Original Article
pISSN 1738-2637
J Korean Soc Radiol 2012;67(5):309-317

대한영상의학회지

Bone Subtraction 3-Dimension CT Angiography Using 64-Slice Multidetector CT for the Evaluation of Steno-Occlusive Intra- and Extracranial Vascular Diseases: Comparison with Digital Subtraction Angiography[1]

두개 내외의 협착과 폐쇄성 혈관질환의 평가에 있어 64채널 다중검출기 CT를 이용한 골감산 3차원 CT 혈관조영술: 디지털감산혈관조영술과의 비교[1]

Sung Eun Park, MD[1], Dae Seob Choi, MD[1,2], Hwa Seon Shin, MD[1], Jin Jong You, MD[1], Mi Jung Park, MD[1], Jae Min Cho, MD[1], Ho Cheol Choi, MD[1], Seungnam Son, MD[3], Nack-Cheon Choi, MD[2,3], Jae Wook Ryu, MD[4]

[1]Department of Radiology, [2]Gyeongsang Institute of Health Science, [3]Department of Neurology, Gyeongsang National University School of Medicine, Jinju, Korea
[4]Department of Radiology, Samsung Seoul Hospital, Seoul, Korea

Purpose: To investigate the efficacy of bone subtraction CT angiography (BSCTA) for the evaluation of steno-occlusive intra- and extracranial vascular diseases.
Materials and Methods: Fifty-six patients were examined using 64-slice multidetector CT and digital subtraction angiography (DSA). For BSCTA, both nonenhanced CT and enhanced CT angiography (CTA) data sets were obtained. The stenotic degree of each vascular segment was assessed and classified into 5 grades. With DSA as the standard, CTA images were compared.
Results: For the evaluation of the extracranial vessels, 370 arterial segments were analyzed, and the stenotic degree revealed by CTA and DSA agreed in 359 (97.0%). There was a significant correlation between CTA and DSA (Rs = 0.974). For depiction of ≥ 50% stenosis, the sensitivity, specificity, and diagnostic accuracy of BSCTA were 100%, 98.2%, and 98.6%, respectively. For the intracranial arteries, 1029 segments were analyzed, and CTA agreed with DSA in 966 (93.9%). There was a significant correlation between CTA and DSA for stenotic degree (Rs = 0.880). For the depiction of ≥ 50% stenosis, the sensitivity, specificity, and diagnostic accuracy of CTA were 100%, 95.8%, and 96.0%, respectively. In all 74 segments of disagreement, the degree of stenosis was overestimated on CTA.
Conclusion: BSCTA is comparable to DSA for the evaluation of steno-occlusive intra- and extracranial vascular diseases. However, the stenotic degree tends to be overestimated on BSCTA, especially in cases of wall calcifications.

Index terms
CT Angiography
Bone Subtraction
Carotid Stenosis
Digital Subtraction Angiography

Received June 16, 2012; **Accepted** August 9, 2012
Corresponding author: Dae Seob Choi, MD
Department of Radiology, Gyeongsang National University School of Medicine, 79 Gangnam-ro, Jinju 660-702, Korea.
Tel. 82-55-750-8211 Fax. 82-55-758-1568
E-mail: choids@gnu.ac.kr

INTRODUCTION

CT angiography (CTA) is a noninvasive imaging method to detect arterial stenosis, cerebral aneurysm, and other vascular abnormalities. With the development of multidetector CT (MDCT) technology, the scan range and diagnostic accuracy of CTA has increased. But there are some limitations for the evaluation of intra- and extracranial vascular diseases with conventional CTA technique. Separating vessels from the bone or perivascular calcifications can be difficult, particularly in areas such as the skull base (1). This limitation can be a barrier to its use in clinical practice. A further difficulty is that three dimension (3D) reconstruction of CTA source data using conventional methods is time-consuming and highly operator dependent. Bone subtraction technique offers the potential for an effective, rapid, and semi-automated procedure with improved distinction between bones and vessels (2, 3).

There have been several reports of bone subtraction CTA (BSCTA) for the evaluation of steno-occlusive intra- and extracranial vascular diseases. However, most of them were limited in case numbers and confined to only the carotid bifurcations or the intracranial vessels (4-7).

The purpose of this study was to investigate the efficacy of BSCTA for the evaluation of the steno-occlusive diseases in all intra- and extracranial arteries at the same time.

