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Unregistered subtracted CT angiography for the visualization of intracranial arteries at or near the skull base: preliminary experience

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PURPOSE
Restrictions with computed tomography angiography (CTA) regarding the visualization of arteries near the skull base are well known. Today, the gold standard for overcoming this is the matched mask bone elimination method. Worldwide use of this method is limited since it requires advanced imaging physics and software. A more simple method was introduced recently that avoided motion artifacts significantly by restraining the patient's head with a vacuum-type head holder. The purpose of this study was to investigate the feasibility of using unregistered subtracted CTA without such head-holding methods.

MATERIALS AND METHODS
Of the 42 patients that underwent subtracted CTA, 39 were recruited for this study. Two patients were excluded due to agitation during examination and one due to artifacts of an embolized aneurysm. All the examinations were performed in an 8-channel multidetector CT suite. After performing a non-contrast low-dose CT examination, CTA was carried out using the same scan planes as on the scout images. Images were transferred to a workstation and subtraction was performed. Hard-copy images through identical locations were reviewed by 2 observers, a radiologist and a clinician (neurologist), and visualization of the internal carotid artery and posterior artery systems were scored. Data were analyzed using the Wilcoxon signed-rank test.

RESULTS
Significant statistical differences, in favor of subtracted images, were noted in both observers' scores, both for the internal carotid artery and posterior system arteries. The differences in the clinician's scores were more prominent than that of radiologist's.

CONCLUSION
These results are promising for the expanded use of the subtraction method, especially in radiology departments that lack the staff and equipment for registered methods.

Key words: • computed tomography • cerebral angiography • internal carotid artery

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Computed tomography angiography (CTA) is an important first-line diagnostic tool to detect or rule-out intracranial aneurysms, especially in emergency settings (1, 2). State-of-the art 16-channel or more multidetector CT devices provide diagnostic accuracy close to digital subtraction angiography (DSA). Nevertheless, detection of vascular pathologies by CTA at or near the skull base is still a challenging issue. As spiral CT technology evolved, slice-by-slice subtraction became possible, though significant image degradation was reported due to inevitable patient movement (3). A method called "matched mask bone elimination" (MMBE), developed by Venema et al., is an established way of compensating for patient movement and eliminating only bone, without a decrease in the signal to noise ratio (4). However, due to the requirements of advanced imaging physics and complex software, this method has not yet come into wide use. As an alternative method, Jayakrishnan et al. used a vacuum-type head holder to restrain the patient's head and successfully avoided movement artifacts (5). There are also several newer attempts to accomplish selective bone removal in CTA by means of commercially available software provided by vendors, which will become a routine software component of CT equipment in near future (6). In the literature, no study exists that compares the efficacy of slice-by-slice subtraction in imaging quality of the arteries at the skull base to non-subtracted CTA using multidetector technology. The purpose of this study was to determine the feasibility of unregistered subtracted CTA, without complex software applications and specific head-holders.

Materials and methods

Of 42 patients referred for CTA, 39 were recruited for this study. Two patients were excluded due to agitation during the examination and one due to artifacts of an embolized aneurysm. Informed consent was obtained from each patient or their next of kin. All the examinations were performed in an 8-channel multidetector CT suite (GE Medical Systems, Milwaukee, WI, USA). The patients were asked to avoid slight head movements during examination and a simple fixation chin band provided by the vendor was attached to the chin. After performing a non-contrast low-dose CT examination (120 kV, 50 mAs, 8 × 1.25 mm collimation), CTA was carried out using the same scan planes as on the scout images (120 kV, 200 mAs, 8 × 1.25 mm) using commercially available SmartPrep software, following the administration of 1 ml/kg non-ionic contrast medium containing 370 mg I per ml via an automated injector through a 20G cannula inserted into an antecubital vein. Images were transferred to a workstation (AW 4.2, GE Medical Systems, Milwaukee, WI, USA) and then slice-by-slice subtraction was performed. The compare function of the same workstation was used to produce hard-copy prints of the sagittal and coronal oblique thick maximum intensity projection (MIP) images through identical locations of subtracted and non-subtracted images (10 mm thick sagittal images were prepared for the internal carotid artery [ICA] and 5 mm thick coronal oblique images for the posterior system).

