MR Imaging of Peritoneal Malignancy

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Introduction

Accurate depiction of tumor involving the peritoneum is critical to the diagnosis and management of cancer patients. Unfortunately, the small size of peritoneal tumor implants renders them difficult to image by helical CT and non-enhanced MR imaging. We have shown that gadolinium-enhanced MRI with fat-suppression is exquisitely sensitive for depicting peritoneal tumors. At our institution gadolinium-enhanced MR imaging has become the exam of choice for all patients with known or suspected peritoneal tumor.

The parietal and visceral peritoneal lining covers the free peritoneal surfaces of the abdominal cavity and envelops the abdominal organs and bowel. The peritoneum thus provides an extensive and continuous surface area which may be involved by malignant or inflammatory diseases of the abdomen and pelvis. Malignant involvement of the peritoneum may occur as a result of intraperitoneal seeding of tumor cells from primary malignancies of the ovary and gastrointestinal tract. These tumor cells will then spread according to the pathways of ascitic flow. Eventually, dissemination of intraperitoneal tumor may involve all of the peritoneal surfaces of the abdomen and pelvis, including the free peritoneal surfaces, the bowel serosa, perihepatic and perisplenic ligaments, mesentery, and omentum. Alternatively, these same peritoneal structures may serve as pathways of direct tumor spread from contiguous or non-contiguous tumors within the abdomen and pelvis. For example, primary tumors of the pancreas, liver, gall bladder, stomach, or spleen often spread to contiguous organs via the peritoneal reflections of the upper abdomen. A thorough understanding of these potential anatomic pathways of tumor spread will assist the radiologist in interpreting cross-sectional examinations in patients with abdominal malignancy.

Imaging Evaluation

Multidetector CT Scanning

At most centers multidetector CT is used to evaluate the abdomen and pelvis in oncology patients. The speed of the examination and familiarity of helical CT scans with radiologists and clinicians make it natural choice for routine abdominal imaging. Compared to MR imaging CT scans exhibit far less soft tissue contrast limiting its ability to discriminate tumor from normal abdominal structures. When looking for very small tumors involving the peritoneum the limited contrast resolution of CT becomes a serious handicap. It is not uncommon for diffuse peritoneal tumor or carcinomatosis to be missed entirely on CT scans, only to be discovered at the time of surgical exploration. As an alternative, we use capitalize on the inherently superior contrast resolution of MR imaging combined with intravenous gadolinium to depict all forms of peritoneal tumor.

MR Imaging

Intraluminal Contrast Material

One can improve the depiction of bowel and serosal tumor by distending the bowel with water soluble contrast material. We have patients drink 1.0 – 1.5 liters of water soluble contrast material starting 45 min to 1 hour before the MR examination. Dilute barium sulfate or a similar volume of Metamucil (0.8 g/kg bw) mixed in 1-1.5 liters water (Proctor and Gamble, Cincinnati, OH), is administered starting one hour prior to the examination. Rectal water 500-1000 cc can be administered thru a balloon tipped barium enema catheter to distend the colon.

MR Imaging Protocol for Imaging Peritoneal Malignancy

Phased array surface coil imaging of the abdomen and pelvis is performed with axial gradient-echo T1-weighted images; fat suppressed, T2-weighted images, diffusion weighted imaging (B400-500) and immediate and delayed fat suppressed gadolinium-enhanced gradient-echo images. The time for the MR examination is 30-40 minutes.

Imaging parameters for the T1-weighted images include TR 140-160, TE 4.4, 1 NEX, matrix 256x192, 7 mm slice thickness, 3 mm inter slice gap. Time of acquisition is 12 sec per 24 slices. For the fat suppressed T2-weighted images we used a either a breath-hold FSE sequence with TR 2500, TE 77, 1 nex, 256x192, chemical fat suppression, 7 mm slice thickness, 3mm interslice gap, requiring a 25 second breath-hold for each 12 slices.
Diffusion-weighted MR imaging of the abdomen and pelvis is performed in the axial plane using a breath-hold single shot spin-echo EPI acquisition. DWI parameters included b value 400-500 s/mm², TR 3000, TE minimum (58 ms), matrix 256x128 or 192x224, slice thickness 7-8mm, 2-3 NEX, gradient overplus to combine the diffusion signal from all three vectors. Time of breath hold is 24 seconds for 24 slices with the abdomen and pelvis acquired as two separate breath hold acquisitions. Fat suppression was employed for background suppression using a SPIR or spectral spatial fat suppression technique.

