Turk J Gastroenterol *2014; 25: 416-23*

Assessment of surgical resectability of pancreatic adenocarcinomas with multidetector computed tomography: What are the possibilities and problems?

PANCREAS

Esra İşcanlı[1], Aysel Türkvatan[1], Erdal Birol Bostancı[2], Zişan Sakaoğulları[3]

[1]Department of Radiology, Türkiye Yüksek İhtisas Hospital, Ankara, Turkey
[2]Department of Gastroenterological Surgery, Türkiye Yüksek İhtisas Hospital, Ankara, Turkey
[3]Department of Pathology, Türkiye Yüksek İhtisas Hospital, Ankara, Turkey

Original Article

ABSTRACT

Background/Aims: To investigate the accuracy of multidetector computed tomography (MDCT) in preoperatively determining the surgical resectability of pancreatic adenocarcinomas.

Materials and Methods: Multidetector computed tomography, surgery, and pathological results of 274 patients with pancreatic adenocarcinoma were evaluated retrospectively. MDCT findings were compared with surgical and pathological findings to determine the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of MDCT in determining surgical resectability.

Results: A total of 124 of 274 (56%) patients (83 males, mean age: 60 years) underwent laparoscopy and/or laparotomy. The sensitivity, specificity, PPV, NPV, and accuracy of MDCT in determining the surgical resectability of pancreatic adenocarcinomas were 100%, 72%, 78%, 100%, and 86%, respectively. Liver metastases in 9 cases, peritoneal metastases in 3 cases, and vascular invasion in 5 cases, which were determined during surgery, were not reported by MDCT. On re-review of the MDCT images of these 17 patients, no metastatic lesions could be seen in 9 patients with liver metastases and in 2 of 3 patients with peritoneal metastases. In 1 patient, a peritoneal implant of a diameter of 8 mm was missed on MDCT. There was no vascular invasion according to Lu criteria on the MDCT images in the 5 cases that had vascular invasion in the surgical exploration.

Conclusion: The accuracy of MDCT is high in the preoperative determination of surgical resectability of pancreatic adenocarcinomas, but the detection of small liver and peritoneal metastases and accurate determination of vascular invasion are still major problems. Surgeons should be aware of the limitations of preoperative MDCT.

Keywords: Pancreas, adenocarcinoma, surgical resectability, multidetector computed tomography, accuracy

INTRODUCTION

Pancreatic adenocarcinoma is one of the most aggressive tumors of the digestive system, with a prevalence of 10%. It is the fourth leading cause of cancer-related deaths and the second most frequent cause, after colorectal cancer, when considering digestive tract cancers alone (1). Due to the late clinical symptoms and aggressive course of the disease, the estimated life expectancy may be very short. Despite treatment options involving chemotherapy and radiotherapy, surgical resection offers the only chance for a cure. However, only 10%-20% patients are appropriate for resection at the time of diagnosis (2,3). The 5-year survival rate can increase from 5% to 20% in patients who undergo surgical resection (4). On the other hand, surgery has a 5% mortality and 20%-30% morbidity rate. In addition, resection of the tumor in patients with unresectable tumors does not improve the prognosis (5). Moreover, palliative laparoscopic procedures for biliary or duodenal decompression in patients with unresectable tumors are unnecessary, because endoscopic or percutaneous treatment options are available for these cases. Therefore, accurately distinguishing patients with potentially resectable tumors from patients who have unresectable tumors is vital to prevent the morbidity, mortality, and costs associated with attempted surgical resection, as well as the delay in initiating alternative therapies.

Address for Correspondence: Aysel Türkvatan, Department of Radiology, Türkiye Yüksek İhtisas Hospital, Ankara, Turkey
E-mail: aturkvatan@yahoo.com
Received: 7.2.2013 **Accepted:** 4.6.2013

Unresectability criteria for pancreatic adenocarcinomas consist of distant metastases (liver, peritoneum, omentum, distant lymph nodes); direct invasion of adjacent organs (except the duodenum); and invasion of the celiac artery, hepatic artery, superior mesenteric artery (SMA), portal vein, or superior mesenteric vein (SMV). Studies showed that multidetector computed tomography (MDCT) has a higher accuracy than endoscopic ultrasonography (US), conventional angiography, and magnetic resonance imaging (MRI) in the detection of primary tumors, vascular invasion, and distant metastases, and currently, MDCT is the most important and reliable imaging method for preoperative staging of patients with pancreas adenocarcinoma (6-22). Studies have reported high sensitivity rates, such as 100%, in determining the resectability of pancreas adenocarcinomas with MDCT, but highly variable ranges may be seen for more important parameters, like positive predictive value (PPV) and accuracy rates. According to studies, PPV rates were reported to be between 45%-89%, and negative predictive value (NPV) rates were 85%-100% for determining resectability (6-22). However, these studies included small groups of patients; accordingly, further studies including larger groups are necessary for testing the accuracy of MDCT in predicting the surgical resectability of pancreatic adenocarcinomas.

In this retrospective study, we aimed to identify the reliability of MDCT in determining the surgical resectability of pancreatic adenocarcinomas by analyzing MDCT images of 124 patients and comparing the MDCT findings with surgical and pathological results.

MATERIALS AND METHODS

The MDCT images of consecutive 274 patients with pancreatic adenocarcinoma, which were confirmed by surgery-pathology (n=124) or clinical follow-up (n=150), were retrospectively evaluated for determining the surgical resectability, including vascular invasion, distant metastases, and direct invasion of adjacent organs. The sensitivity, specificity, PPV, NPV, and accuracy of MDCT were investigated by comparing the surgical and pathological results.

