The Value of Barium as a Gastrointestinal Contrast Agent in MR Imaging: A Comparison Study in Normal Volunteers

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Preliminary data suggest that barium sulfate suspension is a potentially useful negative gastrointestinal contrast agent for MR imaging. To evaluate this hypothesis in a controlled fashion, abdominal and pelvic MR studies of 10 normal volunteers were performed before and after both oral (600–900 ml) and rectal (400 ml) administration of barium. Standard spin-echo coronal T1-, axial T1-, proton density–, and T2-weighted images were obtained at 1.5 T. Images obtained were randomized and interpreted by three observers, who evaluated bowel visualization and delineation of normal anatomy. Bowel segments evaluated were stomach, duodenum, proximal small bowel, proximal colon, distal colon, and rectum. Anatomic structures examined were pancreatic head, pancreatic body, pancreatic tail, retroperitoneum, spleen, liver, pelvic side walls, uterus, vagina, bladder, prostate, and seminal vesicles. Data concerning barium tolerance and safety were recorded. Descriptive, percent change, and kappa statistics were analyzed. Pairwise agreement techniques and repeated measures analysis of variance were performed. This statistical assessment showed a significant improvement in both bowel visualization (59–123% improvement, depending on the segment) and delineation of normal anatomy (23–68% improvement, depending on the structure) after barium administration, particularly on T1-weighted images. In addition, barium was a well-tolerated and safe contrast agent that did not produce artifacts.

Our results show that barium sulfate is a useful negative gastrointestinal contrast agent for MR because it improves bowel visualization and delineation of abdominal anatomy, particularly on T1-weighted sequences.

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Preliminary data, both in vitro and in vivo, suggest that commercially available barium sulfate suspensions may be useful oral contrast materials for MR [1, 2] (Parikh AM, Mezrich RS, presented at the annual meeting of the Society of Magnetic Resonance in Medicine, August 1988; Ballinger R et al., SMRM, August 1990). Barium sulfate is a particularly appealing potential gastrointestinal contrast agent for MR imaging because it has a long-standing record of safety, tolerance by patients, low cost, and wide availability.

No data are currently available from a well-controlled, randomized, prospective series comparing MR images before and after administration of barium in the same subjects. Although the safety and tolerance of barium used in conjunction with diagnostic radiographs is well known, we thought that it was necessary to document any potential unusual effects of barium interacting within a strong magnetic field.

Therefore, the purpose of this study was twofold: (1) to assess the potential of oral and rectal barium sulfate as a gastrointestinal MR contrast agent for visualizing bowel segments (e.g., bowel visualization or opacification) and delineating normal abdominal and pelvic anatomy and (2) to assess tolerance by patients and the potential side effects of oral and rectal barium administration in MR.

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Subjects and Methods

Ten normal volunteers (seven men and three women 25–53 years old) participated in the study. All were healthy, with no history of gastrointestinal disease, prior surgery, or allergy to barium. Each subject underwent abdominal and pelvic MR imaging before and after administration of barium, both orally and rectally. The unenhanced images served as controls for images obtained after oral and rectal administration of barium.

The oral contrast agent used was a 95% barium sulfate suspension (E-Z-pake, E-Z-EM, Inc., Westbury, NY) mixed to 60% weight/weight (w/w). The rectal contrast agent used was a 97% barium sulfate suspension (Sol-O-pake, E-Z-EM, Inc.) mixed to 66% w/w.

All volunteers drank 600–900 ml barium administered in three aliquots of 300 ml each (60 min, 30 min, and immediately before the scan). In addition, all volunteers received 400 ml barium as an enema.

Imaging was performed in all cases with a 1.5-T Signa unit (General Electric, Milwaukee, WI). Standard spin-echo sequences were used: coronal T1-weighted images, 600/20 (TR/TE); axial T1-weighted images, 600/20; axial proton-density-weighted images, 2700/30; and axial T2-weighted images, 2700/80, were obtained with a 256 × 256 or 256 × 128 matrix, two excitations, 5- to 10-mm slice thickness, and 0.5- to 2-mm gap. These variations pertain to differences between pulsing sequences or planes, because identical imaging protocols were used in all cases.

Tolerance to barium was evaluated by recording spontaneous comments by the subjects immediately after imaging and 24 hr later.

