TOPIC HIGHLIGHT

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State-of-the-art preoperative staging of gastric cancer by MDCT and magnetic resonance imaging

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Abstract

Gastric cancer is one of the most common and fatal cancers. The importance of accurate staging for gastric cancer has become more critical due to the recent introduction of less invasive treatment options, such as endoscopic mucosal resection or laparoscopic surgery. The tumor-node-metastasis staging system is the generally accepted staging system for predicting the prognosis of patients with gastric cancer. Multidetector row computed tomography (MDCT) is a widely accepted imaging modality for the preoperative staging of gastric cancer that can simultaneously assess locoregional staging, including the gastric mass, regional lymph nodes, and distant metastasis. The diagnostic performance of MDCT for T- and N-staging has been improved by the technical development of isotropic imaging and 3D reformation. Although magnetic resonance imaging (MRI) was not previously used to evaluate gastric cancer due to the modality's limitations, the development of high-speed sequences has made MRI a feasible tool for the staging of gastric cancer.

Core tip: With the technical development of multiplanar imaging and 3D reformation, the diagnostic performance of Multidetector row computed tomography for T-staging has improved. N-staging of advanced gastric cancer has also improved, but the diagnostic effectiveness of N-staging is limited for patients with early gastric cancer. The limitations of magnetic resonance imaging (MRI) once prevented its use in evaluating gastric cancer; however, the development of high-speed sequences has made MRI a feasible tool. The intrinsic strength of MRI is the ability to produce contrast in soft tissue, and the use of tissue-specific contrast agents may aid in gastric cancer staging.

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INTRODUCTION

Although its prevalence is decreasing in Western countries, gastric cancer remains the second most common cause of cancer-related death. Gastric cancer is more common in Asian countries, particularly China, Japan, and South Korea[1-3]. Complete surgical resection was

Table 1 T-staging of gastric cancer, American Joint Committee on Cancer 7th manual

TX	Primary tumor cannot be assessed
T0	No evidence of primary tumor
Tis	Carcinoma *in situ*: intraepithelial tumor without invasion of the lamina propria
T1	Tumor invades the lamina propria, muscularis mucosae, or submucosa
T1a	Tumor invades the lamina propria or muscularis mucosae
T1b	Tumor invades the submucosa
T2	Tumor invades the muscularis propria
T3	Tumor penetrates the subserosal connective tissue without invasion of the visceral peritoneum or adjacent structures. T3 tumors also include those extending into the gastrocolic or gastrohepatic ligaments or into the greater or lesser omentum, without perforation of the visceral peritoneum covering these structures
T4	Tumor invades the serosa (visceral peritoneum) or adjacent structures
T4a	Tumor invades the serosa (visceral peritoneum)
T4b	Tumor invades adjacent structures, such as the spleen, transverse colon, liver, diaphragm, pancreas, abdominal wall, adrenal gland, kidney, small intestine, and retroperitoneum

once thought to be the only successful option for curing gastric cancer[4]. However, the development of endoscopic procedures that can be used to treat early gastric cancer, such as endoscopic mucosal resection (EMR) and endoscopic submucosal dissection, has reduced the morbidity and mortality rates with minimally invasive curative therapy[5]. Furthermore, the recent development of chemotherapeutic agents can prolong the survival of patients with advanced disease. Multiple treatment options make the choice of the appropriate treatment for each patient more important, and the accurate staging of a patient's disease can have a major role in determining the final clinical outcome. The tumor-node-metastasis (TNM) staging system, which is a generally accepted staging system in clinical practice, has been shown to accurately predict patient prognosis[6]. Traditionally, deep tumor infiltration into an adjacent structure (T4) and the presence of multiple, metastatic lymph nodes (N3 or N4) or distant metastases limited the resectability of gastric cancer, and the major function of preoperative staging was to detect these conditions. However, due to the widespread use of EMR for treating early gastric cancer, more precise and accurate staging is required, and differentiating between T1 and T2 (or even between T1a and T1b) is currently necessary for endoscopists to determine the appropriate prognosis[5,7]. Additionally, because the presence of nodal metastases is a contraindication for EMR, the accuracy of N-staging (N0 *vs* N1) now receives more attention.

The standard imaging modalities used for the preoperative staging of gastric cancer include computed tomography (CT) and endoscopic ultrasonography (US). Endoscopic US is regarded as the most accurate imaging tool for evaluating tumor depth, and CT is the principal imaging modality used for staging because of its ability to detect distant metastases. Magnetic resonance imaging (MRI) and diagnostic laparoscopy are other imaging tools that can be successfully used to stage gastric cancer.

The currently used multidetector row computed tomography (MDCT) with 16 or more channels and thin collimation can provide 1-mm-thick, high-resolution imaging, and the effect of motion is very limited due to the high image acquisition speed of MDCT. Isotropic imaging can be used to obtain multiplanar reformation (MPR) images at any angle, and virtual gastroscopy or CT gastrography with 3D reformation is also available. Virtual gastroscopy provides 3D-reconstructed, endoluminal images, such as those used in CT colonography. These benefits have improved the diagnostic performance of MDCT when detecting and staging gastric cancer in daily, clinical practice. Technical developments improving MRI, such as parallel imaging and fast sequences, have increased its use in abdominal imaging. Although the reported results of MRI for abdominal imaging have not been completely successful, the intrinsic strength of MRI as a contrast imaging method may allow for T-staging accuracy that is comparable to that of MDCT. Additionally, new contrast agents can also enhance MRI performance in N- and M-staging of gastric cancer.

In this manuscript, we provide the review of the recently revised TNM staging system for gastric cancer and then discuss the performance of MDCT and MRI in the preoperative staging of gastric cancer. We will also discuss some of the state-of-the-art techniques that can be used to assess gastric cancer, with special emphasis on preoperative staging.

