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ORIGINAL ARTICLE

Observational Study

Accuracy of routine multidetector computed tomography to identify arterial variants in patients scheduled for pancreaticoduodenectomy

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Abstract

AIM: To assess the efficacy of cross-sectional multidetector computed tomography (MDCT) imaging without arterial reconstruction to identify aberrant right hepatic artery (RHA) and celiac artery stenosis (CAS) in patients scheduled for pancreaticoduodenectomy.

METHODS: Patients with peri-ampullary and pancreatic head tumors who underwent routine preoperative MDCT and subsequent computed tomography (CT) angiography (CTA), conventional angiography or pancreaticoduodenectomy between September 2007 and August 2013 were identified. Retrospective analysis of imaging data was undertaken using CTA, conventional angiographic and surgical findings as the reference standards. The accuracy, sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) of MDCT in evaluation of aberrant RHA and CAS were calculated.

RESULTS: A group of 458 patients met the inclusion criteria of this study to detect aberrant RHA, and 181 cases were included to identify CAS. Fifty-four (11.8%) patients were confirmed to have aberrant RHA, while 12 (6.6%) patients with CAS were demonstrated. MDCT yielded an accuracy of 98.5%, sensitivity of 96.3% and specificity of 98.8% in the detection of aberrant RHA. The sensitivity, specificity, PPV and NPV of MDCT for detecting CAS were 58.3%, 98.2%, 70% and 97.1%, respectively.

CONCLUSION: Routine MDCT is recommended such that surgeons and radiologists be alerted to the importance of arterial variants on preoperative CT scans in patients scheduled for pancreaticoduodenectomy.

Key words: Pancreaticoduodenectomy; Aberrant hepatic artery; Celiac artery stenosis; Multidetector computed tomography; Angiography

Core tip: Few studies have investigated the ability of routine multidetector computed tomography (CT) scans without arterial reconstruction, which are commonplace in medical practice, to assess peri-pancreatic arterial variants such as aberrant right hepatic artery and celiac artery stenosis prior to pancreaticoduodenectomy. This study demonstrated that a routine multidetector CT scan is useful to evaluate aberrant right hepatic artery in the preoperative planning of pancreatic surgery, although it is limited by lower sensitivity for evaluating celiac artery stenosis. It is recommended that surgeons and radiologists be alerted to the importance of arterial variants on preoperative CT scans in patients scheduled for pancreaticoduodenectomy.

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INTRODUCTION

The complex nature of the peri-pancreatic vasculature and its variations add to the difficulty of surgical resection. Previous reports[1-5] demonstrated that hepatic artery anomalies and celiac artery stenosis (CAS) were not rare in patients with peri-ampullary and pancreatic head neoplasms. One relatively common aberration in hepatic artery anatomy is the replaced or accessory right hepatic artery (R/A RHA), but it failed to be identified in nearly half of patients preoperatively[6]. R/A RHA usually runs laterally to the portal vein (PV) behind the pancreatic head and enters the right side of the hepatoduodenal ligament posterolateral to the common bile duct (CBD). The presence of R/A RHA may modify the surgical approach when special conditions, such as CAS or occlusion[7-9], are encountered. Usually the presence of CAS is of no clinical significance, as blood supply to the pancreas, liver, stomach and spleen is maintained through a well-developed system of pancreaticoduodenal collateral pathways from the superior mesenteric artery (SMA). However, it can lead to liver ischemia after occlusion of the gastroduodenal artery (GDA), which may cause severe complications after a Whipple procedure[10]. Thus, surgeons should be vigilant for these anomalous arteries to avoid potentially disastrous complications.