All images obtained were separated into unenhanced and enhanced sets, so that for any given volunteer studied, two image sets (unenhanced and enhanced) were created. These 20 sets were then provided to each of the three blinded evaluators in a random sequence, which underwent rerandomization between interpreters. The independent observers analyzed all images without knowledge of whether barium was administered. The parameters evaluated were (1) bowel marking or opacification, defined as the degree of visualization of contrast material within the bowel, and (2) delineation of normal anatomy, defined as the distinctness of normal anatomic structures of the abdomen and pelvis (including bowel and solid organs). The six bowel segments analyzed were stomach, duodenum, proximal colon, distal colon, and rectum. The 12 anatomic structures studied were pancreatic head, pancreatic body, pancreatic tail, retroperitoneum, spleen, liver, pelvic side walls, uterus, vagina, bladder, prostate, and seminal vesicles. Each item analyzed was given a value on a scale of 1–5: 1 = no marking/delineation, 2 = poor marking/delineation (<20%), 3 = fair marking/delineation (20–50%), 4 = good marking/delineation (50–80%), and 5 = excellent marking/delineation (>80%).

Computer-coded evaluation forms were analyzed descriptively (mean, standard deviation, range, and percent change), for trends and for variability between interpreters.

For each item analyzed (six bowel segments and 12 anatomic structures), descriptive statistics were calculated for the evaluators independently and as a pooled score of all evaluators combined. For all items, percent change scores comparing responses made before and after barium administration were calculated with regard to MR pulse sequence and plane. Summary scores were calculated from the individual bowel and anatomy grades. Kappa statistics [3, 4], based on the degree of improvement for all items, were used to assess overall agreement between evaluators. Summary scores were calculated from the individual bowel and anatomy grades. Repeated measures analyses of variance were performed to assess differences due to evaluator, MR pulse sequence/plane, presence (or absence) of barium, and interactions between these factors.

Specifically, bowel and anatomy summary scores were calculated for each combination of evaluator, MR pulse sequence/plane, and presence of barium. Bowel scores were calculated for bowel marking, and consisted of the sum of the six bowel segments considered for each of the 10 volunteers. Anatomy scores were calculated in an identical manner, and consisted of the sum of the scores for the 12 anatomic structures examined for the 10 subjects, and for each combination of evaluator, MR pulse sequence, and presence of barium.

At the component level, we focused on the amount of change for each response before and after barium administration. We evaluated this variable in both continuous and categorical fashions. The categories of worse, same, and better were calculated, and pairwise agreement was determined for the evaluators by using the kappa statistic.

Results

The summary scores indicated consistent improvement with barium administration for each MR pulse sequence/plane studied and each evaluator, although the magnitude of improvement varied. Grouping all scores for each evaluator's responses showed a consistent trend of improvement after barium administration for all pulse sequences evaluated irrespective of anatomic region. A repeated measure analysis of variance was performed, and significant effects ($p < .01$) due to barium administration and pulse sequence/plane were observed for both bowel opacification (marking) and anatomy. Also, effects due to evaluator and evaluator–barium administration interaction were noted.

To illustrate these results, Table 1 displays the means and standard deviations of the anatomy scores by evaluator, MR pulse sequence, and presence of barium.

Next we considered variability between interpreters. The tested hypothesis, no agreement between interpreters ($\kappa = 0$), vs agreement between interpreters ($\kappa > 0$) was evaluated. Kappa statistics were calculated, where z corresponds to the hypothesis test (Table 2). While these statistics are significantly different ($p < .01$) from 0 (no agreement), they do not indicate strong agreement.

Percent change scores were calculated for each item. These scores are particularly sensitive to improvements in

TABLE 1: Means and Standard Deviations of Anatomy Scores

Interval/MR Sequence	Mean Anatomy Score (SD)		
	Observer 1	Observer 2	Observer 3
Before barium			
Axial T1 weighted	36.4 (3.6)	28.4 (5.2)	31.4 (2.0)
Coronal T1 weighted	29.0 (2.9)	23.8 (4.1)	24.4 (3.0)
T2 weighted	28.9 (2.2)	21.0 (2.7)	28.7 (2.7)
Proton-density weighted	33.3 (3.4)	25.6 (4.4)	30.0 (4.1)
After barium			
Axial T1 weighted	42.4 (3.8)	45.2 (2.8)	36.2 (2.9)
Coronal T1 weighted	31.6 (2.8)	34.7 (4.4)	27.2 (2.8)
T2 weighted	31.0 (2.5)	40.7 (4.7)	31.3 (3.8)
Proton-density weighted	35.5 (9.6)	41.2 (4.1)	31.9 (6.2)

Note.—Twelve anatomic structures in 10 subjects were evaluated for delineation of normal anatomy on the basis of a 1–5 scale: 1 = no delineation, 2 = poor delineation (<20%), 3 = fair delineation (20–50%), 4 = good delineation (50–80%), and 5 = excellent delineation (>80%). The maximum mean score possible per observer was 46.5.

