patient models<br>Demonstrate protocol adherence, image quality, and image reproducibility | Submit at least 10 measured scans to a core laboratory with published accuracy and reproducibility data<br>-Mean $\Delta$ reader core laboratory $< 0.11$ mm<br>-95% of CIMT values within 0.11 mm of core laboratory[87,88,95] |
| Maintenance of certification and quality assurance | Perform least 25 CIMT studies/y<br>Annual retesting of repeatability*<br>Quarterly detailed, objective feedback<br>If inactivity $>$ 2 months, perform two mock studies to show continued competence | Read at least 25 CIMT studies/y<br>Annual testing of intraobserver and interobserver repeatability* |

*CIMT*, Carotid intima-media thickness; *CVD*, cardiovascular disease; h, hour; y, year.
*Benchmarks for interscan/interread repeatability are a mean absolute difference of less than 0.055 mm and a coefficient of variation of less than 6%, where the coefficient of variation is calculated as SD divided by the mean using the root mean square (or equivalent) approach and is based on a minimum of 10 studies.[96]

or if the artery is imaged from only a few angles of incidence, rather than the recommended continuous screen of all the available circumferential angles. Careful evaluation of near wall boundaries helps avoid missing homogenous plaques on the near wall of the bulb and internal carotid artery. Regions where the arterial diameter changes abruptly and the images are not perpendicular to the scan lines, such as at the transition of the CCA into the bulb, can give a false appearance of focal thickening. Artifacts are common and the sonographer has to consider possible surrounding structures that can cause them. Color Doppler can be used with careful adjustment of the velocity scale to demonstrate a complete lumen filling, or an irregular arterial interface. Because of the complex shape of plaque, accurate measurement of size is difficult with the current tools. Some groups have used the measurement of total plaque area.[10,42] This promising approach deserves further study and validation, but is not recommended because its generalizability and incremental predictive value are not known.

## OVERVIEW AND TIPS FOR CIMT IMAGING

After the plaque screen, longitudinal images of the CCA at 3 different angles are acquired for CIMT measurement (Table 5 and Figure 2). A cine-loop of 3 to 5 beats' duration should be recorded with selection of 3 optimized R-wave gated still frames from each angle of interrogation. Loops and still frames provide temporal information and insure good image quality at the crucial time of the cycle when measurements are performed, since cine-loops typically are compressed and still frames usually are not. The plane in which the bifurcation of the carotid bulb into the internal and external carotid

arteries at the tip of the flow divider can be visualized simultaneously with the bulb and distal CCA can be defined as the optimal angle of incidence (OAI) or "tuning fork" view. It is a reproducible view in most patients and relies on internal landmarks. If the head rotation is standardized, the OAI can be easily reproduced. The OAI can be determined during the transverse scan when the orientation of the internal and external carotid arteries is noted. Although a reliable point to start CIMT scanning, it often is not the best window to scan the bulb and internal carotid arterial segments.

The region to be measured includes the far wall of the distal 1 cm of the CCA. The distal CCA should be perfectly horizontal on the screen with simultaneous double lines in the near and far walls of the CCA ("double-line" sign) (Figure 3). This is accomplished by a combination of small adjustments in transducer tilt, rotation, and differential pressure of proximal-to-distal end of the probe (heel-toe movement). After the OAI is identified, the distal 1 cm of the CCA should be imaged from two additional complimentary angles, approximately 45 degrees anteriorly and posteriorly to cover a representative range of the neck circumference (anterior, lateral, and posterior) (Figure 3). If the patient's OAI is extremely anterior or posterior, two additional images approximately 45 degrees apart should be obtained. Applying different degrees of pressure and use of gel as an acoustic standoff will improve resolution and reduce artifacts. Some frequently observed pitfalls and possible solutions to CIMT image acquisition problems are listed in Table 6 (Figure 4).