The patients were informed before the MDCT examination, and written inform consent was taken from each patient. The study protocol was approved by the local ethics committee.

MDCT scanning protocol

All MDCT examinations were performed using 16-detector (Lightspeed Ultra, General Electrical Medical Systems, Milwaukee, Wisc; USA) or 64-detector (Aquilion 64, Toshiba, Tokyo, Japan) CT scanners. In all cases, an unenhanced scan and a triphasic protocol, including arterial, pancreatic, and portal venous phases, were obtained. At least 3 hours of starvation was suggested, and 1000 ml water was given as an oral contrast agent just before the scan. The images were obtained from the top of the diaphragm to the bottom level of the uncinate processes for the unenhanced, arterial, and pancreatic phases and from top of the diaphragm to the symphysis pubis for the portal venous phase. Also, 90-110 ml non-ionic iodinated contrast agent (Iodixanol, Visipaque 320 mgI/mL, GE Healthcare, USA or Iopromid, Ultravist 370 mgI/mL, Schering AG, Germany) was given through an 18-20-gauge cannula positioned in the right antecubital vein at a flow rate of 4-5 mL/s by using a power injector, and then, 40 mL saline was given at the same rate. The start time of the acquisition was determined using the automatic bolus tracking method (Sure Start; Toshiba Medical Systems, Tokyo, Japan). The region of interest (ROI) was placed on the proximal abdominal aorta, and an adjustment was carried out so that arterial phase scanning would start automatically when maximum contrast reached 180 HU. Pancreatic phase images were obtained after 45 seconds, and portal phase images were obtained after 65 seconds. The scanning parameters were: tube voltage: 120 kV, tube current: 200-440 mAs, gantry rotation time: 0.5 sec, collimation: 16x1.25 mm or 64x0.25 mm, slice thickness: 1-1.25 mm, and slice interval: 1-1.25 mm.

Analysis of MDCT images

For two- and three-dimensional image reconstruction, the volumetric MDCT data were processed on a separate workstation (Advanced Workstation 4.2, GE Medical System, Wisc.; USA or Vitrea 2, Vital Images Inc., Minnesota, USA). Two- and three-dimensional images were obtained from axial slices by using multiplanar reformatted (MPR), curved planar reformatted (CPR), maximum intensity projection (MIP), and volume rendering (VR) techniques. MDCT images were evaluated by one of two radiologists (EI and AT, 5 years and 12 years' experience reading pancreatic images, respectively).

Tumor size and location, peripancreatic vascular invasion by the tumor (celiac artery, hepatic artery, SMA, portal vein, and SMV), distant metastases (liver, peritoneum, etc.), and adjacent organ invasions were reported. The presence or absence of intra-abdominal lymphadenopathy was also noted, but it did not factor into determining the resectability.

A tumor was considered unresectable if any of the following was found: distant metastases to the liver, peritoneum, or omentum; direct invasion of the adjacent organs (expect the duodenum), and vascular invasion of a major peripancreatic vessel. Criteria defined by Lu et al. (8) were used for estimation of the vascular invasion. The Lu criteria evaluate vascular involvement by the degree of contact of the vessel with the tumor: grade 0: no contiguity of tumor to vessels; grade 1: tumor contiguous less than one-quarter (<90°) of vessel circumference; grade 2: tumor contiguous between one-quarter and one-half (90°-180°); grade 3: between one-half and three-quarters (180°-270°); and grade 4: greater than three-quarters (>270°) or any evidence of focal vessel narrowing or irregularity on the vessel wall, regardless of degree of contiguity. A Lu grade 0 to 2 was considered operable, whereas grade 3 and above were radiologically inoperable. A degree of contact of the vessel with the tumor of 180° was considered indeterminate.

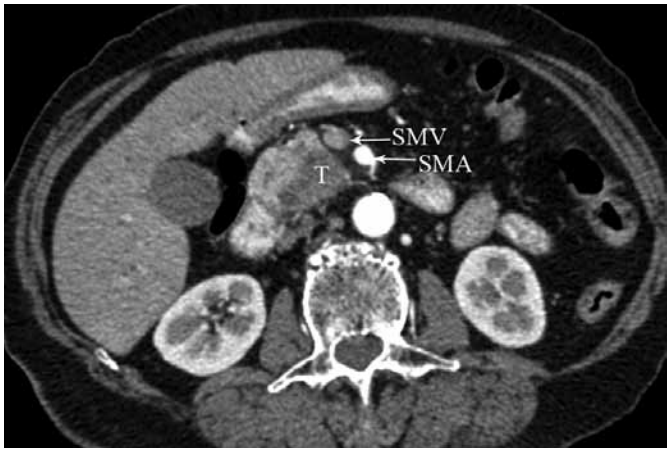

Figure 1. 49-year-old man with resectable pancreatic adenocarcinoma according to MDCT. Axial arterial phase MDCT image shows a hypovascular tumor (T) in the pancreatic head. A fat plane is seen between the tumor and the superior mesenteric artery (SMA) and superior mesenteric vein. No evidence of vascular invasion is seen. In the surgical exploration, the tumor was found to be resectable.

