INTRODUCTION

Peripheral arterial disease (PAD) is a chronic and progressive disease mainly influencing the lower extremities, and it is a major cause of hypofunction which worsens quality of life in a large portion of western populations. PAD occurs in approximately 20% of adults older than 55 years of age and in an estimated 27 million patients in North America and Europe (1). Conventional angiography is the gold standard for evaluation of peripheral arterial occlusive disease of lower extremity. However, it is an invasive technique that requires hospitalization, and it has a small risk of variable complications such as dissection, micro-emboli, and even pseudo-aneurysms (2). Since clinical applications of CT angiography (CTA) have been reported, CTA has been...
proven to be comparable to conventional angiography for evaluation of peripheral arteries (3). CTA is an accurate and non-invasive technique for detection and assessment of the presence and extent of PAD; its sensitivity and specificity are 95% and 96%, respectively (4). In addition, CTA is less expensive and offers an additional advantage that it can detect another condition that might be related to vascular disease. Due to its high accuracy, CTA is useful for establishment of an optimal therapeutic strategy (3).

However, due to its wide range of image acquisition, patients with PAD who undergo CTA of the lower extremity are exposed to high-dose radiation. There are many strategies for reducing radiation dose in CTA, and one of these is to increase the pitch. Pitch is defined as the ratio of the table increment to the total nominal beam width. However, deterioration of image quality begins to occur with increasing of helical pitch. To date, no studies evaluating the effect of peripheral CTA with high pitch on radiation doses have been reported. Therefore, the objective of this study is to compare radiation dose and image quality of high pitch CTA with 128-slice dual-source CT in lower-extremity arteries with that of low pitch CTA.

MATERIALS AND METHODS

Patient Population

This study was approved by the Institutional Review Board, and the requirement for informed consent was waived. We retrospectively enrolled 290 consecutive patients who underwent peripheral CTA for the evaluation of lower extremity arteries, between July 2010 and May 2012. Then, 154 subjects were excluded for the following reasons: amputation (n = 6), aneurysm of aorta or iliac arteries (n = 11), segmental occlusion of any arteries (n = 29), total occlusion of run-off vessels (n = 4), history of bypass surgery (n = 39), stent insertion (n = 57), atherectomy (n = 5), and outrun (n = 3). Finally, 136 patients (107 men and 29 women; mean age 63.08 years) were selected. In our hospital, pitch value was changed in November 2011, from 0.6 to 3. Of the 136 patients, 67 patients who had undergone CTA with high pitch (3) were included in the protocol 1 group. Another 69 patients who had undergone CTA with low pitch (0.6) were included in the protocol 2 group. The protocol 1 group consisted of 53 men and 14 women, ranging in age from 23 to 90 years (mean, 62.85 years); and the protocol 2 group consisted of 54 men and 15 women, ranging in age from 24 to 85 years (mean, 63.31 years). Characteristics of the patient population including age, height, weight, and body mass index (BMI) were evaluated using medical records. BMI was calculated by dividing subject’s weight (kg) by height squared (m²).

CTA Data Acquisition

All peripheral CTA scans were performed using 128-slice dual-source CT (Definition FLASH, Siemens Medical Solutions, Forchheim, Germany); 100 kVp was used in both protocols. CT scans were acquired craniocaudally from 2 cm above the renal artery origin to the ankle. The acquisition parameters for the high pitch (3) protocol were as follows: using both a large A tube and a small B tube, tube current modulation setting (reference dose, 160 mAs), collimation of 0.6 × 128 mm, slice thickness of 3 mm, and increment of 3 mm. Contrast enhancement was achieved with intravenous injection of 120 mL of nonionic contrast medium (Ultravist®; Bayer, Leverkusen, Germany) and 30 mL of saline solution at a flow rate of 4 mL/sec. To optimize the delay time before data acquisition, a circular region of interest (ROI) was placed within the abdominal aorta just above the renal artery origin to the ankle. The acquisition parameters for the low pitch (0.6) protocol were as follows: using a large A tube, tube current modulation setting (reference dose, 160 mAs), collimation of 0.6 × 128 mm, slice thickness of 3 mm, and increment of 3 mm. Contrast enhancement was achieved with intravenous injection of 120 mL of nonionic contrast medium (Ultravist®; Bayer, Leverkusen, Germany) and 30 mL of saline solution at a flow rate of 4 mL/sec. To optimize the delay time before data acquisition, a circular region of interest (ROI) was placed within the abdominal aorta just above the bifurcation. In the high pitch (3) protocol group, CT scan began 25 seconds after the threshold attenuation of 100 Hounsfield units (HU) was reached, due to shortened scanning time; and in the low-pitch (0.6) protocol group, scanning began 20 seconds later. The CT acquisition protocols for each group are shown in Table 1.

