Carotid Doppler Ultrasound in Stroke Patients

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Background: *Strokes constitute a major public healthcare problem in Thailand. Stroke prevalence in Thailand is high, but lower than in highly developed countries, probably due to the high fatality rate here. Carotid pathology is known to be associated with strokes, and carotid doppler ultrasonography (CDU) is a powerful tool for use in evaluating atherosclerosis of the carotid artery.*

Objective: *To evaluate carotid imaging pathology by CDU in stroke patients.*

Material and Method: *This was a retrospective study of 170 stroke patients who underwent CDU in Rajavithi Hospital between January 2011 and May 2016.*

Results: *In all, there were 170 stroke patients with mean age of 63.92±13.97 years (21 to 91 years old); 61.2% were men, and 38.8% were women. Mean carotid IMT of the right and left common carotid artery were 1.08±0.55 mm and 1.11±0.58 mm respectively. Plaque levels at the right and left internal carotid artery were 1.51±0.81 mm and 1.60±0.86 mm, respectively, and total occlusion of carotid artery was found in 12 patients. Follow-up studies were obtained in 10 cases of whom all had progressive disease: in one patient, the progression of carotid stenosis increased from 70% stenosis to total occlusion, and in another from 53% stenosis to total occlusion. Total occlusion of carotid artery was found in 14 patients.*

Conclusion: *Most of these stroke patients had carotid pathology. Many of them had normal carotid velocity, but increasing intima-media thickness and plaque of varying morphology. There were varying degrees of vessel stenosis ranging from no significant stenosis to more than 50% stenosis, 50 to 69% stenosis, more than 70% stenosis, near occlusion and total occlusion.*

Keywords: *Carotid pathology, Carotid IMT, Ischemic stroke, TIA, Permanent stroke, Carotid doppler ultrasonography*

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Intima-media thickness (IMT), carotid plaque morphology, carotid peak systolic velocity detected by B-mode, and Doppler-mode ultrasound are noninvasive methods of looking for carotid pathology. Gray scale mode can be used in measuring the IMT, which is a very good biomarker for atherosclerosis and can aid in plaque characterization. Plaque morphology is related to the risk of stroke, and ulceration of plaque is known to be one of the strong predictors of risk of future embolic events. Color Doppler mode and pulse Doppler mode have been used to detect carotid artery stenosis[1]. This is an operator-dependent examination that requires a good understanding of Doppler physics and hemodynamic physiology[2].

The carotid artery is a large artery. The common carotid artery (CCA) arises from the aortic arch, widens into the carotid bulb (bifurcation), and then divides into the internal carotid artery (ICA), which supplies the brain, and the external carotid artery (ECA). Plaque often builds up at that division and causes narrowing (stenosis). Pieces of plaque can break off and block the small arteries above in the brain, and this can cause ischemic stroke.

Atherosclerosis is a chronic inflammatory multi-stage process in the medium-sized and large-sized vessels that mainly result from endothelial dysfunction and accumulation of fat in the vessel wall. The continuous atherosclerotic process causes narrowing of the luminal vessel wall[3] that eventually causes transient ischemic attack (TIA), ischemic stroke, myocardial infarct and cardiovascular disease. Coronary disease is an indicator of diffuse atherosclerosis, including coronary heart disease, and manifestation of the disease at one site increases the chances that it will be found at other vascular beds as well. Pathological studies support this theory: in 200 consecutive medicolegal autopsies Mathur et al[4], found a significant correlation between coronary and intracranial arterial atherosclerosis. Coronary atherosclerosis appeared to develop first, about 20 years

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earlier than cerebral atherosclerosis.

CDU is a direct, noninvasive imaging method of diagnosis of carotid artery disease. In the United States, CDU is sometimes the only diagnostic imaging modality performed before carotid endarterectomy or carotid stent. Important factors in diagnosis of atherosclerotic disease of the extracranial carotid arteries are the IMT, plaque morphology, criteria for grading stenosis, limiting factors such as the presence of dissection or cardiac abnormalities, and distinguishing between near occlusion and total occlusion. One of the challenges to the consistency of CDU is that its accuracy depends on the standard of performance of the radiologist who needs to utilise the right technique and have experience in interpretation[2].

