Magnetic Resonance Imaging, Vol. 4 pp. 207–213, 1986
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0730-725X/86 $3.00 + .00
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MOTION ARTIFACTS IN QUANTITATIVE MAGNETIC RESONANCE IMAGING

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Several investigators have emphasized the potential value of quantitative relaxation times in the assessment of diseases. In performing such measurements using the spin-echo technique, we have encountered several anomalous results, whereby the intensity of the organ parenchyma on second-echo images is greater than on first echo images. This is most likely a result of respiratory motion, and it occurs only rarely. Several volunteers were studied before and after exercise to see if respiratory motion could reproduce the anomalous intensity reverse; a reversal of intensities in renal parenchyma was observed in two of five individuals. We conclude that respiratory motion artifacts will seriously limit quantitative magnetic resonance imaging of the upper abdomen if respiratory gating during imaging is not used.

Keywords: **Magnetic resonance imaging, Relaxation times, Motion artifact.**

It is well known that magnetic resonance imaging (MRI) is sensitive to motion due to the movement of protons into or out of the imaging volume between the RF pulses of the imaging sequence. Motion can influence the appearance of NMR images; when two-dimensional Fourier reconstruction of the data is used, motion artifact typically takes the form of aliasing; multiple "ghost" images appear in the direction of the phase-encoding gradient.[1,2] These are generally easy to recognize; however, more subtle effects can occur and prove difficult to visually identify. In this preliminary report, we describe discrepancies in MRI intensity measurements of the kidney, which are likely the result of organ motion. As a result of this phenomena, inaccuracies may be produced in relaxation time measurements.

MATERIALS AND METHODS

The University of Michigan Magnetic Resonance Imager is a Diasonics MT/S system, based on a superconducting magnet operating at 3.5 kilogauss. Detailed descriptions of the unit have appeared elsewhere,[3] but several pertinent aspects of its operation will be reviewed. The primary pulse sequence used is a dual spin-echo sequence, whereby two images at each anatomic level are acquired simultaneously, one with an echo-delay time (TE) of 28 msec, the second with a TE of 56 msec. Images are obtained using a multiplanar technique, with adjacent parallel planes excited sequentially during the imaging process. The number

Table 1. Magnetic resonance intensities for 3 patients

Organ	Intensities I_1(TE = 28 msec)	I_2(TE = 56 msec)	I_1/I_2
Patient 1: 30 YO with SLE			
	(TR = 0.5 sec)		
left kidney	3315	4129	0.80
left paraspinal muscle	3659	2438	1.54
right kidney	4853	5356	0.91
right paraspinal			
muscle liver	3302	2397	1.38
	6017	4282	1.41
Patient 2: 27 YO with retroperitoneal fibrosis			
	(TR = 0.5 sec)		
left kidney	3771	4255	0.89
left paraspinal muscle	1515	1469	1.03
right kidney	4823	4263	1.13
right paraspinal			
muscle liver	1477	1453	1.02
	7098	4789	1.48
Patient 3: 51 YO with hepatic hemangioma			
	(TR = 1.0 sec)		
dome of liver	761	863	0.88
left paraspinal muscle	990	532	1.86
right paraspinal			
muscle	1177	319	3.68

