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Feasibility of Ultralow-dose CT with Deep-Learning Reconstruction for Aneurysm Diameter Measurement in Post-EVAR Follow-up: A Prospective Comparative Study with Conventional CT

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Declaration of conflicting interest

The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

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Institutional Review Board approval was obtained. (approval ID: B21006)

Written informed consent was obtained from all patients in this study.

Data availability statement

The data supporting this study's findings are available from the corresponding author, T.O., upon reasonable request.

ABSTRACT

OBJECTIVES: To evaluate the feasibility of ultralow-dose computed tomography (ULD-CT) with deep-learning reconstruction (DLR) for postendovascular aneurysm repair (EVAR) surveillance, we conducted a prospective comparative study against conventional standard-dose CT (SD-CT).

MATERIALS AND METHODS: We prospectively performed post-EVAR surveillance using ULD-CT at a single center following SD-CT in 44 patients. ULD-CT images were subjected to DLR, whereas SD-CT images were subjected to iterative reconstruction. Three blinded radiologists independently measured the aneurysmal sac diameter and evaluated the overall image quality. Bland–Altman analysis and a linear mixed-effects model were used to assess the equivalence of measurement accuracy between SD-CT and ULD-CT.

RESULTS: The mean CT dose index volume and dose–length product were significantly lower for ULD-CT (1.0 ± 0.3 mGy and 71.4 ± 26.5 mGy•cm) than for SD-CT (6.9 ± 0.9 mGy and 500.9 ± 96.0 mGy•cm) ($p < 0.001$). The mean short diameters of the aneurysmal sac measured by the three observers were 46.7 ± 10.8 mm on SD-CT

and 46.3 ± 10.8 mm on ULD-CT. The mean difference in the short diameter of the aneurysmal sac between ULD-CT and SD-CT was -0.37 mm (95% confidence interval [CI], -0.6 to -0.12 mm). The intraobserver limits of agreement (LOA) for measurements in ULD-CT and SD-CT were -3.5 – 2.6 , -2.8 – 1.9 , and -2.9 – 2.3 for observers 1, 2, and 3, respectively. The pairwise LOAs for assessing interobserver agreement, such as the differences between measurements by observers 1 and 2 in SD-CT, were largely within the predetermined acceptable range. The mean image-quality score was lower for ULD-CT (3.3 ± 0.6) than for SD-CT (4.5 ± 0.5) ($p < 0.001$).

CONCLUSION: ULD-CT with DLR can sufficiently measure sac diameter with substantial radiation reduction during post-EVAR surveillance.

KEYWORDS: abdominal aortic aneurysm, deep-learning reconstruction, endovascular aneurysm repair, standard-dose computed tomography, ultralow-dose computed tomography

INTRODUCTION

Endovascular aneurysm repair (EVAR), along with surgical aneurysm repair, is the standard treatment for abdominal aortic aneurysms (AAAs). Patients who undergo EVAR require long-term follow-up because the aneurysmal sac diameter can increase during the remote period.^{1,2} Although computed tomography (CT) is a typical surveillance method after EVAR, the associated radiation exposure is a concern. Guidelines for AAA management and previous studies on post-EVAR surveillance have recommended ultrasonography (US) and magnetic resonance imaging, which do not emit ionizing radiation^{3,4}; however, the former has problems with accuracy and

reproducibility, and the latter has problems with metal artifacts induced by stent grafts and medical economics. CT has many advantages, such as objectivity and simplicity, and if radiation exposure from CT scans can be reduced, they could be more commonly used for post-EVAR follow-up. Low-dose CT is one way of reducing the CT radiation dose; however, excessive dose reduction may increase noise and reduce image quality, making assessment of aneurysms after EVAR more difficult.

Recently, improvements in CT equipment and the introduction of a method for image reconstruction based on successive approximation reconstruction have made it possible to perform imaging at lower radiation doses, and this technique is gaining popularity in clinical practice. Furthermore, recently, image reconstruction using deep-learning (an artificial intelligence method) has been developed, which has improved the quality of low-dose CT images.⁵⁻⁷ The goal of CT in post-EVAR follow-up is to assess the aneurysm morphology and sac diameter, which does not require high image quality. We hypothesized that ultralow-dose CT (ULD-CT) combined with deep-learning reconstruction (DLR) of images would be sufficient to assess aortic aneurysm size, which would minimize radiation exposure during post-EVAR surveillance and greatly benefit patients after EVAR.

This study evaluated the validity and feasibility of ULD-CT with DLR for post-EVAR surveillance.

Primary and Secondary Endpoints

The primary endpoint of this study was the degree of agreement of the aortic aneurysmal diameter measurements between standard-dose CT (SD-CT) and ULD-CT to determine whether they were clinically equivalent. The secondary endpoints included

the radiation dose differences between ULD-CT and SD-CT, the degree of agreement in the measured diameters of sites other than the aneurysm, image quality, and quantitative evaluation of the organ.

MATERIALS AND METHODS

Patients

This single-center prospective study included 44 consecutive patients. We included the following categories of patients: (1) patients who underwent EVAR for AAAs; (2) those scheduled to undergo noncontrast-enhanced CT to evaluate the aortic aneurysmal sac diameter; and (3) those aged >50 years at the time of enrollment. Fifty consecutive post-EVAR patients who were undergoing follow-up in the cardiovascular surgery and radiology departments of our institution were enrolled in this study. Therefore, we considered that the patient selection bias was negligible and determined that representativeness was ensured. We excluded four patients whose CT scans were not obtained because of schedule changes after enrollment, one patient who was lost to follow-up, and one patient who had undergone surgical aneurysmal repair but was incorrectly enrolled; 44 patients were ultimately included in this study. This study was approved by the Institutional Review Board of Kobe University Hospital (approval ID: B21006), and all participants provided written informed consent.

