Functional joint studies on the Panorama 1.0 T open MR system

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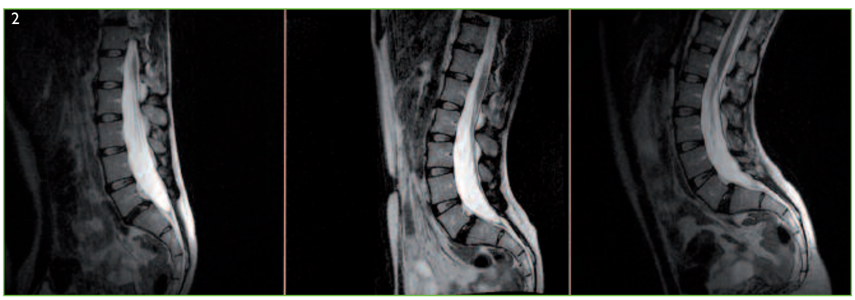

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Figure 1. The Panorama 1.0T.

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Figure 2. Flexion/extension study of the spine. T2 weighted images in flexion, neutral position and extension.

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Figure 3. Single-shot T2 TSE MR myelography in flexion and extension.

Functional joint studies

Joint problems do not always present clearly in the standard supine imaging position. Open MR systems offer the possibility of functional joint studies, in which the joint is imaged in different degrees of flexion/rotation. Challenging the joint in this way can reveal suspected pathology that would have remained undetected if the joint were only imaged in the neutral position.

There are many ways for setting up functional joint studies, ranging from high-resolution imaging of the static joint in multiple positions to near real time imaging of the moving joint. In this article we describe the clinical work at the University of Cologne on functional imaging of the knee and spine. The associated Intermezzo showcases the work of the Philips Research Laboratories in Hamburg on the development of a viewing environment for functional joint examinations, consisting of sequential high-resolution 3D datasets.

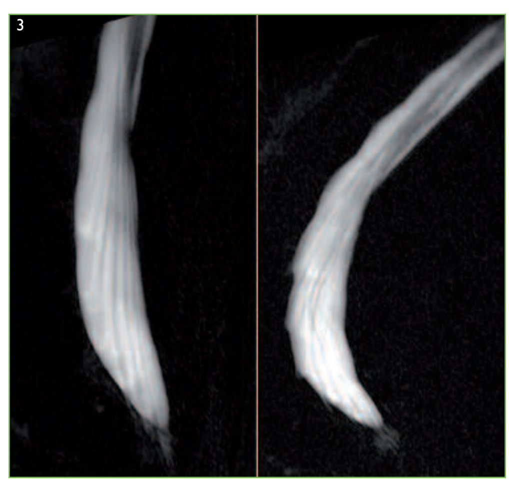
The first installation

In June 2005, the first Panorama 1.0T system in Europe was installed at the University of Cologne. The Panorama 1.0T (Figure 1) features a 160 cm patient aperture that greatly reduces patient anxiety, while its vertical field design affords an imaging performance comparable to that of cylindrical high field scanners. We at the University of Cologne decided that we needed an open MRI scanner among our new system purchases, which also included Philips Achieva 1.5T and 3.0T systems. We use the Panorama 1.0 T for the whole application spectrum of modern MRI but, in addition, we are also exploring the system's capabilities for sophisticated functional joint studies.

There are a number of applications conceivable for functional joint imaging, including flexion/extension studies of the spine, assessment of acetabular impingement in the shoulder and evaluation of ACL reconstructions in the knee. The list can be expected to grow now that an open system design is paired with the high-field imaging capabilities of the Panorama 1.0 T.

Flexion/extension imaging of the spine

High-resolution flexion and extension MR images of the lumbar spine were obtained in a series of studies. Imaging included sagittal high spatial resolution T2-weighted and T1-weighted turbo-spin-echo (TSE) sequences, as well as axial T2-weighted TSE sequences of the lumbar spine (Figures 2, 3).



The spine was positioned in maximal flexion, neutral position, and in maximal extension, with the patient positioned comfortably on the side. Images were analyzed for different clinically relevant anatomical structures, such as vertebral bodies and discs, dural tube, nerve roots, facet joints, and ligamenta flava.