RECEIVED 3/8/85; ACCEPTED 11/11/85.
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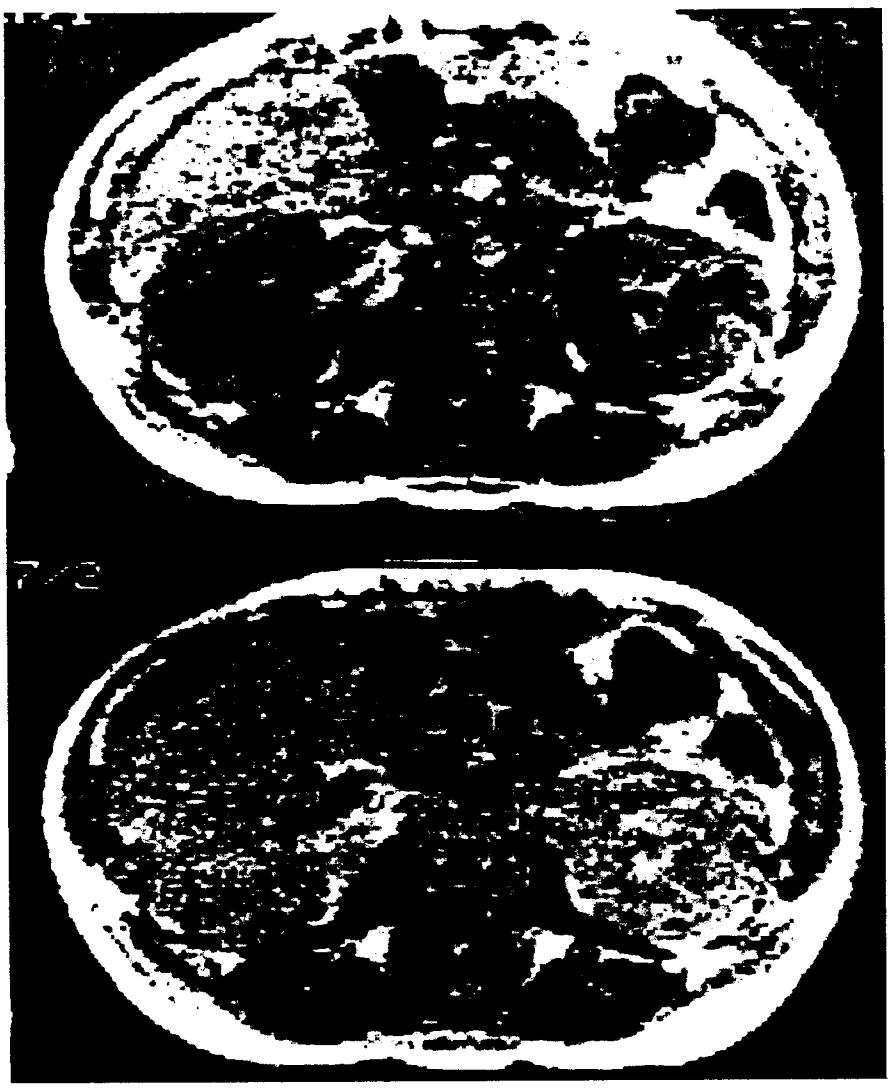

Fig. 1. First echo (top) and second echo (bottom) images of patient with SLE. Intensity normalization is suppressed, so that intensities on the two images can be compared directly. $TR = 0.5$ sec., and $TE = 28$ and 56 msec, respectively. A blood flow artifact is incidentally noted in the aorta.

of images produced during a single imaging sequence is dictated by the repetition time (TR); for example, 5 sequential planes are imaged using a TR of 0.5 sec in about 4½ minutes time, while 20 are produced in 18 minutes when a TR of 2.0 sec is employed.

The intensity of the signal in each pixel of the MR image is given approximately by the formula

$$I = H\,F(v)\exp(-\mathrm{TE}/T2)\exp(1 - \mathrm{TR}/T1)$$

where H is the local tissue hydrogen density, $F(v)$ is a flow function which is a constant in the absence of motion, TE and TR are known timing intervals used by the imager, and $T1$ and $T2$ are the local tissue relaxation times.[3] Since two images in each plane are always acquired simultaneously, it is possible to compute $T2$ using the equation $T2 = 28$ msec / $\ln(I_1/I_2)$, derived from the above intensity relation, where I_1 and I_2 are the local image intensities at 28 and 56 msec, respectively. Since $T2$ must be a positive number, the ratio of I_1 to I_2 must always be greater than one, that is the intensity at each point in the "second-echo" image must always be less than the corresponding point in the "first-echo" image, except under certain circumstances to be enumerated below. This fact is not obvious while viewing the images on the display consoles or photographic film, since the system "normalizes" the intensity of each image to improve viewabili-