## INTERPRETATION OF CAROTID ULTRASOUND STUDIES FOR CVD RISK ASSESSMENT

The main steps for evaluating carotid ultrasound studies for CVD risk assessment are described in Table 7. **Evaluating for the presence or absence of plaque in conjunction with measuring CCA CIMT offers a better representation of subclinical vascular disease and CVD risk than only measuring CIMT. Carotid plaque is defined as the presence of focal wall thickening that is at least 50% greater than that of the surrounding vessel wall or as a focal region with CIMT greater than 1.5 mm that protrudes into the lumen that is distinct from the adjacent boundary.**[15,38,44,45] The presence of shadowing also may be reported; however, further plaque quantification and characterization by B-mode ultrasound is not sufficiently reproducible outside of research settings and does not appear to add significantly to the predictive value of carotid plaque presence.[84] Because of the complex, asymmetric nature of plaques, risk stratification based on plaque diameter or area is not recommended, as it may misrepresent plaque burden.[15,85]

Measurement of CIMT involves tracing the blood-intima and media-adventitia interfaces of the far wall using a leading edge–to–leading edge technique (Figure 5). The best image for CIMT measurement demonstrates the blood-intima and media-adventitia boundaries clearly. The reader should be able to see these interfaces on both near and far walls of the carotid artery to ensure that the sonographer has imaged the vessel through its truest diameter ("double-line" sign) (Figure 3), otherwise the CIMT may be thicker or thinner than is anatomically correct.[75,86] If the images do not show a complete 1-cm segment, the tracing maybe shortened. Avoid tracing interfaces that are not clearly visualized. If plaques are detected in the segment being measured, they should be traced as part of the CIMT because they appear to have been included in CIMT measurements in most of the epidemiologic studies in Table 1.[25] An alternate reading protocol, based on published nomograms and risk prediction associations, also may be used (Table 1, and Appendices 1 and 2). In general, segments should be measured in triplicate and CIMT values averaged. Most studies that provided reference values in Appendices 1 and 2 used manual reading techniques; however, semiautomated border detection programs were used by some. Semiautomated border detection programs are widely available and, when used on high-quality images, tend to improve reproducibility and shorten reading time, especially among newer readers.[87-90] **The task force recommends use of a semiautomated border detection program with validated accuracy.** Border detection programs should allow the reader to edit the tracked borders if those generated by the program's algorithm are not optimal. These programs tend to produce somewhat thicker CIMT values than manual tracing, especially if the generated borders are left unedited. Software that assists with manual tracing using electronic calipers also is an option, especially considering that most outcome data are based on studies that used manual tracings. Simple point-to-point measurements of CIMT are not acceptable.

**Mean CIMT values from the far walls of the right and left CCAs (mean-mean) should be reported.** Use of additional segments or maximum values is an alternative if there is local expertise and these measurements can be mapped to normative values with published associations to CVD risk (Table 1, and Appendices 1 and 2). Most reading software will report mean-mean (average of segmental mean CIMT values) and mean-maximum (average of segmental maximum CIMT values) CIMT values. Mean-mean values are more reproducible because multiple points along the traced segment are averaged, but are less sensitive to change. Mean-maximum values are more sensitive to change, but less reproducible, because they are derived from a single point (or regional maximum) measurement along the 1-cm region.

## REPORTING CAROTID ULTRASOUND STUDY RESULTS

Study results should be provided to the ordering provider in an understandable and clinically applicable fashion. **Recommended components of the report are described in Table 8.** The report should clearly identify the type of study being performed (ie, "carotid ultrasound study for cardiovascular risk assessment"), that it is not a replacement for a clinically indicated carotid duplex ultrasound, and that the results do not indicate the presence or absence of clinically significant obstruction, unless noted otherwise.

