Description of tumor enhancement in the arbitrary layer of the gastric wall on 3D MDCT

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Learning objectives

• To overview current techniques for gastric tumors on contrast-enhanced 3D-MDCT

• To recognize the relationship between the sub-mucosal vascular plexus and the enhancement profile of the gastric wall in the "wall-carving" (WC) technique

• To demonstrate the major expression of gastric tumors on contrast-enhanced 3D-MDCT with gas-extension protocol, correlated with conventional endoscopy and gastrography
Background

In the wake of the recent promotion and technical development of MDCT, faster, simpler, and more accurate gastric imaging has been utilized in clinical settings. Contrast-enhanced MDCT allows relatively noninvasive assessment of the gastric wall and various gastric tumors. Several computer algorithms for 3D volumetric data have been applied for the evaluation of the stomach; e.g., multi-planar reconstruction (MPR), vessel probe reconstruction (VP), shaded-surface display (SSD), virtual endoscopy (VE), and volume rendering (VR). To date, two major protocols have been attempted to visualize gastric tumors on contrast-enhanced 3D-MDCT: the gas-extension protocol and the water-filling protocol. Three-dimensional display (e.g., SSD, VE, and VR) has been confined to the gas-extension protocol, while cross-sectional display (e.g., MPR and VP) is available for both protocols. One of the 3D VR displays for the gas-extension protocol, called the "wall-carving" (WC) technique, can create not only a rough drawing of the mucosal surface, but can also visualize the underlying arbitrary depth of the gastric wall layer, which is parallel to the air-mucosa interface. In this article, we describe the major expression of gastric tumors on contrast-enhanced MDCT especially using the WC technique and compare these techniques with conventional X-ray gastrography and optical endoscopy. For 50 years or more, X-ray gastrography and optical endoscopy have been thought to be indispensable techniques; they have been compared to the wheels on which vehicles that promote the development of diagnostic imaging in gastric diseases rely. In this exhibition, we introduce a hybrid concept in diagnostic imaging of gastric tumor.

<table>
<thead>
<tr>
<th></th>
<th>MDCT</th>
<th>X-ray Gastrography</th>
<th>Optical Endoscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel size (xy)</td>
<td>1000µm&gt;</td>
<td>100µm&gt;</td>
<td>10µm&gt;</td>
</tr>
<tr>
<td>Dimension</td>
<td>3D</td>
<td>2D</td>
<td>2D</td>
</tr>
<tr>
<td>Color</td>
<td>Gray scale</td>
<td>Gray scale</td>
<td>Color</td>
</tr>
<tr>
<td>Viewpoint</td>
<td>Variable</td>
<td>Extra-luminal</td>
<td>Intra-luminal</td>
</tr>
<tr>
<td>Visualized area</td>
<td>Air-tissue interface to deep layer</td>
<td>Barium between air and mucosal surface</td>
<td>Mucosal surface (OE) to deep layer (EUS)</td>
</tr>
<tr>
<td>Tomography</td>
<td>Yes</td>
<td>NA</td>
<td>Yes (EUS)</td>
</tr>
<tr>
<td>Vascularity</td>
<td>Yes (VR, MRP, MIP)</td>
<td>NA</td>
<td>Yes (NBI, FICE)</td>
</tr>
<tr>
<td>Biopsy</td>
<td>NA</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td>Invasiveness</td>
<td>Radiation, IV</td>
<td>Radiation</td>
<td>Bleeding, Perforation</td>
</tr>
</tbody>
</table>
Table 1. Comparison of Main Features in Gastric Imaging

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR</td>
<td>volume rendering</td>
</tr>
<tr>
<td>MPR</td>
<td>multi-planar reconstruction</td>
</tr>
<tr>
<td>MIP</td>
<td>maximum intensity projection</td>
</tr>
<tr>
<td>OE</td>
<td>optical endoscopy</td>
</tr>
<tr>
<td>EUS</td>
<td>endoscopic ultrasound</td>
</tr>
<tr>
<td>NBI</td>
<td>narrow band imaging</td>
</tr>
<tr>
<td>FICE</td>
<td>FUJI Intelligent Color Enhancement</td>
</tr>
</tbody>
</table>
**Imaging findings OR Procedure details**