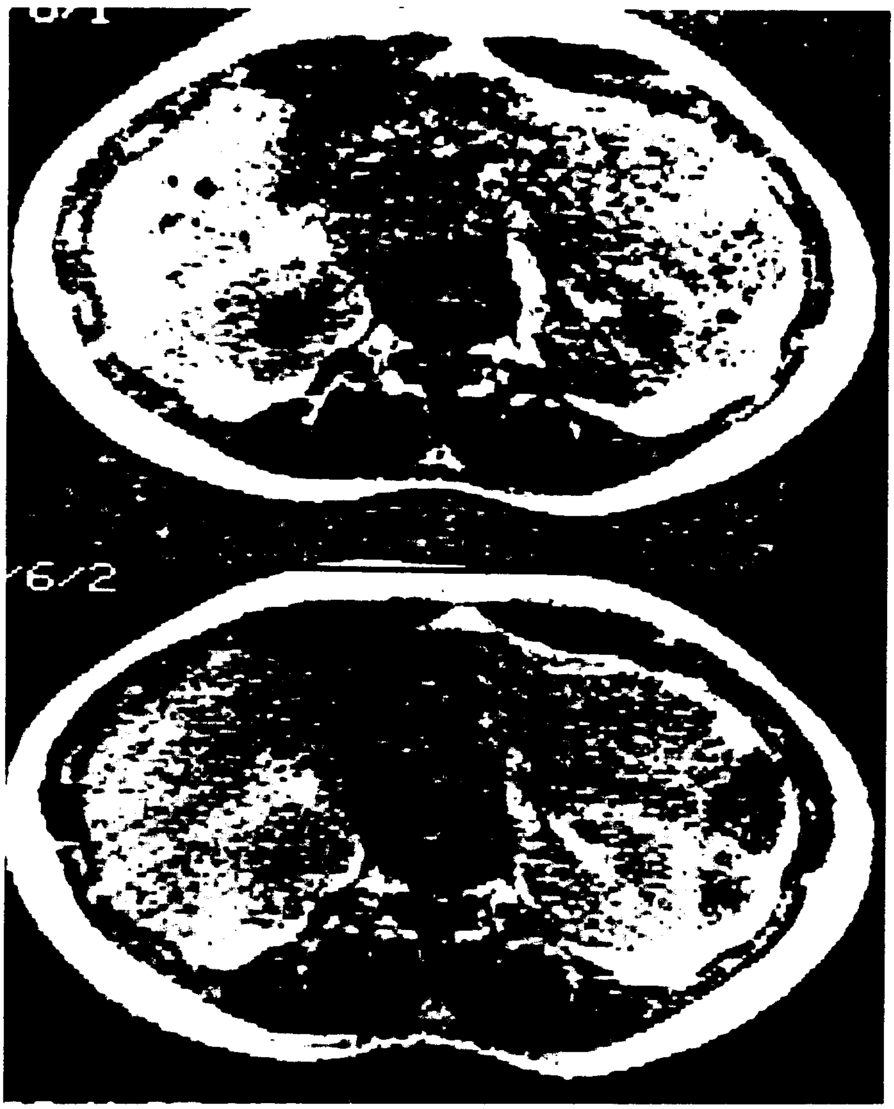

Fig. 2. First echo (top) and second echo (bottom) images of patient with retroperitoneal fibrosis, with intensity normalization suppressed. $TR = 0.5$ sec., and $TE = 28$ and 56 msec, respectively. Both the kidneys and the paraspinal muscles in the first echo image are of diminished relative intensity.

ty; thus the displayed intensity of the second-echo images are increased relative to the first. Measurements of renal relaxation times were made using regions of interest which included both renal medulla and renal cortex; the hilar structures were excluded. In reviewing these calculations we noted several with "negative" $T2$ values.

To determine approximately how often such anomalous data will occur in routine clinical scanning, we reviewed images for 101 patients (54 were selected randomly; the remainder were available from an unrelated study). In 55 patients, both kidneys were examined, and in the majority of patients data were available from two imaging sequences with different TR intervals. Thus, intensities were measured and $T2$ values calculated for a total of 220 kidney images.