Because semiautomated border detection programs tend to produce somewhat thicker CIMT values than seen with manual tracing, their use should be considered by the reader when making recommendations concerning the findings of the study, especially if the normative data set was obtained using manual tracing. Current ultrasound instrumentation and digital imaging also provide better resolution, which may make CIMT values somewhat smaller. **Communication of CIMT results is facilitated by qualitatively describing broad ranges of percentiles. This avoids the appearance of greater precision than is achievable when mapping CIMT values to a reference population.** Because percentile estimates in the population studies have confidence intervals, and because the instrumentation, scanning, and measurement techniques in a clinical laboratory will not be exactly the same as used in these studies, reporting ranges helps mitigate some of these differences. The normative reference values used in the report must describe the same CIMT measurement (ie, mean or maximum) because these values differ substantially.

**CIMT values greater than or equal to 75th percentile are considered high and indicative of increased CVD risk. Values in the 25th to 75th percentile are considered average and indicative of unchanged CVD risk. Values less than or equal to 25th percentile are considered lower CVD risk, but whether or not they justify less aggressive preventive therapy than standard care is not known. These broad levels of risk should be reported.** Relative risk estimates for key percentile values (eg, the upper quartile or quintile) or the presence of carotid plaque also may be included (Tables 1 and 2).

Incidental findings that may require further evaluation such as the possibility of high-grade carotid artery stenosis (ie, visual appearance of obstructive plaque, increased color or spectral Doppler flow velocities), carotid tumor, carotid dissection, a large thyroid mass (1 cm or per local thresholds), lymphadenopathy, or others should be described. Each laboratory should have a mechanism for reporting urgent findings in a timely manner. Although carotid ultrasound for CVD risk assessment is not meant to screen for these findings or to replace a medically indicated diagnostic ultrasound study of these structures, the reader and sonographer should be able to recognize significant pathology if it is discovered incidentally during the course of the examination.

## TRAINING AND CERTIFICATION OF SONOGRAPHERS AND READERS

To date, there is no clinical standard for training and certification for sonographers or readers. A training program for sonographers participating in clinical research has been published, however, standards vary by study and laboratory.[91] Reproducibility standards in clinical trials also have been described.[86,92] **Sonographers and readers should have appropriate training to perform and understand the findings on ultrasound examinations (Table 9). Sonographers and readers should complete a formal educational program covering the content areas in Table 9 with hands-on training and follow-up.** Recommendations for the number of hours dedicated to training are not based on educational outcomes research, but are a consensus recommendation regarding the minimum time it typically takes to achieve the recommendations in this document. They also reflect the minimum amount of time invested by attendees at currently available CIMT training programs that have tracked training outcomes. Recommendations for maintenance of certification also are in Table 9. Quality assurance measures should be documented with plans for remedial training and possible disqualification, if needed. Ideally, a national certification and registry for carotid ultrasound scanning for CVD risk assessment, as described in this document, would be developed. Laboratories with significant CIMT expertise should determine and document their measurement accuracy and reproducibility, to assure that it is similar to that reported in the literature.[86-88,91-94]

## CONCLUSIONS

Ultrasonic detection of carotid plaque and CIMT measurements can be useful for refining CVD risk assessment in some asymptomatic patients. This noninvasive approach can detect subclinical vascular disease and help identify patients at increased risk of CVD. Strict attention to quality control in image acquisition, measurement, interpretation, and reporting are necessary for implementation of this technique in clinical practice.

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**Appendix 1** Common carotid artery carotid intima-media thickness values and percentiles from large North American cohort studies

A. Mean far wall common carotid artery carotid intima-media thickness values from the Atherosclerosis Risk in Communities Study[76]

Right

| Age, y/percentile | White male | | | White female | | | Black male | | | Black female | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 45 | 55 | 65 | 45 | 55 | 65 | 45 | 55 | 65 | 45 | 55 | 65 |
| 25th | 0.496 | 0.572 | 0.648 | 0.476 | 0.542 | 0.608 | 0.514 | 0.614 | 0.714 | 0.518 | 0.578 | 0.638 |
| 50th | 0.570 | 0.664 | 0.758 | 0.536 | 0.616 | 0.696 | 0.604 | 0.724 | 0.844 | 0.588 | 0.668 | 0.748 |
| 75th | 0.654 | 0.774 | 0.894 | 0.610 | 0.710 | 0.810 | 0.700 | 0.850 | 1.000 | 0.664 | 0.764 | 0.864 |