TABLE 2: Variability Among Interpreters

Observer	κ	SE	z	p
1 vs 2	.055	.018	3.134	<.01
1 vs 3	.248	.027	9.213	<.01
2 vs 3	.084	.017	4.854	<.01

quality, if initial assessment was poor. Detailed results are given in bar graph format (Figs. 1 and 2) with pre- and postbarium scores displayed for each pulse sequence and plane used (coronal T1-weighted images, axial T1-weighted images, axial T2-weighted images, and axial proton density–weighted images), as well as major parameters (bowel marking and anatomy; Figs. 1 and 2, respectively).

Improved marking or opacification of bowel and enhanced delineation of upper abdominal and pelvic structures were observed with all pulse sequences and planes (Figs. 3–9). The only exception was imaging of the vagina with T1-weighted coronal images, which displayed decreased visualization after barium was administered (Fig. 2A). It should be noted, however, that axial T1-weighted images, T2-weighted images, and proton density–weighted images (Figs. 2B–2D) showed improvement of vaginal delineation after barium administration.

In general, the structures that benefited most (greatest percent change) from barium administration were the rectum and distal colon (Fig. 6). Additionally, the duodenum, stomach, and proximal small bowel displayed significantly improved visualization after barium administration (Figs. 4, 5, 7, and 8). Axial T1-weighted images displayed consistent improvement with maximal postbarium scores for all anatomic regions evaluated (Fig. 2). Although T1-weighted images improved significantly after barium was administered, it may be interesting to note that visualization of the uterus and vagina was most improved with T2-weighted images obtained after barium administration (Figs. 2C and 9) and visualization of the