SEVENTH EDITION OF THE AMERICAN JOINT COMMITTEE ON CANCER STAGING SYSTEM FOR GASTRIC CANCER

The latest version of TNM staging by the Union for International Cancer Control and the American Joint Committee on Cancer (AJCC) is the seventh edition, released in 2009, and is summarized in Tables 1, 2 and 3[8]. This staging system has been periodically revised based on newly collected scientific data. In the latest revision, tumors arising at the esophagogastric (EG) junction and those arising in the stomach within 5 cm of the EG junction and involving the EG junction are considered esophageal cancer. The T-staging system has also been modified in a manner similar to other bowel tumors (*i.e.,* esophagus and small and large bowel); T2 is now defined as a tumor invading the muscularis propria and T3 as a tumor invading the subserosal connective tissue. Stage T2b as defined in the 6th edition was restaged as T3 in

Table 2 N-staging of gastric cancer, American Joint Committee on Cancer 7th manual	
NX	Regional lymph node(s) cannot be assessed
N0	No regional lymph node metastasis
N1	Metastasis in 1 to 2 regional lymph nodes
N2	Metastasis in 3 to 6 regional lymph nodes
N3	Metastasis in 7 or more regional lymph nodes

Table 3 Stage and prognostic group of gastric cancer, American Joint Committee on Cancer 7th manual			
Stage X	TX	NX	MX
Stage I A	T1	N0	M0
Stage I B	T2	N0	M0
	T1	N1	M0
Stage II A	T3	N0	M0
	T2	N1	M0
	T1	N2	M0
Stage II B	T4a	N0	M0
	T3	N1	M0
	T2	N2	M0
	T1	N4	M0
Stage III A	T4a	N1	M0
	T3	N2	M0
	T2	N3	M0
Stage III B	T4b	N0 or N1	M0
	T4a	N2	M0
	T3	N3	M0
Stage III C	T4b	N2 or N3	M0
	T4a	N3	M0
Stage IV	Any T	Any N	M1

the 7th edition, and T3 as defined in the 6th edition was restaged as T4a. As early gastric cancer (EGC) is traditionally defined as a tumor confined to the mucosa and submucosa, cancers staged T1a and T1b are considered EGC by definition. The previously adopted Japanese classification for N-staging, with designations based on the anatomical location of the involved regional lymph nodes, is not used now[9,10]. Currently, the number of cancer-involved lymph nodes is the only factor determining the N-stage. The advantages of this method are its relative ease and independent reporting by pathologists and the strong correlation between the number of affected lymph nodes and patient survival rates. However, the current method for N-staging can be biased by the number of collected lymph nodes; several authors reported that the total number of collected lymph nodes can influence a patient's prognosis[11,12]. Regardless, this opinion is not yet reflected in the AJCC 7th edition, a version in which the number of lymph nodes for each N-staging was decreased (Table 2). Retropancreatic, para-aortic, hepatoduodenal, retroperitoneal, and mesenteric lymph nodes are considered distant metastases (M1) in gastric cancer.

MDCT

MDCT protocols

A fasting time of at least six hours is required for complete gastric emptying. Patients usually receive 10-20 mg of butylscopolamine bromide intramuscularly or intravenously 10-15 min before CT scanning to minimize peristaltic movement[13,14]. Any history of glaucoma, urinary outflow obstruction, or cardiac arrhythmia is checked to avoid the use of butylscopolamine in patients with contraindications. To obtain optimal distention of the stomach, several types of oral contrast agents are used. Among them, positive contrast agents, such as diluted barium or water-soluble iodine, mask the enhancement of the gastric mucosa and inhibit 3D reformation, both of which are critical for cancer staging[15,16]. Therefore, negative (air) or neutral (water or methyl cellulose) contrast agents are generally used. Negative and neutral agents help to depict the detailed enhancement pattern of gastric wall layers[17,18]. In 3D reformation and virtual gastroscopy, air is the preferred oral contrast agent. A recent study reported that MDCT using gas distention and 3D CT gastrography provided T-staging of preoperative gastric cancer comparable to hydro-CT (*i.e.*, using water as the oral contrast agent) but that gas distention was more effective for lesion detection. We therefore recom-

