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Musculoskeletal Techniques and Studies with the Altaire High Field OPEN MRI

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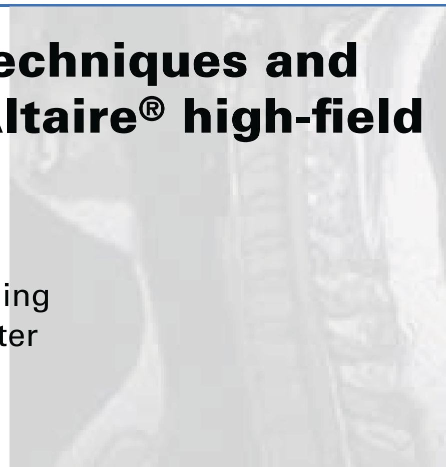

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Advantages of the Altaire for musculoskeletal imaging

Musculoskeletal imaging is challenging at all field strengths: Numerous anatomic structures need to be demonstrated, and the pathology is diverse. Inflammatory, infectious, and neoplastic conditions may be encountered, in addition to traumatic injuries.[1,2] There is little doubt that MR, with its soft-tissue contrast and multiplanar capabilities, is the diagnostic modality best suited for the musculoskeletal system.

The Altaire provides several specific advantages for musculoskeletal imaging. At 0.7 T, there are fewer susceptibility effects, for two reasons. First, the Altaire has a highly uniform magnetic field, enhanced by an active shimming capacity. The variable bandwidth setting and lower overall field strength of the magnet allow metallic susceptibility artifacts to be diminished. This is extremely useful in postoperative cases where chemical shift from orthopedic hardware can degrade image quality. An additional advantage of the Altaire is seen with T1 imaging, as relative T1 contast of nonfatty tissue is better discriminated at 0.7 T than at 1.5 T.

The open vertical-field geometry of the Altaire, coupled with its solenoid volume coil design, provides another advantage in musculoskeletal imaging. The volumetric application of the solenoid coil in the vertical-field orientation of the Altaire results in a higher uniformity of image signal-to-noise ratio (SNR) when compared with images achieved with conventional high-field closed MR systems and solenoid-type coils (**see figure on page 5**). When the field orientation is horizontal, the design of solenoid coils is less efficient. In our opinion, the uniformly high SNR obtained with the Altaire, an advantage of the system's vertical-field architecture, produces an image quality that surpasses expectations for a field strength of 0.7 T.

Freedom of lateral positioning within the magnet is also an advantage for musculo-skeletal imaging. For any open MR system, the side-to-side movement of the table allows the body part of interest to be imaged at, or very close to, the magnet isocenter. Imaging at the isocenter takes advantage of the most homogeneous magnetic field,

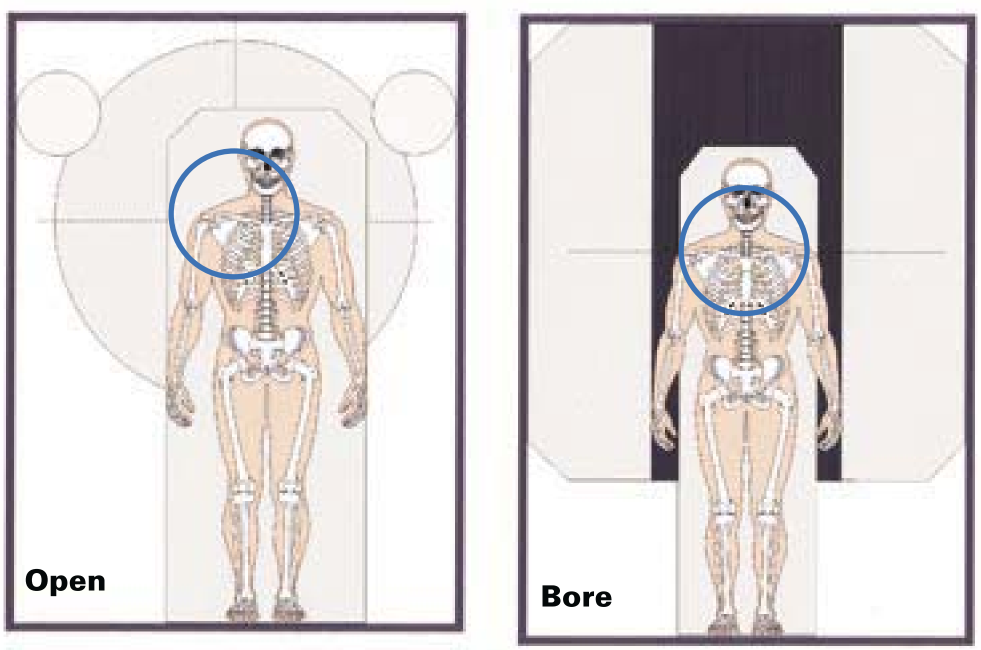


Figure 1. The positioning advantage of open architecture. The Altaire readily allows for true positional isocenter imaging, as seen in this schematic for a shoulder study.

also optimizing uniformity of SNR. Patients presenting for certain examinations, like those of the wrist and elbow, can be imaged with their arms by their sides, significantly increasing patient comfort and cooperation, while the body part of interest is placed at the magnet isocenter. For shoulder imaging in particular, the wide table and lateral access of the Altaire make possible the achievement of isocenter without compromise (**Figure 1**) and increase the comfort of the abduction-external-rotation (ABER) position.