To further investigate such phenomena, 5 normal volunteers underwent upper abdominal MRI before and immediately after 5 to 10 minutes of vigorous exercise, employed to increase both blood flow and respiratory motion. Transverse images were obtained at a TR of 0.5 sec.

RESULTS

The results on the patients in whom the reversal of second echo intensity was noted are summarized in Table 1. The first patient had marked renal disease

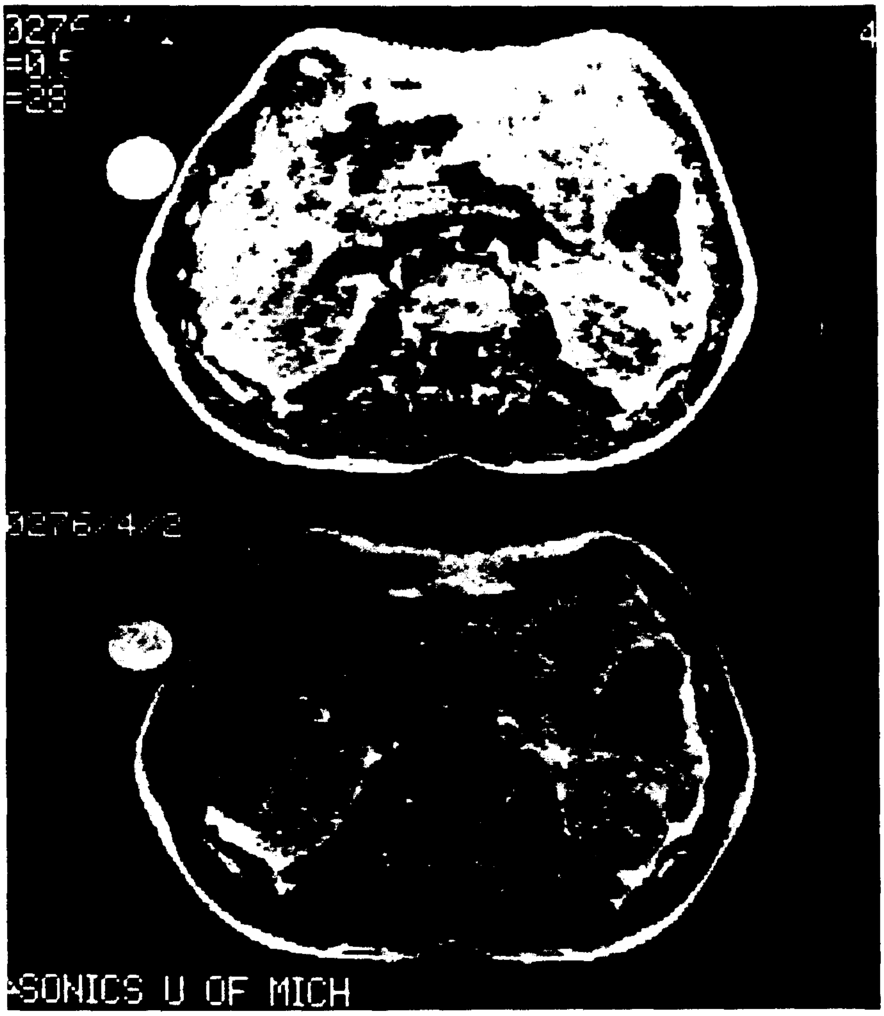

Fig. 3. First echo (top) and second echo (bottom) images in a normal volunteer prior to exercise, with intensity normalization suppressed. *TR* = 0.5 sec, *TE* = 28 and 56 msec, respectively. The renal parenchymal signal is greater on the first echo image than on the second.

secondary to systemic lupus erythematosus; the second had retroperitoneal fibrosis without evidence for renal disease; and the third had a hepatic hemangioma.