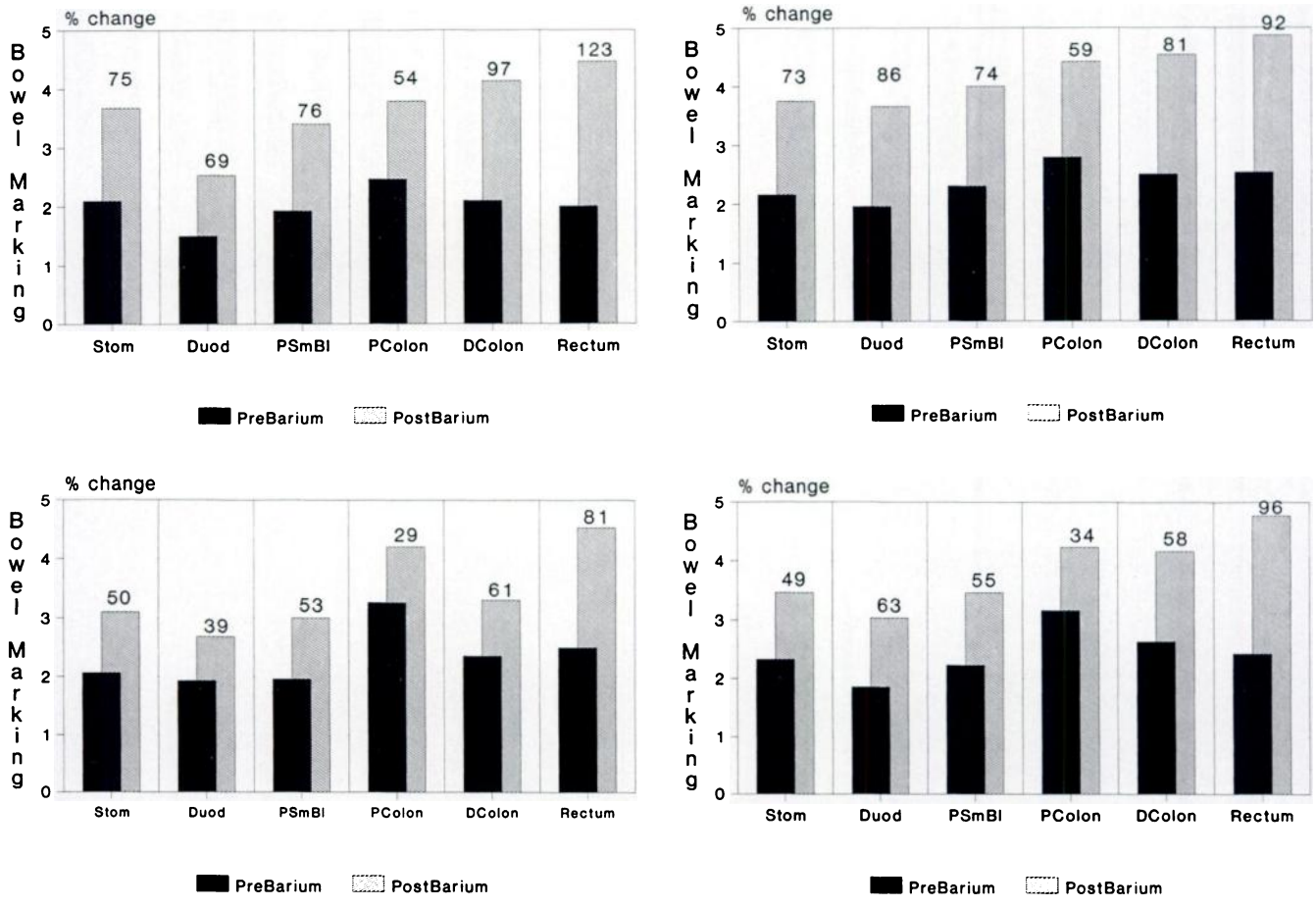

Fig. 1.—Effect of barium on MR bowel marking. In each graph, percent change in bowel marking, or opacification, is given by bowel segment.
***A*, Coronal T1-weighted image.**
***B*, Axial T1-weighted image.**
***C*, Axial T2-weighted image.**
***D*, Axial proton density–weighted image.**
Stom = stomach, Duod = duodenum, PSmBl = proximal small bowel, DColon = distal colon.

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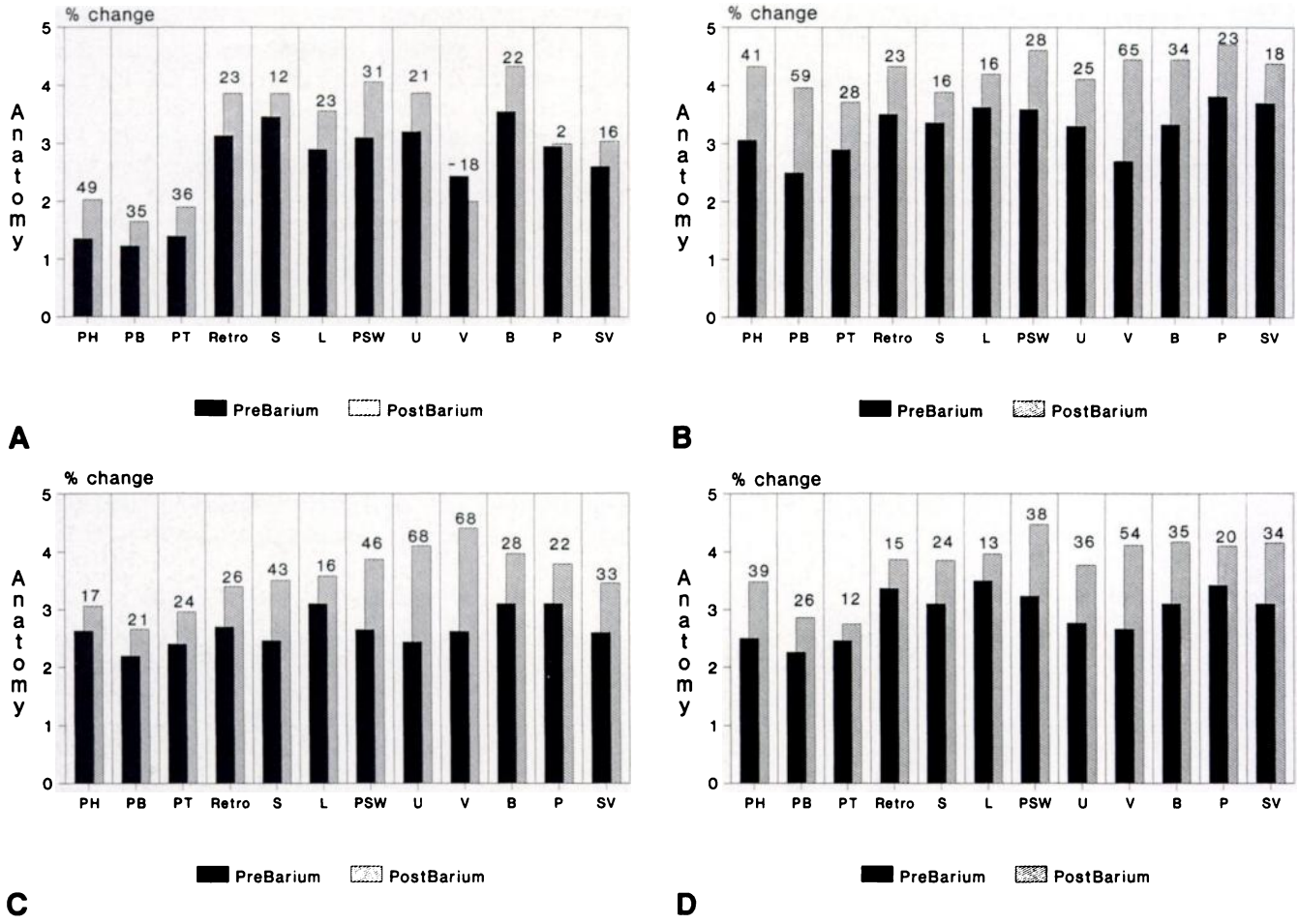

