Dynamic Weight-bearing Cervical Magnetic Resonance Imaging: Technical Review and Preliminary Results

Todd W. Vitaz, MD, *Christopher B. Shields,* MD, *George H. Raque,* MD, *Stephen G. Hushek,* PHD, *Robert Moser,* RT(R), *Neil Hoerter,* RT(R), *and Thomas M. Moriarty,* MD, PHD

Background: Conventional magnetic resonance imaging (MRI) of complex cervical spine disorders may underestimate the magnitude of structural disease because imaging is performed in a nondynamic non-weight-bearing manner. Myelography provides additional information but requires an invasive procedure.

Methods: This was a prospective review of the first 20 upright weight-bearing cervical MRI procedures with patients in the flexed, neutral, and extended positions conducted in an open-configuration MRI unit.

Results: This technique clearly illustrated the changes in spinal cord compression, angulation, and spinal column alignment that occur during physiologic movements with corresponding changes in midsagittal spinal canal diameter ($P < 0.05$). Image quality was excellent or good in 90% of the cases.

Conclusions: Dynamic weight-bearing MRI provides an innovative method for imaging complex cervical spine disorders. This technique is noninvasive and has adequate image quality that may make it a good alternative to cervical myelography.

Key Words: degenerative spinal disorders, dynamic spine imaging, magnetic resonance imaging, weight-bearing

From the Department of Neurological Surgery, University of Louisville School of Medicine, and the Norton Healthcare Intraoperative MRI Center, Louisville, KY.

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Reprint requests to Todd W. Vitaz, MD, Department of Neurosurgery, University of Louisville School of Medicine, 210 E. Gray Street, Suite 1102, Louisville, KY 40202. Email: tvitaz@niky.com

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The development of interventional magnetic resonance imaging (MRI) systems has provided novel opportunities for cervical spine imaging. Although conventional MRI may be adequate for most spinal disorders, it has several limitations. First, patients are imaged in a recumbent supine position; second, it is not possible to obtain dynamic weight-bearing images. These limitations may decrease the sensitivity of conventional MRI systems, especially in cases of severe degenerative conditions that cause cervical spinal stenosis. Myelography remains an alternative; however, this is an invasive procedure, with associated risks, side effects, and patient discomfort.[1–3]

Open-configuration MRI systems have enabled the development of new techniques of upright weight-bearing dynamic spine imaging. The preliminary results from other centers, which have focused on the lumbar region, have shown significant changes between supine and upright weight-bearing images and differences between the flexed and extended positions.[4–7] In addition, they have also found good correlation between these new upright techniques and myelography.[6] In this study, we review our method for dynamic upright imaging of the cervical spine and present our preliminary results.

Materials and Methods

All patients who were referred to our interventional MRI center for dynamic weight-bearing cervical imaging were followed in a prospective fashion once appropriate institutional

Key Points

- Cervical magnetic resonance imaging scans can be easily obtained in the sitting, weight-bearing position.
- Imaging can be conducted over a wide range of neck positions including full flexion and extension.
- This technique is safe, reliable, and noninvasive and can be used for a variety of pathologic disorders.

review board approval was obtained. Demographic information about the patient's age, sex, and previous surgeries were recorded. Patients were referred to the MRI center by either their neurosurgeon or their orthopedic spine surgeon, and all patients had neck pain and symptoms consistent with either a radiculopathy or myelopathy. In approximately half of the cases, the dynamic study was the first imaging study performed, whereas the remainder of the patients were referred because it was felt that dynamic weight-bearing imaging would add beneficial information about the patient's condition. Appropriate institutional review board approval was granted for this study.

Image Acquisition

Imaging was performed in our 0.5-T Signa SP/i interventional MRI system (GE Medical Systems, Milwaukee, WI), which has a vertical gap configuration (Fig. 1). The patient was seated on a plastic chair in the gap of the magnet and a flexible radiofrequency transmit/receive coil was then secured around the patient's cervical region. Custom foam padding with a recess for the coil and an opening over the face surrounded the patient's head. This padding and a rigid, variable-position resting bar helped to stabilize the patient's head to prevent excessive movement during imaging and thus prevent motion artifacts.

