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Combination of Colour Duplex and Contrast Enhanced Ultrasound as an Alternative to Computed Tomography Angiography in Isolated Mesenteric Artery Dissection Surveillance

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WHAT THIS PAPER ADDS
The combination of colour duplex ultrasound (CDU) and contrast enhanced ultrasound (CEUS) was found to be successful in showing the morphological characteristics of isolated mesenteric artery dissection (IMAD), and ultrasound imaging also allowed the detection and assessment of peak systolic velocity at the point of the minimum inner diameter. CDU plus CEUS was as successful as computed tomography angiography alone in the follow up for patients with IMAD, without the need for radiation exposure or iodine containing contrast use.

Objectives: The aim was to investigate the effectiveness of colour duplex ultrasound (CDU) plus contrast enhanced ultrasound (CEUS) *vs.* computed tomography angiography (CTA) for surveillance in patients with isolated mesenteric artery dissection (IMAD).
Methods: Patients who underwent CDU, CEUS, and CTA for surveillance of IMAD between January 2012 and May 2019 were included in the study. The accuracy of CDU, CEUS, and CTA for determining the morphological characteristics of IMAD was analysed.
Results: A total of 42 patients undergoing 76 total imaging examinations during follow up were included. Both CTA and CDU plus CEUS demonstrated the thrombosed false lumen for 28 (36.8%) examinations and the dissecting aneurysm for 20 (26.3%) examinations (both $\kappa = 1.0$). The diameter of the dissecting aneurysm was 5.03 ± 1.25 mm using CDU and CEUS *vs.* 5.27 ± 1.23 mm on CTA (coefficient of consistency, 0.997; $p < .001$). The entry points were visualised by CDU and CEUS for 20 (26.3%) examinations and by CTA for 14 (18.4%) examinations ($\kappa = 0.769$); no re-entry points were visualised by CDU and CEUS for any examinations but re-entry points were visualised by CTA for two (2.6%) examinations. The minimum inner diameter was 2.80 ± 1.30 mm on CDU and CEUS *vs.* 2.52 ± 1.29 mm on CTA (coefficient of consistency, 0.999; $p < .001$). The peak systolic velocities were 128.2 ± 13.0 cm/s at diagnosis and 98.7 ± 4.9 cm/s after one month ($p < .001$).
Conclusions: The combination of CDU and CEUS can be used in place of CTA for the surveillance of IMAD.

Keywords: Colour duplex ultrasound, Computed tomography, Dissection, Mesenteric artery
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INTRODUCTION

Spontaneous isolated mesenteric artery dissection (IMAD) is an uncommon but sometimes catastrophic condition that leads to variable and unpredictable outcomes.[1,2] Although most cases of IMAD can be managed successfully conservatively according to the European Society for Vascular Surgery guidelines, approximately 20% of patients eventually require an intervention because of disease progression.[3] Follow up is therefore important in these patients, with most undergoing follow up imaging until complete remodelling of the mesenteric artery has occurred.[4,5]

Computed tomography angiography (CTA) has been used most commonly for the long term surveillance of IMAD, but this modality is expensive, requires repeated radiation exposure, and carries the risk of contrast related nephropathy.[4,5] Consequently, CTA is not ideal for ongoing surveillance of IMAD. Ultrasound imaging techniques, including colour duplex ultrasound (CDU) and contrast enhanced ultrasound (CEUS), can be used to show abnormalities in visceral arteries.[6] As such, transitioning from CTA to ultrasound imaging for the long term surveillance of IMAD seems reasonable.[7] However, the clinical effectiveness of a

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combination of CDU and CEUS *vs.* CTA for IMAD surveillance has not been explored previously.

In this study, the clinical effectiveness of CDU plus CEUS *vs.* CTA for long term surveillance in patients with IMAD was investigated retrospectively.

METHODS

Study design

This study was approved by the Institutional Review Board with a waiver of informed consent. Consecutive patients who were diagnosed with spontaneous IMAD by CTA and who underwent CDU, CEUS, and CTA for IMAD surveillance between January 2012 and May 2019 were included in this study. Patients with an interval between CTA examination and CDU plus CEUS examinations of >1 week, patients who underwent surgical treatment, and patients who were lost to follow up were excluded from the study. Imaging data were gathered from the Picture Archiving and Communications System, and clinical data were gathered from the electronic medical records.

