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IN VIVO ^{1}H NMR RELAXOMETRY MAPS OF WOMEN NORMAL AND CANCEROUS PELVIS

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ABSTRACT. Transverse relaxation time (T_2) and ^{1}H spin density (ρ_{1_H}) parameter maps were obtained for the pelvis of two women. For that, two anatomical magnetic resonance (MR) images were recorded in axial orientation with a low echo time (TE1 ≅ 30 ms) and a large echo time (TE ≅ 200 ms) for a volunteer with normal pelvis and a patient with endometrial cancer. The largest T_2^{av}–value was obtained for the right pelvic bones of patient with endometrial cancer and the lowest one was obtained for the uterus of volunteer with normal pelvis.

Keywords: *In vivo ^{1}H NMR imaging, T_2 and ρ_{1_H} parameter maps, axial normal pelvis images, axial pelvis with endometrial cancer, T_2^{av}–values of woman pelvis components.*

INTRODUCTION

The pelvis is the lower part of the trunk of the human body. It is situated between the abdomen and the thighs. Together with the lower limbs sustains the entire weight of the upper body and have an essential role on the body posture, stability and balance [1]. The pelvic region is delineated by the pelvic bones and divided in pelvic cavity, pelvic floor and perineum. The pelvic skeleton is formed posteriorly by the sacrum and the coccyx and anteriorly by left and right hip bones. The pelvis anatomy varies between male and female. The female pelvis is wider and lower than de male pelvis and includes the uterus with its endometrium, myometrium and serous layers.

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The cells in human bodies have a certain role. The normal ones divide in an orderly way. Then they die when they are worn out or damaged, and new cells take their place. Cancer is a cureless disease caused by the "out of control cells" growth. The cancer cells keep on growing and dividing into new cells which crowd out normal cells. This means that old or damaged cells survive when they should die, and new cells form when they are not needed. These extra cells can divide without stopping and may form growths called tumors. There are many types of cancer in the pelvic area. One of the most frequent malignancies diagnosed in women is the uterine cancer [2].

Nuclear magnetic resonance (NMR) is a powerful technique used to investigate the living tissues by particular methods like magnetic resonance imaging [2, 3], ordered tissues [4] but also for imaging of materials [5]. Nevertheless, this can be successfully used in many areas. Recently, ^{1}H NMR relaxometry was used, for example, for assessing the wastewater treatment via the distributions of transverse relaxation time distributions [6].

The medical magnetic resonance imaging (MRI) is based on the phenomenon of nuclear magnetic resonance involving radiofrequency pulses applied to the human body being into a static magnetic field and appropriate magnetic field gradients for producing images with excellent soft tissue contrast [7]. To identify pathological anatomy it is necessary to obtain sufficient signal contrast between pathological and healthy tissue and sufficient spatial resolution to resolve small structures [8].

In everyday practice, radiological diagnosis is mainly based on the various magnetic resonance images weighted by relevant NMR parameters. A weighted image does not mean that it is influenced exclusively by that parameter [2]. To obtain for example transverse, T_2^*, longitudinal T_1^* or residual dipolar coupling parameter maps, simpler approaches are based on only two MR images [2, 4, 5, 9].

The aim of this paper is to obtain transverse relaxation time T_2 and ^{1}H spin density ρ_{1_H} parameter maps and to compare the specific values (minimum, maximum and the average) obtained for women's normal and cancerous pelvis. Statistical distributions of T_2 and ^{1}H spin density for four pelvic areas such as uterus, bone, fat and muscles are evaluated.

EXPERIMENTAL

Patients

Prior to the start of the clinical investigations, a written informed consent was obtained from all volunteers. Two female patients were enrolled in this study, one with normal endometrium (age 46) and the other with endometrial cancer (age 72).

The first one has an regulate menstruation and the other is at menopause. Both of them had 2 previous gestations (caesarian section) and underwent gynecological examinations (Papanicolaou test [10]) and pelvic ultrasonography.