In the patient with SLE, the anomalous intensity values were limited to the kidneys. The patient was felt to have a hyperdynamic circulation by the clinical service, and the possibility that either a motion effect or possibly a flow phenomenon might be present was considered. The scan did not show obvious motion artifact, but respiratory movement of the kidneys, especially in the cranial-caudad direction perpendicular to the image plane, may certainly have been present. Figure 1 demonstrates the first and second echo images, showing inversion of the expected MR intensities for both kidneys; no such effect was observed in the other tissues, which served as controls.

In the second patient, intensity inversion was limited to the left kidney (Table 1) and the images did show artifacts caused by respiratory motion (Fig. 2). In the third patient, the inversion was noted in the normal hepatic parenchyma of the dome of the liver.

Inverted intensities and negative calculated T2 values did not occur in any of the 101 patient sample. For these patients, the mean calculated *T*2 value of the kidneys was 69, with a standard deviation of 62 ($n = 220$).

All five volunteers had unremarkable pre-exercise images without intensity inversion. On post-exercise images, however, two volunteers demonstrated an inversion in the relative intensities of the renal parenchyma on the first and second echo images; whereas the paraspinal muscles and liver did not show the

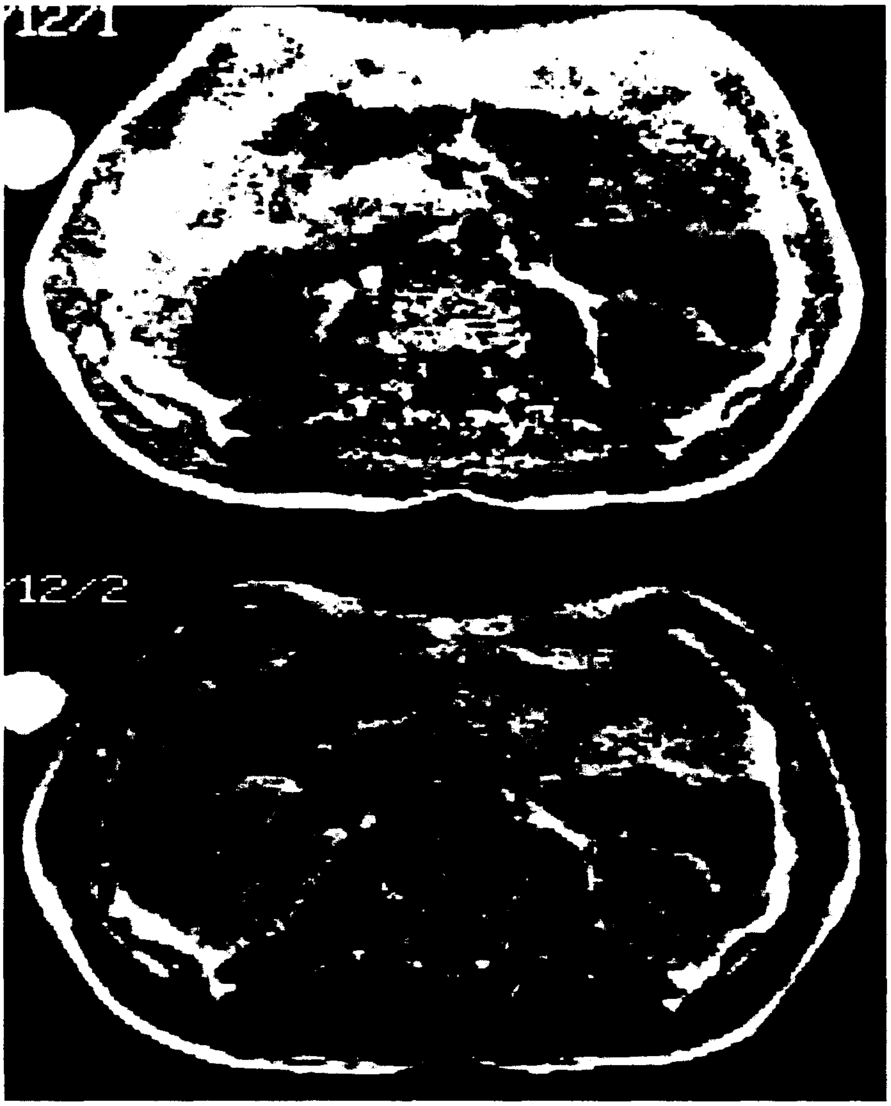

Fig. 4. First echo (top) and second echo (bottom) images in the same normal volunteer after exercise, again with intensity normalization suppressed. *TR* = 0.5 sec, *TE* = 28 and 56 msec, respectively. The renal parenchymal signal in the first echo image is diminished compared to the surrounding structures, and compared to the second echo image.