Fig. 2.—Effect of barium on MR delineation of anatomy. In each graph, percent change in delineation of anatomy is given by anatomic structure.
***A*, Coronal T1-weighted image.**
***B*, Axial T1-weighted image.**
***C*, Axial T2-weighted image.**
***D*, Axial proton density–weighted image.**
PH = pancreatic head, PB = pancreatic body, PT = pancreatic tail, Retro = retroperitoneum, S = spleen, L = liver, PSW = pelvic side walls, U = uterus, V = vagina, B = bladder, P = prostate, SV = seminal vesicles.

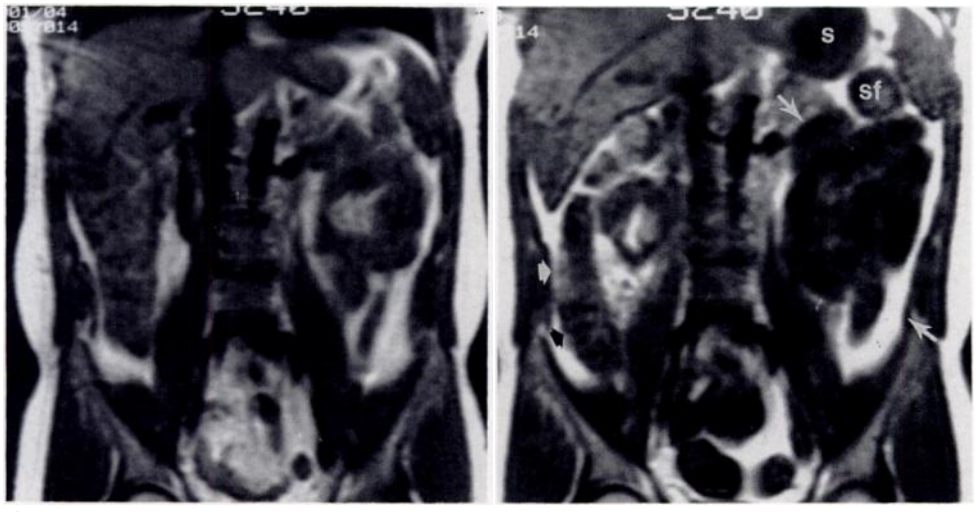

Fig. 3.—Coronal T1-weighted MR images of abdomen.
***A*, Before barium administration, superior border of liver is indistinct, as are splenic flexure, ascending colon, and stomach.**
***B*, After barium administration, delineation of proximal small bowel (*long arrows*), pelvic bowel, ascending colon (*short arrows*), splenic flexure (sf), stomach (s), and inferior border of liver is improved.**

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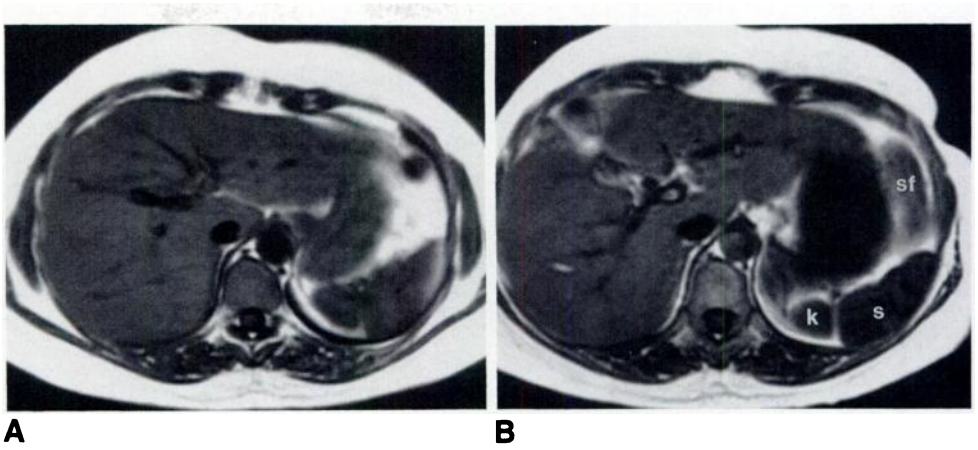