Left

| Age, y/percentile | White male | | | White female | | | Black male | | | Black female | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 45 | 55 | 65 | 45 | 55 | 65 | 45 | 55 | 65 | 45 | 55 | 65 |
| 25th | 0.524 | 0.588 | 0.652 | 0.472 | 0.540 | 0.608 | 0.530 | 0.610 | 0.690 | 0.494 | 0.558 | 0.622 |
| 50th | 0.598 | 0.684 | 0.770 | 0.538 | 0.622 | 0.706 | 0.614 | 0.714 | 0.814 | 0.566 | 0.646 | 0.726 |
| 75th | 0.690 | 0.806 | 0.922 | 0.610 | 0.710 | 0.810 | 0.704 | 0.840 | 0.976 | 0.644 | 0.748 | 0.852 |

B. Maximum far wall common carotid artery carotid intima-media thickness values from the Bogalusa Heart Study[77]

Right

| Age, y/percentile | White male | | | | White female | | | | Black male | | | | Black female | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25 | 30 | 35 | 40 | 25 | 30 | 35 | 40 | 25 | 30 | 35 | 40 | 25 | 30 | 35 | 40 |
| 25th | 0.611 | 0.636 | 0.662 | 0.687 | 0.562 | 0.586 | 0.611 | 0.635 | 0.637 | 0.675 | 0.712 | 0.750 | 0.616 | 0.650 | 0.685 | 0.719 |
| 50th | 0.663 | 0.702 | 0.740 | 0.779 | 0.633 | 0.654 | 0.676 | 0.697 | 0.719 | 0.756 | 0.793 | 0.830 | 0.682 | 0.718 | 0.754 | 0.790 |
| 75th | 0.768 | 0.807 | 0.845 | 0.884 | 0.717 | 0.735 | 0.754 | 0.772 | 0.839 | 0.884 | 0.929 | 0.974 | 750 | 0.793 | 0.837 | 0.880 |

Left

| Age, y/percentile | White male | | | | White female | | | | Black male | | | | Black female | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25 | 30 | 35 | 40 | 25 | 30 | 35 | 40 | 25 | 30 | 35 | 40 | 25 | 30 | 35 | 40 |
| 25th | 0.577 | 0.617 | 0.658 | 0.698 | 0.554 | 0.586 | 0.618 | 0.650 | 0.640 | 0.676 | 0.713 | 0.749 | 0.587 | 0.629 | 0.670 | 0.712 |
| 50th | 0.655 | 0.707 | 0.760 | 0.812 | 0.621 | 0.657 | 0.693 | 0.729 | 0.736 | 0.774 | 0.812 | 0.850 | 0.646 | 0.691 | 0.736 | 0.781 |
| 75th | 0.763 | 0.814 | 0.864 | 0.915 | 0.660 | 0.713 | 0.766 | 0.819 | 0.794 | 0.844 | 0.894 | 0.944 | 0.714 | 0.768 | 0.822 | 0.876 |

C. Maximum near and far wall common carotid artery carotid intima-media thickness Values from the CHS Study (Alice M. Arnold, PhD, personal communication, December 2006)

| Age, y/percentile | Male | | | | | Female | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 65-69 | 70-74 | 75-79 | 80-84 | 85+ | 65-69 | 70-74 | 75-79 | 80-84 | 85+ |
| 25th | 0.94 | 0.95 | 1.00 | 1.03 | 1.05 | 0.87 | 0.89 | 0.92 | 0.96 | 0.99 |
| 50th | 1.03 | 1.07 | 1.10 | 1.15 | 1.18 | 1.96 | 0.99 | 1.03 | 1.05 | 1.12 |
| 75th | 1.16 | 1.21 | 1.25 | 1.30 | 1.32 | 1.07 | 1.10 | 1.16 | 1.19 | 1.28 |