MATERIALS AND METHODS

Patients

This retrospective study was approved by our Institutional Review Board. Informed consent was waived. Between February 2006 and April 2011, seventy patients with suspected intra- and extracranial atherosclerotic disease were examined using CTA and digital subtraction angiography (DSA) in our institution. Among them, 14 patents were excluded because of a long interval (> 30 days) between CTA and DSA examinations. Fifty-six patients were included in this retrospective study. There were 41 males and 15 females, aged from 49 to 85 years (mean, 62.1 years). In 54 patients, stenting angioplasties for their intra- or extracranial arterial stenosis were performed. Only diagnostic DSA was obtained in the remaining two patients. In all patients, CTA examinations were performed before DSA. The mean interval between CTA and DSA examinations was 9.3 days (range: 0-28 days).

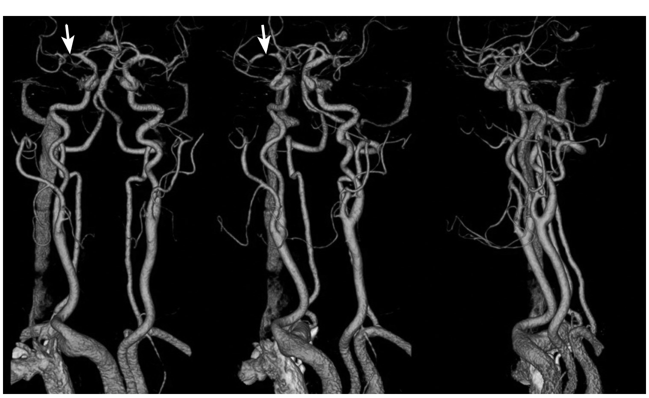


Fig. 1. A 75-year-old female patient with right MCA stenosis. Serial projection images of BSCTA show the entire neck and intracranial vessels with high quality. There is focal severe stenosis in M1 segment of the right MCA (arrow).
Note.—BSCTA = bone subtraction CT angiography, MCA = middle cerebral artery

CTA Protocol

All CTA examinations were performed with 64-slice MDCT systems (Brilliance 64; Philips Healthcare, Best, the Netherlands/LightSpeed VCT; GE Healthcare, Milwaukee, WI, USA). After the acquisition of nonenhanced CT (NECT) data, contrast-enhanced CTA was performed. Parameters for the CT angiographic acquisition were 140-mm field of view, 64 × 0.625-mm detector collimation, 48-mm/rotation table speed, 0.75-sec/rotation gantry rotation speed, 120 kVp, 100 mAs (NECT), 200 mAs (enhanced CTA), 1-mm reconstructed section thickness, and 0.5-mm reconstruction increment. The scan range included the aortic arch up to a point 1 cm above the level of the lateral ventricles. A total of 100 mL of nonionic iodinated contrast medium (Ultravist 370; Shering, Berlin, Germany) was administered intravenously with a power injector at a rate of 4 mL/sec via an 18-gauge catheter positioned in a peripheral vein, and the scan delay was individually adapted by using a bolus-tracking technique. For the bolus-tracking, a single nonenhanced low-dose scan (20 mAs) at the level of the aortic arch was first obtained. A region-of-interest with an area of 20-50 mm^2 was set in the lumen of the aorta. With the start of contrast material administration, repeated low-dose monitoring scans were obtained every second. When the Hounsfield units in the preset lumen rose by 100, the CTA scan was triggered automatically 6 seconds later.

Imaging Post-Processing

The data were transferred to a personal computer. Subtraction process of the transverse source images and 3D reconstruction of the subtracted images were performed with commercially available software (Rapidia; Infinitt, Seoul, Korea). After loading both nonenhanced and contrast-enhanced data sets in memory, registration (translation and rotation) of both data sets was performed. The software then started subtraction process. From the subtracted data, 3D CTA images were reconstructed using volume rendering and maximum intensity projection techniques. A series of 36 projection images at every

10-degree around the cephalocaudal axis were generated (Fig. 1), which were then transferred to picture archiving and communication system. The mean postprocessing time needed for the subtraction process and 3D reconstruction of CTA images, including the time for data transfer, was 8.5 minutes.

DSA

Intra-arterial DSA was performed transfemorally in all patients with a 5 Fr angiographic catheter by using single plane or biplane DSA systems (Angiostar; Siemens, Erlangen, Germany/Integris Allura; Philips Healthcare, Best, the Netherlands/Artis Zee; Siemens, Erlangen, Germany).

Bilateral (n = 54) or unilateral (n = 2) common carotid artery (CCA) injections were performed. For each vessel, posteroanterior and lateral projection views were obtained by injection of 8-10 mL of nonionic contrast material (Visipaque 320; Amersham Health, Oslo, Norway). The carotid bifurcation and intracranial vessels were separately evaluated. In 24 patients, either unilateral (n = 9) or bilateral (n = 15) vertebral artery (VA) injections were also performed.

Image Analysis

Two investigators independently reviewed each BSCTA and DSA images in a separate session without knowledge of other imaging findings. In the cases of disagreement, the final assessment of the degree of stenosis was made by consensus.