Quantitative Evaluation

All CTA images were reviewed in randomized order by two radiologists with 3 and 16 years of vascular CT experience, who were blinded to the protocol that had been applied. This review was performed as consensus based measurement. The arterial attenuation values (HU) were obtained from the placement of circular ROIs in the arteries. The method reported by Utsunomiya et al. (5) was used for measurement of arterial attenuation values of multiple arteries as follows: 1) the juxta-renal abdominal aorta (ROI-1), 2) the abdominal aorta just above the
bifurcation (ROI-2), 3) the right and left common femoral arteries (ROI-3 and -4, respectively), 4) the right and left mid-superficial femoral arteries (ROI-5 and -6, respectively), 5) the right and left popliteal arteries (ROI-7 and -8, respectively), and 6) the right and left mid-anterior tibial arteries (ATA, ROI-9 and -10, respectively). ROIs were manually set to be as large as possible, and we tried not to include vessel wall calcification and mural thrombosis. For comparison of the attenuation of the column of opacified arteries, mean arterial attenuation was calculated as the average of the attenuation values from ROI-1 to ROI-10 for each patient. For comparison of the uniformity of the attenuation of opacified arteries, the coefficient variation (CV) of arterial attenuations was evaluated. CV was calculated as the standard deviation divided by the mean. Next, the contrast-to-noise ratio (CNR) was calculated between one of the common femoral arteries and surrounding muscle, using the following equation: \( \text{CNR} = (\text{ROI-3} - \text{CTD}_M) / \text{SD}_M \). In this equation, CT density in the muscle (CTD_M) and standard deviation of CT density of the muscle (SD_M) were measured at the muscle surrounding the common femoral artery. Finally, for comparison of radiation dose between the two protocols, the CNR was normalized by the dose-length product (DLP) using a figure of merit (FOM) defined as \( \text{FOM} = \text{CNR}^2 / \text{DLP} \). Then, the FOM was used as a parameter for image quality independent of radiation dose (6). Effective radiation dose, which reflects the relative risk from exposure to radiation, was calculated using the method proposed by the European Working Group for Guidelines on Quality Criteria for CT (7). The effective radiation dose was calculated by the DLP and a conversion coefficient (k). According to the literature (8), conversion coefficients in the abdomen-pelvis and lower extremity (excluding pelvis) are 0.015 and 0.0012 (mSv/mGy·cm), respectively. As mentioned above, our CTA acquisition range included abdominopelvic cavity and lower limbs, so calculating effective radiation dose was difficult. Therefore, DLP was chosen for the comparison of radiation dose. In addition, we measured total scan time and scan length of each protocol. However, there was a possibility of statistical difference in the scan length between the two groups, so we also compared volume CT dose index (CTDI\text{vol}) of both groups. The CTDI\text{vol} averages the radiation dose over the center slice of a CT examination consisting of multiple parallel slices (5). DLP and CTDI\text{vol} could be obtained from radiation dosimetry information from each CT scan.

**Qualitative Evaluation**

Visual evaluation of the peripheral CTA was performed by consensus of two experienced radiologists. The visualization evaluation scores were measured at four segments: common femoral, superficial femoral, popliteal, and anterior tibial artery. Scoring criteria were as follows: 3 (good) = excellent visualization; 2 (fair) = sufficient visualization of arteries; 1 (poor) = undiagnosable visualization of arteries on CTA image. In patients with different scores for the right and left sides of individual arteries, we chose the worse score.

**Statistical Analysis**

Statistical software (SPSS II, version 11.0.1; SPSS Inc., Chicago, IL, USA) was used in performance of all statistical analyses. The two-tailed Student's t-test was used for analysis of quantitative results, including patient characteristics. Mann-Whitney U
No significant difference in mean scan length was observed between the two protocols (1250.25 ± 128.49 cm vs. 1219 ± 63.96 cm; \( p = 0.06 \)). The mean scan time of the high pitch protocol group was significantly lower than that of the low pitch protocol group (3.06 ± 0.25 seconds vs. 26.3 ± 1.21 seconds; \( p < 0.05 \)). These quantitative results are shown in Table 4.

Significant stenosis (50% or greater) at the proximal artery (above the popliteal artery) was detected on CTA, in 17 patients of the protocol 1 group (16 men and one woman) and in 19 patients of the protocol 2 group (17 men and two women). The mean CV of arterial attenuations was significantly lower in patients with stenosis than in patients without stenosis in each protocol group (12.40 ± 6.93% vs. 21.97 ± 6.98% in the protocol 1 group; \( p < 0.05 \); 8.68 ± 5.28% vs. 20.13 ± 8.78% in the protocol 2 group; \( p < 0.05 \)).

