Intravenous Magnetic Resonance Arthrography of the Knee

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Purpose: Knee MR images were repeatedly obtained after intravenous administration of gadopentetate dimeglumine to evaluate the arthrographic effect and to determine the optimal scan timing and technique.

Materials and Methods: Sagittal T1-weighted (650/15) sequences were repeated before and after intravenous gadolinium enhancement in 26 patients who were divided into exercise (14/26) and nonexercise (12/26) groups. Fourteen patients in exercise group were allowed to move the affected knee joint actively for 10 minutes immediately after the first post-enhancement scan and before repeating scans. The signal intensities in central and peripheral portions of the joint were measured and compared between these two groups.

Results: In all cases, enhancement of joint fluid began at peripheral portion and progressed toward central portion. The diffusion rate in exercise group was far faster than that in nonexercise group and homogeneous arthrographic image was revealed within 10 minutes after completion of joint movement. The arthrographic effect continued and the rate of signal decrease was quite slow.

Conclusion: MR arthrographic image of knee joint can be obtained within 10 minutes after completion of a few minute exercise following intravenous injection of gadopentetate dimeglumine. Intravenous MR arthrography is expected to become an useful method as a convenient alternative to direct MR arthrography.

Index Words: Knee, abnormalities
Knee, MR
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INTRODUCTION

Magnetic resonance (MR) imaging has become the method of choice for the evaluation of internal derangement of the knee. The standard sequences of the knee MR imaging have not been absolutely established and are quite variable depending on the kind of the MR machine and its imaging capability, the status of software including surface coil, the philosophy of radiologists and clinicians, the patient’s condition, and the suspected lesion.

It has been suggested that MR arthrography is superior to nonenhanced MR images with regard to the evaluation of cartilage thickness and internal derangement (1, 2). MR arthrography by direct intraarticular injection, however, is somewhat inconvenient, time-consuming, and sometimes not achievable. There have been several reports about MR arthrography by intravenous injection of contrast medium (IV MR arthrography) (3-6).

The current study investigated the enhancement of joint fluid with intravenous injection of gadopentetate dimeglumine and focused on the determination of the optimal timing and technique.

MATERIALS and METHODS

Twenty-six knee MR images, all of which included the enhancement studies in their imaging series and were performed between December 1993 and April 1994, were evaluated. The ages of the patients ranged from 17 to 66 years (mean, 39 years). The study group consisted of 23 cases of trauma, 2 cases of degenera-
tive osteoarthritis and 1 case of synovitis. The interval between trauma and MR examination ranged from 3 days to 3 years.

All subjects underwent MR imaging with 1.5T superconducting magnet (Signa: GE Medical Systems, Milwauk ee, USA) equipped with a dedicated transmit-receive knee coil (GE Medical Systems). Imaging sequences which were performed in all cases were sagittal double-echo T2-weighted (2500/15, 60), T1-weighted (650/15), and enhanced T1-weighted spin echo (SE) sequences. The imaging parameters were a 256 x 192 matrix, 3 mm section thickness with 1 mm gap, 13 to 18 cm field of view, and 1 excitation. Additional imaging sequences including axial T1-weighted SE and gradient echo (GRE) sequences and coronal double-echo T2-weighted SE sequences were variably applied to each subject.

For the enhancement study, gadopentetate dimeglumine (Magnevist; Schering, Germany) (0.1 mmol/kg body weight) was administered by bolus injection via an intravenous route. Just after completion of the injection, T1-weighted SE sequence was immediately performed and then repeated. 12 patients who were appointed to be grouped into nonexercise group were remained motionless within the coil till all the sequences were finished. Repetition of T1-weighted SE sequences was performed at 10, 20, 30, and 60 minutes after completion of intravenous injection of gadopentetate dimeglumine, and in three patients, 2 hour-delayed images were also obtained. The other 14 patients of exercise group removed from the coil just after the first post-enhancement T1-weighted images were completed, and the knee joints were exercised by active walking for about 10 minutes. They were immediately returned into the magnet coil to undergo five repeated sagittal T1-weighted MR images at 10 minute interval. The enhancement pattern of joint fluid was evaluated and the signal intensities of both central and peripheral parts of joint fluid were measured by using the software package provided with the imager. The mean values of the signal intensities of the compartments (central/peripheral) in both groups were evaluated.