1. *Gastric protocols in IV contrast-enhanced MDCT*

Gastric tumors are often visualized as segmental or diffuse wall thickening that may appear to be a pathognomonic enhancement pattern compared to that of the normal gastric wall. To improve visualization of the gastric tumor, two different protocols with negative contrast material have been applied: a "gas-extension" protocol and a "water-filling" protocol. Both protocols provide low attenuation within the gastric lumen and improve visualization of the normal gastric wall. Adequate luminal distention of the stomach is achieved by the administration of 3.5 to 7 g effervescent agents with a small amount of water in the gas-extension protocol, or by the administration of 400 to 1500 ml water in the water-filling protocol. An antispasmodic agent, such as 10 to 20 mg scopolamine, should be administered as a standard preparation to avoid "peristalsis non grata", which mimics a gastric tumor in either protocol. The recommended scanning position for one protocol is the opposite of that for the other; for example, adequate distention of the gastric body is obtained in the supine position with the gas-extension protocol, whereas it is obtained in the prone position with the water-filling protocol. The gas-extension protocol permits the accurate delineation of tumor morphology and, in the case of early gastric cancer, can result in a tumor detection rate of up to 90% with a combination of MPR and VE. Various displays using 2D or 3D algorithms are readily available in the gas-extension protocol. The water-filling protocol provides cross-sectional details of the gastric wall and improves the accuracy of T-staging of gastric cancer. When thin-slice collimation is used, isotropic voxels and better z-axis resolution produce high-quality MPR images; when only a cross-sectional display is used, morphological assessment of a tumor may be ambiguous.

<table>
<thead>
<tr>
<th>Oral administration</th>
<th>Gas-extension protocol</th>
<th>Water-filling protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effervescent agent (3.5-7g) &amp; a small amount of water</td>
<td>Tap water (400-1500ml)</td>
<td></td>
</tr>
<tr>
<td>Antispasmodic agent</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Scanning position</td>
<td>Supine</td>
<td>Prone</td>
</tr>
<tr>
<td>- body to antrum</td>
<td>Prone</td>
<td>Supine</td>
</tr>
<tr>
<td>- fundus to cardia</td>
<td>Adequate</td>
<td>Adequate</td>
</tr>
<tr>
<td>Current computer algorithms for interpretation</td>
<td>SSD, VE, VR, MPR</td>
<td>MPR, VP</td>
</tr>
</tbody>
</table>
Detection rate for early gastric cancer

20-89%

62-90%

Table 2. Gastric protocols in IV Contrast-enhanced MDCT

SSD: surface-shaded display, VE: virtual endoscopy, VR: volume rendering, MPR: multi-planar reconstruction, VP: vessel probe technique

2. CT scan technique

At our institution, CT scanning for gastric tumors is performed on a 64-channel scanner (Aquilion 64; Toshiba Medical Systems Corporation, Tokyo, Japan). The scanning parameters are: a rotation time of 0.5 sec, collimation of 2 mm, pitch of 5.5 field of view (FOV) of 32 cm, 120 kVp, 200 mAs, and a reconstruction voxel of 0.675x0.675x1.0 mm (xyz) with a standard interpolator and algorithm. Before scanning, an oral effervescent agent is adopted to obtain adequate distention of the stomach. An antispasmodic agent of 10 mg scopolamine is also given intra-muscularly. Adequate distention without unnecessary peristalsis is essential for dedicated imaging of the stomach. If the entire stomach is not well distended, disease may be overlooked or, conversely, the collapsed gastric wall may mimic disease. Gastric distention is checked with a scout image; if gastric distention is inadequate, additional effervescent granules are given. After the start of injection of contrast material with 370 mg I/ml iodine (Iopamiron, Bayer Healthcare, Bayer-Schering Pharma AG, Leverkusen, Germany) at a rate of 3 ml/sec using a power injector (Dual Shot GX, Nemoto Kyorindo, Tokyo, Japan), CT scans for the first two arterial phases are initiated after 40 and 60 sec at the supine position and after 240 sec for the delayed phase at the prone position. To obtain good contrast of gastric tumors, CT scanning should be performed during the arterial phase. Adequate distention is obtained in the supine position for gastric body and antrum, followed by the prone position for gastric fundus and cardia. An intravenous contrast agent should not be used at the same time as oral contrast materials because of the obscurity of gastric wall enhancement.

