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Magnetic Susceptibility Artifacts by Air Space in Lumbar MRI Sagittal Fat Suppression

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The purpose of this study was to investigate whether the air space formed by the normal anatomical lordosis of the lumbar spine and the table affects magnetic susceptibility artifacts in sagittal MRI images using fat suppression. Thirteen patients complaining of simple low back pain were examined using a 3.0 Tesla MR system and 12-channels dS posterior coil. T2 fat-suppressed sagittal images were examined when the knee was extended and when it was supported by a 50° tilt support. The mean standard deviation of the images when the knee support was used was 131.00 ± 19.31, and it was 220.58 ± 26.86 when the knee was extended. In conclusion, it was confirmed that the air space formed between the table and the anatomical structures due to the curvature of the lumbar spine led to uniform images because of the magnetic susceptibility artifacts.

Keywords : magnetic susceptibility, MRI fat suppression, air in MRI, lumbar spine MRI, MRI fat suppression

1. Introduction

Low back pain (LBP) does not directly cause death in humans, but it is important in terms of quality of life. Approximately 80 % of the population experiences LBP at least once in their lifetimes, and chronic back pain is reported in 4-33 % of the whole population [1, 2]. The main cause of back pain is lumbar disc herniation, which causes pain due to neuromuscular pressure, resulting in various symptoms such as weakness and sensory abnormality [3]. The diagnosis of lumbago is based on physical and radiological examinations. Among these, magnetic resonance imaging (MRI) results in superior soft tissue resolution, and the entire lumbar vertebra can be seen in one image plane [4]. Therefore, MRI is useful for diagnosing most spinal diseases including lumbar spinal stenosis. T2-weighted images (T2 WI) are important for diagnosing LBP because in lumbar MRI, signal intensity decreases on T2 WI due to the water content of the intervertebral disc [5]. Adding fat suppression to T2 WI is known to be useful for visualizing the difference in fat content between lesions and normal tissues to diagnose back pain. This is expressed in the lightness and darkness of the signals when T2 fat suppression lumbar MRI is performed in lesions that contain a great deal of fat tissue and in normal fat tissue [6]. However, fat suppression cannot partially suppress fat for a number of reasons, and this can lead to confusion in diagnosis. Therefore, the uniformity of fat suppression must be maintained in the image, and various studies are required for this. In general, the fat suppression technique is affected by magnetic susceptibility and shimming is performed to increase the uniformity of the magnetic field. However, due to the curvature of the human spine, air space is generated between the table and the normal anatomical lordosis of the lumbar spine, which can distort the magnetic susceptibility in the image region and thus inhibit the uniformity of the fat suppression. The method of minimizing the air space between the lumbar lordosis and the table is to elevate the knee; when the knee is elevated, the vertebral body is flattened or the diameter of the spinal canal and the cross-sectional area within the dural sac change [7]. Recently, lumbar MRI has been used for knee and lumbar spine support to flatten the vertebral body and reduce the magnetic susceptibility artifacts; however, quantitative studies on the uniformity of fat suppression signals due to

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lumbar planarization are lacking. Therefore, in this study, we aimed to analyze the signal uniformity of T2 WI fat suppression when a 50° tilt support was placed under the knee to flatten the lumbar lordosis and when an air space occurred between the lumbar lordosis and the table.

2. Subjects and Methods

From March to April 2017, we studied 13 patients with LBP as their main symptom for a total of one month; the mean age was 57.7 ± 13.3 years, with five males and eight females. The instruments we used were a 3.0 Tesla MRI system (Ingenia, Philips, The Netherlands) and a 12-channel dS posterior coil (Philips); the receiving coil serves to increase the signal-to-noise ratio by collecting signals from the surface of the patient, who is laid back on the examination table. We obtained the sagittal T2 WI with fat suppression when the lumbar curve was flattened using a piece of urethane foam placed at a 50° angle from the table to the patient's knee and when the knee was straightened without using the support (Table 1). The fat suppression technique we used in this study is a hybrid of chemical shift selective sequence (CHESS) and short inversion time inversion recovery (STIR) by spectral pre-saturation by inversion recovery (SPIR). Kaldoudi [8] *et al.* observed that the longitudinal magnetization M_z follows the Bloch equation because the inversion time must be given at the time of zeroization (the nulling point) in SPIR.

