

Original Article

CT features and common causes of arc of Riolan expansion: an analysis with 64-detector-row computed tomographic angiography

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Abstract: Objective: To study the manifestations of arc of Riolan expansion (ARE) using multi-detector computed tomography angiography (MDCTA). Materials and methods: The manifestations and clinical data of 626 consecutive mesentery CTA images were retrospectively analyzed. The 47 cases with ARE and 47 patients without expansion were involved. The average diameter of arc of Riolan was measured. Two radiologists after reaching consensus analyzed the shapes of mesenteric artery, CT findings and the occurrence and causes of ARE. Results: The mean diameter of arc of Riolan was 1.2 mm, 4.6 mm, 2.5 mm, 2.3 mm, 1.9 mm, 2.5 mm, and 2.0 mm at baseline and following obstruction of superior mesenteric artery (SMA), stenosis of SMA, obstruction of inferior mesenteric artery (IMA), stenosis of IMA, colon cancer, and active ulcerative colitis, respectively. The expansion of arc of Riolan was the most significant following obstruction of SMA. The diameters of arc of Riolan were significantly different between the upward flow group and the downward or the two-way flow groups, and between the colon tumor group and the active ulcerative colitis group. CT findings such as bowel wall thickening, contrast enhancement, intestinal obstruction, marginal artery expansion, lymph node enlargement varied and were help to identify the cause of ARE. Conclusions: ARE often suggests the occurrence of obstructed intestinal feeding artery or intestinal lesions. MDCTA can clearly display the situation of arc of Riolan and collateral circulation, and together with CT symptoms, can guide the selection of diagnosis and treatment schemes in clinic.

Keywords: Mesenteric artery, abdominalarteries anomalies, MDCT angiography

Introduction

The arc of Riolan (AOR), also known as the central anastomotic mesenteric artery or meandering mesenteric artery, is an inconstant artery which links the proximal superior mesenteric artery (SMA) or one of its principal branches to the proximal inferior mesenteric artery (IMA) or one of its primary branches [1]. It made the connection between the middle colic branch of the SMA and the left colic branch of the IMA and can form a short loop that runs close to the root of the mesentery. Several studies indicate the AOR is to reflect enlargement of a pre-existing collateral vessel in the setting of an important stenosis of an SMA or IMA. According to the location of the stenosis, the direction of blood flow may be antegrade or retrograde [2]. It also provides collateral flow from SMA to IMA to iliac vessels and then to the lower limbs

in distal abdominal aortic occlusion. Both AOR's real existence and general need for terms always have been mentioned and questioned by surgeons to reflect its clinical significance. Recessive AOR is the common state, with small amount of blood or even without blood inside of it. So normally it presents minuteness in the images. Since the blood vessel course is meandering, the term of "meandering mesenteric artery" is considered more visual and accurate [3]. In case of blood insufficiency in SMA or IMA, the vessels will undergo compensatory expansion to become arcs. The expansion has much relationship with the occurrence of acute and chronic ischemia. Along with the advances in spiral computed tomography (CT), the multi-detector CT angiography (MDCTA) like digital subtraction angiography (DSA) can clearly display and elucidate the vascular anatomy in human body [3].

Considering the invasion and complications of DSA, many researches focus on the application of CT angiography on the studying of vascular structures in many diseases [4-6]. Keeping track of the collateral circulations in SMA and IMA is not only beneficial for prognostic evaluation of acute and chronic ischemia, but also for ensuring intestinal blood supply in selection of schemes for colon surgery [7]. In this study, the retrospectively analysis was performed by studying a large amount of patients who have abdominal large-vascular lesion or intestinal disease with treatment of the 64-detector-row spiral CTA in the recent 5 years and finally we summarize the manifestations of the arc of Riolan expansion.