Patients were seated in the magnet gap with their neck in the neutral position and coronal scout images followed by T2-weighted sagittal images were acquired. Then, the patients were repositioned with their neck maximally flexed (determined by patient) and imaging was repeated. Finally, the patients were repositioned with their neck maximally extended (determined by the patient) and a third set of images was obtained (Fig. 2). Images were acquired using FSE-xl (TR, 4,000; TE, 102; ETL, 8; FOV, 24 cm; 4 mm thick with 0.5-mm gap; 256 $\times$ 128 matrix). The number of excitations ranged from two to four, depending on the patient's comfort and lack of motion. Axial images were not routinely obtained because of the length of time required for patients to hold still during this type of examination; however, it is possible to perform these sequences through selected areas of interest.

Image Analysis

A single investigator (TWV) reviewed all of the imaging examinations. Patients were divided into one of the following groups on the basis of imaging findings: 1) one- or two-level herniated disc or cervical spondylosis (uncovertebral spurs or osteophytes), 2) multilevel herniated disc/spondylotic disease, or 3) craniocervical junction abnormalities. The presence of cervical spine instability defined as greater than 3.5 mm of subluxation or 11 degrees of angulation was also documented.[8] In addition, each patient's images were analyzed for qualitative changes in spinal cord compression between the

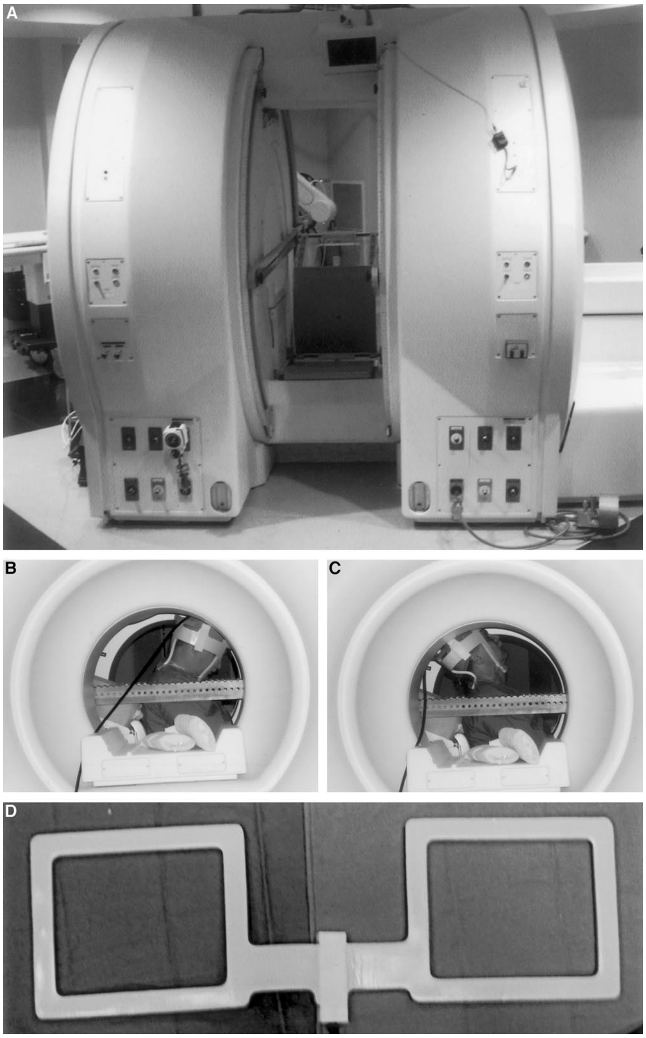

Fig. 1 ***A*, Photograph of the GE Signa SP Intraoperative MRI system with chair for spine imaging in place. Side views (*B*, flexion; *C*, extension) showing a patient positioned in the magnet with transmit/receive coil (*D*) in place.**