IMT has been widely used as one of the parameters of atherosclerorosis[5,6] and is measured on a two-dimensional (2D) gray-scale image (Fig. 1). The optimal gray-scale image of the longitudinal scan of the carotid artery shows two bright interfaces along the artery wall. In the far wall, the upper bright line is the interface between the blood and the intima, and the lower bright line is the interface between the media and adventitia layers.

Fig. 1 Measuring the IMT. The distal CCA is the proper site for measuring the IMT at far wall. Normal IMT should be less than 1 mm.

Objective

To evaluate carotid imaging pathology by CDU in stroke patients.

Material and Method

This was a retrospective review of CDU in stroke patients from January 2011 to May 2016. Data collected and analyzed were the gender and age of the patients, their clinical presentation, carotid imaging pathology including carotid IMT, carotid plaque morphology, echogenicity of the plaque, carotid peak systolic velocity and percent diameter stenosis.

Results

Of the 170 patients included in the research, 104 (61.2%) were men and 66 (38.8%) were women. Their ages ranged from 21 to 91 years old (mean ± SD = 63.92±13.97 years). The clinical presentations were ischemic stroke 119 persons (70%), transient ischemic attack 29 (17.1%), acute blindness 3 (1.8%), blurred vision 6 (3.5%) and central retinal artery occlusion 13 (7.6%). The data is shown in Table 1. Mean IMT at right and left CCA were 1.08±0.55 and 1.11±0.58 mm respectively. Plaque levels at the right and left carotid bifurcation were 1.83±0.92 and 1.68±0.76 mm respectively. Plaque at the right and left ICA were 1.51±0.81 and 1.60±0.86 mm respectively. Plaque morphology includes isoechoic, echolucent (Fig. 2), hyperechoic, calcified (Fig. 3) or heterogenous plaque (Fig. 4), and some are mixed types (Fig. 5). The data is shown in Table 2.

Table 1. Baseline characteristics (n = 170)

Characteristics	Number	Percent
Sex		
Male	104	61.2
Female	66	38.8
Age (years)		
Mean ± SD (min-max)	63.92±13.97 (21-91)	
<40	9	5.3
40-59	51	30.0
60-69	42	24.7
70-79	50	29.4
80+	18	10.6
Diagnosis		
Permanent ischemic stroke	119	70.0
Transient ischemic attack	29	17.1
Acute blindness	3	1.8
Blur vision	6	3.5
Central retinal artery occlusion	13	7.6

The velocities of the right and left CCA respectively were less than 125 cm/sec in 166 (97.6%) and 165 patients (97.1%) and between 125-230 cm/sec in 4 (2.4%) and 5 patients (2.9%). The velocities of the right and left ICA respectively were less than 125 cm/sec in 153 (90%) and 160 patients (94.1%)

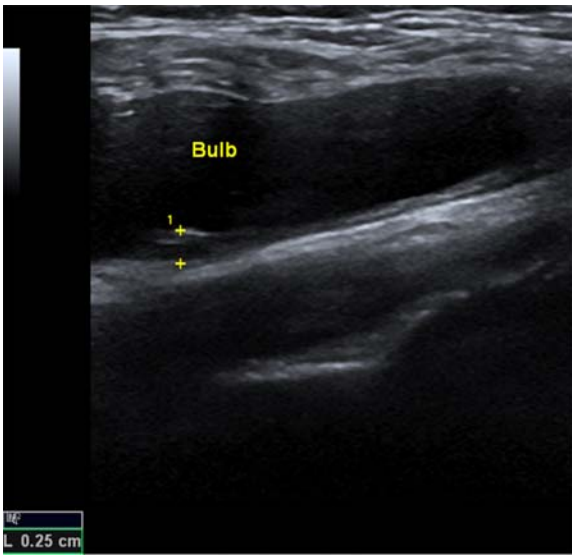

Fig. 2 A gray-scale image of a longitudinal scan of carotid bulb shows echolucent or anechoic plaque with thin fibrous cap. Plaque containing an echo-poor area may be hemorrhage or lipids which are likely to become symptomatic (unstable plaque).

Fig. 3 A gray-scale image of a longitudinal scan of common carotid artery shows calcified plaque (stable plaque).

