



# Attenuation-Based Automatic Tube Potential Selection in Cerebral Computed Tomography Angiography: Effects on Radiation Exposure and Image Quality

뇌혈관 컴퓨터단층촬영 조영술에서의 감쇄 기반 자동 관전압 선택 알고리즘: 방사선 조사와 영상 품질에 미치는 영향

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**Objective:** To investigate the feasibility of using the attenuation-based automatic tube potential selection (ATPS) algorithm for cerebral computed tomography angiography (CTA) and to assess radiation dose, vascular attenuation, and image quality compared to a conventional fixed 120-kVp protocol.

**Materials and Methods:** Among 36 volunteers for cerebral CTA, a total of 18 were scanned with fixed 120 kVp and 140 effective mAs using automatic tube current modulation. The other 18 were scanned with an ATPS algorithm. Radiation doses, attenuation, contrast-to-noise ratio (CNR) of the cerebral arteries, subjective scores for arterial attenuation, edge sharpness of the artery, visibility of small arteries, venous contamination, image noise, and overall image quality were compared between the groups.

**Results:** The volume CT dose index and effective dose of the ATPS group were lower than those of the fixed 120-kVp group. The ATPS group had significantly higher arterial attenuation and no significant difference in CNR, compared with the fixed 120-kVp. The ATPS group had higher subjective scores for arterial attenuation, edge sharpness of the artery, visibility of small arteries, and overall image quality.

**Conclusion:** The ATPS algorithm for the cerebral CTA reduced radiation dose by 43% while maintaining image quality and improved the attenuation of cerebral arteries by selecting lower tube potential.

## Index terms

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## INTRODUCTION

With technologic innovations in computed tomography (CT), cerebral CT angiography (CTA) has been established as a useful non-invasive diagnostic modality to assess patients with neurovascular disease (1). Meanwhile, as the remarkable growth in the use of CT, awareness is increasing of the potential risk of relatively low doses of ionizing radiation from medical diagnostic imaging (2, 3). Therefore, reducing radiation exposure to the patient has become an important issue. Recently, various tech-

niques have been developed to reduce radiation dose during CT examinations, including X-ray beam collimation, filtration, automatic tube current modulation (ATCM) and iterative reconstruction algorithms (4-7).

Using a lower tube potential is an important technique to reduce radiation dose (8-13). It also increases iodine attenuation and improves visibility of hypervascular pathologies and vascular anatomy (8, 9, 14), but the image quality is impaired by higher noise. To compensate for the higher noise, other options must be adjusted, such as increasing effective tube current-time prod-

uct ( $mAs_{eff}$ ) or applying iterative reconstruction (15-19). However, the optimal relationship between tube potential, tube current, patient size and image quality have not been determined. An automatic tube potential selection (ATPS) algorithm was recently developed, which is based on patient-specific anthropometric measures (attenuation and size estimated from the topogram) and specific diagnostic study objectives. Recent studies have used ATPS to reduce the radiation dose while maintaining image quality for contrast-enhanced abdominal CT and CTA of the thoracoabdominal aorta or coronary artery (20-25).

The purpose of our study was to determine whether using ATPS for cerebral CTA could effectively reduce radiation dose and maintain acceptable image quality when compared with ATCM alone.

## MATERIALS AND METHODS

### Normal Volunteers

The Institutional Review Board of our institute reviewed and approved the study protocol (3-2017-0064). Written informed consent was obtained from all volunteers. Thirty-six healthy volunteers with normal renal function were enrolled in the study. The volunteers were randomly assigned to one of two CTA protocols: group A (fixed 120-kVp protocol) and group B (ATPS protocol). The average age and standard deviation (SD) of the volunteers were  $45.9 \pm 10.0$  years (range, 23–65 years).

### Image Acquisition

All scans were obtained with a 128-slice multidetector CT (SOMATOM Definition AS Plus, Siemens Healthineers, Forchheim, Germany). Group A was scanned with similar scanning parameters to those used in daily practice at our institution. Scanning parameters were exposure setting of fixed 120 kVp and 140  $mAs_{eff}$  with ATCM (CARE Dose 4D, Siemens Healthineers), pitch of 0.45, rotation time of 0.5 seconds, a beam collimation of  $64 \times 0.6$  mm and slice acquisition of  $128 \times 0.6$  mm with a z-flying focal spot technique. The expected volume CT dose index ( $CTDI_{vol}$ ) was 20.2 mGy. The scanning volume ranged from the vertex of the skull to the C1 vertebral body. Reconstructed images with 0.6 mm slice thickness were sent to 3D workstations (Aquarius iNtuition, Terarecon Inc, San Mateo, CA, USA) for image quantitative and qualitative analyses.

