

Study of Inversion Time of Double Inversion Recovery Technique in Knee Synovial Hypertrophy: Comparison with T2-Weighted Image and PD-Weighted Image in 3.0 Tesla MR System

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The purpose of this study was to aid in the diagnosis of knee synovial hypertrophy using DIR sequences without contrast agents. In the 3.0T MR system, the TI value was set to TI1/TI2 (2805/229 msec) and applied to the DIR technique. At this time, no contrast agent was used. In synovium and effusion, DIR showed higher SNR and CNR than T2WI and PDWI. In conclusion, the DIR technique using the proposed TI value is useful for the diagnosis of knee synovial hypertrophy as compared with the conventional image. In the future, this study will provide basic data in the study applying DIR technique to various diseases.

Keywords : Bloch equation, double inversion recovery, DIR, knee synovial hypertrophy

무릎활액막비대의 이중반전기법에서 반전시간 연구: 3.0 Tesla 자기공명영상 시스템에서 T2-강조영상과 PD-강조영상의 비교

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본 연구의 목적은 이중반전기법을 이용하여 무릎활액막비대 진단에 도움을 주는 것이다. 3.0T 자기공명영상 시스템에서 반전회복 값을 TI1/TI2(2805/229 msec)로 설정하여 이중반전기법에 적용하였다. 이때 조영제는 사용하지 않았다. 활액막과 삼출액의 SNR, CNR 값에서 이중반전기법이 T2-강조영상, PD-강조영상 보다 높은 결과를 얻을 수 있었다. 결론적으로 본 연구에서 제안하는 반전회복 값을 이용한 이중반전기법은 기존의 영상에 비해 무릎활액막비대 진단에 유용함을 알 수 있었다. 향후 다양한 질환에 이중반전기법을 적용하는 연구에서 본 연구가 기초 자료를 제공할 것이라 사료된다.

주제어 : 블록 방정식, 이중반전회복, 무릎활액막비대

I. Introduction

Magnetic Resonance Imaging (MRI) is widely used in the assessment of musculoskeletal disorders by facilitating the extraction of soft tissues, tendons, ligaments, cartilage, bones, joints, and nerves [1]. In addition, malignant tumors provide important information for determining the treatment plan or treatment effect, including determining the timing of the disease, delineating the extent of progression [2]. Furthermore, signal-to-noise ratio (SNR) and resolution have been improved using magnetic resonance imaging of the head of the head and software has been developed to facilitate local cartilage lesion discovery [3]. Especially in the small joints, it was possible to increase the resolution and to observe the degree of cartilage and the synovial membrane proliferation. Among the musculoskeletal exams, knee arthroplasty is useful for diagnosis of injury to the lateral collateral ligament, rupture of the cruciate ligament, damage to the meniscus, and arthritis [4]. In addition, it is easy to diagnosis synovial hypertrophy, which is a secondary disease due to inflammation of the synovium of the joint due to infection or immune status and which is filled with effusion in the empty bursa [5]. Synovial hypertrophy is a disease in which it is difficult to bend the knee, and when the bending of the synovial swells, it feels pain. In the anatomy of the knee joint, there is a joint capsule surrounded by a synovial membrane that has a constant space between the bones and bones to allow free exercise [6]. The articular cavity is enclosed in the capsule, and the articular cavity is filled with the synovial fluid secreted in the synovial membrane to prevent friction [Fig. 1]. However, when synovium is hypertrophy, it is stimulated by trauma or inflammation, producing mucus containing blood cells

and protein fibers, limiting the movement of the joint to swelling and bending, which is called synovial hypertrophy [4-6]. To date, MRI has been used to diagnose synovial hypertrophy using a T1-weighted image that is injected intravenously [7]. However, it is necessary to improve various aspects such as invasive procedure, side effects, and increase of scan time. When contrast media is not used, synovial hypertrophy images show mixed signal of fat and effusion. Therefore, if the two signals can be removed at the same time, it would be possible to improve the diagnosis of the image without using the contrast agent. In this study, we used Double Inversion Recovery (DIR) as a pulse sequence that can simultaneously suppress fat and effusion signals. The TI of fat and effusion was calculated using the Bloch equation and compared with the DIR, T2-weighted image, and PD-weighted image techniques.

