

RT

# image

the weekly source for radiology professionals

ASHPE  
2004 Award Winner

2004  
APEX  
AWARDS FOR  
PUBLICATION EXCELLENCE

## Innovations in MRI

### Worlds Collide:

With the help of a pig's hindlimb, researchers use MR/CT fusion imaging to study the complex structure of the knee.

August 9, 2004 • VOL. 17, NO. 32 • [www.rt-image.com](http://www.rt-image.com)

► Plus

*MR Safety*

*Intraoperative MRI*

*Neuroradiology*



**Worlds Collide:**

With the help of a pig's hindlimb, researchers use MR/CT fusion imaging to study the complex structure of the knee.

# The Best of Both Worlds

Integrating CT and MR

By Lawrence M. Witmer, PhD, Ryan Ridgely, BS,  
Heather Mayle, BA, RT(R)(CT), and Debra Adams

**J**oints, such as the knee and elbow, are complex and dynamic systems, consisting of the bones, muscles, ligaments, cartilage, menisci and joint capsules. Accurately characterizing the normal anatomical relationships of these tissues is central to understanding how the joint works, which in turn is prerequisite for diagnosis and treatment. Although the gross anatomy of joints can be visualized through dissection or surgery, these methods are inherently destructive.

Fortunately, imaging technologies, such as CT and MR, are widely available and allow excellent visualization of the internal anatomy. However, each modality has its own strengths and weaknesses. CT resolves differences in densities and is excellent at imaging bone. Conversely, MR has become the imaging modality of choice for joints because of its ability to image soft-tissue detail in the muscles and cartilage. Since joints are essentially soft tissues sandwiched between two or more bones. Our goal was to look for a way to combine the best attributes of each imaging modality to create a more complete picture of the joint.

Here we present a novel way to integrate information from MR and CT datasets. Our choice of study system was the knee joint of pigs. Domestic pigs (swine) are increasingly being used as animal models for a wide range of biomedical research projects, ranging from organ transplants to temporomandibular joint (TMJ) disorders to drug testing. Our interests in the knee relate to exploring pigs as animal models for human degenerative joint diseases and for experimental testing of joint prostheses.

## Registration: A Radiological Rubik's Cube

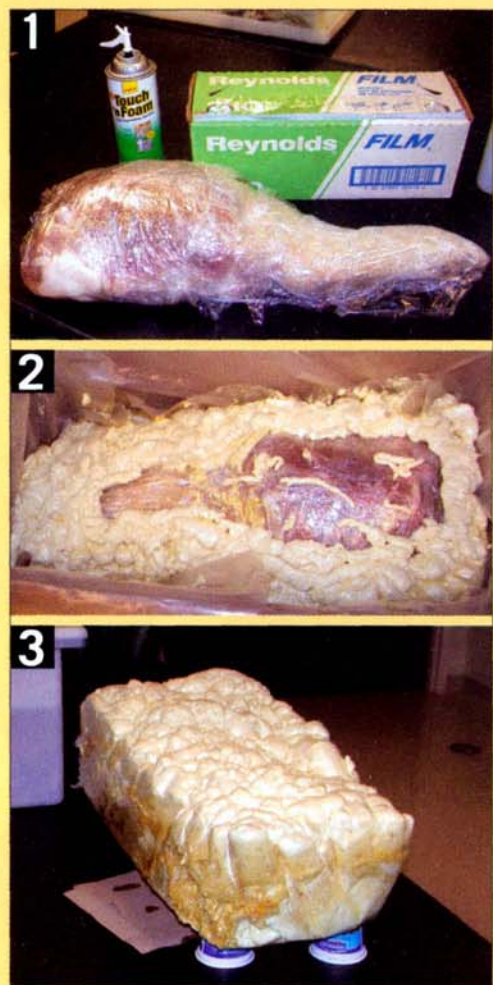
Registration is the "lining up" of two different images or datasets derived from the same object or even different objects. CT and MR datasets can be thought of as a 3-D grid of boxes resembling a Rubik's Cube. If one had the same object within each cube, it should be possible to superimpose one cube onto the other cube and rotate it to align the objects within. More technically, registering two objects conceptually involves at least three processes: translation (moving the two objects through space to the same approximate location), rotation (spinning the objects so that they align) and scaling (adjusting the two objects to the same size). We used this model to combine an MR and a CT dataset of the hindlimb of a Hanford mini-pig that had been euthanized in the course of other projects.