At the field strength of 0.7 T, the relative precession rates between fat and water protons can be distinguished, allowing for true chemical fat suppression. In contrast, most open systems with lower field strengths make use of the Dixon method to obtain fat suppression.

High-field open imaging of the knee

The knee is perhaps the easiest of all the musculoskeletal structures to image, and solenoidal coils are extremely efficient. But detection of pathology can be far more difficult: Meniscal tears, ligamentous and tendon pathology, and cartilage defects can be subtle lesions. The utility of true chemical fat suppression by the Altaire offers a diagnostic advantage for orthopedic imaging over most lower field strength open MR imaging. Indeed, because of the quality of the magnetic field in the Altaire, there is a limited need for sagittal gradient-echo scans for detecting and evaluating meniscal tears.

Our standard protocol for imaging the knee with the Altaire calls for proton-density-weighted (PD) and proton-density fat-suppressed (PD fatsat) scans in the axial, coronal, and sagittal planes. Obtaining PD fatsat images in exactly the same locations as PD images allows for comparison between these images and increased conspicuity of pathologies with T2 prolongation — such as meniscal tears, ligament and tendon pathology, osteochondral injuries, and edema. **Figures 2 to 6** demonstrate the fine detail of images — particularly those with fat suppression — achieved with the Altaire.

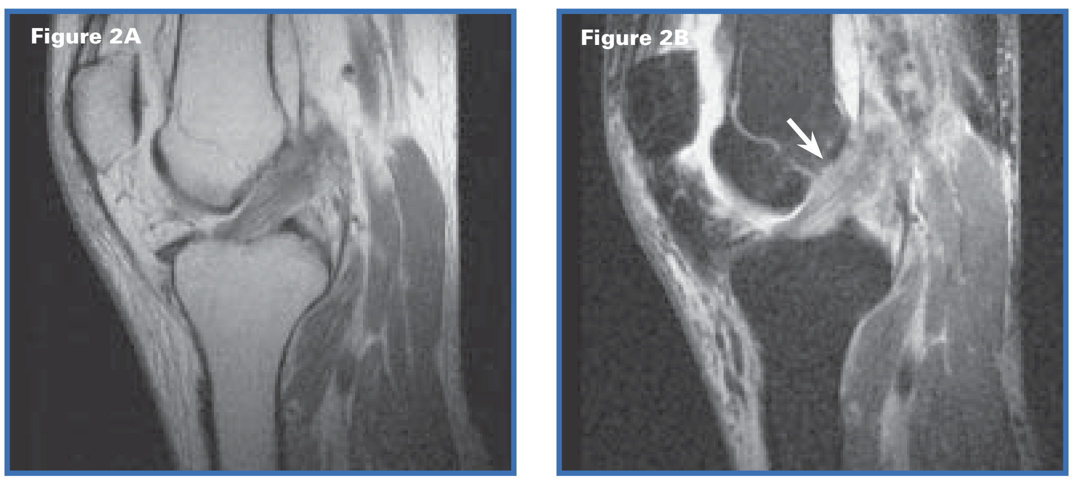


Figure 2. Sagittal proton-density-weighted (PD) (**Figure 2A**) and PD fat-suppressed (**Figure 2B**) images of a high-grade sprain of the anterior cruciate ligament (ACL) (**arrow**). A thickened, amorphous appearance of the ACL is seen with increased intrasubstance signal. The ACL was brought into the sagittal plane by externally rotating the knee 10 to 15 degrees of external rotation within the knee coil.