II. Subjects and Methods

The subjects were ten adult men with synovial hypertrophy. Ten subjects were those who had confirmed synovial hypertrophy, who were volunteers during the study period. The instrument was 3.0 Tesla (Achieva release 2.0, Philips medical system, Netherland) and 8 channel receive only knee coil. The parameters used in the study are shown in [Table I]. Each image was transverse, with a FOV of 160 mm, 25 slices, and a thickness/gap of 3/0 mm. Scan range was examined from the tibial tuberosity to the upper part of the T2 sagittal image. The images were randomly selected from the images with the most synovial effusion. The Inversion Recovery (IR) sequence is a method of inverting the longitudinal magnetization in the opposite direction by applying a

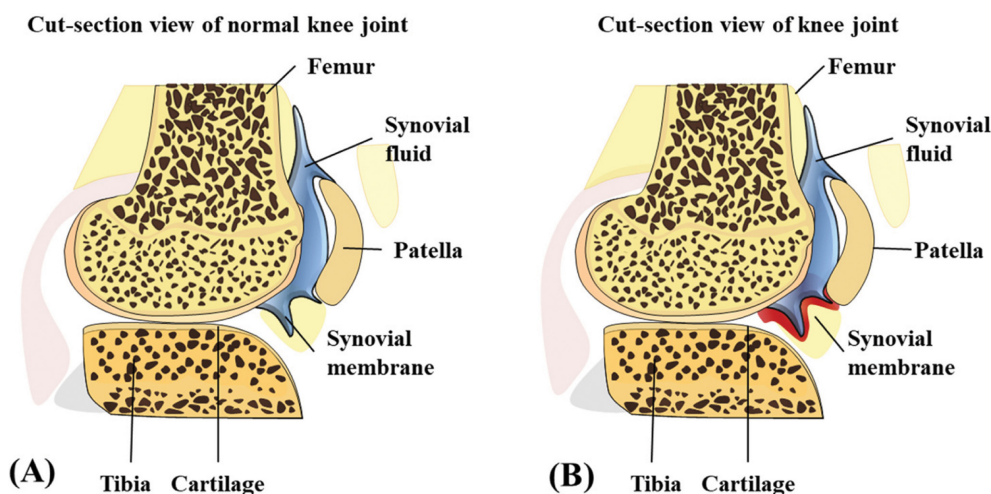


Fig. 1. (Color online) Anatomy of normal knee (A), knee when synovial hypertrophy occurs (B).

Table I. Sequence-specific parameters used in this study.

Contrast	Sequence	TR/TE (msec)	Mat (f × p)	NEX	Scan time (sec)	TI_1/TI_2 (msec)
T2WI	TSE	7950/100	292 × 204	1	93	None
PDWI	TSE	3000/25	292 × 203	1	162	None
DIR	TIR	10000/25	292 × 206	2	260	2805/229

Note: T2WI (T2-Weighted Image), PDWI (Proton Density Weighted Image), DIR (Double Inversion Recovery), TSE (Turbo Spin Echo), TIR (Turbo Inversion Recovery), Mat (Matrix) f × p (frequency encoding × phase encoding), NEX (Number of Excitation), TI (Inversion Time).

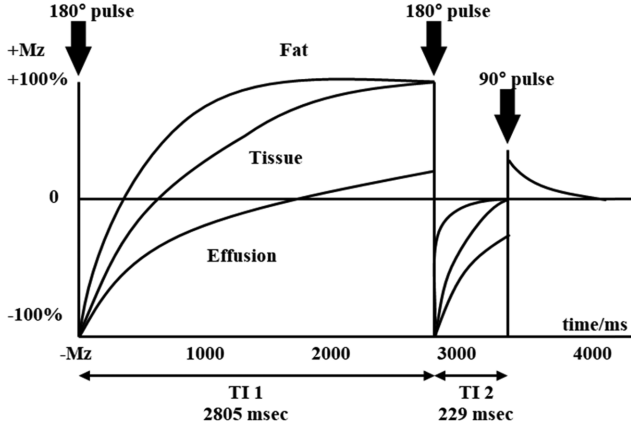


Fig. 2. The pulse sequence diagram of the double inversion recovery used in this study.

