Original Research

Impact of Diet on Stool Signal in Dark Lumen Magnetic Resonance Colonography

Susanne C. Goehde, MD,* Waleed Ajaj, MD, Thomas Lauenstein, MD, Joerg F. Debatin, MD, and Mark E. Ladd, PhD

Purpose: To examine the magnetic resonance (MR) properties of different foods and their effect on the colonic stool signal to potentially support fecal tagging strategies for dark lumen MR colonography (MRC).

Materials and Methods: T1 relaxation times of 120 different foods (partially diluted with sufficient water) were determined by use of a multi-flip-angle two-dimensional gradient echo (GRE) sequence and correlated to the foods' signal in a three-dimensional GRE volumetric interpolated breath-hold examination (VIBE) sequence. Different dilutions of six foods were examined. VIBE stool signal was determined in six volunteers under two different conditions: after a three-day diet of short T1 food and of long T1 food, respectively.

Results: Most foods exhibit short to very short T1 relaxation times. T1 correlates well with the fat-saturated VIBE signal except for fatty products. Diluted food exhibits T1 times similar to water; concentrated food strongly varies according to their T1 values. No significant difference in stool signal could be found in the in vivo examination comparing the two diets.

Conclusion: According to our results, a restricted diet strategy to reduce fecal signal for dark lumen MRC is unlikely to be successful. Moreover, the stool signal reduction found in the other fecal tagging studies can be explained at least to a great extent by the relative content of other material with long T1 relaxation times, such as water or oral barium.

Key Words: magnetic resonance imaging; magnetic resonance colonography; barium; fecal tagging; nutrition; food; relaxation time; signal
J. Magn. Reson. Imaging 2004;20:272–278.

MAGNETIC RESONANCE COLONOGRAPHY (MRC) has evolved as an attractive alternative to conventional colonoscopy (CC) for the detection of colorectal masses. For polyps exceeding 10 mm, high-accuracy values of 92% to 100% are reported (1–3). Initial studies proposed the use of bright lumen techniques, based upon either water enemas in conjunction with T2-weighted steady-state free precession (i.e., TrueFISP) imaging or T1-weighted imaging in conjunction with a gadolinium-doped enema (4–6). Since the detection of a colorectal mass is based on a luminal filling defect, the differentiation of polyps from residual stool or air bubbles is most difficult. This problem could partially be overcome by imaging the patient both prone and supine; polyps remain stationary while stool is displaced between the two scans (1).

Recently, dark lumen MRC has been proposed (7). The technique is based upon the acquisition of a T1-weighted three-dimensional gradient echo (GRE) sequence following a rectal water enema and the intravenous administration of a paramagnetic contrast agent (8). The colonic lumen distended by the water enema is rendered dark, while colorectal tumors are identified by their avid uptake of paramagnetic contrast. Reflecting the inherent lack of spins, air bubbles remain dark and hence no longer can mimic polyps. Similarly, the lack of enhancement inherent to stool permits easy differentiation of enhancing polyps from residual stool. This observation has motivated the evaluation of dark lumen MRC without prior colonic cleansing (9). The advantages of such a strategy mainly relate to improved patient acceptance (10,11). Initial experience, however, revealed an unforeseen problem: stool can be characterized by relatively high signal on T1-weighted sequences. In the presence of abundant bright stool in the colonic lumen, differentiation from enhancing colorectal masses can be difficult (12). Subtraction techniques have been evaluated and found to be of limited value, reflecting minimal bowel peristalsis between the pre- and postcontrast data acquisitions. Hence, strategies have been concentrating on rendering the stool signal dark. Thus, the addition of barium to regular meals has been recommended. In addition, several food additives such as manganese are suspected to profoundly impact stool signal. The goal of this study was to experimentally examine the magnetic properties of different foods and their effect on the colonic stool signal.

Department of Diagnostic and Interventional Radiology, University Hospital Essen, Essen, Germany.
*Address reprint requests to: S.C.G., Department of Diagnostic and Interventional Radiology, University Hospital Essen, Hufelandstrasse 55, 45122 Essen, Germany. E-mail: susanne.goehde@uni-essen.de
Received October 13, 2003; Accepted February 23, 2004.
DOI 10.1002/jmri.20098
Published online in Wiley InterScience (www.interscience.wiley.com).