The stenosis of extracranial arteries was measured according to the North American Symptomatic Carotid Endarterectomy Trial method (8) {% stenosis = $[1 - (D_{stenosis} / D_{normal})] \times 100$, $D_{stenosis}$ = diameter of stenosis, D_{normal} = diameter of distal normal vessel}. For the intracranial arteries, the stenosis of an arterial segment was measured with following the Warfarin-Aspirin Symptomatic Intracranial Disease method (9) {% stenosis = $[1 - (D_{stenosis} / D_{normal})] \times 100$, $D_{stenosis}$ = diameter of stenosis, D_{normal} = diameter of proximal normal vessel}. The degree of arterial stenosis was assessed and classified as 5 grades: I (0-29%), normal or minimal stenosis; II (30-49%), mild stenosis; III (50-69%), moderate stenosis; IV (70-99%), severe stenosis; V (100%), occlusion.

Each arterial segment was considered to be a separate vessel and was scored. The extracranial arteries were separately evaluated as eight anatomic segments: right and left CCA, internal carotid artery (ICA) bulb, cervical segment of ICA, and VA, and the intracranial vessels as 21 anatomic segments: right and left petrous, cavernous, and supraclinoid segments of ICA, A1 and A2 segments of anterior cerebral artery (ACA), M1 and M2 segments of middle cerebral artery, P1 and P2 segments of posterior cerebral artery (PCA), basilar artery, and distal VA. When a diffusely small diameter of the A1 segment of the ACA, P1 segment of the PCA, or the VA was identified, it was excluded from the analysis.

Statistical Assessment

The relationship between BSCTA and DSA in terms of grades of stenosis was estimated with Spearman rank correlation coefficient (Rs). The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and diagnostic accuracy of BSCTA for detection of ≥ 50% stenosis were calculated, with DSA as the standard of reference.

RESULTS

Extracranial Carotid and Vertebral Arteries

For the evaluation of the extracranial arteries, 370 arterial segments were analyzed, and DSA identified 109 (29.5%) stenotic (≥ 30%) segments (22 with mild stenosis, 12 with moderate stenosis, 55 with severe stenosis, and 20 with occlusion). The most common steno-occlusive segment was ICA bulb (74/109, 67.9%) (Table 1). The agreement between the degree of stenosis revealed by BSCTA and DSA was almost perfect except for 11 segments (359/370, 97.0%) (Table 2) (Figs. 2, 3). There was a significant correlation between CTA and DSA (Rs = 0.974, $p < 0.001$) for the degree of stenosis. In all 11 segments of disagreement, the stenotic degree was overestimated at BSCTA by one (n = 8), two (n = 2), or three grades (n = 1), respectively. For the depiction of ≥ 50% stenosis, the sensitivity, speci-

Table 1. Location of Lesions in the Extracranial Carotid and Vertebral Arteries

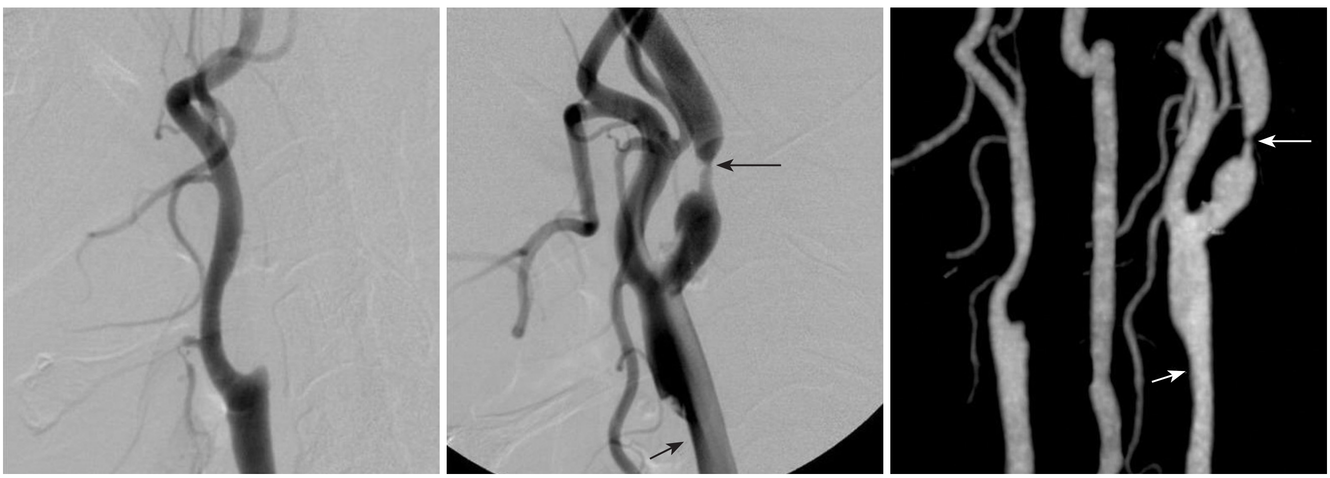
Arterial Segment	No. (%) of Lesions (n = 109)
CCA	11 (10.1)
ICA-bulb	74 (67.9)
ICA-cervical	11 (10.1)
VA	13 (11.9)