Methods

The volunteer and the patient were investigated on a GE 3T MRI Discovery MR750w. The average total scanning time was 1 hour. A body coil transmission with 16-channel phased-array receiver was used. 10 Minutes before starting the MRI investigation, an antispasmodic drug was administrated intravenously to reduce movement artifacts. Additional to axial T2 Spin Echo FRFSE-XL pulse sequence used for obtaining the T_2^* and ρ_{1_H} parameter maps, the protocol include at the beginning a localization pulse sequence and a diffusion weighted imaging sequence at the final of investigation. Two acquisitions were obtained with the same repetition time (TR – recycle delay) 5000 ms but different echo times TE_1 = 30 ms and TE_2 = 200 ms. The section thickness was 4 mm, the field of view (FOV) 350-400 mm, the intersection gap was 0.8 mm, matrix size (in frequency and in phase encoding) was 384x256.

RESULTS AND DISCUSSION

Figure 1 presents the anatomic MR images in axial orientation recorded for a normal woman pelvis (left images) and a woman pelvis with endometrial cancer with two values of echo time (TE) of 30 ms (top) and 200 ms (bottom). Some major anatomic components that can be distinguished are: i) the uterus (located in the center-top of approximately circular shape and a neutral gray color); ii) The bladder observed only for the woman with cancer on top of uterus (see Figs. 1 c) and d)); iii) sections in the left and right innominate bones (as a thin formation with diagonal orientation starting from top left and right toward bottom center of open gray color surrounded by a darker color); iv) muscles: puborectalis, pubococcigeus, ilicoccygeus, ischiococcygeus, obturator internus and piriformis (having a darker color); v) fat (lipid cells) surrounding the body's internal organs observed with the lighter color and vi) rectum (with darker color in centrum). One can remark that existence of cancerous cells the uterus is deformed (see Figs. 1 c) and d)).

In order to obtain the T_2 parameter map ($T_2^{(x,y)}$), one have to calculate voxel by voxel (for all *x* and *y* coordinates) the ratio between the upper MR image in Fig. 1 expressed as an $S_1^{(x,y)}$ matrix characterized by