Fig. 4.—Axial T1-weighted MR images of upper abdomen (stomach and left upper quadrant).

***A*, On prebarium T1-weighted image, stomach appears somewhat collapsed and contains normal gastric secretions. Gastric wall cannot be distinguished.**

***B*, On postbarium image, stomach appears distended. This may allow, as in this case, clearer delineation of upper pole of kidney (k), spleen (s), most lateral portion of left lobe of liver, and splenic flexure of colon (sf).**

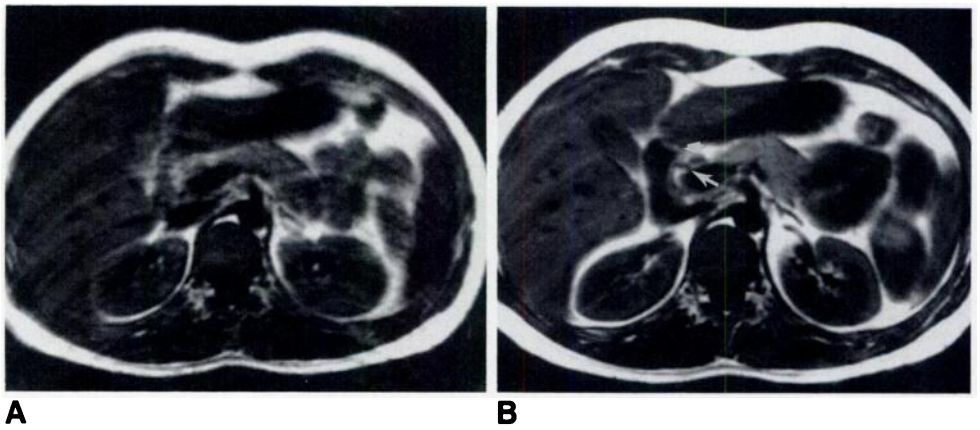

Fig. 5.—Axial T1-weighted MR images of duodenum/pancreas.

***A* and *B*, Compared with prebarium MR image (*A*), good marking of duodenal sweep and proximal jejunum is seen after administration of barium (*B*). Duodenum and proximal small bowel are also well delineated, with good visualization of adjacent structures, such as portal vein, body of pancreas, and left adrenal gland. Note how hepatic artery (*long arrow*) and common bile duct (*short arrow*) can be identified.**

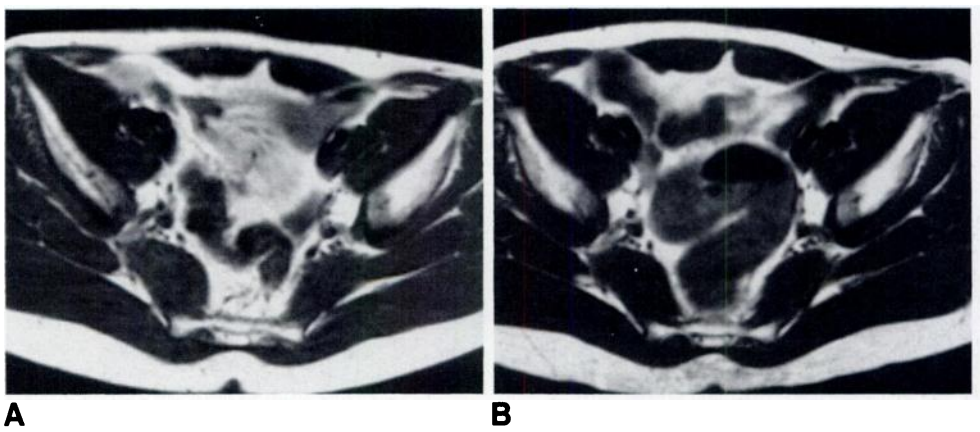

Fig. 6.—Axial T1-weighted MR images of sigmoid colon.

