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Predicting Blood Flow from the Superior Mesenteric Artery to the Celiac Arterial Region on CT Angiography in Patients with Median Arcuate Ligament Syndrome

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ABSTRACT

Purpose: This study aimed to assess whether computed tomography (CT) findings can be used to predict blood flow from the superior mesenteric artery (SMA) to the celiac artery (CA) region in patients with median arcuate ligament syndrome (MALS).
Materials and methods: Two radiologists who reviewed 1,290 conventional SMA angiograms and CT scans identified 36 patients with MALS. MALS was classified by their blood flow angiography findings as type A (CA region not or barely visualized) and type B (CA region clearly visualized). The association between patient age, sex, post-stenotic dilatation ratio of the celiac axis, maximum diameter of the pancreaticoduodenal arcade (PDA), and MALS classification based on SMA angiography was assessed.
Results: Of 36 MALS patients, 17 had MALS type A and 19 had MALS type B. The mean of the maximum diameter of the PDA in MALS type A was 1.6 ± 0.9 mm (SD) and 4.3 ± 1.3 mm in MALS type B. The post-stenotic dilatation ratio of the celiac axis was 2.4 ± 1.2 in MALS type A and 2.2 ± 1.4 in MALS type B. Only maximum diameter of the PDA was a predictor of MALS type B (odds ratio, 15.7; 95% confidence interval, 2.3–108.1).
Conclusion: The maximum diameter of the PDA on CT angiography can be used to predict the blood flow from the SMA to the CA region in patients with MALS.

Key words: *pancreaticoduodenal arcade aneurysms, median arcuate ligament syndrome, MALS, CT angiography*

INTRODUCTION

The median arcuate ligament (MAL) is a fibrous arch that unites the diaphragmatic crura on either side of the aortic hiatus. In 10–24% of humans, the ligament is located low and compresses the proximal portion of the celiac axis[5)]. In a small subset of these patients, the median arcuate ligament can compress the proximal celiac axis enough to be hemodynamically significant and cause symptoms. This phenomenon, known as median arcuate ligament syndrome (MALS), may elicit symptoms due to ischemia[1–3)].

The rupture of a pancreaticoduodenal arcade (PDA) aneurysm, one of the most critical complications related to MALS, carries a mortality rate of 20–30%[4–9)]. Compression of the celiac axis can increase retrograde blood flow from the superior mesenteric artery (SMA) to the region of the celiac artery (CA) via pancreaticoduodenal arterial collaterals. This may increase the flow in these small-caliber vessels, resulting in local arterial hypertension leading to focal arterial wall thickening and true aneurysm formation[4,5,10–12)]. Consequently, assessing the blood flow from the SMA to the CA region via pancreaticoduodenal arterial collaterals is important for predicting PDA aneurysms.

Although MALS is traditionally diagnosed using catheter angiography, non-invasive multidetector computed tomography (MDCT) is an alternative diagnostic tool[1,2,13)] that reportedly detected 1–4% of MALS cases among patients who underwent MDCT[2,13,14)]. However, blood flow direction and degree cannot be assessed using traditional catheter angiography or Doppler ultrasonography. We tested our hypothesis that the diameter of the celiac axis or the PDA on computed tomography angiograms (CTAs) can predict the blood flow from the SMA to the CA region.

MATERIALS AND METHODS

This retrospective study was approved by our institutional review board, which waived the need for informed patient consent.

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Subjects

Between 2014 and 2016, 1,290 patients underwent both conventional SMA angiography and computed tomography (CT) studies at our institution. The interval between SMA angiography and CT was no longer than 6 months. Two board-certified radiologists with 8 and 7 years of experience with abdominal radiology consensually reviewed the SMA angiographic and CT images. MALS, defined as the characteristic focal narrowing of the proximal celiac axis resulting in a hooked appearance on three-dimensional (3D) CTAs[5] , was diagnosed in 36 patients (29 men, seven women; median age, 69 years; range, 47–90 years). Their imaging studies diagnosed liver tumour in 12 patients, were performed before transcatheter arterial chemoembolization (TACE) for hepatocellular carcinoma (HCC) in 21, were performed before transcatheter arterial embolization for PDA aneurysm in two, and were used to obtain a preoperative diagnosis for pancreatic cancer in one.

Conventional SMA angiography

A 4F shepherd hook catheter was placed into the SMA and 20–25 mL of contrast medium was injected at a flow rate of 4–5 mL/sec using an automatic injector (Dual Shot; Nemoto Kyorindo; Tokyou, Japan). Angiograms were acquired during expiration at 3 frames/sec.