Table 1
Parameters for the In Vitro and In Vivo MR Sequences

	Two-dimensional spoiled gradient echo	Three-dimensional VIBE
B_0	1.5 T	1.5 T
TE	1.8 msec	1.2 msec.
TR	100 msec	3.2 msec.
Flip angle θ	10–90° (Δθ = 10°)	12°
Fat saturation	No	Yes (for in vivo study) No (for dilution study)
Slice thickness	8 mm	1.6 mm
Number of slices	11	96
Orientation	Coronal	Coronal

MATERIALS AND METHODS

MR Technique

All imaging was performed on a 1.5-T whole-body scanner (Sonata, Siemens, Erlangen, Germany). The body surface array coil and the spine array coil were used for signal reception in all experiments. For determination of T1 relaxation times, a two-dimensional spoiled GRE sequence fast low angle shot (FLASH) was used. Nine scans were performed, each with a different flip angle (10°, 20°, . . . , 90°). The GRE signal intensity (SI) is

$$SI(\theta) = \rho_0 \exp\left(-\frac{T_E}{T_2^*}\right)\frac{(1 - E_1)\sin\theta}{(1 - E_1\cos\theta)} \qquad (1)$$

where θ denotes the flip angle, $E_1 = \exp(-T_R/T_1)$, and ρ_0 is the spin density. The two quantities to be determined, ρ_0 and T_1, can be estimated from the signal measured at multiple flip angles at a fixed T_R value by performing a linear fit of the transformed Eq. (1):

$$\frac{SI(\theta)}{\sin(\theta)} = E_1\frac{SI(\theta)}{\tan(\theta)} + \rho_0 \exp(-T_E/T_2^*)(1 - E_1) \qquad (2)$$

which transforms the measured data into a straight line with slope E_1 and ordinate intercept of $\rho_0\exp(-T_E/T_2^*)(1 - E_1)$. T_1 can thus be calculated from the slope E_1, and for T_E values $\ll T_2^*$, ρ_0 is then yielded by the ordinate intercept, which simplifies to $\rho_0(1 - E_1)$ (13).

All other parameters were held constant between the nine series. Parameters are shown in Table 1. T2 relaxation was considered insignificant, i.e., $\exp(-T_E/T_2^*) \approx 1$, as $T_2^* \gg T_E$.

Additionally, a three-dimensional spoiled GRE volumetric interpolated breath-hold examination (VIBE) sequence (14) was acquired. This VIBE sequence is analogous to the sequence that is used for clinical dark lumen MRC; only the field of view (FOV) was individually adapted to the different samples. In particular, a fat saturation pulse was used to suppress signal from fat. In the in vitro study for the determination of diluted food properties (described below), the VIBE sequence was acquired without the use of fat saturation pulses. The parameters of all sequences are given in Table 1.

To assess the dependability of the two-dimensional measurements, the goodness of fit of the linear fit of Eq. (2), as given by r^2, was noted, and the measured VIBE signal was correlated with the calculated VIBE signal as given by Eq. (1), with use of the flip angle and TR used for the VIBE sequence according to Table 1.

In Vitro Evaluation of Different Foods

A total of 120 different commercially available food products were evaluated (examples shown in Table 2). Except for tea, coffee, natural lemon juice, sugar, chocolate, cornflake cereal, instant cocoa powder, chili powder, and pepper, the food was not diluted with water. Rice, noodles, and vegetables were cooked for 20 minutes in sufficient water (Fig. 1), and excess water was drained.

T1 relaxation times and spin densities were calculated with aid of the two-dimensional sequence, and the intrinsic signal on the three-dimensional VIBE (with fat saturation) sequence was measured.

Food Dilution

No direct control was available over the water content or the hydration state of the food. Furthermore, there is generally no control over the grade of food dehydration on its way through the digestive system. To estimate the possible effects of dehydration or dilution on the magnetic properties of food, four dilutions of several different foods were measured. For this purpose, six representative foods (with short, intermediate, and long T1 times in their natural states as commercially available) were studied with the varying flip angle two-dimensional GRE sequence. The foods were diluted (by volume) by adding water, resulting in dilutions of 1:0, 1:1, 1:3, and 1:7, and their respective T1 relaxation times were calculated. An approximate calculation of the VIBE signal was performed using the known flip angle and TR of the sequence combined with the calculated T1 relaxation times and proton density values. The measured VIBE signal (without fat saturation) was compared to the calculated VIBE signal for estimating the suitability of this approach.