effect. The anomalous data appear to result from a peculiar lowering of the renal intensity on the first echo image. Figure 3 shows the first and second echo images of volunteer 1 before exercise; figure 4 is a post-exercise image. Intensity calculations from the TR = 0.5 sec data show very significant quantitative differences between the kidneys (Table 2). Table 2 also reports data for volunteer 2 whose kidneys also exhibited intensity reversal.

DISCUSSION

Our data clearly shows anomalous intensity reversal (higher intensity on second echo images) within organ parenchyma using spin-echo MR imaging; calculated T2 values from such anomalous intensity images would give spurious, negative values. The signal intensity on second echo images can be greater than on the first echo in the following circumstances:

1. when flow effects are present
2. when there is patient motion
3. due to random, statistical variation in the intensities; this is most apparent when the intensities are measured using small regions of interest.
4. when the imager is mistuned, malfunctioning (e.g., abnormally low intensity first echo images), or when artifacts are present.

Table 2. Magnetic resonance intensities pre- and post-exercise

Organ	Pre-exercise				Post-exercise			
	I_1(TE = 28 msec)	Intensities I_2(TE = 56 msec)	I_1/I_2	T_2	I_1(TE = 28 msec)	Intensities I_2(TE = 56 msec)	I_1/I_2	T_2
Volunteer 1								
left kidney	1974	1435	1.38	88	1121	1169	0.96	−668
left paraspinal muscle	1483	625	2.37	32	1668	602	2.77	28
right kidney	1858	1474	1.26	121	592	1151	0.51	−42
right paraspinal muscle	1437	607	2.37	32	1133	380	2.98	26
liver	2247	1091	2.05	39	2089	1121	1.86	50
Volunteer 2								
left kidney	1689	1153	1.47	73	959	981	0.98	−1234
left paraspinal muscle	1062	433	2.45	31	1298	512	2.53	30
right kidney	1872	1170	1.60	60	530	821	0.64	−64
right paraspinal muscle	1181	426	2.77	28	1009	408	2.47	31
liver	1659	972	1.71	52	1217	706	1.72	51
Volunteer 2, level several centimeters cranial to above slice								
left kidney	1747	993	1.76	50	699	718	0.97	−1044
left paraspinal muscle	849	304	2.79	27	1267	474	2.67	29
right kidney	1425	809	1.76	50	410	967	0.42	−32
right paraspinal muscle	1125	452	2.49	31	1103	438	2.51	30
anterior liver	1790	978	1.83	46	953	679	1.40	83
posterior liver	1696	898	1.89	44	556	592	0.94	−446

Note: Pre- and post-exercise data are taken from approximately the same anatomic level; slice numbers in the multi-slice imaging sequence differed due to slight discrepancies in repositioning the subjects on the scanner table. TR = 0.5 sec.

Molecular diffusion effects may also affect T2 measurements, though they are likely to produce falsely low values.[4]

Statistical fluctuations can be excluded since the observed effects involved large areas, and imager malfunction was also discounted by examination of phantom and patient head and low pelvis images. In reviewing all of the available data, respiratory motion, particularly in the cranial-caudad direction, seems the most likely explanation for the intensity reversal we report. The asymmetry of the intensity inversion would be explained by greater respiratory motion of the left kidney than the right. Blood flow effects[5–7] cannot be excluded as an explanation of the anomalous intensi-