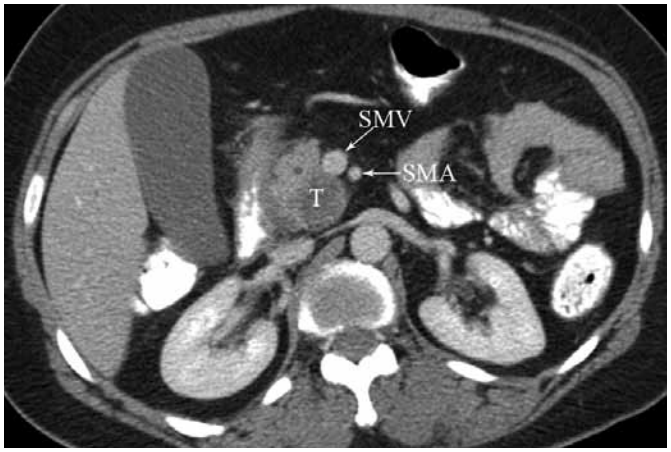

Figure 2. A 47-year-old woman with resectable pancreatic adenocarcinoma according to MDCT. Axial portal venous phase MDCT image shows a hypovascular tumor (T) in the pancreatic head. The tumor is contiguous with 90° of the superior mesenteric vein (Lu grade 1). A fat plane is seen between the tumor and the superior mesenteric artery (SMA). In the surgical exploration, the tumor was found to be resectable.

Statistical analysis

Statistical analyses were performed using the SPSS 15.0 (SPSS Corp., Chicago, IL, USA) statistical data program. Surgical and pathological results were taken as a reference, and the sensitivity, specificity, PPV, NPV, and accuracy of MDCT on determining the surgical resectability of pancreatic adenocarcinomas were investigated.

RESULTS

The surgery was not performed in 150 of 274 (54%) patients who were not suitable for curative surgery according to the MDCT findings; 46% patients (83 males and 41 females; mean age, 60.2 years; range: 28-84 years) underwent laparoscopy and/or laparotomy. A definitive histological diagnosis of pancreatic adenocarcinoma in these patients was obtained from either biopsy or analysis of the resected specimens. The time

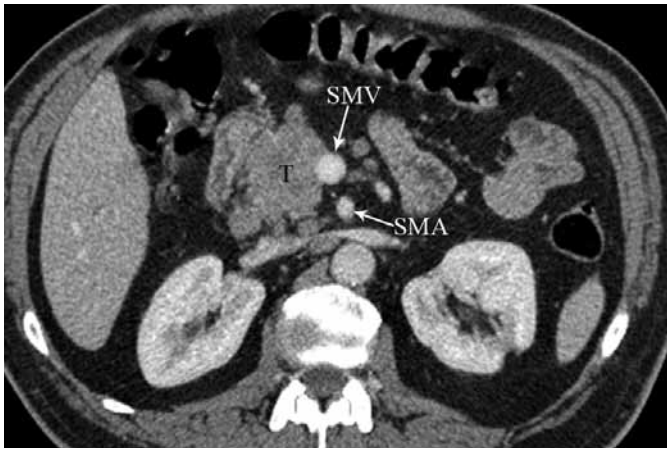

Figure 3. A 57-year-old man with resectable pancreatic adenocarcinoma according to MDCT. Axial portal venous phase MDCT image shows a low-attenuating tumor (T) in the pancreatic head and multiple surrounding peripancreatic lymph nodes. The tumor is contiguous with 90°-180° of the superior mesenteric vein (Lu grade 2). There is no narrowing or wall irregularity of the SMV. No evidence of superior mesenteric artery (SMA) invasion is seen. In the surgical exploration, the tumor was found to be adherent to and invading the SMV.

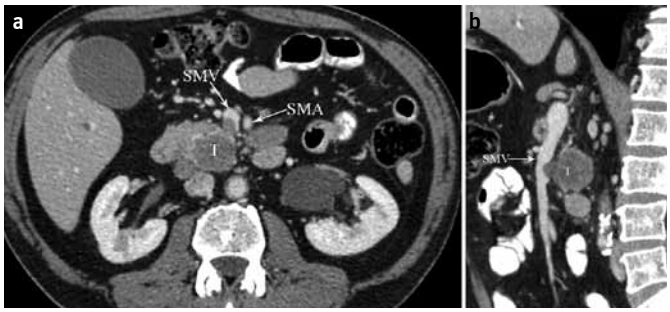

Figure 4. a, b. A 53-year-old man with unresectable pancreatic adenocarcinoma according to MDCT. Axial **(a)** and sagittal **(b)** portal venous phase MDCT images show a hypoattenuating tumor (T) in the head of the pancreas eroding the wall of the superior mesenteric vein (SMV) and penetrating it to form a tumor thrombus. No evidence of superior mesenteric artery (SMA) invasion is seen. Surgical exploration confirmed tumor invasion of the SMV.

that passed between MDCT and the surgery was 3-21 days. The mean tumor size was 3.1 cm, ranging from 1.5 to 10 cm. The locations of the tumor were the head of the pancreas in 77 cases (62.2%), uncinate process in 27 cases (21.7%), body of the pancreas in 16 cases (12.9%), and on the tail of the pancreas in 4 cases (3.2%).