$$\frac{dM_z}{d_t} = -\frac{M_z - M_0}{T_1} \tag{1}$$

In the conventional method, the STIR sequence is expressed as TI_{STIR} and is given by the following equation:

$$TI_{STIR} = T_1 \ln 2 \tag{2}$$

Equation (2) can be derived from the Bloch equation. Due to the limited amount of T1 relaxation occurring between the 90° read pulse and the next repeated sequence, the inversion pulse given immediately before longitudinal relaxation M_0 follows this formula:

$$M_{z(STIR)} = M_0(1 - e^{-(TR - TI_{STIR})/T_1}) \tag{3}$$

However, because the inversion pulse, 180°, is applied to the SPIR to perform chemical shift selection, the entire proton receives an inversion pulse. Therefore, what is affected by TR is a form that divides the number of slices from the TR value, as follows:

$$TR_{eff} = \frac{TR}{N} \tag{4}$$

In general, the fat magnetization M_n can be calculated by integrating equation (1) for 30 pulses applied at the repletion time of TR_{eff}.

$$M_n(\beta^{o}) = M_0 \frac{\cos\beta(e^{-(TR_{eff}/T_1)} - 1) + \cos^n\beta e^{-n(TR_{eff}/T_1)} + (\cos\beta - 1)}{\cos\beta e^{-(TR_{eff}/T_1)} - 1} \tag{5}$$

Here, when n is given as infinite (when there are numerous iterations), the steady state is reached and the fat magnetization is given by

$$M_n = M_0 \frac{e^{-(TR_{eff}/T_1)} - 1}{e^{-(TR_{eff}/T_1)} + 1} \tag{6}$$

In the SPIR sequence, the longitudinal magnetization M_n and the steady state value M_{ss} can be derived directly from equations (5) and (6) and can be derived from equations (7) and (8) by setting the tip angle β to 180°.

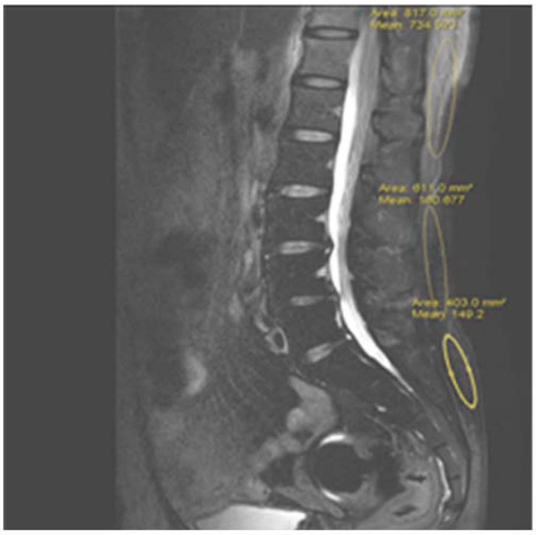

Fig. 1. (Color online) Measurements of signal intensity of subcutaneous fat in T12 to L2, L3 to L5, and the sacrum.

Table 1. The parameters used in this study.

Pulse Sequence	Knee Support	TR(ms)	TE(ms)	Matrix	NEX	Scan Time
T2_TSE_SPIR	Used	2000	120	564 × 269	2	2'16"
T2_TSE_SPIR	Not used	2000	120	564 × 269	2	2'16"

Note) T2_TSE_SPIR : T2 Weighted Image Turbo Spin Echo Spectral Presaturation with Inversion Recovery

$$M_n = M_0 \frac{e^{-(TR_{eff}/T_1)} - 1 + 2(-1)^n e^{-(TR_{eff}/T_1)}}{e^{-(TR_{eff}/T_1)} + 1} \quad (7)$$

$$M_{ss} = M_0 \frac{e^{-(TR_{eff}/T_1)} - 1}{e^{-(TR_{eff}/T_1)} + 1} \quad (8)$$

The time of the null point can be calculated using equations (1) and (8) in the steady state:

$$TI_{SPIR} = T_1 \ln 2 - T_1 \ln(1 + e^{-TR_{eff}/T_1}) \quad (9)$$

Therefore, the SPIR sequence uses the frequency difference of 3.3 ppm between water and fat in the CHESS technique and fat suppression is possible by applying the STIR inversion pulse [8]. After the test, we measured the average signal intensity of three subcutaneous fats using the measurement program provided by the equipment manufacturer (Fig. 1); the three sites were from thoracic spine 12 (T12) to lumbar spine 2 (L2), from L3 to L5, and the sacrum. The standard deviations of the signal intensities obtained at the three points reflect the uniformity of the images, and thus, we analyzed the mean image standard deviations both with and without the support by paired t-test (SPSS for Windows 18.0, IBM, USA). We judged p less than 0.05 to be statistically significant.