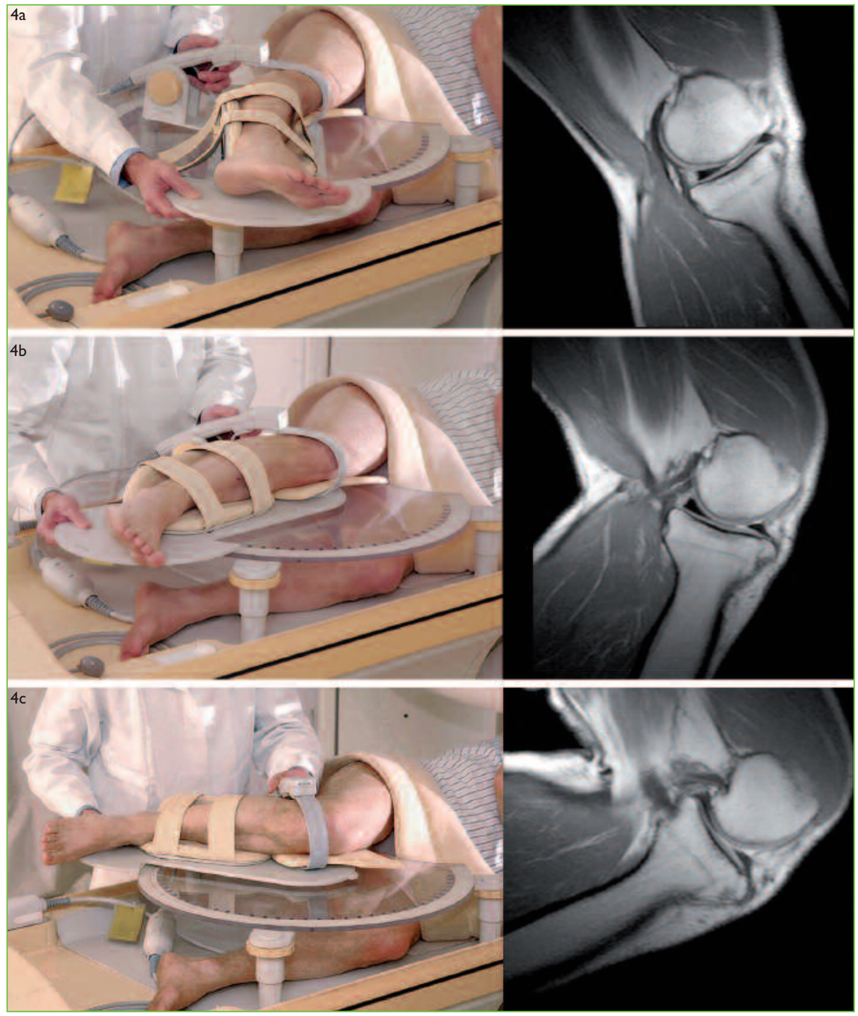
The images of the spine in the neutral position, as well as in flexion and extension, yielded excellent image quality with good delineation of clinically relevant anatomical structures. Even small structures, such as intradural roots, could be clearly demonstrated. Imaging in flexion and extension positions enabled potential displacement of the vertebral bodies and disc bulges to be assessed in images comparable to lateral myelograms.

It was concluded that flexion/extension studies of the spine on a high-field open scanner such as the Panorama 1.0 T are feasible, and show the spine in great detail in every position. Due to the capability of assessing the displacement of vertebral bodies and disc bulges, the functional MR spine exam may have a diagnostic value comparable to that of lateral myelograms in combination with CT-myelograms, which are significantly more invasive.

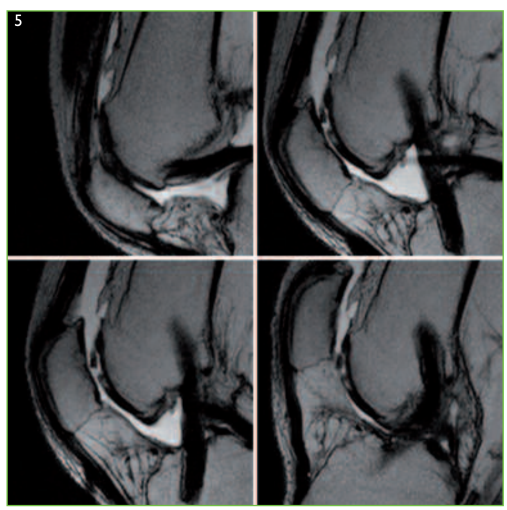
Functional knee imaging

With the patient on his or her side, and supported by dedicated kinematic devices, the MR system can also be used for functional knee studies. In these studies, high spatial resolution T2-weighted and PD-weighted images are acquired, with the knee in seven different positions between full extension and approximately 90° flexion (Figure 4). During the whole extent of flexion and extension, the knees remain in the isocenter of the magnet. Images are then analyzed for different clinically relevant anatomical structures such as the cruciate ligaments, menisci, cartilage, collateral ligaments, as well as the positions of the patella and femoral condyles.