D. Common carotid artery carotid intima-media thickness values from the Multi-Ethnic Study of Atherosclerosis Study (Robyn L. McClelland, PhD, personal communication, January 2007)[6]

Mean far wall–right

| Age, y/percentile | White male | | | | White female | | | | Black male | | | | Black female | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 |
| 25th | 0.52 | 0.57 | 0.65 | 0.72 | 0.51 | 0.55 | 0.65 | 0.72 | 0.58 | 0.61 | 0.71 | 0.74 | 0.55 | 0.60 | 0.65 | 0.71 |
| 50th | 0.62 | 0.68 | 0.77 | 0.83 | 0.58 | 0.65 | 0.75 | 0.83 | 0.67 | 0.74 | 0.85 | 0.85 | 0.64 | 0.71 | 0.76 | 0.83 |
| 75th | 0.71 | 0.81 | 0.92 | 0.97 | 0.67 | 0.76 | 0.87 | 0.93 | 0.80 | 0.92 | 0.99 | 1.02 | 0.74 | 0.81 | 0.92 | 0.96 |

**Appendix 1** Continued

| Age, y/percentile | Chinese male | | | | Chinese female | | | | Hispanic male | | | | Hispanic female | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 |
| 25th | 0.54 | 0.56 | 0.62 | 0.66 | 0.55 | 0.54 | 0.59 | 0.67 | 0.53 | 0.60 | 0.65 | 0.71 | 0.51 | 0.57 | 0.65 | 0.63 |
| 50th | 0.64 | 0.70 | 0.73 | 0.79 | 0.60 | 0.63 | 0.71 | 0.77 | 0.62 | 0.67 | 0.78 | 0.81 | 0.58 | 0.69 | 0.76 | 0.78 |
| 75th | 0.73 | 0.83 | 0.92 | 0.98 | 0.70 | 0.77 | 0.84 | 0.96 | 0.73 | 0.82 | 0.90 | 0.92 | 0.67 | 0.77 | 0.87 | 0.92 |

**Mean far wall–left**

| Age, y/percentile | Chinese male | | | | Chinese female | | | | Hispanic male | | | | Hispanic female | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 |
| 25th | 0.55 | 0.57 | 0.62 | 0.69 | 0.49 | 0.52 | 0.58 | 0.64 | 0.55 | 0.61 | 0.68 | 0.72 | 0.51 | 0.58 | 0.62 | 0.68 |
| 50th | 0.63 | 0.70 | 0.72 | 0.84 | 0.58 | 0.63 | 0.71 | 0.76 | 0.64 | 0.72 | 0.80 | 0.86 | 0.58 | 0.68 | 0.72 | 0.77 |
| 75th | 0.73 | 0.84 | 0.86 | 0.97 | 0.67 | 0.72 | 0.87 | 0.94 | 0.75 | 0.85 | 0.98 | 0.97 | 0.68 | 0.79 | 0.86 | 0.91 |

| Age, y/percentile | White male | | | | White female | | | | Black male | | | | Black female | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 |
| 25th | 0.54 | 0.57 | 0.67 | 0.71 | 0.50 | 0.55 | 0.63 | 0.70 | 0.56 | 0.63 | 0.69 | 0.72 | 0.54 | 0.59 | 0.63 | 0.68 |
| 50th | 0.63 | 0.69 | 0.81 | 0.85 | 0.58 | 0.64 | 0.73 | 0.80 | 0.69 | 0.75 | 0.82 | 0.85 | 0.63 | 0.67 | 0.76 | 0.78 |
| 75th | 0.78 | 0.82 | 0.95 | 1.00 | 0.67 | 0.75 | 0.85 | 0.94 | 0.81 | 0.92 | 0.99 | 1.02 | 0.73 | 0.80 | 0.90 | 0.91 |

