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Image Quality and Vessel Rendering Ability of Dynamic Range Compression-Processed Images of Peripheral Vessels in Digital Subtraction Angiography

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Background: In emergency interventional radiology (IR), patient motion and poor breath-holding often result in misregistration during digital subtraction angiography (DSA). As a countermeasure, digital angiography (DA) without subtraction processing is used for observation; however, evaluation is limited to areas overlapping with low X-ray transmissivity structures, such as bone. Dynamic trace (DT) is capable of real-time background compression processing of peripheral blood vessels in DA images and ensures visibility of blood vessels in such areas, without being affected by body motion. We evaluated the image quality and visualization of peripheral vascularity of DA and DT images obtained from DSA of the trunk and examined the usefulness of DT.

Methods: Data from 13 patients who underwent emergency IR involving trunk DSA between October 2022 and June 2023 were analyzed. DA and DT images were created from these angiographic images, and two independent IR specialists used a 4-point scale to visually evaluate the contrast, sharpness, and peripheral vascular visibility of the proximal and distal portions of 42 arteries. The image quality scores for DA and DT images were compared using the Wilcoxon signed-rank test, and inter-rater agreement was evaluated using weighting coefficients.

Results: As compared with the DA images, the DT images were significantly better at all endpoints ($P < 0.001$). Inter-rater agreement was moderate for all assessment items.

Conclusions: DT images are not affected by body motion and display better image quality and visualization of peripheral vascularity than DA images, making them useful for emergency IR of the trunk.

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Key words: interventional radiology, digital subtraction angiography, digital angiography, dynamic trace, Canon Medical Systems

Introduction

Angiography of the trunk is essential for interventional radiology (IR) of vascular diseases such as abdominal organ injuries, pelvic fractures, gastrointestinal bleeding, and other emergencies[1–4]. Digital subtraction angiography (DSA) subtracts the image before contrast medium injection from that after contrast-medium injection to obtain an image of only the injected contrast medium, thereby improving vascular imaging by eliminating interference from overlapping bones and other objects. DSA is thus often performed during emergency IR of the trunk. However, three problems have been observed with its use. The first is misregistration due to patient motion, poor breath-holding, and intestinal peristalsis, resulting in in-

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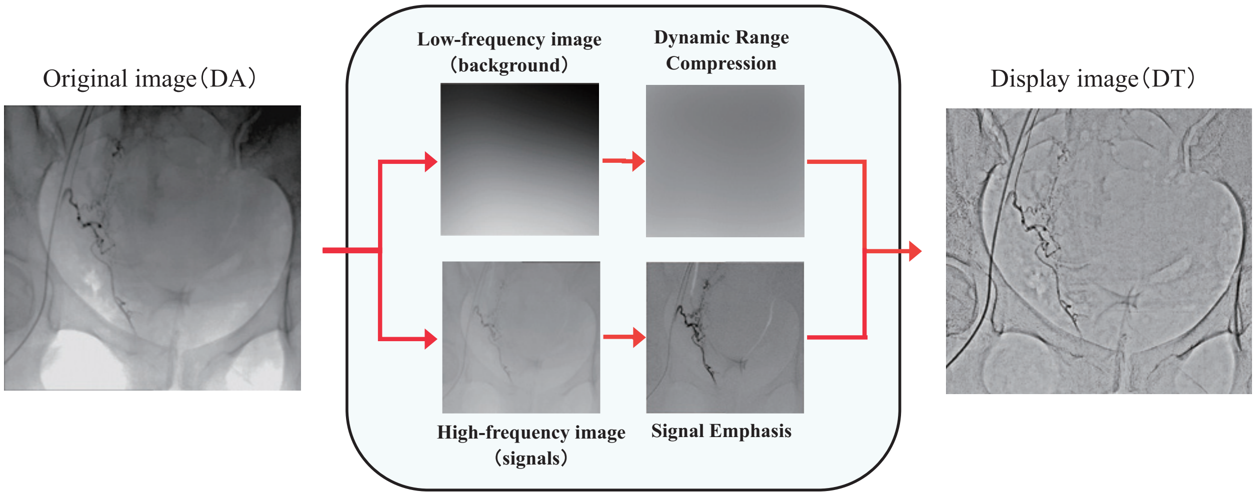


Fig. 1 Processing method for converting a digital angiography image to a dynamic trace image.

appropriate subtraction[5-7]. Second, imaging the entire lower extremities before endovascular therapy/treatment for peripheral arterial disease is difficult. Third, masked image acquisition before contrast injection increases radiation exposure.