three positions. Images were evaluated for changes in the anterior disc/osteophyte and posterior ligamentous structures, which was defined as increased disc herniation, ligamentous buckling, or decreases in spinal canal diameter. These changes were considered 1) mild if there was either no contact with the spinal cord or effacement of cerebrospinal fluid (CSF) on one side with preservation of the CSF signal on the opposite side and no deformation or impingement of the spinal cord, 2) moderate if there was contact with the cord and loss of CSF signal on both sides of the cord, or 3) severe if there was obvious compression or deformation of the cord.

The midsagittal image in each of the three positions was chosen for quantitative analysis to determine the level of most severe spinal stenosis. The diameter of the spinal canal was then measured at this level using the distance measurement software on the MRI console, and the Student's t test was used for statistical analysis.

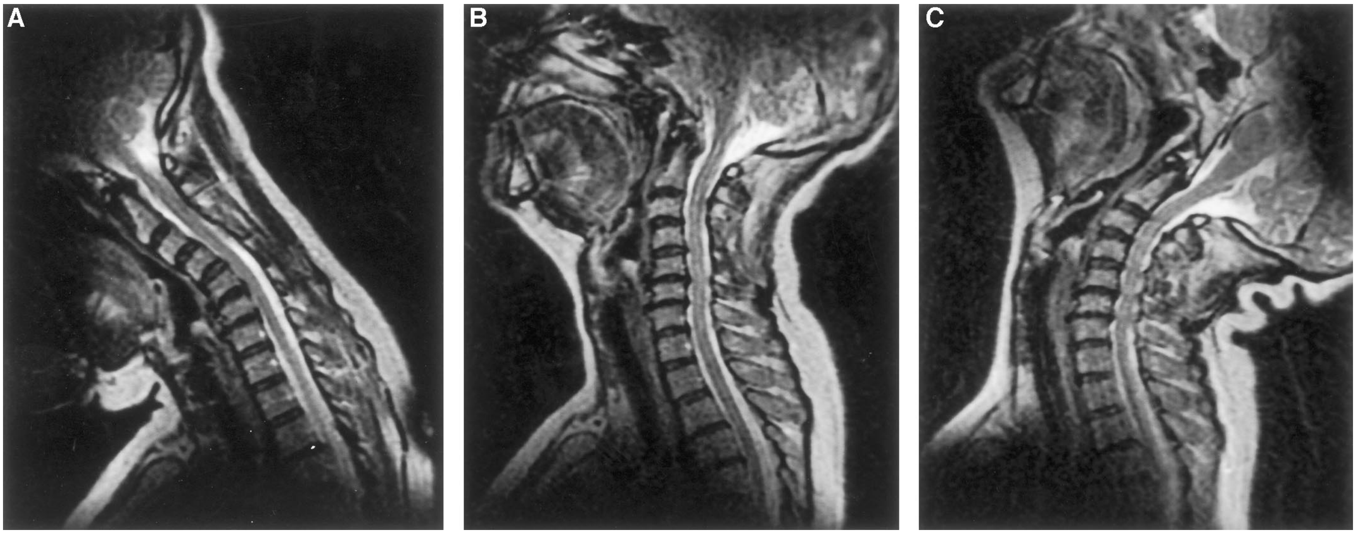

Fig. 2 **Dynamic imaging (*A*, flexion; *B*, neutral; *C*, extension) of a patient with multilevel degenerative cervical spinal stenosis showing how the compressive structures change with positional changes.**

Results

Twenty patients underwent upright weight-bearing dynamic imaging between April and December 2000. There were 9 male patients and 11 female patients; the average age was 53 years (range, 15–78 yr). Abnormalities that were seen are listed in Table 1. Image quality was considered excellent or acceptable in 18 (90%) of the 20 patients. The quality was poor in the other two patients (10%), both of whom had resting tremors and were unable to hold still during imaging.

