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Original article

Aberrant branches of the superior mesenteric artery detected by MDCT angiography of abdominal aorta

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***Background*:** The anatomy of superior mesenteric artery (SMA) is complicated and has numerous variations. Awareness of aberrant branches of SMA can result in accurate interpretation of disease and vascular involvement, optimal selection of treatment options or operative planning, and help avoid iatrogenic injury from surgical and interventional radiological procedures.

***Objective*:** We determined different aberrant arterial branches of SMA and their order of frequencies by using MDCT angiography of the abdominal aorta in order to achieve accurate diagnostic interpretation and for safety of surgical, laparoscopic, and interventional procedures.

***Material and Methods*:** One hundred ninety nine MDCT angiography of abdominal aorta or whole aorta studies, done between January 1, 2007 and December 31, 2009, were retrospectively reviewed by consensus of two radiologists. Interobserver reliability is obtained using κ-statistics. Assessment for the presence of aberrant arterial branches of SMA was performed. The number and specific name of each aberrant arteries of mesenteric circulation were recorded.

***Results*:** One hundred sixty three patients (81.8%) have classic normal branches of SMA. Thirty-six patients (18.1%) have single arterial variant identified, and none has multiple arterial variant from SMA. Identified aberrant branches of SMA are replaced right hepatic artery (8.5%), celiacomesenteric trunk (3.5%), inferior pancreatic artery (2.5%), common hepatic artery (2%), right gastroepiploic artery (0.5%), splenic artery (0.5%), and cystic artery (0.5%). Associations of single arterial variant of SMA with other variation of mesenteric circulation are found in seven patients.

***Conclusion*:** Aberrant branches of SMA in Thai people present in 18.1% of cases. The highest incidence is replaced right hepatic artery arising from SMA (8.5%). Incidence and order of frequency are conformed to previous reports in other nationalities. There is also associated variation of other mesenteric circulation in 3.5% of cases presented with aberrant arterial branch from SMA, while none has shown multiple aberrant branches from SMA.

***Keywords*:** Aberrant branch, MDCT angiography, superior mesenteric artery (SMA), Thai, variation

Superior mesenteric artery (SMA) arises from the abdominal aorta to supply the midgut. Anatomy of SMA is complicated and has numerous variations owing to multiple processes during development which include persistence, incomplete regression or disappearance of parts of primitive vitelline arteries [1, 2] (**Figure 1**). Generally, SMA arises approximately 1 cm below the celiac artery, or usually at the level of L1 vertebral body. It then courses inferiorly and toward the right, to terminate at the level of cecum. Major branches of the right side of SMA include inferior pancreaticoduodenal artery, middle colic artery, right colic artery, and iliocolic artery. The 4-6 jejunal arteries and 9-13 ileal arteries arise from the left side of SMA [1, 3] as shown in **Figure 2**.

Detailed knowledge of the different anatomical variations of the mesenteric circulation is extremely important in this era of increasing number of laparoscopic surgery and interventional radiological procedures in the upper abdomen, and in surgical procedures such as liver transplantation [2-4]. The awareness of variant anatomy can result in more accurate interpretation of diseases and vascular involvement in diagnostic imaging, optimal selection of treatment options or operative planning, and help avoid iatrogenic injury from both surgical and interventional radiological procedures [5-6].

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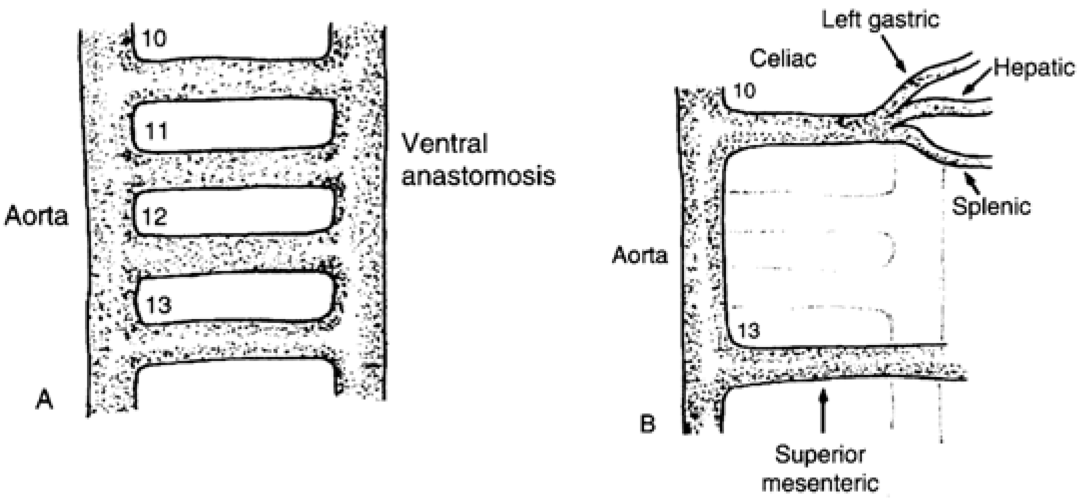