**Maximum far wall–right**

| Age, y/percentile | White male | | | | White female | | | | Black male | | | | Black female | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 |
| 25th | 0.61 | 0.66 | 0.73 | 0.83 | 0.59 | 0.66 | 0.77 | 0.82 | 0.66 | 0.72 | 0.79 | 0.83 | 0.63 | 0.72 | 0.72 | 0.79 |
| 50th | 0.72 | 0.79 | 0.89 | 0.94 | 0.67 | 0.74 | 0.88 | 0.94 | 0.77 | 0.83 | 0.94 | 0.96 | 0.74 | 0.83 | 0.87 | 0.94 |
| 75th | 0.87 | 0.94 | 1.05 | 1.11 | 0.79 | 0.88 | 1.00 | 1.07 | 0.89 | 1.05 | 1.11 | 1.13 | 0.87 | 0.94 | 1.05 | 1.10 |

| Age, y/percentile | Chinese male | | | | Chinese female | | | | Hispanic male | | | | Hispanic female | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 |
| 25th | 0.66 | 0.63 | 0.66 | 0.72 | 0.62 | 0.61 | 0.66 | 0.72 | 0.61 | 0.67 | 0.72 | 0.78 | 0.61 | 0.67 | 0.72 | 0.72 |
| 50th | 0.75 | 0.79 | 0.83 | 0.90 | 0.72 | 0.72 | 0.80 | 0.88 | 0.74 | 0.82 | 0.88 | 0.89 | 0.67 | 0.77 | 0.87 | 0.88 |
| 75th | 0.86 | 0.94 | 1.05 | 1.07 | 0.83 | 0.82 | 0.94 | 1.05 | 0.87 | 0.95 | 1.05 | 1.05 | 0.78 | 0.91 | 1.00 | 1.03 |

**Maximum far wall–left**

| Age, y/percentile | White male | | | | White female | | | | Black male | | | | Black female | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 |
| 25th | 0.64 | 0.68 | 0.77 | 0.77 | 0.61 | 0.66 | 0.72 | 0.82 | 0.66 | 0.72 | 0.82 | 0.83 | 0.62 | 0.66 | 0.72 | 0.77 |
| 50th | 0.73 | 0.79 | 0.90 | 0.97 | 0.67 | 0.77 | 0.84 | 0.94 | 0.79 | 0.86 | 0.93 | 0.95 | 0.72 | 0.78 | 0.84 | 0.89 |
| 75th | 0.89 | 0.94 | 1.09 | 1.12 | 0.78 | 0.88 | 1.00 | 1.11 | 0.94 | 1.04 | 1.11 | 1.11 | 0.86 | 0.94 | 1.03 | 1.00 |

| Age, y/percentile | Chinese male | | | | Chinese female | | | | Hispanic male | | | | Hispanic female | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 | 45-54 | 55-64 | 65-74 | 75-84 |
| 25th | 0.65 | 0.64 | 0.72 | 0.77 | 0.61 | 0.61 | 0.66 | 0.72 | 0.62 | 0.72 | 0.77 | 0.77 | 0.61 | 0.66 | 0.72 | 0.77 |
| 50th | 0.75 | 0.79 | 0.81 | 0.94 | 0.72 | 0.73 | 0.82 | 0.83 | 0.72 | 0.83 | 0.94 | 0.94 | 0.66 | 0.77 | 0.83 | 0.88 |
| 75th | 0.88 | 0.95 | 1.00 | 1.06 | 0.80 | 0.83 | 0.96 | 1.05 | 0.88 | 0.97 | 1.11 | 1.11 | 0.78 | 0.89 | 0.97 | 1.02 |

Y, years. All values are in mm.

