SPINAL RESTABILIZATION PROCEDURES

Diagnostic and Therapeutic Aspects of Intervertebral Fusion Cages, Artificial Discs and Mobile Implants

edited by

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2002

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CHAPTER 6

Upright, weight-bearing, dynamic–kinetic MRI of the spine: pMRI/kMRI

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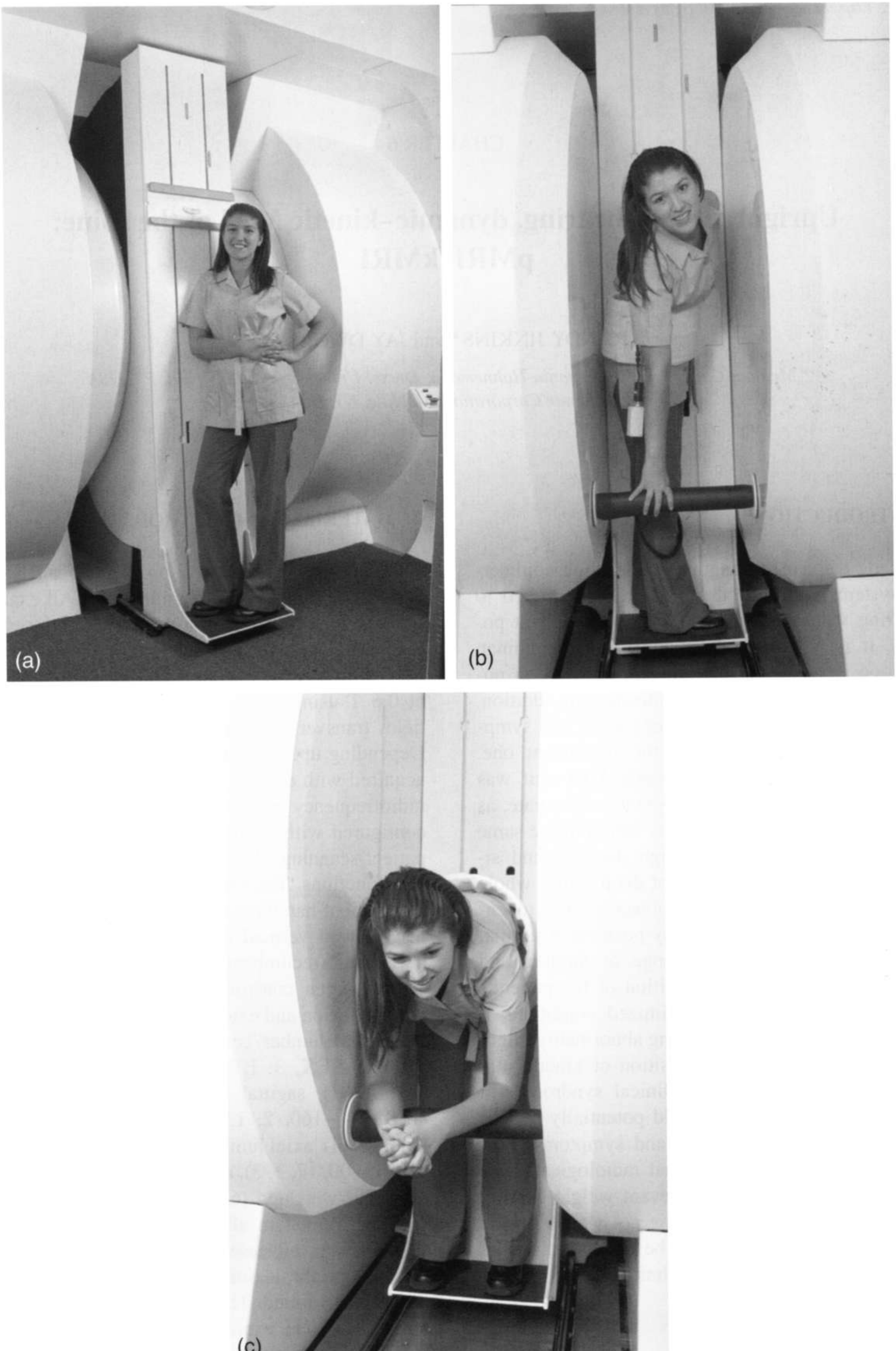
1. INTRODUCTION