How the hindlimb is positioned and oriented in the CT and MR scanners is not particularly important because the Rubik's Cube can be moved and rotated. However, what is important is that the knee be immobilized so that the orientation, or flexure, of the joint is the same in both datasets so that the two can be lined up, or "registered," more easily.

To keep the limb stable and to prevent movement about the knee, the hindlimb of the Hanford pig was removed from the body at the hip joint and embedded in an expandable, insulating foam (Figure A), which is of extremely low density and quite rigid when cured. The limb, now embedded in a foam block, was then scanned in CT and MRI at O'Bleness Memorial Hospital in Athens, Ohio. The CT scans were performed on a GE Healthcare HiSpeed FX/i Helical CT scanner (120.0 kV, 100.0 mA, axial slice thickness of 1 mm). MR imaging was performed on a 1.0T GE Healthcare Signa Short-Bore MRI system (T1, axial and sagittal slice thickness of 3 mm). The entire hindlimb was CT scanned, but the MR field of view was limited to the knee region.

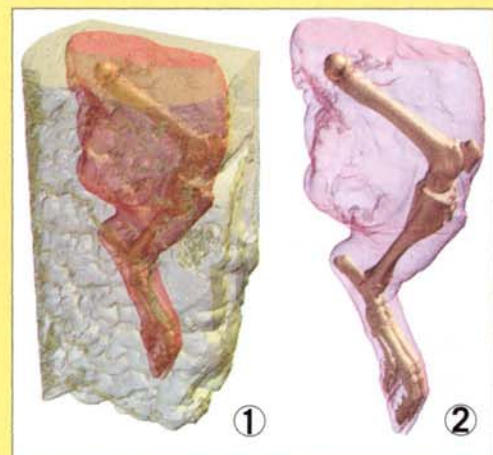
DICOM data were imported into a Dell Precision 360 workstation equipped with an nVidia Quadro FX 3000 graphics card. The data were analyzed, and 3-D

**Figure A**



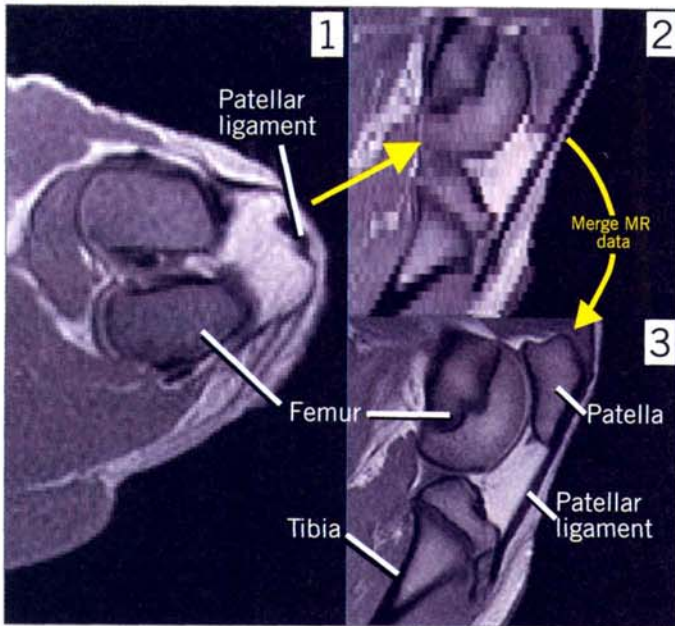
The hindlimb of the Hanford mini-pig was wrapped in plastic (1) and embedded in foam (2), which cured to form a rigid medium to prevent movement at the knee (3).