Recent advances in image processing technology for angiography have enabled clinical application of background compression processing for peripheral vessels. This method ensures vascular visibility by reducing differences in background density in digital angiography (DA) images that have not undergone subtraction through real-time processing. This technology was originally developed for use in cases for which endovascular therapy/treatment was indicated, as patients with peripheral arterial disease are prone to body movements because of the heat and pain associated with contrast injection during angiography. Poor subtraction due to misalignment is a frequent problem in DSA[8]. Although this method is widely used under functional names such as dynamic trace (DT) (Canon Medical Systems), CLEAR LEG (Siemens Healthineers), and SCORE RSM (Shimadzu), few centers have used it for trunk vascular imaging[9-11].

A new hybrid emergency room that includes DT was installed at our institution in January 2022. In cases of poor subtraction due to patient motion, poor breath-holding, or intestinal peristalsis during DSA of the trunk for emergency IR, the operator traditionally relies on DA images. In such cases, vascular imaging performance is often insufficient in areas with overlapping low-transmission structures, such as bones and organs, or in highly transparent structures, such as lung fields. DT images are therefore used as an alternative to DSA images. Moreover, peripheral vascular imaging capability is much improved as compared with DA images, resulting in less operator stress, fewer imaging sessions, and improved procedural efficiency. However, no studies have compared the peripheral vascular imaging performance of DA and DT images. In this study, we compared the image quality and the peripheral vascular imaging performance of DA and DT images obtained using DSA of the trunk during emergency IR and investigated the usefulness of DT.

Materials and Methods

This retrospective study was approved by the relevant Institutional Review Board (approval number: 2024-0075) and was conducted according to the principles of the Declaration of Helsinki.

Basic principles of DT

First, filter processing (low-pass filter) was used to separate the original DA image into low- and high-frequency images. Next, the low-frequency image corresponding to the background component was processed to compress the dynamic range. In contrast, processing was performed to enhance the signal regarding high-frequency images corresponding to signal components, such as blood vessels. Finally, the two processes were combined to create a DT image, ie, the displayed image (**Fig. 1**).

Study patients

This study analyzed data from 13 patients (seven men, six women; mean ± SD age, 59 ± 21 years; range, 19-89 years) who underwent trunk DSA during emergency IR with an angiography system (Alphenix, Canon Medical Systems. Co., Ltd., Tochigi, Japan) in the hybrid emer-