The high spatial resolution images have a signal-to-noise ratio comparable to that of cylindrical 1.5 T scanners in all the different positions of the knees. The excellent image quality allows precise delineation of the anatomical structures, with visualization of the movement of the cruciate ligaments and the sliding of the femoral condyles and the patella. In addition, the contact area of the cartilage of the femoral condyles with the tibial plateau in relation to the menisci could be shown as a function of knee position.



▲ Figure 4. Isocentric kinematic imaging of the knee with high spatial resolution, and full 90° flexion.



◄ Figure 5. Patient with ACL reconstruction with complaints of anterior knee pain. Images demonstrate how a cartilage chip is displaced by the patella as it slides in the patellar grove.

Figure 5 shows an interesting case of a patient with an ACL reconstruction, presenting with anterior knee pain. The images show a chip of cartilage on the femur, which dislocates as the patella moves in the patellar groove.

Functional knee studies on an open high-field MR scanner allow precise assessment of the clinically relevant anatomical structures of the knee, and have the potential to enable the diagnosis of various diseases of the knee, especially transient patellar dislocation.

Additional applications

We first witnessed the capabilities of the Panorama 1.0T for all types of routine scans, and particularly for these advanced studies, at Philips Medical systems in Best, the Netherlands. The results achieved were impressive, but we are now even more impressed with the versatility of the Panorama 1.0T as one of our key day-to-day scanners.

Apart from its value for functional studies, the Panorama 1.0T design offers more general benefits. The spacious aperture has made an immediate impact. Claustrophobic patients simply have no problems with this system. In addition, larger patients are more easily accommodated and pregnant patients can be scanned in more comfortable positions. Because parents can be present right next to children having scans, pediatric patients are more relaxed as well.

▶ **The open system makes it possible to view pathology dynamically in all planes.**

The spine images are truly exceptional and we can clearly see the nerve roots with virtually no artifacts. In musculoskeletal imaging, we obtain great T1 contrast and the cartilage images look superb. Angiographic MR techniques, such as time-of-flight MRA or contrast-enhanced MRA of the carotid artery, also show impressive image quality.

The ample space between the magnet poles and the ability to slide the patient support in the lateral direction make it very easy to position off-center anatomy such as the wrist and shoulder in the magnet isocenter, yielding high-quality images with a uniform signal level throughout.

Conclusion

In conclusion, we have observed the first results of the Panorama 1.0T's capabilities for functional joint imaging. The knee, shoulder and spine studies we have performed could not be done in a cylindrical system. The open system makes it possible to achieve full joint flexion, enabling us to view pathology dynamically in all planes. A classic example would be a case in which, for example, a neutral knee joint position shows no obvious pathology, but where dynamic hyperflexion demonstrates the precise point where meniscal pathology results in abnormal bone-to-bone contact. ■

INTERMEZZO:

Motion-compensated viewing of 4D functional MRI joint studies

Figure 1. In one of the 3D datasets, four landmark points are indicated in red (a). These can be placed by the user in the anatomy he wants to keep fixed, e.g. the femur.

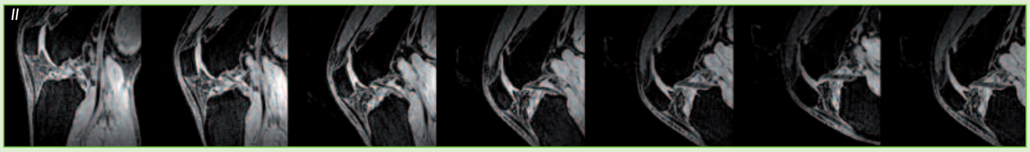
From the elastic registration phase, the positions of these points in all other datasets are known (b). Correcting for the displacement and rotation of the landmarks defines the selected anatomy as the new frame of reference (c). Motion can then be displayed relative to this anatomy, fixing it when viewing the data in cine mode.

MRI has been used for imaging of moving joints since the late 1980's [1-3]. With its excellent soft tissue contrast MRI is, in principle, able to show the involvement of soft tissues in normal and abnormal joint motion, e.g. impingement between bony structures.