Qualitative Evaluation

Visual evaluation scores of the four arterial segments using the two protocols are shown in Table 5. In the common femoral segments, superficial femoral segments, popliteal segments, and anterior tibial segments, there were a few cases of undiagnosable visualization. No statistically significant differences were observed in the results of visual evaluation between the two protocols.

### RESULTS

**Demographic Parameter**

All CT examinations were performed without complications. A summary of the characteristics of the patient population is shown in Table 2. No significant differences in the mean age, mean height, mean weight, and mean BMI were observed between the two groups.

**Quantitative Evaluation**

The mean DLP was significantly lower in the high pitch protocol group than in the low-pitch protocol group (409.49 ± 37.71 mGy·cm vs. 592.98 ± 59.69 mGy·cm). Compared to CTA with low pitch, a radiation dose reduction of 31% was achieved using CTA with a high pitch. The mean CTDI\text{vol} was also significantly lower at high pitch than at low pitch (2.91 ± 0.14 mGy vs. 4.70 ± 0.30 mGy).

No significant difference in the mean CNR or the mean SD\text{M} was observed between the two protocols (high pitch vs. low pitch: 27.89 ± 10.18 vs. 27.63 ± 9.61; \( p = 0.94 \), 15.88 ± 2.90 vs. 15.45 ± 2.58; \( p = 0.33 \), respectively). However, the mean FOM was significantly higher in the high pitch group than in the low pitch group (2.24 ± 1.72 vs. 1.49 ± 1.05; \( p = 0.01 \)).

No significant difference in the mean arterial attenuation from ROI-1 to ROI-10 was observed between the two protocols (high pitch vs. low pitch: 441.07 ± 89.36 HU vs. 443.87 ± 95.06 HU; \( p = 0.59 \)). The mean arterial attenuation from each artery is shown in Table 3. No significant difference in the mean CV of arterial attenuations was observed between the two protocols (19.99 ± 7.94% vs. 18.03 ± 9.35%; \( p = 0.25 \)).

**Table 2. Patient Population Characteristics**

| Parameter           | High Pitch     | Low Pitch      | \( p \)-Value |
|---------------------|----------------|----------------|---------------|
| Mean age            | 62.85 ± 10.31  | 63.31 ± 12.42  | 0.62          |
| Sex (male/female)   | 53/14          | 54/15          | 0.90          |
| Mean height (cm)    | 165.42 ± 7.42  | 164.80 ± 6.85  | 0.61          |
| Mean weight (kg)    | 63.15 ± 10.75  | 63.72 ± 13.13  | 0.78          |
| Mean BMI            | 22.99 ± 3.10   | 23.32 ± 3.76   | 0.68          |

*Note. \( \text{BMI} = \) body mass index*

**Table 3. Mean Arterial Attenuation from Each Artery**

| Segment | High Pitch   | Low Pitch    | \( p \)-Value |
|---------|--------------|--------------|---------------|
| ROI-1   | 384.57 ± 102.11 | 453.8 ± 89.73 |               |
| ROI-2   | 437.55 ± 119.21 | 483.56 ± 100.73 |             |
| ROI-3   | 488.88 ± 113.73 | 476.1 ± 105.63 |             |
| ROI-4   | 485.52 ± 110.17 | 472.5 ± 103.87 |             |
| ROI-5   | 515.54 ± 110.72 | 480.83 ± 119.19 |             |
| ROI-6   | 514.93 ± 110.78 | 478.25 ± 115.06 |             |
| ROI-7   | 484.78 ± 87.17  | 476.45 ± 134.95 |             |
| ROI-8   | 484.07 ± 89.73  | 474.38 ± 133.17 |             |
| ROI-9   | 320.71 ± 119.53 | 336.83 ± 116.33 |             |
| ROI-10  | 316.34 ± 127.4  | 337.86 ± 114.30 |             |