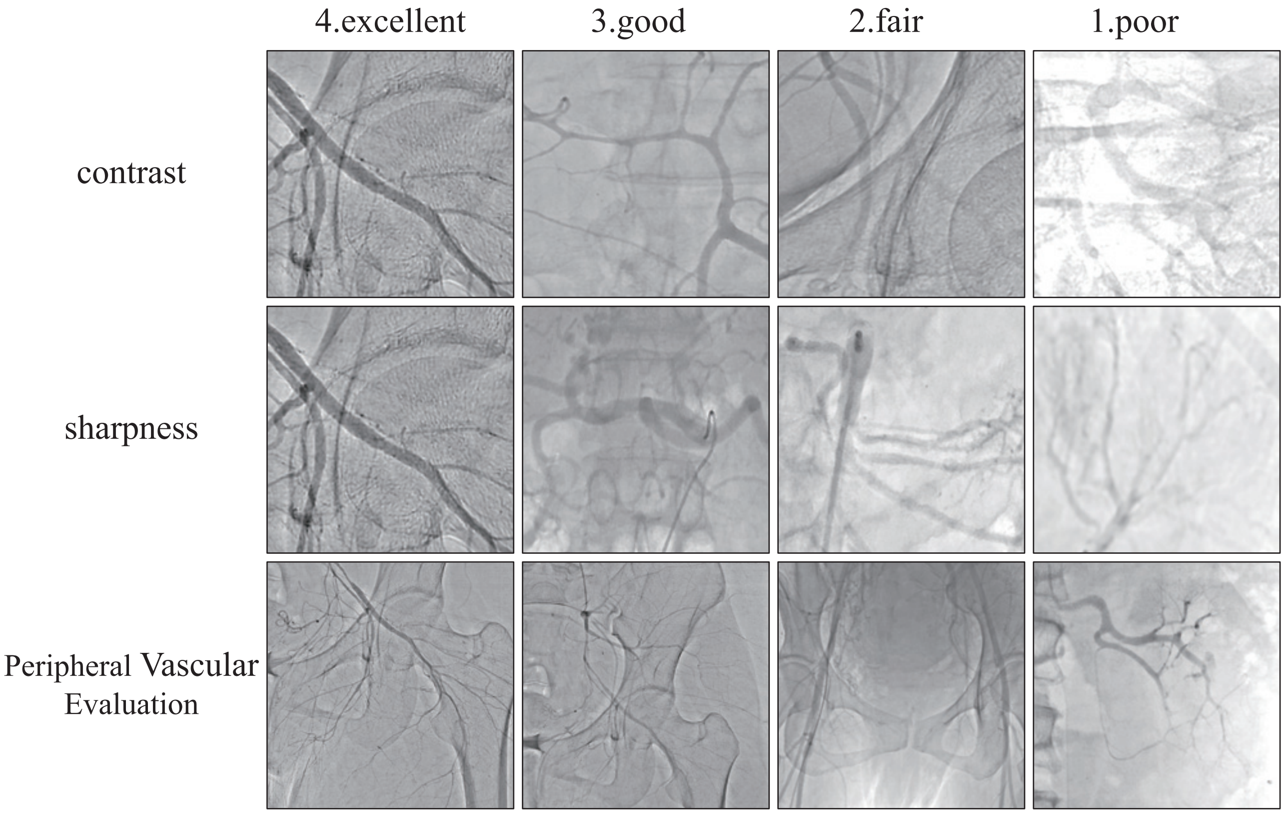


Fig. 2 Representative images for the 4-point scale used to assess contrast, sharpness, and peripheral vascular delineation.
Contrast IQ: 4) excellent image quality—clear difference in density between the blood vessels and background; 3) good image quality—moderate difference in density between blood vessels and background; 2) fair image quality—density contrast between background and vessels is fair, but vessels can be evaluated; 1) poor image quality—poor vascular and background density contrast makes vascular evaluation impossible.
Sharpness IQ: 4) the boundary between the blood vessels and background is quite clear; 3) mildly blurred boundary between the blood vessels and background; 2) moderately blurred boundary between the vessels and background, but vessels can be evaluated; 1) marked blurring of the boundary between the vessels and background makes evaluation of the vessels impossible.
Peripheral Vascular Evaluation: 4) even peripheral blood vessels can be evaluated; 3) peripheral vessels are evaluable but a little blurry; 2) some peripheral blood vessels are barely evaluable; 1) few vessels are evaluable to the periphery.
IQ, image quality.

gency room between October 2022 and June 2023. IR was performed for gastrointestinal bleeding (n = 4); splenic, renal, and uterine bleeding (n = 2 each); and pancreatic bleeding, pelvic fracture, and bladder bleeding (n = 1 each).

Assessment of visual image quality

We used angiographic data to create DA and DT images, which were delivered to a Picture Archiving and Communication System. Two blinded IR specialists independently evaluated the contrast and sharpness of the proximal and distal portions of the 42 arteries in both images and the peripheral vascularization of each vessel on the Picture Archiving and Communication System. These arteries included 14 celiac artery branches, 13 internal iliac artery branches, 10 superior mesenteric artery branches, and four renal artery branches, as well as one inferior mesenteric artery branch. A 4-point scoring system was used for visual evaluation, with 1 point scored as poor image quality, 2 as fair image quality, 3 as good image quality, and 4 as excellent image quality (**Fig. 2**)[12,13].

Statistical analyses

The SPSS software package (version 24.0; SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Visual evaluation scores for the DA and DT images were compared with the Wilcoxon signed-rank test. A P value of < 0.05 was considered to indicate statistical significance. Inter-rater agreement for the visual evaluation scores was assessed using weighted kappa coefficients: κ < 0.20 was classified as poor; κ = 0.21-0.40 as fair; κ = 0.41-0.60 as moderate; κ = 0.61-0.80 as good; and κ = 0.81-1.00 as excellent.