(Fig. 6) and between 125-230 cm/sec (indicating 50 to 69% stenosis) in 8 (4.7%) and 2 patients (1.2%) (Fig. 7). The velocity of the left ICA was more than 230 cm/sec in 3 patients (1.8%) indicating a state of more than 70% stenosis to near occlusion. In one case the velocity of the left ICA was 787 cm/sec, indicating severe stenosis

Fig. 4 A gray-scale image of a longitudinal scan of common carotid artery shows heterogenous plaque.

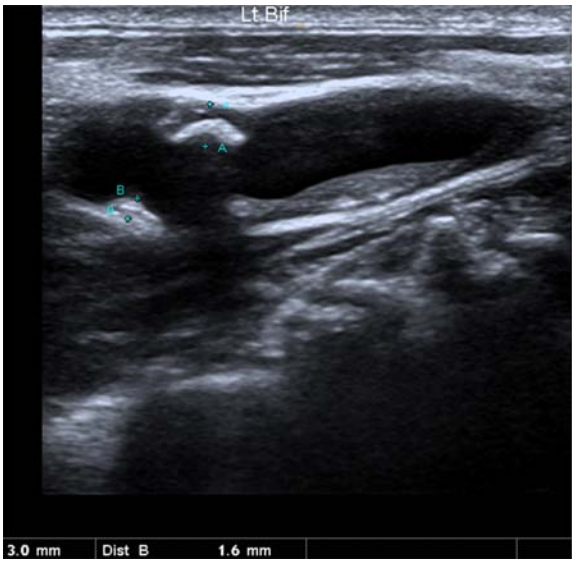

Fig. 5 A gray-scale image of a longitudinal scan of carotid bifurcation shows plaque with mixed echogenicity, indicating soft and calcified plaque.

(Fig. 8). Total occlusion of the right ICA was found in 7 patients (4.1%) (Fig. 9) and of the left ICA (Fig. 10) in 5 patients (2.9%). A velocity of ICA of less than 125 cm/sec indicates that there is no significant stenosis (less than 50% stenosis). The data is shown in Table 3. Follow-up studies were performed in 10 patients: one case was found to have progression of carotid disease from 70% stenosis to total occlusion, while another patient's progressed from 53% to total occlusion. All of the 10 patients had progression of atherosclerosis

Table 2. Plaque morphology by CDU

	Right	Left
CCA intima-media thickness	n = 170	n = 170
Mean ± SD (mm)	1.08±0.55	1.11±0.58
Calcified	1 (0.6)	0 (0.0)
Isoechoic	151 (88.8)	149 (87.6)
Isoechoic/calcified	12 (7.1)	17 (10.0)
Isoechoic/echolucent	6 (3.5)	4 (2.4)
Bulb	n = 128	n = 120
Mean ± SD (mm)	1.83±0.92	1.68±0.76
Calcified	4 (3.1)	7 (5.8)
Echolucent	1 (0.8)	0 (0.0)
Isoechoic	71 (55.5)	71 (59.2)
Isoechoic/calcified	46 (35.9)	37 (30.8)
Isoechoic/echolucent	4 (3.1)	2 (1.7)
Isoechoic/inhomogenous/ echolucent	1 (0.8)	0 (0.0)
Isoechoic/inhomogenous	1 (0.8)	1 (0.8)
Isoechoic/hyperechoic	0 (0.0)	2 (1.7)
ICA	n = 108	n = 108
Mean ± SD (mm)	1.51±0.81	1.60±0.86
Isoechoic	76 (70.4)	77 (71.3)
Isoechoic/calcified	28 (25.9)	28 (25.9)
Isoechoic/calcified/inhomogenous	1 (0.9)	0 (0.0)
Isoechoic/echolucent	1 (0.9)	0 (0.0)
Isoechoic/hyperechoic	2 (1.9)	0 (0.0)
Calcified	0 (0.0)	1 (0.9)
Isoechoic/inhomogenous	0 (0.0)	2 (1.9)

Values were represented as mean ± SD and number (percent)

or raised plaque size. Total occlusion was found in 14 patients.

In one case, there was restenosis of the carotid vessel due to soft plaque causing more than 70% stenosis after 2 years of post left carotid stent.