The qualitative review of the images showed no change between the three imaging positions (flexion, neutral, and extension) in two patients (10%). Two patients (10%) exhibited isolated increases in anterior compression, five patients (25%) had changes in the posterior structures (buckling of ligamentum flavum), and 11 patients (55%) had changes in both the anterior and posterior structures. These changes were judged as mild in four (20%), moderate in seven (35%), and severe in seven (35%).

The average spinal canal diameters in each position as determined by the quantitative analysis are shown in Table 2. The cross-sectional diameter of the spinal canal was greatest in flexion and least in extension, with an average change of 2.8 ± 1.4 mm (Figs. 2–5). The differences in cross-sectional spinal canal diameter between the three positions were statistically significant: flexion versus neutral, $P < 0.05$; neutral versus extension, $P < 0.01$; and flexion versus extension, $P < 0.0001$.

Table 1. **Pathologic processes (n = 20)**

	No. (%)
One- or two-level disc/spondylotic disease	4 (20)
Multilevel degenerative disc/spondylotic disease	14 (70)
Craniocervical junction abnormalities	2 (10)
Previous cervical spine operations	5 (25)
Cervical spine instability	7 (35)

Discussion

Upright weight-bearing dynamic imaging has several advantages. Intradiscal pressures are highest in the sitting position and lowest in the recumbent position.[9–12] Previous work has also shown significant changes in the cross-sectional area of the spinal canal during flexion and extension.[4,6,13–20] These facts are important when considering the imaging of complex disorders of the cervical spine. Conventional MRI may underestimate the degree of disease because imaging is performed with the patient supine and often with the neck slightly flexed, because this is the most comfortable position. Thus, the patient is most cooperative, which results in the best image quality; however, this is also the position with the greatest cervical spinal canal diameter. Myelography has been used to overcome these limitations; however, this requires an invasive procedure with the associated risks and high patient anxiety levels.[6]

This new technique of upright spine imaging overcomes many of these issues. It is a noninvasive technique that allows

Table 2. **Spinal canal diameters[a]**

	Average (mm)	Range (mm)
Flexion	10.2 ± 1.5	8–13
Neutral	9.2 ± 2.0	7–13
Extension	7.4 ± 2.2	5–12

[a] *Measured at the level of most significant stenosis.*

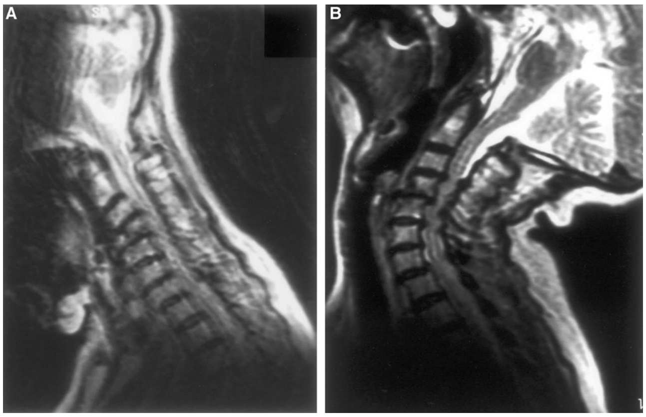

Fig. 3 **Dynamic imaging (*A*, flexion; *B*, extension) of a patient with multilevel degenerative cervical spinal stenosis showing dynamic changes seen with positional changes (flexion image moderately degraded by motion artifact).**

for dynamic imaging, with excellent soft tissue visualization under conditions that are similar to everyday physiologic stresses.