For group B using the ATPS protocol (CARE kV, Siemens Healthineers), the reference tube potential and reference effective tube current-time product were 120 kVp and 140  $mAs_{eff}$  as in group A. The other scanning parameters were also the same as group A.

Sixty-four milliliters of contrast media with 370 mg iodine/mL (Ultravist 370, Schering Korea, Seoul, Korea) was administered at 4 mL/s through an 18-gauge cannula placed in the antecubital vein of the right arm using a power injector (Dual shot, Nemoto Kyorindo, Tokyo, Japan). Afterward, a 40-mL saline chaser was injected at 4 mL/s. Individual contrast was optimized with a bolus-tracking technique (CARE Bolus, Siemens Healthineers) in the common carotid artery at the level of C4 vertebra with a trigger level of 160 Hounsfield units (HU). A 4-s delay was added before every examination.

### Technical Background of the Automatic Tube Potential Selection Tool

The ATPS algorithm is designed to automatically suggest an optimal combination of tube potential and tube current for each patient according to the patient's topogram and planned examination. Each patient's topogram is used to provide information about the patient's size and attenuation characteristics. Using the attenuation profile, the algorithm calculates various combinations of tube potential and tube current that will generate the desired contrast-to-noise ratio (CNR) with the lowest radiation dose. Then, the algorithm selects the most dose-efficient combination of tube potential and tube current in accordance with the examination type as follows: CTA imaging, post-contrast imaging for soft tissue enhancement, or non-contrast imaging (20-22, 25-27).

### Quantitative Analysis

The arterial attenuation, signal-to-noise ratio (SNR), and CNR of cerebral arteries was measured and calculated in quantitative analysis. A radiologist with 4 years' experience in neurovascular imaging, who did not conduct the qualitative analysis, measured arterial attenuation (in HU) in the internal carotid artery at the T-junction (8, 9). Region of interest (ROI) were carefully drawn to be as large as the vessel lumen while omitting the outline of the vessel lumen to avoid partial volume effects (range of ROI size: 1.5–5.5  $mm^2$ ). The mean attenuation and SD of the

brain parenchyma were measured at the center of an occipital lobe avoiding vessels with a 250 mm<sup>2</sup> ROI (8, 9). The SD of the attenuation of the occipital lobe parenchyma was defined as the image noise. All measurements were obtained three times to minimize bias from a single measurement and the mean of these values was used for analyses. The SNR and CNR of cerebral artery were calculated with the following formulas (8, 9, 28): SNR = arterial attenuation value/image noise; and CNR = arterial attenuation value-brain parenchymal attenuation value/image noise.

### Qualitative Analysis

The subjective score for the arterial attenuation, edge sharpness of the artery, detail visibility of small arteries, venous contamination, image noise and overall image quality of cerebral arteries was independently assessed by two radiologists with 11 years and 4 years of experience in cerebral CTA. They reviewed the volume rendered images and the maximum intensity projection images (axial, coronal, and sagittal) of the cerebral artery. Before beginning the assessments, the two readers were instructed on the criteria for image rating, and they assessed 10 test cases that were not included in the study to reduce interobserver variability. They independently scored vascular enhancement, edge sharpness of the cerebral artery and visibility of small arteries such as the superior cerebellar, anterior and posterior communicating, anterior choroidal, and ophthalmic arteries (1 = bad, 2 = poor, 3 = moderate, 4 = good, and 5 = excellent) and estimated image noise and venous contamination on a 5-point scale (1 = major, no diagnosis possible; 2 = substantial; 3 = moderate, acceptable; 4 = minor; 5 = no graininess, no contamination). Observers subjectively rated overall diagnostic image quality on a 5-point scale (1 = non-diagnostic, 2 = substandard, 3 = standard, 4 = better than standard, 5 = excellent). CT images were randomized and observers were blinded to the scanning parameters. A window level of 200 and width of 800 were fixed only during the qualitative assessment of arterial attenuation and image noise to compare differences between the groups.

### Measurement of Radiation Exposure

The CTDI<sub>vol</sub> and dose length product, which were provided by the CT scanner after scanning, were recorded and an approx-

imate effective dose was calculated for each patient by multiplying the dose length product by a conversion factor (0.0023 mSv/mGy · cm) (29, 30).