Effect of Two Different Diets (Long vs. Short T1 Time) on Stool Signal: In Vivo Evaluation

Six volunteers were examined with a coronal three-dimensional VIBE sequence, using the same parameters as for clinical routine MRC (Table 1). Each volunteer underwent MR examination twice: once after a three-day period of eating only foods that were found to have long T1 times, and again after three days of eating foods that revealed short T1 times in the in vitro evaluation. The volunteers did not undergo colonic filling with enema, nor did they receive intravenous contrast agent, as only the change in stool signal was compared. Signals of stool as well as contrast-to-noise ratios (CNRs) with respect to the colonic wall were determined. For this purpose, a region of interest (ROI) was chosen that was as large as possible, but did not include structures other than those to be measured. In each volunteer, five different ROIs were set inside the stool and colonic wall, respectively, in the ascending, transverse, descending, sigmoid colon, and rectum. The inherent water content in the colon was excluded

Table 2
List of Three-dimensional VIBE Signal With Fat Saturation and T1 Relaxation Time Measurements for Various Foods, Ordered by T1 Time*

Food	T1 (msec)	VIBE signal	Food	T1 (msec)	VIBE signal
Honey	41	97	Hot dogs	616	37
Strawberry jam	53	168	Chicken breast	617	36
Cherry jam	77	172	Carrots	666	52
Chocolate	94	22	Cauliflower	677	39
Margarine	103	52	Ground beef	715	40
Cashew nuts	115	60	Water with sugar	725	44
Sugar syrup	118	64	Ground lamb	734	36
Olive oil	128	109	Chocolate cornflakes with milk	739	21
Butter	132	21	Peppermint tea	753	22
Peanuts	134	27	Orange yoghurt drink	754	25
Nutella (chocolate spread)	136	18	White grapes	769	20
Beef liver	137	79	White wine	774	20
Apricot jam	138	149	Nutraprep Chicken Soup[a]	800	35
Sunflower oil	148	58	Gherkin	841	31
Asian dressing	186	72	Curd cheese with herbs	848	12
Chocolate cornflakes with water	220	28	Lettuce	849	24
Whole grain toasting bread	224	69	Whipped cream from Chocolate pudding desert	853	18
Nutraprep Stroganoff[a]	252	96			
Kidney beans	255	67	Varibar barium nectar 40g/100mL[b]	870	32
White toasting bread	258	54	Nutraprep Potato Poppers[a]	871	20
Chocolate pudding	260	66	Orange juice	899	35
Liver sausage	299	36	Kiwi	915	37
Raw egg	311	91	Raw onion	935	29
Chicken liver	313	60	Nutraprep Cinnamon Apple Sauce[a]	945	36
Cheese	314	35	Apple juice	1030	32
Canned corn	318	95	Aloe Vera yoghurt drink	1057	37
Spinach	375	76	Cola	1061	18
Canned peas	389	93	Beer	1068	24
Black tea	401	56	Multivitamin juice	1149	36
Nutraprep Chocolate[a]	406	5	Seven-Up	1161	34
Nutraprep Sugar[a]	417	58	Raw carrots	1191	31
Rice	431	30	Strained tomatoes	1247	29
Cottage cheese	458	35	Tap water	1401	15
Broccoli	475	46	Water with salt	1510	16
Milk rice desert	492	68	White milk	1515	18
Lamb kidneys	513	60	Water and coffee	1534	15
Noodles	524	35	Mineral water	1563	21
Potatoes	549	33	Orange soft drink	1567	25
Fruit tea	552	48	Water with instant cocoa powder	1587	17
Nutraprep* Vanilla Shake[a]	557	52	Grapefruit juice	1649	24
Cooked salmon	565	44	Water with chili powder	1660	17
Farmer's cheese	565	53	Coffee cream	1893	16
Banana	566	46	Micropaque barium 100%[c]	1946	14
Plain yoghurt	599	41	Water and pepper	2013	13
Red grape juice	608	60	Water and lemon juice	2321	13

*This list is not complete.
[a]Nutraprep products for bowel preparation by E-Z-EM, Westbury, NY.
[b]Varibar barium sulfate suspension, E-Z-EM, Westbury, NY.
[c]Micropaque 100% barium,Guerbet, Sulzbach, Germany.

from the ROIs. For each subject and each structure (stool and colonic wall), an average value was calculated from these measurements at three different colonic levels. The difference in the two diets were evaluated by comparing signals and CNRs by the paired *t*-test. A P value of <0.05 was required for statistical significance.