**RESULTS**

Arthrographic effect was obtained in all cases by the intravenous administration of gadopentetate dimeglumine. The T1-weighted images obtained immediately following intravenous injection and prior to exercise demonstrated a bright rim of enhancement about the periphery of the joint fluid. The enhancing rim was then widened to progress centrally (Fig. 1, 2, 3)

The degree of signal intensity change, particularly in the central portion, was different between exercise and nonexercise groups. The diffusion rate of gadopente-
Dimeglumine from periphery to center in nonexercise group was so slow that the central signal intensity could not reach the same level as the peripheral signal intensity (Fig. 4). The enhanced joint fluid looked apparently homogeneously hyperintense on the image obtained 60 minutes after injection of gadopentetate dimeglumine (Fig. 1), but the measurement of the signal intensity still revealed the difference between peripheral and central parts even at 2 hours after injection.

The joint fluid in exercise group demonstrated initial peripheral enhancement and became rapidly and uniformly enhanced on the subsequent images (Fig. 2, 3).

The signal intensity of central part already reached or exceeded that of peripheral part on the image obtained just after completion of 10 minute exercise. Then it exhibited a plateau phase that lasted until the end of imaging at 50 minutes after exercise (Fig. 5).

IV MR arthrogram provided obvious contrast between the enhanced hyperintense joint fluid and the iso or hypointense cartilages through outlining the surfaces of articular cartilages and menisci by enhanced fluid (Fig. 2, 3).

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Fig. 2. Joint fluid enhancement in an exercised knee.

a. On T1-weighted image, the definition between the articular cartilage and the joint fluid is indistinct, and the synovial lining looks isointense.
b. Immediately after IV injection of gadolinium, peripheral rim enhancement of joint cavity is noted.
c. The homogeneous MR arthrogram obtained just after completion of exercise and about 20 minutes after IV injection produces good contrast between hypointense cartilage, enhanced joint fluid, and bright fatty bone marrow.

Fig. 3. Another example of enhanced fluid in an exercised knee.

a. There is peripheral rim enhancement with nodular enhancing synovial component on the first IV enhanced T1-weighted image.
b. After exercise, the enhanced joint fluid is noted in the medial recess and lining the articular cartilages and meniscus. The contrast between joint fluid, articular cartilage, meniscus, and bone marrow is definitely improved on this postenhancement study.
c. T2-weighted image also produces arthrographic effect, however, the contrast between articular cartilage and bone marrow looks lower than that noted in IV MR arthrogram (b).
DISCUSSION

MR imaging has evolved into the most accurate imaging modality for the assessment of the knee. Many institutions therefore preferably perform knee MR imaging only after performing plain radiography.

MR protocols for knee imaging is varied according to the status of patient, equipment, the kind of pathology suspected, and structure of knee in interest. There are several MR imaging strategies for articular evaluation, including T1-weighted and double-echo T2-weighted SE sequences (1, 7-10), 2-dimensional or 3-dimensional GRE sequences (11, 12), fat suppression pulse sequences (13), magnetization transfer images (14), and intravenous or intraarticular enhancement studies (1, 2, 13, 15, 16).

MR arthrography has been known to be superior to nonenhanced SE and GRE images with regard to the evaluation of articular cartilage owing to improved contrast between enhanced joint fluid and hypointense articular cartilage (2). Better evaluation of cartilage defects, as small as 2 mm in defect size, can be achieved by MR arthrography (1). It can also accurately depict loose bodies and meniscal abnormalities (2). Direct intraarticular injection of contrast agent is the classical technique for the performance of MR arthrography, and it has made many satisfiable results in variable joints. But, MR arthrography by direct intraarticular injection has potential shortcomings including failure to achieve successful injection (8%)(2), inconvenience, time-consuming, and a rare possibility of potential to introduce infection.

Arthographic effect, however, can be obtained via intravenous route as well as via intraarticular route. The rationale of IV MR arthrography is based on the histologic characteristics of the joint. The synovial intima is a layer of synovial lining varying from one to four cells in thickness, and there is no tight junction. Subsynovium contains numerous blood and lymphatic vessels and the majority of synovial capillaries can be found within 25-50 μm of the intimal surface (17-19). In addition, there is no basement membrane between blood vessel and joint space. All these conditions make the synovium permeable to small molecules like gadolinium. Gadopentetate dimeglumine administered by intravenous route is distributed exclusively to the extracellular fluid space (20, 21) and diffuses into joint cavity via numerous gaps between loose synovial cellular junctions, and ultimately produce arthrographic effect. Comparing with intraarticular route, intravenous route is the approved one of gadolinium administration without serious risk or inconvenience.