In 38 cases, there was direct measurement of the percent of stenosis (Fig. 11): 16 to 42% diameter stenosis was found in the right common carotid artery (n = 26); 16 to 49% stenosis was found in the left common carotid artery (n = 26); 15 to 58% stenosis was found in the right carotid bifurcation (n = 34); 16 to 47% stenosis was found in the left carotid bifurcation (n = 38); 18 to 69% stenosis was found in the right internal carotid artery (n = 28); and 17 to 70% stenosis was found in the left internal carotid artery (n = 32). The data is shown in Table 4.

Discussion

The IMT is generally measured on the distal CCA at the far wall because the CCA is easier to image and less variable than the ICA due to the angle of the beam or depth of the vessel[1].

In one study, the success rate for far-wall measurement was 89% in the CCA and 38% in the ICA[5]. The IMT should be measured on a segment without a focal lesion, and focal atherosclerotic lesions are much more common in ICA than in CCA[1]. Carotid artery atherosclerosis as measured by IMT is an independent risk factor for stroke and myocardial infarction[5,6].

In one study by Ivan Benaduce Casella et al[7], between February and September 2005, 210 stroke patients underwent duplex scan of carotid vessels performed by a single radiologist, and the carotid IMT in longitudinal scan was found to be 1.18±0.58 mm. This is similar to the findings of the present research in which the author found that mean IMT at the right and left CCA were 1.08±0.55 and 1.11±0.58 mm, respectively.

Plaque morphology

Plaque morphology, such as the echogenicity of the plaque, the surface, presence of ulceration, as well as the presence of plaque and stenosis, is important in predicting further cardiovascular events[8], and a description of plaque morphology is highly recommended during CDU. The description should include the echogenicity of the plaque, the surface, and the presence of ulceration. The echogenicity of the plaque could be described as hypoechoic, hyperechoic, isoechogenic, echolucent, calcified or heterogeneous plaque. Isoechoic plaque indicates that the echogenicity of plaque is the same as that of the intima-media complex. The plaque surface can described as smooth, irregular, or ulcerated[1], and plaque ulceration is associated with an increased risk of ischemic stroke[9,10].

However, it is very difficult to detect plaque ulceration by CDU, which is operator-dependent. The sensitivity of detecting carotid plaque ulceration ranges from under 30% to over 80% when it is compared with pathologic specimens[12,13]. Careful gray-scale examination may increase accuracy in detecting plaque ulceration.

A depression of the plaque surface of more than 2 mm is thought to indicate ulceration. The pattern of plaque ulceration can be cystic, bridge-shaped, sponge-shaped, or a simple depression[13-15].

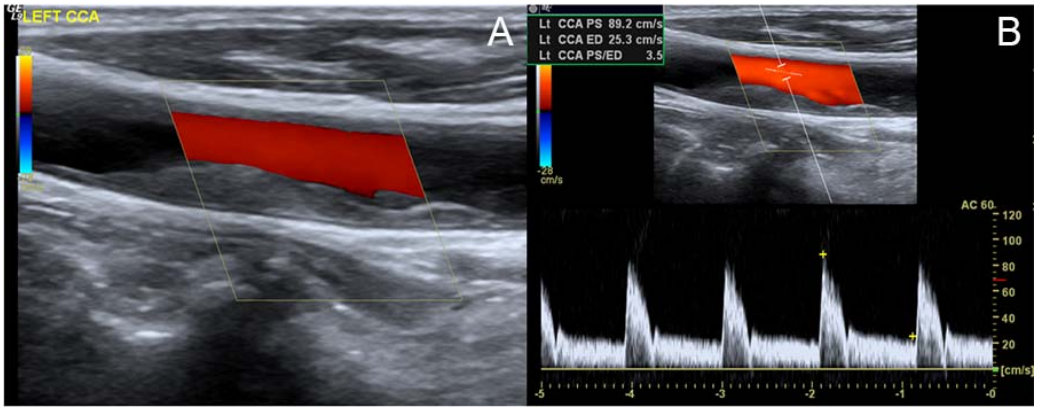

Fig. 6 A) Visible large isechoic plaque in the left CCA. B) Doppler spectrun of the left common carotid artery, PSV less than 125 cm/sec, indicating degree of stenosis less than 50%.

