



Risk stratification of symptomatic carotid stenosis: based on ultrasonography

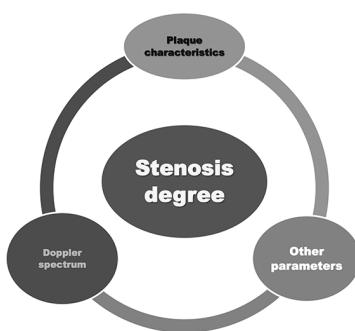
고려의대

정진만

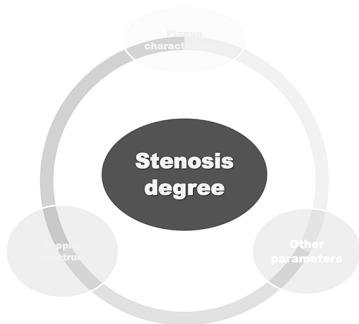
Duplex ultrasonography (DUS)

- Clinical trials of carotid artery revascularization methods such as carotid endarterectomy (CEA) and carotid artery stenting (CAS)
; guidance to clinicians about the choice of therapy
- Noninvasive DUS as a standard method for the clinical evaluation of the carotid arteries
- DUS as often the diagnostic modality used prior to intervention

Risk assessment for symptomatic carotid stenosis



Risk assessment for symptomatic carotid stenosis



Symptomatic carotid stenosis

- Definition by randomized controlled trial of symptomatic carotid stenosis [NASCET 1991, ECST 1998, Leicester 1998, EVA-3S 2006, SPACE 2007, ICSS 2010]
; amaurosis fugax (retinal infarction), hemispheric TIA, non-disabling stroke (symptom-based, *not* image-based)
; randomization within < 6 month of symptom onset
- Stenosis degree criteria based on invasive angiography only [NASCET 1991, ECST 1998, SPACE 2007], DUS only [Leicester 1998, SAPPHIRE 2004], combined non-invasive tools such as MRA, CTA or carotid sono [CAVATAS 2001, EVA-3S 2006, CREST 2010, ACT 1 2016/ICSS 2010, angio or DUS]

RCT comparing CEA vs. CAS			
	Baseline carotid stenosis degree		
	Angio	MRA/CTA	DUS
BACASS	+ (common carotid method)	+	+ (Sidhu suggestion)
Steinbauer	+ (NASCET)	-	-
Kentucky A,B	+ (NASCET)	-	-
TECAS-C	+?	-	-
WALLSTENT	+ not described	-	-
Leicester	-	-	+ (center criteria)
SAPHIRE	-	-	+ (Mayo clinic criteria)
EVA-3S	+ (NASCET)	+	+ (not described)
SPACE	+ (NASCET/ECST)	-	-
CAVATAS	+ (common carotid method)	+	+ (Sidhu suggestion)
ICSS	+ (NASCET)	-	+ (not described)
CREST	+ (NASCET)	+	+ (UWURC)
ACT 1	+ not described	-	+ (own strict criteria)

DUS criteria 1

❖ Kentucky
70% ; B-mode imaging plus an angle-corrected peak systolic velocity more than 200 cm/sec and an end-diastolic velocity more than 110cm/sec¹

❖ CAVATAS/BACASS

Diameter reduction(%) by NASCET method	PSV (cm/s)	EDV (cm/s)	PSV _{ICA} /PSV _{CCA}
0-29%	<100	<40	<3.2
30-49%	110-130	<40	<3.2
50-59%	>130	<40	<3.2
60-69%	>130	40-110	3.2-4.0
70-79%	>230	110-140	>4.0
80-85%	>230	>140	>4.0
96-99%	String flow		
100%	No flow		

1. Naylor AR, et al. Journal of Vascular Surgery 1998;28:326-34 (Kentucky)
2. Sidhu PS, Allen PL. Clin Radiol. 1997; 52:654-6 (CAVATAS)
3. Moneta GL, et al. Journal of Vascular Surgery 1993; 17:152-159.

DUS criteria 2

❖ SAPPHIRE

	PSV (cm/s)	EDV (cm/s)	ICA:CCA PSV ratio
Normal or mild disease, <50%	<130	Not reliable	<1.6
Moderate disease, 50%-69%	130-229	<70	1.6-3.1
Severe disease, 70-99%	≥230	≥70	≥3.2

Angiography was performed in 382 patients with >70% stenosis

1. Huston J 3rd, et al. Mayo Clin Proc. 2000 Nov;75(11):1133-40.

Society of Radiologists in Ultrasound Consensus Panel criteria for carotid duplex interpretation of internal carotid artery atherosclerotic disease