Materials and methods

Patients

This study was conducted with approval from the hospital's Ethics Committee and informed consents from all patients in China. We retrospectively analyzed patients clinically suspected as aorta or abdominal intestinal lesions and received CTA in aorta abdominal or mesenteric artery between June 2007 and June 2012. The patients' scale is larger than similar studies in order to confirm the representativeness of the paper. The major clinical manifestations include: bellyache, abdominal distension, intestinal disorder, changes in defecation traits or habits, and hemafecia that are inconsistent with clinical observations, or medical history of diseases in aorta or mesentery vessels. Five patients were excluded from CTA because of severe contrast-agent contraindications, such as history of adverse reactions (1 case) and renal inadequacy (4 cases). Finally, after informed consent was obtained, 626 subjects (age range between 24-81 years; the mean value, 51 years) were examined, including 359 males and 267 females MDCTA shows that arc of Riolan expansion occurred in 47 cases consisted of 29 males and 18 females (age range, 26-81years; mean 53 years). A control group was sampled from patients without vasodilation of the arc, exclusion criteria including: ① stenosing atherosclerosis; ② tumor lesions in the middle and lower abdomen (except cysts in liver, kidney or spleen); ③ history of surgery; ④ vascular deformation or variation; ⑤ liver cirrhosis and portal hypertension. As a result, 47 subjects consisted of 27 males and 20 females

(age range 35-79 years, mean 50 years) were selected into the control group.

Imaging and evaluation

MDCT angiography examinations were performed by using a 64-detector scanner (Aquilion 64, Toshiba Medical Systems, Otawara, Japan). In our standard CT protocol for abdomen examinations, dual scan gram area from Diaphragm to the pubic symphysis in a supine position was adopted as field of view (FOV). During examination, an 18 to 20 gauge angiocath in the antecubital vein was used to inject 60-80 ml of non-ionic iodinated contrast media (Iopromide Injection 350 mg/ml; Schering Pharmaceutical Co. Ltd, Guangzhou, China) using bolus-tracking method with an automatic injector at a rate of 5 mL/sec and 30 mL of saline (0.9% NaCl) solution at a rate of 3 ml/sec (Nemoto Kyorindo Co. Ltd, Tokyo, Japan), respectively. The region of interest was positioned at the thoracoabdominal aorta, and the threshold for CT angiography was set as 160 HU. Arterial phase scan delay was established with the automatic bolus tracking technique. When the threshold was surpassed, helical scanning was automatically initiated. Portal venous phase acquisition was set 25 sec delay after the previous protocol. Biphasic scan parameters were 120 kV, 100-300 mA (3D Sure-exposure, noise SD: 15), 500 msec rotation time with a slice thickness of 0.5 mm and increments of 0.4 mm, using a detector collimation of 64 × 0.5 mm (pitch: 0.828).

The obtained volume images reconstructed with a standard filter convolution algorithm (FC43) and a image matrix of 512 × 512 pixels from MDCT were transferred to a workstation VITREA 2 (version 6.1, Vital Images, Inc, Minnesota, America) for analysis.

In addition to the axial source data, post-processed multiplanar-reconstruction (MPR), maximum-intensity projection (MIP), and 3D volume-rendering (VR) images were evaluated by two radiologists (with 4 and 6 years of experience in CT angiographic imaging), and the decisions were made in consensus.

CT value of mesenteric artery greater 250 HU was considered as an appropriate and evaluable imaging. 3-5 mm thin cross section images and coronal slap-MIP images were used to measure vascular diameter; the mean diame-



Figure 1. Male, 56-year-old, Control group, thin-layer MIP, the white arrowhead indicates the arc of Riolan.

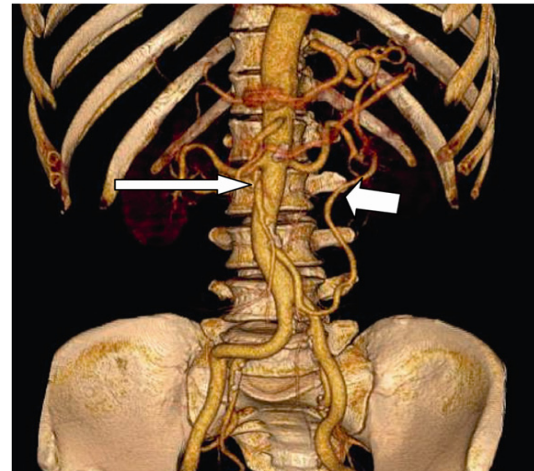


Figure 2. Female, 74-year-old, VR image shows severe SMA stenosis (long arrowhead), short arrowhead indicates arc of Riolan expansion.

