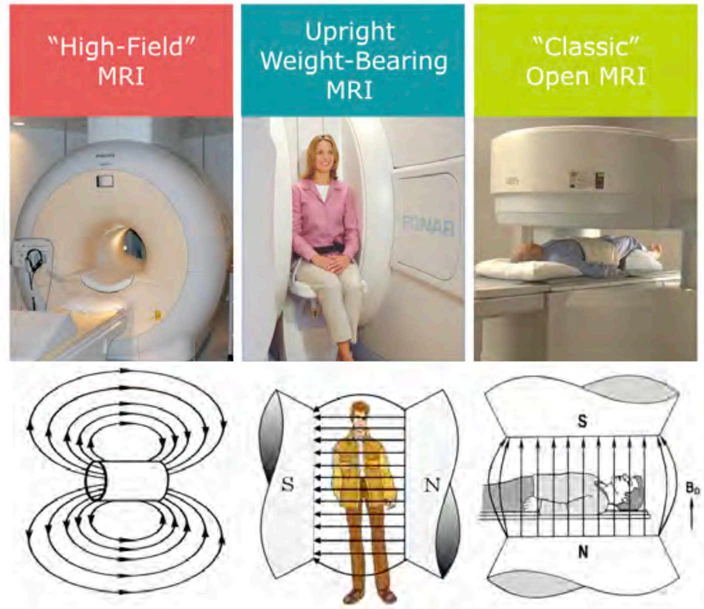
Misunderstanding Field Strength

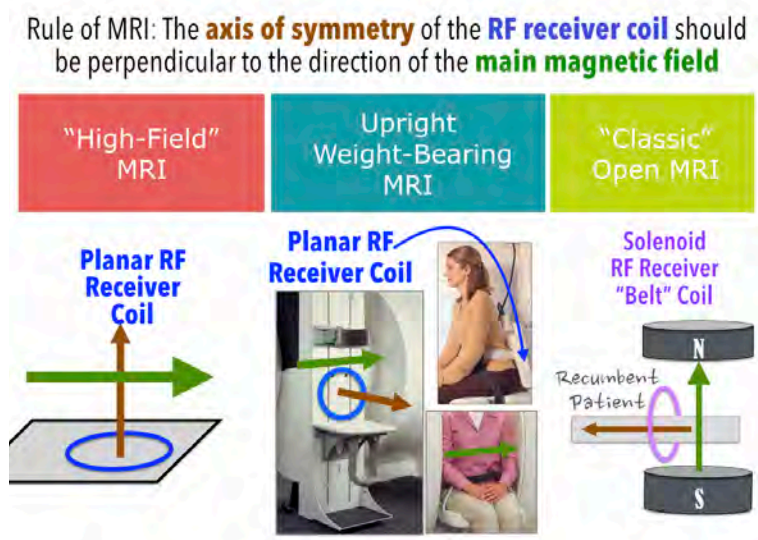
It is a commonly accepted myth that there are just two types of MRI scanners:

- **High-Field MRIs** that are considered to be the "standard' magnets with the best image quality. They operate at 1.5 Tesla or 3.0 Tesla. Their cylindrical configuration yields a magnet that resembles a tube with its horizontal magnetic field parallel to the longitudinal axis of the patient lying down in the magnet.

- **"Classic" Open MRIs** that are perceived to be be useful only for claustrophobic patients, with reduced spatial & temporal image resolution, longer scan times and the limitation that they don't do anything clinically valuable that the high-field MRIs don't already do. In this configuration with two horizontal magnetic poles, the patient can extend their arms and see out the sides while recumbent in the vertical magnetic field. Low-field Open MRIs operating at magnetic field strengths between 0.2T and 0.35T proliferated over many years so often physicians are unaware of technology advances in the late 1990s that resulted in higher field strength Open MRIs operating at 0.6T, 0.7T, 1.0T and even 1.2T.