***A* and *B*, Sigmoid colon is identified well on images obtained before (*A*) and after (*B*) barium administration. However, after rectal administration of barium, sigmoid colon shows opacification, with improved delineation of pelvic side walls.**

seminal vesicles and pelvic side walls was most improved with proton density–weighted images (Fig. 2D).

As expected, anatomic structures that were not near bowel structures and that were well imaged before barium administration displayed modest improvement after barium administration (liver and retroperitoneum) (Fig. 2). On the postbarium images, no artifacts were specifically related to barium administration.

The secondary effects observed were nausea in four patients, cramps in three, and mild constipation in two. All patients recovered fully without therapeutic intervention. These symptoms were similar to those produced by the administration of barium for gastrointestinal examinations other than MR. Therefore, it appears that MR does not produce specific secondary effects for barium administered orally or rectally.

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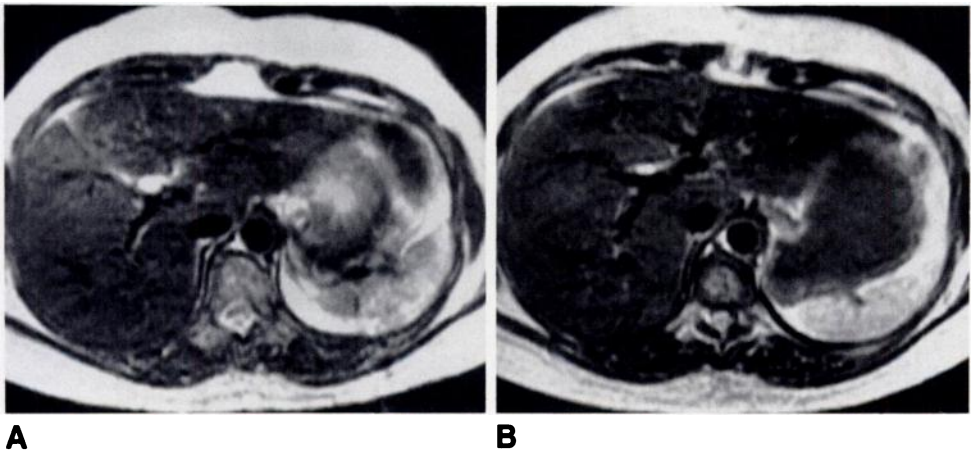

Fig. 7.—Axial T2-weighted MR images of stomach and left upper quadrant.

***A*, On prebarium image, ghost artifacts from residual gastric contents deteriorate visualization of structures in left upper quadrant, such as spleen and lateral segment of left lobe of liver.**

***B*, After contrast administration, low intensity of barium allows better visualization of spleen and left lobe of liver, predominantly by reduction of ghost artifacts. Gastric wall can be easily identified; note negative contrast effect of barium on this heavily T2-weighted image.**

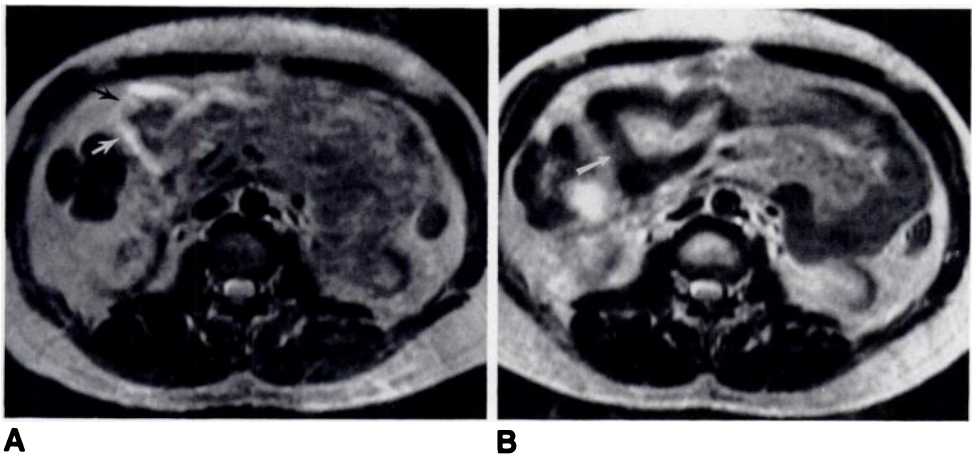

Fig. 8.—Axial T2-weighted MR images of proximal small bowel.