ter of arc of Riolan was based on the diameter of mid-segment of the left branch of ACM and the diameter of mid-segment of the ascending branch of ACS. Depending on this diameter and the whole imaging profiling, we evaluated the fineness of arc of Riolan and make a degree of it. According to data, we describe the diameter of AOR into three degrees, +++, ++, + representing different level. Referred to mesenteric artery expansion and cerebral artery expansion were described by CTA or DSA [8, 9], criterion on arc of Riolan expansion: arterial diameter > 1.5-fold of the control group. Axial source data, MPR, MIP and VR images were independently and blindly evaluated by two radiologists (with 3 and 5 years of experience in CT angiographic imaging), and the decisions were made in consensus. Based on the intraoperative observations by Fisher [10] and the Doppler ultrasonic results [11], the blood flow direction in arc was defined as upward when SMA was obstructed or severely stenosis ($\geq 75\%$), which manifested as the ascending branch of ACS of the arc dilating greater than the left branch of ACM. Conversely, the blood flow direction was defined as downward or bi-directionally (depending on body position). Namely, upward means that IMA supplies blood to SMA along arc of Riolan; downward means SMA supplies blood to IMA; bi-directionally means blood flow direction is not fixed. Therefore, the observed of obstruction or severe stenosis of SMA were divided into upward group; the cases suffered from obstruction or severe stenosis of IMA, sigmoid colon cancer and active ulcerative colitis were grouped in downward or bi-directionally.

Clinical final diagnosis and pathological report

All patient charts and pathologic reports were reviewed to determine the final diagnosis. All patients with arc of Riolan expansion had either surgical proof ($n = 8$), DSA ($n = 15$), colon endoscope and tissues pathology proof ($n = 14$), or both DSA and colon endoscope ($n = 10$), except for 5 patient in whom the diagnosis was made on the basis of clinical and serial CT findings. Patients without arc of Riolan expansion had an alternative diagnosis confirmed either at biphase CT scan or on the basis of appropriate laboratory values and clinical findings, or they had no diagnosis and recovered spontaneously without treatment. Charts were also reviewed for documented evidence that information provided by the CT angiogram affected ultimate patient care, either by influencing the decision to perform surgery or endovascular interventional treatment.

Statistical processing

For continuous data, average diameter and range (min-max) values were used for descriptive statistics, respectively. A Kolmogorov-Smirnov test was used to assess normal distribution. For normal or abnormal distribution, one-way ANOVA test or Kruskal Wallis one-way ANOVA tests were used. The arc of Riolan diameters of the group divided by blood flow directions were compared using analysis one-way ANOVA. The Fisher exact test was used to compare incidence of CT findings of SMA obstruction, IMA