CT Technique and Estimation of the Patient Radiation Dose

All patients underwent ULD-CT in addition to SD-CT during post-EVAR surveillance. All acquisitions were performed on a 320-row detector CT scanner (Aquilion ONE, Canon Medical System). The SD-CT series (120 kVp with automatic

exposure control [AEC]; standard deviation [SD]: 20, 250–600 mA) used iterative reconstruction (adaptive iterative dose reduction 3D) and the ULD-CT series (120 kVp with AEC; SD: 50, 10–600 mA) used DLR (Advanced Intelligent Clear-IQ Engine). The ULD-CT imaging protocol was set up assuming an effective dose of approximately 1 mSv, which is equivalent to a plain abdominal radiograph.⁸ For each examination, the volume CT dose index ($CTDI_{vol}$) and dose–length product (DLP) of SD-CT and ULD-CT were recorded from the dose reports generated by the CT scanner. The radiation effective dose (ED) was calculated by multiplying the DLP by an abdomen-specific correction coefficient (0.015 mSv/mGy•cm).⁹ All CT images were reconstructed at thicknesses of 1 and 5 mm.

Measurements of the Aneurysmal Sac Diameter

CT images with fixed window settings (window width; 250 HU and window level; 50 HU) and 5-mm thickness were used for the measurements. First, the conductor (T.O.) compared the SD-CT and ULD-CT images of the same patient to determine the cross-section of the CT series for measurements. Next, three board-certified diagnostic radiologists in Japan (K.M., K.S. and T.G. with 9, 13, and 13 years of experience, respectively) who were blinded to the patient information and CT conditions used the same viewer (OsiriX Lite; Pixmeo, Switzerland) to randomly measure the aneurysmal sac diameter in the specified slice. Each measurement was based on the external diameter of the aorta or arteries. Regarding the aneurysmal sac diameter, the short and long (the diameter perpendicular to the short one) diameters were measured from the slice with the maximum aortic aneurysm. For the analysis, the maximum short diameter of the aortic aneurysm were utilized. If differences in the aneurysmal diameter

measurements were observed, the following confounding factors were assumed: the presence of patient obesity, aneurysmal wall calcification, presence of metal in the body other than the stent graft, and motion artifacts. Patients with body mass index (BMI) $> 25 \text{ kg/m}^2$ were considered overweight. Aneurysmal wall calcification, the presence of metal in the body other than the stent graft, and motion artifacts were evaluated by one observer (K.M.), and these were assessed in the same cross-section used to measure the aortic aneurysmal diameter.

Qualitative Analysis of CT Images

CT images with a thickness of 5 mm were used for image-quality evaluations. A five-point Likert scale (5 = excellent, 4 = good, 3 = acceptable, 2 = suboptimal, and 1 = unacceptable) was used to evaluate the quality of each reconstructed CT image by three radiologists (K.M., K.S. and T.G.) who were blinded to the CT conditions and patient information. Each radiologist used the same viewer to evaluate the overall and specific image qualities of the aorta, liver, and colon. The CT images were initially presented with a preset soft-tissue window setting (window width: 250 HU and window level: 50 HU), and each radiologist was allowed to modify the window setting at their discretion. Figure 1 presents the SD-CT and ULD-CT images of the same patient and their respective qualitative evaluations by the three radiologists.

Quantitative Analysis of CT Images

CT images measuring 5 mm in thickness were used for quantitative CT image assessments, which were independently performed by one radiologist (K.M.). Circular regions of interest (ROIs) within the abdominal aorta, abdominal aneurysmal sac,

hepatic parenchyma, paraspinal muscle, and subcutaneous fat in the buttocks were drawn twice, and the mean CT values and SDs of the ROIs were recorded. The SDs in the ROIs of each organ were defined as the image noise of the respective organ, and the signal-to-noise ratio (SNR) was calculated as the ratio of the mean CT value to noise. ROIs were placed in the right hepatic lobe parenchyma while carefully avoiding blood vessels, bile ducts, focal lesions, and artifacts. ROIs were placed in the aorta and aneurysmal sac in the same slice where the diameter was measured to avoid calcifications, macroscopic thrombi, stent grafts, and artifacts-

Sample Size

Aortic aneurysmal diameter measurements on ULD-CT with DLR are potentially comparable to those on SD-CT. Reportedly, the mean AAA measurement for both measures was -0.19 ± 1.52 mm, while the repeatability coefficient ($1.96 * SD$) for the difference in aneurysmal diameter measurements was 3.8 mm.¹⁰ Based on these estimates and the expected tolerance in clinical applications, this study set the criterion for judging equivalence at ± 3 mm.

Herein, we explored the agreement between ULD-CT with DLR and SD-CT in assessing the validity and feasibility of ULD-CT with DLR across various patient populations. Therefore, we determined the sample size based on the feasibility within the study period and set the sample size to 50, ensuring a minimum of 10 patients in each subgroup categorized by BMI, the presence or absence of aneurysmal wall calcification, and the presence or absence of metals in the body, excluding stent grafts.