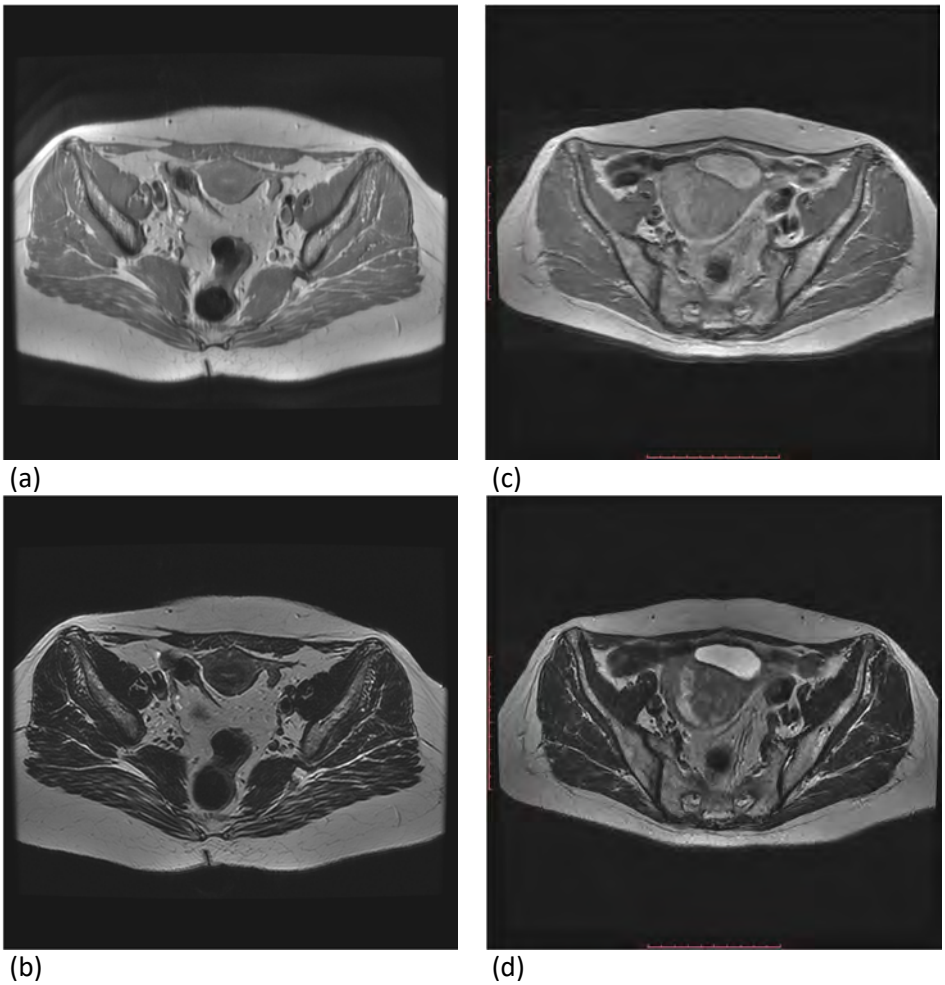
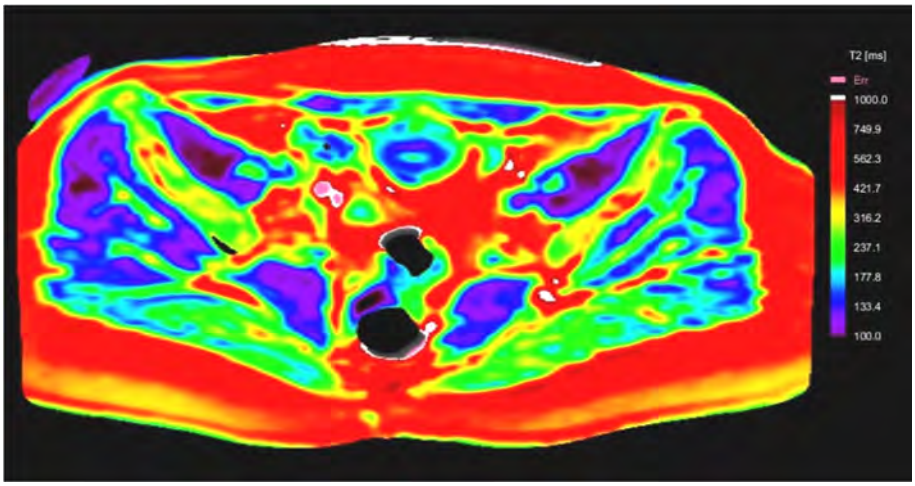


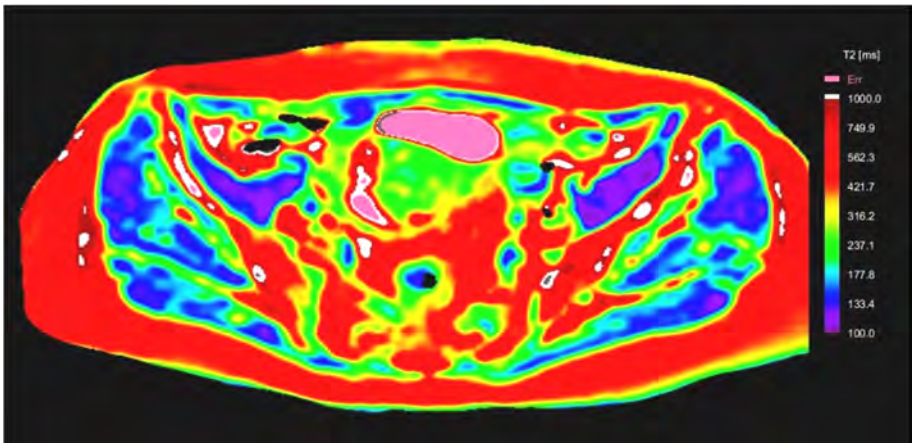
Fig. 1 Axial T2 weighted MR images of a volunteer woman (left) recorded with (a) TE = 30 ms and (b) TE = 200 ms and a patient woman with endometrial cancer (right) recorded with (c) TE = 30 ms and (d) TE = 200 ms.

the low echo time ($TE_1 \cong 30$ ms in our case) and the lower MR image expressed as an $S_2^{(x,y)}$ matrix characterized by the high echo time ($TE_2 \cong 200$ ms in our case) as [2],

$$T_2^{(x,y)} = \frac{TE_2 - TE_1}{ln\left[\frac{S_1^{(x,y)}}{S_2^{(x,y)}}\right]}. \quad (1)$$



(a)



(b)

Fig. 2 The T_2 maps obtained using eq. (1) from images presented in Figs. 1 for a) normal pelvis and b) endometrial cancer.