Further, 79 of 124 patients who had undergone surgery were determined as resectable (Figure 1-3), 41 of them were unresectable (Figure 4-6), and 4 of them were equivocal by MDCT. While 62 of 79 cases were determined as resectable by MDCT, 17 of them were unresectable during the surgery. Also, 41 patients who were determined to be unresectable by MDCT were taken to surgery for a palliative biliary, duodenal, or gastric bypass procedure, and it was decided that all of them were unresectable during the surgery (Figure 4-6). Four cases whose peripancreatic vessels were surrounded by the tumor at 180° were determined as equivocal by MDCT. On surgical explora-

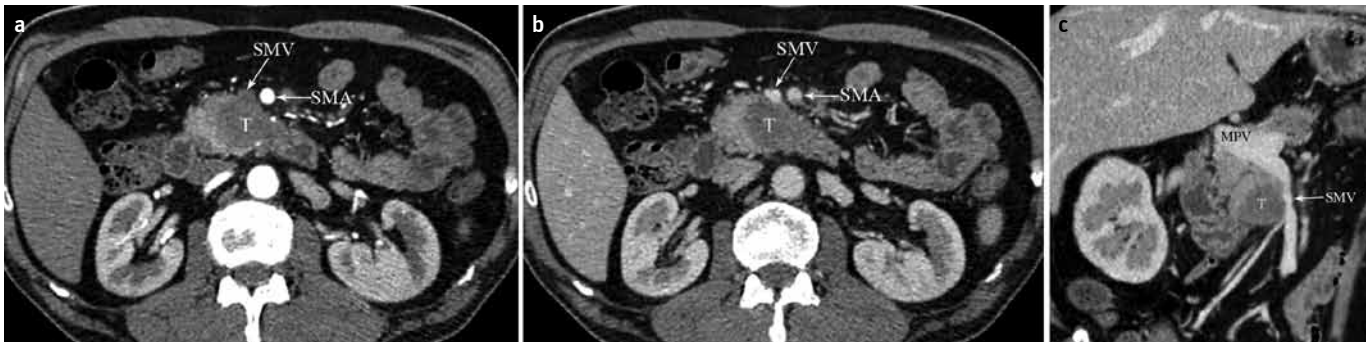

Figure 5. a-c. A 62-year-old man with unresectable pancreatic adenocarcinoma according to MDCT. Axial arterial phase **(a)** and axial **(b)** and coronal **(c)** portal venous phase MDCT images show a hypovascular tumor (T) in the head of the pancreas. A fat plane is seen between the tumor and the superior mesenteric artery (SMA). There is deformity of the superior mesenteric vein (SMV), which is an indication of vascular invasion, regardless of the degree of contact between the vessel and tumor. In image **(c)**, narrowing and wall irregularity of the superior mesenteric vein are seen. In the surgical exploration, the superior mesenteric vein was found to be invaded (MPV: main portal vein).

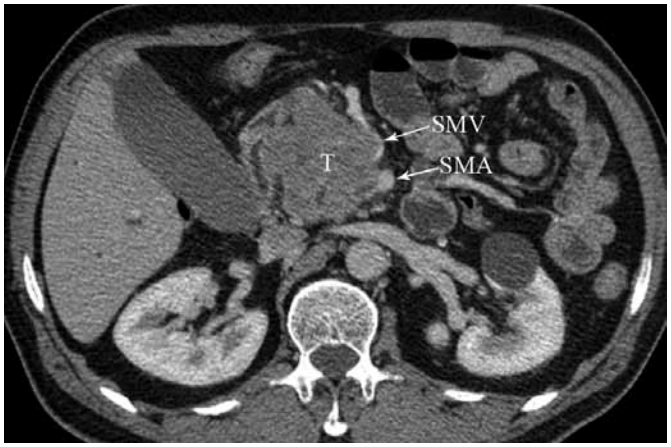

Figure 6. A 56-year-old man with unresectable pancreatic adenocarcinoma according to MDCT. Axial multidetector computed tomography image shows a large tumor (T) in the pancreatic head. The superior mesenteric artery (SMA) was surrounded at 90-180° of the vessel circumference by the tumor. The tumor eroded the wall of the superior mesenteric vein (SMV) and penetrated it to form a tumor thrombus. The tumor was found to be unresectable because of invasion of the superior mesenteric vein on surgical exploration.

tion, tumors of all 4 cases were found to be unresectable due to invasion of the SMA in 1 cases and invasion of the SMV in 3 cases. Comparison of the surgical and MDCT results is seen in Table 1.

Seventeen cases were suggested as resectable tumors by MDCT and were found to be unresectable on surgical exploration (Figure 3). None of these patients had undergone previous chemotherapy; there was a mean time interval of 13 days between MDCT imaging and surgery. In these patients, the tumors were found to be unresectable during surgery due to liver metastases in 9 cases, peritoneal metastases in 3 cases, and vascular invasion in 5 cases. On blinded re-review of the CT images of these patients by an experienced gastrointestinal radiologist, no metastatic lesions could be seen in 9 patients with liver metastases and in 2 of 3 patients with peritoneal metastases. In 1 patient with peritoneal metastases, an 8-mm-diameter peritoneal implant was not reported by MDCT. There was no

Table 1. The comparison of MDCT and surgery results in determining the surgical resectability of pancreatic adenocarcinomas (4 equivocal cases taken as unresectable)

MDCT	Surgery		
	Resectable	Unresectable	Total
Resectable	62	17	79
Unresectable	0	41	41
Total	62	58	120

MDCT: multidetector computed tomography

Table 2. The accuracy of MDCT in determining the surgical resectability of pancreatic adenocarcinomas

	Equivocal taken as resectable	Equivocal taken as unresectable
Sensitivity	100% (62/62)	100% (62/62)
Specificity	66% (41/62)	72% (45/62)
PPV	74% (62/83)	78% (62/79)
NPV	100% (41/41)	100% (45/45)
Accuracy	83% (103/124)	86% (107/124)

PPV: positive predictive value; NPV: negative predictive value

vascular invasion according to the Lu criteria on the MDCT images in the 5 cases that had vascular invasion in the surgical exploration. The contact angle between the tumor and vessel was 90°-180° (Lu grade 2), and no other abnormalities, such as vessel diameter change, contour irregularity, or 'teardrop SMV,' were detected in these cases. The mean time between MDCT scanning and operation was 6 days (3-11 days) in these cases.