**Figure B**



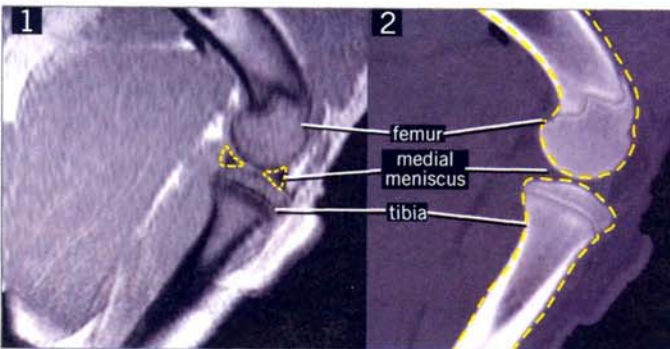
3-D rendering in Amira 3.1 of the pig hindlimb embedded in the foam (1) and revealing the skeletal elements inside (2)

**Figure C**



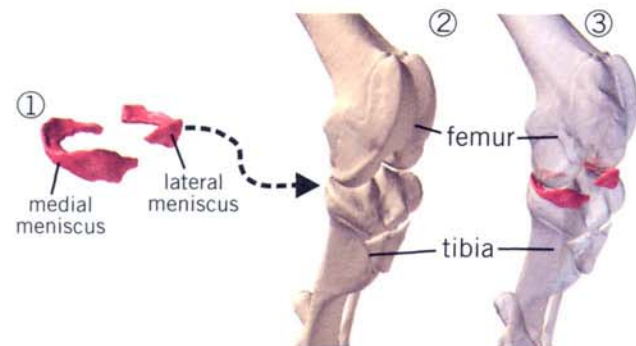
Axial T1 MR slice of the pig hindlimb through the knee, viewed axially (1). The same dataset viewed sagittally (2) reveals the slice artifact, or "jaggies," resulting from the coarseness of the dataset. To minimize the artifact, the sagittal series was combined with a true sagittal MR series to create a composite dataset (3).

**Figure D**



Sagittal MR (1) and CT (2) sections of the pig hindlimb at the level of the medial femoral condyle. Highlighted are the structures segmented from each dataset. Notice that the medial meniscus is slightly visible in the CT, but much more visible in the MR volume.

**Figure E**



3-D rendering in Amira 3.1 of the menisci from MR data (1) and the bones of the hindlimb from CT data (2). To place the menisci into anatomical position in the knee, MR data were registered to the CT data (3).

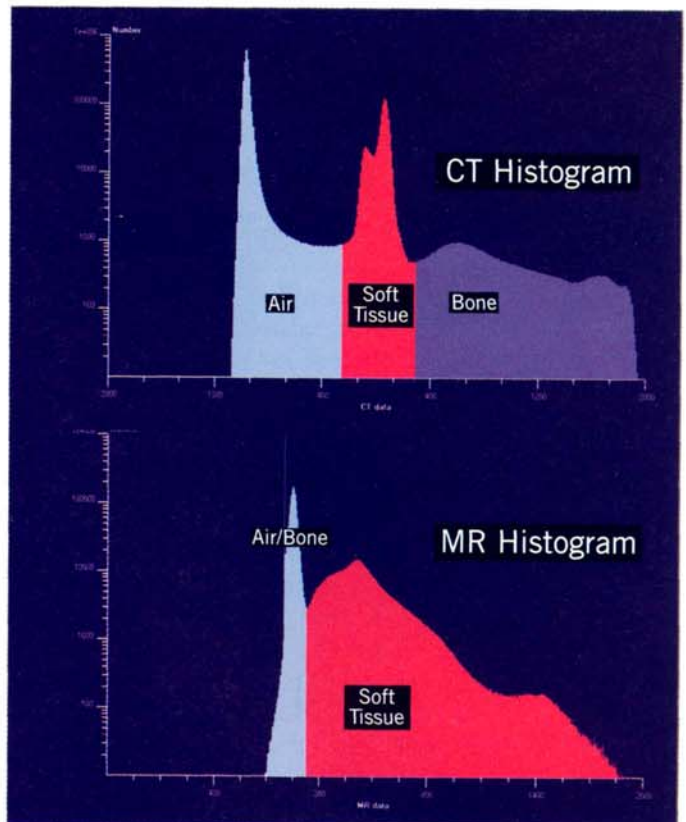
virtual models were generated using Amira 3.1 from TGS Inc. in San Diego (Figure B). Because 3 mm slice thicknesses are rather coarse for generating 3-D models, the axial and sagittal MR datasets were combined and resampled to produce a composite volume of 1 mm intervals (Figure C). Using this composite MR dataset, the medial and lateral menisci of the knee were segmented from the MR data (Figure D1), as were the knee ligaments (not shown). The bones of the hindlimb were segmented from the CT data (Figure D2) and rendered in 3-D (Figure E). Because the bone and menisci are from two separate data sets (CT and MR, respectively), it was necessary to register the two datasets in order to put them into the proper anatomical position.