### Statistical Analysis

All statistical analyses were performed with SPSS version 21 (IBM Corp., Armonk, NY, USA). Demographic and morphometric data of the volunteers and quantitative and qualitative data were tested for normal distribution with the Shapiro-Wilk test. The Mann-Whitney U test for nonparametric data of the qualitative analysis and independent t-test for normally distributed data of the quantitative analysis was used. A linear-weighted kappa statistic was used to assess interobserver agreement in scoring and was interpreted using the guidelines of Landis and Koch (31). *p*-values less than 0.05 were considered statistically significant.

## RESULTS

Age, height, weight, and body mass index did not differ significantly between groups A and B (Table 1). All volunteers had no intracranial aneurysm or arterial stenosis. A tube potential of 80 kVp was automatically selected for all 18 volunteers in group B.

### Quantitative Analysis

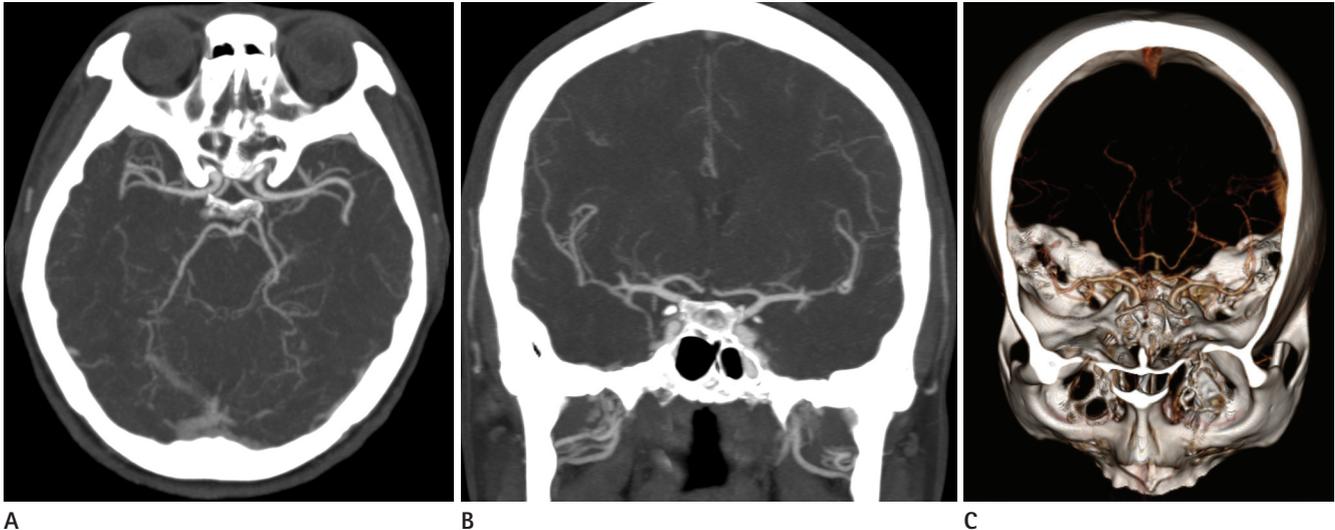
The mean arterial attenuation value at the internal carotid artery T-junction was 377.3 ± 58.4 HU (range, 310.0–487.0 HU) for group A (Fig. 1) and 587.7 ± 74.6 HU (range, 488.5–707.5 HU) for group B (Fig. 2). Group B had 55.8% higher arterial attenuation (mean 210.4 HU) than did group A (Table 2).