Figure 1. The embryologic origin of the visceral arteries. **A:** Primitive ventral segmental arteries **B:** Normal anatomy demonstrating the celiac trunk arising from the tenth segmental artery and SMA arising from the thirteenth.

Although there have been previous studies that describe mesenteric variations, those studies usually discuss concerning the variation of celiac trunk or hepatic arteries. Few studies have summarized data of all aberrant branches arising from SMA, the more uncommon arterial variants that also have surgical significance [4, 7, 8]. In addition, limited information was documented on Thai population. The previously identified different types of mesenteric arterial variants and their frequencies are reported in **Table 1**.

CT angiography has distinct advantages over conventional angiography in imaging of the mesenteric arterial vasculature due to noninvasive nature, easy applicability, accessibility, and diagnostic accuracy of the technique [4]. Furthermore, multidetector row CT (MDCT) offers distinct advantages over conventional dynamic CT, owing to faster scanning and narrower collimation that allows optimal opacification of the mesenteric vessels and their branches together with capability for image-postprocessing techniques that enable excellent overview of the vascular anatomy [9-10].

The purpose of this study is to determine different aberrant arterial branches of the superior mesenteric artery by using noninvasive imaging technique, MDCT angiography of the abdominal aorta.

Table 1. Frequency of reported different mesenteric arterial variants

Aberrant branches	Rosenblum 1997 [1]	Winston 2007 [8] n = 371	Winter 1995 [11] n = 115	Futara 2001 [12] n = 110	Michels, 1955 [13]	Saad, 2005 [14] n = 120	Lippert, 1985 [15]
Replaced RHA	10-18%	15%	10-12%	8.2%			
Accessory RHA		1%	4-6%	6.3%			
CHA	2.5%	2%	2.5%				1.5-7%
Arc of Buhler						3.3%	
MHA				2.7%			
CMT	<1%	<1%			<2%		2%
Right Gastroepiploic					1.5%		
Left colic							1%
Splenic					1%		<1%
GDA		<1%					

RHA = right hepatic artery, MHA = middle hepatic artery, CMT = celiacomesenteric trunk, GDA = gastroduodenal artery

Material and methods

Patient population

Consecutive MDCT angiography of the abdominal aorta or the whole aorta obtained at the Department of Radiology, King Chulalongkorn Memorial Hospital (KCMH) between January 1, 2007 and December 31, 2009 were included and retrospectively reviewed. Each patient was included only once.

Patients who have undergone previous upper abdominal surgery or organ transplantation that altered the normal mesenteric vascular structures and its branches or patients with any condition that could modify normal arterial blood flow or associate with abnormal collateral vessels, such as stenosis or occlusion, dissection, vasculitis, or suprarenal aortic aneurysm, were excluded from the study. In addition, the images obtained with inadequate technique were not included.

Image acquisition

All CT examinations were performed on a 16-MDCT scanner (Somatom sensation 16, Siemens Medical Solution, Germany) using 120 kV and 140 mAs. Patients received 100 ml (or 2 ml/kg) of intravenous nonionic contrast material, Iohexol (Omnipaque®; GE Healthcare, Cork, Ireland) or Iopromide (Ultravist®; Bayer HealthCare Pharmaceuticals, Berlin, Germany), by mechanical power injector through 18-G catheter at the rate of 4 ml/s. Craniocaudal scan from the dome of the liver to pubic symphysis was performed with 16×0.5 mm collimation, slice width 1.0 mm with a 0.8 mm overlap and 0.5 sec gantry rotation time. MDCT angiographic acquisition was initiated after a delay of 6 seconds when the threshold enhancement of 100 HU was exceeded in the abdominal aorta.