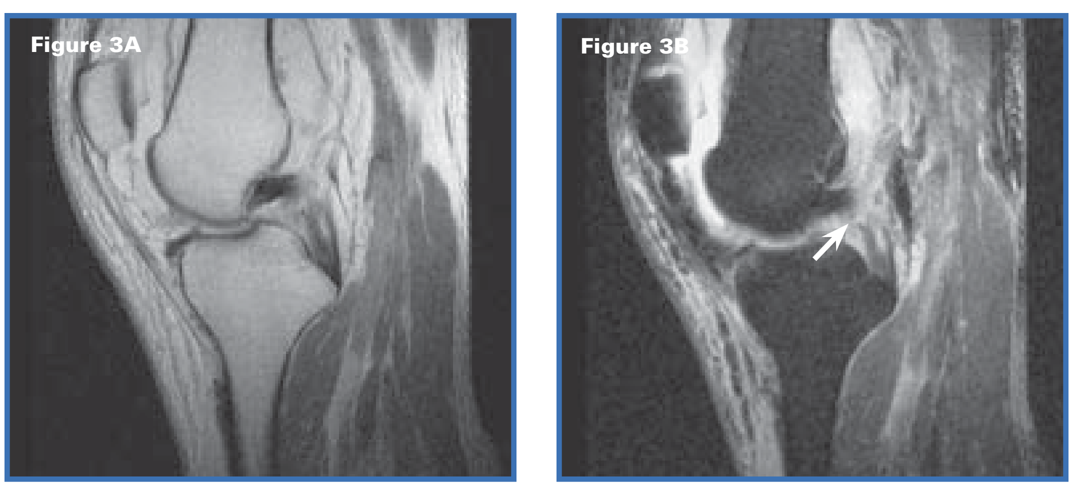


Figure 3. Sagittal proton-density-weighted (PD) (**Figure 3A**) and PD fat-suppressed (**Figure 3B**) images of a complete tear of the posterior cruciate ligament (**arrow**). The joint effusion and debris within the fluid are compatible with a diagnosis of synovitis.

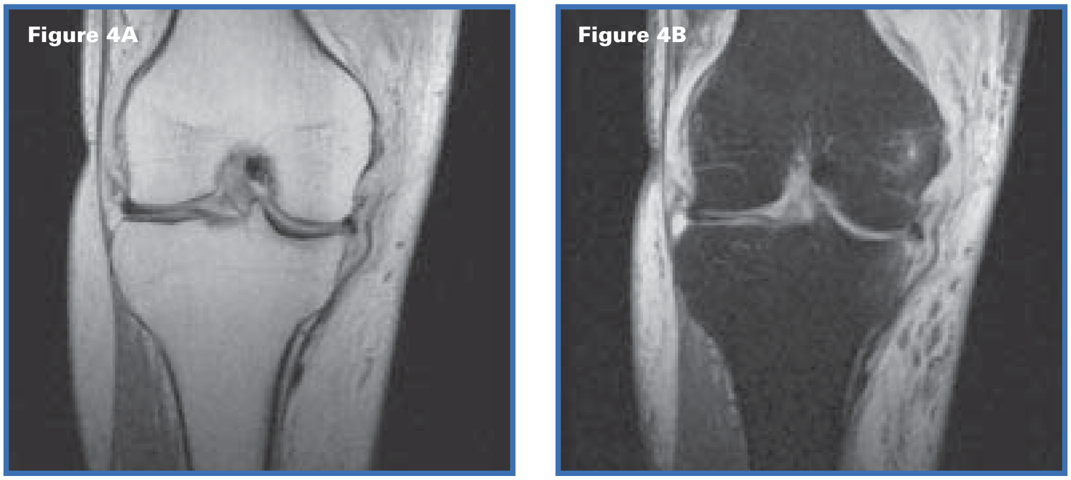


Figure 4. Coronal proton-density-weighted (PD) (**Figure 4A**) and PD fat-suppressed (**Figure 4B**) images of a complete tear of the proximal medial collateral ligament (**arrow**). A high-grade sprain of the anterior cruciate ligament and a tear of the medial meniscus are also visible. In **Figure 4B,** there is mild reactive hyperemia along the peripheral aspect of the medial tibial plateau.