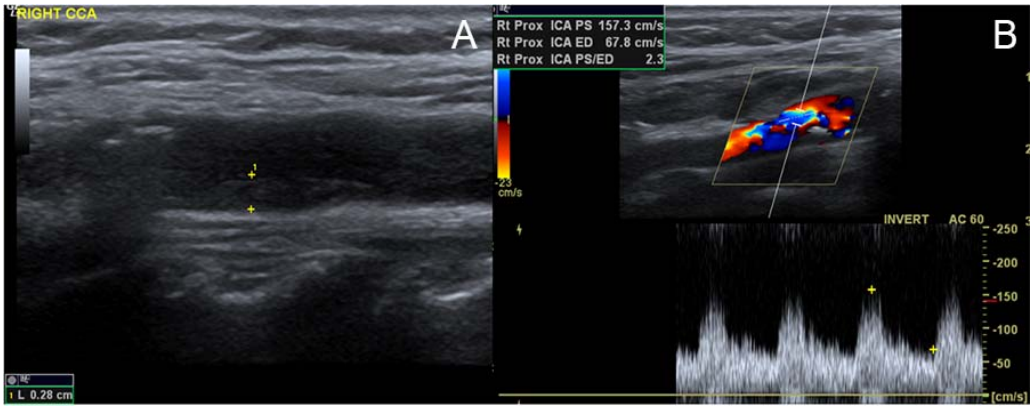

Fig. 7 A) Gray-scale image shows heterogenous plaque in the proximal right ICA. B) Duplex US image of the right ICA shows a rather high PSV (157 cm/sec), indicating 50 to 69% stenosis.

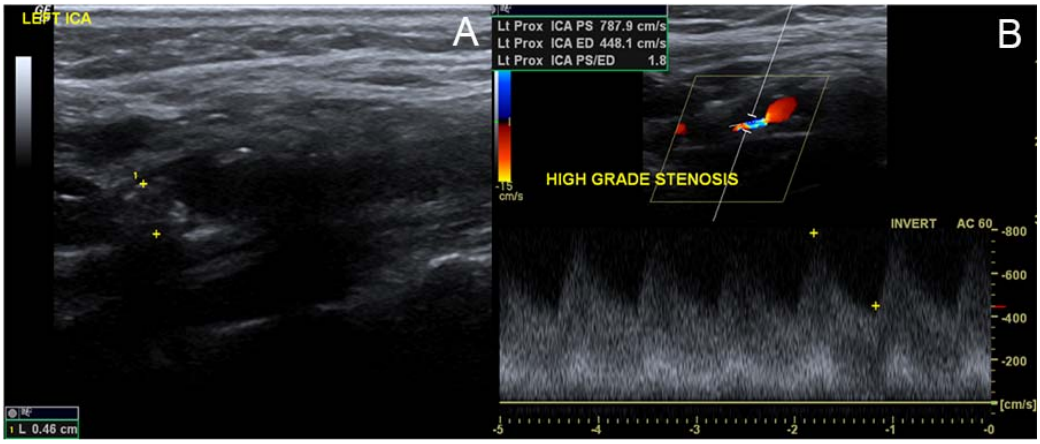

Fig. 8 Severe stenosis (70% to near occlusion) of the ICA. A) Gray-scale image shows large visible heterogenous plaque. B) Duplex US image of the left ICA shows a high PSV(787 cm/sec). The presence of aliasing despite a high color scale setting, broadening of the PW Doppler spectrum, and a high end-diastolic velocity (448 cm/sec).