The sensitivity, specificity, PPV, NPV, and accuracy were 100%, 66%, 74%, 100%, and 83% with equivocal cases taken as resectable and 100%, 72%, 78%, 100%, and 86%, respectively, with equivocal cases taken as unresectable (Table 2).

DISCUSSION

The main imaging modalities used in the preoperative determination of surgical resectability of pancreatic adenocarcino-

Original Article

mas are transabdominal or endoscopic US, MRI, and CT. The aim of preoperative evaluation is to determine the location, stage, and local resectability of the tumor and accompanied vascular variations. MDCT provides a comprehensive assessment of all of these criteria; hence, currently, it has become the most valuable imaging method for determining the surgical resectability and treatment options of pancreatic adenocarcinomas (6). MDCT obtains two- and three-dimensional images with high spatial resolution due to a shorter image acquisition time, narrower collimation, increased spatial resolution, and better isotropic data acquisition than conventional spiral CT.

In a study by Valls et al. (11), determining the surgical resectability of pancreatic adenocarcinomas by spiral CT, the PPV was reported as 73% and the accuracy was 77%. In a meta-analysis by Bipat et al. (12), the sensitivity and specificity of spiral CT were reported as 81% and 82%, respectively. According to studies performed with spiral CT, NPV rates ranged from 56% to 79% for determining resectability (accurate identification of unresectable tumors), and NPV rates ranged from 96% to 100% for determining unresectability (accurate identification of resectable tumors) (10,11,13-15). While PPV and accuracy rates of spiral CT in determining unresectability range from 85% to 95% and 89% to 100%, respectively, PPV rates for determination of resectability range from 45% to 79% (7,8,11,13,15).

In the preoperative staging of pancreatic adenocarcinomas, different rates have been reported in studies performed with MDCT in the literature. In a study conducted by Catalano et al. (17) with 4-slice MDCT for determining unresectability, the sensitivity, specificity, and accuracy rates were reported as 96%, 86%, and 93%, respectively. Ellsmere et al. (18) reported that the sensitivity was 96% and the specificity was 33% in determining resectability. In studies performed using 4-detector MDCT in the preoperative determination of the surgical resectability of pancreatic cancer by Soriano et al. (7), DeWitt et al. (19), and Ellsmere et al. (18), the accuracy rates were detected as being between 83% and 87%. Although some previous studies of MDCT have shown a slight increase in accuracy in determining the unresectability of pancreatic adenocarcinomas with an increasing number of detectors, Smith et al. (20), Vargas et al. (21), and Zamboni et al. (22) reported that there are no significant differences between different generations of MDCT devices. In a study performed by Smith et al. (20) using 4- and 8-detector MDCT in 140 (40 of whom were operable) pancreatic head adenocarcinomas, the sensitivity, specificity, PPV, NPV, and accuracy were found to be 81%, 68%, 56%, 88%, and 72%, respectively. In another study conducted by Kaneko et al. (6) with 16- and 64-detector MDCT for the evaluation of the surgical resectability of 203 (109 operable) pancreatic head adenocarcinomas, the sensitivity, specificity, PPV, NPV, and accuracy were found to be 100%, 71%, 85%, 100%, and 89%, respectively (6). In our study, we found the sensitivity, specificity, PPV, NPV, and accuracy of MDCT to be 100%, 72%, 78%, 100%, and 86% using 16- and 64-detector MDCT devices in 274 (124 of them were operable) patients with adenocarcinoma of the pancreas. The rates detected in our study were in accordance with the range of rates reported in the literature (6-22).

In the study of Kaneko et al. (6), while all of the 22 patients with an unresectable tumor by MDCT were found to be unresectable during surgery, 67 (85%) of 79 patients with a resectable tumor by MDCT were found to be resectable, and 12 (15%) of them were found to be unresectable during surgery. In 4 (33%) of these underestimated 12 cases, there were liver metastases, and in 4 (33%) of them, there were peritoneal metastases; the 4 (33%) other patients had vascular invasion that could not be determined on MDCT. In our study, 41 patients who were operated on although they were unresectable according to MDCT were found to be unresectable during surgery. While 62 (78%) of 79 patients who were resectable according to MDCT were resectable, 17 of 79 (22%) patients were unresectable during surgery. Nine (52%) of these 17 cases had liver metastases, 5 (29%) had vascular invasion, and 3 (19%) had peritoneal metastases that were not reported by MDCT. When our study was compared with the Kaneko et al. study (6), more hepatic metastases could not be determined by MDCT in our study. However, on blinded re-review of the CT images of these patients, no metastatic lesions could be seen in any of the 9 patients with liver metastases. The metastatic liver lesions in these cases may have been too small to be detected by MDCT, they did not have sufficient density difference with the liver parenchyma, or they were located on the surface of liver. The sensitivity of MDCT to determine hepatic metastases ranges from 75% to 87% in the literature (23-25). In a study on the detection of liver metastases with MRI and spiral CT, the accuracy of spiral CT and MRI were reported as 87% and 93%, respectively (24). The sensitivity of positron emission tomography (PET) was found to be 70%, and the specificity was found to be 95%; a positive correlation was found between decreases in metastatic lesion size and decreases in those rates (26). According to all this information, laparoscopy will be more beneficial in determining small-size or surface-located liver metastases that can not be seen on MDCT images.