180° reversal pulse and then obtaining an echo using a 90° excitation pulse after the inversion time has elapsed [Fig. 2]. The DIR technique is a modification of the IR technique, in which an image is acquired using another 180° inversion pulse between a 180° inversion pulse and a 90° excitation pulse. This determines the contrast of the image using the inverse excitation pulse after the time TI_1 and TI_2 have elapsed in one TR. Use a linear profile to fill the half-scan and K-space to minimize the T2 effect and shorten the echo spacing by using a short TE to relax the magnetization of the tissue by making the TR very long. To obtain both TI_1 and TI_2 times that simultaneously suppress the fat and effusion signals, the Bloch equation was calculated using the Mathematica 8.0 (Wolfram, Champaign, IL) program to obtain TI_1 and TI_2.

The appropriate TI value for the null point in the inversion pulse sequence in the Turbo Spin Echo (TSE) can be calculated as follows [8]. Let the longitudinal axis of the inversion pulse sequence be M_0 and the inverted state of 180° inversion pulse be αM_1 . When the inversion pulse is perfect, $\alpha = -1$, which can be regarded as a cosine according to the flip angle. M_1' represents the longitudinal magnetization after TI after the inversion pulse and the longitudinal magnetization is recovered from αM_1 to M_1' by longitudinal relaxation during TI time. That is, when $M_0(0) = \alpha M_1$ and $t = TI$, $M_0(t) = M_1'$ holds.

$$M_1' = M_0 \left\{ 1 - (1 - \alpha) \exp\left(-\frac{TI}{T_1}\right) - \alpha \cdot \exp\left(-\frac{TR - ES \cdot ETL}{T_1}\right) \right\} \quad (1)$$

Here, ES means echo space and ETL means echo train length. If $TI = TI_{null}$ and $M_1' = 0$ are assigned at the point of the null point, the following answer can be obtained.

$$TI_{null} = T_1 \left[\ln(1 - \alpha) - \ln \left\{ 1 - \alpha \cdot \exp\left(-\frac{TR - ES \cdot ETL}{T_1}\right) \right\} \right] \quad (2)$$

If the inversion pulse is completely inverted ($\alpha = -1$) as in the first assumption, TI_{null} is given by the following equation.

$$TI_{null} = T_1 \left[\ln 2 - \ln \left\{ 1 + \exp\left(-\frac{TR - ES \cdot ETL}{T_1}\right) \right\} \right] \quad (3)$$

It is important to note that when $TR - ES \cdot ETL$ is much longer than T_1 , TI_{null} has a maximum value of $T_1 \cdot \ln 2$.

In this study, we used the following formula given by Redpath and Smith because we used two inversion pulses [9, 10].

$$M_1' = M_0 \left[1 - 2 \exp\left(-\frac{TI_2}{T_1}\right) + 2 \exp\left(-\frac{(TI_1 + TI_2)}{T_1}\right) - \exp\left(-\frac{TR}{T_1}\right) \right] \left(\frac{2}{\exp\left(-\frac{\tau}{T_1}\right)} - 1 \right) \quad (4)$$

Where, $\tau = \frac{TE}{2}$, TE is the echo time, TR is the repetition time

In the above equation, TI_1 can be obtained by summarizing TI_1, and TI_2 can be obtained by summarizing TI_2. Here TI_1 is the nulling point of effusion at 2805 msec and TI_2 is the nulling point of fat at 228 msec. Therefore, the two TI values used in this study were set to 2805/229 msec. The signal intensity (SI) value was obtained by plotting the regions of interest (ROI) as a line on the synovial membrane (S) using the