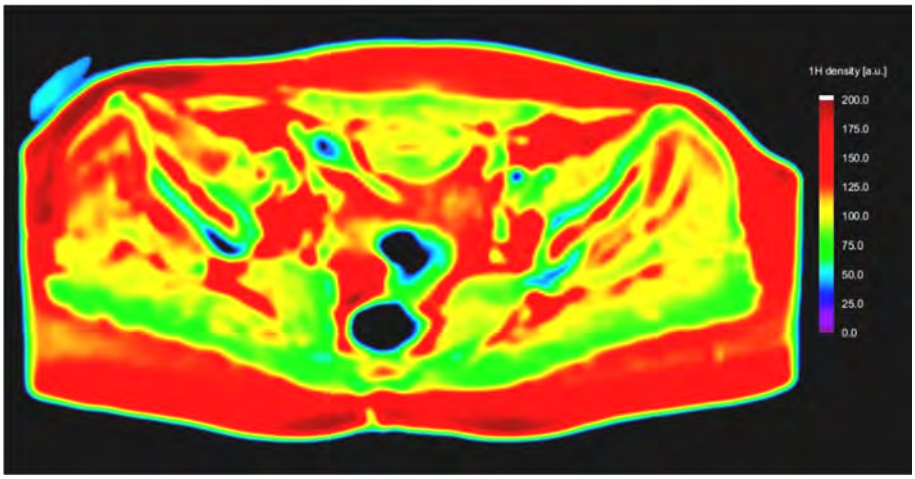
The T_2 parametric maps calculated using eq. (1) from T2 weighted MR images for the normal and affected by endometrial cancer with myometrial invasion are presented in Fig. 2. Compared with the T_2 parameter maps reported in

[9] obtained for a three tube phantom, the contrast and resolution of our map are net superior. The limits for T_2-values were set to 100 ms for the minimum value and 1000 ms for the maximum value. A T_2-value larger than 1 s is represented with white color, while a T_2-value smaller than 100 ms is represented with black color. The fat cells present large T_2-values and are observed as extended red regions. The muscular formations presents the smallest T_2-values and are observed as regions colored in violet, blue up to green colors (for the patient with cancer), meaning that the specific T_2-values are in the range of 100 ms up to 180 ms and containing the green for the normal patient with the T_2-values in the range of 100 ms up to 300 ms. The bones being a porous/spongy biomaterial is characterized also by large T_2-values. Differences can be observed between the volunteer and patient, meaning that the volunteer with normal uterus present lower T_2-values (see Fig. 2a) compared to the patient with endometrial cancer (see Fig. 2b). The uterus of the volunteer with normal pelvis presents lower T_2-values than the values measured for the volunteer with endometrial cancer. This malign formation can be observed as the green area surrounding a red colored region characterized by high T_2-values.

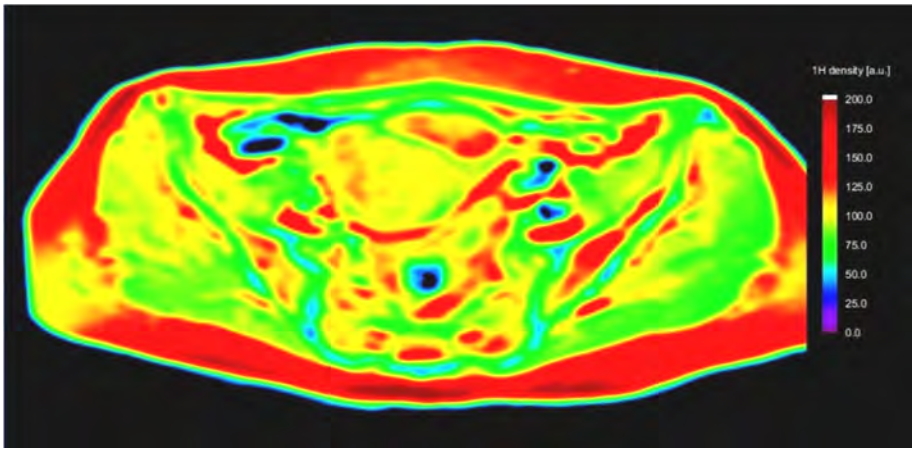
Additional to the T_2 parameter map, for a radiologist, which usually establishes a diagnostic only from anatomic images (gray MRI presented in Fig. 1) significant information can be obtained from ρ_{1_H} parameter maps. In order to obtain the ρ_{1_H} parameter map one can use the previously calculated T_2^* parameter map. The specific equation for a ρ_{1_H} parameter map is given by [2],