3. Cross-sectional image of the gastric wall
Fig.: Cross-sectional illustration of the gastric wall

References: Radiology, Kyushu University Hospital - Fukuoka/JP
Schematic illustration shows the layer structure of the gastric wall, revealing the sub-mucosal vascular plexus just beneath the MM (Figure 1). The inner high attenuation layer consists mostly of M to SMVP, while the outer intermediate attenuation layer represents from MP to the margin of the surrounding fat tissue. (M: mucosa, MM: muscularis mucosae, SM: submucosa, SMVP: sub-mucosal vascular plexus, MP: muscularis propria, SS: sub-serosa)

Fig.: Magnified CT image of the gastric wall
**References:** Radiology, Kyushu University Hospital - Fukuoka/JP

Normal "double-layered" pattern of the gastric wall on IV contrast-enhanced CT with gas-extension protocol (Figure 2). Inner high attenuation layer (white obi) and outer intermediate attenuation layer (gray obi) are visualized. Linear sub-mucosal low attenuation (LSMLA) is unclear in the normal gastric wall. The visible LSMLA may be attributable to a pathological condition, such as edema or marked deposition of fat tissue. Also, the boundary between sub-serosa and surrounding peritoneal fat is unclear. The profile curve plot analysis of MDCT data in the normal gastric wall revealed a mean wall thickness of 3.75 to 6.25 mm from the gastric body to the antrum when luminal distention is adequate.

4. Vascular anatomy in the gastric wall

**Blood supply:** The stomach receives blood from six medium-sized arteries: (1) left gastric, (2) right gastric, (3) left gastro-epiploic, (4) right gastro-epiploic, (5) short gastrics, and (6) gastro-duodenal. Each artery penetrates the serosa, branches off, and continues beneath the serosa. Small arterial branches called arterioles penetrate the muscularis propria (MP) to the sub-mucosa (SM) without any offshoots to the MP. In the SM, an extensive vascular plexus, called the "sub-mucosal vascular plexus" (SMVP), is formed that has ramifications for the muscularis mucosae (MM) and the mucosa (M). The SMVP extends almost all the way through the gastric wall, except for the antral to pre-pyloric lesser curvature.

**Mucosal capillary network:** It is generally accepted that the mucosal capillary network (MCN) is located around the gastric glands and that the MCN anastomizes laterally with each other and convey blood toward the mucosal surface, where the MCN drains into rather sparsely scattered small veins, called venules, leading back to the SMVP.

**Venous drainage:** The venous drainage of the gastric wall is similar in distribution to the arterial supply. Five veins drain blood from the stomach: (1) left gastric or coronary, (2) right gastric, (3) right gastro-epiploic, (4) left gastro-epiploic, and (5) short gastric, running along with the main arteries.

5. Profile curve plot in the gastric wall
**Fig.:** Profile curve plot in the normal gastric wall

**References:** Radiology, Kyushu University Hospital - Fukuoka/JP

The profile curve plot shows a gray value by depth from the air-mucosa interface in the gastric body and antrum [N=32, X-axis: depth (mm), Y-axis: gray value at windows bitmap (bmp), WW/WL=350/50] (Figure 3). Each profile shows only one peak at a depth of 1.875 millimeter, probably due to the anatomical existence of sub-mucosal vascular plexus. The gray value in the gastric body is slightly higher than that in the gastric antrum at the same depth.

**Fig.:** Typical profile curve plots in the normal gastric wall and early gastric cancer (Type 0-IIc, SM)

**References:** Radiology, Kyushu University Hospital - Fukuoka/JP

Typical profile curve plots in the normal gastric wall and early gastric cancer (Type 0-IIc, SM) are shown (Figure 4). Within the depth of the "estimated normal gastric wall layer", the gray value of tumor (t) is higher than that of gastric body (b) and that of antrum (a), corresponding to the depth at 1.25 to 3.75 mm from the air-mucosa interface. The profile
curve of the tumor shows a continuously high gray value through a deeper layer due to gastric wall thickening. There is no difference in gray value between tumor and normal gastric wall at the mucosal surface.

6. Applied VR techniques for IV contrast-enhanced MDCT in gastric tumors

Fig.: Early gastric cancer (25×25 millimeter in size) in a 55-year-old man.