Gadolinium-enhanced imaging is performed with immediate gadolinium-enhanced 3D Gradient-echo acquisition (LAVA, THRIVE, VIBE) TR 4 ms, TE 1.7 ms, 320x192, 1 NEX, 4.4 mm slice thickness with 50% slice overlap, chemical fat suppression, flip angle 12 degrees, and acceleration factor 2.0. Linear k-space ordering is utilized. Time of acquisition is 24 seconds for 68 slices. Delayed dynamic gadolinium-enhanced imaging used a breath-hold, fat suppressed 2D spoiled gradient-echo; TR = 140 - 165 / TE = 1.9 - 2.6, 512 x 192 matrix, 1 NEX, 8-10-mm thick contiguous slices, +16 - 20 kHz receiver bandwidth, and 70° flip angle, requiring a 24-sec. breath hold for each 12 slices. PURE algorithm is used to reduce shading artifacts in all images from the RF coil inhomogeneity.

**MR Image Interpretation**

The key images for evaluating peritoneal disease are the fat suppressed, gadolinium-enhanced MR images. Due to the slow accumulation of gadolinium within peritoneal tumor a delayed set of images obtained 3 - 5 minutes after injection of gadolinium is most sensitive in depicting peritoneal disease. We obtain two sets of axial MR images at 0 min and approximately 3 - 5 minutes after injection of 0.2 mmol / kg gadolinium. Fat suppression is a critical element in this protocol as it accentuates subtle peritoneal enhancement by suppressing the competing high signal of subcutaneous, retroperitoneal and mesenteric fat. Since the SGE MR images are sensitive to bowel peristalsis we administer 0.25 mg of IV Levsin 5 min before gadolinium injection. As an alternative one mg of IV glucagon can be administered at the time of the gadolinium injection. In our experience this improves depiction of peritoneal tumor involving bowel serosa and mesentery.

Diffusion-weighted imaging is also useful for depicting peritoneal tumors and may be particularly effective in demonstrating serosal or mesenteric tumors and tumors involving the complex peritoneal reflections around the liver. We have found that the combination of delayed gadolinium-enhanced imaging and diffusion weighted imaging is most sensitive for depicting peritoneal tumors.

MR imaging in patients with peritoneal malignancy capitalizes on the inherent high contrast of MR images, which allows one to distinguish tumor from normal abdominal structures. By combining gadolinium IV injection with breath-hold MR images we routinely produce images with excellent anatomic detail and exquisite depiction of peritoneal disease.

**Clinical Applications**

**I. Ovarian Cancer**

Epithelial ovarian cancer is the second most common gynecologic malignancy, and is the fifth most frequent cause of cancer-related death in women. Determining response to therapy has relied upon following serum CA 125 levels, which is initially elevated in 80% of women with epithelial ovarian cancer. Serial measurements of CA 125 have been shown to correlate with tumor response to chemotherapy and an elevated serum CA 125 level is a strong indicator of residual or recurrent tumor. However, the detection of clinically occult tumor is problematic. It is well recognized that a normal CA 125 level does not exclude the presence of tumor. In a summary of six studies comparing CA 125 level with operative findings at secondary surgery for ovarian cancer, 82 of 173 patients (47%) with a normal CA-125 level had tumor documented surgically.

Gadolinium-enhanced, fat suppressed MR imaging is highly effective in depicting small volume peritoneal tumor and carcinomatosis. As fewer second look surgeries are now being performed our oncologists have come to rely on the results of MR imaging to help determine tumor response to chemotherapy. Confirming complete clinical response or the
need for additional consolidative chemotherapy is often based upon the information from the MR examination combined with serial serum CA 125 values.

In a study comparing results of MR imaging with those of second-look laparotomy (SLL) and serum CA-125 value we found that gadolinium-enhanced MR imaging depicts residual tumor in women with treated ovarian cancer with accuracy comparable to SLL and superior to serum CA-125 values alone. Out of 76 women with treated ovarian cancer sixty-eight women had residual tumor proven by surgery and biopsy or clinical follow up. Eight patients had no evidence of tumor. Gadolinium-enhanced MR imaging depicted residual tumor in 61 patients (sensitivity 90%, specificity 88%, accuracy 89%), compared to 59 patients for SLL (sensitivity 88%, specificity 100%, accuracy 89%), and 45 patients for serum CA 125 (sensitivity 65%, specificity 88%, accuracy 68%) (p<.01).