It is also generally unappreciated that there are significant advantages in reconfiguring the "classic" Open MRI magnet design to feature the vertical magnetic poles characteristic of FONAR's **0.6 Tesla Upright MRI**. This MRI, with a horizontal transaxial magnetic field, can use flat planar RF receiver coils to image the spine just like the 1.5 & 3.0 Tesla high-field MRI systems. Since Open MRI systems utilize a vertical magnetic field, they cannot do this ... so the Upright MRI is dramatically different than an Open MRI. This is simply a consequence of the physics of MRI that requires the axis of symmetry of the RF receiver coil to be perpendicular to the direction of the main magnetic field. A patient scanned in the Upright MRI can sit comfortably with her back against the planar RF receiver coil. This will also work with the patient recumbent. As the choice of the RF receiver coil has a direct impact on image quality, the Upright MRI has a competitive edge over all the Open MRIs. In fact if one defines an Open MRI as a magnet that cannot use a flat planar RF receiver coil to image the spine, then the Upright MRI is not an Open MRI.

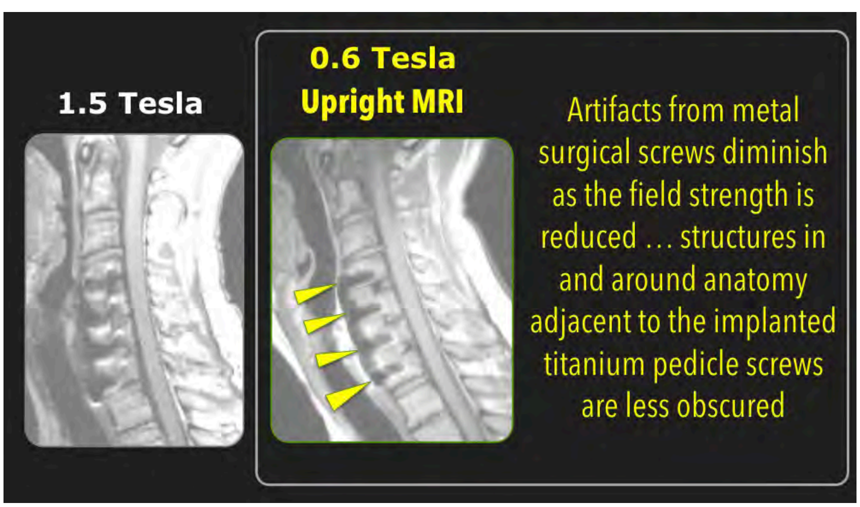


Which RF Receiver Coil is compatible with which type of MRI?

Magnet ↓ / RF Coil →	Planar (flat)	Solenoid ("belt")
High-Field MRI	✓	
Open MRI		✓
Upright Weight-Bearing MRI	✓	✓

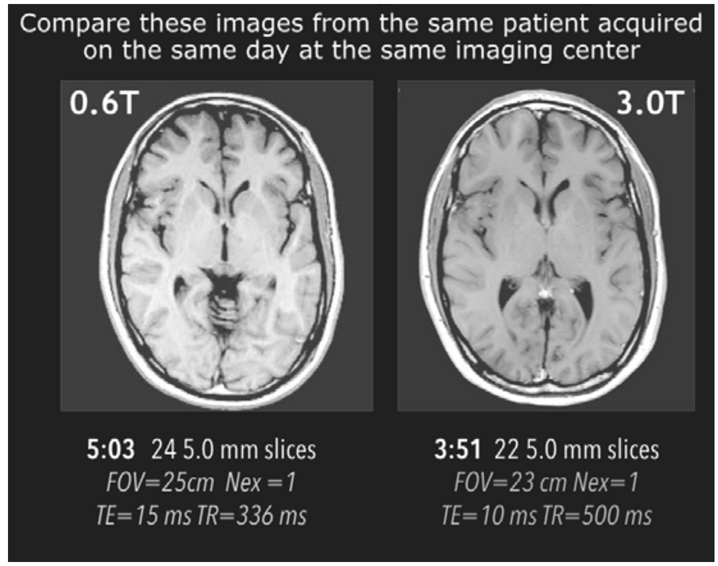
Is the 0.6 Tesla field strength sufficient for acquiring high quality images? Yes it is. The Upright MRI's magnetic field strength is two to three times stronger than that of many Open MRIs still in operation today. Their improved image resolution is directly tied to the image signal-to-noise which is well known to increase as the magnetic field strength is raised.