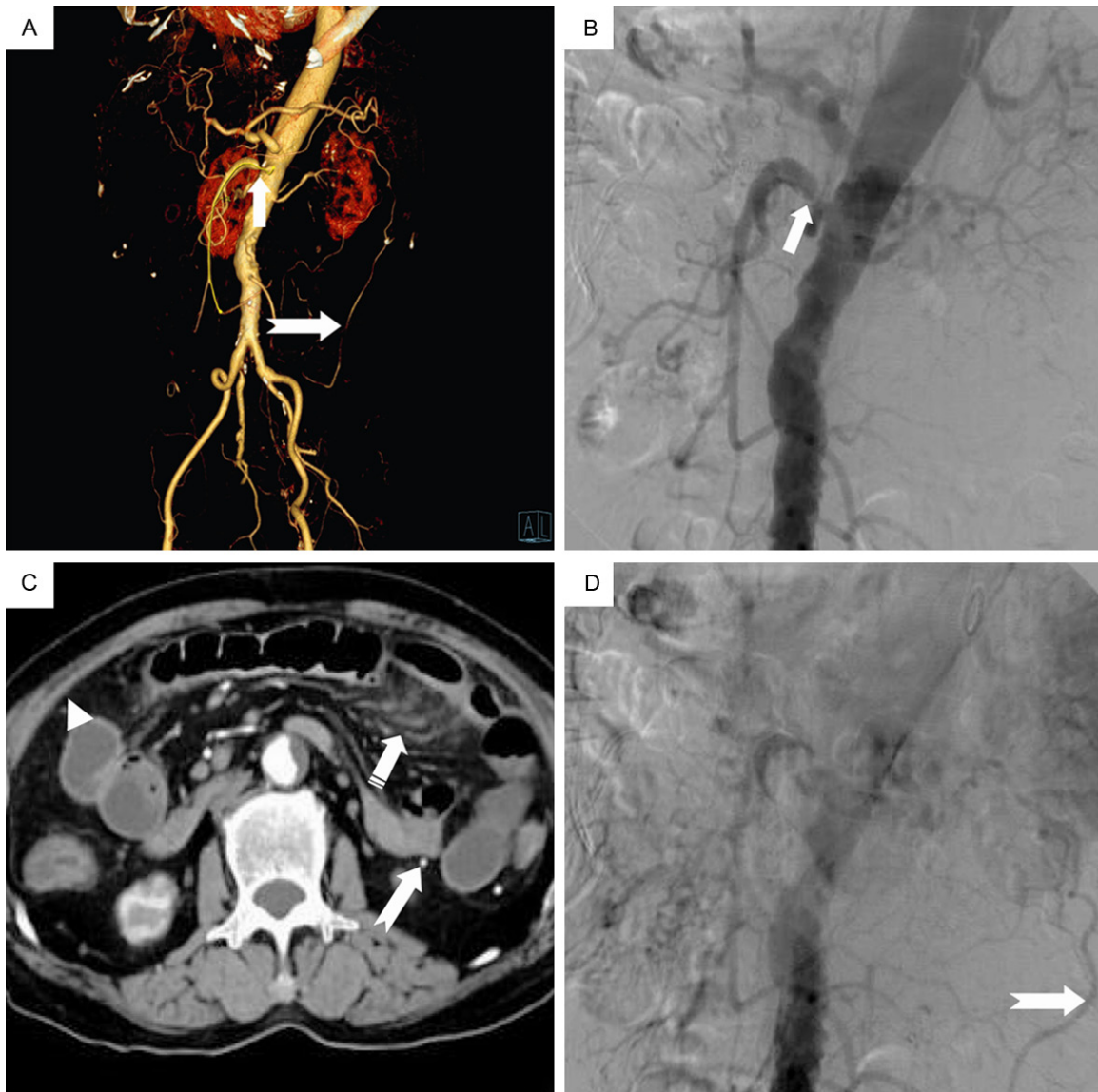


Figure 3. Male, 69-year-old. A VR (A), DSA-abdomen aorta (B), axial view (C), DSA-IMA (D). Images showed severe stenosis in SMA (white arrow), arc of Riolan expansion (dovetail arrow), by atherosclerosis, complicated with intestinal wall, mesentery oedema (dovetail arrow), small intestine incomplete obstruction and expansion (arrowhead), mesenteric edema(virtual tail arrow); DSA artery displays arc of Riolan (white arrow), lack of view.

obstruction, Colon cancer, UC accompanying with arc of Riolan expansion respectively. *P* values less than 0.05 were accepted as significant. Statistical analysis was done with the Statistical Package for the Social Sciences version 17.0 (SPSS, Chicago, IL, USA).

Results

Large-scale cases (626) were examined. No patients experienced a reaction to the contrast agent. Three patients were excluded because the concentration of contrast collected at arterial phase was not high enough.

In the control group, only 12.7% of cases ($n = 6$, 5 males and 1 female) were showed the whole view of the arc with a displaying common diameter, and 87.3% of cases ($n = 41$, 23 males and 18 females) were displayed only the most of the left branch of ACM and the ascending branch of ACS (Figure 1).

The 47 cases of arc of Riolan expansion included 16 cases of severe SMA stenosis (Figures 2, 3), 9 cases of SMA obstruction (Figure 4), 7 cases of IMA obstruction (Figure 5), 2 cases of severe IMA stenosis, 8 cases of advanced descending colon-sigmoid colon cancer (Figure