Fortunately, Amira 3.1 has an auto-registration function allowing the user to automatically register the MR and CT datasets once they have been grossly aligned. After the two datasets have been registered, we can then apply that registration to the 3-D model of the menisci that we had already generated, and it slides right into the knee (Figure E).

## Fusion

While 3-D modeling of CT and MR data is extremely useful, it is still necessary to use the raw slice data when examining the relationships between bone and soft tissues in the skull. Even with the MR and CT data registered, having two separate slice volumes is cumbersome and thwarts integrating the information from each set. To produce a single dataset from separate CT and MR volumes, we merged the two datasets.

**Figure F**



Histogram of grayscale values for the CT and MR datasets. Note that the peaks roughly correspond to the major tissue types.

Since both datasets provide at least some information on similar structures (muscle, for example), we stripped away the redundant data. In other words, we removed all of the gray values that were less dense than bone from the CT volume (e.g., soft tissue, air). From the MR volume, we removed anything below the soft-tissue threshold (Figure F). We then resampled the MR dataset so that each slice in the MR volume corresponded directly to a slice at the same position in the CT dataset. Once this was done, we were able to merge the two datasets, which essentially blends a given CT slice with the corresponding MR slice. The result is a single dataset with bone from CT and the soft tissue from the MR (Figure G). The time required for this process from beginning to end using Amira 3.1 is less than an hour.

An obvious question is, "Why not segment the menisci and bone after merging the MR and CT datasets?" We have found that when segmenting data, it is helpful for it to be as "raw" as possible. In other words, re-sampling and re-slicing data tends to degrade the image somewhat, which can obscure fine detail and make resolving the edges of a given structure more difficult.

This technique has proven successful so far under controlled experimental conditions. However, there still remains a considerable amount of work to make it viable in a clinical environment. The hardware present in today's hospitals, with sub-millimeter resolution, is certainly adequate. Future research should concentrate on improved methods to immobilize the joint or even to develop methods that would not require strict immobilization. Programming innovations include improving, and perhaps automating, fusion techniques.

► Lawrence M. Witmer, PhD, and Ryan Ridgely, BS, are from O'Bleness Memorial Hospital in Athens, Ohio. Heather Mayle, BA, RT(R)(CT), and Debra Adams are employed in the department of biomedical sciences at Ohio University in Athens. Questions and comments can be directed to [editorial@rt-image.com](mailto:editorial@rt-image.com).

Figure G



Fused CT/MR sagittal section of the pig hindlimb (roughly at the same plane as Figure C). Both the bone and the meniscus are clearly visible. It is also possible to distinguish ligaments, tendons, cartilage, fat and the fascia between muscles.



Can't believe  
your eyes?

Visit [www.rt-image.com/fusion](http://www.rt-image.com/fusion)  
and watch exclusive video  
demonstrations of CT/MR fusion.