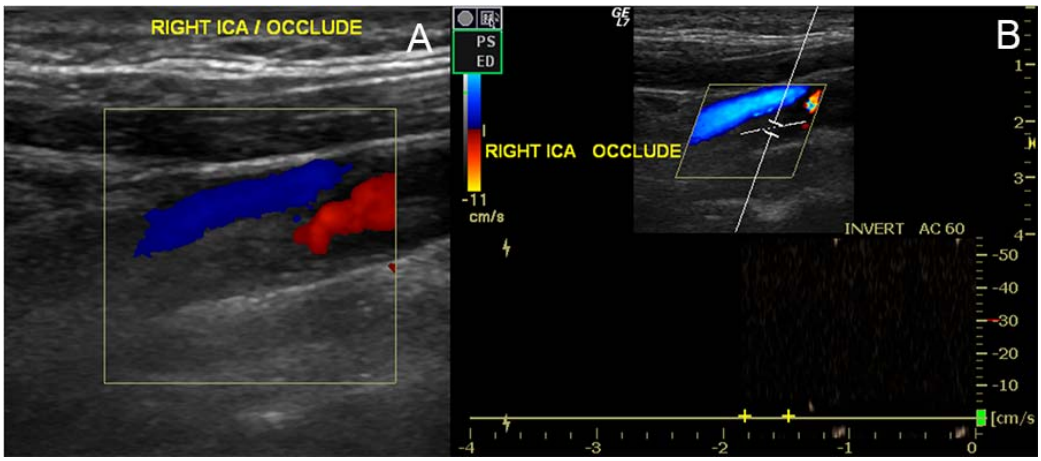

Fig. 9 Total occlusion. Duplex US image (A, B) shows total occlusion of the right ICA with undetectable flow.

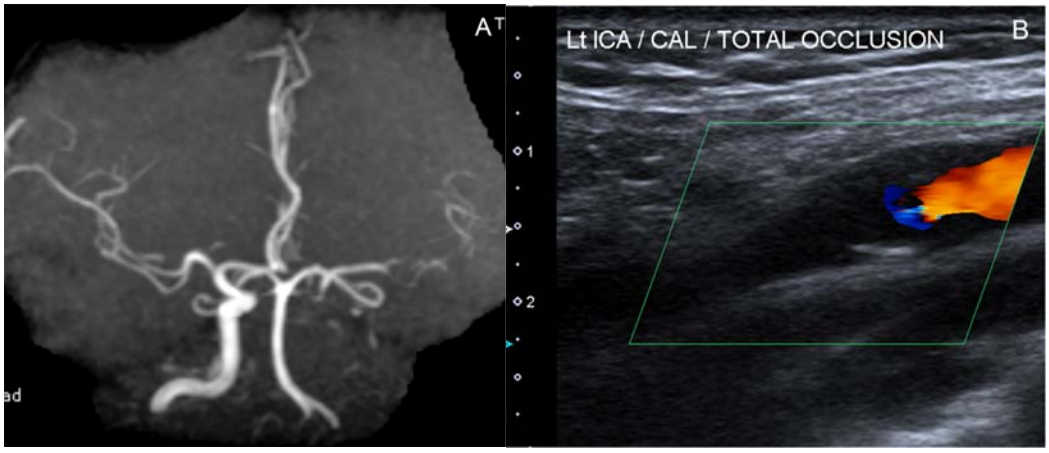

Fig. 10 A) MRA shows no flow in left ICA. B) Duplex US image shows total occlusion of the left ICA.

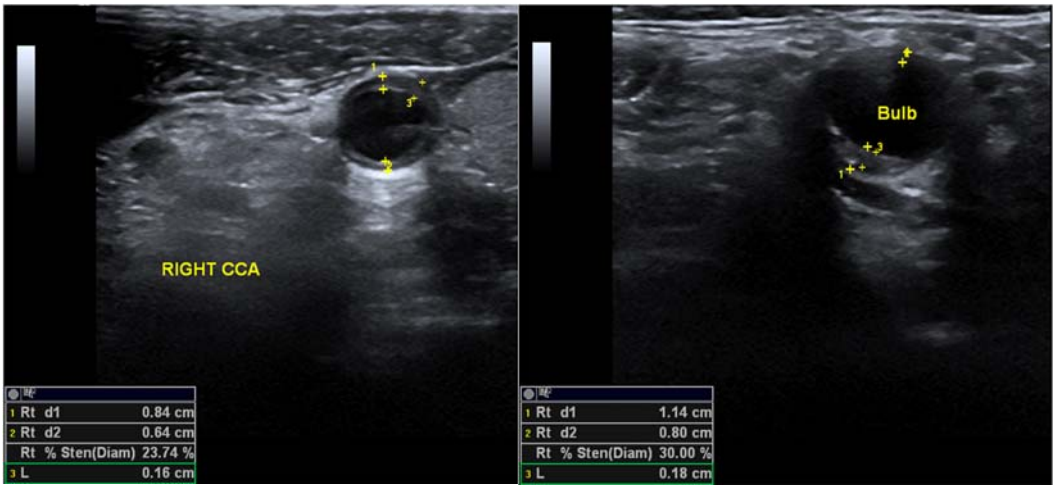

Fig. 11 Direct measurement of percent stenosis using gray scale image.