Preoperative angiography helps to identify abnormalities in the peri-pancreatic vasculature, enabling better preparation for management during surgery. It also provides a reliable method to diagnose CAS in the presence of direct visualization of stenosis on lateral views, retrograde blood flow through markedly developed pancreaticoduodenal arcades and prominent collateral vessels in the peri-pancreatic region. CT angiography (CTA) is an effective alternate imaging tool to conventional angiography that has high spatial resolution, making noninvasive evaluation of the vascular architecture surrounding the pancreas from any angle possible. It also allows the display of both the pancreas (including the mass) and the vascular map in a single view. Studies have demonstrated that there is no significant difference in sensitivity between CTA and conventional angiography with the use of multiplanar and volume set analysis[9]. Nevertheless, the necessity for conventional angiography remains controversial because of its invasive nature. Conventional angiography cannot visualize the pancreas directly. In addition, whether or not it can thoroughly depict the vascular variations depends on the site of vascular access.

Routine multidetector CT (MDCT) is the standard examination method for the initial detection and characterization of pancreatic tumors, and for evaluation of resectability. However, there are few studies focusing on the assessment of peri-pancreatic arterial variants by means of preoperative MDCT without arterial reconstruction. The question is how accurately can MDCT show aberrant RHA or CAS in clinical practice? The purpose of this study was to assess the efficacy of routine MDCT to identify aberrant RHA and CAS in patients scheduled for pancreaticoduodenectomy using CTA, conventional angiographic and surgical findings as the reference standard.

MATERIALS AND METHODS

Patients

All patients with peri-ampullary and pancreatic head tumors who underwent routine preoperative MDCT and subsequent CTA, conventional angiography, or pancreaticoduodenectomy between September 2007 and August 2013 were identified from a review of patients treated at the Huashan Hospital. The patients who did not have a CTA examination or conventional angiography, and those who did not receive pancreaticoduodenectomy, were excluded. The remaining patients comprised the final study population. Medical records, surgical notes and imaging reports of these patients were reviewed. Two pancreatic surgeons familiar with the peri-pancreatic vascular anatomy but blinded to all other information including surgical records and the findings of CTA and conventional angiography reviewed the radiological films of the arterial phase of MDCT retrospectively. The Huashan Hospital institutional review board approved this study, and patient informed consent was obtained for all procedures.

Imaging techniques

MDCT was used to evaluate the tumor and its relationship with peri-pancreatic vascular structures. CT investigations were performed on 16-slice or 64-slice MDCT equipment (GE Medical Systems) after intravenous injection of 2

mL/kg of 300 mg I/mL Omnipaque (GE Healthcare Shanghai Co., Ltd.) at a flow rate of four mL/s. The major scanning parameters were set at a voltage of 120 kV, tube current of 280 mA, rotation time of 0.5-0.8 s and a section thickness of 3.75 mm. Arterial phase images of the routine MDCT were reviewed to evaluate aberrant RHA and CAS in all patients. Neither multiplanar reformation (MPR) nor maximum intensity projection (MIP) was used to review the MDCT images. These arterial variants were graded as "visualized" or "non-visualized".

Abdominal CTA was performed using 64-slice CT. Approximately 100 mL of iodine contrast agent (300 mg I/mL Omnipaque) was administered into the antecubital vein at a flow rate of three mL/s with a power injector. The collimation was set to 64 mm × 0.6 mm. The delay time, which depended on a bolus test using smartprep software (GE Healthcare), was roughly 15-18 s. The reconstructed slice thickness was one mm (field of view, 26 cm × 26 cm; matrix, 512 × 512; pixel size, 0.5 mm × 0.5 mm). Axial images were reconstructed with both three mm slice thickness and a reconstruction interval. An experienced technician in the 3D laboratory performed the three-dimensional arteriography on a dedicated 3D workstation (Siemens syngo MultiModality Workplace). MIP and volume rendering (VR) were used for the 3D post processing to analyze the arteries on the workstation.

The indication of conventional angiography was patients with locally advanced pancreatic head cancer who received adjuvant interventional chemotherapy (regional intra-arterial infusion chemotherapy). During the procedure, we also assessed the resectability of the tumors. Conventional angiography was performed as previous described[1,11]. In brief, a catheter (5-Fr Rosch hepatic catheter; Wilson-Cook Medical Inc., Winston-Salem, N.C., United States) was introduced through the right femoral artery by the Seldinger technique. The celiac or selective hepatic angiography and superior mesenteric angiography were carried out with selective injections of contrast medium in the celiac trunk and in the SMA. Serial anterior-posterior images were obtained at a rate of one of every two seconds for the first eight seconds and a slower rate thereafter.