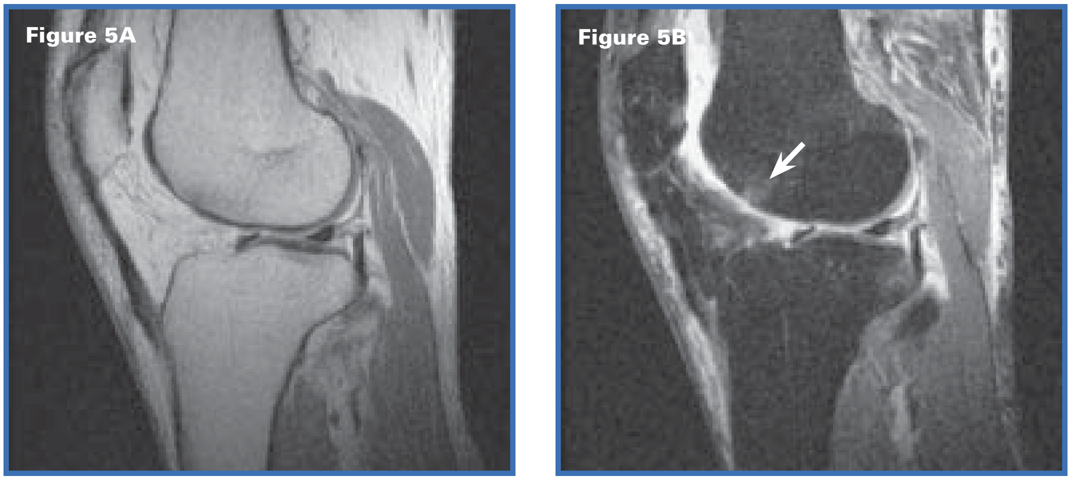


Figure 5. Sagittal proton-density-weighted (PD) (**Figure 5A**) and PD fat-suppressed (**Figure 5B**) images of a full-thickness chondral defect (grade 4) involving the midtrochlear groove (**arrow**). **Figure 5B** shows the deep subcortical reactive hyperemia from the chondral defect. There is also a chondral defect (grade 3 to 4) involving the inferior patellar articular surface.

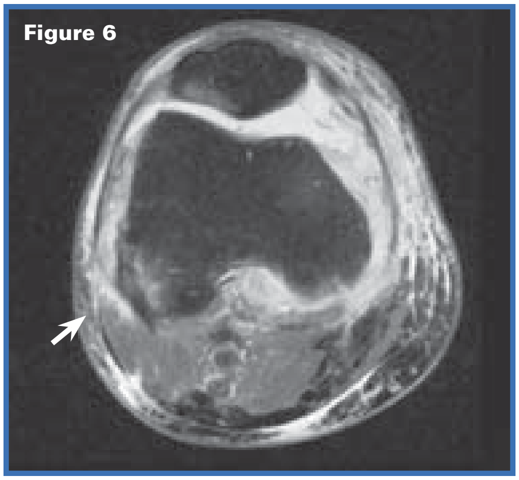
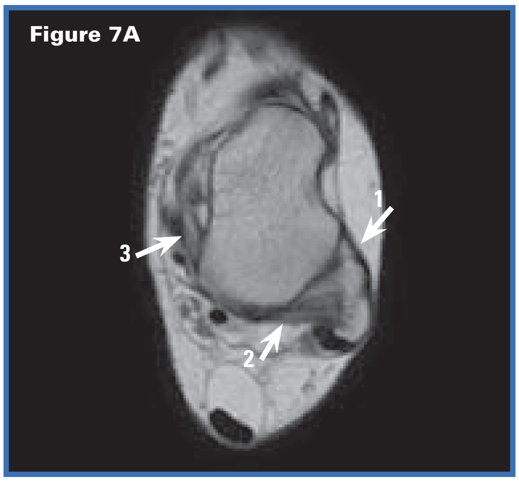


Figure 6. An axial proton-density-weighted fat-suppressed image of subcortical edema/reactive hyperemia along the lateral patellar facet. The image is of a postero-medial and postero-lateral corner injury, with bone-marrow edema involving the posterior medial and lateral tibial plateau (**arrow**). Injury to the anterior cruciate ligament and synovitis are also visible.

High-field open imaging of the ankle

Our standard protocol for imaging the ankle with the Altaire also involves PD and PD fatsat scans in the axial, coronal, and sagittal planes. The ankle is usually imaged unilaterally for smaller field-of-view imaging. Although many of the tendons can be identified in the sagittal plane, axial images are most useful in identifying tendon pathology, especially when differentiating partial- from full-thickness tears.

In cases of trauma, short-tau-inversion-recovery (STIR) scans are complementary and present edema changes very homogeneously. **Figure 7** shows axial images of normal ankle anatomy, and **Figure 8** shows coronal images of a posterior tibial tendon tear.



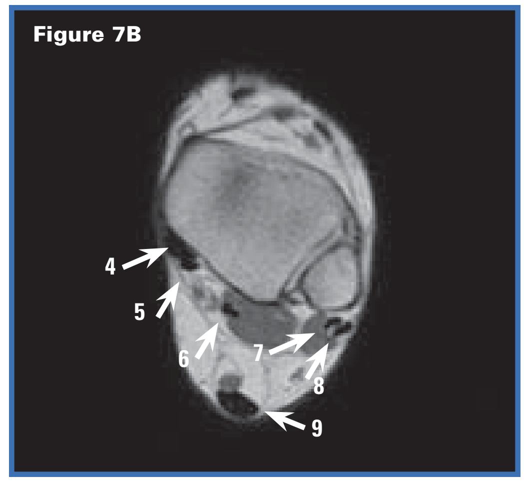


Figure 7. Axial proton-density-weighted images of (**Figure 7A**) normal ligamentous anatomy and (**Figure 7B**) normal tendon anatomy of the ankle. In **Figure 7A**, normal anterior talofibular (**1**), posterior talofibular (**2**), and deltoid (**3**) ligaments can be seen. In **Figure 7B**, the normal posterior tibial (**4**), flexor digitorum longus (**5**), flexor hallicus longus (**6**), peroneus brevis (**7**), and peroneus longus (**8**) tendons can be seen along the posterior aspect of the ankle. A normal Achilles tendon (**9**) can also be identified.