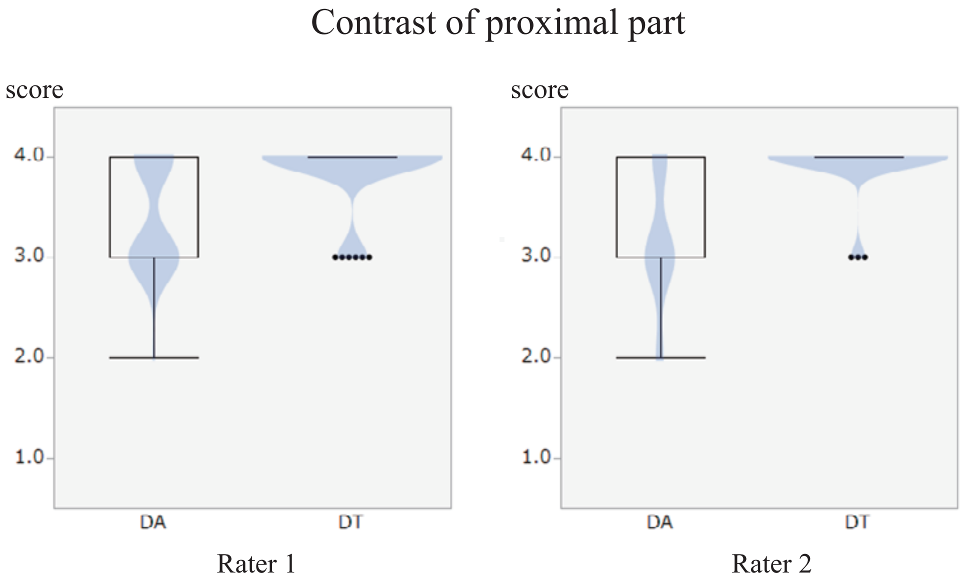


Fig. 3 Boxplot showing visual evaluation scores for contrast in proximal vessels on digital angiography (DA) and dynamic trace (DT) images evaluated by raters 1 and 2.
For the proximal segment of the vessel, raters 1 and 2 rated the DT image as significantly better than the DA image in terms of contrast (*P<0.001).

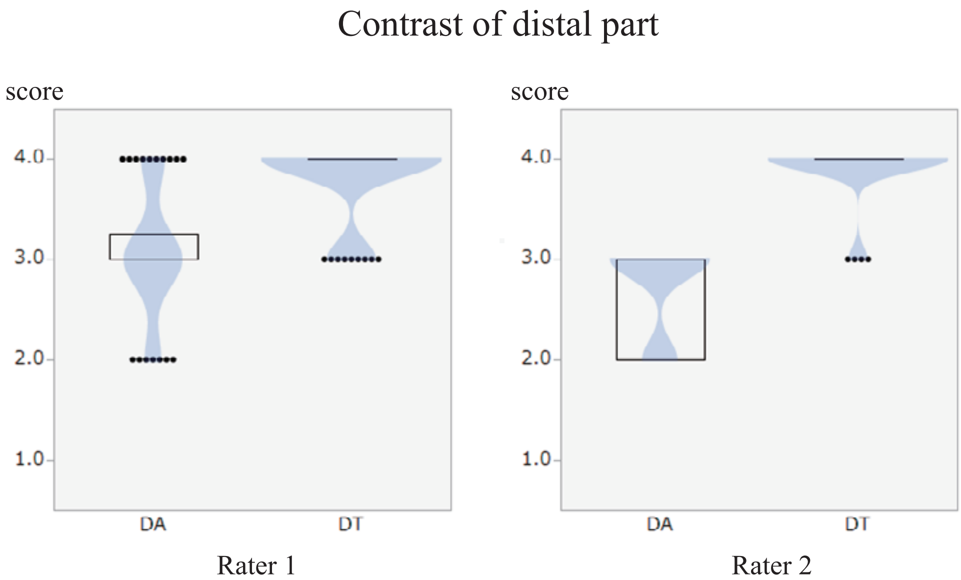


Fig. 4 Boxplot showing visual evaluation scores for contrast in distal vessels on digital angiography (DA) and dynamic trace (DT) images evaluated by raters 1 and 2.
For the distal segment of the vessel, raters 1 and 2 rated the DT image as significantly better than the DA image in terms of contrast (*P<0.001).