Statistical Analysis

Continuous data are presented as means $\pm$ SDs for normally distributed data and medians with interquartile ranges for data with skewed distributions. Categorical data are presented as frequencies and percentages. Student's *t*-test, the Mann–Whitney U test, or the Wilcoxon signed-rank test was used for quantitative data analyses, as appropriate. To evaluate intraobserver agreement, defined as the agreement between the measurements obtained by ULD-CT and SD-CT for each observer, Bland–Altman analysis and its extension for multiple measurements per patient were performed.^{11,12} To evaluate interobserver agreement, defined as the agreement between measurements obtained by different observers for the same patient in SD-CT and ULD-CT, we calculated pairwise Bland–Altman limits of agreement (LOA), including the agreement between measurements obtained by observers 1 and 2 in SD-CT. The intraclass correlation coefficient (ICC) was used to assess the interobserver agreements to measure the degree of agreement between the three radiologists. ICCs < 0.5 were interpreted as poor agreement, 0.50–0.75 as moderate agreement, 0.75–0.90 as good agreement, and ≥ 0.90 as excellent agreement. The threshold for statistical significance was set at $p < 0.05$. EZR (version 1.64; Saitama Medical Centre, Jichi Medical University, Saitama, Japan) was used for all statistical analyses.¹³

RESULTS

Patients

In total, 44 patients (40 men and 4 women) were included in the study. The mean ($\pm$ SD, range) age and BMI of the patients were 79.7 ($\pm$ 6.6, 60–90) years and 23.2 ($\pm$ 3.2, 13.8–30.6) kg/m², respectively.

Radiation Dose

The mean CTDI_{vol} (1.0 ± 0.3 mGy, range = 0.4–1.9 mGy), DLP (71.4 ± 26.5 mGy•cm, range = 23.7–153.6 mGy•cm), and ED (1.1 ± 0.4 mSv, range = 0.4–2.3 mSv) were significantly lower on ULD-CT than on SD-CT (mean CTDI_{vol} = 6.9 ± 0.9 mGy, range = 5.3–10.3 mGy; mean DLP = 500.9 ± 94.9 mGy•cm, range = 312.8–821.9 mGy•cm; and mean ED = 7.5 ± 1.4 mSv, range = 4.7–12.3 mSv) ($p < 0.001$). The average reduction rates of CTDI_{vol}, DLP, and ED were 86.0%, 86%, and 86.0%, respectively. Figure 2 presents the box plots of the CTDI_{vol} and DLP for SD-CT and ULD-CT.

Measurements of the Aneurysmal Sac Diameter

The mean short diameters of the aneurysmal sac measured by the three observers were 46.7 ± 10.8 mm on SD-CT and 46.3 ± 10.8 mm on ULD-C. The mean difference in the short diameter of the aneurysmal sac between ULD-CT and SD-CT was -0.37 mm (95% confidence interval [CI], -0.6 to -0.12 mm). Figure 3 presents a Bland–Altman analysis to assess the agreement of aneurysm sac diameter between measurements obtained from ULD-CT and SD-CT. The estimated range that contains 95% of the potential differences between measurements by ULD-CT and SD-CT was almost within the prespecified range of ± 3 mm, supporting the high agreement between the measurements. These results were generally consistent even when evaluated across patient subgroups according to BMI, presence or absence of aneurysmal wall calcification, and presence or absence of metals in the body other than a stent graft. Furthermore, the agreement between the measurements obtained from ULD-CT and SD-CT was assessed by stratifying the data by each of the three observers (Figure 4).

The intraobserver LOA for measurements obtained from ULD-CT and SD-CT were -3.5 – 2.6 , -2.8 – 1.9 , and -2.9 – 2.3 for observers 1, 2, and 3, respectively (Table 1).

Figure 5 presents the Bland–Altman analysis, assessing the agreement between aneurysm sac diameter measurements obtained by observers 1 and 2 using SD-CT.

Bland–Altman plots for other pairs, such as the comparison between observer 2 and observer 3 in SD-CT, are provided in the supplementary file. Table 1 presents the LOA values from all pairwise evaluations of the interobserver agreement. The estimated range encompassing 95% of the potential differences between measurements obtained by each observer were largely within the predetermined ± 3 mm range, indicating a high level of agreement between measurements. For both methods, ICCs among the observers were 0.993 (95% CI: 0.988–0.996) for SD-CT and 0.989 (95% CI: 0.981–0.994) for ULD-CT. No motion artifacts were observed in the CT scans of either patient; therefore, the effects of motion artifacts on the measurements were not assessed.

Qualitative Analysis of CT Images

Table 2 presents the image-quality scores for each observer. In all measurements by each observer, the overall and specific image qualities of the aorta, liver, and colon on ULD-CT were significantly worse than those on SD-CT (e.g., the overall image quality, observer 1: SD-CT 4.1 ± 0.3 vs. ULD-CT 3.4 ± 0.5 , $p < 0.001$; observer 2: SD-CT 4.6 ± 0.5 vs. ULD-CT 3.5 ± 0.8 , $p < 0.001$; observer 3: SD-CT 4.9 ± 0.3 vs. ULD-CT 3.1 ± 0.3 , $p < 0.001$).