mend air as the preferred oral contrast agent[15]. In our medical institution, effervescent granules with a minimal amount of water are orally administered immediately prior to CT scanning to obtain optimal gastric distention using air[13]. Each patient receives intravenous contrast agent at a rate of 3-4 mL/s using a power injector, and CT images are obtained approximately 70 s following the injection, which is the optimal time for evaluating the enhancement of gastric tumor and hepatic metastases. In some medical institutions, early arterial phase imaging can be added to assess possible vascular anomalies in the vessels supplying the stomach[19,20]. The left posterior oblique and right decubitus positions are used for evaluating the entire distended stomach. In the left posterior oblique position, the lower part of the stomach, including the antrum, is distended, and residual fluid collects in the fundus of the stomach. In the right decubitus position, the upper part of the stomach, including the fundus, is fully extended[21]. When using water as the oral contrast agent, the supine and prone positions are recommended. An MDCT unit with 16 or more channels is recommended to acquire isotropic imaging with less than 1.25-mm collimation. Two-dimensional axial, coronal, and sagittal images provide a quick view of the stomach and tumor and allow for instant evaluation of the tumor location and depth. Three-dimensional rendering, such as virtual gastroscopy or CT gastrography, can provide additional information on depth perception, fold change, and superficial lesions[22,23]. In our medical institution, axial CT images are reconstructed using a 3-mm section thickness and a reconstruction interval of 2-3 mm; an additional image set using a 1-mm section thickness and reconstruction interval is reconstructed for 3D rendering. Coronal and sagittal MPR images are also reconstructed with a 3-mm section thickness and interval. Virtual gastroscopy[24] and barium-study-looking 3D CT gastrography using a surface-shaded, volume-rendering technique[13] are
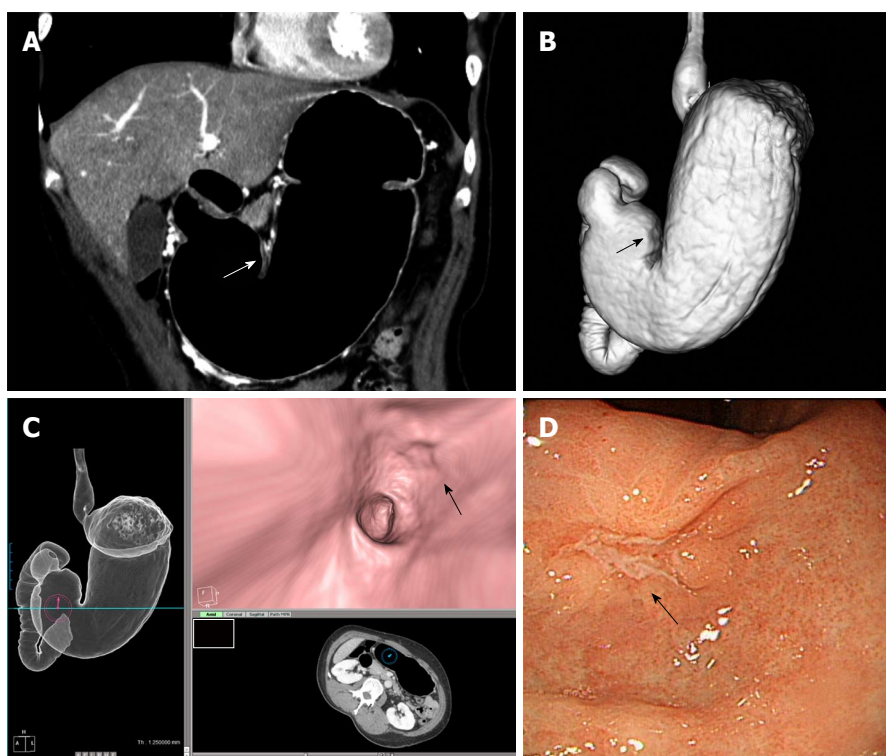
Figure 1 T1a gastric cancer in a 53-year-old female patient. A: Coronal 2D image shows small mucosal enhancement (arrow) in the lesser curvature side of the antrum; B: Computed tomography gastrography shows a small mucosal irregularity (arrow) in the same area; C: Virtual gastroscopy delineates a shallow, depressed lesion (arrow); D: Endoscopy reveals a small mucosal irregularity confined to the mucosa (arrow). Endoscopic submucosal dissection was performed and pathological examination revealed pT1a early gastric cancer.

reconstructed with thin-section, isotropic data (Figure 1).

Lesion detectability and T-staging

Pathologically, the gastric wall consists of the following five layers: mucosa, submucosa, muscularis propria, subserosa, and serosa. However, on CT images, the gastric wall is observed as three layers: well-enhancing mucosa, submucosa as a low attenuated stripe, and musculoserosal layers of slightly elevated attenuation[25]. Gastric cancers manifest as having enhancing wall thickening on CT, and the destruction of normal gastric wall structures can suggest the possible depth of invasion. Therefore, the extent of gastric wall thickening and the degree of enhancement can influence the detection rate and T-staging accuracy. T1 tumors are sub-staged as T1a and T1b: a stage T1a tumor is confined to the mucosa, and T1b tumors have invaded the submucosa. Because the incidence of lymph node involvement is much higher in T1b tumors than in T1a tumors (17.9% *vs* 2.2%) and endoscopic procedures for a tumor invading the submucosa are challenging, tumor sub-staging has a substantial clinical impact[14,26-28]. EUS is known to be effective for differentiating between T1a and T1b tumors[29]. On MDCT images, T1a tumors are usually not visible, and T1b tumors more frequently show mucosal thickening and enhancement. To differentiate between T1b and T2, T1b tumors show a low-attenuated stripe at the base of the tumor, which suggests a submucosa layer, while T2 tumors show loss of a low-attenuated stripe, which indicates involvement of the entire submucosal layer[14] (Figure 2). T3 tumors have subserosal invasion, and discrimination between a gastric mass and the outer layer is visibly impossible, and smooth outer margin of the outer layer or a few small linear strandings in the perigastric fat plane can be noted[30]. Stage T4a tumors also demonstrate serosal involvement, which makes differentiating between T3 and T4a using MDCT very difficult (the gastric serosa is not delineated on CT images). In addition, the amount of adipose tissue in the subserosal area varies from person to person[16] (Figures 3 and 4). In our experience, T4a tumors frequently show micronodules or dense, band-like stranding and can be found in the perigastric area. Stage T4b tumors show direct extension into an adjacent organ or structure and show obliteration of the fat plane between the gastric mass and adjacent organs.