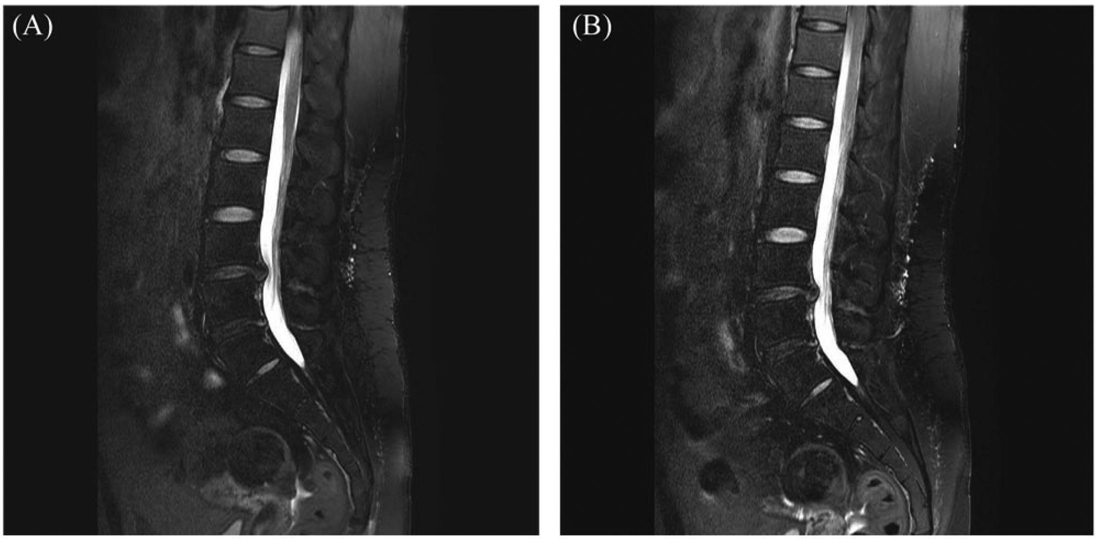

Fig. 2. Fat-suppressed T2-weighted images with a 50° tilt knee support device (A) and fat-suppressed T2-weighted images without knee support device (B).

Table 2. Signal intensity and standard deviations measured at three sites.

n	T12 to L2		L3 to L5		Sacrum		StD		P
	used	Not used	used	Not used	used	Not used	used	Not used	
1	406.5	500.9	127.8	183.3	394.9	329.9	128.7	129.8	
2	478.3	662.7	143.5	216.9	191.3	337.4	147.9	188.3	
3	245.9	288.3	79	81.1	131.7	144.2	69.7	86.7	
4	944.8	1080.3	327	187.9	254.4	219.2	309.8	413.5	
5	464.4	896.9	414.6	272	381.4	350	34.1	278.0	
6	320.2	516.8	166.1	151.3	426	289.9	106.7	150.7	
7	623.1	716.7	190.7	201.2	165.3	188.6	210.1	246.0	
8	480.3	528.2	203.8	137.2	232.9	137.2	124.1	184.3	.001
9	752.6	1048.9	362.9	218.5	443.5	262.2	168.0	381.6	
10	476.3	734.5	243.5	160.7	328.1	149.2	96.2	273.2	
11	381.2	566.3	122.3	100.8	122.3	62.1	122.0	229.1	
12	429.3	551.9	198.4	304.8	211	205	106.0	145.8	
13	234.1	507.6	380.4	219.5	195.1	131.7	79.8	160.6	
mean	479.7	661.5	227.6	187.3	267.5	215.8	130.9	220.5	

Note) StD: Standard deviation; used: used the knee support device; not used: did not use the device.

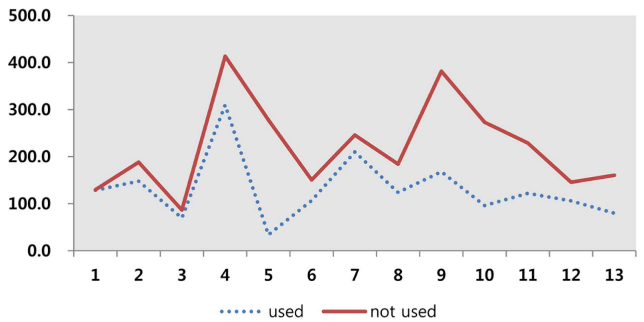

Fig. 3. (Color online) Standard deviation graph of when the knee support was used and when it was not. The mean standard deviation was lower with the knee support, which demonstrates that the fat suppression was effective when the knee support was used.