The transport rate of small solutes such as gadolinium from capillary bed to joint fluid depends on the permeability of the synovium, the bulk flow from the capillary bed to the joint space, and the concentration gradient across the synovium (22). The joint space of the normal relaxed knee is at a subatmospheric pressure of −5 mmHg to −1.6 mmHg (23). The normal negative pressure within the joint space is accentuated by exercise like walking or straight leg lifting with resultant increased bulk flow into the joint (24). The mixing action of exercise will dilute the peripheral fluid and effectively increase the concentration gradient across the synovium resulting in increased diffusion rate. Exercise also facilitates diffusion by the modification of intercellular distances by mechanical stretching, and increases the local blood flow and the supply of diffusible substances including gadolinium (14). The mixing action by exercise makes the enhancement to be homogeneous.

Our result says that good arthrographic effect can be obtained within 10 minutes after completion of active
movement of the joint following intravenous administra-
tion of gadopentetate dimeglumine. Diffusion rate of
gadopentetate dimeglumine in nonexercise group is
disappointingly slow to be utilized practically.

It should be remembered that the peripheral portion
of the joint fluid can be enhanced so early through dif-
fusion after intravenous injection of contrast medium.
We, of course, think the enhanced peripheral portion
could include not only the true peripheral joint cavity
but also the synovium itself. Whatever the matter is,
we must consider that the intravenous arthrographic effect
due to steady diffusion occurs in any cases of intra-
venous enhancement of the joint. The peripheral rim
of enhancing joint fluid may be misinterpreted as an
enhanced thickened synovium and one may overesti-
mate the thickness of synovium. The duration of the
"synovium only" phase is very short, probably shorter
than 5 minutes (15). There are, therefore, at least two
prerequisites for the evaluation of the enhancement
pattern of the synovium itself. The one is very rapid
study like dynamic study before the delivered gadolin-
imum to the synovium diffuses into the joint fluid, and the
other is that the patient should not move the joint during
MR examination.

IV MR arthrography has several limitations (13). First
of all, it depends on the enhancement of preexisting
joint fluid, and cannot distend the joint like classical di-
ect intraarticular MR arthrography. It means that we
cannot get satisfiable arthrographic effect through in-
travenous enhancement if there is not enough joint
fusion after intravenous injection of contrast medium.
Hypervascular tissue is also enhanced, there­
fore, the arthrographic image can be polluted by adjacent
hyperemic tissue. Also selective enhancement of
single joint compartment in not feasible.

In conclusion, arthrographic effect can be obtained
by intravenous injection of gadopentetate dimeglu-
ine, and exercise is mandatory for practical purpose
because it facilitates the diffusion of the contrast me-
dium and makes the joint fluid be homogeneously
enhanced within 10 minutes. Thus, IV MR arthro-
graphic method is expected to become a more convenient
alternative to MR arthrography with direct intraar-
ticular injection.

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경정맥 자기공명 슬관절조영술

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목적: 경정맥 조영제 주입후 반복적으로 시행한 슬관절 자기공명영상은 관찰하므로써 경맥조영을 통해서도 관절강 조영효과를 얻을 수 있는지의 유무와 작용하면 적절한 스캔시간과 방법이 무엇인지를 알고자 연구를 시작하였다.

대상 및 방법: 26명의 환자에서 경맥을 통해 gadopentetate dimeglumine을 주입하기 전과 후 T1 강조영상(650/15)을 반복적으로 얻었으며, 이들을 14명의 운동군과 12명의 비운동군으로 구분하였다. 운동군에 포함된 14명의 환자는 첫번째 조영제 주입후 T1 강조영상은 얻은 직후 10분간 슬관절 운동을 하도록 하고 바로 스캔을 반복하였다. 활액의 중심부와 주변부에서 신호강도를 측정하였고 각 군의 결과를 비교하였다.

결과: 모든 예에서 관절강 조영효과를 볼 수 있었고, 조영증강은 주변부부터 시작되어 활액의 중심부로 진행되었다. 운동군에서의 활액조영 진행속도가 비운동군보다 빨리 빠르게 운동 후 10분내에 균질한 관절강 조영효과를 얻을 수 있었다. 활액조영효과는 이후 지속되었고, 신호강도의 감소는 매우 느리게 진행되었다.

결론: 조영제의 경정맥 주입과 수분의 관절운동을 통해 운동후 10분내에 관절강 조영효과를 얻을 수 있었다. 경정맥 자기공명관절조영술은 직접 관절강 침착에 의한 자기공명관절조영술의 보조 내지 대체방법으로서 유용할 것으로 사료된다.