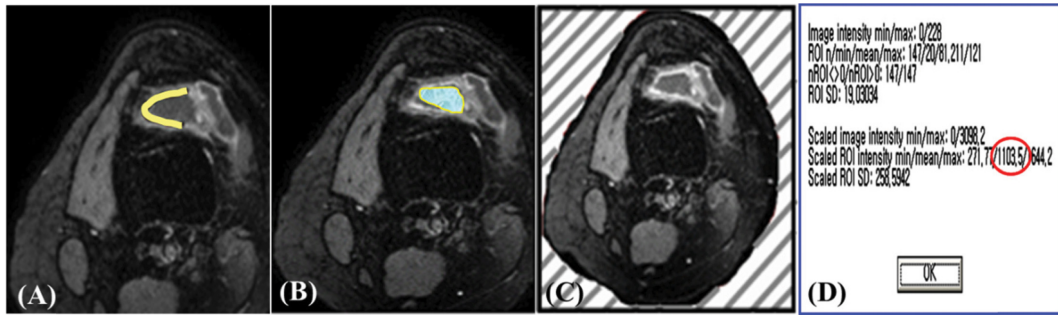


Fig. 3. (Color online) Measure synovial membrane (A), measuring effusion (B), measure background (C), and use MRIcro to check signal intensity (D).

MRIcro (Rorden and Brett, 2000) program. The irregular ROI for effusion (E) was also plotted to determine the SI value [Fig. 3]. The SI value of the background was also obtained by plotting the irregular ROI. The SNR and CNR values were obtained after SI values were obtained from three images, respectively. The obtained formulas are shown in Eqs. (5) and (6).

$$SNR = \left| \frac{Signal(synovium, Effusion)}{Background} \right| \quad (5)$$

$$CNR = \left| \frac{Synovium - Effusion}{Background} \right| \quad (6)$$

The signal intensity, SNR, and CNR values obtained from the T2WI, PDWI, and DIR techniques were compared using the Kruskal-Wallis test of SPSS (IBM, 22.0, USA)

and statistically significant when the p value was less than 0.05.

III. Results

The synovial hypertrophy image by sequence is shown in [Fig. 4]. Synovium had the highest signal intensity at 1269.97 ± 67.27 in DIR and lowest at 1096.26 ± 61.79 in T2WI ($p < 0.05$). In effusion, T2WI showed the highest signal intensity at 1913.26 ± 305.18 and lowest in DIR at 480.74 ± 56.05 ($p < 0.05$). In the background, T2WI showed the highest signal intensity at 12.82 ± 2.31 and the lowest at DIR 0.98 ± 0.28 ($p < 0.05$) [Table II].

The SNR of synovium was highest at 1404.54 ± 408.72 in DIR and lowest at 87.93 ± 15.47 in T2WI ($p < 0.05$). The SNR of effusion was the highest at 886.79 ± 308.77

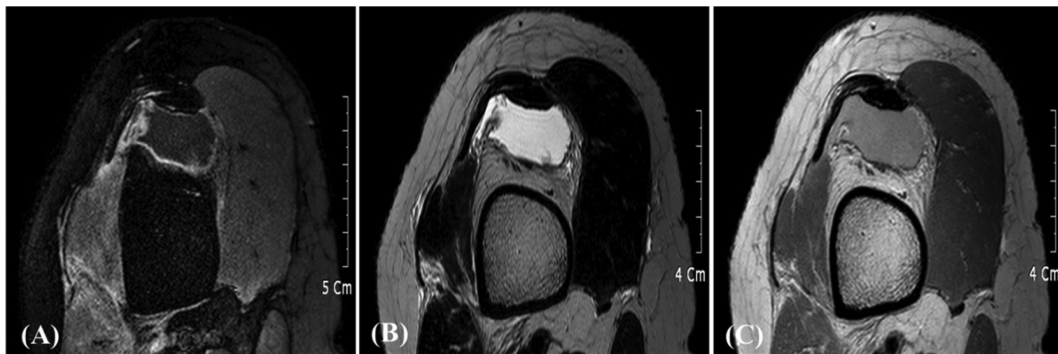


Fig. 4. Case with effusion at the knee joint due to trauma. The image according to the pulse sequence used in this study. DIR (A), T2WI (B), PDWI (C).

Table II. The signal intensity of knee synovium, effusion, background in this study.

Region	T2WI	PDWI	DIR	p
Synovium	1096.26 ± 61.79	1154.93 ± 67.53	1269.97 ± 67.27	0.000
Effusion	1913.26 ± 305.18	1226.92 ± 54.49	480.74 ± 56.05	0.000
Background	12.82 ± 2.31	9.26 ± 3.48	0.98 ± 0.28	0.000

Note: The p-value was calculated using the non-parametric statistical method, Kruskal-Wallis test.