The mean attenuation value and SD (image noise) of the oc-

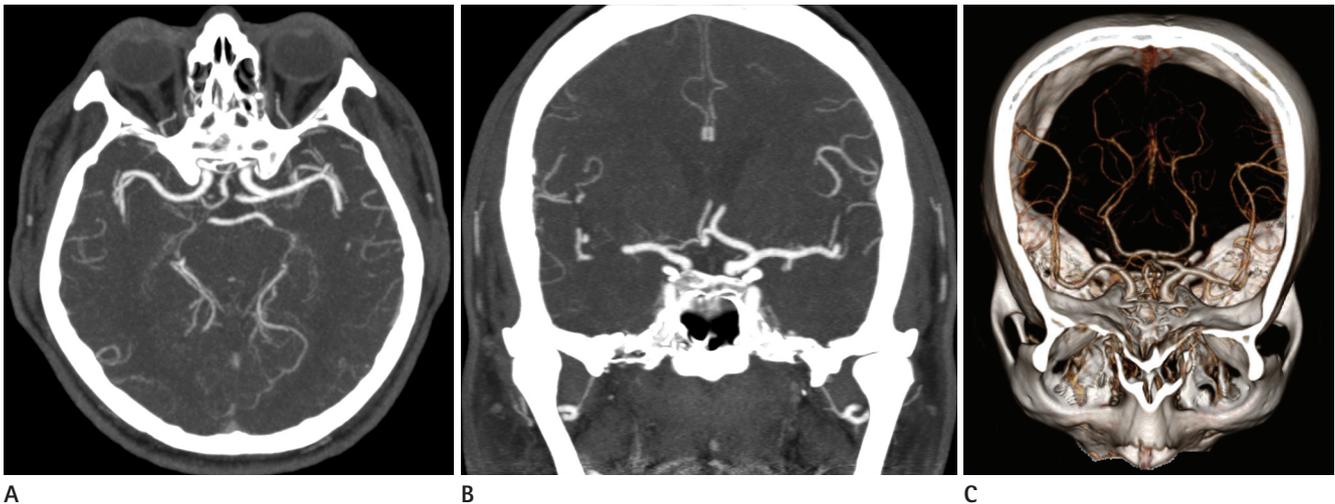
**Table 1. Volunteer Characteristics**

Characteristics	Group A	Group B	<i>p</i> -Value
Age (years)	45.9 ± 9.6	45.8 ± 12.6	0.986
Gender (male/female)	6/12	8/10	0.500*
Height (cm)	162.9 ± 7.2	164.3 ± 7.9	0.610
Weight (kg)	59.5 ± 10.5	62.8 ± 8.5	0.343
BMI (kg/m <sup>2</sup> )	22.3 ± 2.6	23.2 ± 1.9	0.278

Data are presented as mean ± standard deviation. Differences were considered significant when the *p*-value was less than 0.05. Unpaired t-test or \*Mann-Whitney U test were used to compare values. Group A, fixed 120-kVp protocol; Group B, automatic tube potential selection protocol. BMI = body mass index



**Fig. 1.** Cerebral CTA of 38-year-old woman, using the fixed 120-kVp protocol. Axial **(A)** and coronal **(B)** maximum intensity projection images with a slab thickness of 10 mm and volume rendering image **(C)** were assessed. The mean attenuation value of the cerebral arteries (397.5 HU) and CNR (25.5) in this volunteer were similar to the mean attenuation value (377.3 HU) and mean CNR (24.7) for cerebral CTA in group A. CNR = contrast-to-noise ratio, CTA = computed tomography angiography, HU = Hounsfield units



**Fig. 2.** Cerebral CTA of 50-year-old man, using the automatic tube potential selection protocol. Axial **(A)** and coronal **(B)** maximum intensity projection images with a slab thickness of 10 mm and volume rendering image **(C)** were assessed. A tube potential of 80 kVp was selected. The mean attenuation value of the cerebral arteries (560.5 HU) and CNR (22.8) in this volunteer were similar to the mean attenuation value (587.7 HU) and mean CNR (24.2) for cerebral CTA in group B. CNR = contrast-to-noise ratio, CTA = computed tomography angiography, HU = Hounsfield units

capital lobe of group B (40.7 HU and 4.7 HU, respectively) were significantly higher than those of group A (34.8 HU and 2.1 HU, respectively). Although the noise level was significantly higher in group B, the mean SNR and CNR of the arteries did not differ significantly between groups A and B (Table 2).

**Qualitative Analysis**

The interobserver agreement between the two readers was almost perfect agreement, with a kappa value of 0.817. In qualita-

tive image analysis, the images acquired with the ATPS (group B) were rated significantly higher than those obtained with the fixed 120-kVp protocol (group A) with regard to arterial attenuation, edge sharpness of cerebral artery, visibility of small arteries and overall image quality (Table 3). Venous contamination did not differ significantly between groups. For image noise, group A had statistically better subjective scores than group B for observer 2 ( $p = 0.047$ ), and there was no significant difference between groups for observer 1 ( $p = 0.104$ ).

## Radiation Exposure

The mean CTDI<sub>vol</sub> and estimated effective dose for group B were 44.0% and 42.9% lower than those of group A, both of which were statistically significant (Table 2).

## DISCUSSION

The present investigation demonstrates that an ATPS applied to cerebral CTA decreased radiation dose by 42.9% without compromising image quality, compared with a standard CTA protocol using a fixed 120 kVp.