RESULTS

T1 Relaxation Times of Food

Figure 2 shows an example of the two-dimensional SI of various foods with respect to the flip angle. Tap water is displayed as representative of food with a long T1 relaxation time and is plotted together with foods exhibiting a typical spread in T1 relaxation times. Figure 3 shows a scatter plot of the corresponding values for tomato juice, where abscissa and ordinate are the rescaled SI according to Eq. (2). Superposed is the linear fit line, resulting in an excellent fit with $r^2 = 0.999$. All food with a calculated T1 relaxation time greater than 500 msec had a goodness of fit of $r^2 > 0.90$, and only 3 of 43 foods with a calculated T1 relaxation time below 500 msec had a goodness of fit below 0.90 (honey, 0.52; chocolate bar and water, 0.78; and apricot jam, 0.59).

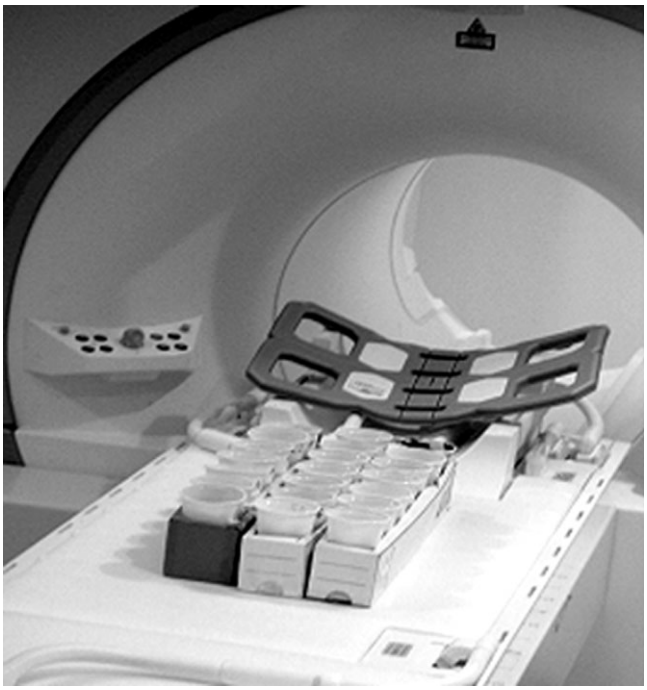

Figure 1. Set up of in vitro T1 assessment of various foods. Food was placed into plastic cups. Three rows of plastic cups were placed into the magnet bore concurrently for each measurement. Data acquisition was performed with a phased array coil for signal detection (wrapped toward the magnet for demonstration purpose). The cups were covered with thick tissue to prevent evaporation.

Table 2 shows calculated T1 values and measured SIs in the three-dimensional VIBE sequence (with fat saturation) for a variety of foods. The range of T1 relaxation times varies widely from 41–2123 (Fig. 4, Table 2). Values over 1400 msec are achieved only by watery suspensions, such as water mixed with sugar, salt, chili powder, lemon juice, coffee, grapefruit juice, orange soft drink, and 100% barium. Values lower than 400 msec are found for all oils, margarine and butter, nuts, vegetables (peas, spinach, kidney beans, corn), marmalade, honey, sugar syrup, chocolate products, Nutraprep Stroganoff (E-Z-EM, Westbury, NY), eggs, and bread.

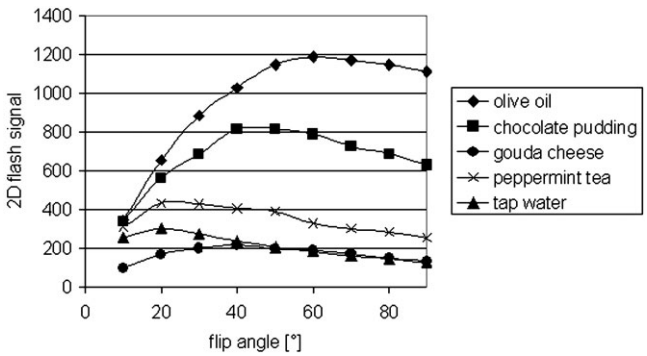

Figure 2. Dependency of the two-dimensional GRE signal on the flip angle for four different foods and tap water.