Surgery

Patients who had lesions that were definitely resectable according to preoperative evaluation received surgical therapy. Two experienced pancreatic surgeons, who perform more than 60 Whipple procedures every year, performed the surgery. During the procedure, they paid particular attention to whether the patients had aberrant RHA. They were informed of the CTA and conventional angiography results regarding hepatic arterial anatomy before surgery if the patients had preoperative angiography examination. The MDCT results were compared with intra-operative findings, which were used as a standard of reference.

Image interpretation and data analysis

We assessed the studies for the presence of R/A RHA, replaced common hepatic artery (RCHA) and CAS. The presence or absence of aberrant hepatic arteries was evaluated using CTA, conventional angiography and surgery as the standards of reference. For CAS, we used CTA and conventional angiography as the reference standards. The sensitivity, specificity and accuracy of the diagnosis of these arterial variants on MDCT were calculated using the following definitions. True positives included patients with arterial variants identified by both reference standards and MDCT. True negatives included patients without arterial variants identified by both reference standards and MDCT. False positives included patients without arterial variants identified by reference standards, but positive indication by MDCT. False negatives included patients with arterial variants identified with reference standards, but received a negative indication by MDCT.

RESULTS

During the study period, 932 patients with pancreatic head and peri-ampullary tumors were evaluated with preoperative routine contrast-enhanced MDCT. Among them, 376 patients underwent pancreaticoduodenectomy, 122 received CTA and 102 received conventional angiography. Four hundred and seventy-four patients were excluded from the study that evaluated the accuracy of routine MDCT identification of aberrant RHA. Seven hundred and fifty-one patients were excluded from the study assessing the accuracy of routine MDCT in identifying CAS. Hence, 458 patients who underwent CTA, conventional angiography or surgery and 181 patients who received CTA or conventional angiography met the inclusion criteria of this study (Figure 1). The demographic and clinical characteristics of the patients are shown in Table 1.

The diagnostic accuracy results for routine MDCT in identifying arterial variants compared with the gold standards are summarized in Table 2. Among the 458 patients, 54 were confirmed to have aberrant RHA, with an incidence of 11.8%. MDCT demonstrated a sensitivity of 96.3%, a specificity of 98.8% and an overall diagnostic accuracy of 98.5%. A replaced right hepatic artery (RRHA) was found in 6.3% (29/458) of patients (Figure 2). MDCT demonstrated a sensitivity of 89.7%, a specificity of 99.1% and a diagnostic accuracy of 98.5%. Three patients with false-negative MDCT were all misdiagnosed with accessory right hepatic arteries (ARHA), and the four false positive results were as follows: two cases with ARHA were misdiagnosed as RRHA and two cases without aberrant RHA were misdiagnosed as RRHA. ARHA was found in 3.3% (15/458) of patients (Figure 3). MDCT identified 11/15 patients with ARHA and gave a false positive result in six of 443 patients without ARHA. Therefore, the sensitivity, specificity, positive

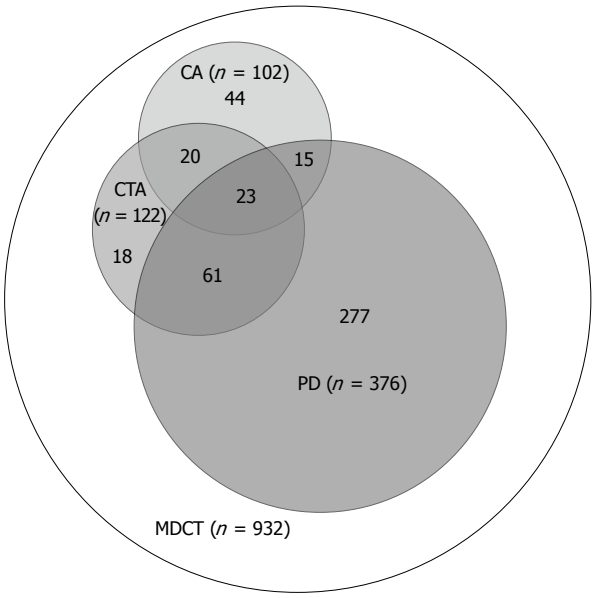


Figure 1 Patients included (grey) in the analysis and those excluded (white). PD: Pancreaticoduodenectomy; CTA: Computed tomography angiography; CA: Conventional angiography; MDCT: Multidetector computed tomography.