Computed tomography

All CT scans were obtained on a 320- (Aquilion One; Toshiba Medical Systems, Otawara, Japan), 256- (Revolution; GE, Milwaukee, WI, USA), or 64-detector-row (Light Speed VCT; GE, Milwaukee, WI, USA) CT scanner during inspiration. The scanning parameters were: (Aquilion One scanner) rotation time of 0.50 sec, beam collimation 0.5 × 80 mm, section thickness and intervals of 5.0 mm, helical pitch (beam pitch) of 0.813, table movement of 65.0 mm/sec, scanning field-of-view (FOV) of 50 cm, voltage of 120 kV, auto mA (noise index 10); (Revolution scanner) rotation time of 0. 275 sec, beam collimation of 0.625 × 64 mm, section thickness and intervals of 5.0 mm, helical pitch (beam pitch) of 0.938, table movement of 75.0 mm/sec, FOV of 50 cm, voltage of 120 kV, auto mA (noise index 10); (Light Speed VCT) rotation time of 0.45 sec, beam collimation 0.625 × 64 mm, section thickness and intervals of 5.0 mm, helical pitch (beam pitch) of 0.938, table movement of 93.8 mm/sec, FOV of 50 cm, voltage of 120 kV, auto mA (noise index 10).

The contrast medium dose in all patients was 600 mgI/kg body weight. The contrast medium was injected into the cubital vein for 30 sec through a 22-G intravenous catheter using an automatic injector. The scan timing for the arterial phase was determined with a bolus tracking system; axial-, coronal-, and sagittal-section images were reconstructed at a 1-mm slice thickness.

Image analysis

The two radiologists consensually classified MALS in terms of blood flow from the SMA to the CA region on SMA angiograms (type A: CA region not or barely visualized [Figures 1a, b]; type B: CA region clearly visualized [Figure 2]). They then measured the minimum and maximum diameter of the celiac axis and the maximum diameter of the PDA on axial-, sagittal-, and coronal-section CT angiograms. The diameter of the anterior or posterior superior pancreaticoduodenal artery, the inferior pancreaticoduodenal artery, and the dorsal pancreatic artery was calculated to obtain PDA data. The largest was adopted as the maximum diameter of the PDA. The post-stenotic dilatation ratio of the celiac axis was calculated with the formula: maximum/minimum diameter of the celiac axis.

Fig. 1a

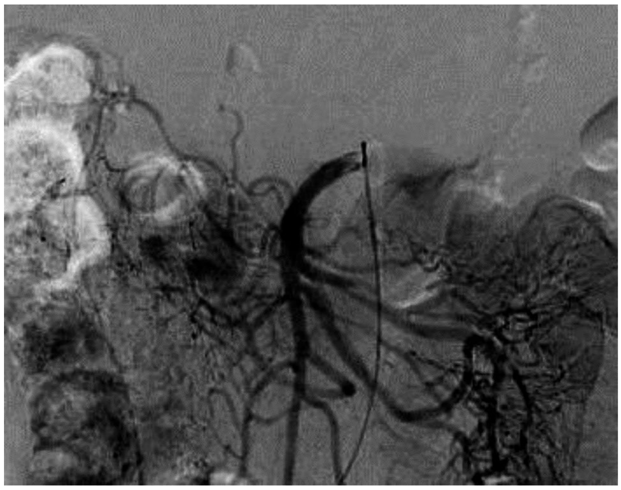

Fig. 1b

Figure 1 a. A 68-year-old man with hepatocellular carcinoma (HCC) underwent conventional angiography of the superior mesenteric artery (SMA) prior to transcatheter arterial chemoembolization (TACE). The celiac artery (CA) region was not visualized on the SMA angiogram. The diagnosis was median arcuate ligament syndrome (MALS) type A.
b. An 86-year-old man with hepatocellular carcinoma underwent conventional angiography of the SMA before TACE. The CA region was barely visualized on the SMA angiogram (*arrow*). The diagnosis was MALS type A.

Figure 2 A 65-year-old man with hepatocellular carcinoma. Conventional angiography of the superior mesenteric artery was performed before transcatheter arterial chemoembolization. The celiac artery region was clearly visualized (*arrow*). The diagnosis was median arcuate ligament syndrome type B.

Statistical analysis

Statistically significant differences were identified using the two-sided Student's *t* test. A univariate logistic regression analysis was also used to assess the association between patient age and sex, post-stenotic dilatation ratio of the celiac axis, and maximum diameter of the PDA (independent variables) and MALS type on SMA angiograms (outcome variables). We adopted a univariate rather than multivariate analysis because the number of patients was small.

A receiver operating characteristic curve (ROC) analysis was used to calculate the most appropriate cut-off value for the best predictor to obtain a threshold for predicting the blood flow from the SMA to the CA region on SMA angiograms. The statistical analysis was performed using statistical software (MedCalc v16.4; MedCalc BVBA, Belgium). Differences of $p < 0.05$ were considered statistically significant.