References: Radiology, Kyushu University Hospital - Fukuoka/JP

By using MDCT data, the volume-rendering (VR) technique for the stomach becomes more practical and useful in the detection and evaluation of gastric tumors. This technique preserves the dynamic range of the image, taking the entire volume of data, summing the contribution of each voxel along a line from the viewer's eye through the data, and displaying the resulting composite for each pixel of the display. Several VR techniques are applicable in hollow organs such as the stomach, colon, and rectum. In the gas-extension protocol, conventional virtual endoscopy (VE) and simple transparency rendering have revealed the morphological features of the air-mucosa interface in the stomach. The combination of VE and multi-planar reformation visualizes interactive endoscopic imaging with cross-sectional information. The figures show early gastric cancer (type 0-IIa+IIC, depth of invasion; submucosa) in the posterior gastric body using optical endoscopy (Figure 5-A), VE (Figure 5-B), and VE with MPR (Figure 5-C).

7. Wall carving technique for luminal organs
The wall-carving (WC) technique is a VR method where a subtraction technique is applied to two different 3D datasets of a hollow organ. Figures with calculating formula show the subtraction step to generate WC images (Figure 6-A, B, and C). First, the target of an air-filled lumen was manually segmented from source data using the reconstruction threshold under -150 HU with a sharpness of 50 at negative gradient display. In the next repetition step, the mask of the air-filled lumen was distended in an arbitrary voxel and followed by image subtraction from different levels of the digitally expanded target with a portion of the volume of data in the gastric wall. The WC image depicts the enhancement pattern in the gastrointestinal wall at an arbitrary depth on a plane parallel to the air-mucosa interface. The wall structure at different depths was clearly observed from both intra-luminal and extra-luminal standpoints. The gray scale for interpretation was adjusted to a conventional abdominal window (level 40 to 60 HU, width 100 to 300 HU) in a positive gradient.

8. Clinical cases

Case 1; Early gastric cancer with ulceration (83x73 mm in area) in a 66-year-old woman. Optical endoscopy (Figure 7-A) shows a slightly depressed lesion with ulceration (white arrow) at the gastric body. This lesion is unremarkable on virtual endoscopy (black arrow) (Figure 7-B). WC at a depth of 2.5 mm from the air-mucosa interface (Figure 7-C) shows nodular enhancement with an indistinct margin (white arrowhead). This lesion was revealed to be a poorly differentiated adenocarcinoma (type IIc+III, stage T1 within mucosa, combined with peptic ulcer down to submucosa).
Figure: Early gastric cancer

References: Radiology, Kyushu University Hospital - Fukuoka/JP

Case 2; Early gastric cancer (13x11 mm in area) in a 76-year-old man. Optical endoscopy (Figure 8-A) and VE (Figure 8-B) shows a slightly depressed lesion (white arrow). WC at a depth of 2.5 mm (Figure 8-C) shows a central low attenuation area (white arrowhead), corresponding to the slightly depressed lesion on VE. This lesion was diagnosed as a well-differentiated adenocarcinoma (type IIc, stage T1 with invasion into the upper third of the sub-mucosa).

Figure: Early gastric cancer

References: Radiology, Kyushu University Hospital - Fukuoka/JP

Case 3; Early gastric cancer (15x11 mm in area) in a 55-year-old man. Optical endoscopy (Figure 9-A) and X-ray gastrography (Figure 9-B) show a slightly elevated lesion with a small central depression (white arrow). This lesion is undetectable on
VE (Figure 9-C) alone (black arrow). A ring-like enhancement is visible on WC at a depth of 2.5 mm from both intra-luminal (Figure 9-D) and extra-luminal (Figure 9-E) viewpoints (arrowheads). This lesion was diagnosed as a well- to moderately differentiated adenocarcinoma (type IIa+IIc, stage T1 with invasion into the upper third of the submucosa).

**Fig.** Advanced gastric cancer, mimicking early gastric cancer

**References:** Radiology, Kyushu University Hospital - Fukuoka/JP

**Case 4; Advanced gastric cancer, mimicking early gastric cancer** (90x60 mm in area) in a 58-year-old man. Optical endoscopy (Figure 10-A) shows a broad elevated lesion with linear depression (white ellipsoid of solid line) along the anterior gastric wall. This lesion is unremarkable on VE (Figure 10-B) alone (black ellipsoid of broken line). Geographic enhancements are recognizable on WC (Figure 10-C-1,2,3) at each depth by 1.25 mm from the air-mucosa interface (white ellipsoid of broken line). This lesion was diagnosed as a moderately to poorly differentiated adenocarcinoma (type IIa+IIc, stage T2 with sub-serosal invasion). The location of the gastric cardia is denoted by an asterisk.