Clinical follow up

Outpatient follow up was scheduled for the first and sixth months after discharge and annually thereafter until complete remodelling of the mesenteric artery had occurred. Complete remodelling of the mesenteric artery was defined as complete resorption of the false lumen thrombosis and morphological recovery of the mesenteric artery to its normal state without any aneurysm formation.

CTA technique and imaging analysis

CTA was performed on a 64 detector row scanner (Philips, Rotterdam, The Netherlands; or GE LightSpeed VCT, General Electric Healthcare, Chicago IL, USA) using a technique reported in a previous study.[4] The following parameters were used: matrix, 512 $\times$ 512; 5 mm slice; 200–300 mAs; and 100–120 kV. Data acquisition began at 4 s after a region of interest in the abdominal aorta reached a threshold of 100 HU (bolus tracking technique). Data were acquired at a 5 mm scan thickness at a pitch of 0.75 mm; these results were reconstructed to overlapping sections of 0.625 mm. Multiplanar reconstructions and three dimensional (3D) models including maximum intensity projection (MIP), multiplanar reconstruction (MPR), and volume rendered (VR) images were reconstructed.

Image interpretation focused on the morphological characteristics of IMAD, including the presence of a thrombosed false lumen, the presence and diameter of the dissecting aneurysm, entry and re-entry points, and minimum inner diameter. All images were analysed separately by two independent radiologists, both with >10 years' experience in vascular radiology; both were blinded to the ultrasound imaging findings.

CDU and CEUS technique and imaging analysis

The Philips EPIQ 7 ultrasound system was used for CDU and CEUS. CDU was performed before CEUS. SonoVue (Bracco Inc, Geneva, Switzerland) was used for CEUS. During CEUS, still images and cine loops were recorded for image analysis. The mesenteric artery was studied in its long axis in the sagittal plane, and the characteristics and extent of the thrombotic false lumen and narrowed true lumen were evaluated when there was hyperechoic segmentation.

The morphological characteristics of IMAD mentioned earlier were assessed, as well as the peak systolic velocity (PSV) at the point of the minimum inner diameter. The sonographer who performed the examinations had >15 years of experience in vascular ultrasonography and was blinded to the CTA findings.

Statistical analysis

Interobserver agreement values for evaluations of the presence of thrombosed false lumen, presence of dissecting aneurysm, and entry and re-entry points using CTA were calculated using the percentage agreement between observers. Inter-observer reproducibility values for evaluations of the diameter of the dissecting aneurysm and minimum inner diameter on CTA were analysed with the intra-class correlation coefficient (ICC). ICC and a Bland–Altman plot were used to evaluate the consistency of quantitative data; a kappa (κ) test was used to evaluate the consistency of qualitative data. Consistency between the two methods was considered good when the coefficient of consistency was >0.75, $p < .05$, and there were <5% points out of 95% limits of agreement. A *t* test and one way analysis of variance (ANOVA) were used to compare the PSV between groups, and least significant difference *post hoc* analysis was performed if the ANOVA result was statistically significant at $p < .05$. All statistical analyses were performed with SPSS version 17.0 (SPSS Inc., Chicago, IL, USA) and MedCalc software (Mariakerke, Belgium).

RESULTS

Patients

From January 2012 to May 2019, 54 patients were diagnosed with IMAD via CTA; all of these patients had superior mesenteric artery dissection. Of these 54 patients, eight were excluded because the interval between ultrasound imaging and CTA was more than one week, two were excluded because the ultrasound images were of insufficient quality due to obesity (body mass index of 33 and 35 kg/m^2), and two were excluded because they were lost to follow up. The remaining 42 patients (40 men, two women; mean age, 52.5 $\pm$ 6.3 years; range 40–75 years) were included in this study. The baseline characteristics for all study patients are summarised in Table 1.

Clinical outcomes

Of the 42 study patients, 38 (90.5%) were treated conservatively and four (9.5%) underwent endovascular stent

Characteristic	Value
Mean age ± SD, years	52.5 ± 6.3
Sex, n (%)	
Female	2 (4.8)
Male	40 (95.2)
History of hypertension, n (%)	10 (23.8)
Mean BMI ± SD	25.3 ± 2.1
Symptomatic, n (%)	
Yes	39 (92.9)
No	3 (7.1)
IMAD located at the main trunk of the mesenteric artery, *n* (%)	42 (100)
Mean distance from the mesenteric artery ostium to the beginning of the dissection ± SD, mm	17.2 ± 10.3
Management, n (%)	
Conservative treatment	38 (90.5)
Endovascular stent placement	4 (9.5)
Order of ultrasound and CTA examinations, n (%)	
Ultrasound examinations before CTA	15 (19.7)
Ultrasound examinations after CTA	61 (80.3)
Mean interval between ultrasound and CTA examinations ± SD, days	3.4 ± 1.4
Number of patients undergoing same week imaging examinations, n (%)	
1 set of imaging examinations	18 (42.9)
2 sets of imaging examinations	14 (33.3)
3 sets of imaging examinations	10 (23.8)