Magnetic resonance imaging (MRI) using commercial systems has until the present been limited to acquiring scans with patients in the recumbent position. It is a logical observation that the human condition is subject to the effects of gravity in positions other than that of recumbency. In addition, it is clear that patients experience signs and symptoms in positions other than the recumbent one. For this reason, a new fully open MRI unit was configured to allow upright, angled-intermediate, as well as recumbent imaging. This would at the same time allow partial or full weight bearing and simultaneous kinetic maneuvers of the patient's whole body or any body part. The objective was to enable imaging of the body in any position of normal stress, across the limits of range of motion, and importantly in the specific position of the patient's clinical syndrome. Under optimized conditions it was hoped that a specific imaging abnormality might be linked with the specific position or kinetic maneuver that reproduced the clinical syndrome. In this way imaging findings could potentially be tied meaningfully to patient signs and symptoms. Furthermore, it was anticipated that radiologically occult but possibly clinically relevant weight-bearing and/or kinetic-dependent disease not visible on the recumbent examination would be unmasked by the positional-dynamic imaging technique [1–4].

2. MATERIALS AND METHODS

This study consisted of a prospective analysis of cervical or lumbar MRI examinations. All examinations were performed on a recently introduced full-body MRI system (Indomitable™, Fonar Corporation, Melville, NY) (Figure 1). The system operates at 0.6 T using an electromagnet with a horizontal field, transverse to the axis of the patient's body. Depending upon spinal level, all examinations were acquired with either a cervical or lumbar solenoidal radiofrequency receiver coil. This MRI unit was configured with a top-open design, incorporating a patient-scanning table with tilt, translation and elevation functions. The unique MRI-compatible, motorized patient-handling system developed for the scanner allowed vertical (upright, weight bearing) and horizontal (recumbent) positioning of all patients. The top-open construction also allowed dynamic–kinetic flexion and extension maneuvers of the spine.

Sagittal lumbar/cervical T1-weighted (TR, 680; TE, 17; NEX, 3; ETL, 3) fast-spin echo imaging (T1FSEWI), sagittal lumbar/cervical T2-weighted 4000, 140–160, 2, 13–15) fast-spin echo imaging (T2FSEWI), axial lumbar T1WI (600, 20, 2) or T1FSEWI (800, 17, 3, 3), axial cervical gradient recalled echo T2*-weighted (620–730, 22, 2) (T2*GREWI) were performed in all cervical/lumbar studies, respectively. In all cases, recumbent neutral, upright neutral, upright flexion, and upright extension imaging was performed. The patients were seated for the upright cervical examinations and for the neutral