Table III. SNR and CNR values according to image technique.

Contrast	T2WI	PDWI	DIR	p
SNR(S)	87.93 ± 15.47	142.74 ± 55.46	1404.54 ± 408.72	0.000
SNR(E)	63.37 ± 15.21	8.84 ± 6.43	886.79 ± 308.77	0.000
CNR	151.30 ± 20.75	151.58 ± 59.90	517.74 ± 106.91	0.000

Note: The p-value was calculated using the non-parametric statistical method, Kruskal-Wallis test. SNR(S) is the signal to noise ratio of synovium, SNR(E) is the signal to noise ratio of effusion.

in DIR and lowest at 8.84 ± 6.43 in PDWI ($p < 0.05$). CNR was 151.30 ± 20.75 in T2WI, 151.58 ± 59.90 in PDWI, and DIR was the highest at 517.74 ± 106.91 ($p < 0.05$) [Table III].

IV. Discussion

The knee is an organ that is able to withstand the lower part of the body weight and to participate in the movement of the body through the bending and extension movement of the knee. These knee joints consisted of bones such as femur, tibia, and patella, and their connections were fixed by medial & lateral collateral ligament and anterior & posterior cruciate ligament. In addition, there is a joint capsule that is difficult to observe under normal conditions, and there is a synovial membrane in it that makes it smooth between the bones and bones. There are suprapatellar bursa, subcutaneous pre-patellar bursa, and deep infrapatellar bursa in the knee capsule, and some of them are connected with the joints, which is a very important part of clinical practice [11-13]. Anatomically, it is a bursa that is difficult to observe under normal MRI, but it may appear in the image when a secondary disease occurs [14]. These diseases, such as synovial hypertrophy, have been identified and evaluated after T1WI enhancement [15-17]. There have been reports of delayed gadolinium-enhanced MRI of cartilage (dGEMRIC), sodium MR imaging, T2 mapping, diffusion-weighted magnetic resonance imaging and magnetization transfer [18-22]. In this study, double inversion recovery without contrast agent was used to observe synovial hypertrophy. Synovial hypertrophy is composed of fat and effusion signals. T2WI using Turbo Spin Echo (TSE) show bright water and fat signals. The reason why the fat and water signals are bright is that the j-coupling phenomenon becomes weak due to the continuous 180° RF pulse [2]. Therefore, the effusion of T2WI due to synovial hypertrophy is not known and it is difficult to diagnose the extent of inflammation. Likewise, the PDWI image has a moderate intensity distribution of the fat and water signals, so it is possible to diagnose effusion, but it is difficult to know the boundary between effusion and synovium. However, the DIR technique proposed in this study can clearly show the

boundary of synovium by abolishing both fat and effusion signals. The diagnosis of synovial hypertrophy is possible by non-invasive technique without contrast agent.

In this study, the images using the DIR technique can obtain high CNR images compared to the existing T2WI and PDWI. The TI values of the fat and water signals were calculated using the bloch equation and TI_1 and TI_2 were 2805/229 msec. However, it is necessary to change the IT value according to difference between simple effusion and hemorrhage, and further study is needed accordingly. Also, the TR value is long and the scan time is about 4 minutes and 20 seconds. However, the DIR technique proposed in this study can help diagnose the synovial membrane state freely in the controversy about the stability of the contrast agent.

V. Conclusion

In conclusion, this study confirms that DIR can provide important information for diagnosis of synovial hypertrophy without using contrast agent. Also, the most important TI value in the DIR technique was obtained by the bloch equation of the mathematica program. Therefore, the DIR technique can be applied to various diseases, and this study is expected to provide basic data.