Note.—CCA = common carotid artery, ICA = internal carotid artery, VA = vertebral artery

Table 2. Comparison of the Degree of Stenosis in the Extracranial Carotid and Vertebral Arteries with CTA and DSA

CTA	DSA					
	< 30%	30-49%	50-69%	70-99%	100%	Total
< 30%	255					255
30-49%	4	19				23
50-69%	1	3	10			14
70-99%	1		1	55		57
100%			1		20	21
Total	261	22	12	55	20	370

Concordance rate = 359/370 = 97.0%.
Note.—CTA = CT angiography, DSA = digital subtraction angiography



A B C

Fig. 2. A 65-year-old male patient with right ICA occlusion and left CCA and ICA stenosis.
A. Lateral view of the right CCA angiogram shows complete occlusion of the right proximal ICA.
B. Lateral view of the left CCA angiogram reveals mild segmental and severe focal narrowing in the left CCA (short arrow) and proximal ICA (long arrow).
C. BSCTA also shows the lesions as the same as on DSA (long and short arrows).
Note.—BSCTA = bone subtraction CT angiography, CCA = common carotid artery, DSA = digital subtraction angiography, ICA = internal carotid artery

A B

Fig. 3. A 67-year-old female patient with left proximal VA and subclavian artery stenosis.
A. DSA shows severe and moderate degree stenosis in the left proximal VA (arrow) and subclavian artery.
B. BSCTA reveals the stenotic lesions as the same degree as on DSA (arrow).
Note.—BSCTA = bone subtraction CT angiography, DSA = digital subtraction angiography, VA = vertebral artery

ficity, PPV, NPV, and diagnostic accuracy of CTA were 100%, 98.2%, 94.6%, 100%, and 98.6%, respectively.

Intracranial Arteries

Among the 1029 intracranial arterial segments examined, 105 diseased segments (10.2%) were identified with DSA (48 with mild stenosis, 15 with moderate stenosis, 8 with severe stenosis, and 34 with occlusion). There was a heterogeneous distribution of disease through all intracranial vessel segments (Table 3). Of these, intracranial ICA was 63.8% (petrous ICA; 14.3%, cavernous ICA; 30.5%, supraclinoid ICA; 19.0%). The concordance between the degree of stenosis revealed by BSCTA and DSA was in 966 (93.9%) of 1029 segments (Table 4). There was a significant correlation between CTA and DSA (*Rs* = 0.880, $p < 0.001$) for the stenotic degree. In all 63 segments of disagreement, the degree of stenosis was overestimated at BSC-

TA by one (n = 32), two (n = 24), or three (n = 7) grades (Figs. 4, 5). The most common segment of the discordance was cavernous ICA (84/109, 77.1%), followed by supraclinoid ICA (92/109, 84.4%) and distal VA (62/70, 88.6%) (Table 5). For the depiction of ≥ 50% stenosis, the sensitivity, specificity, PPV, NPV, and diagnostic accuracy of CTA were 100%, 95.8%, 58.2%, 100%, and 96.0%, respectively.

DISCUSSION

CTA is a non-invasive widely available technique. There have been many studies on its accuracy and comparability for detecting major intra- or extracranial arterial stenosis (8, 10, 11). However, there are few reports which include, as in our study, the entire intra- and extracranial arteries in a single scan range by CTA. Conventional CTA has several limitations, one of which is that separating vessels from the skull can be difficult, time consuming, and highly operator dependent jobs. 3D angio-