Table 1 Patient baseline characteristics *n* (%)

Characteristics	Patients assessed for aberrant RHA (*n* = 458)	Patients assessed for CAS (*n* = 181)
Age, (yr)	57.2 ± 12.9	57.3 ± 13.6
Male	242 (52.8)	102 (56.4)
Unresectable disease	82 (17.9)	82 (45.3)
Diagnosis		
Pancreatic adenocarcinoma	291 (63.5)	150 (82.9)
Pancreatic cystic neoplasm	34 (7.4)	6 (3.3)
Pancreatic neuroendocrine tumor	14 (3.1)	4 (2.2)
Ampullary adenocarcinoma	31 (6.8)	9 (5.0)
Duodenal adenocarcinoma	19 (4.1)	1 (0.6)
Others	69 (15.1)	11 (6.1)
Surgery		
Whipple	318 (69.4)	87 (48.1)
PPPD	58 (12.7)	12 (6.6)
Palliative bypass	13 (2.8)	4 (2.2)

CAS: Celiac artery stenosis; RHA: Right hepatic artery.

predictive value (PPV) and negative predictive value (NPV) of MDCT for detecting ARHA were 73.3%, 98.6%, 64.7% and 99.1%, respectively. RCHA was found in 2.2% (10/458) of patients (Figure 4). MDCT showed an accuracy of 100%, sensitivity of 100% and specificity of 100%.

Among the 181 patients scheduled for evaluation of CAS (Figure 5), twelve (6.6%) demonstrated positive results by CTA and conventional angiography. Three patients had false positive results and five had false negative results by routine MDCT. Thus, the sensitivity, specificity, PPV and NPV of MDCT for detecting CAS were 58.3%, 98.2%, 70% and 97.1%, respectively.

DISCUSSION

Visceral ischemia after pancreaticoduodenectomy caused by intraoperative hepatic artery injury or pre-existing CAS is a rare, but potentially serious, complication[5,10]. The prevention and adequate management of these ischemic complications are challenging. Many studies have highlighted the importance of identifying peri-pancreatic arterial variants before pancreaticoduodenectomy[12-16]. Variant hepatic and celiac arterial anatomy have been reported in 49% of the patients with pancreatic or hepatobiliary neoplasms[17]. Intra-operative palpation for the presence of the aberrant hepatic artery can be unreliable when the patient has prior surgery or is obese, when there is local inflammation, enlarged lymph nodes or an existing biliary stent. Despite advances in imaging technology, cross sectional CT scans are commonly used in the initial detection of peri-ampullary tumors, and are often performed to determine tumor resectability and stage[18].

Few studies have investigated routine MDCT without arterial reconstruction, which is commonplace in medical practice, in the assessment of peri-pancreatic arterial variants prior to surgery. Although conventional angiography is obsolete in primary staging, it is occasionally used to evaluate peri-pancreatic vessels before surgery. In our institution, we used this invasive technique mainly for multiphase regional intra-arterial infusion chemotherapy for pancreatic cancer[1,11]. Compared with routine arteriography, MDCT is noninvasive and directly visualizes the pancreas and the tumor. The introduction of modern MDCT scanners has greatly advanced the role of CTA in clinical practice and makes visualization of small visceral vessels possible[19]. In this study, we found that MDCT without arterial reconstruction could detect right hepatic arterial variants before pancreatic surgery very accurately. The result is consistent with other reports, which demonstrated that axial spiral CT scan (8-mm section thickness, 4-mm overlapping reconstructions) had a sensitivity, specificity and accuracy of 96%, 87% and 88%, respectively, for detecting aberrant hepatic arteries[20].