Detection of small peritoneal and lymph node metastases is a major problem for all imaging modalities. Lymph node diameter above 1 cm is an important criterion for metastases. PET has more specificity compared with CT and MRI in the detection of lymph node metastases, but determining lymph node metastases below 1 cm is still a major problem of PET (14,27). Therefore, laparoscopic surgery and laparoscopic US are recommended for more accurate determination of peritoneal, nodal, and liver metastases (28,29). In our study, when we re-reviewed MDCT images of 3 cases that had peritoneal metastases in surgery but were missed by MDCT, in 2 cases, peritoneal metastases could not be seen on MDCT; in 1 case, an 8-mm-diameter peritoneal implant was seen that was not reported by MDCT. Studies in the literature showed that laparoscopic evaluation has a higher sensitivity than CT in determining peri-

toneal metastases. Jimenez et al. (29) found liver and peritoneal metastases on laparoscopic examination in 25% of 125 patients who were resectable according to CT. However, Pisters et al. (30) suggested that laparoscopic surgery contributes to MDCT in only 4%-13% of cases that are evaluated as resectable on MDCT.

In the absence of distant metastases or local tumor spread, the resectability of pancreatic tumors depends on vascular involvement, as well as involvement of major peripancreatic arteries, such as the celiac trunk, SMA, and hepatic artery, which makes surgery impossible; surgery may be preferred for gastroduodenal artery involvement on smaller branches. For single-detector helical CT, the sensitivity for determination of vascular invasion was in the range of 60%-89%, and the accuracy was 62%-92%. Accuracy rates were 90%, 87%, and 90%, respectively, in a study that compared the role of biphasic MDCT, MRI, and MR angiography with MRI in determining vascular invasion (31). Raptopoulos et al. (32) suggested that CT angiography has higher accuracy in the determination of unresectability than only axial images of CT. Researchers found the NPV of axial images alone in the determination of tumor resectability to be 70% and found the NPV of CT angiography images evaluated with axial images to be 96%. Brügel et al. (33) suggested using MPR images in the determination of vascular invasion, and they reported that the sensitivity of MDCT had risen from 58% to 74% by using axial images and MPR images together in the determination of vascular invasion.

In Lu et al.'s (8) study for the determination of vascular invasion in pancreatic adenocarcinomas, while the sensitivity of contact angle between the tumor and vessel above 180° (Lu grade 3 and 4) was reported as 84%, the specificity was reported as 98%. In other studies about the determination of vascular invasion, it was reported that cases that were compatible with Lu grade 2 (contact angle between tumor and vessel is 90°-180°) were located at a critical point, and only 43%-71% of these cases were resectable in surgery (28). Brügel et al. (33) reported that the probability of vascular invasion in cases that had Lu grade 2 criteria on axial images was 50%. As a result of their studies, in which Lu criteria were used, Nakayama et al. (34) suggested that different criteria should be used to evaluate vascular involvement. Researchers noticed that Lu criteria are not be useful in determining vascular invasion if there is inflammatory or fibrous tissue around the peripancreatic arteries. In studies of O›Malley et al. (35) and Fishman et al. (36), they confirmed the Lu criteria, but they also reported that it is important to evaluate vessel diameter changes or occlusion with contact angle in the determination of vascular invasion. Hough et al. (37) reported that a «teardrop SMV sign» is important evidence in determining the resectability of pancreatic head cancers. Kaneko et al. (6) re-evaluated images of 4 patients whose vascular invasion were missed on MDCT; they detected that there was no vascular invasion according to the Lu criteria (Lu grade 2) in 3 patients, but they detected that 1 of these 3 patients had a «teardrop SMV sign» on the MDCT images. In images of the fourth case, they identified that there was a replaced right hepatic artery that was completely invaded by the tumor. In our study, we re-evaluated the images of 5 cases that had vascular invasion at surgery but was missed on MDCT; in all of their MDCT images, there was no evidence of vascular invasion. In all of these 5 cases, the contact angle between the tumor and vessel was in the range of 90°-180° (Lu grade 2), and there was no other evidence, like vessel diameter change, occlusion, or "teardrop SMV sign." The mean time between MDCT scan and operation was 6 days (3-11 days) in these cases. Based on information in the literature and the results of our study, we suggest that it is not always possible to determine local vascular invasion correctly, and vascular invasion can not be determined correctly according to only the Lu criteria. In the study of Kaneko et al. (6), it was reported that in 8 patients who had vessels surrounded by the tumor at 180° and thus were grade 2-3 according to the Lu criteria, all of them were unresectable in surgery. Similarly, in our study, it was determined that all 4 patients who had vessels surrounded by the tumor at 180° were unresectable in surgery as well. For cases that are borderline, like these, other imaging modalities should be used in the preoperative evaluation, or other treatment options, such as chemotherapy or radiotherapy, should be considered.