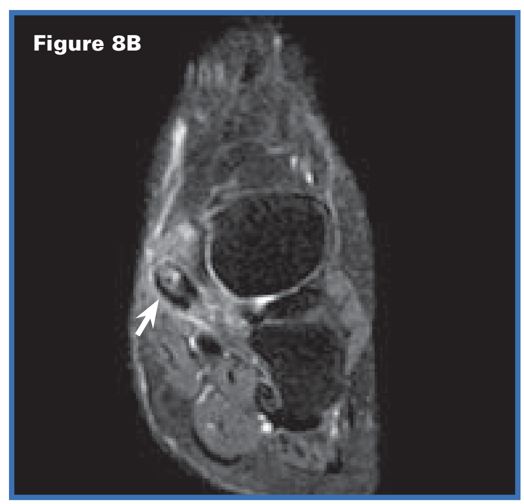


Figure 8. Coronal proton-density-weighted (PD) (**Figure 8A**) and PD fat–suppressed (**Figure 8B**) images of a partial posterior tibial tendon tear (**arrow**). Intrasubstance degeneration and edema are visible in the surrounding soft tissues.

High-field open imaging of the shoulder

Our standard protocol for imaging the shoulder with the Altaire employs PD scans and PD fatsat scans in the oblique sagittal and oblique coronal and axial planes. If intra-articular or intravenous gadolinium is administered, the MR arthrography protocol sequence changes to T1-weighted scans followed by PD fatsat scans in the axial, oblique sagittal, and oblique coronal planes. The ABER position is added to the protocol if intra-articular gadolinium is administered.

Administering intra-articular gadolinium distends the shoulder joint and increases the conspicuity of labral pathologies. There are four common indications for using intra-articular gadolinium in shoulder imaging. We prefer MR arthrography if the patient is under 40 years of age, if the shoulder is postoperative, if there is concern for adhesive capsulitis, or if there is suspicion of microinstability that is difficult to diagnose both clinically and radiographically. When intravenous gadolinium is administered, the standard protocol calls for spin-echo T1-weighted scans followed by PD fatsat scans in three orthogonal planes. In patients for whom motion artifacts are problematic, ABER positioning early in the imaging sequence may result in better patient compliance. With ABER positioning, one can view the footplate of the supraspinatus muscle attachment site and the undersurface of the tendon. One can also possibly see fluid entering the tear.

Figure 9 shows an anterior labral periosteal sleeve avulsion injury. **Figures 10 and 11** show superior labral injuries that extend from anterior to posterior (aka, SLAP tears). **Figure 12** shows a tear of the distal supraspinatus tendon.