Two meta-analyses of preoperative gastric cancer staging have been reported[31,32]. However, these two studies are collections of data from the 1990s to 2006 or 2009 and have not been adapted to the updated AJCC staging system. Additionally, most of the data used in the two meta-analyses were obtained using MDCT with fewer than 4 channels. Kwee *et al*[31] reported that the diagnostic accuracy of MDCT for overall T-staging varied between 77.1% and 88.9%. Sensitivities and specificities for serosal invasion (T4a or T4b in the AJCC 7th edition) have been reported to be between 82.8% and 100% and between 80% and 96.8%, respectively[13,17,33,34]. The authors also reported that the overall T-staging and identification
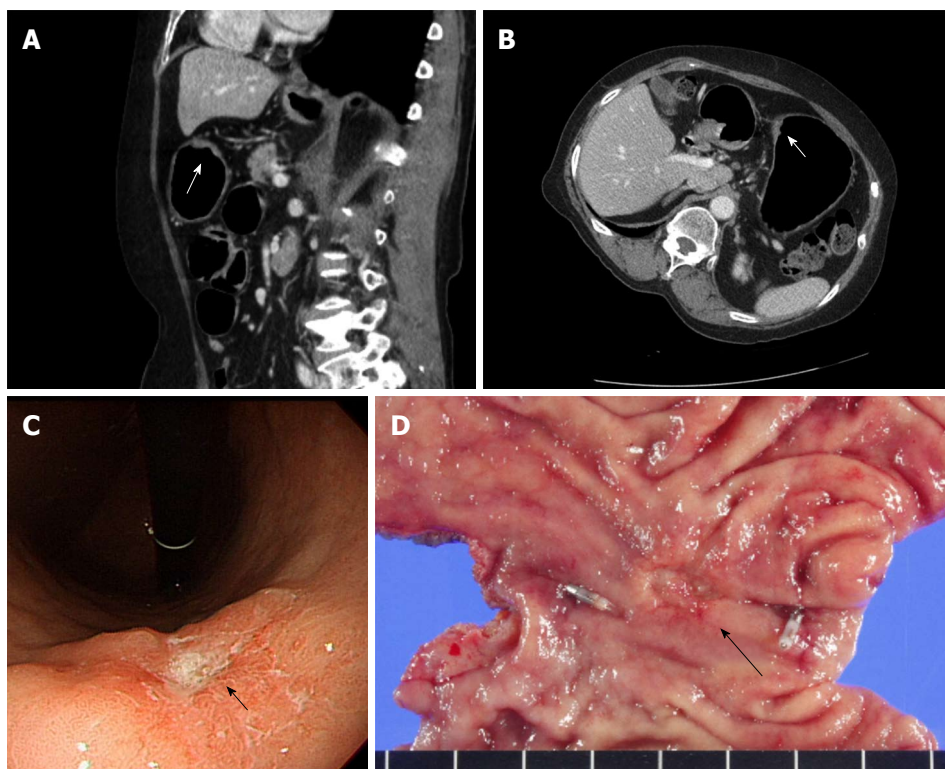
Figure 2 T2 gastric cancer in a 66-year-old female patient. A: Sagittal 2D image shows enhancing wall thickening with ulceration (arrow) in the lesser curvature side of the low body of the stomach; B: Left posterior oblique axial 2D image also delineates enhancing wall thickening (arrow) in the lesser curvature side of the low body of the stomach. The enhancing lesion involves the entire gastric wall layer, and no low attenuated stripe is visible at the base of the tumor; C: Endoscopy reveals a protruding mass with ulceration (arrow). The impression of the endoscopist was early gastric cancer; D: Subtotal gastrectomy was performed and pathological examination revealed pT2 gastric cancer (arrow).
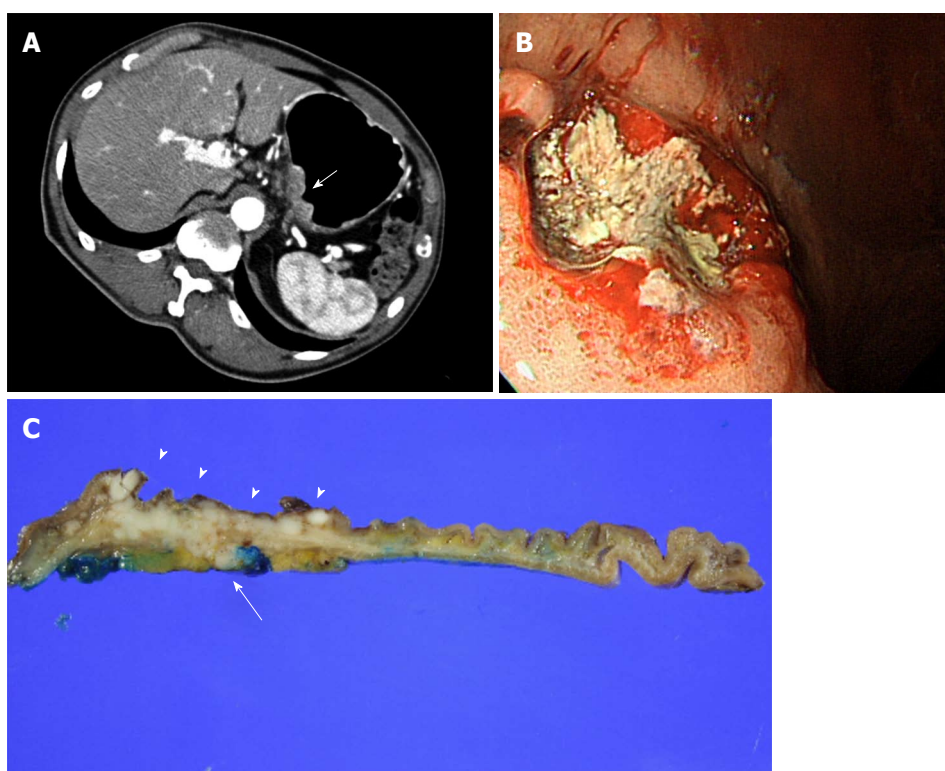