Image post-processing techniques were also acquired in all patients. They include multiplanar reformation (MPR), maximum-intensity-projection reconstruction (MIP), and 3D volume-rendered images.

Image analysis

All MDCT angiography images of the abdominal aorta were reviewed using Picture Archiving and Communications Systems (PACS) by two radiologists of KCMH. Both readers were briefed of all patients' information. Different interpretations were finalized by consensus. Interobserver reliability was also obtained from a pilot study in a distinct group of 30 patients (consecutive MDCT angiography of the abdominal aorta or the whole aorta obtained at the Department of Radiology, King Chulalongkorn Memorial Hospital (KCMH) between January 1, and June 30, 2010) using the □-statistics.

All images were privately reviewed in the film-reading room by radiologists. The patients' data were kept secret. The research proposal has been reviewed and approved by the Ethics Committee of Faculty of Medicine, Chulalongkorn University.

Data collection

The demographic data, including age, and sex of every patient were collected. Both radiologists assessed for the presence of aberrant arterial branches of SMA. As for patients in whom variation was depicted, the number of aberrant arteries of the mesenteric circulation was recorded and each branch was specified.

Results

Three hundred ninety eight patients underwent MDCT angiography of the abdominal aorta or the whole aorta during the study period. One hundred ninety patients (48.84%) were excluded from the study due to presence of any condition of the following, namely, history of upper abdominal surgery (13.7%), history of previous intra-abdominal organ transplantation (0.5%), compromised mesenteric vascular flow (60%), suprarenal abdominal aortic aneurysm (21.1%), or inadequate image acquisition technique (4.7%) as shown in **Table 2**. The remaining 199 patients, 122 (61.3%) men and 77 (38.7%) women, with their age range between 2 years and 96 years and mean age of 65.1 years in men, and age range between 10 days and 93 years and mean age of 61.9 years in women, underwent MDCT angiography of the abdominal aorta in 57 patients and MDCT angiography of the whole aorta in 142 patients, were included in this study.

Of all 199 patients, 163 patients (81.8%) have classic normal branches of SMA identified at CTA (**Figure 2A**). Thirty-six patients (18.1%) have a single arterial variant identified, 28 in men and eight in women; and none has multiple arterial variant from SMA. The most common aberrant branch of SMA is replaced right hepatic artery, which was seen in 17 patients (8.5%) (**Figure 2B**). The second most common aberrant branch of SMA is celiacomesenteric trunk, seen in seven patients (3.5%)

(**Figure 3A**). Other aberrant branches observed are inferior pancreatic artery in five patients (2.5%) (**Figure 3B**), common hepatic artery in four patients (2%) (**Figure 3C**), and right gastroepiploic artery (**Figure 4A**), splenic artery (**Figure 4B**), and cystic artery (**Figure 4C**) in one patient each (0.5%). Our results are summarized in **Table 3**.

Although there is none presented with multiple aberrant branches of SMA, association of single arterial variant of SMA with other variation of mesenteric circulation (celiac axis and IMA) is shown in seven patients. Five patients have associated replaced left hepatic artery arising from left gastric artery (two with replaced right hepatic artery, another two with common hepatic artery and one with inferior pancreatic artery), and associated left gastric artery arising from aorta and splenic artery arising from aorta in one patient each **(Table 4)**.

Interobserver agreement is almost perfect between the two radiologists (κ = 0.911).