Quantitative Analysis of CT Images

Table 3 presents the mean image noise and SNR for the SD-CT and ULD-CT protocols. The noise values of the aneurysmal sac, aorta, liver, paraspinal muscle, and subcutaneous fat were significantly higher with ULD-CT than with SD-CT. The SNRs of the aneurysmal sac, liver, and paraspinal muscle were significantly lower on ULD-CT than on SD-CT, and no significant differences in the SNRs of the aorta and subcutaneous fat were observed between ULD-CT and SD-CT.

DISCUSSION

This study demonstrated that the measurement values for the aneurysm and abdominal aortic diameters exhibited high agreement between SD-CT and ULD-CT with DLR, indicating that this method is sufficiently effective for post-EVAR surveillance at reduced radiation doses.

US and CT have equivalent accuracy in measuring post-EVAR aortic aneurysmal diameters, with a high correlation between their measurements. US offers advantages such as lower cost, absence of ionizing radiation, and the ability to assess blood flow dynamics. On the other hand, CT offers objectivity and accuracy independent of the examiner's skill and facilitates the easy assessment of stent graft and overall vessel morphology. While the issue of radiation exposure has meant that US has often been preferred for monitoring aneurysm diameter, the low radiation exposure of ULD-CT demonstrated in this study suggests that, in environments or cases where sonographer skill is insufficient to ensure accuracy, where stent graft migration is a concern due to short sealing lengths, or where concomitant internal iliac artery embolization is present, for example, the physician may find it easier to select CT for post-EVAR surveillance.

An increased risk of cancer due to radiation exposure on CT has been reported.^{20,21} A problem with post-EVAR surveillance is that it requires periodic CT scans. Although abdominal exposure to radiation in noncontrast-enhanced CT scans of the chest is often approximately 10 mSv (which is low compared with health-hazardous radiation doses of 100 mSv), routine post-EVAR CT examinations over a long period can result in considerable radiation exposure. According to the findings of a previous study, the excess relative risk of carcinogenesis associated with routine post-EVAR CT was 0.43 in a relatively young population (age, 50–55 years).²² With the CT protocol used in this study, a single exposure to a dose of approximately 1 mSv is equivalent to the dose of plain abdominal radiograph, and even if CT examinations are performed annually for 10 years for surveillance after EVAR, the estimated accumulated radiation dose would only be 10 mSv. This dose is almost equivalent to that of a single routine CT scan from the chest to the abdomen, which has a negligible risk of carcinogenesis.

The quantitative and qualitative analyses performed in this study exhibited that the image quality was significantly lower and that image noise was significantly higher for ULD-CT than for SD-CT. These results suggest that ULD-CT with DLR may have lower sensitivity for detecting incidental findings such as incidentalomas (including malignant tumors) compared to SD-CT. Previous studies have reported that incidentalomas were found in 2%–12.2% of cases on post-EVAR follow-up using contrast-enhanced CT²⁶. While SD-CT, being non-contrast, is presumed to have lower detection sensitivity than contrast-enhanced CT, ULD-CT with DLR may exhibit an even further reduction in sensitivity.

Our clinical experience suggests that ULD-CT images reconstructed using conventional iterative methods exhibit excessive noise, making them clinically

unsuitable for effective post-EVAR surveillance. Therefore, a comparative analysis was not performed. However, several studies have suggested the validity and feasibility of low-dose CT for post-EVAR surveillance and AAA screening. Hansen et al. demonstrated that low-dose CTA with model-based iterative reconstruction enables significant dose reduction during post-EVAR surveillance while maintaining adequate image quality and diagnostic accuracy.²⁶ The CT technique used in Hansen et al.'s study approximately achieved a 73% dose reduction compared with conventional methods. However, the dose remained slightly higher than that of the method used in this study, with 4.4 ± 4.4 and 2.4 ± 2.2 mSv in the arterial and delayed phases, respectively. Given these considerations and the potential risk of contrast-induced renal impairment, the necessity for repeated examinations remains a significant concern. Borgbjerg et al. demonstrated that ULD noncontrast-enhanced CT with 0.7 ± 0.4 mSv allows for accurate and reproducible measurement of the abdominal aortic diameter compared with CTA.²⁷ However, they evaluated a population similar to the AAA screening cohort, and the effects of increased noise in ULD-CT on measuring aneurysm diameters larger than 4 cm are unclear. Moreover, when measuring the aneurysm diameter or aortic diameter in post-EVAR patients, the extent to which metal artifacts caused by stent grafts in ULD-CT affect the measurement values remains unclear. Considerably, our study demonstrates that ULD-CT with DLR offers a reliable method for aneurysm measurement in post-EVAR surveillance.

This study has some limitations. First, the CT results at multiple doses were not compared, and whether 1 mSv is the optimal dose is unclear. Additional examinations will be required to determine whether the CT dose indicated in this study is optimal, and such a study would increase the number of patients exposed to extra radiation and be

ethically problematic. Second, no differences in aneurysmal sac diameter were observed between ULD-CT and SD-CT in patients with aneurysmal wall calcification, the presence of metal in their body other than a stent graft, and obesity; however, the number of patients with these factors was too small to determine statistically significant differences. Furthermore, because no cases of body motion were observed during CT, examining the extent to which motion artifacts may have affected the measurement results for the aneurysmal sac diameter was not possible. Third, specifying the slice in which the aneurysm diameter was measured could reduce measurement variability and underestimate differences between ULD-CT and SD-CT. Herein, we preselected axial images for measurement. Although cross-sectional imaging is recommended for aneurysm diameter assessment in clinical practice, this study evaluated the quality of two imaging techniques rather than examining methods for measuring the maximum diameter. Consequently, we adopted this approach to minimize biases, such as errors arising from the generation of cross-sectional images. Furthermore, we restricted the measurements to experienced radiologists to avoid inaccuracies caused by less experienced individuals. Nonetheless, measurement errors in routine clinical practice may exceed the ones observed in this study. Finally, the DLR used in this study is a proprietary reconstruction technique from a single manufacturer, which limits its availability. However, similar DLR technologies have been introduced by multiple vendors, and their adoption is expected to expand rapidly. Further studies are required to evaluate potential differences among DLR techniques from different manufacturers; however, comparable performance is likely. Consequently, ULD-CT with DLR is anticipated to become widely available across medical facilities.