In the preoperative evaluation of patients with pancreatic adenocarcinomas, MDCT should be used primarily, and correlating the results of MDCT by endoscopic US would be valuable in tumor staging and the treatment approach. Soriano et al. (7) suggested that MDCT had a higher accuracy rate than endoscopic US, MRI, and conventional angiography in determining the resectability of pancreatic cancers. Studies also suggested that endoscopic US had more accurate results on tumor size and lymph node invasion (7). Smith et al. (20) suggested that early local invasion of tumors could not always be detected by MDCT. Tio et al. (38) reported that endoscopic US had an accuracy rate of 83% in staging pancreatic cancer.

In the preoperative evaluation of pancreatic adenocarcinomas, early local invasion, vascular invasion, and small peritoneal and liver metastases could not be detected by MDCT, but unnecessary operations can be prevented by correlation of MDCT results with other imaging modalities. It is suggested that minimally invasive modalities, like laparoscopy, which have high specificity, will still continue to have an important role in staging pancreatic adenocarcinomas.

In conclusion, MDCT has high accuracy in determining the preoperative surgical resectability of pancreatic adenocarcinomas. However, detecting small liver and peritoneal metastases and determining local vascular invasion accurately still remain major problems. Pancreatic surgeons should be aware of the intrinsic limitations of MDCT while deciding on surgery for patients with pancreatic adenocarcinomas.

Ethics Committee Approval: Ethics committee approval was received for this study.

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Peer-review: Externally peer-reviewed.

Author contributions: Concept - A.T., E.İ., E.B.B.; Design - A.T., E.İ.; Supervision - A.T., E.İ., E.B.B.; Resource - A.T., E.İ., Z.S.; Materials - E.İ., A.T., Z.S.; Data Collection&/or Processing - E.İ., A.T., E.B.B.; Analysis&/or Interpretation - A.T., E.İ., Z.S.; Literature Search - A.T., E.İ.; Writing - E.İ., A.T.; Critical Reviews - A.T, E.İ.

Acknowledgements: We thank Erhan Dursun for reviewing and editing this manuscript.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study has received no financial support.

Original Article

REFERENCES

1. Jemal A, Siegel R, Xu J, Ward E. Cancer statistics, 2010. CA Cancer J Clin 2010; 60 :277-300. **[CrossRef]**
2. Lillemoe KD. Current management of pancreatic carcinoma. Ann Surg 1995; 221: 133-48. **[CrossRef]**
3. Balcom JH 4th, Rattner DW, Warshaw AL, Chang Y, Fernandez-del Castillo C. Ten-year experience with 733 pancreatic resections: Changing indications, older patients, and decreasing length of hospitalization. Arch Surg 2001; 136: 391-8. **[CrossRef]**
4. Prokesch RW, Schima W, Chow LC, Jeffrey RB. Multidetector CT of pancreatic adenocarcinoma: diagnostic advances and therapeutic relevance. Eur Radiol 2003; 13: 2147-54. **[CrossRef]**
5. Warshaw AL, Fernández-del Castillo C. Pancreatic carcinoma. N Engl J Med 1992; 326: 455-65. **[CrossRef]**
6. Kaneko OF, Lee DM, Wong J, et al. Performance of multidetector computed tomographic angiography in determining surgical resectability of pancreatic head adenocarcinoma. J Comput Assist Tomogr 2010; 34: 732-8. **[CrossRef]**
7. Soriano A, Castells A, Ayuso C, et al. Preoperative staging and tumor resectability assesment of pancreatic cancer: prospective study comparing endoscopic ultrasonography, helical computed tomography, magnetic resonance imaging, and anjiography. Am J Gastroenterol 2004; 99: 492-501. **[CrossRef]**
8. Lu DS, Reber HA, Krasny RM, Kadell BM, Sayre J. Local staging of pancreatic cancer: criteria for unresectability of major vessels as revealed by pancreatic-phase, thin-section helical CT. Am J Roentgenol 1997; 168: 1439-43. **[CrossRef]**
9. Neoptolemos JP, Stocken DD, Dunn JA, et al. European Study Group for Pancreatic Cancer. Influence of resection margins on survival for patients with pancreatic cancer treated by adjuvant chemoradiation and/or chemotherapy in the ESPAC-1 randomized controlled trial. Ann Surg 2001; 234: 758-68. **[CrossRef]**
10. Park DI, Lee JK, Kim JE, et al. The analysis of resectability and survival in pancreatic cancer patients with vascular invasion. J Clin Gastroenterol 2001; 32: 231-4. **[CrossRef]**
11. Valls C, Andia E, Sanchez A, et al. Dual-phase helical CT of pancreatic adenocarcinoma: assesment of respsctability before surgery. Am J Roentgenol 2002; 178: 821-6. **[CrossRef]**
12. Bipat S, Phoa SS, van Delden OM, et al. Ultrasonography, computed tomography and magnetic resonance imaging for diagnosis and determining resectability of pancreatic adenocarcinoma: a meta-analysis. J Comput Assist Tomogr 2005; 29: 438-45. **[CrossRef]**
13. Bluemke DA, Cameron JL, Hruban RH, et al. Potentially resectable pancreatic adenocarcinoma: Spiral CT assessment with surgical and pathologic correlation. Radiology 1995; 197: 381-5. **[CrossRef]**
14. Diehl SJ, Lehmann KJ, Sadick M, Lachmann R, Georgi M. Pancreatic cancer: Value of dual-phase helical CT in assessing resectability. Radiology 1998; 206: 373-8. **[CrossRef]**
15. Procacci C, Biasiutti C, Carbognin G, et al. Spiral computed tomography assessment of resectability of pancreatic ductal adenocarcinoma: Analysis of results. Dig Liver Dis 2002; 34: 739-47. **[CrossRef]**
16. Brennan DD, Zamboni GA, Raptopoulos VD, et al. Comprehensive preoperative assessment of pancreatic adenocarcinoma with 64-section volumetric CT. Radiographics 2007; 27: 1654-67. **[CrossRef]**
17. Catalano C, Laghi A, Fraioli F, et al. Pancreatic carcinoma: the role of high-resolution multislice spiral CT in the diagnosis and assessment of resectability. Eur Radiol 2003; 13: 149-56.
18. Ellsmere J, Mortele K, Sahani D, et al. Does multidedector-row CT eliminate the role of diagnostic laparoscopy in assesing the resectability of pancreatic head adenocarcinoma? Surg Endosc 2005; 19: 369-73. **[CrossRef]**
19. DeWitt J, Devereaux B, Chriswell M, et al. Comparison of endoscopic ultrasonography and multidedector computed tomography for detecting and staging pancreatic cancer. Ann Intern Med 2004; 141: 753-63. **[CrossRef]**
20. Smith SL, Basu A, Rae DM, et al. Preoperative staging accuracy of multidetector computed tomography in pancreatic head adenocarcinoma. Pancreas 2007; 34: 180-4. **[CrossRef]**
21. Vargas R, Nino-Murcia M, Trueblood E, Jeffrey RB Jr. MDCT in pancreatic adenocarcinoma: prediction of vascular invasion and resectability using a multiphasic technique with curved planar reformations. Am J Roentgenol 2004; 182: 419-25. **[CrossRef]**
22. Zamboni GA, Kruskal JB, Vollmer CM, et al. Pancreatic adenocarcinoma: value of multidetector CT angiography in preoperative evaluation. Radiology 2007; 245: 770-8. **[CrossRef]**
23. Richter GM, Simon C, Hoffmann V, et al. Hydrospiral CT of the pancreas in thin section technique. Radiologe 1996; 36: 397-405. **[CrossRef]**
24. Trede M, Rumstadt B, Wendl K, et al. Ultrafast magnetic resonance imaging improves the staging of pancreatic tumors. Ann Surg 1997; 226: 393-405. **[CrossRef]**
25. Calculli L, Casadei R, Diacono D, et al. Role of spiral computerized tomography in the staging of pancreatic carcinoma. Radiol Med 1998; 95:344-8.
26. Diederichs CG, Staib L, Vogel J, et al. Values and limitations of 18F-fluorodeoxyglucose-positron-emission tomography with preoperative evaluation of patients with pancreatic masses. Pancreas 2000; 20: 109-16. **[CrossRef]**
27. Murakami K, Nawano S, Moriyama N, et al. [Staging of pancreatic ductal adenocarcinoma using dynamic MR imaging]. Nihon Igaku Hoshasen Gakkai Zasshi 1997; 57: 596-601.
28. Van Delden OM, de Wit LT, Nieveen van Dijkum EJ, Reeders JW, Gouma DJ. Laparoscopic ultrasonography for abdominal tumor staging. Eur Radiol 1998; 8: 1405-8. **[CrossRef]**
29. Jimenez RE, Warshaw AL, Fernandez-Del Castillo C. Laparoscopy and peritoneal cytology in the staging of pancreatic cancer. J Hepatobiliary Pancreat Surg 2000; 7: 15-20. **[CrossRef]**
30. Pisters PW, Lee JE, Vauthey JN, Charnsangavej C, Evans DB. Laparoscopy in the staging of pancreatic cancer. Br J Surg 2001; 88: 325-37. **[CrossRef]**