*Note. \( \text{ROI} = \) region of interest*
arterial attenuations in patients with stenosis, regardless of pitch, than in patients without stenosis. This suggests that the extent of variability of the attenuation of opacified arteries is lower in patients with stenosis than in patients without stenosis. Currently, the issue of radiation dose reduction has drawn worldwide attention to the principle of ALARA (As Low As Reasonably Achievable). Because restenosis following percutaneous transluminal angioplasty was reported in 56 patients (33%) within six months (9), additional performance of CTA will be needed in patients with recurrent symptoms or signs after treatment. Patients will then be exposed to a high dose of radiation again. As the pitch is increased, the total scanning time is shortened and the radiation dose is eventually decreased in proportion to the pitch. Despite these advantages, higher pitch generally leads to increased noise on multidetector CT (MDCT), and increasing pitch has not been known as a practical method for decreasing radiation dose in MDCT (10). However, Apfaltrer et al. (6), who studied high pitch CTA of the aorta using 128 slice dual-source CT, reported of an association of the high pitch mode with low radiation exposure on preserved image quality. Results of this study showed comparable image quality for depiction of PAD on CTA with high pitch, compared to those with low pitch. In this study, the high pitch protocol used dual-source tubes in order to cover data loss caused by wide intergap. On the other hand, low pitch protocols used only a single A tube. High pitch CTA yielded vascular enhancement comparable to that of low pitch CTA using 128-slice dual-source CT. Due to use of a narrow filter, the radiation dose of the high pitch group was lower than that of the low pitch group, even when all scan parameters were the same. According to the vendor’s manual, narrowing fil-

### DISCUSSION

The goal of this study was to compare image quality and radiation dose between high-pitch CTA and low-pitch CT performed on 128 slice dual-source CT. No statistical difference was observed in visual score of peripheral arteries between the high pitch group and low pitch group. In addition, SDM and CNR, which are the best criteria for objective assessment of image quality, did not differ significantly between the two groups. A reduction of the radiation dose by approximately 31% was observed in the high pitch group; this is another encouraging result of our study.

Results of our study showed significantly lower mean CV of arterial attenuations in patients with stenosis, regardless of pitch, than in patients without stenosis. This suggests that the extent of variability of the attenuation of opacified arteries is lower in patients with stenosis than in patients without stenosis. Currently, the issue of radiation dose reduction has drawn worldwide attention to the principle of ALARA (As Low As Reasonably Achievable). Because restenosis following percutaneous transluminal angioplasty was reported in 56 patients (33%) within six months (9), additional performance of CTA will be needed in patients with recurrent symptoms or signs after treatment. Patients will then be exposed to a high dose of radiation again. As the pitch is increased, the total scanning time is shortened and the radiation dose is eventually decreased in proportion to the pitch. Despite these advantages, higher pitch generally leads to increased noise on multidetector CT (MDCT), and increasing pitch has not been known as a practical method for decreasing radiation dose in MDCT (10). However, Apfaltrer et al. (6), who studied high pitch CTA of the aorta using 128 slice dual-source CT, reported of an association of the high pitch mode with low radiation exposure on preserved image quality. Results of this study showed comparable image quality for depiction of PAD on CTA with high pitch, compared to those with low pitch.

### Table 4. Quantitative Results

| Parameter                           | High Pitch (HU ± SD) | Low Pitch (HU ± SD) | p-Value |
|-------------------------------------|----------------------|---------------------|---------|
| Mean arterial attenuation (HU)      | 441.07 ± 89.36       | 443.87 ± 95.06      | 0.59    |
| Mean CV of arterial attenuations (%)| 19.99 ± 7.94         | 18.03 ± 9.35        | 0.25    |
| Mean CNR                            | 27.89 ± 10.18        | 27.63 ± 9.61        | 0.94    |
| Mean FOM                            | 2.24 ± 1.72          | 1.49 ± 1.05         | 0.01    |
| Mean SDm                            | 15.88 ± 2.90         | 15.45 ± 2.58        | 0.33    |
| Mean scan length (cm)               | 1250.25 ± 128.49     | 1219 ± 63.96        | 0.06    |
| Mean scan time (second)             | 3.06 ± 0.25          | 26.3 ± 1.21         | < 0.05  |
| Mean DLP (mGy·cm)                   | 409.49 ± 37.71       | 592.98 ± 59.69      | < 0.05  |
| Mean CTDIvol (mGy)                  | 2.91 ± 0.14          | 4.70 ± 0.30         | < 0.05  |

#### Table 5. Mean Scores for Visualization of the Arteries

| Segment   | Visual Evaluation Score | p-Value |
|-----------|-------------------------|---------|
|           | 3 (Good) | 2 (Fair) | 1 (Poor) |   |
| CFA       |          |          |          | 0.09 |
| High pitch| 61       | 5        | 1        |     |
| Low pitch | 56       | 11       | 2        |     |
| SFA       |          |          |          | 0.94 |
| High pitch| 60       | 7        | 0        |     |
| Low pitch | 55       | 10       | 4        |     |
| PA        |          |          |          | 0.058|
| High pitch| 63       | 4        | 0        |     |
| Low pitch | 58       | 8        | 3        |     |
| ATA       |          |          |          | 0.68 |
| High pitch| 56       | 6        | 5        |     |
| Low pitch | 60       | 1        | 8        |     |