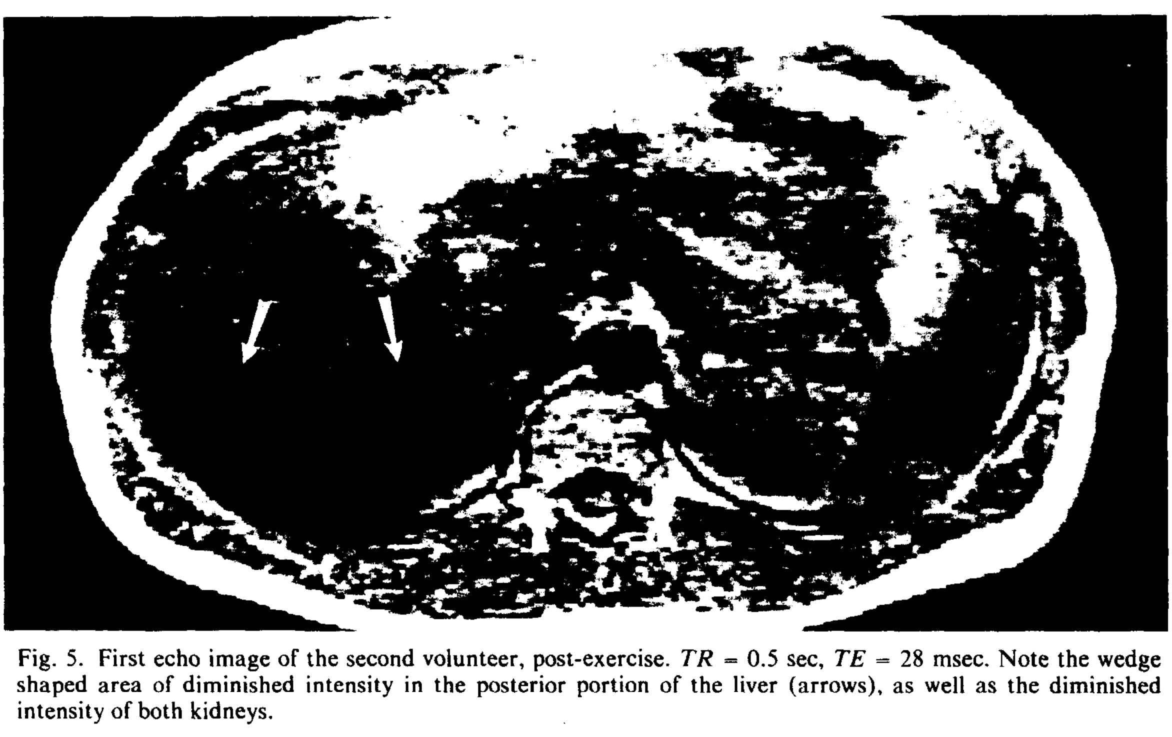

Fig. 5. First echo image of the second volunteer, post-exercise. TR = 0.5 sec, TE = 28 msec. Note the wedge shaped area of diminished intensity in the posterior portion of the liver (arrows), as well as the diminished intensity of both kidneys.

ties, though they seem unlikely to be an adequate explanation given their asymmetric distribution.

Whatever its origin, the intensity reversal phenomenon carries important implications for MR imaging, as it introduces inaccuracies in the quantitation of the magnetic parameters. Such measurements have been suggested to be diagnostically useful.[8,9] Even in those patients without actual intensity reversals, the reliability of in vivo relaxation time determinations from ungated, dual spin-echo images is likely to be limited, judging by the wide variation we encountered in our 101 patient sample. Routine abdominal MRI scans are performed with patients as relaxed as possible; nonetheless we have noted obvious areas of anomalous intensity in a small percentage of the studies. Generally, these are crescent shaped regions of the liver or involve the kidneys in a manner similar to the cases described here. Presumably, respiration in these individuals is greater than with most patients. It seems likely that cranial-caudad respiratory motion of the kidneys, which may well not be obvious on the images, can be a source of considerable error. It should, however, be possible to correct for such effects, through the use of respiratory gating, different pulse sequences, or improved algorithms for image quantitation. More work is clearly required, if optimal use is to be made of measured relaxation times in the upper abdominal viscera.

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