	Primary Parameters		Additional Parameters	
	ICA PSV, cm /sec	Plaque Estimate, %	ICA/CCA PSV ratio	ICA EDV, cm /sec
Normal	<125	None	<2.0	<40
<50%	<125	<50	<2.0	<40
50-69%	125-230	≥50	2.0-4.0	40-100
≥70% but less than near occlusion	>230	≥50	>4.0	>100
Near occlusion	High, low, or uncheckable	Visible	Variable	Variable
Occlusion	Undetectable	Visible, no detectable lumen	Not applicable	Not applicable

1. Grant EG, et al. Ultrasound Q. 2003;19(4):190-198.

UWURC recommendation¹

❖ CREST

	Primary Parameters	Additional Parameters	
	ICA PSV, cm /sec	ICA/CCA PSV ratio	ICA EDV, cm /sec
Normal	<125	<2.0	<40
<50%	<125	<2.0	<40
50-69%	125-230	2.0-4.0	40-100
≥70% but less than near occlusion	>230	>4.0	>140
Near occlusion	High, low, or uncheckable	Variable	Variable
Occlusion	Undetectable	Not applicable	Not applicable

1. Beach KW, et al. Cardiovascular Ultrasound. 2010;8:39.

DUS criteria 3 (ACT 1)

❖ SAPPHIRE

Stenosis ≥ 80% and ≤ 99% defined as:
 + ICA Peak Systolic Velocity ≥ 220 cm/sec
 + ICA End Diastolic Velocity ≥ 135 cm/sec
 + without significant (60%) contralateral stenosis

Rosenfield K, et al. N Engl J Med. 2016 Feb 17

Sensitivity and specificity of DUS in estimation of carotid artery stenosis

Table III. Pooled weighted means of sensitivity and specificity for detection of stenosis $\geq 50\%$ and $\geq 70\%$

Measure	Threshold cm/s	Angiographic stenosis							
		>50%			>70%				
		N*	Sensitivity	95% CI	Specificity	95% CI	N*	Sensitivity	95% CI
PSV	≥ 120	3,001	96 ^t	91-100	82 ^t	72-93	76-100	93.98	80 ^t
	≥ 130	1,716	98 ^t	97-100	88 ^t	1,996	96 ^t	84.94	94 ^t
	≥ 150					2,140	90 ^t	77.92	88.97
	≥ 200					2,108	90 ^t	83.96	85 ^t
	≥ 230					1,904	76 ^t	63.89	93 ^t
	≥ 250					999	83 ^t	81.96	84 ^t
Ratio ^s	≥ 8					1,933	80 ^t	70.90	88 ^t
	≥ 4					1,419	89 ^t	84.94	80 ^t
EDV	≥ 70					1,607	82	70.93	90 ^t
	≥ 100					1,478	79	71.87	92 ^t
	≥ 120								86.98

CI, Confidence interval; EDV, end-diastolic velocity (cm/s); PSV, peak systolic velocity (cm/s).

*Total number of subjects in combined studies.

^tHeterogeneity identified by Fischer-Freeman-Halton exact test, $P \leq .05$.^sInternal carotid artery PSV/common carotid artery PSV.

Jahromi AS, et al. J Vasc Surg. 2005;41:962-72.

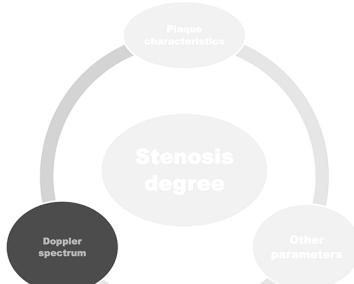
DUS criteria based on stenosis degree

- confusing, no standardized criteria
- DUS alone can be insufficient^{1,2}: Other image tool such as angiography (MRA, CTA or cerebral angiography) is needed.
- But, ICA peak systolic velocity (**>230 cm/sec**) is common/important parameter for determining **sym. carotid stenosis (>70%)** according to RCT criteria
- If you want to use established criteria, compare diverse criteria.
- Consider establish its own criteria in each center through comparing with angiography

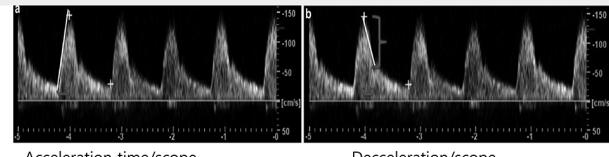
1. Collins P, et al. Br J Radiol. 2005;78:1034-7.