RESULTS

Based on SMA angiography findings, of the 36 patients, 17 had MALS type A and 19 had MALS type B. The mean of the maximum diameter of the PDA in MALS type A was 1.6 ± 0.9 mm (SD), while that of MALS type B was 4.3 ± 1.3 mm. The mean diameter of PDA in MALS type A was significantly smaller than that in MALS type B ($p < 0.01$). The minimum and maximum dilatation ratio of the celiac axis was 3.2 ± 1.1 mm and 6.8 ± 1.7 mm in MALS type A and 2.7 ± 1.0 mm and 5.4 ± 2.4 mm in MALS type B. The post-stenotic dilatation ratio of the celiac axis was 2.4 ± 1.2 in MALS type A and 2.2 ± 1.4 in MALS type B. There was no significant differences between types A and B ($p = 0.62$).

In the univariate logistic regression analysis, only the maximum diameter of the PDA was a variable predictor of MALS type B (odds ratio [OR], 15.7; 95% confidence interval [CI], 2.3–108.1; $p < 0.01$]; neither patient age or sex nor post-stenotic dilatation ratio was a predictor of MALS type B (Table 1).

ROC analysis of the relationship between maximum diameter of the PDA and blood flow type from the SMA to the CA region showed that the area under the ROC curve was 0.97 ($p < 0.01$), while the threshold for the maximum diameter of the PDA for predicting blood flow type from the SMA to the CA region was 3 mm. The sensitivity and specificity of this threshold were 100% and 88.2%, respectively.

Of the 36 patients, three had clinical significance for MALS: two suffered rupture of a PDA aneurysm (Figures 3a–c) and the other required revascularization of the celiac axis during pancreaticoduodenectomy for pancreatic cancer. These three patients had MALS type B.

DISCUSSION

Our findings show that the maximum diameter of the PDA on CTAs can predict blood flow from the SMA to the CA region in MALS. Because PDA aneurysms are thought to be attributable to increased retrograde blood flow via the PDA[4,5,10–12], patients with MALS type B may be at high risk for PDA aneurysms. Both patients with ruptured PDA aneurysms in the current study had MALS type B. Thus, the maximum diameter of the PDA may be useful stratifying the risk for PDA aneurysms.

Ours is the first report to describe the prediction of blood flow in patients with MALS based on CTAs. MDCT appears to be the most appropriate modality for diagnosing MALS because it is relatively non-invasive and facilitates visualization via an optimal viewing angle[1,2,13]. However, as most MALS cases diagnosed by CT are asymptomatic and may not be clinically significant, an assessment that addresses the blood flow in patients with

Table 1 Univariate logistic regression analysis of MALS type based on SMA angiogram findings.

Variable	Type A (n = 17)	Type B (n = 19)	Odds ratio*	P value
Mean age	74.7 ± 8.1 (SD)	68.7 ± 9.8	0.9 (0.9, 1.0)	0.06
Sex			3.5 (0.6, 21.4)	0.17
M	12	17		
F	5	2		
Mean maximum PDA diameter (mm)	1.6 ± 0.9	4.4 ± 1.3	15.7 (2.3, 108.1)	< 0.01
Mean post-stenotic dilatation ratio	2.4 ± 1.2	2.2 ± 1.4	0.9 (0.5, 1.5)	0.62

Numbers in parentheses are 95% confidence intervals.