Results

Visual evaluation scores by both raters 1 and 2 were significantly better for DT images than for DA images for all evaluation items ($P < 0.001$) (**Fig. 3〜7**). The trend was similar for the peripheral vasographic performance of each branch (**Table 1**). The percentage of peripheral vascular images with a visual evaluation score of ≥3 (good) was 75% for DA images and 99% for DT images. The kappa coefficients were 0.47, 0.52, and 0.56 for the evaluation of contrast, sharpness, and peripheral vascular imaging, respectively, and inter-rater agreement was moderate for all endpoints. **Figure 8** shows a representative clinical image. A case of bladder hemorrhage treated with bladder artery embolization using a small sponge

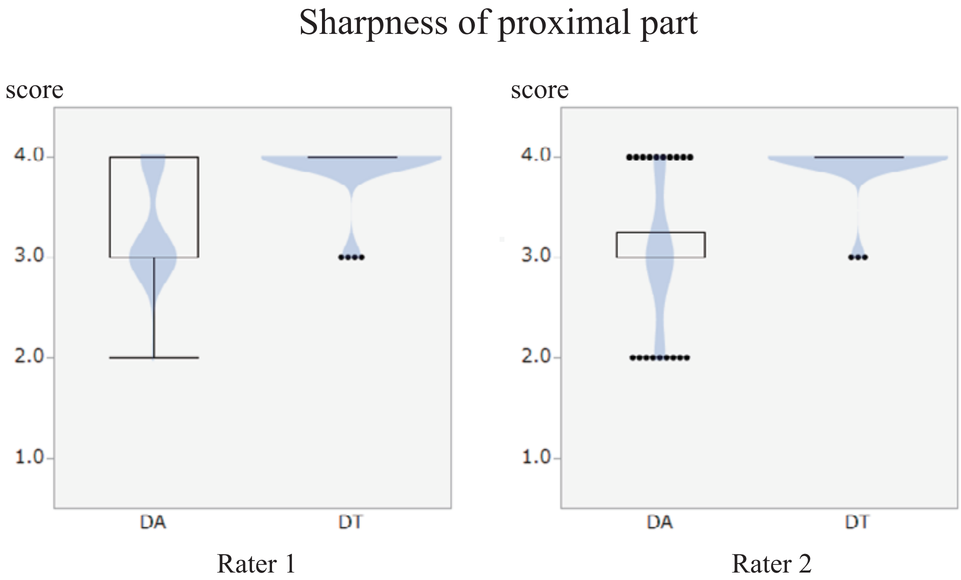


Fig. 5 Boxplot showing visual evaluation scores for sharpness of proximal vessels on digital angiography (DA) and dynamic trace (DT) images evaluated by raters 1 and 2.
For the proximal segment of the vessel, raters 1 and 2 rated the DT image as significantly better than the DA image in terms of sharpness (*P<0.001).

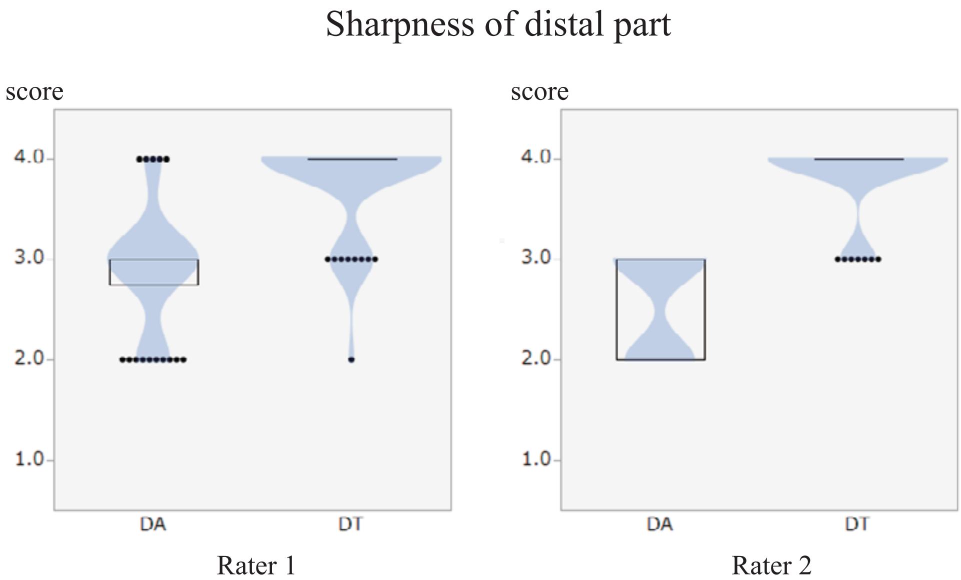


Fig. 6 Boxplot showing visual evaluation scores for sharpness of distal vessels on digital angiography (DA) and dynamic trace (DT) images evaluated by raters 1 and 2.
For the distal segment of the vessel, raters 1 and 2 rated the DT image as significantly better than the DA image in terms of sharpness (*P<0.001).

right internal iliac artery angiography clearly improved delineation of the right internal iliac artery branches, including the right superior gluteal artery, on DT images as compared with DA images.