Table 2. Conditions for exclusion in 190 patients

Conditions	No. of patients	Percent (%)
Previous upper abdominal surgery	26	13.7
Previous intraabdominal organ transplantation	1	0.5
Compromised mesenteric vascular flow	114	60
Stenosis / Occlusion	50	26.3
Aortic dissection	56	29.5
Vasculitis	8	4.2
Suprarenal abdominal aortic aneurysm	40	21.1
Inadequate technique	9	4.7

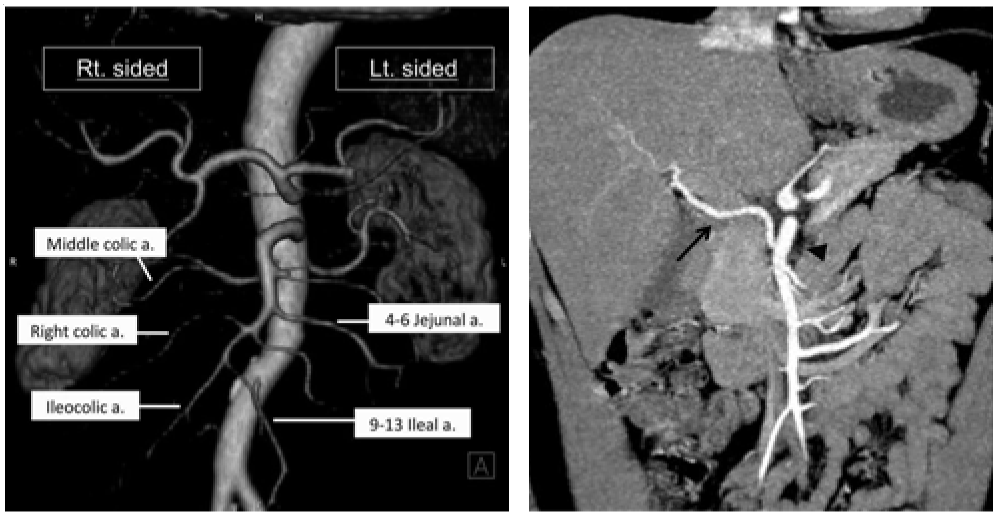

Figure 2. **A:** 3D volume-rendered image of a 58-year-old man shows classic normal branches of SMA. **B:** Coronal MIP image of a 15-year-old female patient shows replaced right hepatic artery (arrow) arising from SMA (arrow head).

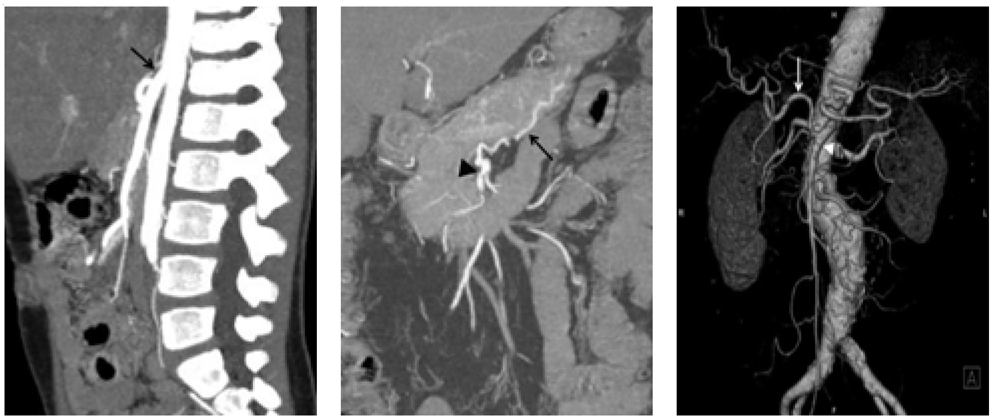

Figure 3. **A:** Sagittal MIP image of a 4-year-old boy shows presence of celiacomesenteric trunk (arrow). **B:** Coronal MIP image of a 74-year-old man shows inferior pancreatic artery (arrow) arising from SMA (arrow head). **C:** 3D volume-rendered image of a 77-year-old woman shows common hepatic artery (arrow) arising from SMA (arrow head).