Turrini and colleagues[6] analyzed preoperative CT scans and showed that the detection rate of R/A RHA was 29% by radiologists and 51% by surgeons. Their results revealed that surgeons were more likely to identify aberrant RHA than radiologists on a CT scan. The reason for such a low detection rate may relate to technical aspects, such as the small caliber of R/A RHA identified on thick-cut CT images and not enough attention being paid to the arterial variants. Pre-operative radiological information about peri-pancreatic arterial variations was not always included. Although CT image reconstruction could provide preoperative vascular information, it was only done in a small number of patients. The excessive workload of radiologists, lack of interest in some cases, and lack of consolidated multidisciplinary teams may explain why on many occasions, image reconstruction was not available. In the present study, we found that aberrant RHA was usually well demonstrated with routine

Table 2 Diagnostic accuracy of routine multidetector computed tomography in preoperative identification of arterial variants

Arterial variants	Sensitivity	Specificity	Accuracy	PPV	NPV
Aberrant RHA	96.3 (86.2-99.4)	98.8 (97-99.5)	98.5	91.2 (80-96.7)	99.5 (98-99.9)
RRHA	89.7 (71.5-97.3)	99.1 (97.5-99.7)	98.5	86.7 (68.4-95.6)	99.3 (97.8-99.8)
ARHA	73.3 (44.8-91.1)	98.6 (96.9-99.4)	97.8	64.7 (38.6-84.7)	99.1 (97.5-99.7)
RCHA	100 (65.5-100)	100 (98.9-100)	100	100 (65.5-100)	100 (98.9-100)
CAS	58.3 (28.6-83.5)	98.2 (94.5-99.5)	95.6	70 (35.4-91.9)	97.1 (92.9-98.9)

RCHA: Replaced common hepatic artery; ARHA: Accessory right hepatic artery; RHA: Right hepatic artery; CAS: Celiac artery stenosis; RRHA: Replaced right hepatic artery; PPV: Positive predictive value; NPV: Negative predictive value.