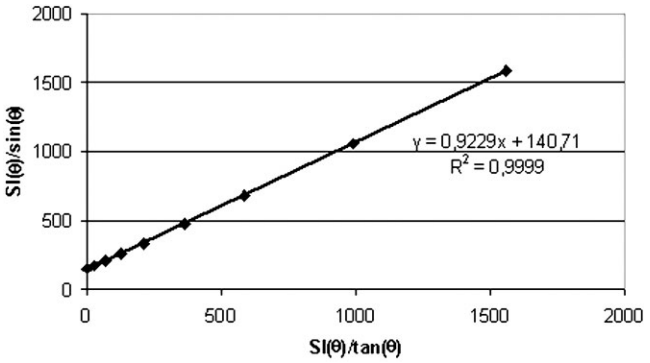

Figure 3. Determination of the T1 relaxation time of tomato juice according to Eq. (2). The slope of the linear fit renders T1, and the proton density can be determined through use of the y-axis intercept.

Figure 5 depicts the agreement between the measured and calculated VIBE signal. Agreement is not perfect with an r^2 value of 0.69, but the tendency is visible. Oily and fatty products tend to show poor agreement, with calculated signals exceeding the measured equivalents, probably due to the fat saturation pulse of the VIBE sequence. If these five products are eliminated from the fit, the linear fit reaches a value of $r^2 = 0.8$.

Effect of Dilution on T1 Time of Food

For the single foods, the goodness of the fit between the measured and calculated VIBE signals was >0.94, except for cream and chocolate pudding. With increasing dilution with water, all six foods exhibited a signal decrease in the non-fat-saturated VIBE sequence, tending toward the signal of pure water. By decreasing the dilution, the six foods exhibited increasing VIBE signals, which were highest for jam, honey, and chocolate pudding (Fig. 6), as was expected from the T1 measurements (Table 2). Accordingly, toward higher dilutions, T1 times resemble that of pure water; the undiluted foods show T1 values that differ from each other by a factor of 20 (range = 36–706 msec).

Effect of Diets on Stool Signal

No statistically significant difference was found for the stool signal between the two diets (short T1 relaxation

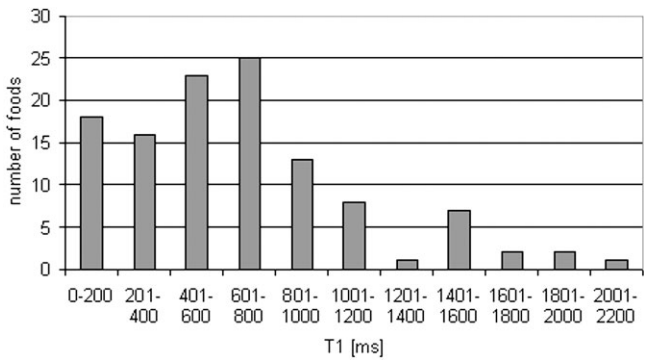

Figure 4. Distribution of the calculated T1 relaxation times of 120 different foods. The major parts of the tested foods show T1 relaxation times lower than that of water (<800 msec).

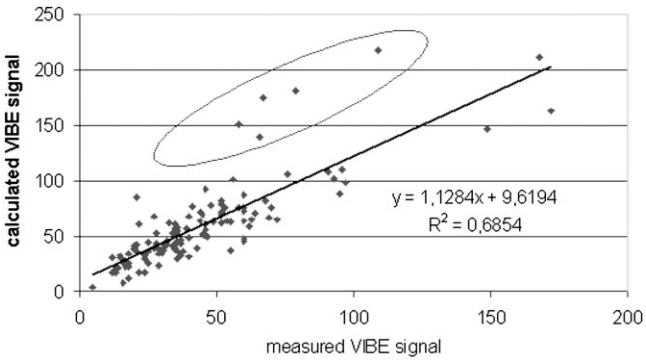

Figure 5. The measured and calculated VIBE signals show a good correlation, except for oily and fatty products such as sunflower oil, olive oil, beef liver, and kidney beans (marked by the ellipses). In general, the calculated VIBE signal is too high for almost all foods.