Discussion

Few facilities have used DT or other peripheral vascular background compression processes for trunk DSA. Tateishi et al.[10] discussed the clinical usefulness of CLEAR LEG. Patient motion and poor breath-holding associated with pain, restlessness, involuntary movement, dyspnea, impaired consciousness, mental retardation, and dementia result in poor subtraction because of misalignment in trunk DSA imaging. Peristalsis of the intestinal and uri-

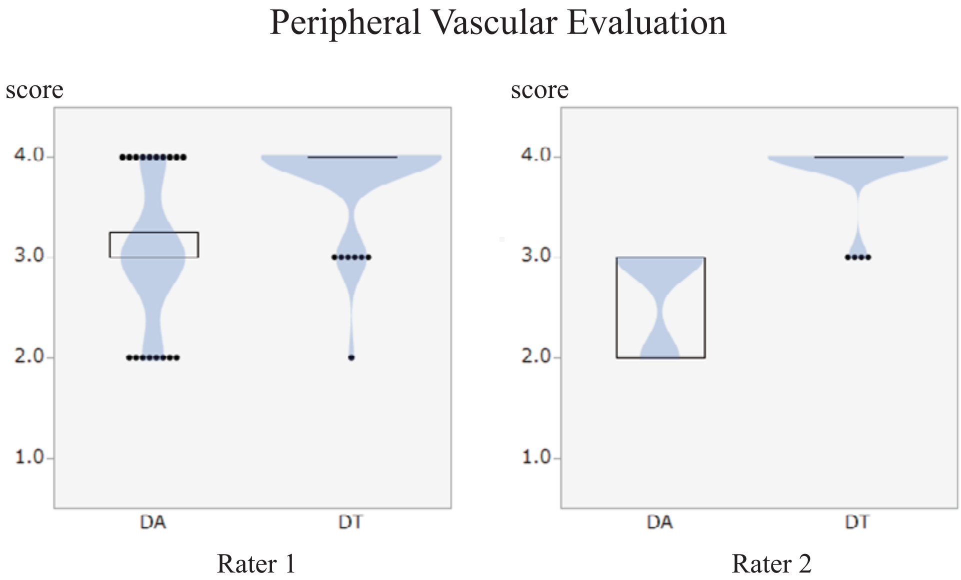


Fig. 7 Boxplot showing the visual evaluation score for peripheral vascular depiction in digital angiography (DA) and dynamic trace (DT) images evaluated by raters 1 and 2.
Raters 1 and 2 rated DT images significantly better than DA images for peripheral vascular delineation (*P<0.001).

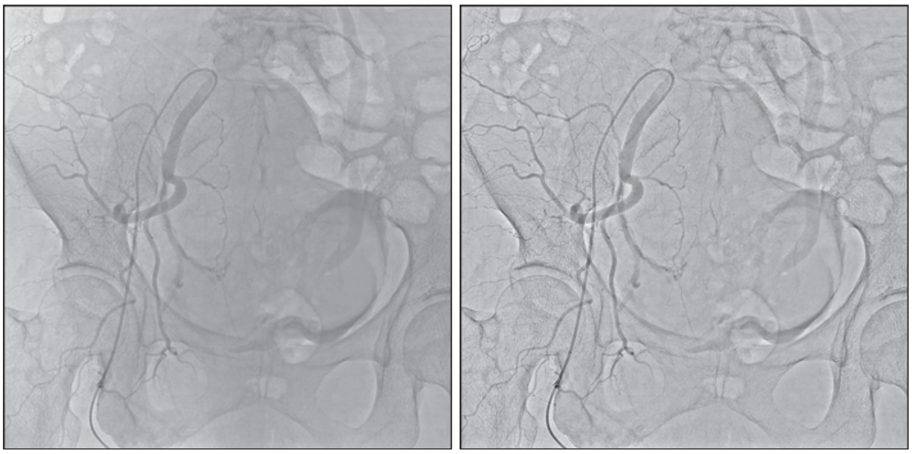
Table 1 Scores of peripheral vasography for each branch by raters 1 and 2