There is also a competitive advantage that relates to reducing image artifacts arising from metal implants such as surgical screws. It is well known that such artifacts get smaller as the MRI magnet's field strength is reduced, so the anatomy adjacent to implanted hardware will be less obscured with the Upright MRI. This is particularly valuable for surgeons referring their postoperative patients for diagnostic imaging studies. In addition, image artifacts from physiological motion are similarly reduced relative to the higher field systems; note the area anterior to the spine in the kyphosis patients scanned sitting upright (since it is difficult for them to be scanned lying down).

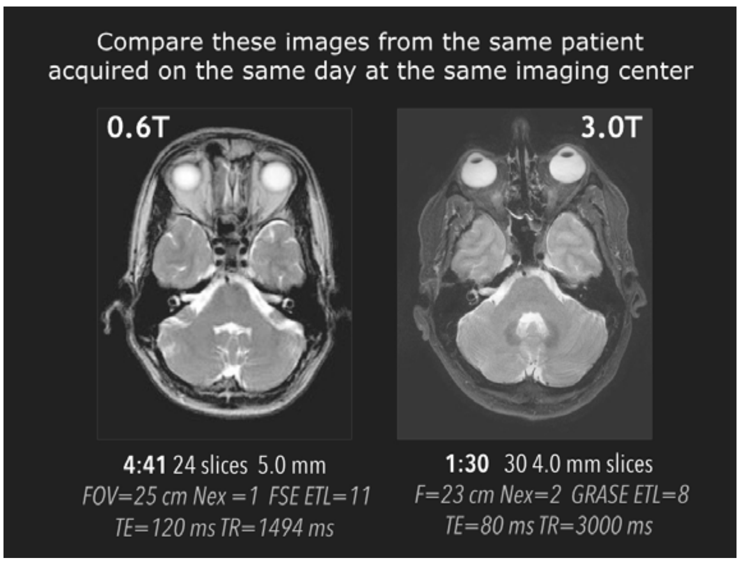


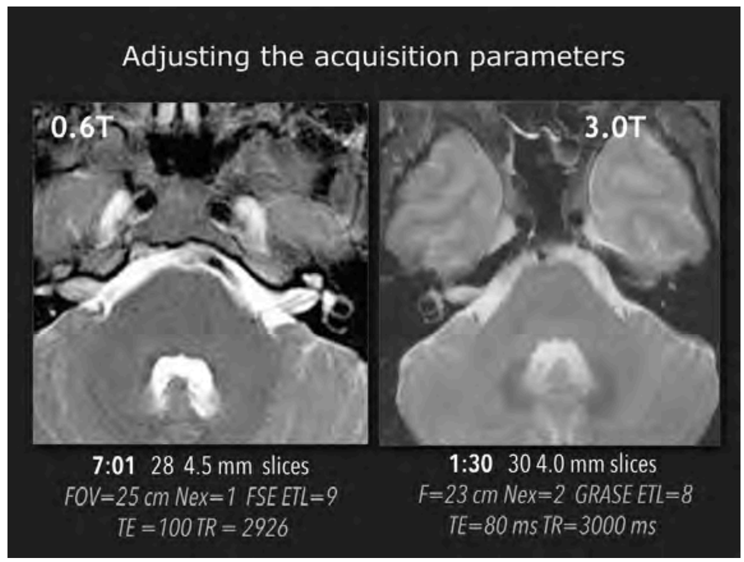
Severe Kyphosis
Patients unable to lay down

How do routine images from the 0.6 Tesla Upright MRI compare to those, say, from a high-field 3.0 Tesla MRI system?