According to previous studies on the application and prospects of DLR,²⁸ the diagnostic performance of DLR remains unclear, and further prospective studies are needed. This study may serve as one of the studies demonstrating the diagnostic performance of DLR in a specific task.

CONCLUSION

In conclusion, ULD-CT with DLR could adequately measure the aneurysmal sac diameter with substantial radiation dose reduction (approximately one-seventh that of SD-CT) during post-EVAR surveillance. Although the overall image quality was inferior to that of SD-CT, the image quality for the intended purpose was sufficient for long-term post-EVAR aneurysmal sac diameter surveillance.

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FIGURE CAPTIONS

FIGURE 1: Representative SD-CT and ULD-CT images.

Although (a) SD-CT provides superior image quality, (b) ULD-CT with deep-learning reconstruction can substantially reduce radiation dose, approximately one-seventh that of SD-CT. (c) ULD-CT image reconstructed filtered back projection exhibits increased noise. Abbreviations: CTDI_{vol}, CT dose index volume; DLP, dose-length product; SD-CT, standard-dose computed tomography; ULD-CT, ultralow-dose computed tomography.

FIGURE 2: Comparison of the CTDI_{vol} and DLP between ULD-CT and SD-CT.

Box plots show that ULD-CT has a significantly lower (a) CTDI_{vol} and (b) DLP than SD-CT.

Abbreviations: CTDI_{vol}, CT dose index volume; DLP, dose–length product; SD-CT, standard-dose computed tomography; ULD-CT, ultralow-dose computed tomography.

FIGURE 3: Comparison of measurements between SD-CT and ULD-CT for the aneurysm sac diameter (short diameter).

(A) Results of the Bland–Altman analyses. Red horizontal lines indicate ± 3 mm range for differences between measurements by ULD-CT and SD-CT; black solid lines indicate the mean differences between measurements by ULD-CT and SD-CT; and black dotted lines indicate the estimated range that contains 95% of the potential difference between measurements by ULD-CT and SD-CT. (B) Results regarding the BMI < 25 kg/m² subgroup. (C) Results regarding the BMI ≥ 25 kg/m² subgroup. (D) Results regarding the aneurysmal wall calcification (–) subgroup. (E) Results regarding the aneurysmal wall calcification (+) subgroup. (F) Results regarding the metals in the body other than a stent graft (–) subgroup. (G) Results on the metals in the body other than a stent graft (+) subgroup.

Abbreviations: SD-CT, standard-dose computed tomography; ULD-CT, ultralow-dose computed tomography.

FIGURE 4: Results of the Bland–Altman analyses.

Red horizontal lines indicate ± 3 mm range for the differences between measurements by ULD-CT and SD-CT; black solid lines indicate the mean differences between measurements by ULD-CT and SD-CT; black long-dashed lines indicate the estimated range that contains 95% of the potential differences between measurements by ULD-CT

and SD-CT; and black short-dashed lines indicate the 95% confidence intervals of the estimated range.

(A) Bland–Altman plot for observer 1. (B) Bland–Altman plot for observer 2. (C) Bland–Altman plot for observer 3.

FIGURE 5: A Bland–Altman plot for a pair of measurements in SD-CT

Red horizontal lines indicate ± 3 mm range for the differences between measurements by observer 1 and 2 in SD-CT; black solid lines indicate the mean differences between measurements by observer 1 and 2 in SD-CT; black long-dashed lines indicate the estimated range that contains 95% of the potential differences between measurements by observer 1 and 2 in SD-CT; and black short-dashed lines indicate the 95% confidence intervals of the estimated range.

Abbreviations: Obs1, observer 1; Obs2, observer 2; SD-CT, standard-dose computed tomography

Table 1: Intraobserver LOA values for each observer and interobserver LOA values for SD-CT, ULD-CT, and SD-CT vs ULD-CT.