Table 3. Location of Lesions in the Intracranial Arteries

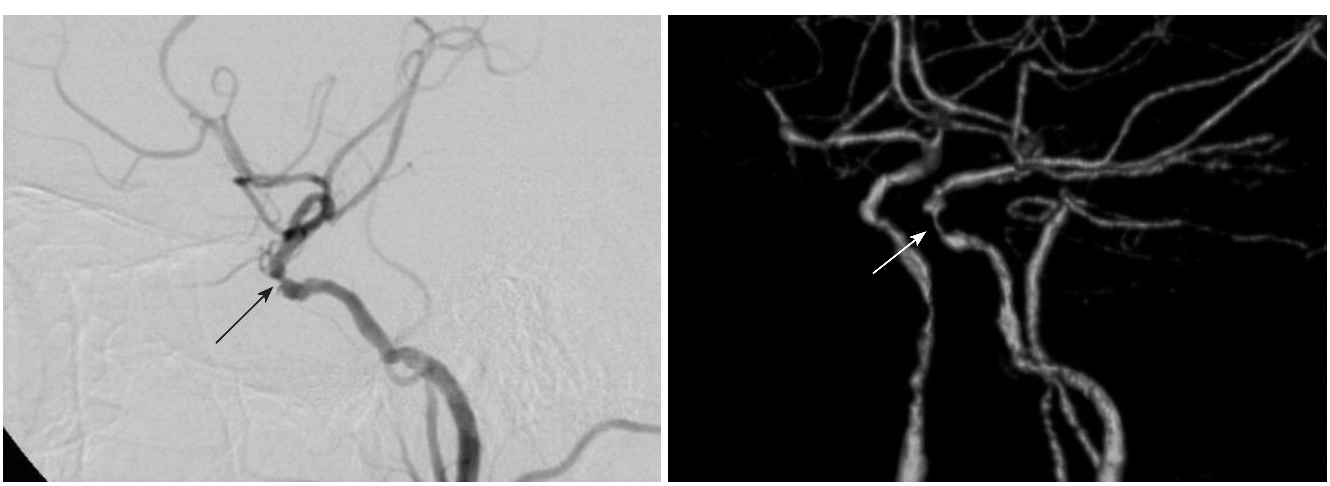
Arterial Segment	No. (%) of Lesions (n = 105)
ICA-petrous	15 (14.3)
ICA-cavernous	32 (30.5)
ICA-supraclinoid	20 (19.0)
ACA-A1	4 (3.8)
ACA-A2	1 (1.0)
MCA-M1	9 (8.6)
MCA-M2	4 (3.8)
PCA-P1	2 (1.9)
PCA-P2	5 (4.8)
BA	1 (1.0)
Distal VA	12 (11.4)

Note.—ACA = anterior cerebral artery, BA = basilar artery, ICA = internal carotid artery, MCA = middle cerebral artery, PCA = posterior cerebral artery, VA = vertebral artery

Table 4. Comparison of the Degree of Stenosis in the Intracranial Arteries with CTA and DSA

CTA	DSA					
	< 30%	30-49%	50-69%	70-99%	100%	Total
< 30%	895					895
30-49%	15	21				36
50-69%	7	10	8			25
70-99%	7	17	7	8		39
100%					34	34
Total	924	48	15	8	34	1029

Concordance rate = 966/1029 = 93.9%
Note.—CTA = CT angiography, DSA = digital subtraction angiography



A B

Fig. 4. A 59-year-old male patient with left cavernous ICA stenosis.
A. DSA image shows focal luminal narrowing in the left cavernous ICA (arrow).
B. On BSCTA, the stenotic lesion (arrow) is overestimated compared to DSA.
Note.—BSCTA = bone subtraction CT angiography, DSA = digital subtraction angiography, ICA = internal carotid artery

A B C

Fig. 5. A 65-year-old male patient with pseudostenosis.
A. DSA of the left VA injection shows no significant stenosis without mild luminal irregularity in the left distal VA (arrow).
B. On BSCTA, there is severe segmental narrowing in the left distal VA (arrow).
C. NECT reveals circumferential calcification in the left distal VA (arrow).
Note.—BSCTA = bone subtraction CT angiography, DSA = digital subtraction angiography, NECT = nonenhanced CT, VA = vertebral artery

Table 5. Concordance for the Stenotic Degree between CTA and DSA

Arterial Segment	No. of Agreement/ Total Segment (%)	*Rs*
CCA	109/110 (99.1)	1.000
ICA-bulb	104/109 (95.4)	0.983
ICA-cervical	108/109 (99.1)	0.961
ICA-petrous	103/109 (94.5)	0.914
ICA-cavernous	84/109 (77.1)	0.891
ICA-supraclinoid	92/109 (84.4)	0.858
ACA-A1	95/96 (99.0)	0.892
ACA-A2	108/108 (100)	1.000
MCA-M1	103/108 (95.4)	0.837
MCA-M2	105/106 (99.1)	0.983
PCA-P1	82/82 (100)	1.000
PCA-P2	87/87 (100)	1.000
Basilar artery	45/45 (100)	1.000
Distal VA	62/70 (88.6)	0.774
Extracranial VA	38/42 (90.5)	0.928
Extracranial artery	359/370 (97.0)	0.974
Intracranial artery	966/1029 (93.9)	0.880
Total	1325/1399 (94.7)	0.925

Note.—*Rs* = Spearman rank correlation coefficient ($p < 0.001$).
ACA = anterior cerebral artery, CCA = common carotid artery, CTA = CT angiography, DSA = digital subtraction angiography, ICA = internal carotid artery, MCA = middle cerebral artery, PCA = posterior cerebral artery, VA = vertebral artery

graphic reconstruction of the entire intra- and extracranial arteries with CTA is usually difficult and could be a barrier in clinical practice. With bone subtraction technique, we obtained 3D CTA images of the entire intra- and extracranial arteries in most cases. The mean postprocessing time including data transfer was 8.5 minutes, acceptable in daily clinical practice.