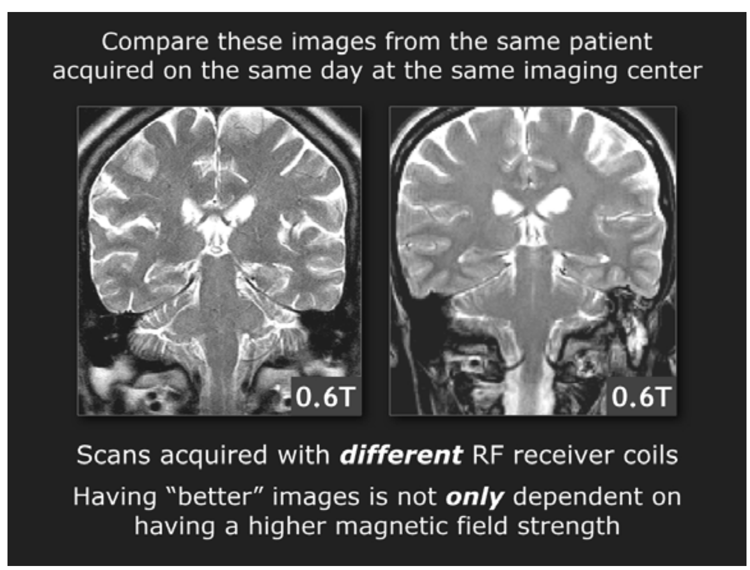


There are numerous tradeoffs. For instance, as T1 NMR tissue relaxation times are known to increase with magnetic field strength, higher field magnets typically suffer from reduced T1 contrast in T1W images. On the other hand, the high-field MRI's increased signal-to-noise means that in a fixed scan time it can obtain higher resolution images. Of course with a mid-field MRI the technologist can increase the scan time to match the high resolution obtained with the higher field strength MRIs.



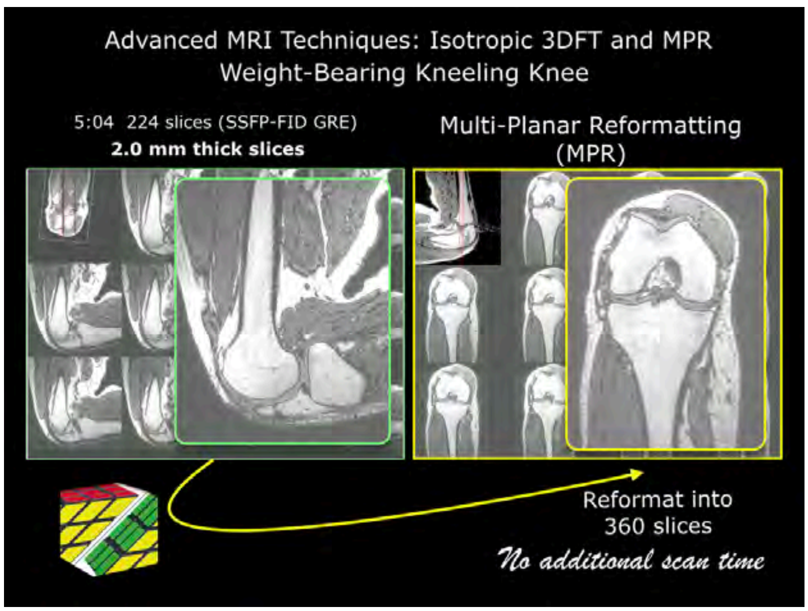


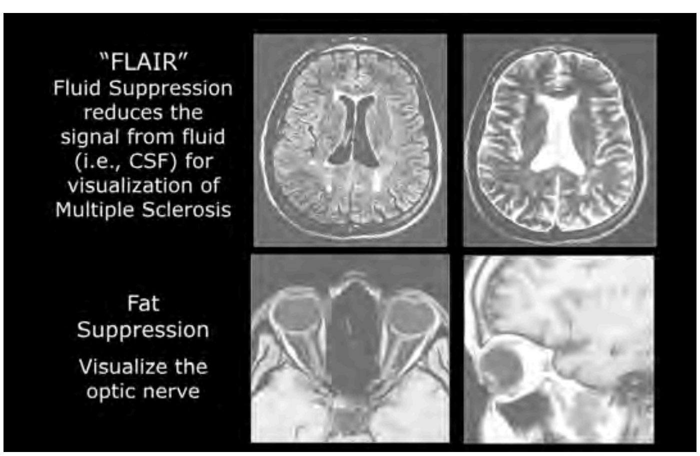
It is also important to recognize that signal-to-noise at a given field strength can be increased by incorporating innovative RF receiver coil design improvements.