Branches	Rater 1		Rater 2	
	DA	DT	DA	DT
IIA	3.0±0.6	3.8±0.4	2.8±0.4	4.0±0.0
SMA & IMA	3.0±0.7	3.6±0.6	2.8±0.4	3.8±0.4
CA	3.3±0.6	3.9±0.3	2.6±0.5	3.9±0.3
RA	2.5±0.5	4.0±0.0	2.0±0.0	4.0±0.0

DA, digital angiography; DT, dynamic trace; IIA, internal iliac artery; SMA, superior mesenteric artery; IMA, inferior mesenteric artery; CA, celiac artery; RA, renal artery.

nary tracts and heartbeat can cause additional problems. These artifacts complicate diagnosis and treatment, and reimaging unnecessary prolongs the procedure time and increases exposure. However, such artifacts are not a concern with DA images that do not require subtraction. Therefore, when DSA images are unexpectedly non-assessable because of such artifacts, assessing DA images without subtraction processing is important. In contrast to DSA images, DA images have the advantage that bones and other structures can be used as landmarks. When DSA is likely to be difficult, DA imaging, which does not require masked images before contrast injection, is often performed and would lead to reductions in procedure time and exposure. In addition, unlike DSA imaging, DA imaging does not require prolonged breath-holding after deep breathing, thereby reducing the risk of catheter deviation. Thus, when catheter deviation during angiography is a concern, DA imaging may be preferred over DSA imaging. Although DA images are often the key to evaluation during emergency IR, a major concern is that peripheral vascular imaging is highly susceptible to deterioration due to overlapping bones and halation artifacts in the lung field. Background compression processing for peripheral blood vessels will likely improve peripheral vascular imaging because it smooths density differences in high absorbers, such as bone, and low absorbers, such as lung fields, on DA images and emphasizes vascular signals. Therefore, real-time peripheral vascular background compression processing on DA images is a good substitute for DSA images and can replace DSA imaging in appropriate cases.

The present study compared DA and DT images obtained from DSA imaging of the trunk during emergency IR. Image quality, including contrast and sharpness, and peripheral vessel rendering ability were significantly better with DT images than with DA images. In particular, almost all DT images were scored ≥3 (good), supporting their active clinical use. Specifically, the use of DT and other peripheral vascular background compression processes is required when body movement or breath-holding failure is expected, when catheter deviation is a concern, when intestinal peristalsis or other effects might adversely affect the diagnosis or procedure, or when bones are used as anatomical landmarks. This type of image



(a) (b)

Fig. 8 Angiogram of right internal iliac artery taken during transcatheter arterial embolization for bladder hemorrhage.
Because the bone was paler and the vessels were darker in the dynamic trace image (b) than in the digital angiography image (a), delineation of the right internal iliac artery branch, including the right superior gluteal artery, was clearly improved.

processing may also be useful when the ability to depict blood vessels and DSA images is unnecessary. DA imaging is sufficient when prompt assessment and reduced radiation exposure are priorities.

Because DT images are processed with high-frequency enhancement, noise may increase along with vascular signal enhancement. In a phantom experiment using simulated blood vessels, Sato et al.[14] showed that although noise was higher in DT processing than in DA, the contrast of blood vessels was also increased. Additionally, the contrast-to-noise ratio, which contributes to the evaluation of image quality in vascular imaging, is higher in DT images[14]. The same effect was observed in the present clinical images; thus, DT images should be regarded as superior for evaluation.

This study has some limitations. DT images might produce undershoots at the vessel boundaries, possibly affecting vessel diameters. In addition, vascular evaluation was difficult in areas where overlapping bone ends. In the future, we hope to conduct clinical studies with a greater number of cases, as well as multicenter collaborative studies. We plan to consider DT images instead of DSA images as the first choice and conduct a clinical study using DA imaging.

Conclusion

As compared with DA images, DT images obtained during trunk DSA were not affected by poor subtraction due to body movement and have better image quality and peripheral vascularity visualization ability, making them useful for emergency IR. DT images helped improve emergency medicine by increasing diagnostic performance and procedural efficiency while reducing radiation exposure and use of contrast media, without substantial drawbacks.

Conflict of Interest: The authors declare no conflict of interest.

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