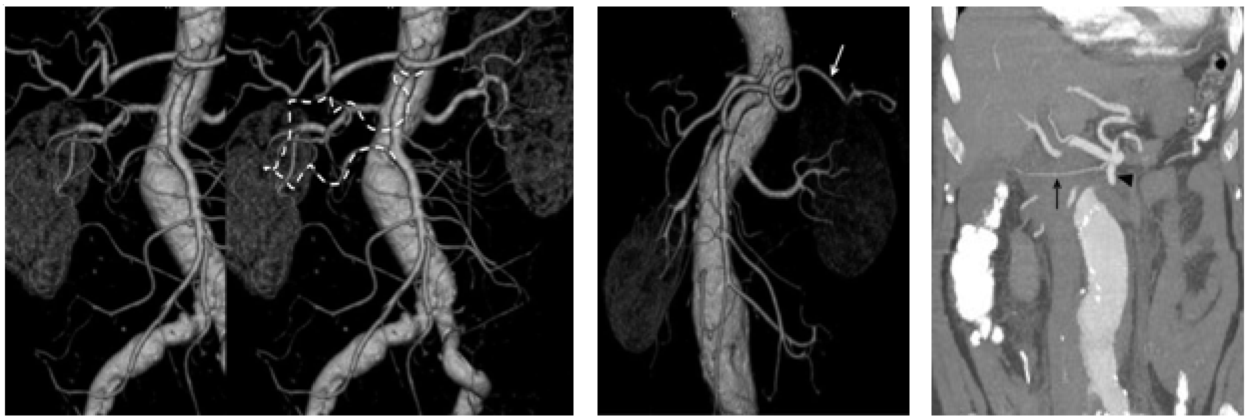

Figure 4. **A:** 3D volume-rendered image of a 70-year-man faintly shows right gastroepiploic artery (dash line) arising from SMA. Combining axial images and postprocessing techniques help identifying these small-sized arterial branches. **B:** 3D volume-rendered image of a 72-year-old man shows splenic artery (arrow) arising from SMA. **C:** Coronal MIP image of a 79-year-old man shows faint visualization of cystic artery (arrow) arising from SMA (arrow head).

Table 3. The incidence of aberrant branches of SMA detected by MDCT angiography

Aberrant branches of SMA	No. of patients	Percent (%)
Replaced right hepatic artery	17	8.5
Celiacomesenteric trunk	7	3.5
Inferior pancreatic artery	5	2.5
Common hepatic artery	4	2
Right gastroepiploic artery	1	0.5
Splenic artery	1	0.5
Cystic artery	1	0.5

Table 4. Details of all seven patients that have associated variation of mesenteric circulation (celiac axis and IMA) with aberrant branches from SMA

Variation of mesenteric circulation	No. of patients
Replaced left hepatic artery arising from gastric artery with	5
Aberrant inferior pancreatic artery from SMA	1
Aberrant common hepatic artery from SMA	2
Replaced right hepatic artery from SMA	2
Left gastric artery arising from aorta with celiacomesenteric trunk	1
Splenic artery arising from aorta with celiacomesenteric trunk	1

Discussion

Developmental process of mesenteric vessels has been explained by Tandler's hypothesis. The mesenteric vessels are developed from the primitive ventral segmental arteries (vitelline arteries) which arise from the abdominal aorta and connect to each other by longitudinal anastomosis vessels (**Figure 1**). There is regression of all segmental arteries as development proceeds, except for three of these primitive communications, with only precursors to the three major mesenteric vessels and longitudinal anastomosis vessels remained. The 10th segmental artery gives rise to the celiac artery, the 13th segmental artery gives rise to the superior mesenteric artery (SMA) and the 21st or 22nd artery gives rise to the inferior mesenteric artery (IMA). The longitudinal anastomosis vessels between the celiac trunk and SMA, and between the SMA and IMA disappear [1, 3, 16]. Persistence, incomplete regression, or disappearance of parts of these primitive ventral segmental arteries could give rise to numerous variations of SMA [2].

Understanding the different anatomical variations of mesenteric circulation is mandatory in various surgical procedures such as liver transplantation and resection, gastrectomy, biliary reconstruction, right hemicolectomy, resection of the transverse colon, left hemicolectomy, sigmoidectomy, and pancreaticoduodenectomy [2-4]. Visualization of the surgical field can often be limited in patients with pancreatic and hepatobiliary malignancy, especially when there has been prior surgery, local inflammation accompanying a biliary stent or obesity. In diagnostic radiology, accurate interpretation of diseases and vascular involvement is in need in patients who are about to undergo pancreatoduodenectomy, to preserve the vessels and avoid fatal hepatic injury during surgery. Accidental ligation of aberrant hepatic artery may result in hepatic necrosis, ischemic biliary injury, or graft injury. Aberrant arterial branches may also interfere with interventional radiological procedures as in patients with anatomic variations of hepatic arterial system are at high risk for misperfusion during chemotherapy to extrahepatic organs including spleen, stomach, bowel, and pancreas [6].