	LoA (mm)	95%CI of lower LoA (mm)	95%CI of upper LoA (mm)
ULD-CT - SD-CT (Observer 1)	-3.5 to 2.6	-4.1 to -2.8	2.0 to 3.3
ULD-CT - SD-CT (Observer 2)	-2.8 to 1.9	-3.2 to -2.3	1.4 to 2.4
ULD-CT - SD-CT (Observer 3)	-2.9 to 2.3	-3.4 to -2.3	1.8 to 2.9
SD-CT (Observer 1) - SD-CT (Observer 2)	-1.8 to 2.9	-2.3 to -1.3	2.4 to 3.4
SD-CT (Observer 1) - SD-CT (Observer 3)	-2.5 to 2.8	-3.0 to -1.9	2.2 to 3.4
SD-CT (Observer 2) - SD-CT (Observer 3)	-2.7 to 2.0	-3.2 to -2.2	1.5 to 2.5
ULD-CT (Observer 1) - ULD-CT (Observer 2)	-2.4 to 3.5	-3.0 to -1.7	2.8 to 4.1
ULD-CT (Observer 1) - ULD-CT (Observer 3)	-3.5 to 3.5	-4.2 to -2.7	2.8 to 4.2
ULD-CT (Observer 2) - ULD-CT (Observer 3)	-3.5 to 2.5	-4.1 to -2.9	1.8 to 3.0
ULD-CT (Observer 1) - SD-CT (Observer 2)	-2.6 to 2.9	-3.2 to -2.1	2.3 to 3.5
ULD-CT (Observer 1) - SD-CT (Observer 3)	-3.5 to 3.0	-4.2 to -2.8	2.3 to 3.7
ULD-CT (Observer 2) - SD-CT (Observer 3)	-3.7 to 2.1	-4.2 to -3.1	1.5 to 2.6

Abbreviations: LOA, limit of agreement; SD-CT, standard-dose computed tomography; ULD-CT, ultralow-dose computed tomography.

Table 2: Mean image-quality scores in SD-CT and ULD-CT.

	SD-CT	ULD-CT	<i>P</i> -values
Observer 1			

	Overall	4.1 ± 0.3	3.4 ± 0.5	<0.001
	Aorta	4.1 ± 0.3	3.7 ± 0.6	<0.001
	Liver	4.0 ± 0.3	3.1 ± 0.5	<0.001
	Colon	4.1 ± 0.3	3.4 ± 0.5	<0.001
Observer 2				
	Overall	4.6 ± 0.5	3.5 ± 0.8	<0.001
	Aorta	4.8 ± 0.4	3.6 ± 0.9	<0.001
	Liver	4.5 ± 0.5	3.3 ± 0.7	<0.001
	Colon	4.7 ± 0.5	3.8 ± 0.7	0.001
Observer 3				
	Overall	4.9 ± 0.3	3.1 ± 0.3	<0.001
	Aorta	4.9 ± 0.3	3.4 ± 0.3	<0.001
	Liver	4.9 ± 0.3	3.2 ± 0.5	<0.001
	Colon	4.6 ± 0.5	2.9 ± 0.5	<0.001

Data are presented as means $\pm$ standard deviations. The Wilcoxon matched-pairs signed-rank test was used to calculate p -values.

Abbreviations: SD-CT, standard-dose computed tomography; ULD-CT, ultralow-dose computed tomography.

Table 3: Comparison of image noise and SNR between SD-CT and ULD-CT.

		SD-CT	ULD-CT	<i>P</i> -value
Image noise				
	Aneurysmal sac	10.6 ± 1.9	14.7 ± 1.6	<0.001
	Aorta	8.8 ± 0.9	12.7 ± 0.8	<0.001
	Liver	9.3 ± 9.7	12.4 ± 0.7	0.041
	Paraspinal muscle	9.3 ± 1.1	13.1 ± 0.8	<0.001
	Subcutaneous fat	−9.1 ± 1.6	12.4 ± 1.7	<0.001
SNR				
	Aneurysmal sac	4.1 ± 1.1	2.8 ± 0.7	<0.001
	Aorta	4.5 ± 0.9	3.8 ± 4.3	0.315
	Liver	9.4 ± 10.6	5.6 ± 4.1	0.035
	Paraspinal muscle	5.1 ± 1.3	3.4 ± 0.6	<0.001
	Subcutaneous fat	−9.5 ± 6.5	−7.7 ± 3.1	0.11

Data are presented as means ± standard deviations. The Wilcoxon matched-pairs signed-rank test was used to calculate *p*-values. Abbreviations: SD-CT, standard-dose computed tomography; SNR, signal-to-noise ratio; ULD-CT, ultralow-dose computed tomography.