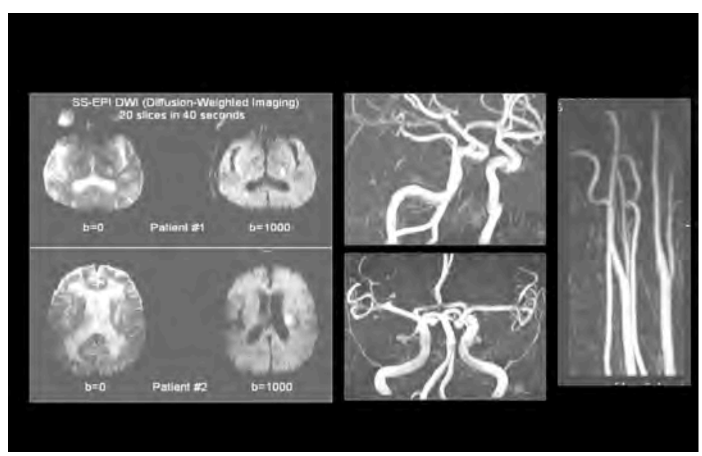


The 0.6 Tesla Upright MRI's field strength and gradient specifications are sufficient for performing **specialized MRI applications**.

3DFT techniques are ideal for mid-field MRI systems because of their increase in signal-to-noise as well as their ability to provide thin contiguous slices.

