TECHNICAL NOTE

Interactive Scan Control for Kinematic Study in Open MRI

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Purpose: A tool to support the subject is generally used for kinematic joint imaging with an open MRI apparatus because of difficulty setting the image plane correctly. However, use of a support tool requires a complicated procedure to position the subject, and setting the image plane when the joint angle changes is time consuming. Allowing the subject to move freely enables better diagnoses when kinematic joint imaging is performed. We therefore developed an interactive scan control (ISC) to facilitate the easy, quick, and accurate setting of the image plane even when a support tool is not used.

Methods: We used a 0.4T magnetic resonance (MR) imaging system open in the horizontal direction. The ISC determines the image plane interactively on the basis of fluoroscopy images displayed on a user interface. The imaging pulse is a balanced steady-state acquisition with rewind gradient echo (SARGE) sequence with update time less than 2 s. Without using a tool to support the knee, we positioned the knee of a healthy volunteer at 4 different joint angles and set the image plane through the patella and femur at each of the angles. Lumbar imaging is also demonstrated with ISC.

Results: Setting the image plane was easy and quick at all knee angles, and images obtained clearly showed the patella and femur. Total imaging time was less than 10 min, a fourth of the time needed when a support tool is used. We also used our ISC in kinematic imaging of the lumbar.

Conclusion: The ISC shortens total time for kinematic joint imaging, and because a support tool is not needed, imaging can be done more freely in an open MR imaging apparatus.

Keywords: *ISC, kinematic imaging, open MRI*

Introduction

Fast imaging sequence, such as steady state free precession (SSFP), and interactive scan control (ISC) are used in dynamic study of the orbit,¹ uterus,^{2,3} and bowel,⁴ but have not been widely used in middle-low-field open magnetic resonance (MR) imaging.

On the other hand, joint disorders are often diagnosed by evaluating information obtained through kinematic imaging^{5,6} at various angles of the joint, and the wide gantry space of an open MR imaging

system with a vertical magnetic field is useful in such imaging. Because it is difficult to set image planes correctly if the patient can move freely, a support tool (Fig. 1) is generally used in conventional kinematic joint imaging. However, use of such a tool complicates positioning the patient; setting the image plane when the joint angle changes is time consuming, and stress tests cannot be performed. When imaging the knee, good images of the transversal and sagittal planes can be acquired using a support tool. However, if the patient can move freely, coronal plane images can be acquired that enable evaluation of the collateral ligament when the joint is in the position that causes the patient pain.

We therefore developed an ISC to facilitate the

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setting of the image plane in open MR imaging when a support tool is not used. Before this study, ISC with open MR imaging had been developed that utilized infrared cameras and reference markers to obtain positional information for use in interventional MR imaging.⁷ In contrast, the ISC we developed determines the image plane interactively on fluoroscopy images displayed on a user interface. The image plane can be set quickly, easily, and accurately without additional positioning tool and is more convenient to use in routine clinical study. We used SSFP sequence and ISC in middle-low-field open MR imaging and conducted a feasibility study that demonstrated the method's utility for clinical application in a healthy volunteer.

Fig. 1. A support tool. Receiver coil and subject are positioned on a support tool.

Methods

We used an open MR imaging apparatus operating at 0.4T (APERTO®, HITACHI Medical Corporation, Tokyo, Japan) that allowed 320° access in the horizontal plane and with a 38-cm vertical gap.

The ISC we have developed allows the user to change and save the image plane at any time. Figure 2 shows the imaging flow during kinematic imaging. The image plane parameters (position, oblique angle, and phase encoding direction) are interactively changed on the basis of fluoroscopy images displayed on the user interface (Fig. 3). The contrast parameters—repetition time (TR), echo time (TE), and flip angle (FA)—can also be changed interactively during the fluoroscopy scan. The user interface consists of 4 windows (called views herein). The user sets slice positions on Views 1 to 3, and a fluoroscopy image of the region being examined is displayed on View 4. When starting an ISC scan, the user loads a scanogram image in one of the 1 to 3 views and sets the image plane. After an ISC scan is begun, at any time, the user can save the fluoroscopy image displayed on View 4 to any of the other three views and set a new image plane. When the image plane is being changed, an image of the new plane will be displayed within 2 s.

The imaging pulse sequence is a balanced steady-state acquisition with rewind gradient echo (BASG) sequence, which is a kind of SSFP sequence that executes in a short TR and rephases in 3 directions (slice, phase encode, and readout). The parameters employed were: TR = 5.4 ms; TE = 2.7 ms; scan time 0.7 s per slice. Active shimming be-

Fig. 2. Schematic diagram showing imaging flow of interactive scan control (ISC) allowing user to change the image plane interactively on the basis of fluoroscopy images displayed on a user interface.

Fig. 3. User interface of interactive scan control (ISC). A fluoroscopy image is displayed on View 4 (lower right). The user can save that image to any of Views 1 to 3 and set a new image plane.

a	b
c	d

Fig. 4. Positioning of the receiver coil and the volunteer's body during kinematic imaging of knee. Without using a tool to support the volunteer's knee, the subject could change his knee angle freely. We positioned the knee at 4 joint angles between extension (a: angle 1) and flexion positions (d: angle 4).