Figure 3 T3 gastric cancer in a 63-year-old male patient. A: Right decubitus 2D axial image shows thickening of the gastric wall (arrow) involving the entire layer. Perigastric infiltrations are noted outside of the tumor; B: Endoscopy reveals a large ulcerative tumor; C: Surgical specimen showing the tumor (arrowheads) and tumor extension to perigastric fat (arrow).
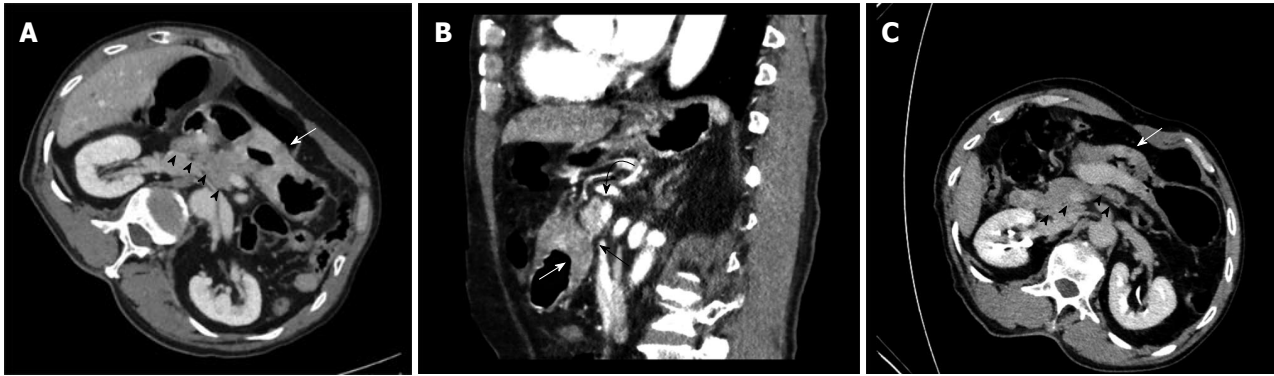
Figure 4 T4a gastric cancer in a 72-year-old male patient. A: Left posterior oblique axial 2D image shows prominent wall thickening of the gastric body (arrow) abutting the pancreas (arrowheads); B: Sagittal 2D image delineates reserved fat plane (black arrow) between the gastric mass (white arrow) and pancreas (curved arrow); C: Right decubitus 2D image delineates a change in positions between the mass (arrow) and pancreas (arrowheads). This finding is called a "sliding sign" and is considered evidence of non-invasion of an adjacent organ on imaging.

of serosal invasion were comparable using EUS and MDCT[31]. In their meta-analysis, Seevaratnam *et al*[32] only reported the accuracy of overall TNM staging, indicating that T-staging was more accurate in ≥ 4 channel MDCT with MPR images than in scanners with < 4 channels.

The detection rate of early gastric cancer (T1) has recently been studied by several researchers using advanced technology. Yu *et al*[35] reported that 98% of the gastric cancers not visualized on optimally performed 2D CT imaging were EGC without LN involvement. Another study of early gastric cancer evaluated hydro-stomach CT (water as the oral contrast agent) without 3D reformation using blinded reviews and unblinded reviews in which the reviewer had knowledge of the tumor location, and no significant difference in EGC detection was found between blinded and unblinded reviews. The sensitivities and specificities for the blinded and unblinded reviews were 19%-27% and 98%-100%, respectively[36]. The results of these studies are disappointing, though a recent study using 64-channel MDCT did report a 90%-94.7% detection rate for EGC[30,37]. Other studies have also discussed the additional value of virtual gastroscopy for detecting EGC, reporting a sensitivity of 78.7%-84.0%[13,38]. Although virtual gastroscopy cannot delineate the color change of mucosa and image interpretation is time consuming for radiologists, adding virtual gastroscopy information to 2D images can enhance the diagnostic performance of MDCT for the detection of EGC. Coronal and sagittal MPR images without virtual gastroscopy or CT gastrography were not helpful for improving the ECG detection rate or accuracy of T-staging[39]; however, 3D reformation images do improve ECG detection. Using 3D reformation of MDCT images can help clinicians make correct treatment decisions. Shallow tumors are good candidates for less invasive procedures, such as EMR or laparoscopic surgery.

Kim *et al*[30] reported on the diagnostic performance of 64-channel MDCT using 2D MPR images and virtual gastroscopy for T-staging according to the AJCC 7th edition guidelines. In that study, the sensitivities for correct T-staging were 62.5%-93.0%, and the specificities

were 90.5%-97.9%; the overall T-staging accuracy was 77.2%[30]. Using the 6th edition AJCC staging guidelines, Chen *et al*[40] reported an improved T-staging accuracy of 89% when using 2D and MPR images compared to 73% accuracy when using only 2D images. Kim *et al*[39] also reported improved T-staging in advanced gastric cancer (AGC) patients when MPR images were added. These results suggest that the use of both MPR images and axial images improves the T-staging accuracy, especially in AGC.

N-staging

To determine the optimal treatment method for each patient, accurate N-staging is as important as T-staging. N-staging provides critical information that is needed to appropriately predict a patient's prognosis. For EMR or endoscopic submucosal dissection, N0 should be confirmed using EUS or MDCT. Additionally, as extensive lymphadenopathy detected surgically is known to be associated with higher morbidity and mortality, aggressive surgical procedures should be avoided for the patients with extensive lymphadenopathy. Indeed, proper evaluation of the lymph node status could be very helpful for determining the optimal treatment options and for planning the extent of lymphadenectomy. Lymph node status is an important prognostic factor for predicting the overall survival rate of patients with gastric cancer[28,41]. The reported five-year survival rates based on the 6th AJCC system for N0, N1, N2, and N3 are 86.1%, 58.1%, 23.3%, and 5.9%, respectively[28]. As enlarged lymph nodes are frequently the only measurable lesions in patients with gastric cancer, evaluation of a patient's treatment response to chemotherapy might depend on the observable lymph node status.