In addition to lowering radiation exposure, the mean arterial attenuation of cerebral arteries in the ATPS group was 55.8% higher than that in the fixed 120-kVp group, because the lower tube potential (80 kVp) was automatically selected and used for

CT scanning all volunteers in the ATPS group. This increased arterial attenuation was similar to previous phantom and clinical studies using lower tube potentials (8, 32). As the mean energy of the X-rays approach the k-edge of iodine (33.2 keV), the use of lower X-ray tube potentials increases X-ray absorption of iodine because the photoelectric effect of the X-ray increases (8, 9, 33). Therefore, a lower tube potentials leads to higher attenuation of iodine.

An 80 kVp tube potential was automatically selected for all 18 volunteers in the ATPS group of our study. However, a previous global observational study showed various tube potentials selection (from 80 kVp to 140 kVp) for cerebral or carotid CTA (27). We guessed that the difference in tube potential selection was due to the reference scanning protocol and reference radiation exposure. The CT scanner used in a previous global study (27) had a maximum tube current capacity of 500 mA. For high radiation exposure setting or fast acquisition of CT images by using accelerated rotation time and high helical pitch, excess tube current capacity may be needed. When more than the maximum possible tube current is needed, the next higher tube potential is suggested by the ATPS algorithm (20, 34). The mean CTDI<sub>vol</sub> of our study was  $9.4 \pm 1.0$  mGy, and that of a previous study (27) was  $16.1 \pm 8.6$  mGy. The 80 kVp tube potential and tube current under maximum capacity seems to be suitable for the scanning parameters of the cerebral CTA protocol used in our study.

The mean CTDI<sub>vol</sub> and estimated effective dose of group B, which used the ATPS algorithm, were 44.0% and 42.9% lower than those of group A, which used a fixed 120 kVp. A decrease in radiation dose leads to an increase in image noise. Therefore, the ATPS algorithm group had an increase in mean image noise

**Table 2. Mean Arterial Attenuation, Objective Image Quality, and Radiation Exposure Values Obtained with Two Cerebral Computed Tomography Angiography Protocols**

	Group A	Group B	p-Value
Attenuation of the cerebral artery (HU)	377.3 ± 58.4	587.7 ± 74.6	< 0.001
Attenuation of the occipital lobe (HU)	34.8 ± 2.1	40.7 ± 4.7	< 0.001
Image noise (HU)	13.9 ± 1.3	22.7 ± 1.7	< 0.001
SNR	27.2 ± 4.1	26.0 ± 3.7	0.361
CNR	24.7 ± 4.1	24.2 ± 3.5	0.697
CTDI <sub>vol</sub> (mGy)	16.8 ± 1.4	9.4 ± 1.0	< 0.001
Effective dose (mSv)	0.7 ± 0.1	0.4 ± 0.0	< 0.001

Data are presented as mean ± standard deviation. Differences were considered significant when the p-value was less than 0.05. The Student's t-test was used to compare group values. Group A, fixed 120-kVp protocol; group B, automatic tube potential selection protocol. CNR = contrast-to-noise ratio, CTDI<sub>vol</sub> = volume CT dose index, HU = Hounsfield units, SNR = signal-to-noise ratio

**Table 3. Subjective Scoring of Pooled Data from Two Observers on a 5-Point Scale**

	Observer 1			Observer 2		
	Group A	Group B	p-Value	Group A	Group B	p-Value
Arterial attenuation	3 (4, 3)	5 (5, 5)	< 0.001	4 (4, 3)	5 (5, 5)	< 0.001
Edge sharpness	3.5 (4, 3)	4 (4.75, 4)	0.005	3 (4, 3)	4 (4.75, 4)	0.013
Detail visibility	3 (3, 3)	4 (4, 3.25)	0.011	3 (3, 3)	4 (4, 3)	0.034
Venous contamination	3 (3, 3)	3 (3, 3)	0.791	3 (3, 3)	3 (3, 2.25)	0.265
Image noise	3 (3, 3)	3 (3, 2.25)	0.104	3 (3, 3)	3 (3, 2)	0.047
Overall quality	4 (4, 3)	4 (5, 4)	0.012	3.5 (4, 3)	4 (4, 4)	0.019

Data are presented as median scores (25% percentile, 75% percentile). Differences were considered significant when the p-value was less than 0.05. The Mann-Whitney U test was used to compare group values. Group A, fixed 120-kVp protocol; Group B, automatic tube potential selection protocol. Detail visibility = visibility of small arteries, Edge sharpness = edge sharpness of the cerebral artery, Overall quality = overall diagnostic image quality

of 63.0%. However, SNR and CNR did not differ significantly between groups because the ATPS group had a 55.8% higher arterial attenuation due to the lower tube potential. The ATPS algorithm is designed to use CNR as the image quality index and to provide equal CNR at all tube potentials in the CTA setting (20, 34). This principle worked well in the current study.