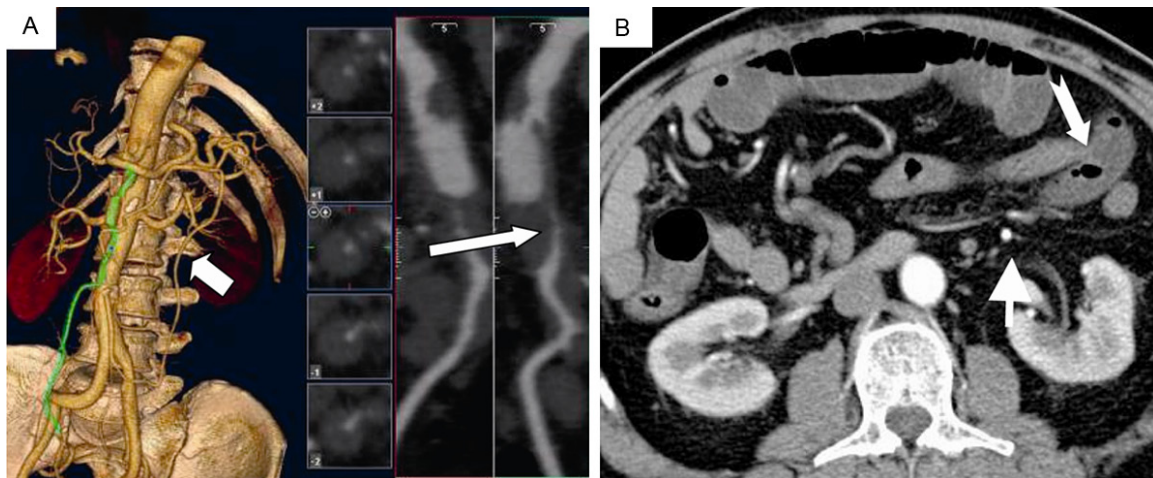


Figure 4. Male, 69-year-old. A VR image shows SMA obstruction (long arrowhead), short arrowhead indicates arc of Riolan expansion; b arterial phase axial view, indicating arc of Riolan section (white arrow), slight oedema and ileus in intestinal wall (dovetail arrow).

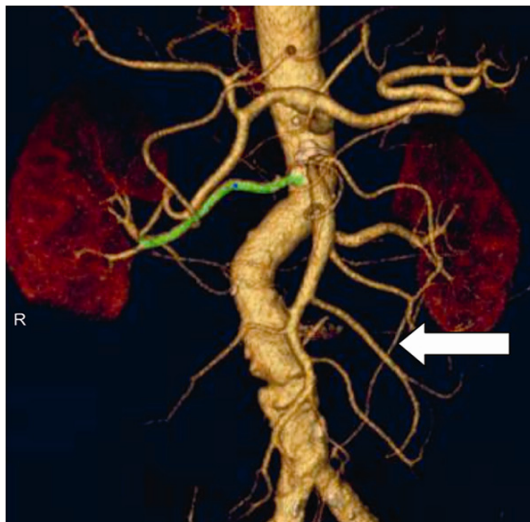


Figure 5. Male, 79-year-old, VR image shows IMA obstruction, proximal segment not displayed, compensated via Riolan (white arrowhead).

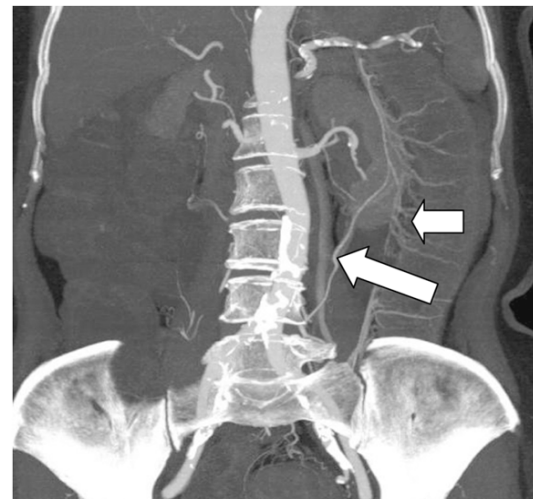


Figure 6. Male, 76-year-old, descending colon tumor, MIP image shows arc of Riolan expansion (long arrowhead) and marginal arc (short arrowhead), obviously strengthened intestinal wall.

6), and 5 cases of active UC (**Figure 7**). **Table 1** presents the diameter degree of the expanding arc of Riolan on account of following different diseases. The arc of Riolan diameter was statistically larger in the study group than in the control group ($Z = -8.403$, $P < 0.01$). Clearly, the expansion of the arc caused by SMA obstruction was higher than other diseases ($\chi^2 = 74.21$, $P < 0.01$; **Figure 8**).

The diameter degree of arc of Riolan in the upward group, the downward group, and the bi-directional group are showed in **Table 2**. The upward group was significantly different from the other two groups.