However, the results of studies evaluating the accuracy of MDCT N-staging are somewhat disappointing. According to the meta-analysis by Kwee *et al*[42], the sensitivity and specificity of MDCT N-staging varied between 62.5% and 91.9% and 50.0% and 87.9%, respectively[13,37,39,40]. These poor and variable results may be due to the lack of standard CT criteria for diagnos-
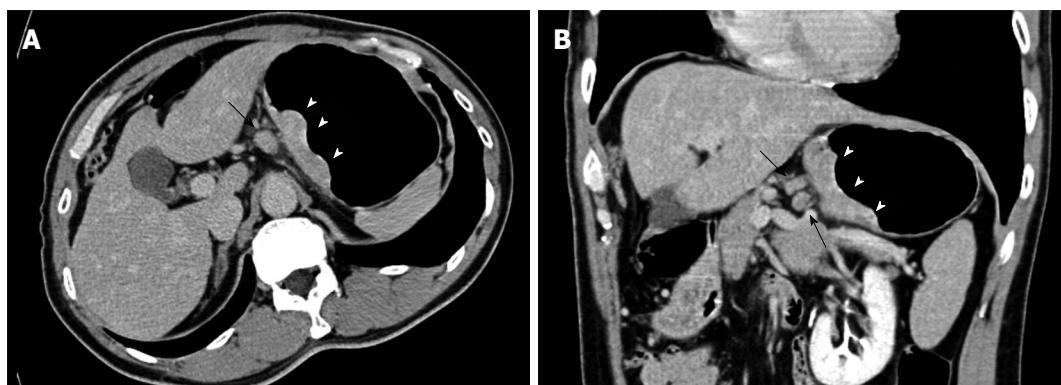
Figure 5 A prominent lymph node in a 57-year-old male patient with advanced gastric cancer. A: Left posterior oblique axial 2D image shows a large gastric mass (arrowheads) in the posterior wall of the gastric body and an enlarged lymph node (arrow). The LN diameter was 12 mm; B: Coronal 2D image shows a gastric mass (arrowheads) and two enlarged lymph nodes (arrows).

ing metastatic lymph nodes. Although many radiologists classify malignant lymph nodes as those with short axis diameters of 6-8 mm for perigastric lymph nodes[43], other criteria are frequently used, including roundness and central necrosis, heterogeneous enhancement, more than 1 cm without fatty hilum, marked enhancement (over 80 or 100 HU), and clustering of more than three lymph nodes[13,37,39,40] (Figure 5). To date, the accuracy of predicting lymph node metastasis has not been satisfactory using any criteria, and there is still no worldwide consensus for diagnosing metastatic lymph nodes using CT. N-staging of gastric cancer is one of the inherent limitations of CT. Although there is a clear correlation between the lymph node size and metastasis, microscopic nodal metastases in normal-size lymph nodes and lymph node enlargement resulting from reactive or inflammatory change are common in gastric cancer patients[16,44,45]. Microscopic metastases can frequently be found in normal-sized lymph nodes of patients with EGC, which makes accurate N-staging more difficult in EGC cases than in patients with AGC[14,44].

The use of MPR images and 3D reformation of isotropic MDCT data did not prevent inaccurate N-staging of gastric cancer. In recent studies, N-staging accuracy was not found to be improved by MPR images or virtual endoscopy[13,40]. Another study reported improved N-staging performance when MDCT with MPR images was used in AGC cases, though there was no improvement in the EGC N-staging accuracy[39]. Therefore, MPR images are expected to be helpful for the evaluation of the preoperative N-staging of AGC.

Some updated techniques for effective lymph node evaluation in gastric cancer have been reported. Kim *et al*[46] reported on the feasibility of mapping the sentinel node (the initial draining node from the tumor) using ethiodized oil in an animal and human study. This CT lymphography technique may help to minimize lymph node dissection in patients with EGC. Quantitative measurement of iodine concentrations using dual-energy spectral CT with monochromatic images has also been reported to improve the accuracy of N-staging[47].

M-staging

The presence of distant gastric cancer metastases is a contraindication for surgical resection. Distant metastases can be classified into the following three groups: hematogenous metastases, lymphatic metastases, and peritoneal carcinomatosis. The liver is the most common location for hematogenous metastases in gastric cancer, and the lungs, bones, and adrenal glands are other organs affected by metastases. Tumor involvement in the lymphatic pathway also informs M-staging. Metastasis in distant lymph nodes, such as the retropancreatic, para-aortic, or retroperitoneal lymph nodes, may be classified as distant metastases (M1). Lymphatic metastases can also invade the liver or lungs. Compared with the limited field of view of EUS or MRI, MDCT is an ideal modality for evaluating distant metastases in patients with gastric cancer. A meta-analysis of data from 1994 to 2010 reported CT sensitivities and specificities for hepatic metastases and peritoneal carcinomatosis of 74% and 99% and 33% and 99%, respectively[48]. However, most of the data used in this meta-analysis were obtained prior to 2005, and the performance of contemporary MDCT might be improved. Pan *et al* reported more than 96.6% accuracy in M-staging 350 patients with gastric cancer using MDCT[49]. As the meta-analysis results indicate, peritoneal carcinomatosis is one of the weak areas for accurate M-staging using CT. Preoperative detection of peritoneal carcinomatosis can prevent unnecessary laparotomy, and some surgeons prefer staging laparoscopy when peritoneal carcinomatosis is suspected[50,51]. One study reported that the sensitivity and specificity for detecting peritoneal carcinomatosis were 50.9% and 96.2% with 16- and 64-channel MDCT, respectively[51]. Known CT findings of peritoneal carcinomatosis include ascites, soft-tissue plaques or nodules on the peritoneal surface and bowel wall, prominent intra-abdominal fat stranding, and irregular peritoneal thickening with enhancement[52] (Figure 6). In addition, a larger gastric tumor size (3-4 cm or more), T3 or T4 staging, and Borrmann type 3 or 4 suggest peritoneal carcinomatosis[51-53]. The presence of greater than 50 mL of ascites is correlated with peritoneal carcinomatosis in 75%-100%
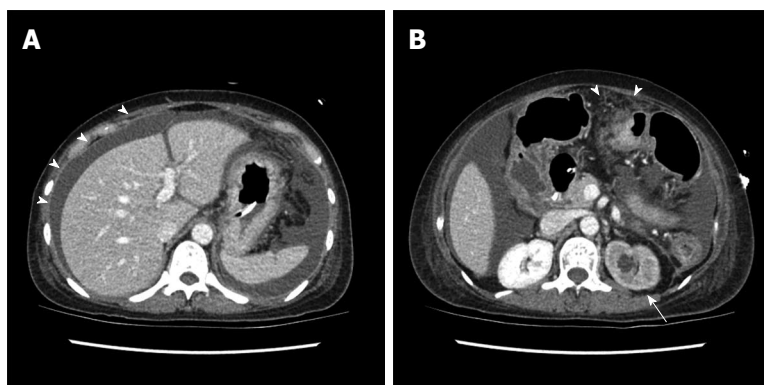
Figure 6 Peritoneal carcinomatosis in a 48-year-old female patient with advanced gastric cancer. A: Axial 2D CT image shows a large volume of ascites and peritoneal thickening (arrowheads); B: Axial 2D CT image at a lower level than (A) delineates ascites, omental infiltration and nodules (arrowheads), and hydronephrosis of the left kidney (arrow).