Table 1. Baseline characteristics of study patients ($n = 42$)

BMI = body mass index; CTA = computed tomography angiography; IMAD = isolated mesenteric artery dissection; SD = standard deviation.

placement (Table 1). No procedure related complications occurred. During 11.2 ± 7.1 months (range 1—72 months) of follow up, a total of 76 same week CDU, CEUS, and CTA examinations were performed (Table 1). No cases of delayed complications or symptomatic relapses occurred during the follow up period.

Interobserver variability

Observers 1 and 2 recorded the presence of a thrombosed false lumen, dissecting aneurysm, and entry and re-entry points on CTA in the same number of patients. Interobserver reproducibility values for the evaluation of the diameter of the dissecting aneurysm (ICC = 0.92) and minimum inner diameter (ICC = 0.89) were good.

Imaging findings

The presence of a thrombosed false lumen was demonstrated on 28 (36.8%) CDU, CEUS, and CTA examinations ($\kappa = 1.0$) (Fig. 1). The presence of a dissecting aneurysm was demonstrated for 20 (26.3%) CDU, CEUS, and CTA examinations ($\kappa = 1.0$; Figs. 2 and 3). The mean diameter of the dissecting aneurysm was 5.03 ± 1.25 mm for CDU and CEUS examinations *vs.* 5.27 ± 1.23 mm for CTA examinations (coefficient of consistency, 0.997; $p < .001$; no points out of 95% limits of agreement). The entry points were visualised by CDU and CEUS in 20 (26.3%) examinations and by CTA in 14 (18.4%) examinations ($\kappa = 0.769$); no re-entry points were visualised using CDU and CEUS but using CTA two were visualised (6.7%). The mean minimum inner diameter was 2.80 ± 1.30 mm in CDU and CEUS examinations *vs.* 2.52 ± 1.29 mm in CTA examinations (coefficient of consistency, 0.999; $p < .001$; 2.6% (2/76) points out of 95% limits of agreement).

Of the 76 CDU and CEUS examinations, the PSV at the point of minimum inner diameter was available for 66 examinations; this value was not available for 10 examinations because of occlusion of the mesenteric artery ($n = 4$) or small diameter of the mesenteric artery ($n = 6$). Another 10 examinations among the four patients who underwent endovascular stent placement were excluded because the PSV value was affected by the stent. Thus, a total of 56 CDU and CEUS examinations were included in the final analysis. In these examinations, the PSVs at the point of the minimum inner diameter were 128.2 ± 13.0 cm/s at the time of IMAD diagnosis, 98.7 ± 4.9 cm/s after one month, 94.4 ± 6.0 cm/s after six months, and 93.8 ± 7.6 cm/s after one year. The only significant difference in velocities was seen between examinations performed at diagnosis and those performed one month later (128.2 ± 13.0 cm/s *vs.*

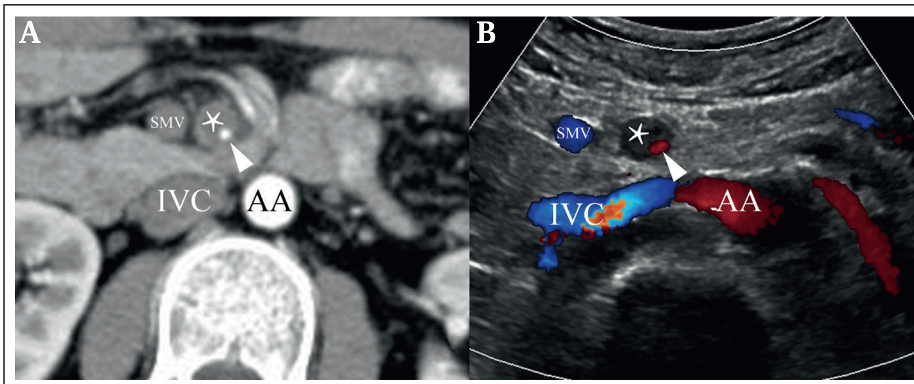

Figure 1. Imaging findings in a patient with a thrombosed false lumen. (A) Cross sectional computed tomography angiography image of the superior mesenteric artery shows that the true lumen (arrowhead) is compressed by the thrombosed false lumen (star). (B) Luminal stenosis (arrowhead) and a thrombosed false lumen (star) can be seen on a colour duplex ultrasound image obtained three days later. AA = abdominal aorta; IVC = inferior vena cava; SMV = superior mesenteric vein.