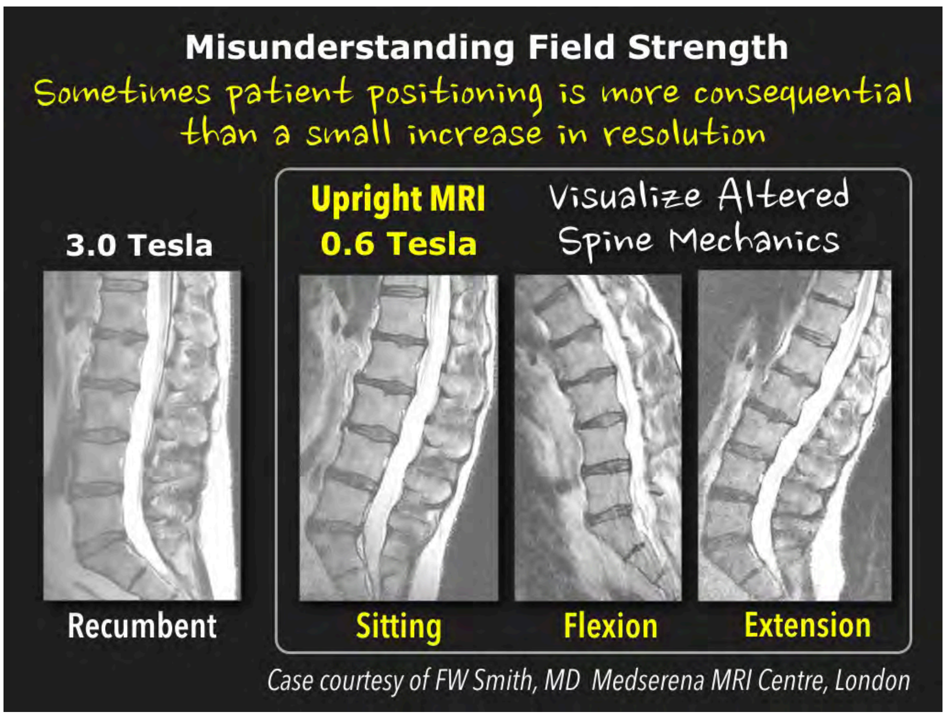


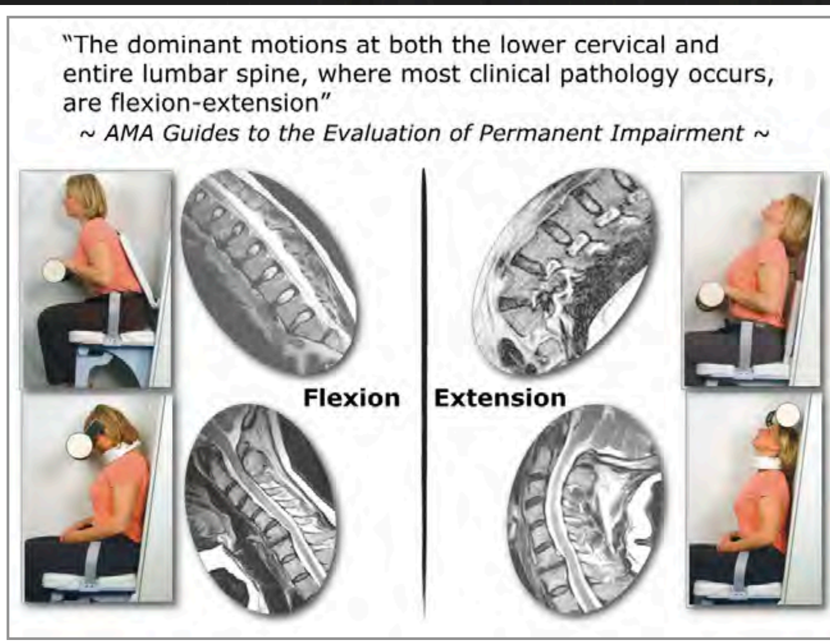




Neuroimaging applications (above) include FLAIR, fat suppression using 3-point Dixon water-fat separation techniques, diffusion-weighted imaging (DWI) and Magnetic Resonance Angiography (MRA).

The FONAR UPRIGHT Weight-Bearing MRI





Upright Weight-Bearing MRI: Selected Peer-Reviewed Publications

SPINE (2009)
"Dynamic Bulging of Intervertebral Discs in the Degenerative Lumbar Spine"
J. Zou, M.D. et al., Dept. of Orthopedic Surgery, UCLA
Upright weight-bearing scans from 513 patients with chronic lower back pain were evaluated. The authors reported that "greater disc bulging under postural loading occurs with advancing degenerative disc disease" and that … Prone extension is a posture commonly used in physical therapy. Based on our study, grade I discs displayed the expected response to dynamic positions. However, more degenerative discs behave less predictably, and extension may result in significant disc bulging. These results question the popular therapeutic techniques."

SPINE (2008)
"Missed Lumbar Disc Herniations Diagnosed With Kinetic Magnetic Resonance Imaging"
J. Zou, M.D. et al., Dept. of Orthopedic Surgery, UCLA
In a study of 553 patients with symptomatic back pain: *"... patients with normal or less than 3 mm bulge in neutral, 19.5% demonstrated an increase in herniation to greater than 3 mm in extension."* Further, 15.3% demonstrated an increase in herniation to greater than 3 mm in flexion.

Brain Injury, (2010)
"A Case-Controlled Study of Cerebellar Tonsillar Ectopia (Chiari) and Head/Neck Trauma (Whiplash)"
M Freeman et al., Oregon Univ. School of Medicine, Univ. of Aarhus, Univ. of Aberdeen, Spinal Injury Foundation, Columbia Univ., Univ. of Nebraska, Wisconsin Chiari Center
A multi-center study of 1200 patients with neck pain showed recumbent MRI underestimates the incidence of herniated cerebellar tonsils. The incidence of tonsillar herniation in non-traumatic neck pain patients was about the same, 5.3-5.7%, for both recumbent and upright positions, while in whiplash patients, 23.3% examined upright showed herniation of the cerebellar tonsils, whereas only 9.3% examined recumbent showed this abnormality.

Clinical Radiology (2008)
"Upright Positional MRI of the Lumbar Spine"
F. Alyas, et. al., Dept. of Radiology, Royal National Orthopaedic Hospital NHS Trust, Stanmore, Middlesex, UK
"... there is no doubt that clinically relevant spinal canal stenosis can be uncovered by imaging the erect position. In cases where conventional MRI shows no evidence of cauda equina or lumbar nerve root compression in the setting of convincing clinical symptoms that warrant surgical intervention, re-imaging in the upright position, with the addition of flexion and extension, is recommended."

The Spine Journal (2007) Volume 7
"Missed Spondylolisthesis in Static MRIs But Found in Dynamic MRIs in Patients with Low Back Pain"
S.W. Hong, M.D. et al., UCLA
"In [510] patients with back pain, missed spondylolisthesis in neutral MRIs but found in flexion MRIs is 18.1% for all the levels if the spondylolisthesis is considered as more than 3 mm translation."