of gastric cancer patients[52]. Yajima *et al*[54] also reported that the presence of ascites on the CT scans of AGC patients predicts peritoneal carcinomatosis with 51% sensitivity and 97% specificity.

MRI

MRI protocols
With recent technological MRI developments, such as the 3.0 T field strength scanner, multichannel phase-arrayed coils, parallel imaging techniques, a more powerful gradient system, and new rapid three dimensional gradient echo techniques, higher quality MR images with reduced blurring and higher spatial resolution can be obtained within a single breath-hold[55]. Given that MR can provide higher intrinsic soft tissue contrast than CT, there have been several studies demonstrating the value of MR in evaluating gastric cancer, especially in patients for whom contrast-enhanced CT is contraindicated due to renal dysfunction or hypersensitivity to iodinated contrast media[56]. In addition, several studies have demonstrated that diffusion-weighted imaging may be helpful for staging malignant tumors of the intestines and for detecting lymph node metastases[57]. However, although high-speed MR techniques can solve some of the disadvantages of MRI for detecting gastric cancer (such as blurring and lower spatial resolution), MRI is not yet widely accepted as a standard imaging modality for staging gastric cancer. Therefore, there is no generally accepted protocol for gastric MRI. However, in general, the use of butylscopolamine bromide to decrease bowel motion and the use of air or water as an oral contrast agent are the same in MRI and MDCT scanning. The supine or prone position is generally accepted as a method for distending the area of the stomach where a tumor may be located. The fat-suppressed, T1-weighted, gradient echo sequence, single-shot fast spin echo or turbo spin echo T2-weighted images, and true fast imaging with steady-state precession (True-FISP) are common sequences used for the detection of gastric cancer. Gadolinium-chelate contrast agents can also be injected for post-contrast imaging using 3D spoiled gradient echo sequences. Axial or coronal images can both be acquired, and protocols may vary in different medical institutions. These images are acquired using phased array coils to increase the signal-to-noise ratio.

In our institution, the MRI protocol for gastric cancer includes the following sequences: half-Fourier acquisition single-shot turbo spin-echo (HASTE) T2-weighted imaging with and without fat saturation, true-FISP, T1-weighted 3D gradient-recalled-echo (GRE) in- and out-of-phase imaging, and T1-weighted fat-suppressed 3D GRE imaging. Diffusion-weighted images are obtained using multiple b values of 0, 100, 500 and 1000 mm^2/s. Dynamic gadolinium contrast-enhanced imaging during the arterial, portal, hepatic venous, and equilibrium phases are obtained. The spectral selection attenuated inversion technique is used for fat suppression (Figure 7).

Staging
Compared to those using MDCT, there are only a small number of MR studies of gastric cancer patients, largely due to the intrinsic limitations of MR, such as the susceptibility to bulk motion (*e.g.,* respiration, pulsation, and peristalsis), high cost, and lower spatial resolution compared to MDCT or EUS. However, the excellent soft-tissue contrast of MRI might be helpful for accurate T-staging, and continuous technical improvements, such as parallel imaging, have made gastric MRI feasible and have resulted in the publication of several studies on this subject.