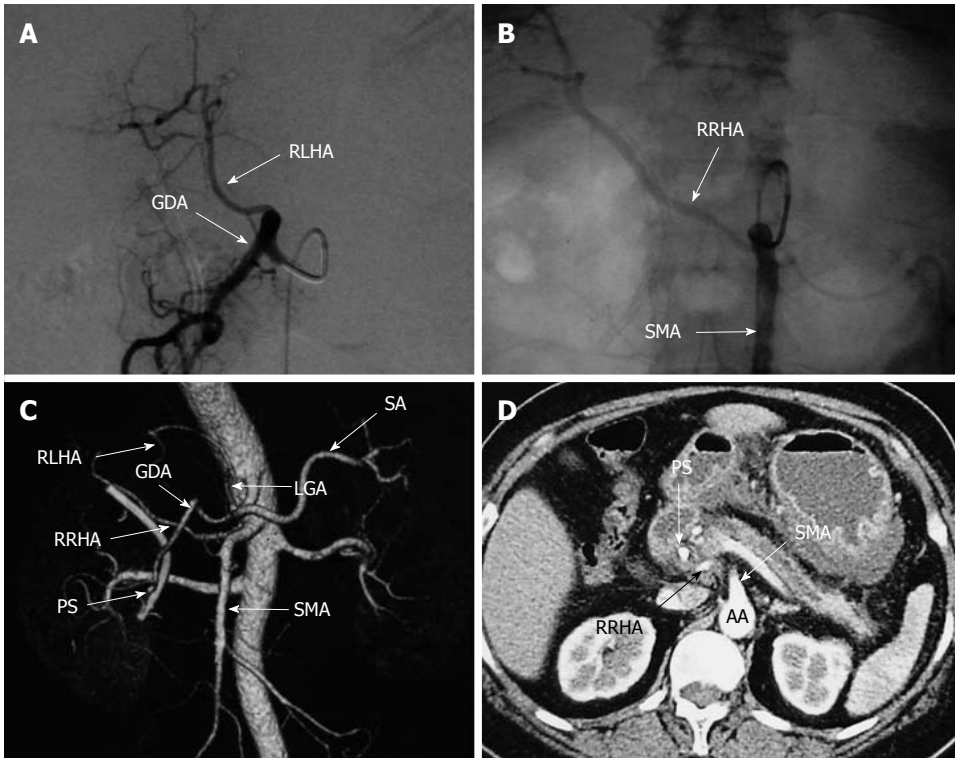


Figure 2 Sixty-year-old woman with replaced right hepatic artery and replaced left hepatic artery. A: Visceral angiogram with celiac injection demonstrating an RLHA; B: Visceral angiogram with SMA injection revealed an RRHA originating from the proximal SMA; C: Volume-rendered reformatted image depicting Michels type Ⅳ; D: MDCT showing an RRHA originating from the SMA traveling behind the portal vein. RRHA: Replaced right hepatic artery; RLHA: Replaced left hepatic artery; SMA: Superior mesenteric artery; SA: Splenic artery; GDA: Gastroduodenal artery; LGA: Left gastric artery; PS: Plastic stent; AA: Abdominal aorta.

MDCT by careful examination of the portacaval space, as well as the SMA and celiac axis. RRHA was shown originating from the SMA, passing behind the superior mesenteric vein (SMV), traveling through or behind the pancreatic head and entering the hepatoduodenal ligament. ARHA was observed as a vessel following a similar path as RRHA, and was found to be an additional vessel to the native RHA. RCHA, which originated from the SMA, was revealed to run behind or cross anteriorly to the PV/SMV, either within or along the ventral side of the pancreas, with no CHA found arising from the celiac axis. In compliance with these rules, we made errors in only a few patients when analyzing the CT images *via* picture archiving and communication systems (PACS). A dilated inferior pancreaticoduodenal artery arising from SMA may also be seen within the portacaval space; however, this is usually found in patients with CAS or arteriovenous malformation. The main difficulty in identifying an aberrant hepatic artery is the close proximity from which the celiac trunk and SMA originate on the aorta.

Previously reported incidences of CAS ranged from 2% to 49.7%[4]. In our study, CTA and conventional angiography detected CAS in twelve (6.6%) of 181 patients, with incidence similar to previous studies[5,21]. Park *et al*[21] showed that the incidence of celiac axis stenosis in an asymptomatic Korean population was 7.3%. Gaujoux and colleagues[5] detected CAS in 11% of patients who underwent pancreaticoduodenectomy. The lower incidence of CAS in the present study may partly reflect the lower incidence of atherosclerosis in the Chinese population compared with Westerners. Few studies have reported the value of MDCT to detect and characterize CAS. In a prospective study, the sensitivity of MDCT with arterial reconstruction to detect significant CAS was 96% with only one false