Clinical MRI (2006) Volume 15
"Positional Upright Imaging of the Lumbar Spine Modifies the Management of Low Back Pain and Sciatica"
FW Smith, M.D. et al., Department of Radiology, University of Aberdeen, Scotland, UK
In a study of 25 patients with low back pain and sciatica referred to the Upright MRI for lumbar spine MRIs following at least one prior "normal" recumbent MRI within 6 months of referral: *"13 patients [52%] demonstrated abnormalities in one or more of the seated postures that were not evident in the … supine exam ... Each of the thirteen patients has undergone appropriate surgery and six months post-surgery they remain symptom free."*

Southern Medical Journal (2004)
"Dynamic Weight-Bearing Cervical Magnetic Resonance Imaging: Technical Review and Preliminary Results"
T. Vitaz, M.D. et al., Department of Neurological Surgery, University of Louisville School of Medicine
20 patients with symptoms consistent with radiculopathy or myelopathy were scanned in an upright weight-bearing position. The neurosurgeons reported that *"when only static supine MRI scanning is performed on these patients, the true abnormality may be overlooked and inappropriate surgical plans instituted because of a lack of illustration of the changes that occur with movement."*

Upright Weight-Bearing MRI: Selected Peer-Reviewed Publications

Musculoskeletal (MSK) Applications

Clinical Biomechanics (2013)
"Tibiofemoral Contact Location Changes Associated with Lateral Heel Wedging: A Weight-Bearing MRI Study"
PJ Barrance et al., Kessler Institute for Rehabilitation, NJ, Rutgers MedicalSchoolNJ
"During flexion, the contact patch of the lateral femoral condyle shifted anteriorly with lateral heel wedging. This study demonstrates that vertical MRI imaging is useful for the investigation of mechanical changes in joints induced by weight bearing. This technology … may help us understand how footwear interventions affect the mechanics of the knee joint."

Knee (2010)
"Upright MRI in Kinematic Assessment of the ACL-deficient Knee"
Nicholson JA, et al, University of Aberdeen, UK
A study of eight sequential patients with ACL deficiency (and control group of five healthy volunteers) *"highlights the importance of upright weight-bearing with regards to pathological kinematic studies. We propose that FFC [flexion facet centre technique] measurement in an upright, weight-bearing position is a reliable and representative tool for the assessment of femoro-tibial movement."*

Journal of Orthopaedic Research (2005)
"Patellofemoral Joint Contact Area Increases with Knee Flexion and Weight bearing"
TF Beiser et al., Stanford University
16 subjects were scanned in an upright weight-bearing position. The authors reported that *"under weight-bearing conditions, contact areas increased by an average of 24%"* and that *"patellofemoral joint contact areas should be measured under loaded conditions to account for cartilage deformation and changes in patellar alignment that may occur with load. This is is particularly relevant when trying to understand potential mechanisms of patellofemoral pain."*

American Society of Mechanical Engineers: Bioengineering Conference (2006)
"Knee Cartilage Contact Determination Using Weight-Bearing MRI"
PJ Barrance, TS Buchanan Center for Biomechanical Engineering Research, University of Delaware
A 46 year old male subject, who had sustained a complete tear to one anterior cruciate ligament six months prior to examination, was scanned in an upright weight-bearing postion. The authors presented a clinical case study showing that "anterior subluxation of the tibia is evident and highlighted by the white arrow" in the weight-bearing image from this patient.

Journal of MRI (2002)
"MR Imaging of the Forefoot under Weight-Bearing Conditions: Position-Related Changes of the Neurovascular Bundles and the Metatarsal Heads in Asymptomatic Volunteers"
D Weishaupt, MD Institute of Diagnostic Radiology, University Hospital, Zurich, Switzerland
32 subjects were scanned in an upright weight-bearing position. The authors reported that *"weight-bearing imaging of the forefoot ... demonstrated position-related changes of the neurovascular bundles relative to the metatarsal heads, as well as position-related changes of the metatarsal heads themselves."*

Body Applications

WomensImagingOnline (2007)
"Pelvic Floor Dysfunction" *H. Pannu, MD, Johns Hopkins University*
"The main drawback of MRI is supine imaging that can limit the dynamic component of the examination. Imaging has been performed on Upright scanners and the increasing availability and fields strength of these scanners may ultimately lead to MRI being the one imaging test for pelvic floor dysfunction."

Practical Radiation Oncology (2014)
"Advantages of simulating thoracic cancer patients in an upright position"
LE Court PhD Dept. of Radiation Physics, University of Texas MD Anderson Cancer Center, Houston, Texas
"The magnitude of motion inside the lung was smaller and the absolute lung volumes were much larger in the upright position than in the supine position, which suggests that treating thoracic patients in the upright position may allow for a reduction in the mean lung dose."