Hard-copy images were reviewed by 2 observers, a radiologist and a clinician (neurologist), visualization of each ICA was scored on a scale of 1-5 and the posterior system arteries on a scale of 1–4 (Tables 1 and 2). Thus, each observer made 6 scores for each patient, comprising the subtracted and non-subtracted thick MIP sections of each intracranial ICA and the posterior system.

Data were analyzed using the Wilcoxon signed-rank test and Z values were calculated in each vascular area for both observers' scores.

Results

Of the 39 patients included in this study, 23 were females and 16 were males. Patient age ranged between 17 and 74 years (median, 48 years). Five patients were imaged under emergency settings with the diagnosis of subarachnoid hemorrhage. Other patients had elective imaging due to various reasons, including intracranial atherosclerosis, vertebrobasilar dolichoectasia, and arteriovenous malformation (AVM). Diagnostic findings were as follows: 3 patients had an anterior communicating artery aneurysm, one patient had a right middle cerebral artery aneurysm, 1 patient had a left middle cerebral artery aneurysm, 1 patient had bilateral posterior communicating artery infundibular dilatations, 2 patients had vertebrobasilar dolichoectasia, 1 patient had an occluded ICA, 2 patients had severe atherosclerotic changes in intracranial arteries, and 2 patients had AVMs. The remainder of the patients had no specific diagnostic findings.

In 2 of the 3 patients who were excluded due to agitation during the examination, the non-subtracted images were sufficient for diagnosis and the patient with an embolized aneurysm underwent MR angiography.

Significant statistical differences, in favor of subtracted images, were noted in both observers' scores, both for the ICA and posterior system arteries. The calculated Z values determined with the Wilcoxon signed-rank test were higher for the intracranial ICA in both observers' scores, and Z values of the clinician's scores were higher than those of the radiologist's (Tables 3 and 4). According to radiologist's scores all but 5 patients benefited from subtraction, to some degree, and the clinician's scores indicated all but 3 patients images were improved by subtraction (Figs. 1–3).

Discussion

Specific bone elimination methods, as well as vacuum-type head holders for subtracted CTA, are not available at all radiology clinics. Even though com-

Table 1. Scoring for the internal carotid artery

Score	Findings
1	Very poor visualization (anterior and posterior contours of the artery cannot be discriminated from the adjacent bone).
2	Less than 50% of the anterior or posterior wall can be visualized properly.
3	More than 50% of the anterior or posterior wall can be visualized properly.
4	All of the anterior or posterior wall can be visualized properly.
5	All of the intracranial part of the artery can be visualized.

Table 2. Scoring for the posterior system arteries

Score	Findings
1	Distal parts of the vertebral artery cannot be discriminated, nor can the posterior inferior cerebellar artery (PICA) and anterior inferior cerebellar artery (AICA).
2	Distal parts of the vertebral artery can be partially discriminated; however, the AICA and PICA still cannot be discriminated.
3	The PICA and AICA can be partially evaluated.
4	The PICA and AICA can be properly evaluated.

Table 3. Z scores of both observers determined with the Wilcoxon signed-rank test

	Observer 1 Right ICA	Observer 1 Left ICA	Observer 1 Posterior system	Observer 2 Right ICA	Observer 2 Left ICA	Observer 2 Posterior system
Z	–4.759[a]	–4.910[a]	–4.755[a]	–5.351[a]	–5.271[a]	–4.818[a]
Asymp. significance (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000

[a] Based on negative ranks.
Note: Observer 1 is a radiologist and observer 2 is a neurologist.
ICA: internal carotid artery

Table 4. The means and standard deviations of the scorings of both observers. Note the more prominent increase in the scores of observer 2 (neurologist) when compared to those of observer 1 (radiologist). Increased standard deviations in the scores of subtracted images of both observers are due to the lack of improvement of 5 patients in observer 1's and 3 patients in observer 2's scorings.