Direct measurement of stenotic segments using gray scale image should be performed because there is a wide range of non-significant stenosis varying between 10 to 49%. When the radiologists report that there is no significant stenosis, this may mislead the clinician, and the patient may not be made aware of having carotid arterial disease with its attendant risk of developing coronary heart disease and stroke.

The author found that in one case where there was 70% stenosis of the ICA, total occlusion of the ICA occurred one year later. In another case in which, there was 53% stenosis of the ICA, total occlusion of the ICA occurred two years later.

In 10 cases in which follow-up studies were performed, most had increased degrees of atherosclerotic change. In one case, a male 76-year-old with TIA, soft and calcified plaque along carotid bifurcation and IMT of ICA about 1.4-1.8 mm, a large area of ischemic stroke occurred two years later.

Table 3. Velocity by CDU

	Right	Left
Common carotid artery	n = 170	n = 170
Mean ± SD (cm/sec)	70.0 (23.0)	72.6 (23.1)
<125	166 (97.6)	165 (97.1)
125-230	4 (2.4)	5 (2.9)
Internal carotid artery	n = 161	n = 165
Mean ± SD (cm/sec)	69.08 (33.16)	74.46 (67.24)
<125	153 (90.0)	160 (94.1)
125-230	8 (4.7)	2 (1.2)
>230	0 (0.0)	3 (1.8)
No data	2 (1.2)	0 (0.0)
Total occlusion	7 (4.1)	5 (2.9)

Values were represented as number and percent

Color doppler ultrasonography and pulsed wave doppler ultrasonography

One of the purposes of CDU is to find any stenotic segment in the vessel. Because the flow volume through the vessel is constant, the velocity of the flow is fastest at the stenotic segment. If the upper limit of the color velocity scale is just below the flow velocity in normal vessels, the increased flow velocity in the stenotic segment will be above the upper limit of the velocity scale, causing an aliasing artifact. If there is a segment showing an aliasing artifact at the proper scale setting, it means that the segment is stenotic.

Conclusion

Most of these stroke patients had carotid pathology, and many had normal carotid velocity but increasing IMT and plaque of varying morphology. It is important to carefully look for plaque morphology including plaque echogenicity, surface and ulceration before performing CDU, in order to discriminate between stable and unstable plaque. There were varying degrees of vessel stenosis ranging from no significant stenosis to more than 50% stenosis, 50 to 69% stenosis, more than 70% stenosis, near occlusion and total occlusion.

What is already known on the topic?

Carotid disease is an indicator of diffuse atherosclerosis. It is necessary to discriminate between stable and unstable plaque, including the plaque surface.

If the diameter stenosis is more than 70%, carotid endarterectomy or carotid stent is recommended.

What this study adds?

The presence of carotid plaque or increased IMT is a warning sign for the development of future stoke. Prevention and proper management are important, as exemplified by the case of a male 76 year-

Table 4. Percent of Stenosis by CDU

Location	Right			Left		
	Stenosis >50%	Mean ± SD	Min-max	Stenosis >50%	Mean ± SD	Min-max
Common carotid artery	0/26 (0.0)	26.73±7.03	16-42	0/26 (0.0)	27.93±7.69	16-49
Carotid bulb	4/34 (11.8)	36.82±10.79	15-58	0/38 (0.0)	33.82±7.93	16-47
Internal carotid artery	3/28 (10.7)	34.33±12.35	18-69	5/32 (15.6)	37.33±12.34	17-70

Values were presented as number (percent)

old with TIA, in whom soft and calcified plaque along the carotid bifurcation and ICA of only about 1.4 to 1.8 mm was detected, and two years later, a large area of ischemic stroke occurred. Early detection of carotid artery disease should be attempted in high-risk patients. If there is no significant stenosis of these arteries (there is less than 50% stenosis or the ICA velocity is less than 125 cm/sec), direct measurement of diameter stenosis is advised to detect the range of 10 to 49% diameter stenosis. This is because when the radiologist reports that there is no significant stenosis, the clinician may be misled, and the patient may be not be made aware of his carotid artery disease and the associated risk of developing coronary heart disease and stroke in the future.