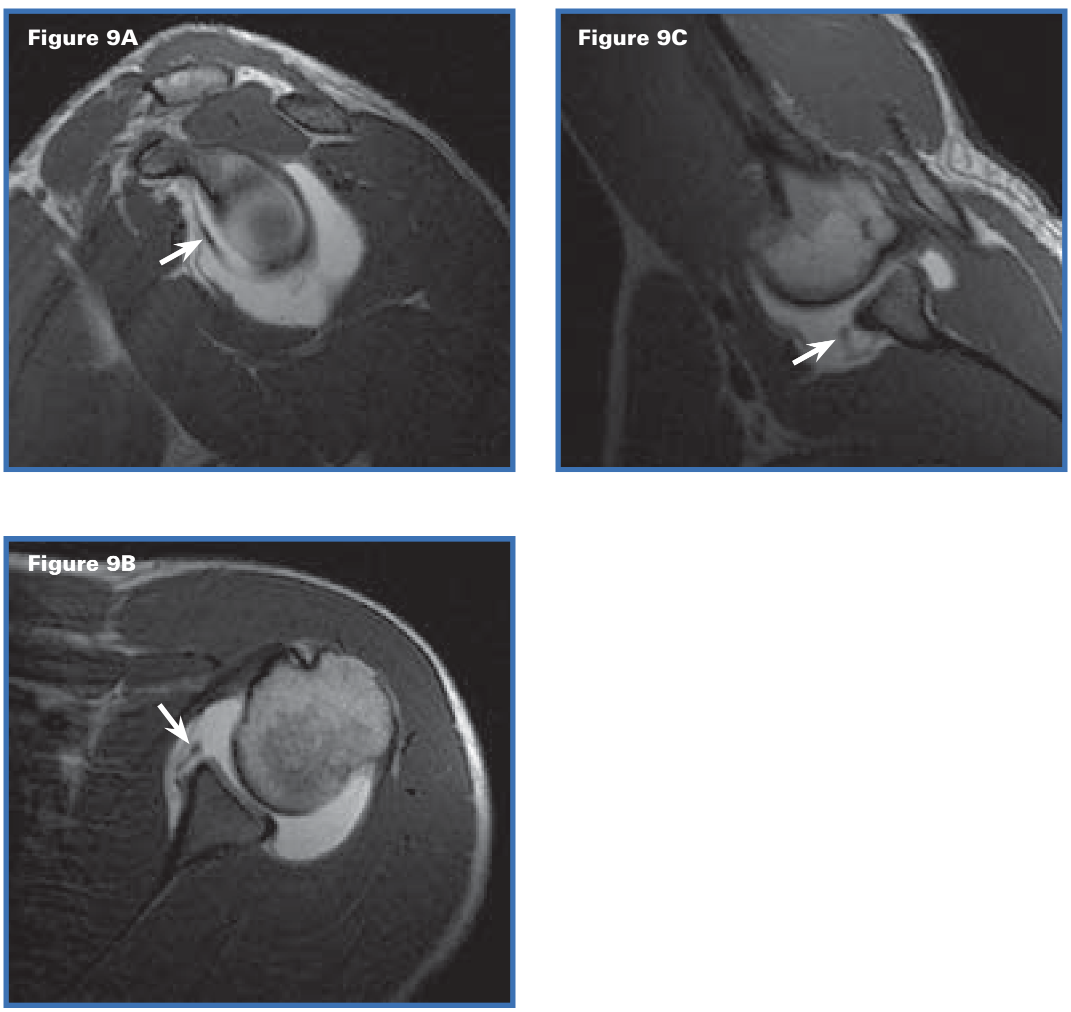
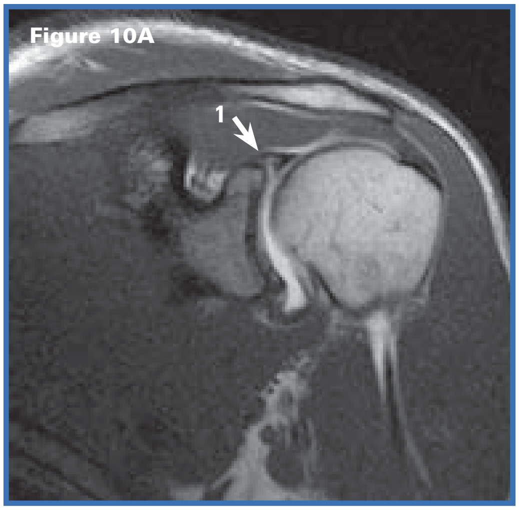


Figure 9. Spin-echo T1-weighted images in the axial plane (**Figure 9A**), oblique sagittal plane (**Figure 9B**), and abduction external rotation position after intra-articular administration of dilute gadolinium (**Figure 9C**) demonstrate an anterior labral periosteal sleeve avulsion injury (**arrows**).



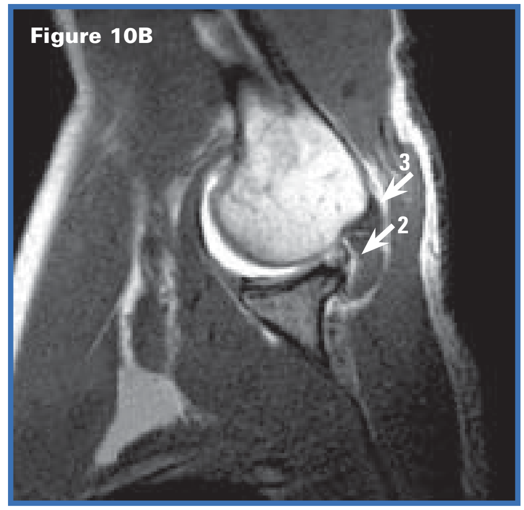
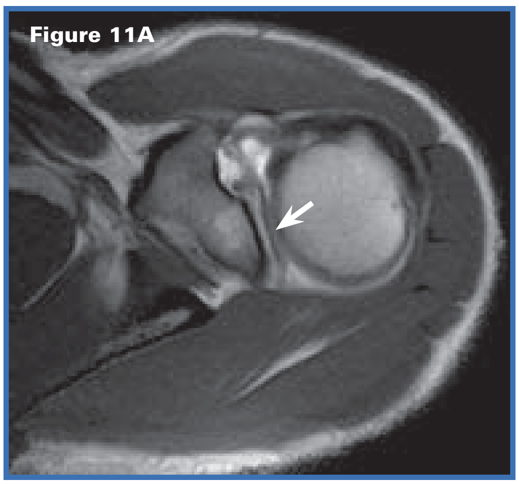


Figure 10A. An oblique coronal spin-echo T1-weighted image, after intra-articular administration of dilute gadolinium, of a superior labral tear (**1**) with contrast extending into the superior labrum tear at its glenoid attachment. **Figure 10B.** A spin-echo T1-weighted image, after intra-articular administration of dilute gadolinium, in the abduction external rotation position of a labral injury (**2**) extending into the anterior superior labrum adjacent to the attachment of the supraspinatus tendon to the greater tuberosity (**3**).