***A*, On prebarium image, bowel marking and delineation of bowel from mesentery are poor. High intensity results from enteric secretions (*arrows*).**

***B*, After administration of barium, enhanced marking and delineation of bowel compared with surrounding structures are seen. Ghosting in this image is mildly reduced by negative contrast effect of barium (*arrow*).**

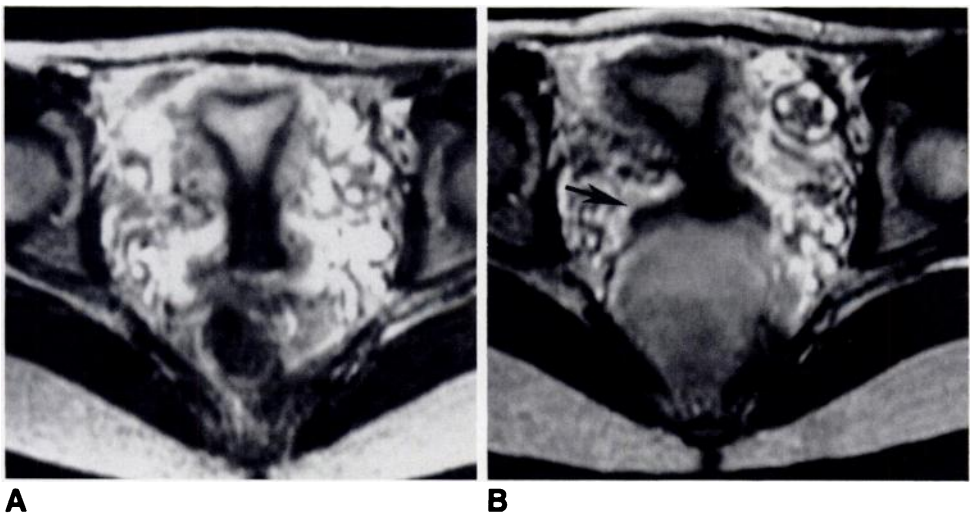

Fig. 9.—Axial T2-weighted MR images of uterus.

***A* and *B*, Although uterus is well seen on images obtained before (*A*) and after (*B*) barium administration, post-barium study shows that by filling rectum with contrast material and thus displacing uterus anteriorly, vaginal fornix (*arrow*) is delineated better than on prebarium image.**

Discussion

This study, designed to evaluate the effect of barium as a gastrointestinal contrast agent, demonstrates a statistically significant improvement in bowel opacification and delineation of abdominal and pelvic structures in almost all pulse/plane sequence combinations analyzed.

It is not well known why barium sulfate produces a negative contrast effect. Barium is a diamagnetic substance, which in aqueous suspension eliminates signal by the following pro-

posed mechanisms: (1) magnetic susceptibility at particle-water interphase (primarily a T2 shortening effect) and (2) particle replacement of water by barium, which contains no hydrogen.

The negative contrast effect of barium is well maintained in bowel segments that are distant from its entry point, such as the jejunum or ileum, where peristalsis and mixture with enteric secretions might dilute it. This may be due to the intrinsic composition of the commercially available barium sulfate suspensions used, which contain additives designed to produce uniform opacification of the gastrointestinal tract.

Regarding tolerance and safety, our results demonstrate that the secondary effects attributable to barium during MR examination are mild and not appreciably different from those observed during routine gastrointestinal barium examinations. Therefore, barium may be a useful negative gastrointestinal contrast agent, with a wide margin of tolerance and safety, and with potential reactions that in complicated cases (obstruction, perforation, allergy, etc.) are well known in the radiologic literature. No artifacts attributable to barium that would decrease its efficacy as an MR gastrointestinal contrast agent were noted. An additional advantage of barium used as an MR gastrointestinal contrast agent is that MR examinations may be performed after upper gastrointestinal examination or barium enema, thus providing an alternative to abdominal CT studies.

Thus, barium sulfate appears to be a useful negative contrast agent for MR imaging because it improves bowel marking and delineation of abdominal anatomy, particularly on T1-weighted sequences.

REFERENCES

1. Burton SS, Ros PR, Torres GM, et al. Barium-MRI of the pancreas: initial experience. *Radiology* **1989**;173(P):517
2. Storm BL, Li KCP, Tart RP, et al. Barium sulfate suspension as an oral contrast agent in MR imaging: initial clinical results. *Radiology* **1989**;173(P):522
3. Kramer MS, Feinstein AR. The biostatistics of concordance. *Clin Pharmacol Ther* **1981**;29;111–123
4. Fleiss JL. *Statistical methods for rates and proportions*, 2nd ed. New York: Wiley, **1981**:212–236

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