**Appendix 2** Common carotid artery carotid intima-media thickness values and percentiles from large European cohort studies

**A. Mean far wall common carotid artery carotid intima-media thickness values from the AXA Study[79,80]**

**Right common carotid artery**

| Age, y/percentile | Male | | | | Female | | | |
|---|---|---|---|---|---|---|---|---|
| | ≤30 | 31-40 | 41-50 | >50 | ≤30 | 31-40 | 41-50 | >50 |
| 25th | 0.39 | 0.42 | 0.46 | 0.46 | 0.39 | 0.42 | 0.44 | 0.50 |
| 50th | 0.43 | 0.46 | 0.50 | 0.52 | 0.40 | 0.45 | 0.48 | 0.54 |
| 75th | 0.48 | 0.50 | 0.57 | 0.62 | 0.43 | 0.49 | 0.53 | 0.59 |

**Left common carotid artery**

| Age, y/percentile | Male | | | | Female | | | |
|---|---|---|---|---|---|---|---|---|
| | ≤30 | 31-40 | 41-50 | >50 | ≤30 | 31-40 | 41-50 | >50 |
| 25th | 0.42 | 0.44 | 0.50 | 0.53 | 0.30 | 0.44 | 0.46 | 0.52 |
| 50th | 0.44 | 0.47 | 0.55 | 0.61 | 0.44 | 0.47 | 0.51 | 0.59 |
| 75th | 0.49 | 0.57 | 0.61 | 0.70 | 0.47 | 0.51 | 0.57 | 0.64 |

**B. Mean far wall common carotid artery carotid intima-media thickness values from the Carotid Atherosclerosis Progression Study (Matthias W. Lorenz, MD, personal communication, December 6)[20]**

| Age, y/percentile | Male | | | | | | | Female | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25 | 35 | 45 | 55 | 65 | 75 | 85 | 25 | 35 | 45 | 55 | 65 | 75 | 85 |
| 25th | 0.515 | 0.585 | 0.634 | 0.68 | 0.745 | 0.814 | 0.83 | 0.524 | 0.575 | 0.619 | 0.665 | 0.718 | 0.771 | 0.807 |
| 50th | 0.567 | 0.633 | 0.686 | 0.746 | 0.83 | 0.914 | 0.937 | 0.567 | 0.615 | 0.665 | 0.719 | 0.778 | 0.837 | 0.880 |
| 75th | 0.633 | 0.682 | 0.756 | 0.837 | 0.921 | 1.028 | 1.208 | 0.612 | 0.66 | 0.713 | 0.776 | 0.852 | 0.921 | 0.935 |

**C. Maximum* far wall common carotid artery carotid intima-media thickness values from the Edinburgh Artery Study (F. Gerald R. Fowkes, MBChB, PhD, personal communication, November 2006)[81]**

| Age, y/percentile | Male | | | | | Female | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 60-64 | 65-69 | 70-74 | 75-79 | >80 | 60-64 | 65-69 | 70-74 | 75-79 | >80 |
| 25th | 0.60 | 0.70 | 0.70 | 0.70 | 0.80 | 0.60 | 0.60 | 0.70 | 0.70 | 0.72 |
| 50th | 0.80 | 0.80 | 0.80 | 0.90 | 1.00 | 0.70 | 0.80 | 0.80 | 0.90 | 0.90 |
| 75th | 0.90 | 1.00 | 1.00 | 1.20 | 1.20 | 0.80 | 0.90 | 0.90 | 1.00 | 1.40 |

Y, years. All values are in mm.
*Maximum of right or left common carotid artery.

**D. Mean far wall common carotid artery carotid intima-media thickness values from the Malmö Diet and Cancer Study (Maria Rosvall, MD, PhD, Bo Hedblad, MD, PhD, and Goran Berglund, MD, PhD, personal communication, December 2006)[23]**

| Age, y/percentile | Men | | Women | |
|---|---|---|---|---|
| | 55 | 65 | 55 | 65 |
| 25th | 0.66 | 0.73 | 0.64 | 0.73 |
| 50th | 0.75 | 0.81 | 0.71 | 0.81 |
| 75th | 0.86 | 0.94 | 0.78 | 0.88 |

Y, years. All values are in mm.