References

- [1] M. Shahabpour, M. Kichouh, E. Laridon, J. L. Gielen, and J. De Mey, *Radiology* **65**, 2 (2007).
- [2] A. Konski, T. Li, E. Sigurdson, S. J. Cohen, W. Small, Jr., S. Spies, J. Q. Yu, A. Wahl, S. Stryker, and N. J. Meropol, *Int. J. Radiat. Oncol.* **74**, 1 (2009).
- [3] P. Marzola, F. Osculati, and A. Sbarbati, *Radiology* **48**, 2 (2003).
- [4] K. P. Spindler, J. P. Schils, J. A. Bergfeld, J. T. Andrish, G. G. Weiker, T. E. Anderson, D. W. Piraino, B. J. Richmond, and S. V. Medendorp, *Am. J. Sport. Med.* **21**, 4 (1993).
- [5] D. McGonagle, W. Gibbon, P. P'Connor, M. Green, C. Pease, and P. Emery, *Clin. Sci.* **41**, 4 (1998).
- [6] R. Garcia-Valtuille, F. Abascal, L. Cerezal, A. Garcia-Caltuille, T. Pereda, A. Canga, and A. Cruz, *Radiograph-*

- ics. **22**, 4 (2002).
- [7] Y. Ragab, Y. Emad, and A. Banakhar, *Clin. Rheumatol.* **26**, 10 (2007).
- [8] M. Kita, M. Sato, K. Kawano, K. Kometani, H. Tanaka, H. Oda, A. Kojima, and H. Tanaka, *Magn. Reson. Imaging.* **31**, 9 (2013).
- [9] P. A. Boulby, M. R. Symms, and G. J. Barker, *Magn. Reson. Med.* **51**, 6 (2004).
- [10] T. W. Redpath and F. W. Smith, *Brit. J. Radiol.* **67**, 804 (1994).
- [11] E. N. Unlu, Y. Turhan, D. M. Kos, and A. A. Safak, *Diag. Interv. Imag.* **98**, 4 (2017).
- [12] F. W. Roemer, M. Jarraya, D. T. Felson, D. Hayashi, M. D. Crema, D. Loeuille, and A. Guermazi, *Osteoarthr. Cartilage.* **24**, 3 (2016).
- [13] F. Lapegue, N. Sans, C. Brun, S. Bakouche, N. Brucher, Z. Cambon, H. Chivassa, A. Larbi, and M. Faruch, *Diag. Interv. Imag.* **97**, 7 (2016).
- [14] Y. W. Liu, M. R. Skalski, D. B. Patel, E. A. White, A. Tomasian, and G. R. Matcuk, Jr., *Skeletal Radiology* **47**, 8 (2018).
- [15] H. J. Yoo, S. H. Hong, H. Y. Oh, J. Y. Choi, H. D. Chae, J. M. Ahn, and H. S. Kang, *Radiology* **283**, 3 (2016).
- [16] R. Hemke, J. M. Denberg, C. M. Nusman, E. C. V. Hulik, A. M. Barendregt, D. Schonenberg-Meinema, K. M. Dolman, T. W. Kuijpers, and M. Maas, *Eur. Radiology* **28**, 3 (2018).
- [17] M. Carotti, F. Salaffi, M. D. Carli, and A. Giovagnoni, *Radiol. Med.* **122**, 12 (2017).
- [18] M. D. Crema, D. J. Hunter, F. W. Roemer, D. Burstein, L. Ki, N. Krishnan, J. R. Silva, Jr., M. D. Marra, M. P. Hellio, L. Graverand, and A. Guermazi, *Osteoarthr. Cartilage.* **23**, 2 (2018).
- [19] G. Madelin, D. Xia, R. Brown, J. Babb, G. Chang, S. Krasnokutsky, and R. R. Regatte, *Eur. Radiology* **28**, 1 (2018).
- [20] S. Jafarzadeh, J. Tamez, S. Totterman, M. Clancy, and D. T. Felson, *Osteoarthr. Cartilage.* **26**, 1 (2018).
- [21] A. M. Barendregt, E. C. V. Gulik, C. Lavini, C. M. Nusman, J. M. V. D. Berg, D. Schonenberg-Meinema, K. M. Dolman, T. W. Kuijpers, R. Hemke, and M. Maas, *Eur. Radiology* **27**, 11 (2017).
- [22] F. Liu, W. F. Block, R. Kijowski, and A. Samsonov, *Magn. Reson. Med.* **75**, 4 (2016).
- [23] P. A. Hardy, R. M. Henkelman, J. E. Bishop, and E. C. S. Poon, *JMRI* **2**, 5 (1992).