Figure 1

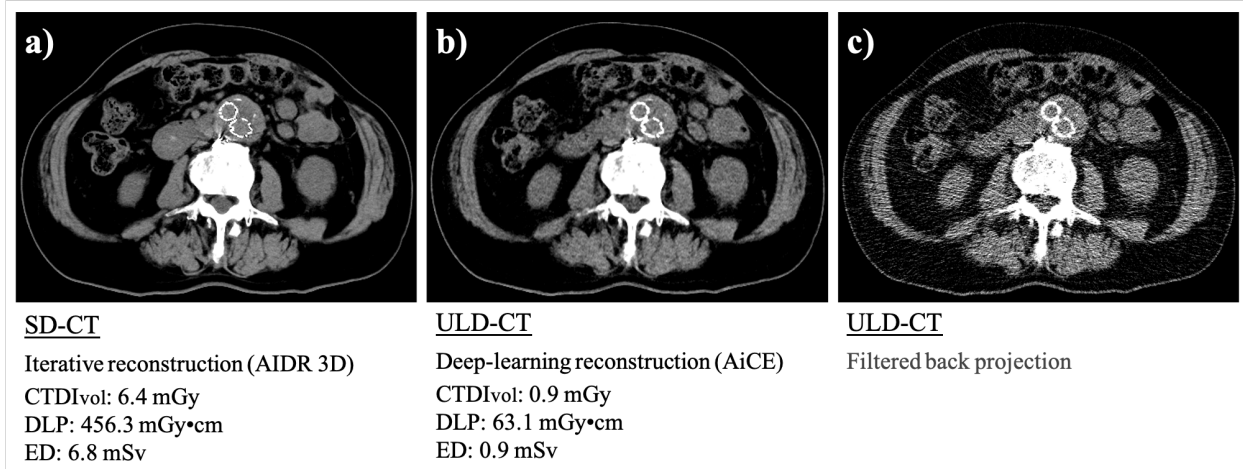


Figure 2

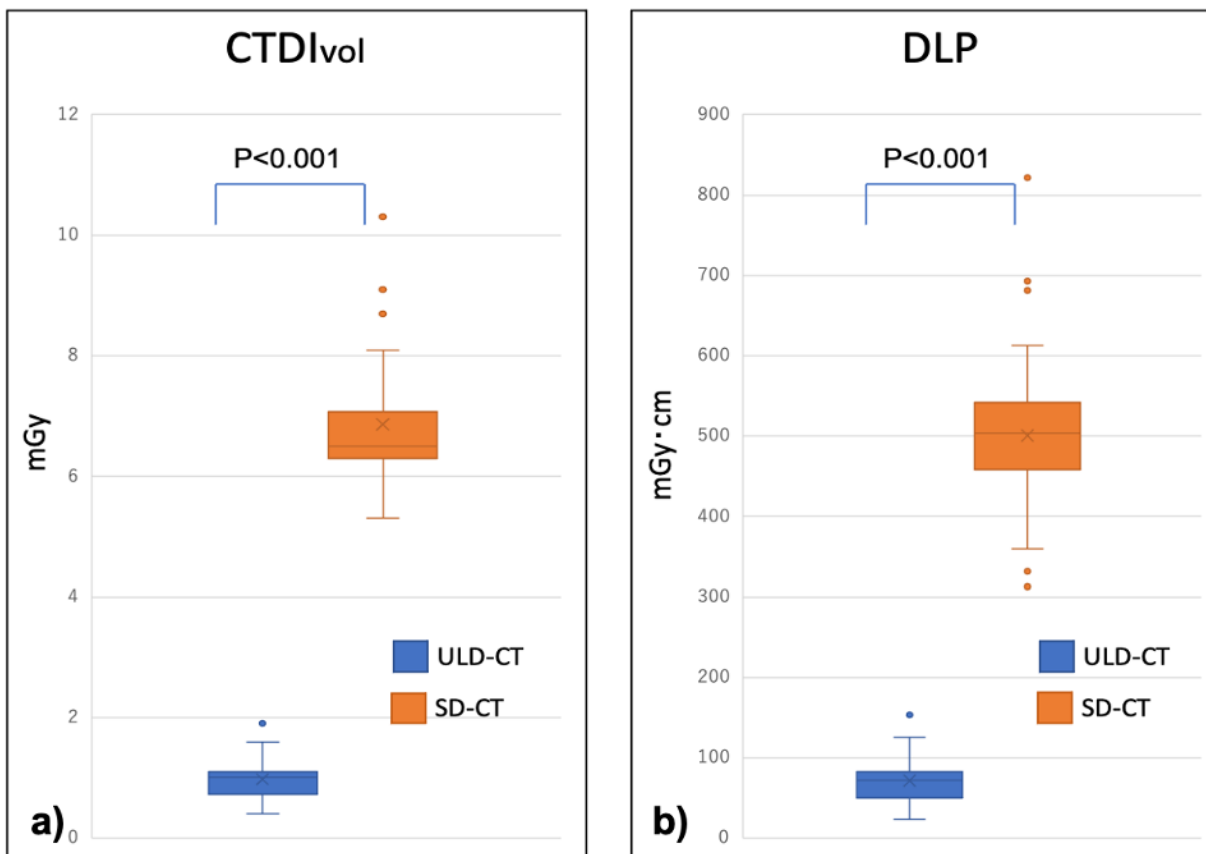


Figure 3

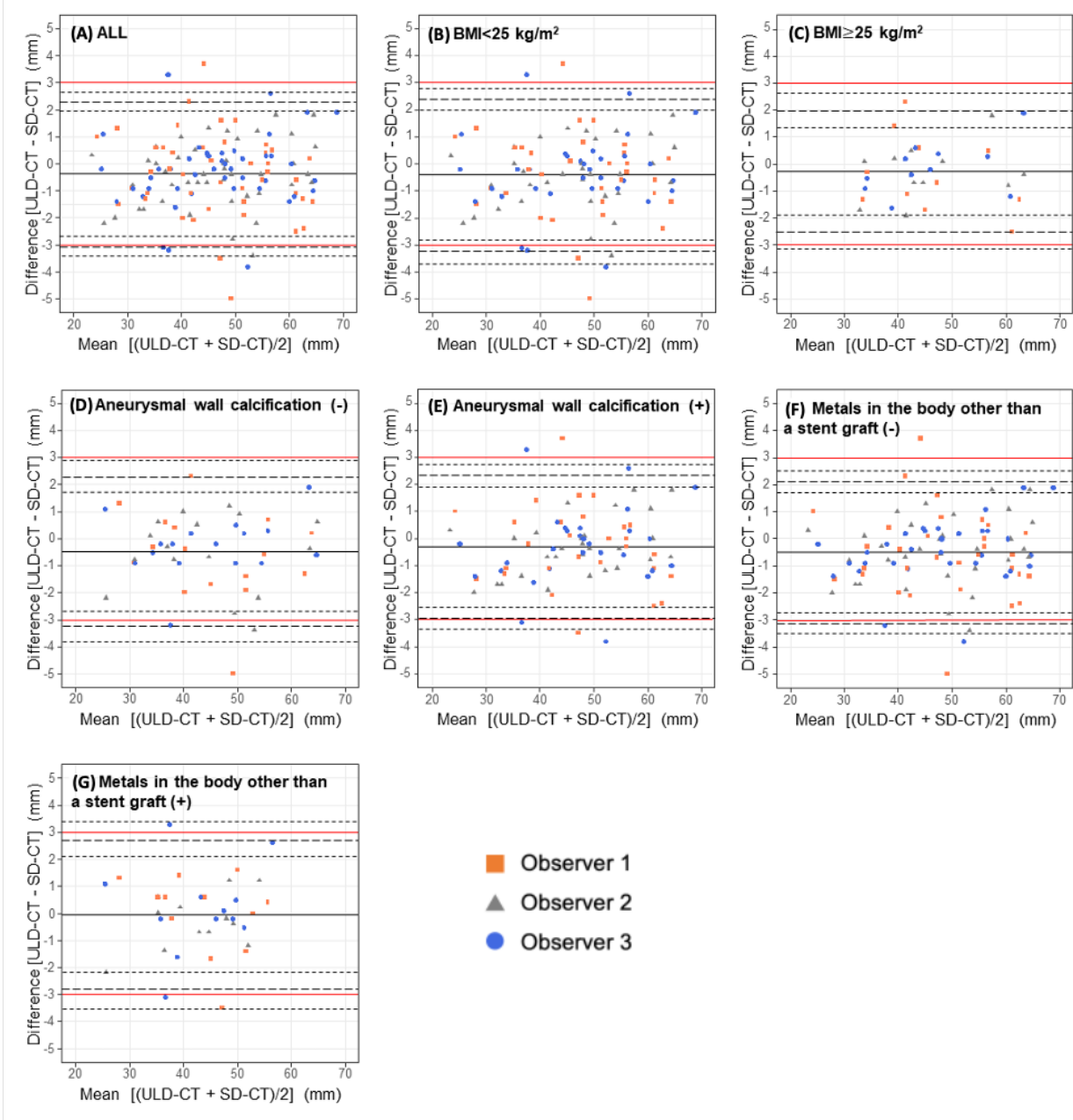