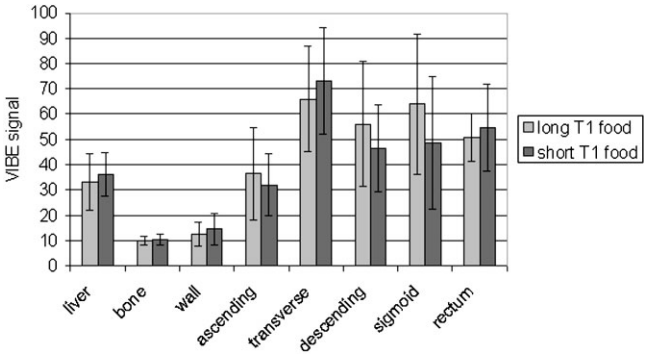

Figure 7. In vivo signal of six individuals. Signals of stool in the ascending, transverse, descending, sigmoid colon, and rectum were measured. For comparison, liver, bone, and colonic wall signals are displayed. Mean values as well as standard deviations are displayed. No statistically significant differences between a diet with short T1 foods and one with long T1 foods could be found for stool in any region.

time diet vs. long T1 relaxation time diet) in the six volunteers (Figs. 7 and 8). Moreover, assessing the single stool signal-to-noise ratios (SNRs) within all five colonic regions in all six subjects, in 17 of 30, thus in the majority of cases, the SNR of stool was higher after the dark-food diet. This was especially true in the sigmoid, in which five of six volunteers had higher stool SNRs after the dark-food diet, as can be seen by Fig. 7.

Mean CNRs of colonic stool with respect to the bowel wall were 4.7 ± 1.5 for long T1 foods and 4.0 ± 1.9 for short T1 foods, with stool signal being higher than the wall signal in every exam and location.

DISCUSSION

MRC has proven to be an accurate alternative to CC for polyps larger than 10 mm. For screening purposes, this size limit does not pose a significant limitation, as smaller polyps exhibit a drastically reduced chance for developing malignancy within the next several years (15,16). MRC fulfills another prerequisite for a successful screening method when compared to CC as the gold standard: it is minimally invasive. Although patient acceptance has not been studied in large populations, the high self-referral rate in our hospital might reflect the potential of MR imaging (MRI) in this respect. As known from CC, one of the greatest impediments for all current colonic screening modalities lies in the need for bowel cleansing. By emulating the idea of fecal tagging in computed tomography (CT) colonography for MRC, there has been some initial success through the use of oral barium, which decreases stool signal in T1-weighted sequences (9). This technique provides promising results; however, it seems theoretically possible to further increase the stool contrast by eliminating paramagnetically active substances from the diet in the 2–3 days of bowel preparation.

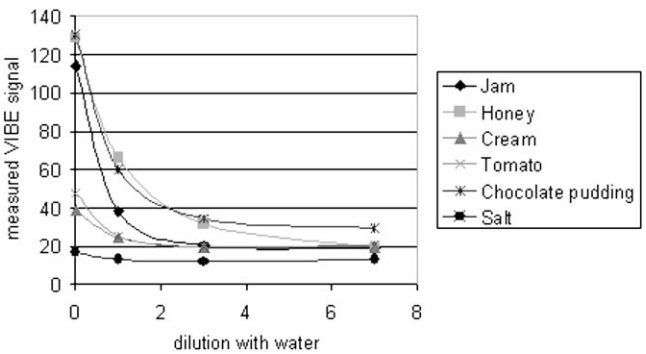

Figure 6. Measured VIBE signal of six different foods vs. their dilution with water (on a volumetric basis). On the horizontal axis, 0 denotes no dilution of the commercially available product and 7 denotes a food dilution with water by a factor of 1:7. At higher concentrations, all foods tended toward higher VIBE signals, as their undiluted T1 times were all shorter than the T1 time of water.

This study strove to categorize foods with respect to their inherent T1 times. The method for calculation of T1 relaxation times seems to be feasible and renders meaningful results. The in vitro studies are certainly not perfect due to a number of error sources, such as imperfect radio frequency (RF) profiles, T_2* effects, a nonhomogeneous T1 relaxation time of the probes, etc., but the goodness of the T1 fits as well as the reproducible and explainable results point toward a low influence by these technical factors.

The comparison of the measured VIBE signals of the foods with the calculated VIBE signals (via the calculated T1 time and proton density, as well as the known flip angle and TR time of the sequence) reveals a good correlation; the fact that oily and fatty products exhibit a lower signal in the VIBE measurements can be explained by the fat saturation pulse that was used, which is specifically intended to attenuate the measured signal from protons in fatty chemical bonds.