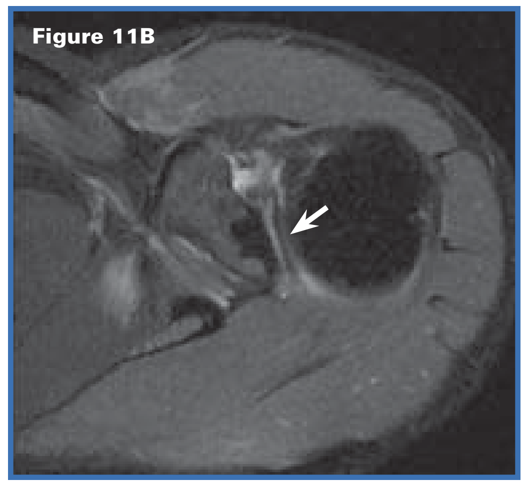


Figure 11. Axial spin-echo T1-weighted (**Figure 11A**) and spin-echo proton-density fat-suppressed images (**Figure 11B**), after intra-articular administration of dilute gadolinium, of a superior labral tear extending anterior to posterior (**arrows**). The fluid within this tear is clearly delineated.

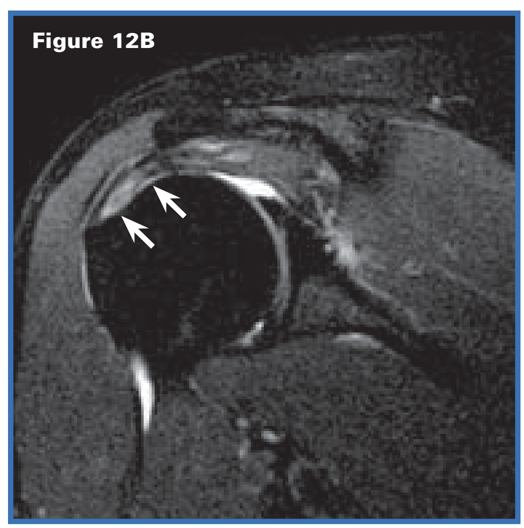


Figure 12. Coronal proton-density-weighted (PD) (**Figure 12A**) and oblique sagittal PD fat-suppressed (**Figure 12B**) images of a partial-thickness articular-sided rotator-cuff tear of the distal suprapinatus tendon (**arrows**). A small joint effusion is present. In **Figure 12B,** there is increased conspicuity of the partial thickness tear.

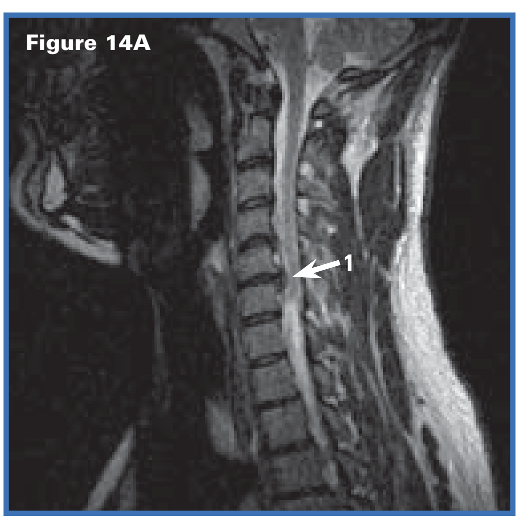
High-field open imaging of the cervical spine

Our standard protocol for imaging the cervical spine with the Altaire employs spin-echo T1-weighted scans in the sagittal plane, fast spin-echo T2-weighted scans in the sagittal plane (excellent for seeing intrinsic cord pathology and lesions), and two-dimensional (2D) gradient-echo scans in the axial plane. Alternatively, a three-dimensional (3D) axial gradient-echo scan can be used, allowing for the acquisition of a thinner slice than the 2D technique due to the elimination of interslice cross-talk with a volumetric acquisition. However, since the 3D data are collected as a data volume rather than as individual slices, any motion artifact that occurs during screening will be propagated throughout the data set. Two-dimensional imaging allows the technologist to repeat only those slices in which motion may have occurred. Therefore, patient selection becomes the most important parameter for our decision to use 2D or 3D axial imaging.