The comparison of the incidence of CT appearances of SMA obstruction, IMA obstruction, colon cancer, UC accompanying with arc of Riolan expansion is given in **Table 3**. Twenty one (84%) of the 25 patients with a diagnosis of SMA obstruction had CT signs of bowel wall thickening compared with 2 (22%) of the 9 patients with IMA obstruction. The gross appearance of the affected bowel wall was circumferential bowel wall incrassated as concentric rings or target sign at an acute phase of ischemic bowel disease (**Figures 3C, 4B**), while homogeneous thickening showed at a chronic ischemia process. Due to the different course,

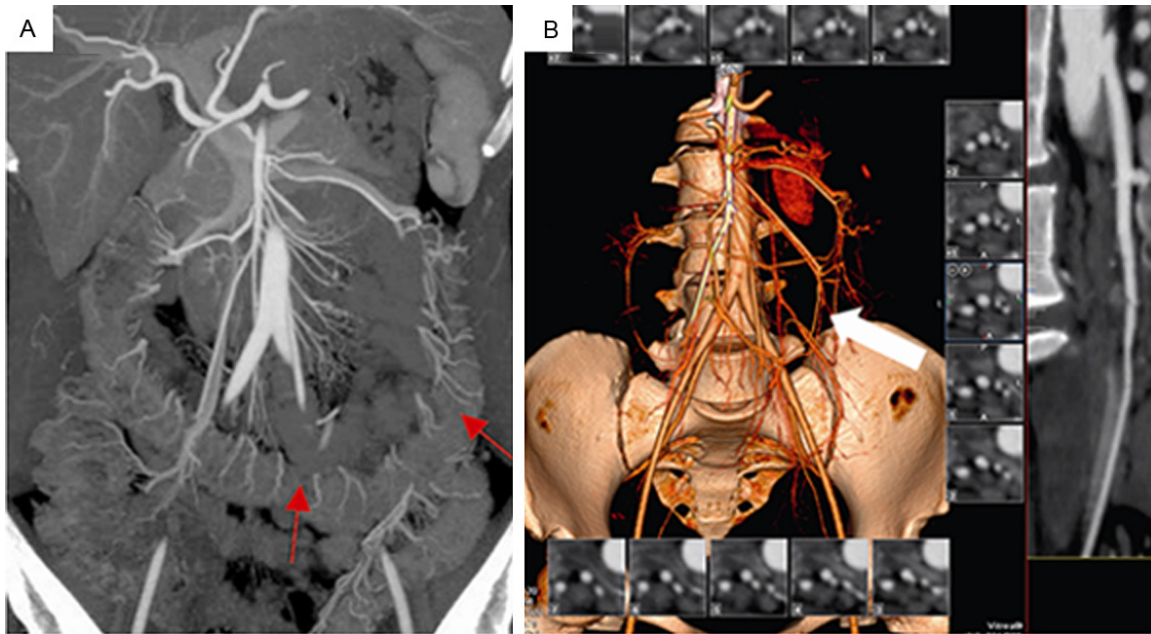


Figure 7. Female, 27-year-old, ulcerative colitis at active phase, coronal slap-MIP (A), VR (B) at arterial phase, white arrowhead indicates expanded arc of Riolan, red arrowhead indicates suffused intestinal wall thickening, obvious strengthening.

Table 1. Comparison of arc of Riolan diameter following different diseases (mm)

	SMA obstruction	SMA stenosis	IMA obstruction	IMA stenosis	Colon tumor	Ulcerative colitis
Cases (n)	16	9	7	2	8	5
Range	3.6-6.1	2.2-2.9	1.8-2.5	1.5-2.2	1.9-2.9	1.6-2.4
Average	4.6 ± 0.7	2.5 ± 0.2	2.3 ± 0.3	1.9 ± 0.2	2.5 ± 0.3	2.0 ± 0.3

intestinal mucosa enhancement and bowel dilation were different accordingly. Conversely, bowel wall thickening, contrast enhancement, intestinal obstruction, marginal artery expansion, lymph node enlargement were not seen in most IMA obstruction, whereas showed commonly in advanced sigmoid colon cancer and active UC respectively, with no difference between the two groups.

Discussion

Arc of Riolan, named by Jean Riolan, an anatomist from France, is a crucial connection between the SMA and IMA in the setting of arterial occlusion or significant stenosis besides Drummond marginal artery, which located in mesocolon, striking along the medial margins [3]. Usually, the fineness of artery is very small and recessive state keeps in most time. Previous studies suggest the arc will obviously expand only following obstruction of SMA, but normally,

arc of Riolan undergoes little and slow blood flow, and cannot be displayed fully in angiography [3]. However, all cases of this study in the control group display full arc of Riolan with CT angiography.