The T1 relaxation times of the commercially available foods tested showed a wide range. Two groups of foods were defined: long T1 time foods (T1 times above 700 msec) and short T1 time foods (T1 times below 700 msec), and their effect on stool signal was evaluated. The in vivo study on six volunteers, surprisingly, showed no difference in stool signal between the two

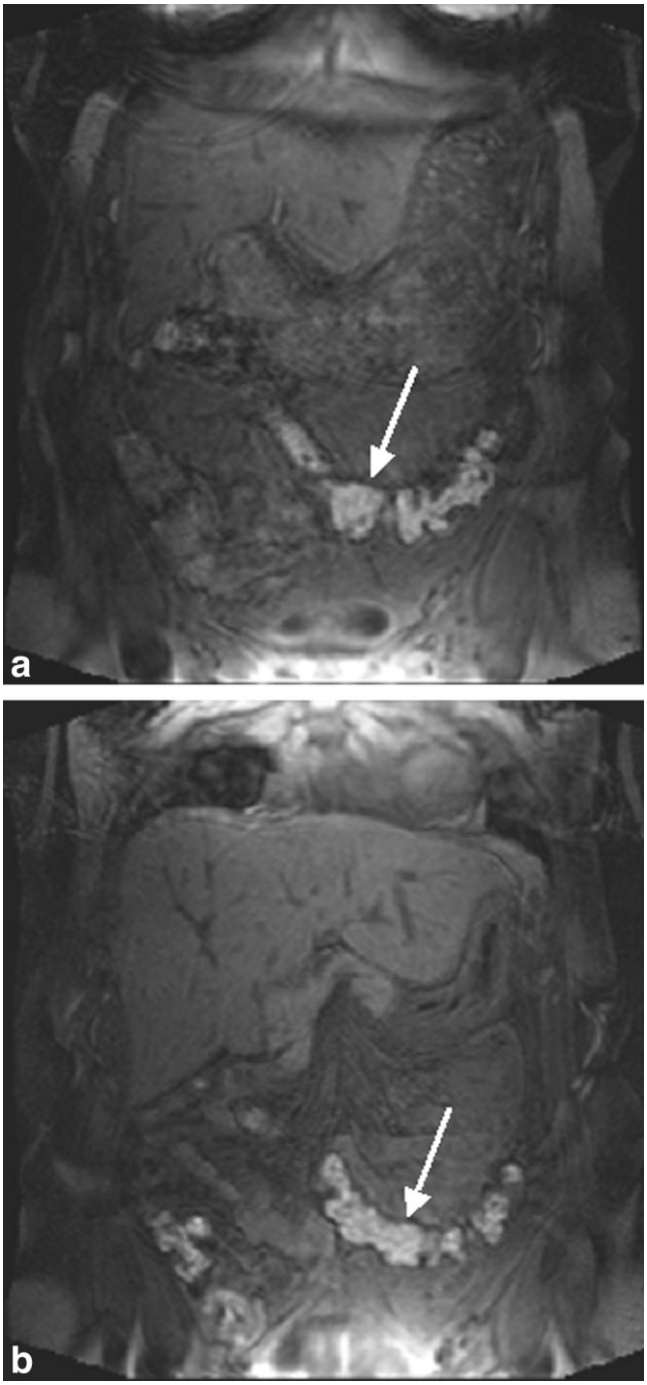

Figure 8. a: Native three-dimensional VIBE with fat saturation, coronal source image, after three days of long T1 relaxation time food. Colonic stool is bright compared to all other structures. **b:** Image after three-day diet of short T1 relaxation time food. No difference is found in signal of stool.

food groups; moreover, there was a tendency for brighter stool signal in the longer T1 time food group. This implies that there has to be another—yet more important—effect at work that tends to homogenize the T1 times of the various nutritional components.

Food will undergo a variety of changes when passing through the digestive system, such as bile excretion, absorption of components such as proteins or ions, detriment of mucosa cells, and dehydration. The composition of ingested substances may also be influenced by chemical changes in the molecular structure such as the decomposition of starch. All these effects might play a competitive role for the stool signal. Many of these effects, such as cell detriment, bile excretion, and food structure decomposition, can in fact not be altered in a study on human beings, and a possible restriction in the patient's diet plays a minor role, as suggested by our data.