In our study, for the assessment of the degree of arterial stenosis, the agreement between BSCTA and DSA was 94.7% (1325/1399). Added to that, for the ICA-bulb, had the highest prevalence of stenosis (67.9%, 74/109) in this study, the agreement rate was 95.4%. This is similar to the total agreement rate in our study. Our result for the ICA-bulb lesions is similar to those of the previous reports in which the agreement rate ranged from 82% to 95% (8, 12-14).

The relatively small diameter and tortuous course of the VA compared to the extracranial carotid artery limit complete and accurate assessment of the degree of stenosis with CTA. In our study, for the evaluation of the extracranial VA stenosis, the agreement rate of the stenotic degree revealed by BSCTA and DSA and the depiction of ≥ 50% stenosis with CTA were comparable to those of the extracranial carotid and intracranial arteries. In a recent prospective study and a meta-analysis, CTA showed high sensitivity and specificity for detecting ≥ 50% stenosis (15, 16). Their sensitivity and specificity were 58-100% and 92-95.2%, respectively, similar to our study (100%, 93.3%). However, for the interpretation of conventional CTA images, it takes longer compared to BSCTA because conventional CTA images are usually analyzed using a combination of axial source images and multiplane reformat images, and 3D reconstruction of CTA images requires an additional workstation, an experienced specialist, and long prosprocessing time. This could be a critical limitation in daily clinical practice, especially for evaluation of the entire extracranial carotid and vertebral and intracranial arteries.

For the assessment of intracranial arterial stenosis, previous reports with conventional CTA showed high sensitivity and specificity (11, 17, 18). However, many did not include the petrous and cavernous segments because separation of these arterial segments from the skull was difficult. In our study, with bone subtraction technique, we could evaluate the entire intra- and transcranial arterial segments. The agreement rate between BSCTA and DSA was 93.9%. For the detection of ≥ 50% stenosis, the sensitivity was 110%, specificity 95.8%, and diagnostic accuracy of CTA in our study was 96.0%. Our result is similar to previous reports (11, 17, 18). The segment of the lowest agreement between the BSCTA and DSA was the cavernous ICA (77.1%, 84/109), followed by supraclinoid ICA (92/109, 84.4%), and distal VA (62/70, 88.6%). In a recent study, which compared BSCTA, standard CTA, and time-of-flight MR angiography (TOF-MRA) for the evaluation of transcranial arterial stenosis, the BSCTA showed a trend towards higher stenosis scores for the ICA cavernous segment in comparison to the standard CTA and TOF-MRA. Segments with different stenosis scores between techniques showed marked vessel wall calcifications (19). Calcifications of the ICA siphon are frequently encountered on NECT images (20). In our study, we also found this phenomenon. When the disagreement cases were reviewed, most had dense calcified plaques or circumferential vessel wall calcifications (Fig. 5). BSCTA is more prone to overestimating the degree of stenosis for the vessels with calcified plaques. Heavy circular calcification of the vessel wall may lead to overestimation of the stenosis on subtracted images. Artificial lumen reduction can be caused by blooming artifacts, partial volume effects, and truncation errors, but the raw data reconstruction filters also influence the edge definition of calcified plaque and therefore may influence the results (1, 4-7, 19). Therefore, BSCTA images have to be correlated to the CTA source data if the stenotic lesions are located in the commonly calcified vessels such as the carotid siphon or distal VA.

BSCTA needs two data sets. Additional radiation exposure for NECT is inevitable. In our study, we reduced radiation exposure by using half radiation dose for NECT. Many recent studies have reported that one fourth or fifth radiation reduction for NECT did not significantly affect the overall image quality of bone removal on BSCTA (1, 3-5, 7). However, they commonly reported artificial luminal reduction in the vessels with calcified plaques and wall calcifications. Reduction of the tube current on CT increases noise and blooming artifacts which affect artificial luminal reduction in the vessels with heavily calcified plaques (21). In our results, the overestimation of the degree of stenosis might also be caused by the reduction in radiation dose for the NECT.