31. Arslan A, Buanes T, Geitung JT. Pancreatic carcinoma: MR, MR angiography and dynamic helical CT in the evaluation of vascular invasion. Eur J Radiol 2001; 38: 151-9. [CrossRef]
32. Raptopoulos V, Steer ML, Sheiman RG, Vrachliotis TG, Gougoutas CA, Movson JS. The use of helical CT and CT angiography to predict vascular involvement from pancreatic cancer: Correlation with findings at surgery. Am J Roentgenol 1997; 168: 971-7. [CrossRef]
33. Brügel M, Rummeny EJ, Dobritz M. Vascular invasion in pancreatic cancer: Value of multislice helical CT. Abdom Imaging 2004; 29: 239-45. [CrossRef]
34. Nakayama Y, Yamashita Y, Kadota M, et al. Vascular encasement by pancreatic cancer: correlation of CT findings with surgical and pathologic results. J Comput Assist Tomogr 2001; 25: 337-42. [CrossRef]
35. O'Malley ME, Boland GW, Wood BJ, Fernandez-del Castillo C, Warshaw AL, Mueller PR. Adenocarcinoma of the head of the pancreas: Determination of surgical unresectability with thin-section pancreatic-phase helical CT. Am J Roentgenol 1999; 173: 1513-8. [CrossRef]
36. Fishman EK, Horton KM, Urban BA. Multidetector CT angiography in the evaluation of pancreatic carcinoma: preliminary observations. J Comput Assist Tomogr 2000; 24: 849-53. [CrossRef]
37. Hough TJ, Raptopoulos V, Siewert B, Matthews JB. Teardrop superior mesenteric vein: CT sign for unresectable carcinoma of the pancreas. Am J Roentgenol 1999; 173: 1509-12. [CrossRef]
38. Tio TL, Sie LH, Kallimanis G, et al. Staging of ampullary and pancreatic carcinoma: comparison between endosonography and surgery. Gastrointest Endosc 1996; 44: 706-13. [CrossRef]