The first part of the study assessed the paramagnetic properties of different foods, as they are commercially available. Only dry or concentrated food was diluted (or cooked) with water. The resulting water content was not further evaluated; rather, the potential effect of water was studied in the second part of the study, in which a specified known dilution series of six different foods was analyzed. The effect of stool hydration on the stool signal can be deduced from these in vitro dilution results. If these are transferred to stool, then it should be probable that the stool signal is also influenced to a large extent by its dilution or hydration state. As no influence of food composition on the stool signal was found, the stool hydration theory seems to be the most reasonable for explaining the variation in stool SI from patient to patient in clinical practice. Stool hydration as one of the most important factors for regulating stool signal is also supported by the observation that usually the small bowel exhibits relatively dark stool signal (own observation), whereas the colon renders high signal (12). The stool signal in the ascending colon in this study was also lower than that of more distal stool (this cannot be satisfactorily explained only by considering the distance to the receive coil). Furthermore, compacted colonic stool seems to demonstrate higher SIs than diarrheic stool, and colonic stool captured in diverticuli as the prime example of compacted stool has a very high T1 signal (own observation).

The question we tried to answer is whether a restricted diet can support the fecal tagging strategy. According to the results of this study, this does not seem to be the case. Further experiments regarding fecal tagging may thus find success by focusing on strategies to increase the colonic stool hydration or by ingestion of substances like barium or relaxatives, which exhibit long T1 relaxation times (inherent or by bowel secretion of water into the stool) and which at the same time are known not to be subject to intestinal chemical structure changes.

REFERENCES

1. Meier C, Wildermuth S. Feasibility and potential of MR-colonography for evaluating colorectal cancer. Swiss Surg 2002;8:21–24.
2. Heuschmid M, Luz O, Schaefer JF, et al. Comparison of volume-rendered and surface-rendered MR colonography. Technol Cancer Res Treat 2003;2:13–18.
3. Luboldt W, Bauerfeind P, Wildermuth S, Marincek B, Fried M, Debatin JF. Colonic masses: detection with MR colonography. Radiology 2000;21:383–388.
4. Luboldt W, Debatin JF. Virtual endoscopic colonography based on 3D MRI. Abdom Imaging 1998;23:568–572.

5. Martin DR, Yang M, Thomasson D, Acheson C. MR colonography: development of optimized method with ex vivo and in vivo systems. Radiology 2002;225:597–602.
6. Luboldt W, Bauerfeind P, Wildermuth S, Debatin JF. Contrast optimization for assessment of the colonic wall and lumen in MR colonography. J Magn Reson Imaging 1999;9:745–750.
7. Lauenstein TC, Herborn CU, Vogt FM, Gohde SC, Debatin JF, Ruehm SG. Dark lumen MR-colonography: initial experience. Rofo Fortschr Geb Rontgenstr Neuen Bildgeb Verfahr 2001;173:785–789.
8. Papanikolaou N, Grammatikakis J, Maris T, Lauenstein T, Prassopoulos P, Gourtsoyiannis N. MR colonography with fecal tagging: comparison between 2D turbo FLASH and 3D FLASH sequences. Eur Radiol 2003;13:448–452.
9. Lauenstein TC, Goehde SC, Ruehm SG, Holtmann G, Debatin JF. MR colonography with barium-based fecal tagging: initial clinical experience. Radiology 2002;223:248–254.
10. Thomeer M, Bielen D, Vanbeckevoort D, et al. Patient acceptance for CT colonography: what is the real issue? Eur Radiol 2002;12:1410–1415.
11. Chen CC, Ng WW, Chang FY, Lee SD. Magnesium citrate-bisacodyl regimen proves better than castor oil for colonoscopic preparation. J Gastroenterol Hepatol 1999;14:1219–1222.
12. Jardine VL, Lomas DJ. The MRI appearance of the unprepared rectosigmoid colon on routine pelvic examination. Eur Coll Radiol Vienna 2003;13(Suppl 1):296.
13. Haacke EM, Brown RW, Thompson MR, Venkatesan R. Magnetic resonance imaging: physical principles and sequence design. In: Spin density, T1 and T2 quantification methods in MR imaging. New York: John Wiley & Sons; 1999. p 654–657.
14. Rofsky NM, Lee VS, Laub G, et al. Abdominal MR imaging with a volumetric interpolated breath-hold examination. Radiology 1999;212:876–884.
15. Martinez ME, Sampliner R, Marshall JR, Bhattacharyya AK, Reid ME, Alberts DS. Adenoma characteristics as risk factors for recurrence of advanced adenomas. Gastroenterology 2001;120:1077–1083.
16. Noshirwani KC, van Stolk RU, Rybicki LA, Beck GJ. Adenoma size and number are predictive of adenoma recurrence: implications for surveillance colonoscopy. Gastrointest Endosc 2000;51:433–437.