Fig. 5. The process for setting the image plane in kinematic imaging of a knee (through the patella and the femur). (a) The scanogram is loaded, transversal plane set, and ISC scan begun. (b) A fluoroscopy image is displayed on View 4 and updated automatically. (c) The user saves the transversal plane image obtained in Step b and sets the sagittal plane perpendicular to the knee. (d) The sagittal plane image obtained in Step c is displayed on View 4 and updated automatically. (e) The user saves the sagittal plane image obtained in Step d and sets the transversal plane through the patella and the femur. (f) The final-purpose transversal plane image is displayed on View 4.

fore ISC scanning eliminated BASG banding artifacts.

In a healthy volunteer, we applied the developed ISC on knee and lumbar imaging to test images and imaging work flow. For both knee and lumbar kinematic imaging, we used the same BASG sequence and determined slice position by ISC for other kinds of high-spatial-resolution scans.

Results

Figure 4 shows the receiver coil and the volunteer's body position during kinematic imaging of the knee. We positioned the knee at 4 joint angles between an extension (a: angle 1) and flexion positions (d: angle 4). We performed kinematic imaging without a tool to support the knee and with the volunteer lying in a lateral position to allow him to change knee angle freely. Figure 5 shows the procedure for the knee kinematic imaging, with the slice position set through the patella and femur. The procedure comprised the following 6 steps, and typical operation time is shown.

- a. Load scanogram, set the transversal plane, and start the ISC scan (typical operation time, 30 s).
- b. A fluoroscopy image is displayed on View 4 (lower right) and updated automatically (2 s for first image and 0.7 s/image for image update)
- c. At any time, the user can save the transversal plane image obtained in Step b and set a sagittal

- plane perpendicular to the patella and along the femur (typically 30 s).
- d. The sagittal plane image set in Step c is displayed on View 4 and updated automatically (2 s for first image and 0.7 s/image for image update).
- e. At any time, the user can save the sagittal plane image obtained in Step d and set a transversal plane through the patella and the femur (typically 30 s).
- f. The transversal plane image that is the purpose of this scan (obtained at angle 1) is displayed on View 4 (2 s for first image and 0.7 s/image for image update). Thus, total examination time was 1 min 36 s for the first angle.

When the knee angle was changed, a similar positioning process was repeated at another angle. Testing at all 4 angles took 6 min 24 s.

Figure 6 shows knee kinematic images of a healthy volunteer that were obtained using the steps in Fig. 5. Setting the image plane was quick and easy at all angles of the knee, and the images we obtained clearly showed the patella and femur.

Figure 7 shows the receiver coil and a volunteer during kinematic imaging of the lumbar. Because it is difficult to bend and stretch the lumbar when using a body coil, we used instead the joint coil that we used for kinematic imaging of a knee. Again, we performed kinematic lumbar imaging without a support tool and with the volunteer lying in a later-

Fig. 6. The result of kinematic imaging of the knee (two-dimensional [2D]-balanced steady-state acquisition with rewind gradient echo [BASG] sequence; field of vision [FOV]=350 mm; repetition time [TR]=5.4 ms; echo time [TE]=2.7 ms; flip angle [FA]=90°; thickness=7 mm; data matrix=128×128). (a)-(d) are sagittal plane images, (e)-(h) are transversal plane images. At all angles, the patella, femur, and cartilage are clearly shown. Total imaging time was less than 10 min.

al position so he could freely change the lumbar curvature. We set the lumbar at 3 positions: recurved (a: angle 1); straight (b: angle 2); and ante-flexion (c: angle 3).

Figure 8 shows lumbar kinematic images of a healthy volunteer. As in the kinematic imaging of the knee, setting the image plane of the lumbar was quick and easy at all angles. Image quality was good, and the images clearly showed the interspinal disks. Total imaging time was less than 10 min for the 3 angles: 2 min for setting the subject and 1 min 36 s for sagittal and coronal imaging for each angle.

Examples of kinematic imaging shown in Figs. 6 and 8 were obtained using protocols with short scan times (0.7 s/image). When images with high spatial resolution are needed, such an ISC scan (1 s/image) can be performed (Fig. 9).

Discussion

MR imaging is quite useful for diagnosing joint disorders because it can clearly show internal lesions and ligament injuries. However, scan time for the MR imaging apparatus is longer than that for x-ray. In our experience, kinematic imaging on an open MR imaging system without ISC and using a support tool typically takes about 40 min when the knee joint angle is changed 4 times because of the time spent setting the positions of the support tool and subject (about 7 min), setting the slice plane position (about 20 s), changing the support tool angle and subject body position (about 5 min) (Fig. 10a). Including the period in which the scan is stopped, these steps require 28 min (sum of gray areas in Fig. 10a), and actual scan time is about 11 min. Thus, total examination time is about 40 min.