3. Results

The images with and without the use of the 50° inclined knee support are shown in Fig. 2. The signal intensity measured from T12 to L2 was lowest at 234.1 but highest, 944.8, when the 50° knee support was used, and the mean was 479.76. When the knee support was not used, the maximum was 1080.3 and the lowest was 288.3, and the average was 661.53. Signal intensity from L3 to L5 ranged from 414.6 to 79 with the knee support and the average was 227.69; when the support was not used, the highest intensity was 304.8, the lowest was 81.1, and the average was 187.3. The signal intensity measured at the sacrum ranged from 443.5 to a minimum of 131.7 with the 50° knee support, with an average of 267.53. When the knee support was not used, the highest score was 350 and the lowest was 62.1, and the mean score was 215.89. The mean standard deviations obtained from the three sites were 13.99 when using the knee support and 220.58 when the support was not used (Table 2, Fig. 3).

4. Discussion

In the radiological diagnosis of LBP, MRI has the advantage of excellent soft tissue resolution and offering the ability to see the whole lumbar region in one image plane [4]. In particular, T2 WI and fat suppression play important roles in the diagnosis of back pain [5]; the difference in lipid content between normal lesions and those that induce LBP is evident. With fat-suppression MRI, there is a contrast difference between images due to these differences in lipid content [6]. However, if the fat suppression does not fully eliminate fat for any reason, there could be confusion in the diagnosis; therefore, the uniformity of fat suppression must be maintained during MRI. Because fat suppression is affected by magnetic susceptibility, shimming in the test area is used to increase the magnetic field uniformity. However, due to the nature of the vertebral curvature of the human body, an air space between the table and the lumbar curve is created by the lordosis of the lumbar vertebrae. Human tissue and air cause susceptibility to local magnetic field non-uniformity, resulting in image distortion [9]. Therefore, the air space generated by the lumbar curve and the table should be kept to a minimum, and this can be accomplished by elevating the knee; when the knee is elevated, the vertebral body is flattened and the diameter of the spinal canal and the cross-sectional area within the dural sac decrease [7]. The purpose of this study was to evaluate the signal uniformity of the T2 WI fat suppression technique when a 50° lumbar support was placed under the knee and the space between the lumbar lordosis and the table was flattened. The fat suppression uniformity was better when the knee support was used than when it was not; even though we used the same parameters for the same pulse sequence, fat suppression uniformity only improved with the knee elevation, and these results can be found in many studies. Martin [10] *et al.* reported that the difference in lung susceptibility between lung parenchyma and air was 9 ppm on lung MRI, which was reported to affect T2*. Bergin [11] *et al.* reported suspicion due to non-uniformity of magnetic field caused by air and lung parenchyma in lung parenchyma MRI. Michael [12] *et al.* reported that 9 ppm, the difference in tissue susceptibility to air, causes magnetic susceptibility artifacts in cardiac MRI. These studies support that the air space created by the lumbar curve and the table makes the magnetic susceptibility non-uniform. Emmanuelle [13] *et al.* reported that fat suppression has the disadvantage of high sensitivity to non-uniformity of the magnetic field. Georgy [14] *et al.* reported less signal to noise, more magnetic susceptibility artifacts, irregular fat suppression, and longer scan time as disadvantages of fat suppression including SPIR. Based on combining these findings, we propose that the air space created by the anatomical structure causes a frequency difference of 9 ppm when using the fat suppression technique, which causes non-uniformity of magnetic susceptibility and is a major cause of irregular fat suppression. Therefore, minimizing surrounding air in the anatomical structures included in imaging studies is a major precaution for fat suppression. In this study, to minimize the air space between the lumbar curve and the table, a 50° tilt support was placed on the patient's knee, which flattened the lumbar spine, which decreased the air space caused by the anatomical structure and improved images from using fat suppression.

5. Conclusion

The fat in the lumbosacral sagittal plane is irregularly suppressed in images due to the large space between the lumbar curve and the table; in this study, we applied a 50° tilt support to each patient's knee and obtained improved images. In addition, the study's findings suggest that the relationship between air and parenchymas should be considered when magnetic susceptibility artifacts occur. It is necessary to study using fat suppression around the air in the human body, such as in the sinuses and cavities, and this study will be used as basic data.

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