$$\rho_{^1\mathrm{H}}^{(x,y)} = S_i^{(x,y)} \cdot e^{+\frac{TE_i}{T_2^{(x,y)}}}, \tag{2}$$

where $S_i^{(x,y)}$ can be the map S_1 corresponding to the short echo time or the second map S_2 recorded with long echo time. Due to the large signal to noise ratio (SNR), we used the MR image recorded with a short echo time. The ρ_{1_H} parameter maps obtained for our women are presented in Figs. 3.



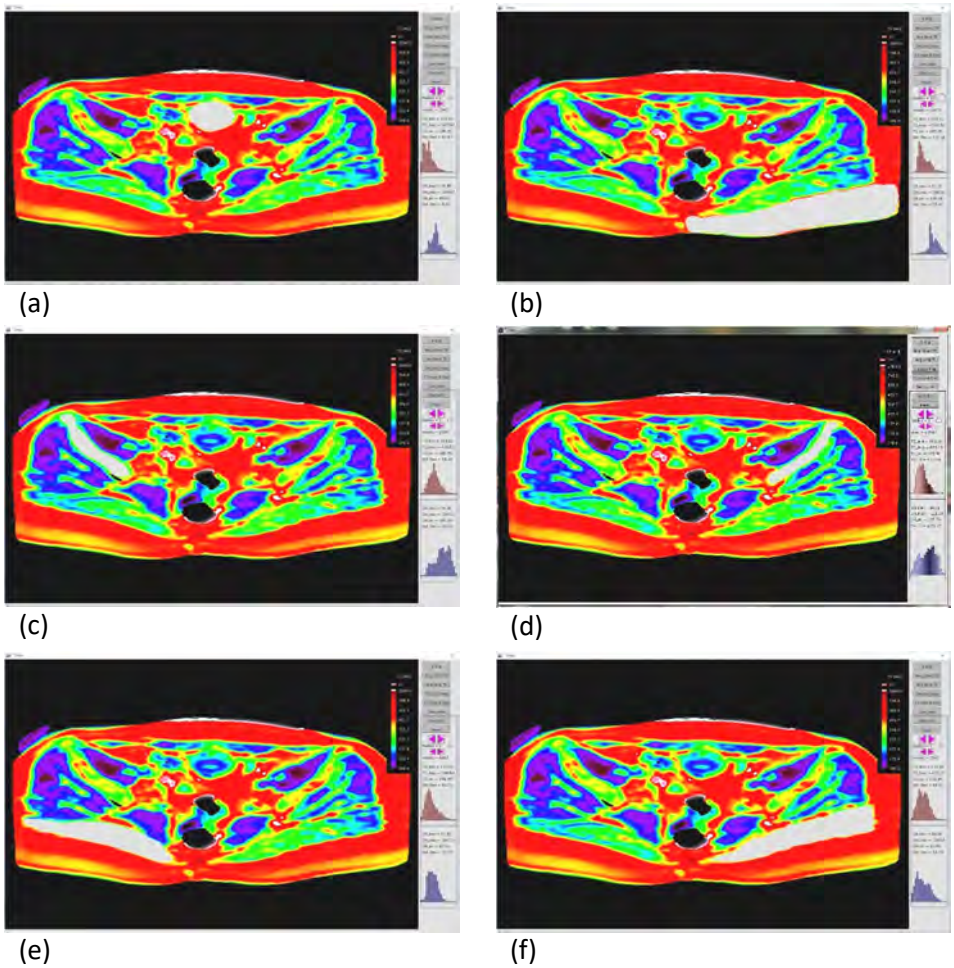
(a)