The increased image noise did not diminish subjective image quality, since higher arterial attenuation and greater attenuation difference between artery and brain parenchyma partially offset the image noise (21). Therefore, images acquired with ATPS in this study had higher subjective scores for arterial attenuation, edge sharpness of cerebral artery, visibility of small arteries, and overall image quality, even though one observer subjectively rated image noise as significantly worse in the ATPS group.

Until recently, the ATPS algorithm has been applied to various body regions such as the aorta, coronary artery, pulmonary artery, head, abdomen and chest (22-27, 34, 35). The ATPS algorithm significantly reduced radiation dose across most body regions and selected various tube potentials with reference to an individual patient's attenuation profile, type of examination and scanning parameters. In our study, the radiation dose was significantly reduced and a single lower tube potential (80 kVp) was automatically selected. As to the reason why various tube potentials were not selected, we assumed that head size or attenuation did not differ significantly among individuals compared with body weight or body mass index (BMI). The previous study showed mean head circumference of an adult increased with height but had no significant difference among individual (36).

Our study had some limitations. First, the size of each group was relatively small; nevertheless, the radiation doses and selected tube potentials of the two groups were significantly different. Second, we could not perform intra-individual comparisons between protocols because of ethical concerns. However, volunteer characteristics (age, height, weight, or BMI) did not differ significantly between groups; thus, data analyses and comparisons were possible between groups. Third, we could not find any report about the diversity of individual head attenuation. One article suggested head circumference of an adult had no significant difference among individuals (36). However, the ATPS algorithm uses patient's head size and attenuation characteristics rather than head circumference. We assumed

that there may be a correlation between the head attenuation and head circumference. Finally, iterative reconstruction was not used in this study. We wanted to determine the quality of fundamental images of the ATPS algorithm. If an iterative reconstruction was used, image noise would be significantly reduced, and SNR and CNR would be significantly improved. Further studies are needed to explore the value of iterative reconstruction with the ATPS algorithm.

In conclusion, the ATPS algorithm for cerebral CTA reduced the radiation dose by 42.9% without compromising image quality, compared with a CTA protocol using a fixed 120 kVp. The ATPS algorithm provided higher arterial attenuation and similar SNR and CNR, despite lower radiation exposure, because lower tube potential was automatically selected. We suggest that the ATPS algorithm is a useful method to reduce radiation during cerebral CTA.

## REFERENCES

1. Lell MM, Anders K, Uder M, Klotz E, Ditt H, Vega-Higuera F, et al. New techniques in CT angiography. *Radiographics* 2006;26 Suppl 1:S45-S62
2. Berrington de González A, Mahesh M, Kim KP, Bhargavan M, Lewis R, Mettler F, et al. Projected cancer risks from computed tomographic scans performed in the United States in 2007. *Arch Intern Med* 2009;169:2071-2077
3. Brenner DJ, Hall EJ. Computed tomography--an increasing source of radiation exposure. *N Engl J Med* 2007;357:2277-2284
4. Rizzo S, Kalra M, Schmidt B, Dalal T, Suess C, Flohr T, et al. Comparison of angular and combined automatic tube current modulation techniques with constant tube current CT of the abdomen and pelvis. *AJR Am J Roentgenol* 2006;186:673-679
5. Mulkens TH, Bellinck P, Baeyaert M, Ghysen D, Van Dijk X, Mussen E, et al. Use of an automatic exposure control mechanism for dose optimization in multi-detector row CT examinations: clinical evaluation. *Radiology* 2005;237:213-223
6. McCollough CH, Bruesewitz MR, Kofler JM Jr. CT dose reduction and dose management tools: overview of available options. *Radiographics* 2006;26:503-512
7. Gunn ML, Kohr JR. State of the art: technologies for com-