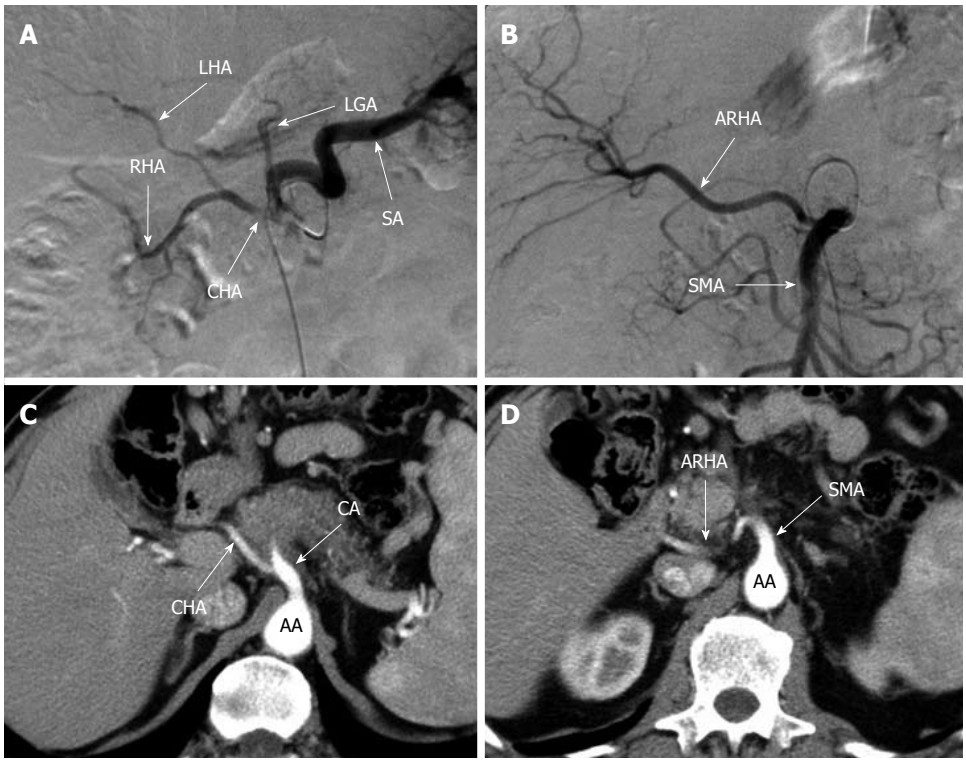
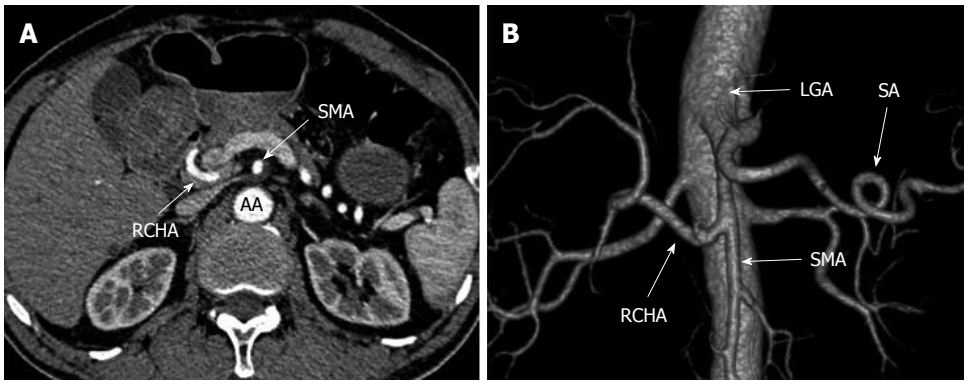


Figure 3 Sixty-five-year-old man with an accessory right hepatic artery. Conventional angiography with celiac injection (A) demonstrating a classic hepatic arterial anatomy, and one with SMA injection (B) showing an ARHA originating from the proximal SMA. MDCT showing the CHA arising from the CA (C), and an ARHA originating from the SMA, traveling behind the pancreatic head (D). ARHA: Accessory right hepatic artery; CHA: Common hepatic artery; SA: Splenic artery; LGA: Left gastric artery; RHA: Right hepatic artery; LHA: Left hepatic artery; SMA: Superior mesenteric artery; AA: Abdominal aorta; CA: Celiac axis.



Figue 4 Sixty-eight-year-old man with a replaced common hepatic artery. A: MDCT demonstrating an RCHA originating from the SMA, running behind the superior mesenteric vein, with no common hepatic artery found arising from the celiac axis; B: Volumetric three-dimensional CT angiography demonstrating Michels type Ⅸ. RCHA: Replaced common hepatic artery; MDCT: Multidetector computed tomography; CT: Computed tomography; SMA: Superior mesenteric artery; SA: Splenic artery; LGA: Left gastric artery; AA: Abdominal aorta.

negative[5]. Typically, a fishhook appearance is seen in sagittal reformatted images in patients with significant CAS. However, this appearance cannot be visualized on a transverse section CT scan, which demonstrates CAS as a stenosis at the origin of the celiac trunk, or a large arcade from the pancreaticoduodenal arcade. Our study used routine MDCT without arterial reconstruction, and revealed a sensitivity of 58.3%, which was significantly lower than that of the above study. The high specificity in our study indicated that routine MDCT without arterial reconstruction had a high rate of missed diagnoses, with few misdiagnoses of CAS. The reason for the low sensitivity may be that only high degree stenosis (hemodynamically significant) was demonstrated, while mild stenosis was hard to see at the origin of the celiac artery. Considering its limitation for evaluating CAS, we suggest that angiography should be performed for patients scheduled for pancreaticduodenectomy who have extensive pancreatic arterial collateralization on preoperative CT imaging[22].