DSA is regarded as the golden standard for the evaluation and description of vascular structures. Nevertheless, some variations can be overlooked when this technology is used in cases where description of the collateral circulation system between SMA and IMA is difficult, where the catheter tip is far from where it should be in the SMA or IMA during selective angiographic processes in spite of using vasodilator [12]. MDCTA allows most of the body to be scanned helically in just one breath hold less than 8 seconds, and thus provides high-contrast resolution without any artifacts. Together with axial images, 3D images provide a very good anatomical orientation. Detailed information regarding vascular, bowel and their relations with one another can be obtained, hence, CTA compared with DSA shows the equal or very similar diagnostic value [13, 14]. Different from the angiograph, MDCTA belongs to antegrade physiological imaging, and the

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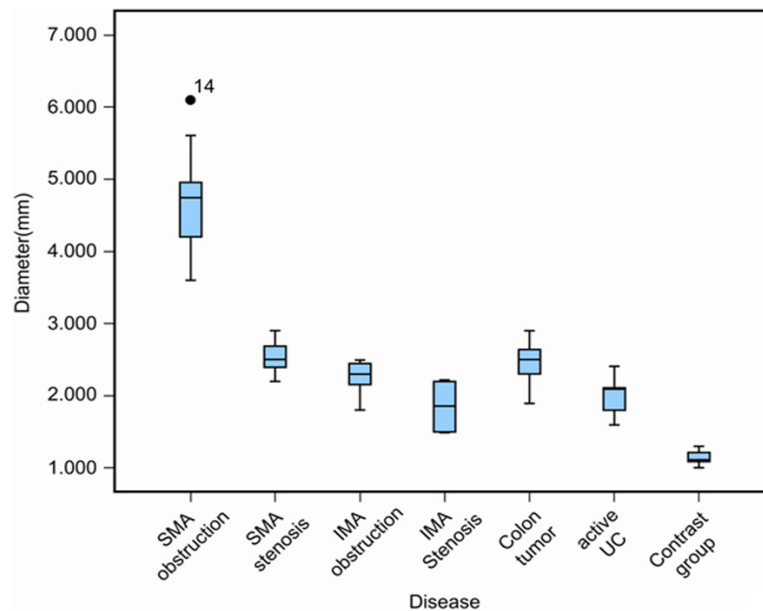


Figure 8. Box figure shows the diameter of arc of Riolan on account of following different diseases.

Table 2. Comparison of arc of Riolan diameter between the upward group, the bi-directional group, and the downward group (mm)

	Upward group	bi-directional or downward group
Cases (n)	25	22
Diameter range	6.1-2.2	1.5-2.9
Average diameter	3.9 ± 1.2	2.2 ± 0.4

developing time interval is very close between SMA and IMA, really reflecting the characteristics of anatomy and blood stream in these vessels. The gross success rate of Mesenteric artery CT angiography with bolus triggered technique was 99.5% , only 3 (0.5%) cases were mistakenly judged at arterial phase, due to difference in concentrations of contrast agent in true and false chamber of aorta dissection.

Fisher and Fry [10] reported that in imaging of artery, the presence of this artery indicates the obstruction of SMA or IMA. The data in this group indicates that the presence of arc of Riolan is closely related to not only the severe obstruction of SMA, but also obstruction of IMA, severe stenosis of SMA (not obstruction) also cause the expanded arc of Riolan. Severe SMA stenosis or obstruction induced the significant expansion degree in arc of Riolan than in IMA, probably because the blood flow load on

SMA was higher than IMA. In case of severe blood supply deficiency in SMA, arc of Riolan becomes the major collateral vessel. The tissues supplied by IMA are limited to the left 1/3 of transverse colon, descending colon, colon sigmoideum and partial rectum. For example, IMA ischemia can not only be compensated by Drummond arc, but can trigger trunk collateral circulation system and plays the role of partial compensation from external iliac artery via rectum arc to internal iliac artery. The reasons causing stenosis or obstruction of SMA or IMA include atherosclerosis, mesenteric artery embolism, aorta lesions, and arteritis.

The 7 cases of IMA obstruction in this group included 6 cases of aorta interlining false lumen and abdomen aorta tumor, forming thrombus complicated with IMA obstruction, and 1 case with history of multiple aorta arteritis.