As alternatives to the above sequence, we sometimes perform a fast spin-echo T1-weighted scan in the sagittal plane to further decrease image acquisition time, a STIR scan in the sagittal plane (for evaluation of trauma, infection, or metastasis), or a T1- or T2-weighted scan in the axial plane when a metallic artifact is present, as the susceptibility artifact will be less prominent than on standard gradient-echo images.

Figure 13 shows the normal cervical spine. **Figure 14** displays a paracentral disk extrusion. **Figure 15** shows a posttraumatic fracture through the anterior inferior C5 vertebra.

Figure 13. Sagittal spin-echo T1-weighted (**Figure 13A**) and T2-weighted (**Figure 13B**) images of a normal cervical spine.



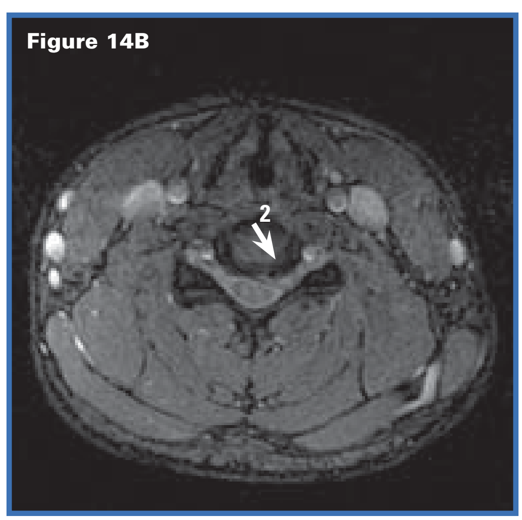


Figure 14. A sagittal fast spin-echo T2-weighted image (**Figure 14A**), and an axial two-dimensional gradient-echo image through C5 and C6 (**Figure 14B**), showing a left paracentral/foraminal disk extrusion (**1**) with flattening of the left paracentral ventral cerebrospinal fluid (**2**).

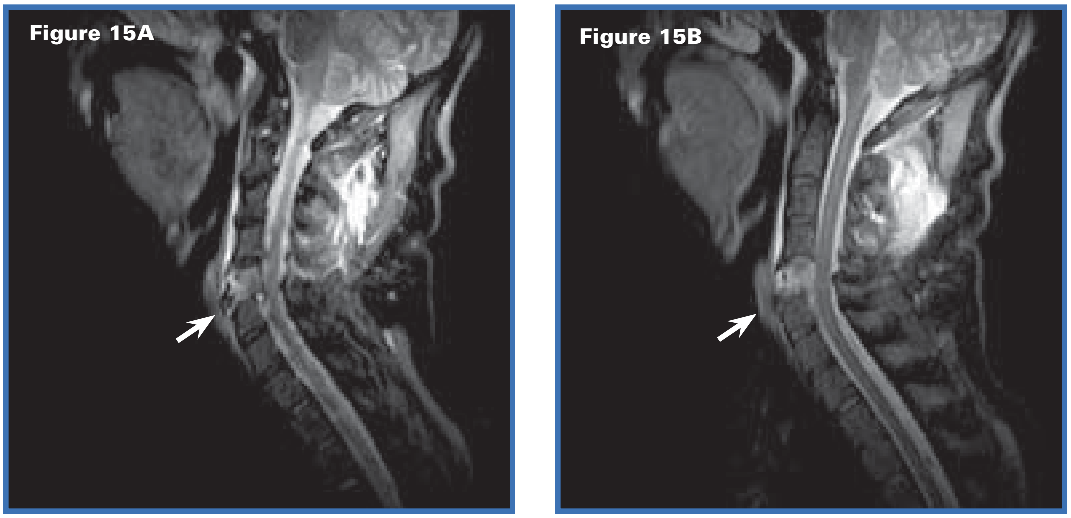


Figure 15. Sagittal short-tau inversion-recovery images (**Figure 15A and 15B**) of a posttraumatic fracture through the anterior inferior C5 vertebral body. There is rupture of both the anterior and posterior longitudinal ligaments (**arrows**). Soft-tissue hematoma is seen in the paraspinal soft tissues of the upper cervical spine.

Summary

Recognizing the quality of the musculoskeletal images achieved with the Altaire is a first step toward acknowledging that the Altaire offers a welcome new third way of MR imaging. The demands that musculoskeletal imaging places on the Altaire are easily and readily met. In particular, the Altaire possesses several advantages over high-field closed MR systems: The open architecture allows for freedom of positioning and direct isocenter imaging, there is stronger relative T1 contrast, and there is better uniformity of SNR.

References

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2. Mitchell DG. ***MRI Principles.*** Philadelphia: WB Sanders Co; 1999.

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