(b)

Fig. 3 The ρ_{1_H} parameter maps obtained using eq. (2) from images presented in Figs. 1 for a) normal pelvis and b) endometrial cancer

The areas with a small number of protons are represented in blue and are mainly observed around the rectum and large bowel section. The areas with a large number of protons are represented in dark red and are found in lateral front and middle back fat regions. A large number of protons (red) can be found in fat that surround the internal organs. In yellow and green are represented the organs with intermediate number of protons.



(a) (b)

(c) (d)

(e) (f)

Fig. 4 Statistical distributions of minimum, maximum and average values of T_2 and ρ_{1_H} parameter for various ROIs of a normal pelvis (a) uterus; (b) fat; (c) left innominate bone; (d) right pelvic bones; (e) left piriformis muscle and (f) right piriformis muscle. The ROI is marked with gray color.

In Fig. 4 are represented (as a screen capture of our processing software) the statistical distributions of minimum, maximum and average values of T_2 and ρ_{1_H} parameters for various regions of interest (ROIs) marked with gray color for a normal pelvis. These are the uterus (Fig. 4a), fat (Fig. 4b), left innominate bone (Fig. 4c), right pelvic bones (Fig. 4d), left piriformis muscle (Fig. 4e) and right piriformis muscle (Fig. 4f).