In the present study, we only investigated the main arteries surrounding the pancreatic head, as these vessels were clinically relevant for pancreatic surgery. Variations in the pancreaticoduodenal arcade, gastric arteries,

Figure 5 Sixty-five-year-old man with celiac axis stenosis. Computed tomography scan of the abdomen (A) and celiac artery angiogram (B) revealing stenosis of the celiac axis (arrow). (C) Superior mesenteric arteriogram demonstrating retrograde filling of the hepatic artery through a dilatation of the pancreaticoduodenal arcade.

gastroepiploic arteries and portosplenic confluence are quite rare and less important for pancreatic surgery[17]. The current study included a large number of patients, and all patients underwent arteriography or surgery (reference standard). Nonetheless, one of the limitations of this study is that it was performed in a single center, albeit one highly experienced in pancreatic CT scans. Thus, the results need to be confirmed in multicenter prospective studies. Another limitation is that we did not assess the differences in the identification rate of arterial variants among various generations of CT scanners. Usui *et al*[23] reported no significant differences in the detection of arteries surrounding the stomach between 8-channel and 16-channel MDCT. We believe this also not likely to generate differences in our results.

Our study demonstrated that routine MDCT without arterial reconstruction is very useful to evaluate aberrant RHA in the preoperative planning of pancreatic surgery, although its usefulness is limited for evaluating CAS. In the case of pancreaticoduodenectomy, preoperative detection of CAS is still advisable, despite its low sensitivity. It is recommended that surgeons and radiologists be alerted to the importance of arterial variants on preoperative CT scans in patients who are scheduled for pancreaticoduodenectomy.

ACKNOWLEDGMENTS

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COMMENTS

Background

Peri-pancreatic arterial variations, such as hepatic artery anomalies and celiac artery stenosis (CAS), add to the difficulty of pancreaticoduodenectomy, and may occasionally lead to potentially disastrous complications.

Research frontiers

Routine multidetector computed tomography (MDCT) is the standard examination for the initial detection and characterization of pancreatic tumors. The current important issue regarding the accuracy of preoperative MDCT without arterial reconstruction to identify arterial variants in patients scheduled for pancreaticoduodenectomy remains to be elucidated.

Innovations and breakthroughs

Although computed tomography (CT) angiography and conventional angiography are effective imaging tools to evaluate the vascular architecture surrounding the pancreas, they are often not available because of the excessive workload of radiologists, lack of interest in some cases, lack of consolidated multidisciplinary teams, or their invasive natures. Few studies have investigated the ability of routine MDCT without arterial reconstruction, which is more commonplace in usual medical practice, in the assessment of peri-pancreatic arterial variants before surgery. The present study demonstrated that routine MDCT was highly accuracy, sensitive and specific to detect aberrant right hepatic arteries, although it was limited by a lower sensitivity to detect CAS.

Applications

The study results suggested that routine MDCT without arterial reconstruction is useful to evaluate aberrant right hepatic arteries in the preoperative planning of pancreaticoduodenectomy. Surgeons and radiologists should be alerted to the importance of arterial variants on preoperative CT scans in patients scheduled for the Whipple procedure.

Terminology

Aberrant hepatic arteries are defined as accessory, occurring in addition to the normal arterial supply; or replaced, representing the primary arterial supply to the lobe. CAS, also known as celiac artery compression syndrome, is a relatively common finding. In the presence of CAS, arterial blood supply to the pancreas, liver, stomach, and spleen is sustained *via* a well-developed system of pancreaticoduodenal collateral pathways in most patients.

Peer review

The results in this well-written manuscript adequately support its objective. In some ways, the present study also supports the necessity of multidisciplinary teams for pancreatic surgery.

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