Fig.3a

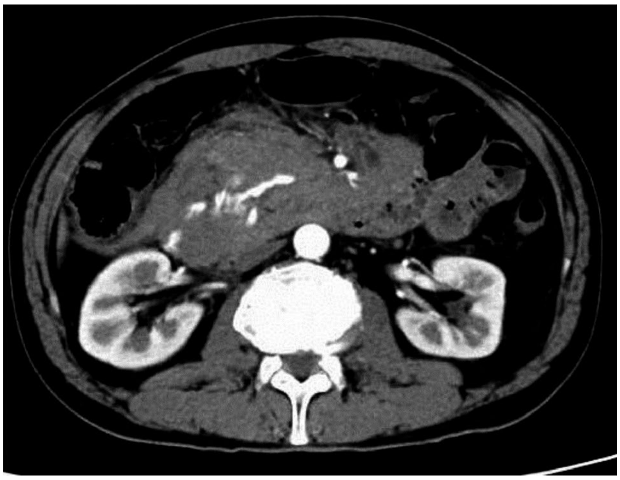

Fig.3b

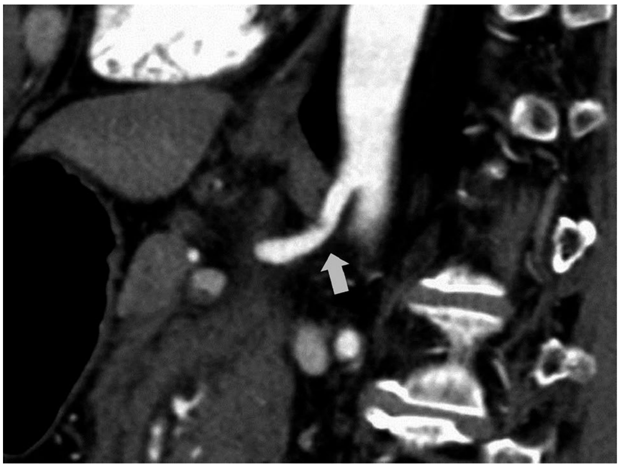

Fig.3c

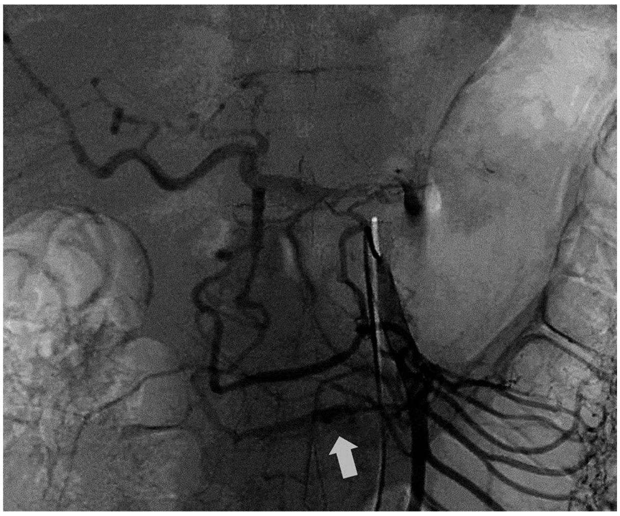

Figure 3 a. A 64-year-old man with abdominal pain and low blood pressure underwent axial computed tomography (CT) that showed a haemorrhage around the pancreas and extravasation from a pancreaticoduodenal arcade (PDA) aneurysm. b. Sagittal CT image revealing a hooked appearance (*arrow*). The post-stenotic dilatation ratio of the celiac axis was 1.5. c. Conventional superior mesenteric artery angiogram clearly demonstrating the celiac artery region. The diagnosis was median arcuate ligament syndrome type B. The PDA aneurysm (*arrow*) was treated with transcatheter arterial embolization.

MALS is necessary. Horton et al.[1] reported that MALS with post-stenotic dilation or collateral vessels may warrant clinical correlation; however, the blood flow in patients with MALS has not been compared on CT and conventional angiography. We found that the threshold for the maximum diameter of the PDA for predicting the degree of blood flow from the SMA to the CA region was 3 mm. Our observations may help assess the necessity for intervention or constant follow-up in individuals with MALS.

The post-stenotic dilatation ratio of the celiac axis was not a predictor of MALS type B. Although post-stenotic dilation of the celiac axis is often seen in MALS, it may not be useful for predicting the development of a PDA aneurysm. Collateral pathways, including the inferior phrenic artery, an aberrant left hepatic artery, and intrahepatic communicating branches, deliver blood to the celiac artery region[15]. Consequently, retrograde blood flow in the PDA might not be increased in MALS with post-stenotic dilation of the celiac axis but without dilation of the PDA when collateral pathways not involving PDA provided sufficient blood flow to the celiac artery region.

MALS can be a problem in patients undergoing pancreaticoduodenectomy. When the gastroduodenal artery, a main collateral pathway for the CA region from the SMA in patients with MALS, is ligated during the procedure, ischemia of the liver, stomach, and spleen may result[16–18]. Therefore, the assessment of blood flow is indispensable before pancreaticoduodenectomy in patients with MALS. Our patient with MALS type B required revascularization of the celiac axis during the procedure because the blood flow to the CA region was insufficient. Our findings may be useful for assessing blood flow before pancreaticoduodenectomy.

Our study has some limitations. First, we did not obtain conventional angiography and CT images on the same day in all patients. However, celiac artery stenosis in MALS patients does not change in the short term. Second, not all patients with MALS type B had aneurysms. To determine the incidence of PDA aneurysms, long-term follow-up is needed. Third, we did not perform ultrasonography because our study was retrospective. Studies to identify differences on CT images and ultrasonograms are underway in our laboratory.

In conclusion, the maximum diameter of the PDA on CTAs predicted the blood flow from the SMA to the CA region in patients with MALS and may help predict the risk for PDA aneurysm formation.

Conflict of Interest form

One co-author (K. Awai) received financial support from Toshiba Medical Systems and Hitachi Health Care in the form of a research grant to our institution.

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