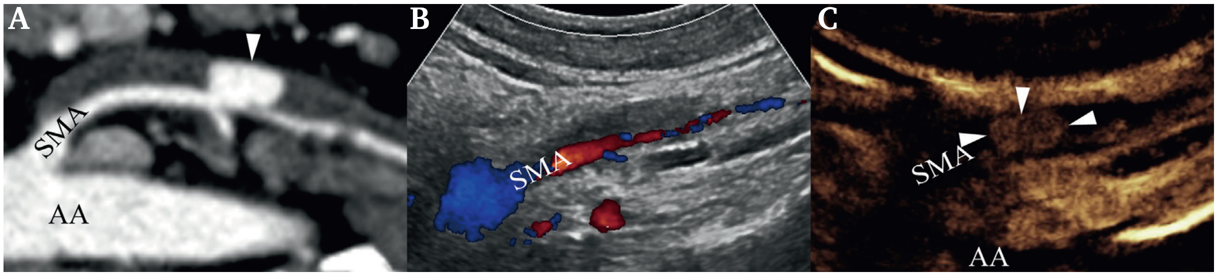

Figure 2. Imaging findings in a patient with a dissecting aneurysm. (A) Computed tomography angiography image shows a double barrelled dissection; the false lumen is dilated (arrowhead). (B) Colour duplex ultrasound image of the SMA shows the lumen stenosis. (C) Contrast enhanced ultrasound image shows contrast enhancement of the false lumen (arrowheads), which represents a dissecting aneurysm. AA = abdominal aorta; SMA = superior mesenteric artery.

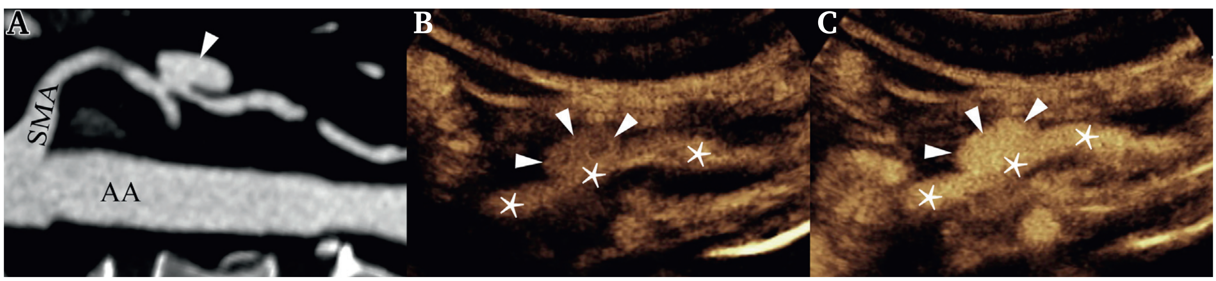

Figure 3. Imaging findings in a patient with a dissecting aneurysm. (A) Computed tomography angiography image shows a dissecting aneurysm (arrowhead) of the SMA and luminal stenosis. (B, C) Contrast enhanced ultrasound images show the dissecting aneurysm (arrowheads) and luminal stenosis (stars). AA = abdominal aorta; SMA = superior mesenteric artery.

98.7 $\pm$ 4.9 cm/s; $p < .001$); the velocity remained relatively stable after one, six, and 12 months (98.7 $\pm$ 4.9 cm/s, 94.4 $\pm$ 6.0 cm/s, and 93.8 $\pm$ 7.6 cm/s, respectively).

DISCUSSION

IMAD has been reported more frequently in recent years.[5,8,9] For the increasing number of patients diagnosed with this condition, clinicians must be able to accurately evaluate the morphological characteristics of IMAD during follow up, as these characteristics have a direct bearing on the status of the IMAD.[10] However, there is currently no gold standard modality for the long term surveillance of patients with IMAD.[7] Although ultrasound imaging and CTA are generally considered the most useful methods for follow up, the value of these modalities for this purpose has not yet been reported.[7] In this study, ultrasound imaging and CTA findings were compared in patients with IMAD and it was found that it may be feasible to use CDU and CEUS in place of CTA for the long term surveillance of IMAD. The use of CDU plus CEUS instead of CTA may also offer cost savings, as the cost for these ultrasound examinations in China is 500 CNY, whereas the cost for a CTA examination is 3200 CNY.