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| High pitch| 56       | 6        | 5        |     |
| Low pitch | 60       | 1        | 8        |     |

Note. — CNR = contrast-to-noise ratio, CTDIvol = volume CT dose index, CV = coefficient variation, DLP = dose-length product, FOM = figure of merit, HU = Hounsfield unit, SDm = standard deviation of CT density of muscle
approximately 10 seconds, in patients with outrun. Because the conversion coefficient in the lower extremity is low (0.0012), radiation hazard from the additional scan was thought to be acceptable in lower legs. Faster CT scan in the more radiosensitive abdomino-pelvic area could counteract the disadvantage of possibility in outrun.

There are several limitations of the current study. First, we used fixed 100 kVp for all patients without regarding the BMI; however, no significant difference in BMI was observed between the two groups. Second, all patients received injection of the same volume of contrast media without using any personalized contrast medium injection protocol software. Third, our study might be valid only for our CT machine (Definition FLASH, Siemens). A narrowing filter resulted in a reduction of approximately 20% (in body examinations) compared to a standard filter (11).

In our study, three outrun cases occurred in high pitch CTA. This phenomenon typically occurs when the CT scanner z-axis coverage proceeds more rapidly than the leading edge of the contrast media bolus or when there is inadequate scanning timing (12). The subjects were elderly patients with medical history such as hypertension, diabetes, and hypercholesterolemia. However, when outrun occurred, additional scanning was helpful in overcoming this weakness of high pitch CTA. In our institution, we obtained an additional scan below the knee after approximately 10 seconds, in patients with outrun. Because the conversion coefficient in the lower extremity is low (0.0012), radiation hazard from the additional scan was thought to be acceptable in lower legs. Faster CT scan in the more radiosensitive abdomino-pelvic area could counteract the disadvantage of possibility in outrun.

There are several limitations of the current study. First, we used fixed 100 kVp for all patients without regarding the BMI; however, no significant difference in BMI was observed between the two groups. Second, all patients received injection of the same volume of contrast media without using any personalized contrast medium injection protocol software. Third, our study might be valid only for our CT machine (Definition FLASH, Siemens).
In conclusion, this study evaluated the image quality and radiation dose of lower extremity CTA images with a high pitch. Despite changing the pitch from 0.6 to 3, the image quality of CTA was not degraded. In addition, we were able to reduce the radiation doses by 31%.

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128 절편 이중선원 전산화단층촬영 하지동맥조영술의 영상 품질 및 방사선량: 고 피치와 저 피치의 비교

박정환1 · 추기석1 · 전웅배1 · 백승국1 · 김용우1 · 김태언1 · 김창원2 · 정동욱3 · 임수진4

목적: 고 피치(3)와 저 피치(0.6)로 시행된 128 절편 이중선원 전산화단층촬영 하지동맥조영술의 영상 품질 및 방사선량을 비교하고자 한다.

대상과 방법: 총 136명의 환자를 2그룹으로 나누었고, 고 피치로 시행된 환자 67명, 저 피치로 시행된 환자 69명으로 구성되었다. 정량적 분석으로 mean arterial attenuation, mean coefficient variation of arterial attenuations, mean contrast-to-noise ratio, mean figure of merit, and mean standard deviation of CT density of muscle을 사용하였고, 정성적 분석으로 육안적 점수를 사용하였으며 방사선량을 비교하였다.

결과: 고 피치 그룹에서의 mean dose-length product는 저 피치 그룹에 비해 31% 낮게 측정되었고 (409.49 ± 37.71 mGy·cm vs. 592.98 ± 59.69 mGy·cm), 또한 mean volume CT dose index도 통계적으로 유의하게 낮았다 (2.91 ± 0.14 mGy vs. 4.70 ± 0.30 mGy). 그러나, 그 외의 정량적 분석 결과, figure of merit을 제외한 양 그룹 간에 통계적으로 유의한 차이를 보이지 않았다. 육안적 점수 또한 통계적으로 유의한 차이를 보이지 않았다.

결론: 피치를 0.6에서 3으로 올리더라도, 이중선원 전산화단층촬영 하지동맥조영술의 영상 품질은 저해되지 않으며 방사선량을 31%가량 줄일 수 있다.

부산대학교 의학전문대학원 양산부산대학교병원 1영상의학과, 3가정의학과,
2부산대학교 의학전문대학원 부산대학교병원 영상의학과, 4김해중앙병원 심장내과