II. Pseudomyxoma Peritonei

Pseudomyxoma peritonei is a rare condition characterized by the accumulation of copious gelatinous masses throughout the peritoneal cavity. Pseudomyxoma peritonei associated with appendiceal mucin producing adenomas or adenocarcinomas. This is typically a slowly progressive disease in which patients present with increasing abdominal girth, an inguinal hernia, or a palpable ovarian mass. While pseudomyxoma does not metastasize via the lymphatics or blood stream, it is a progressive disease which if untreated eventually leads to death by replacement of the peritoneal cavity by mucinous tumor.

The primary tumor of the appendix or ovary is typically inconspicuous at the time of diagnosis. Mucin producing tumor cells escape from the appendix and distribute throughout the peritoneal cavity. The eventual deposition of the tumor cells is determined by pathways of flow of peritoneal fluid and by gravity. Bulky tumor deposits in the omentum and right and left subphrenic spaces is most common. Deposition of tumor cells on bowel surfaces is uncommon except at the ileocecal region, the rectosigmoid regions, and the gastric antrum.

The spectrum of disease of pseudomyxoma peritonei syndrome may be separated into three clinical pathologic categories. Disseminated peritoneal adenomucinosis (DPAM) is a benign condition arising from appendiceal adenomas while peritoneal mucinous carcinomatosis (PMCA) is characterized by architectural and cytological features of adenocarcinoma. PMCA arises from appendiceal or intestinal mucinous adenocarcinomas.

On gadolinium-enhanced MR imaging, pseudomyxoma peritonei is depicted as thick and heterogeneously enhancing peritoneal tumor masses. The peritoneal implants are typically less homogeneous in appearance than in ovarian cancer. This more heterogeneous appearance may reflect various amounts of non enhancing mucinous material versus enhancing cellular tumor in the pseudomyxoma peritoneal implants. As in ovarian cancer, eventually all of the peritoneal surfaces become encased in tumor.

In patients with pseudomyxoma peritonei on fat suppressed gadolinium-enhanced images only the solid cellular tumors enhance while the benign mucinous material and ascites do not enhance. In addition the peritoneal lesions from DPAM and intermediate tumors might show less pronounced enhancement than the more cellular peritoneal metastases from PMCA tumors. Gadolinium-enhanced MR imaging can be used to predict the histologic grade of tumor by assessing the degree of tumor enhancement. On delayed gadolinium-enhanced images high grade PMCA tumors show areas with marked enhancement equal in intensity to intravascular gadolinium while DPAM tumors show only mild enhancement equal or less than that of the liver parenchyma.

MR imaging can be used as the sole preoperative imaging test in patients with pseudomyxoma peritonei. At our institution we use MR imaging to accurately identify the location and size of the solid tumors, assess the likelihood of complete surgical resection and to predict the histologic grade of the tumor.

III. Other Abdominal Malignancies
Gadolinium-enhanced, fat suppressed, MR imaging is equally effective for evaluating peritoneal metastases from other primary malignancies. Primary tumors of the stomach, pancreas, and colon often spread by intraperitoneal tumor shedding and subsequent peritoneal carcinomatosis. Accurate depiction of sometimes subtle peritoneal tumor can completely alter patient management. For instance, in patients with pancreatic cancer surgical resection is not indicated if metastatic peritoneal tumor is confirmed on preoperative MR imaging. In the patient with gastric cancer, we are all familiar with the drop metastases to the pelvis producing large complex Krukenberg tumors. However, it is more common to find subtle peritoneal metastases elsewhere in abdomen on MR images. The ability of gadolinium-enhanced MR imaging to depict subtle peritoneal tumor and carcinomatosis makes it a valuable study in the oncology patient. At our institution we often use MR imaging as the primary imaging study in these patients. This approach becomes especially important when peritoneal tumor is of immediate clinical concern.

**Conclusion**

Gadolinium-enhanced MR imaging is a powerful tool to evaluate patients with possible peritoneal disease. In the oncology patient, the increased sensitivity for depicting small peritoneal tumor and carcinomatosis can provide clinicians with valuable information which can improve patient diagnosis and clinical management.

Patient with ovarian cancer. Delayed gadolinium-enhanced MRI shows enhancing peritoneal carcinomatosis (white arrows) and ascites (A).