However, in vitro studies have reported conflicting results. Palmowski *et al*[58] performed an in vitro study with resected specimens, and reported that 1.0 Tesla MRI with T1- or T2-weighted images could visualize three layers of the gastric wall (mucosa, sub-mucosa, and muscularis propria) and, in some cases, five gastric wall layers. Gastric cancer was localized in 96% of the study patients, though the accuracy of T-staging was only 50%, primarily due to the overstaging of T2 to T3. However, Sato *et al* reported 100% accuracy and clear visualization of all of gastric wall layers in an in vitro study using 1.5 Tesla MRI[59]. Kim *et al*[60] also reported the results of an in vitro study using 1.5 Tesla MR. In their study, T1-weighted images depicted three layers of the gastric wall, and the T-staging accuracy was 74%; they also reported 47% accuracy for gastric cancer N-staging. That study considered lymph nodes 8 mm or larger at the short diameter to be positive. An endoluminal MRI coil attached to endoscopy has also been developed as a T-staging method,
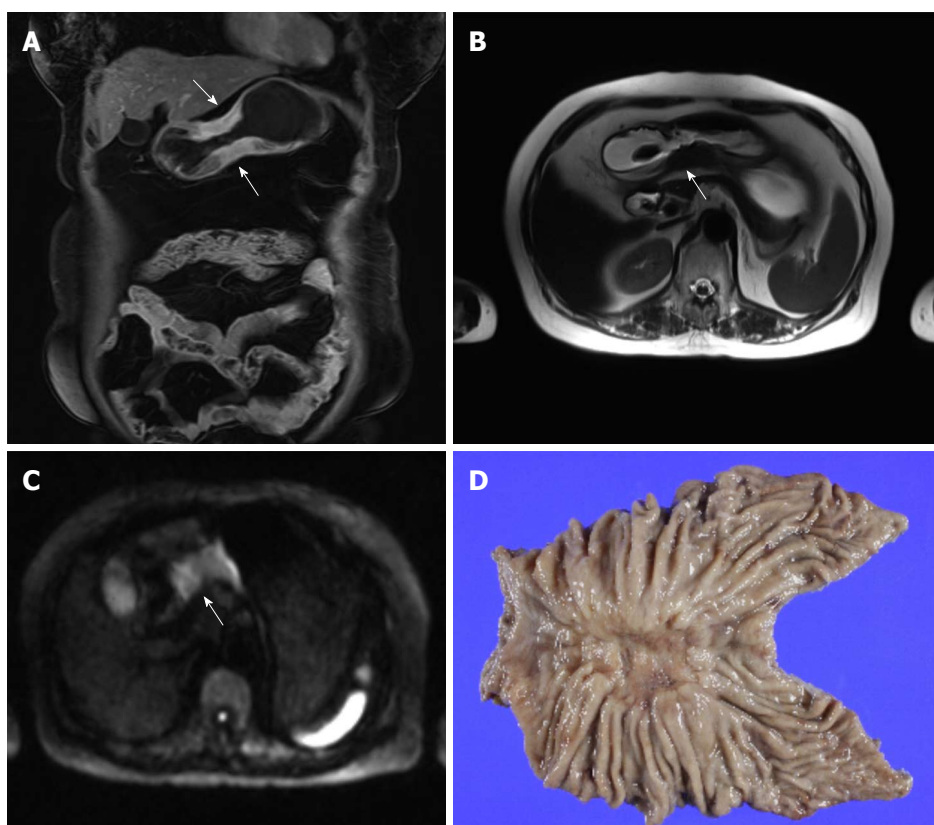
Figure 7 Magnetic resonance imaging of gastric cancer in a 71-year-old female patient. A: Coronal image of contrast enhanced magnetic resonance imaging (MRI) shows enhancing wall thickening of the gastric body (arrows); B: T2-weighted image delineates a low echoic mass (arrow) destroying layers of the gastric wall. The outer border of the mass is irregular; C: Diffusion-weighted image with a b-value of 1000 shows a high signal intensity mass (arrow) with diffusion restriction; D: Subtotal gastrectomy was performed, and pathological examination revealed pT3 cancer.

and an ex vivo study reported significantly more accurate T-staging than EUS[61].

In early 2000, a few reports of in vivo studies were published. The diagnostic accuracy of MRI for T-staging varied between 71.4% and 82.6%, and the sensitivity and specificity for detecting serosal invasion varied between 89.5% and 93.1% and between 94.1% and 100%, respectively[31,62,63]. Kang *et al*[62] reported the rapid enhancement of gastric cancer compared to normal mucosa after the injection of gadolinium chelates and also reported 83% T-staging accuracy. Additionally, these authors reported a 52% detection rate of regional lymph node involvement. Kim *et al*[64] compared spiral CT and 1.0 Tesla MRI and reported that MRI was slightly superior for T-staging. Sohn *et al*[63] reported comparable results using spiral CT and 1.5 T MRI for both T- and N-staging.

Recently, 64-channel MDCT and 1.5 Tesla MRI with contemporary sequences were compared in two studies, with the T-staging accuracy being comparable for MDCT and MRI[65,66]. However, one study reported that MRI was superior for detecting T1 tumors (50% *vs* 37.5% accuracy for MRI and MDCT, respectively)[65]. The cumulative results of these studies indicate that MDCT and contemporary MRI show similar performance in T- and N-staging.

Tissue-specific contrast MR agents can be used for an accurate N-stage diagnosis. T1 lymphotropic contrast agents, including gadofluorine M, or such T2* agents as ultra-small, superparamagnetic iron oxide, might be helpful for differentiating metastatic lymph nodes[67,68].

Peritoneal carcinomatosis can be evaluated on delayed, post-contrast MRI images[69]. Diffusion-weighted imaging is now widely accepted for abdominal MRI and adding diffusion-weighted imaging to delayed gadolinium-enhanced imaging can improve the detection rate of peritoneal carcinomatosis[70].

CONCLUSION

Accurate preoperative staging of gastric cancer is important for treatment planning and prognosis prediction. Due to the development of less invasive treatment options, gastric cancer should be preoperatively staged with accuracy. The technical progress of MDCT and the continuous development of 3D imaging processes have improved MDCT performance in the preoperative staging of gastric cancer. The EGC detection rates can be improved through the use of virtual gastroscopy and CT gastrography. MPR images of MDCT can provide coronal or sagittal images and increase the accuracy of the tumor depth diagnosis. With the development of high-speed techniques, MRI evaluation of gastric cancer is now feasible, and some studies have reported results that are comparable to or better than MDCT. Gastric cancer

N-staging is an unsolved problem for both MDCT and MRI, and generalized standards for metastatic lymph nodes should be established. Additionally, tissue specific contrast agents will improve future N-staging. MDCT is the primary imaging modality used for the detection of distant gastric cancer metastasis, even though the technique has some limitations (such as peritoneal carcinomatosis detection). With continuing technical development, MDCT and MRI will play major roles in the future preoperative staging of gastric cancer.

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