Ultrasound imaging has previously demonstrated its value in demonstrating the anatomy of vascular abnormalities of the mesenteric artery.[11,12] More specifically, CDU can be used to detect abnormal vascular flow as well as flow direction and velocity within the vessel, whereas CEUS can be used to enhance vascular flow and to show the vascular architecture, providing additional information about the vascular anatomy.[6] In this study, the combination of CDU and CEUS was successful in showing the morphological characteristics of IMAD, and ultrasound imaging also allowed for the detection and assessment of PSV at the point of the minimum inner diameter.

The presence of a thrombosed false lumen has been shown to be a favourable risk factor for progression to complete remodelling of the mesenteric artery, whereas the presence of a dissecting aneurysm has been shown to be an unfavourable risk factor.[13] In addition, the presence or absence of re-entry points is considered in the classification of IMAD, and IMAD subtypes are predictive of the failure of conservative treatment.[14,15] Thus, accurate demonstration of these morphologic characteristics during follow up is crucial. In this study, CDU plus CEUS and CTA demonstrated consistent results in the depiction of these characteristics. Of note, all of the entry points of the dissecting aneurysm were identified by ultrasound imaging, suggesting that ultrasound imaging is more sensitive than CTA for this finding.

A dissecting aneurysm with diameter $\geq$1.5 times larger than the normal mesenteric artery diameter and without a re-entry point is an indication for endovascular stent placement.[5] Additionally, luminal stenosis $\geq$90% has been shown to be a risk factor for the failure of conservative treatment.[15] Therefore, accurate measurements of the diameter of the dissecting aneurysm and the minimum inner diameter (which is used to calculate the degree of luminal stenosis) are needed for clinical decision making regarding management and the prediction of outcomes. In this study, CDU plus CEUS and CTA demonstrated good consistency in these measurements. Of note, ultrasound imaging demonstrated a larger minimum inner diameter than CTA in cases of IMAD. A previous study demonstrated that CTA may exaggerate the degree of luminal stenosis, which may explain the larger minimum inner diameter seen on ultrasound imaging in the current study.[4]

In addition to the morphological characteristics mentioned above, CDU can also be used to determine the PSV of the mesenteric artery, which is helpful in assessing the status of the IMAD and, indirectly, the presence of intestinal ischaemia. This study found that the PSV at the point of the minimum inner diameter was reduced significantly at one month after the IMAD diagnosis (one month, 98.7 $\pm$ 4.9 cm/s; baseline, 128.2 $\pm$ 13.0 cm/s; $p < .001$), and the velocity remained relatively stable after one month. These results suggest that luminal stenosis improves rapidly within the first month after diagnosis.

This study had several limitations. First, this was a retrospective analysis. Second, the morphological characteristics of IMAD demonstrated on ultrasound images were more dependent on the examination reports than those demonstrated on CTA; therefore, ICC and κ values for CDU and CEUS could not be calculated, as only one reader was needed to interpret the CDU and CEUS examination reports. Third, statistical analysis could not be performed for re-entry point data because of the small sample size and low incidence of this finding. Fourth, the mean duration between ultrasound imaging and CTA examinations was 3.4 $\pm$ 1.4 days, which may have biased the results. Fifth, there is currently no gold standard modality for depiction of the morphological characteristics of IMAD; therefore, the sensitivity and specificity of ultrasound imaging and CTA for this purpose could not be assessed. Sixth, all cases of IMAD were located in the main trunk of the mesenteric artery, which may have biased the results, leading to high kappa coefficients for the two imaging modalities. Seventh, the use of ultrasound imaging was restricted or impossible in obese patients, as the quality of ultrasound images was affected by the proximal fatty layers. Finally, the comparison of CDU *vs.* CTA and CEUS *vs.* CTA for all respective measurements and diagnoses might be worth making and further study is needed.

In conclusion, the combination of CDU and CEUS may serve as an alternative to CTA for the surveillance of IMAD. Ultrasound imaging is more accurate than CTA in showing the entry points and the minimum inner diameter and also can be used to assess the PSV at the point of the minimum inner diameter. Thus, the use of ultrasound imaging in place of CTA for long term IMAD surveillance should be considered, especially in the light of the decreases in radiation and iodine containing contrast use and the lower costs associated with ultrasound imaging.

CONFLICT OF INTEREST

None.

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