- puted tomography dose reduction. *Emerg Radiol* 2010;17:209-218
8. Cho ES, Chung TS, Oh DK, Choi HS, Suh SH, Lee HK, et al. Cerebral computed tomography angiography using a low tube voltage (80 kVp) and a moderate concentration of iodine contrast material: a quantitative and qualitative comparison with conventional computed tomography angiography. *Invest Radiol* 2012;47:142-147
  9. Waaijer A, Prokop M, Velthuis BK, Bakker CJ, de Kort GA, van Leeuwen MS. Circle of Willis at CT angiography: dose reduction and image quality--reducing tube voltage and increasing tube current settings. *Radiology* 2007;242:832-839
  10. Bahner ML, Bengel A, Brix G, Zuna I, Kauczor HU, Delorme S. Improved vascular opacification in cerebral computed tomography angiography with 80 kVp. *Invest Radiol* 2005;40:229-234
  11. Szucs-Farkas Z, Schaller C, Bensler S, Patak MA, Vock P, Schindera ST. Detection of pulmonary emboli with CT angiography at reduced radiation exposure and contrast material volume: comparison of 80 kVp and 120 kVp protocols in a matched cohort. *Invest Radiol* 2009;44:793-799
  12. Schindera ST, Graca P, Patak MA, Abderhalden S, von Allmen G, Vock P, et al. Thoracoabdominal-aortoiliac multidetector-row CT angiography at 80 and 100 kVp: assessment of image quality and radiation dose. *Invest Radiol* 2009;44:650-655
  13. Heyer CM, Mohr PS, Lemburg SP, Peters SA, Nicolas V. Image quality and radiation exposure at pulmonary CT angiography with 100- or 120-kVp protocol: prospective randomized study. *Radiology* 2007;245:577-583
  14. Schindera ST, Nelson RC, Mukundan S Jr, Paulson EK, Jaffe TA, Miller CM, et al. Hypervascular liver tumors: low tube voltage, high tube current multi-detector row CT for enhanced detection--phantom study. *Radiology* 2008;246:125-132
  15. Kalra MK, Maher MM, Toth TL, Hamberg LM, Blake MA, Shepard JA, et al. Strategies for CT radiation dose optimization. *Radiology* 2004;230:619-628
  16. Brix G, Lechel U, Petersheim M, Krissak R, Fink C. Dynamic contrast-enhanced CT studies: balancing patient exposure and image noise. *Invest Radiol* 2011;46:64-70
  17. Chen GZ, Zhang LJ, Schoepf UJ, Wichmann JL, Milliken CM, Zhou CS, et al. Radiation dose and image quality of 70 kVp cerebral CT angiography with optimized sinogram-affirmed iterative reconstruction: comparison with 120 kVp cerebral CT angiography. *Eur Radiol* 2015;25:1453-1463
  18. Komlosi P, Zhang Y, Leiva-Salinas C, Ornan D, Patrie JT, Xin W, et al. Adaptive statistical iterative reconstruction reduces patient radiation dose in neuroradiology CT studies. *Neuroradiology* 2014;56:187-193
  19. Löve A, Siemund R, Höglund P, Ramgren B, Undrén P, Björkman-Burtscher IM. Hybrid iterative reconstruction algorithm improves image quality in craniocervical CT angiography. *AJR Am J Roentgenol* 2013;201:W861-W866
  20. Yu L, Li H, Fletcher JG, McCollough CH. Automatic selection of tube potential for radiation dose reduction in CT: a general strategy. *Med Phys* 2010;37:234-243
  21. Winklehner A, Goetti R, Baumüller S, Karlo C, Schmidt B, Raupach R, et al. Automated attenuation-based tube potential selection for thoracoabdominal computed tomography angiography: improved dose effectiveness. *Invest Radiol* 2011;46:767-773
  22. Lee KH, Lee JM, Moon SK, Baek JH, Park JH, Flohr TG, et al. Attenuation-based automatic tube voltage selection and tube current modulation for dose reduction at contrast-enhanced liver CT. *Radiology* 2012;265:437-447
  23. Eller A, May MS, Scharf M, Schmid A, Kuefner M, Uder M, et al. Attenuation-based automatic kilovolt selection in abdominal computed tomography: effects on radiation exposure and image quality. *Invest Radiol* 2012;47:559-565
  24. Ghoshhajra BB, Engel LC, Károlyi M, Sidhu MS, Wai B, Barreto M, et al. Cardiac computed tomography angiography with automatic tube potential selection: effects on radiation dose and image quality. *J Thorac Imaging* 2013;28:40-48
  25. Park YJ, Kim YJ, Lee JW, Kim HY, Hong YJ, Lee HJ, et al. Automatic Tube Potential Selection with Tube Current Modulation (APSCM) in coronary CT angiography: comparison of image quality and radiation dose with conventional body mass index-based protocol. *J Cardiovasc Comput Tomogr* 2012;6:184-190
  26. Krazinski AW, Meinel FG, Schoepf UJ, Silverman JR, Canstein C, De Cecco CN, et al. Reduced radiation dose and improved image quality at cardiovascular CT angiography by auto-