	Observer 1		Observer 2	
	Non-subtracted (mean ± SD)	Subtracted (mean ± SD)	Non-subtracted (mean ± SD)	Subtracted (mean ± SD)
Right internal carotid artery	1.51 ± 0.644	3.62 ± 1.648	1.13 ± 0.409	3.90 ± 1.501
Left internal carotid artery	1.51 ± 0.601	3.69 ± 1.559	1.13 ± 0.339	4.03 ± 1.386
Posterior system	2.15 ± 0.489	3.23 ± 0.777	1.85 ± 0.489	33.21 ± 0.801

SD: standard deviation

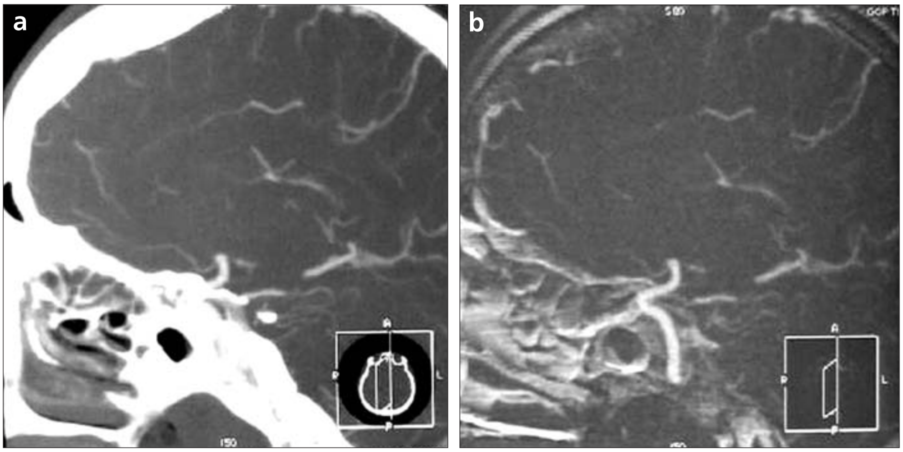

Figure 1. a, b. An example of improved visualization of the intracranial internal carotid artery. Note the difference between the non-subtracted **(a)** and subtracted **(b)** thick sagittal MIP CT angiography images through identical locations.

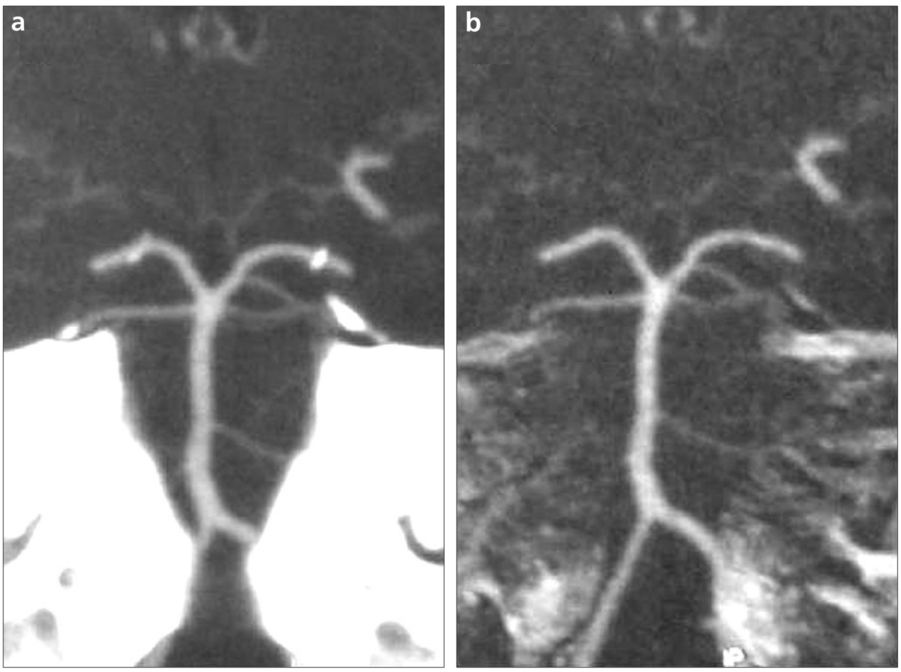

Figure 2. a, b. An example of improved visualization of the posterior system arteries. Note the difference in the non-subtracted **(a)** and subtracted **(b)** CT angiography images.