In contrast, in kinematic imaging with ISC (Fig. 10b), setting the subject requires the scan to be stopped just 2 min, and actual scan time is about 8 min, a total of 10 min for the entire examination—one-fourth the time required for the imaging without ISC.

As described, the use of ISC shortens the preparation time for imaging in kinematic study of the knee. This technique may be applied to kinematic stress tests of the knee⁶ and may shorten the preparation time in kinematic knee imaging with a support tool.⁵ This technique improves work flow of kinematic imaging with ISC using BASG sequence on an open MR imaging system. Because of its superior performance, the technique is also expected to be applied to interventional MR imaging and other applications utilizing an open MR system.^{8,9}

The slice position determined by ISC can be used for other kinds of scans with high spatial resolu-

Fig. 7. Positioning of receiver coil and the volunteer's body position in lumbar kinematic imaging. Without the use of a support tool, the subject could freely change the curvature of the lumbar spine. We set the lumbar region in 3 positions: (a) recurved position, (b) straight position, and (c) ante-flexion position.

tion. Figure 11 shows coronal-plane and sagittal-plane images of the knee, in which the meniscus and the ligaments are clearly shown. Thus, these images are useful for diagnosis of anterior collateral ligament (ACL) injury or meniscus tears. Images with different contrast, such as T₁- and T₂-weighted images, are also useful in lumbar kinematic imaging for diagnosis of hernia (Fig. 12a, b). Furthermore, the slice position determined by ISC can be used in myelography (Fig. 12c).

Moreover, immediate positioning and scanning without a support tool can be used to obtain diagnostic images of the position in which the patient feels pain.

Knee kinematic imaging in the present study clearly showed the positional relationship of the patella and femur and therefore its utility for diagnosing subluxation.

Fig. 8. The results of kinematic imaging of the lumbar of a healthy volunteer (two-dimensional [2D]-balanced steady-state acquisition with rewind gradient echo [BASG] sequence; field of vision [FOV]=350 mm; repetition time [TR]=5.4 ms; echo time [TE]=2.7 ms; flip angle [FA]=90°; thickness=7 mm; data matrix=128×128). (a) coronal plane of antelexion position, (b) coronal plane of straight position, (c) coronal plane of recurved position, (d) sagittal plane of antelexion position, (e) sagittal plane of straight position, (f) sagittal plane of recurved position. They clearly show the lumbar vertebrae and interspinous disks (arrows). Total imaging time was less than 10 min, only a fourth of the time required for the previous positioning technique using a support tool.

Fig. 9. Result of high-spatial-resolution kinematic imaging (two-dimensional [2D]-balanced steady-state acquisition with rewind gradient echo [BASG] sequence; field of vision [FOV]=350 mm; repetition time [TR]=5.4 ms; echo time [TE]=2.7 ms; flip angle [FA]=90°; thickness=7 mm; data matrix=176×176). (a) sagittal plane of the knee, (b) transversal plane of the knee, (c) coronal plane of the lumbar, (d) sagittal plane of the lumbar.

Fig. 10. Work flow of kinematic imaging. (a) without interactive scan control (ISC), (b) with ISC. Scans are not performed during the steps shown in gray.

Fig. 11. The knee images of a healthy volunteer (two-dimensional [2D]-fast spin-echo [FSE]; field of vision [FOV]=160 mm; repetition time [TR]=3300 ms; echo time [TE]=112 ms; flip angle [FA]=90°; thickness=3 mm; data matrix=288×200; echo train length (ETL)=8; acquisition time=5 min 17 s). (a) sagittal plane image, (b) coronal plane image. Meniscus, anterior cruciate ligament (ACL), and posterior cruciate ligament (PCL) are clearly shown. Slice positions of these images were determined by interactive scan control (ISC) scan.

Fig. 12. Lumbar images of a healthy volunteer. (a) sagittal T₁-weighted image (two-dimensional [2D] fast spin-echo [FSE]; field of vision [FOV]=300 mm; repetition time [TR]=440 ms; echo time [TE]=14 ms; flip angle [FA]=90°; thickness=4.5 mm; data matrix=288 × 224; echo train length [ETL]=2; acquisition time=4 min 56 s). (b) sagittal T₂-weighted image (2D-FSE, FOV=300 mm, TR=2700 ms, TE=120 ms, FA=90°, thickness=4.5 mm, data matrix=288×224, ETL=12, acquisition time=4 min 52 s). (c) sagittal image of myelography (2D-FSE, FOV=300 mm, TR=10000 ms, TE=525 ms, FA=90°, thickness=30 mm, data matrix=480×320, ETL=64, acquisition time=40 s).

Conclusion

The ISC we have developed for kinematic joint imaging requiring no support tool not only reduces imaging time, it also enables the imaging to be conducted more freely in an open MR imaging apparatus. It is suitable for kinematic imaging of the lumbar, which is useful for imaging of herniated disks, and can expand the range of uses of open MR imaging systems.

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