Figure 4

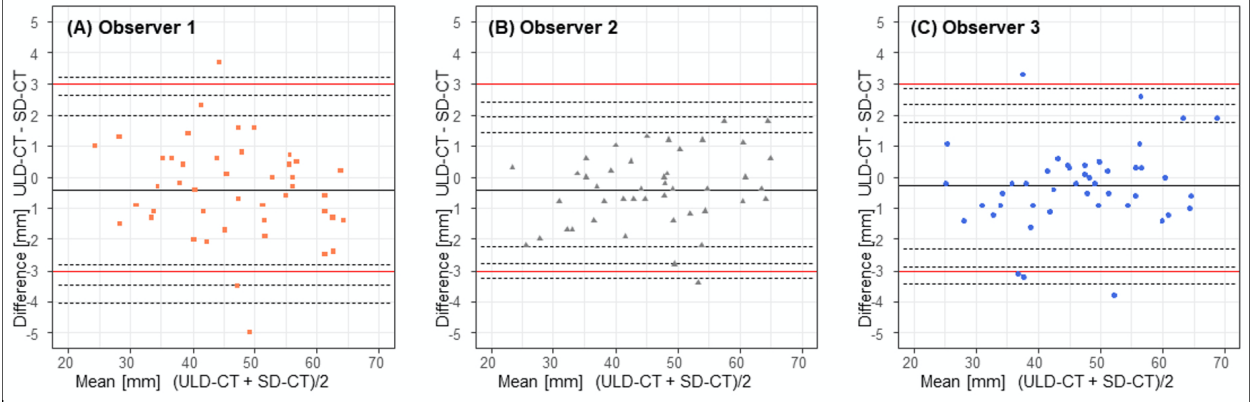
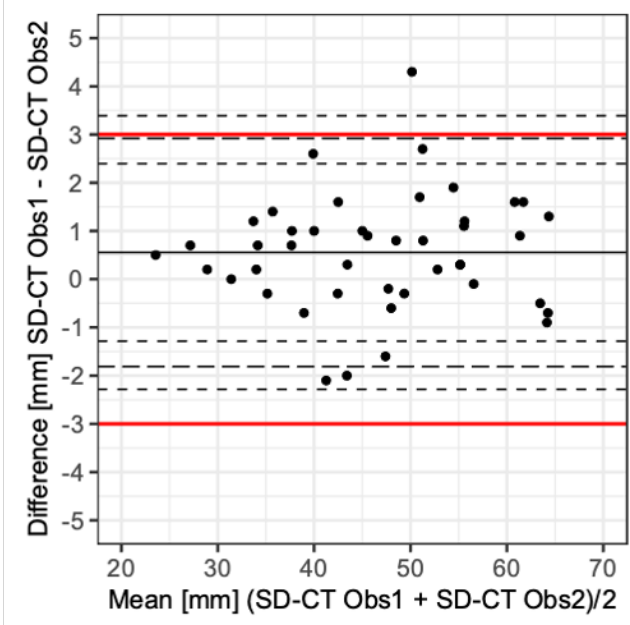


Figure 5



Supplementary file