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Potential conflicts of interest

None.

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การตรวจหลอดเลือดคาโรติดด้วยคลื่นเสียงความถี่สูงในผู้ป่วยโรคหลอดเลือดสมอง

ประภาศรี เอี่ยมทอง

ภูมิหลัง: *โรคหลอดเลือดสมองเป็นปัญหาสำคัญทางสาธารณสุขของประเทศไทยพบความชุกของโรคหลอดเลือดสมองในประเทศไทยสูง แต่ก็ยังต่ำกว่าในประเทศที่พัฒนาแล้ว ซึ่งอาจเป็นเพราะมีอัตราการตายที่สูงกว่าในประเทศไทย เป็นที่ทราบกันว่าพยาธิสภาพของหลอดเลือดคาโรติดมีความสัมพันธ์กับการเกิดโรคหลอดเลือดสมอง การตรวจหลอดเลือดคาโรติดด้วยคลื่นเสียงความถี่สูง เป็นเครื่องมือที่มีประสิทธิภาพสูงในการวิเคราะห์พยาธิสภาพของหลอดเลือดคาโรติด*

วัตถุประสงค์: *เพื่อศึกษาพยาธิสภาพของหลอดเลือดคาโรติดโดยใช้คลื่นเสียงความถี่สูงในกลุ่มผู้ป่วยหลอดเลือดสมอง*

วัสดุและวิธีการ: *เป็นการศึกษาและวิเคราะห์แบบย้อนหลังของผลการตรวจคลื่นเสียงความถี่สูงของหลอดเลือดคาโรติดในผู้ป่วยหลอดเลือดสมอง จำนวน 170 คน ในโรงพยาบาลราชวิถีตั้งแต่ เดือนมกราคม พ.ศ. 2554 ถึง พฤษภาคม พ.ศ. 2559*

ผลการศึกษา: *ผู้ป่วย 170 ราย อายุเฉลี่ย 63.9 ปี (21 ถึง 91 ปี) เป็นเพศชาย 61.2% และเป็นเพศหญิง 38.8% ค่าเฉลี่ยความหนาของหลอดเลือดคาโรติด (common carotid artery) ข้างขวาและซ้ายคือ 1.08±0.55 มิลลิเมตรและ 1.11±0.58 มิลลิเมตร, ตามลำดับ ความหนาหรือคราบไขมัน/หินปูน ที่หลอดเลือดคาโรติดส่วนที่ไปเลี้ยงสมอง (internal carotid artery) ข้างขวา และซ้ายคือ 1.51±0.58 และ 1.60±0.86, ตามลำดับ พบว่ามีหลอดเลือดคาโรติดส่วนที่ไปเลี้ยงสมองอุดตันในผู้ป่วย 12 ราย มีการตรวจด้วยคลื่นเสียงความถี่สูงซ้ำในผู้ป่วยจำนวน 10 ราย ทุกรายพบว่าหลอดเลือดคาโรติดมีความหนามากขึ้น และในจำนวนนี้ผู้ป่วย 2 รายมีการตีบของหลอดเลือดคาโรติดส่วนที่ไปเลี้ยงสมองเพิ่มขึ้นจาก 53% และ 70% เป็นอุดตันทั้งเส้น ดังนั้นการวิจัยครั้งนี้จึงพบว่ามีการอุดตันของหลอดเลือดคาโรติดทั้งสิ้นจำนวน 14 ราย*

สรุป: *คนไข้โรคหลอดเลือดสมองส่วนใหญ่ พบว่ามีพยาธิสภาพในหลอดเลือดคาโรติด ถึงแม้ส่วนมากความเร็วในการไหลของเลือดยังอยู่เกณฑ์ปกติ แต่มีความหนาตัวของหลอดเลือดคาโรติดเพิ่มขึ้นและมีคราบไขมันหรือหินปูนจับหลอดเลือดในลักษณะต่างๆ พบมีการตีบแคบของหลอดเลือดตั้งแต่แบบไม่มีนัยสำคัญ, มากกว่า 50%, 50 ถึง 69%, มากกว่าหรือเท่ากับ 70%, ใกล้อุดตัน และอุดตันทั้งเส้น*