**Case 5; Advanced gastric cancer** (80x60 mm in area) in an 83-year-old man. Optical endoscopy (Figure 11-A) shows an ulcerated carcinoma with sharply demarcated and raised margins (white ellipsoid of solid line). A concavo-convex mound with deep ulceration is visualized on VE (Figure 11-B) (black ellipsoid of broken line). Heterogeneous enhancements are remarkable at the mound of the tumor on WC (Figure 11-C-1,2,3) at each depth by 1.25 mm from the air-mucosa interface (white ellipsoid of broken line). Marked enhancement appeared at a depth of 2.5 mm. The floor of the ulcerations shows low attenuation at each depth. This lesion was diagnosed as a well-to moderately differentiated adenocarcinoma (type 2, stage T3 with invasion to serosa).
Fig.: Malignant lymphoma

References: Radiology, Kyushu University Hospital - Fukuoka/JP

Case 6: Malignant lymphoma (70x60 mm in area) in an 80-year-old woman. Optical endoscopy (Figure 12-A) shows an ulcerated-type tumor. An "auricle-like mound" with ulceration is visualized on VE (Figure 12-B) (black ellipsoid of broken line). Tumoral enhancements at the mound of the tumor are weak on WC (Figure 12-C-1,2,3) (white ellipsoid of broken line). The floor of ulceration shows relatively low attenuation at each depth. This lesion was diagnosed as a malignant lymphoma of diffuse large B cell origin.
Fig.: GIST, gastro-intestinal stromal tumor

References: Radiology, Kyushu University Hospital - Fukuoka/JP

Case 7; GIST, gastro-intestinal stromal tumor (23x14 mm in area) in a 34-year-old man. X-ray gastrography (Figure 13-A), optical endoscopy (Figure 13-B), and VE (Figure 13-C) show a sub-mucosal tumor (black asterisk). Typical bridging fold (black arrow) is visualized in X-ray gastrography. Tumoral enhancement (white asterisk) is unclear in WC of depths between 1.25 and 2.50 mm (Figure 13-D-1, 2), while it is observed with vascular dilatation (white arrowhead) (Figure 13-D-3) at a depth of 3.75 mm, corresponding to the "outer layer of the normal gastric wall".
Fig.: Schwannoma

References: Radiology, Kyushu University Hospital - Fukuoka/JP

Case 8; Schwannoma (25x25 mm in area) in a 28-year-old woman. X-ray gastrography (Figure 14-A) and optical endoscopy (Figure 14-C) show a sub-mucosal tumor (black arrow) with central ulceration. Enhancement of the sub-mucosal tumor (white arrow) locates the anterior portion of the gastro-epiploic vessel in WC (Figure 14-B-1, 2, 3), corresponding to the "anatomical anterior gastric wall". A protruded tumor with central depression (black asterisk) is visualized on VE (Figure 14-D) and WC (Figure 14-E-1, 2). Tumoral enhancements and "bridging vessels without dilatation" are also shown at depths of 1.25 to 2.5 mm (white arrowhead) (Figure 14-E-1, 2).
Images for this section:

**Fig. 0:** Cross-sectional illustration of the gastric wall

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**Fig. 0:** Magnified CT image of the gastric wall

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**Fig. 0:** Profile curve plot in the normal gastric wall

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**Fig. 0:** Typical profile curve plots in the normal gastric wall and early gastric cancer (Type 0-IIc, SM)

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Fig. 0: Early gastric cancer (25x25 millimeter in size) in a 55-year-old man.

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Fig. 0: Wall-carving technique

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Fig. 0: Early gastric cancer with ulceration

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**Fig. 0:** Early gastric cancer

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Fig. 0: Advanced gastric cancer, mimicking early gastric cancer

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Fig. 0: Advanced gastric cancer

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**Fig. 0:** Malignant lymphoma

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**Fig. 0:** GIST, gastro-intestinal stromal tumor

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Fig. 0: Schwannoma

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Conclusion

Recent advances in computer algorithms for 3D display have been giving MDCT a more practical role in gastric imaging.

The "wall-carving" technique for MDCT seems to be a good alternative for visualizing tumoral enhancement and the relationship with the surrounding vascular structure in the gastric wall.
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