2. Tamura H, et al. Ann Vasc Dis 2013;6:590-5.

Risk assessment for symptomatic carotid stenosis



Doppler spectral wave (especially acoustic shadowing)

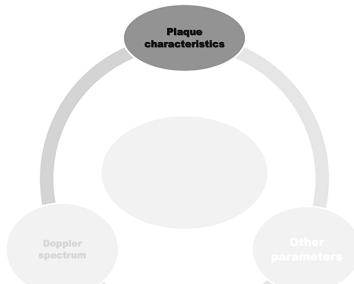


Acceleration time/scope Deceleration/scope

Duplex parameter	MD-CTA-NASCET stenosis category			ANOVA P value
	Mild (n = 24)	Moderate (n = 21)	Severe (n = 40)	
PSV	124.19	180.00	207.42	.001 ¹
EDV	31.79	42.43	53.85	.01 ¹
Acceleration time	119.42	113.75	129.50	.52
Acceleration slope	96.67	158.27	129.00	.20
Deceleration	67.04	95.75	109.43	.002 ²
Deceleration slope	335.22	478.22	547.17	.002 ²
Slope ratio	2.88	3.58	3.21	.73
RI	0.72	0.76	0.74	.51

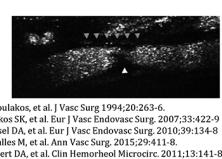
Deceleration/scope¹Acceleration time? (110msec by NASCET 60%)
1. Mohabali J, et al. J Vasc Surg. 2015;62:1236-44
2. Tamura H, et al. Ann Vasc Dis 2013;6:590-5

Risk assessment for symptomatic carotid stenosis



Characteristics of carotid stenosis/plaque

- Plaque echomorphology
 - echoluent plaques associated with symptom ; subjective: visual scale (**type 1~5**)¹
 - objective: Gray-scale median (GSM)^{2,3} & Spatial gray level dependence matrices (**SGLDM**)²
- Plaque volume
 - plaque burden rather than maximum stenosis by 3D ultrasonography⁴
- Neovascularization using CEUS
 - grading by contrast enhancement (0 = absent,..3 = strong)
 - associated with symptom^{5,6}



1. Geroulakos, et al. J Vasc Surg. 1994;29:263-6.
2. Kakkar SK, et al. Eur J Vasc Endovasc Surg. 2007;33:422-9
3. Russel DA, et al. Eur J Vasc Endovasc Surg. 2010;39:134-8
4. Miralles M, et al. Ann Vasc Surg. 2015;29:411-8.
5. Clevert DA, et al. Clin Hemorheol Microcirc. 2011;13:141-8
6. Bipat S, et al. Eur Radiol. 2012;22:2042-52

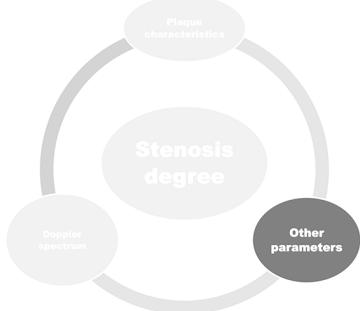
Characteristics of carotid stenosis/plaque

associated with symptomatic compared to asymptomatic carotid artery stenosis

- ✓ **plaque neovascularity**
(OR=19.68, 95% CI=3.14–123.16; $P=72\%$)
- ✓ **plaque ulceration**
(OR=3.58, 95% CI=1.66–7.71; $P=75\%$)
- ✓ **plaque echolucency**
(OR=3.99, 95% CI=3.06–5.19; $P=45\%$)
- ✓ **intraplaque motion**
(OR=1.57, 95% CI=1.02–2.41; $P=0\%$)
- ✓ **complex plaque**
(OR=5.12, 95% CI=3.42–7.67; $P=86\%$)

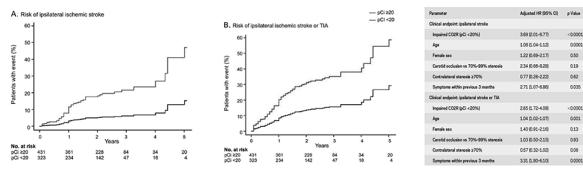
1. Brinjikji, et al. Cerebrovasc Dis. 2015;40:165-174

Risk assessment for symptomatic carotid stenosis



Additional Risk assessment for carotid stenosis

- **Cerebrovascular reactivity:** transcranial Doppler CO₂ reactivity (12 studies)¹



- **Microembolic signals^{2,3,4}**

; surrogate marker of future stroke & TIA

1. Reinhard M, et al. Neurology. 2014;83:1424-31
2. Markus HS, et al. Circulation. 2005;111:2233-40 (CARESS)
3. Ritter MA, et al. J Neurol. 2008;255:953-61.
4. Meiss JC, et al. J Neuroimaging. 2014;14:400-7

Conclusion

- Several ultrasonographic parameters determining symptomatic carotid stenosis
- Stenosis degree using velocity measurements
(especially, considering revascularization
; ICA_{PSV} (m/i) > 230cm/s in >70%)
- Careful interpretation is needed
; no standardized criteria -> center's own criteria?
; combined with other angiographies
- Other parameters...
; More evidences still are needed.