In this study, all of the eight observed colon cancer cases with Riolan expansion were the advance of the sigmoid colon carcinoma infiltrating including sigmoid colon and partial descending colon. Colon cancer is rich in feeding artery and expanded vein, and the richer blood supply indicates low differentiation of tumor and higher malignant degree [15]. When the inferior mesenteric artery cannot fulfill the needs of the tumor growth, the collateral circulation will be activated, supplying blood together by Arc of Riolan and Drummond marginal artery. CT signs such as wider range, rich blood supply, obviously strengthened masses at arterial and portal phase, and enlarged metastatic lymph nodes were displayed accordingly. The transition zone between descending colon and sigmoideum colon is supplied jointly by colon sigmoideum artery and ACS, and the tumors rapidly grow to induce the compensatory blood supply in collateral circulation [16].

Ulcerative colitis is a recurrent chronic nonspecific inflammatory lesion, and angiography and pathophysiological studies show that the blood flow in intestinal wall was enhanced and small

Table 3. Comparison of the incidence of CT appearances of SMA obstruction, IMA obstruction, Colon cancer, UC accompanying with arc of Riolan expansion (%)

	SMA obstruction N = 25	IMA obstruction N = 9	Colon cancer N = 8	Active UC N = 5
Bowel wall thickening	84% (21/25)	22% (2/9)	100% (8/8)	100% (5/5)
Bowel wall enhancement	76% (19/25)	22% (2/9)	100% (8/8)	100% (5/5)
Intestinal obstruction	32% (8/25)	0	38% (3/8)	40% (2/5)
Marginal artery expansion	64% (16/25)	22% (2/9)	88% (7/8)	100% (5/5)
Vein expansion	24% (6/25)	0	100% (8/8)	100% (5/5)
Lymph node (≥ 5 mm)	8% (2/25)	0	88% (7/8)	40% (2/5)

arteries were dense upon the occurrence of enteritis. Relevant pathological changes are induced by *Escherichia coli* infection, leading to intestinal wall hyperaemia, vascular expansion, higher blood flow, and lower vascular resistance. The 5 active UC patients all displayed intestinal vessel expansion, marginal artery expansion and arc of Riolan thickening, and strengthened intestinal wall, which are similar with Doppler ultrasound researches [17-19], namely UC can induce higher IMA blood flow, faster blood flow, and larger inner diameter in blood vessels.

All factors affecting artery load will contribute to changes in mesenteric artery blood flow including position and foods [20]. Therefore, in our study, CT examination schemes adopt supine and scan on an empty stomach, and assumed that arc of Riolan blood flow was only decided by the arterial pressure difference. In case of SMA stenosis, coeliac trunk artery and IMA can supply blood via pancreaticoduodenal arc and expanded arc of Riolan to small intestine and right hemicolon. In case of IMA stenosis or obstruction, SMA will supply blood via arc of Riolan to the left hemicolon and to some branches in left internal iliac artery. Therefore, due to the different positions of mesenteric artery stenosis, the directions of blood stream in the arc of Riolan are different. MDCTA belongs to antegrade image, and the blood flow direction can be determined by the position of stenosis and the size variation of blood vessels. The arc of Riolan expanding degree in the upward group is obviously higher than the downward group and the two-way group.

Thus limitations are inevitably showed in this study. First, a bias in selection of patients, which may affect the occurrence rate of arc of Riolan, at the same time it also reflects the real situation in clinic to some degree. Second, celi-

ac and mesenteric artery variation situation did not be considered in our paper. A previous research [21] suggested that congenital superior-inferior mesenteric arterial variation or arc of Riolan was due to occlusion of proximal superior mesenteric artery. Third, we assume that the arc blood flow direction is based on the difference of vascular lumen diameter is raised, not confirmed by doppler. In fact, the intestinal artery blood flow rely mainly on its own pressure difference, may also be affected by the postures, eating, etc besides. Moreover, CT exposure dose should not be ignored, to decrease radiation exposure, we adopted higher noise value (SD = 15) for the technology of three dimension automatic mA output.

Further research is needed to reveal the arc of Riolan expansion induced by obstruction of the different segments in SMA and course of the disease.

In conclusion, MDCTA clearly display the full view and profile of arc of Riolan expansion and blood stream compensation. Combined with CTA imaging, it can differentiate the formation of the arc, which is very useful for selection of operational scheme.

Disclosure of conflict of interest

None.

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