The primary goal of this study was to determine the feasibility and reproducibility of performing upright-seated MRI in three different positions (90% excellent/good image quality); therefore, supine imaging was not also performed. A secondary analysis comparing prior conventional supine MRI studies with the weight-bearing dynamic studies was not performed because of the small number of patients who had undergone both procedures. Previous work comparing supine versus upright MRI of lumbar spine disorders showed increases in neural compression on weight-bearing imaging.[4–6]

Even though any imaging sequence in any plane (sagittal, coronal, axial) could be used, we chose to perform T2-weighted sagittal sequences because this technique allows excellent soft tissue contrast between the neuronal and surrounding soft tissues. We felt that the T2 sagittal images gave the most reproducible images with the best image quality and soft tissue contrast. The use of this imaging sequence may be slightly disparaged by the fact that T2-weighted sequences have often been criticized for overestimating the degree of spinal stenosis. However, one must remember that the images in all three positions were performed with the same acquisition technique, therefore limiting the variability between them. In addition, previous authors have found good correlation between findings using similar techniques in the lumbar spine when compared with myelography, which is considered the "gold standard" for determining the degree of radiographic stenosis or neuronal impingement.[6]

We have found image quality to be directly related to patient comfort, cooperation, and stabilization and have continuously been modifying our positioning techniques to help maximize this. In addition, we have also found this technique useful in providing an imaging option for patients with poor cardiac or pulmonary function who cannot lay flat and would therefore be unable to undergo conventional MRI.

Now that we have shown that it is possible to reliably reproduce these images, the next step will be to determine the impact of such imaging in terms of differentiating between normal and pathologic changes seen during dynamic imaging. We feel that this new imaging technique will be most helpful for the evaluation of patients with degenerative myelopathy because this process is felt to be secondary to a combination of both static and dynamic compression (Figs. 3 and 4).[13,14,16,17] 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.[13,14,16,17] Upright dynamic weight-bearing MRI now offers an alternative to myelography as an imaging choice for obtaining this essential information (Fig. 4). Further studies are currently being designed to compare pre- and postoperative dynamic cervical MRI findings with patient outcome after either anterior or posterior decompression for cervical myelopathy.

Another group of patients in whom this technique has

Fig. 4 **Dynamic imaging (*A*, flexion; *B*, neutral; *C*, extension) of a patient with persistent myelopathy after anterior decompression and fusion performed at another institution.**

Fig. 5 **Dynamic imaging (plain radiographs: *A*, flexion; *B*, extension; dynamic weight-bearing MRI: *C*, flexion; *D*, neutral; *E*, extension) of a patient with C1–C2 degenerative instability. Note the changes in anterior compression and spinal cord angulation that are seen during normal physiologic movement.**

revealed invaluable information consists of those with cranio-cervical junction abnormalities. Comparison with supine imaging has shown worsening of compression when the patient assumes the upright position as well as illustrating the changes in compression and angulation of the spinal cord and cervicomedullary junction during flexion and extension (Fig. 5).

The most important question is what patient population is appropriate for use of this new imaging technique. At our institution, it is used as an initial study on any patients who have symptoms suggestive of myelopathy, or with plain cervical spine radiographs that are suggestive of degenerative cervical spine subluxation, or any other dynamic nontraumatic process that may be the cause of the patient's symptoms. Furthermore, this technique may add greater information for patients with well-defined neurologic symptoms who have undergone conventional supine imaging that has failed to adequately illustrate the suspected cause. However, we have been cautious in performing dynamic weight-bearing studies on patients who have undergone recent conventional MRI, because insurance companies may be reluctant to reimburse for a second MRI evaluation. We do not suggest that this technique should be used to replace conventional supine MRI, but it may prove useful as an adjunctive study for complex spinal disorders.

Further studies need to be performed with this new imaging technique to correlate clinical symptoms with the imaging results as well as direct comparison of supine and upright imaging. Finally, the incorporation of a newly developed electromagnetic tracking system will provide a reference marker that enables more reproducible imaging in any plane (axial, sagittal, coronal) through the exact same area regardless of body position.

Conclusion

Upright, dynamic, weight-bearing, cervical MRI offers a noninvasive option for the imaging of complex disorders of the cervical spine. Analysis of our results has shown significant changes in spinal cord compression as evidenced by decreased spinal canal diameter in extension versus the flexed or neutral positions.

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