- mated attenuation-based tube voltage selection: intra-individual comparison. *Eur Radiol* 2014;24:2677-2684
27. Spearman JV, Schoepf UJ, Rottenkolber M, Driesser I, Canstein C, Thierfelder KM, et al. Effect of automated attenuation-based tube voltage selection on radiation dose at CT: an observational study on a global scale. *Radiology* 2016;279:167-174
  28. Furtado AD, Adraktas DD, Brasic N, Cheng SC, Ordovas K, Smith WS, et al. The triple rule-out for acute ischemic stroke: imaging the brain, carotid arteries, aorta, and heart. *AJNR Am J Neuroradiol* 2010;31:1290-1296
  29. Ertl-Wagner BB, Hoffmann RT, Bruning R, Herrmann K, Snyder B, Blume JD, et al. Multi-detector row CT angiography of the brain at various kilovoltage settings. *Radiology* 2004;231:528-535
  30. Commission of the European Community. European guidelines on quality criteria for computed tomography. Report EUR 16262 EN, 1999. Available at: <http://www.dr.dk/guidelines/ct/quality/htmlindex.htm>. Accessed May 28, 2017
  31. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977;33:159-174
  32. Cho ES, Chung TS, Ahn SJ, Chong K, Baek JH, Suh SH. Cerebral computed tomography angiography using a 70 kVp protocol: improved vascular enhancement with a reduced volume of contrast medium and radiation dose. *Eur Radiol* 2015;25:1421-1430
  33. Curry TS, Murry RC. *Basic interactions between X-rays and matter*. In Curry TS, Dowdey JE, Murry RC, eds. *Christensen's physics of diagnostic radiology*, 4th ed. Philadelphia, PA: Lippincott Williams & Wilkins 1990:61-69
  34. Niemann T, Henry S, Faivre JB, Yasunaga K, Bendaoud S, Simeone A, et al. Clinical evaluation of automatic tube voltage selection in chest CT angiography. *Eur Radiol* 2013;23:2643-2651
  35. Mayer C, Meyer M, Fink C, Schmidt B, Sedlmair M, Schoenberg SO, et al. Potential for radiation dose savings in abdominal and chest CT using automatic tube voltage selection in combination with automatic tube current modulation. *AJR Am J Roentgenol* 2014;203:292-299
  36. Bushby KM, Cole T, Matthews JN, Goodship JA. Centiles for adult head circumference. *Arch Dis Child* 1992;67:1286-1287

## 뇌혈관 컴퓨터단층촬영 조영술에서의 감쇠 기반 자동 관전압 선택 알고리즘: 방사선 조사와 영상 품질에 미치는 영향

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**목적:** CT 뇌혈관 촬영에서 감쇠 기반 자동 관전압 선택 알고리즘(automatic tube potential selection; 이하 ATPS)의 유용성을 조사하고, 방사선량, 혈관 감쇠도 및 영상 질에 대하여 기존의 120-kVp 고정 프로토콜과 비교 평가한다.

**대상과 방법:** 36명의 건강한 지원자 중 무작위 선출로 18명은 120-kVp로, 나머지 18명은 ATPS 알고리즘을 이용하여 CT 뇌혈관 촬영을 시행했다. 방사선량, 대뇌 동맥의 감쇠 정도와 대조도-대-잡음비, 영상의 질을 정량적, 정성적 분석을 통해 비교하였다.

**결과:** ATPS군의 유효선량(0.4 mSv)은 120-kVp (0.7 mSv)군에 비해 42.9% 낮았다. ATPS군의 혈관 감쇠[587.7 Hounsfield units (이하 HU)]는 120-kVp군(377.3 HU)에 비해 유의하게 높았고, 대조도-대-잡음비는 두 군 간에 유의한 차이가 없었다(각각 24.2와 24.7). 또한 ATPS군은 동맥 감쇠 및 영상의 질에 대한 주관적 점수가 유의하게 높았다.

**결론:** CT 뇌혈관 촬영에서 ATPS 알고리즘은 42.9% 적은 방사선량을 사용했음에도 영상의 질이 유지되었다. 또한 ATPS 알고리즘을 사용했을 때, 120-kVp군과 비교하여 더 낮은 관전압(80 kVp)이 선택되어 혈관의 감쇠 정도가 유의하게 증가하였다.

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