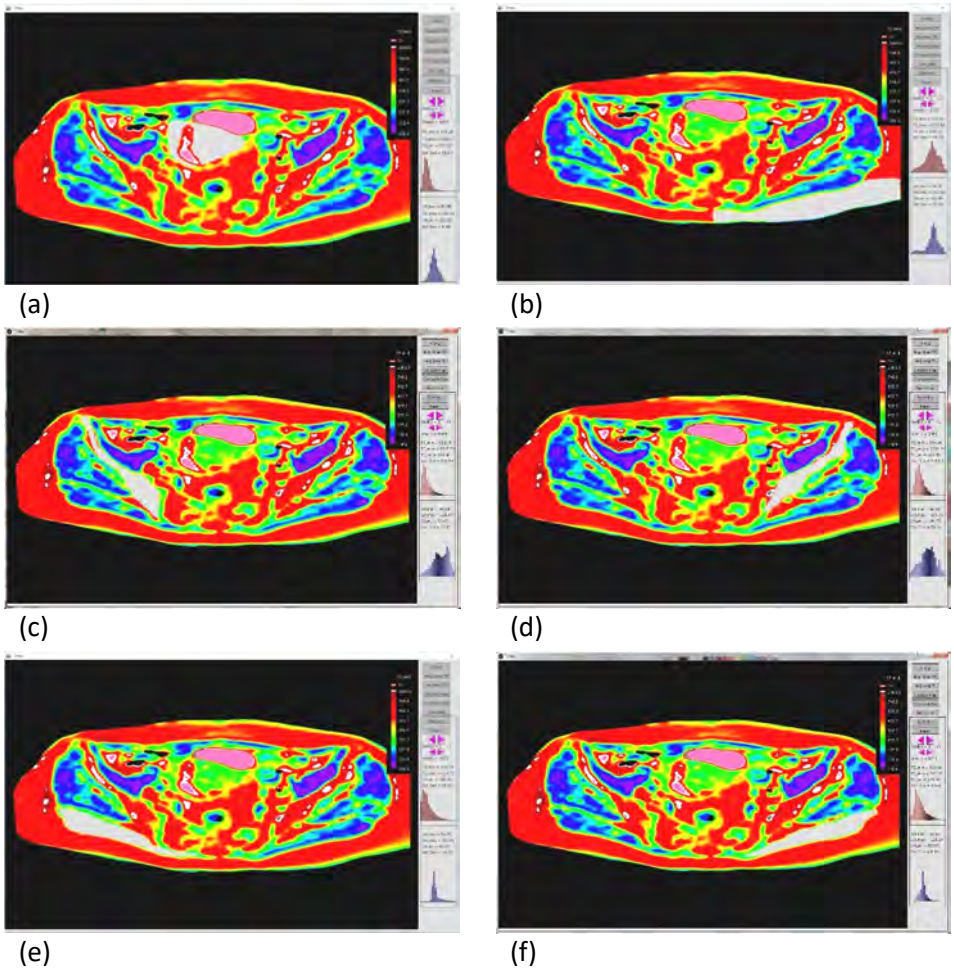


Fig. 5 Statistical distributions of minimum, maximum and average values of T_2 and ρ_{1_H} parameter for various ROIs of a pelvis with endometrial cancer (a) uterus; (b) fat; (c) left pelvic bone; (d) right pelvic bones; (e) left piriformis muscle and (f) right piriformis muscle. The ROI is marked with gray color.

The statistical distributions of minimum, maximum and average values of T_2 and ρ_{1_H} parameter of a pelvis with endometrial cancer are shown in Fig. 5 for the same types of ROIs as in the case of normal pelvis. The measured values are comparatively presented in Table 1 for the normal pelvis and in Table 2 for the pelvis with endometrial cancer. The statistical values are well defines, since the number of voxels are between 2042 for right bone and 13573 for fat both belonging to woman with normal pelvis. For this woman the lowest T_2^{av}-value was measured

Table 1. Minimum, maximum and average values of transverse relaxation times T_2 obtained for various ROI's as: uterus, fat, innominate bone or muscle.

ROI	Normal			Endometrial Cancer		
	T_2^{min} [ms]	T_2^{max} [ms]	T_2^{av} [ms]	T_2^{min} [ms]	T_2^{max} [ms]	T_2^{av} [ms]
uterus	122.6	403.0	186.4	175.3	682.2	273.6
fat	242.7	910.9	487.3	175.3	677.0	459.1
bone left	184.8	478.6	300.8	220.4	1919.8	586.3
bone right	159.6	625.2	329.1	164.4	1769.1	643.3
muscle left	137.5	398.7	218.4	125.8	424.7	186.5
muscle right	115.3	419.2	218.8	112.8	321.9	176.0

Table 2. Minimum, maximum and average values of proton spin density ρ_{1_H} obtained for various ROI's in the pelvis region.

ROI	Normal			Endometrial Cancer		
	$\rho_{1_H}^{min}$	$\rho_{1_H}^{max}$	$\rho_{1_H}^{av}$	$\rho_{1_H}^{min}$	$\rho_{1_H}^{max}$	$\rho_{1_H}^{av}$
uterus	76.9	129.7	99.2	80.9	137.4	102.6
fat	35.1	206.8	140.3	39.2	212.8	141.5
bone left	34.4	154.5	105.8	44.6	130.0	95.4
bone right	60.6	153.7	107.7	42.1	165.1	104.8
muscle left	57.8	144.1	87.3	50.7	151.4	93.6
muscle right	68.5	138.7	91.5	53.2	129.2	82.0

for uterus (186.4 ms), while the largest one was found for fat (487.3). In the case of woman with uterine cancer lower T_2^{av}-value were measured for muscle (186.5 ms and 176.0 ms) while the largest one was found not for fat (459.1 ms) but for innominate (hip) bone (586.3 ms and 643.3 ms). For this woman one can remark an increased T_2^{av} for uterus and bone. As expected the largest $\rho_{1_H}^{av}$– values were measured for fat tissue and the smallest one was measured for muscle, then for uterus and bone. Form $\rho_{1_H}^{av}$ no significant differences between normal and cancerous pelvis are observed.

CONCLUSIONS

T_2 and ρ_{1_H} parameter maps were obtained for the pelvis of two women, a volunteer with normal pelvis and a patient with endometrial cancer. The statistical T_2^{av} and $\rho_{1_H}^{av}$– values calculated from these maps on various pelvic components

such as uterus, fat, bone or muscle show significant differences between normal pelvis compared to the pelvis with endometrial cancer. Abnormalities of T_2^{av}-values are also observed in the case of patient with the endometrial cancer like large T_2^{av} for uterus.

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