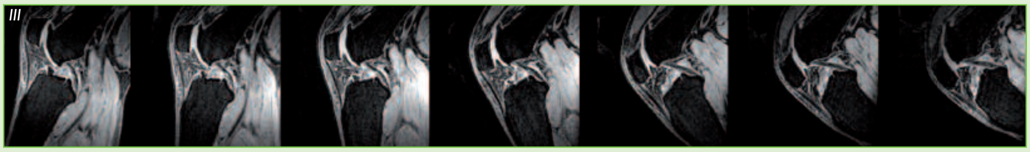
While MRI of moving joints using fast two-dimensional (2D) scanning can provide high temporal resolution of betwen 200 ms and 1 s per frame, it is limited to a single, predefined slice. Even when devices are used to restrain the joint [4], single-slice imaging suffers from through-plane motion of the anatomy of interest. Recent advances in MRI allow fast acquisition of a series of static 3D images in 30s – 2min per image. However, slice-by-slice viewing of these 4D images is cumbersome, and does not give an impression of the movement. Simply presenting the slice data in a cine-loop will be compromised by through-plane displacements of anatomy and "jerks" between frames, both of which hamper visual analysis of the movement. 4D data has the advantage that image processing and visualization techniques can be used after acquisition in order to reformat the images, and to reduce through-plane motion and undesired gross motion superposing relevant joint movement.

Researchers at the Philips Research Laboratories in Hamburg have implemented a viewing tool for exploring 4D kinematic MRI datasets [5,6] that addresses the following requirements:

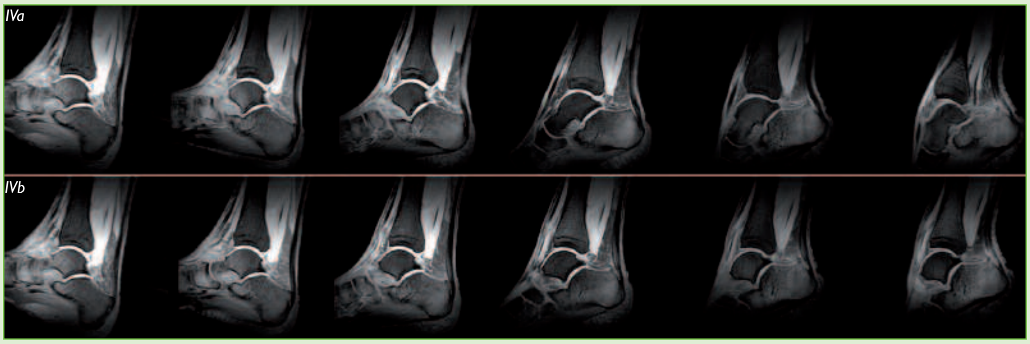
- The motion of any anatomy can be viewed from any perspective



◀ *Figure II.* Slice from 3D dataset of the knee in different degrees of flexion. The femur moves in the field of view, and the PCL moves through the plane.



◀ *Figure III.* Slices from a registered series of 3D volumes where the landmarks were placed to keep the femur fixed. The PCL is now kept in the viewing plane, showing its deformation when the knee is bent.



◀ *Figure IV.* Frames showing the ankle in different positions. *IVa.* Frames without fixation. *IVb*. Frames with fixation. Note that the tibia can be kept completely fixed and the Achilles tendon is in the viewing plane at all times.

- The user can define an object of interest, e.g. the distal femur in kinematic joint imaging of the knee, which then remains fixed in the viewing plane during the movement
- The user interaction is reflected immediately in the viewing plane.

Motion tracking

The key functionality of the application is the fixation of any user-defined object by image post processing. This fixation comprises two steps. First, the movement of an anatomical structure through all 3D data sets is calculated by motion tracking. The object of interest is defined interactively by setting reference points in one of the 3D data sets. These points are then propagated to the other data sets using a motion estimator, calculated in advance by elastic registration of all data sets. Since the positions of these points are known for all the frames, the displacements can simply be compensated for. As a result, the selected anatomy remains stable when the data is viewed in a cine-loop.

4D viewing application

The approach has been tested by tracking various user-defined objects such as the femur, the tibia and the scapula in 4D functional MR images of the knee and the shoulder. The selected anatomies were fixed sufficiently, and in-plane and through-plane motion was prevented. In conclusion, the application developed at Philips Research Laboratories in Hamburg clearly facilitates viewing of 4D kinematic data sets. It allows any user-defined anatomical structure to be viewed from any perspective. Image postprocessing ensures that the movement is smoothly displayed in a cine loop, with any user-defined anatomical structures being fixed after image acquisition.

▶ **Any anatomical structure can be viewed dynamically from any perspective.**

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