Another problem of BSCTA is that patient motion between the two scans can confound the subtraction process, resulting in incomplete bone removal. Through the registration process, we could correct motion artifact. We could also reduce patient motion to educate the patient about the importance of remaining still during the scanning and to use a comfortable restraining device. In most cases of our study, we could obtain CTA images of diagnostic quality.

Dual-energy CT permits the simultaneous acquisition of low- and high-energy data in one examination and thus allows simultaneous imaging without interscan motion and with the application of low additional radiation dose (22). However, the technology is not universally available while BSCTA can be performed with data from all spiral CT systems. Recent studies with dual-energy CT also reported that the degree of arterial stenosis was overestimated on bone removal CTA compared to DSA or conventional CTA (22, 23).

This study has several limitations. First, DSA was considered as the reference data, which may create a standard bias. Second, DSA was performed after CTA in all patients, so difficult segments for catheterization such as stenotic proximal VA did not undergo DSA. This can result in selection bias. Third, most patients in this study had significant stenosis in the extracranial carotid arteries, as revealed on CTA, and they were candidates for stenting angioplasty, which can also cause a selection bias.

In conclusion, we evaluated steno-occlusive intra- and extracranial vascular disease with BSCTA in a single scan range. The agreement and correlation coefficient of the degree of stenosis between BSCTA and DSA was excellent. However, the stenotic degree tends to be overestimated on BSCTA, especially in cases of wall calcifications.

REFERENCES

1. Lell MM, Kramer M, Klotz E, Villablanca P, Ruehm SG. Carotid computed tomography angiography with automated

bone suppression: a comparative study between dual energy and bone subtraction techniques. *Invest Radiol* 2009;44:322-328

2. Imakita S, Onishi Y, Hashimoto T, Motosugi S, Kuribayashi S, Takamiya M, et al. Subtraction CT angiography with controlled-orbit helical scanning for detection of intracranial aneurysms. *AJNR Am J Neuroradiol* 1998;19:291-295
3. Venema HW, Hulsmans FJ, den Heeten GJ. CT angiography of the circle of Willis and intracranial internal carotid arteries: maximum intensity projection with matched mask bone elimination-feasibility study. *Radiology* 2001;218:893-898
4. Siebert E, Bohner G, Dewey M, Bauknecht C, Klingebiel R. Dose related, comparative evaluation of a novel bone-subtraction algorithm in 64-row cervico-cranial CT angiography. *Eur J Radiol* 2010;73:168-174
5. Lell M, Anders K, Klotz E, Ditt H, Bautz W, Tomandl BF. Clinical evaluation of bone-subtraction CT angiography (BSCTA) in head and neck imaging. *Eur Radiol* 2006;16:889-897
6. Morhard D, Fink C, Becker C, Reiser MF, Nikolaou K. Value of automatic bone subtraction in cranial CT angiography: comparison of bone-subtracted vs. standard CT angiography in 100 patients. *Eur Radiol* 2008;18:974-982
7. Lell MM, Ruehm SG, Kramer M, Panknin C, Habibi R, Klotz E, et al. Cranial computed tomography angiography with automated bone subtraction: a feasibility study. *Invest Radiol* 2009;44:38-43
8. Randoux B, Marro B, Koskas F, Duyme M, Sahel M, Zouaoui A, et al. Carotid artery stenosis: prospective comparison of CT, three-dimensional gadolinium-enhanced MR, and conventional angiography. *Radiology* 2001;220:179-185
9. Samuels OB, Joseph GJ, Lynn MJ, Smith HA, Chimowitz MI. A standardized method for measuring intracranial arterial stenosis. *AJNR Am J Neuroradiol* 2000;21:643-646
10. Moll R, Dinkel HP. Value of the CT angiography in the diagnosis of common carotid artery bifurcation disease: CT angiography versus digital subtraction angiography and color flow Doppler. *Eur J Radiol* 2001;39:155-162
11. Bash S, Villablanca JP, Jahan R, Duckwiler G, Tillis M, Kidwell C, et al. Intracranial vascular stenosis and occlusive disease: evaluation with CT angiography, MR angiography, and digital subtraction angiography. *AJNR Am J Neuroradiol* 2005;26:1012-1021
12. Cumming MJ, Morrow IM. Carotid artery stenosis: a prospective comparison of CT angiography and conventional angiography. *AJR Am J Roentgenol* 1994;163:517-523
13. Leclerc X, Godefroy O, Pruvo JP, Leys D. Computed tomographic angiography for the evaluation of carotid artery stenosis. *Stroke* 1995;26:1577-1581
14. Schwartz RB, Jones KM, Chernoff DM, Mukherji SK, Khorasani R, Tice HM, et al. Common carotid artery bifurcation: evaluation with spiral CT. Work in progress. *Radiology* 1992;185:513-519
15. Khan S, Rich P, Clifton A, Markus HS. Noninvasive detection of vertebral artery stenosis: a comparison of contrast-enhanced MR angiography, CT angiography, and ultrasound. *Stroke* 2009;40:3499-3503
16. Khan S, Cloud GC, Kerry S, Markus HS. Imaging of vertebral artery stenosis: a systematic review. *J Neurol Neurosurg Psychiatry* 2007;78:1218-1225
17. Nguyen-Huynh MN, Wintermark M, English J, Lam J, Vittinghoff E, Smith WS, et al. How accurate is CT angiography in evaluating intracranial atherosclerotic disease? *Stroke* 2008;39:1184-1188
18. Hirai T, Korogi Y, Ono K, Nagano M, Maruoka K, Uemura S, et al. Prospective evaluation of suspected stenoocclusive disease of the intracranial artery: combined MR angiography and CT angiography compared with digital subtraction angiography. *AJNR Am J Neuroradiol* 2002;23:93-101
19. Buerke B, Puesken M, Wittkamp G, Stehling C, Ditt H, Seidensticker P, et al. Bone subtraction CTA for transcranial arteries: intra-individual comparison with standard CTA without bone subtraction and TOF-MRA. *Clin Radiol* 2010;65:440-446
20. Woodcock RJ Jr, Goldstein JH, Kallmes DF, Cloft HJ, Phillips CD. Angiographic correlation of CT calcification in the carotid siphon. *AJNR Am J Neuroradiol* 1999;20:495-499
21. Renker M, Nance JW Jr, Schoepf UJ, O'Brien TX, Zwerner PL, Meyer M, et al. Evaluation of heavily calcified vessels with coronary CT angiography: comparison of iterative and filtered back projection image reconstruction. *Radiology* 2011;260:390-399