Accuracy of MDCT angiography has been reported as 97 to 98% compared with conventional angiography for detecting arterial variants [9-10]. This technology enables variety of image postprocessing techniques. Multiplanar reformation (MPR) and curved planar reformation images are useful for evaluation of the luminal diameter of arteries for accurate depiction of arterial stenosis. Maximal intensity projection (MIP) reconstructions are conventional angiogram-liked images demonstrating an excellent overview of the vascular anatomy. Volume-rendered (VR) images can display overall abdominal vasculature in 3D vascular maps and offer more accurate assessment of various conditions such as arterial or venous encasement in patients with pancreatic cancer, mesenteric ischemia or inflammatory bowel disease. This also improves detection of more distal vascular involvement of the disease [4, 7].

To our best knowledge, few documents have discussed variation concerning superior mesenteric artery. Data on the frequencies of the aberrant arterial branches arising from SMA were discussed as parts of studies on entire variation of mesenteric circulation, as shown in **Table 1**. Aberrant branches of SMA other than that are found to be extremely rare. The frequency of IMA arising from SMA has been reported to be less than 1% [15]. The cystic artery has also been reported to occur at a low frequency, 0□8% [17]. Moreover, left gastric and dorsal pancreatic arteries were found as case reports [18, 19].

In this study, we demonstrate presence of aberrant arterial branches arising from SMA in 18.1% of patients. The highest incidence is replaced right hepatic artery (8.5%), followed by celiacomesenteric trunk (3.5%) and inferior pancreatic artery (2.5%). The incidence and order of frequencies are comparable to those of previous reports from other nationalities. From the study of Winston et al. [8] in 371 patients, 183 patients had arterial variant identified and 21(11%) out of 183 patients had more than one arterial variant seen. Katagiri et al. [16] also noticed this information, and described that the frequency for these anomalies to occur in one individual is estimated to be extremely low, if they occur independently. Therefore, they doubted that these anomalies are independent from each other and may be reasonable to assume that any disturbances in embryonic morphogenesis influenced the developing abdominal digestive and associated arterial systems can cause a combination of arterial variants.

None of patients in this study has shown to have more than one aberrant branch from SMA. However, seven (3.5%) out of 199 patients have associated variation of mesenteric circulation with presence of aberrant branch from SMA. The associated variation of mesenteric circulation includes replaced left hepatic artery arising from left gastric artery, left gastric artery arising from aorta, and splenic artery arising from aorta which, individually, are not uncommon (11 to 12%, 3% [1] and <1% [4] respectively).

Limitation of this study is the patients who underwent MDCT angiography of the abdominal aorta or the whole aorta often have some underlying arterial diseases that tend to have compromised arterial blood flow. Almost half of the patients (48.8%) had to be excluded from the study while the remaining carried the possibility to have some degree of non-significant arterial stenosis and have rather small vascular diameter, which may reduce the ability of MDCT to demonstrate these branches. In addition, we do not have surgical or conventional angiography to confirm the accuracy of the MDCT readings. However, previous studies have already reported the accuracy of MDCT angiography as high as 97 to 98%, compared with conventional angiography [9-10]. Inter-observer reliability, using □-statistics, had almost perfect agreement.

Conclusion

Aberrant branches of SMA in Thai people present in 18.1% of cases. The highest incidence is replaced right hepatic artery arising from SMA. Incidence and order of frequency are conformed to previous reports from other nationalities. There is also associated variation of other mesenteric circulation in 3.5% of cases presented with aberrant arterial branch from SMA, while none has shown multiple aberrant branches from SMA. The awareness to search for the combination of arterial anomalies when one anomaly was detected is emphasized. Knowledge of various aberrant branches of SMA can facilitate interpretation in diagnostic and help in performing surgical, laparoscopic, and interventional procedures safely.

The authors have no conflict of interest to declare.

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