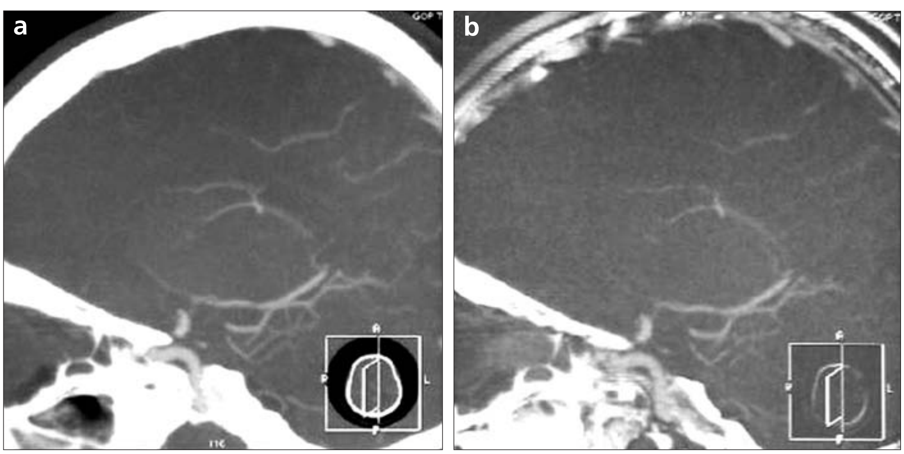

Figure 3. a, b. Images of a case that did not benefit from subtraction. Not much difference in quality between the non-subtracted **(a)** and subtracted **(b)** CT angiography images is seen.

plete removal of bone and high-level image quality could not be obtained, simple subtraction yielded improved image quality of MIP images in this preliminary study. It was Gorzer et al. who first reported the feasibility of section-by-section subtraction using spiral CT technology (3). In the past, the lack of commercially available software and microprocessor technology available today led to postprocessing that took about 15 min, which may be considered slow by today's standards. Slight patient movement during or between scans, which resulted in degradation of image quality, was an important disadvantage. As is expected, patient movement artifacts resulting in misregistration of pre- and post contrast images are inversely correlated to scanning time; therefore, it can be concluded that movement artifacts can be reduced with multidetector technology. Jayakrishnan et al. used an inflatable head holder, which completely restricted patient head movement during and between scans, and obtained satisfactory image quality (5). We did not use any kind of specific head holder, except a chin band provided by the vendor, which can also be routinely used in normal cranial CT examinations. Patients did not express any kind of discomfort due to this band. The subtraction step on the workstation took only seconds; however, some inevitable minor head movement in some patients prevented image quality improvement in those scans.

The MMBE method developed by Venema et al. is the gold standard for subtraction today (4). This method, not a true subtraction in fact, is based on registration of non-enhanced low-dose CT sections with enhanced sections, and elimination of the pixels with bone density; therefore, vascular structures and brain parenchyma are preserved. Registration was reported to be successful with almost every kind of simple head movement, except the complex multidirectional head movements of uncooperative, agitated patients. Another advantage of MMBE is preservation of the signal to noise ratio in bone-free pixels. However, with simple subtraction methods, like ours, it is not illogical to expect a decrease in the signal to noise ratio, theoretically. Using a high-iodine dose per ml and low X-ray dose in pre-contrast scans are 2 factors that helped compensate for loss in the signal to noise ratio.

In all, 3 patients were excluded in this study, 2 of whom were agitated. If we were able to have performed MMBE, it would have failed in those patients since, as has been stated above, MMBE is only effective in correcting simple movements. Regarding the third excluded patient, CTA should have been precluded and the patient should have undergone magnetic resonance angiography, even though it was not requested by the referring physician. Today, there is no way to reduce the severe artifacts of CTA seen in embolized aneurysms with coils (7).

Subtraction does not compensate another universal disadvantage of CTA, that is, venous contamination, which could negatively affect image quality. The only established method for overcoming this drawback is decreasing the scanning time, whether by increasing the pitch or performing the examination in an up-to-date scanner with at least 64 channels.

Finally, questions may arise regarding the radiation dosage in subtracted CTA. Since the pre-contrast mask images are obtained using low-dose, this technique produces a small dose increase. Furthermore, at our institution, routine CTA dosage was 120 kV and 400 mAs, which was recommended by the vendor; we have low values of radiation dose with our new protocol, even with 2 scans.

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