22. Hegde A, Chan LL, Tan L, Illyyas M, Lim WE. Dual Energy CT and its use in neuroangiography. *Ann Acad Med Singapore* 2009;38:817-820
23. Watanabe Y, Uotani K, Nakazawa T, Higashi M, Yamada N, Hori Y, et al. Dual-energy direct bone removal CT angiography for evaluation of intracranial aneurysm or stenosis: comparison with conventional digital subtraction angiography. *Eur Radiol* 2009;19:1019-1024

두개 내외의 협착과 폐쇄성 혈관질환의 평가에 있어 64채널 다중검출기 CT를 이용한 골감산 3차원 CT 혈관조영술: 디지털감산혈관조영술과의 비교[1]

박성언[1] · 최대섭[1,2] · 신화선[1] · 유진종[1] · 박미정[1] · 조재민[1] · 최호철[1] · 손승남[3] · 최낙천[2,3] · 유재욱[4]

목적: 두개 내외의 협착과 폐쇄성 혈관질환의 평가에 있어 골감산 3차원 CT angiography (이하 CTA)의 유용성을 평가하고자 하였다.

대상과 방법: 64채널 다중검출기 CT를 이용한 CTA와 digital subtraction angiography (이하 DSA)를 모두 시행한 56명의 환자를 대상으로 하였다. 골감산 CTA (이하 BSCTA)를 위하여 조영 전 CT와 조영증강 CTA 데이터를 얻었다. 각 혈관분절의 협착 정도를 분석하여 5단계로 분류하였으며, DSA 결과를 기준으로 CTA 영상을 비교하였다.

결과: 두개 외 혈관의 경우 370개의 혈관분절을 분석하였고, 이 중 359(97.0%)개의 분절에서 CTA와 DSA 결과가 일치하였고 통계적으로 유의한 일치도를 보였다(Rs = 0.974). 50% 이상의 협착을 진단하는 데 있어 CTA는 100%, 98.2%, 98.6%의 민감도, 특이도, 진단적 정확도를 보였다. 두개 혈관의 경우 1029개의 분절을 분석하였는데, 이 중 966(93.9%)개의 분절에서 CTA와 DSA 결과가 일치하였고 통계적으로 유의하였다(Rs = 0.880). 50% 이상의 협착을 진단하는 데 있어 CTA의 민감도, 특이도, 진단적 정확도는 각각 100%, 95.8%, 96.0%였다. CTA와 DSA 결과가 일치하지 않았던 74개 분절은 모두 CTA에서 협착의 정도를 과대 평가하였다.

결론: 두개 내외의 협착과 폐쇄성 혈관질환의 평가에 있어 BSCTA는 DSA에 필적할만한 결과를 보였다. 그러나 석회화를 동반한 병변의 경우 협착 정도가 CTA에서 과대평가되는 경향을 보였다.

경상대학교 의학전문대학원 [1]영상의학교실, [2]건강과학연구원, [3]신경과학교실, [4]삼성서울병원 영상의학과