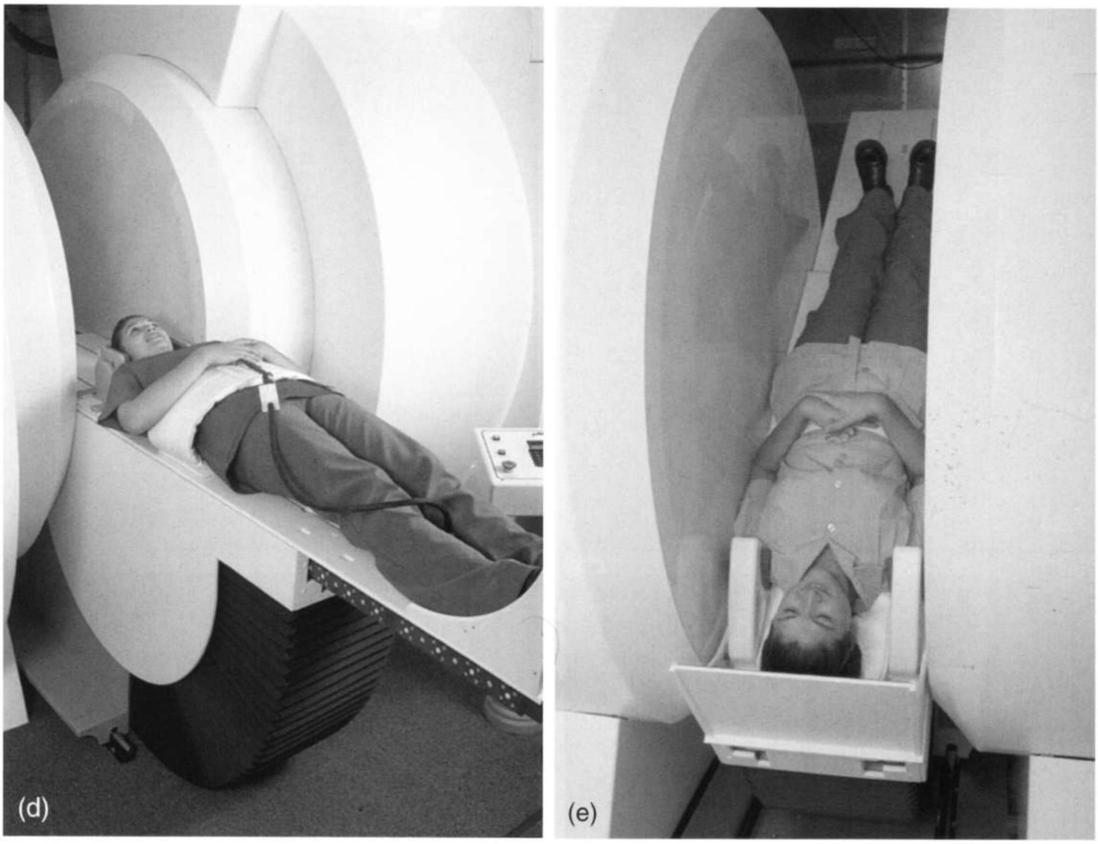


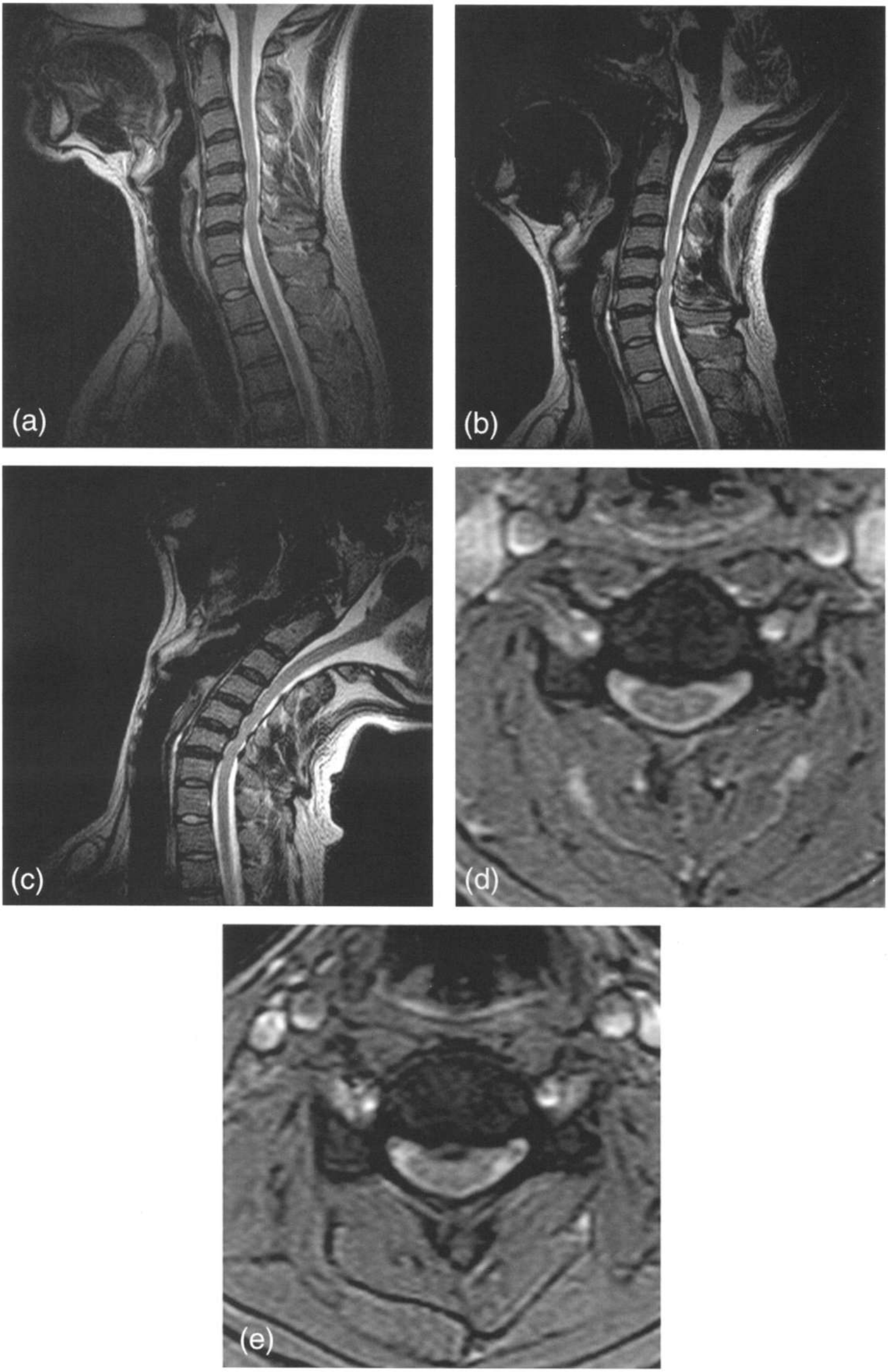
Figure 1. Various patient/table configurations of the 'Stand Up™' MRI unit. (a) Patient standing in unit (standing-neutral pMRI). (b) Patient in lateral bending maneuver (lateral bending kMRI). (c) Patient in lumbar flexion maneuver (flexion kMRI). (d) Patient in recumbent position (rMRI). (e) Patient in Trendelenberg position (negative angled pMRI).

upright lumbar acquisitions, and were placed in the standing position for the lumbar kinetic studies.

Patterns of bony and soft tissue change occurring among recumbent neutral (rMRI) and upright neutral positions (pMRI), and dynamic–kinetic acquisitions (kMRI: upright flexion–extension) were sought. Specifically, degenerative spinal disease, including focal intervertebral disc herniations, spinal stenosis involving the central spinal canal and spinal neural foramina, and hypermobile spinal instability were compared to other visibly normal segmental spinal levels among the rMRI, the pMRI and kMRI acquisitions. Focal disc herniations were defined as localized protrusions of intervertebral disc material that encompassed less that 25% of the total disc periphery in the axial plane; central spinal stenosis was defined as generalized narrowing of the central spinal canal in the axial and/or sagittal plane relative to that of other spinal levels; spinal neural foramen narrowing was defined as general narrowing of the neural foramina as determined from sagittal acquisitions relative to that of other segmental spinal levels; and hypermobile spinal instability was defined as relative mobility between adjacent spinal segments as compared to other spinal levels that in turn demonstrated virtually no intersegmental motion. Generally speaking, degenerative disc disease was defined as both intrinsic discal MRI signal loss as well as morphological alteration to include a reduction in superoinferior dimensional disc space height. Alterations in sagittal spinal curvature were also noted between the neutral rMRI and pMRI acquisitions. Finally, notation was made as to whether or not the patient was referred in part because of an inability to undergo a prior MRI due to subjective feelings of claustrophobia attempted in a 'closed' MRI unit.

3. RESULTS

The neutral upright imaging studies (neutral-pMRI) demonstrated the assumption by the patient of the true postural sagittal lumbar cervical or lumbar lordotic spinal curvature existing in the patient at the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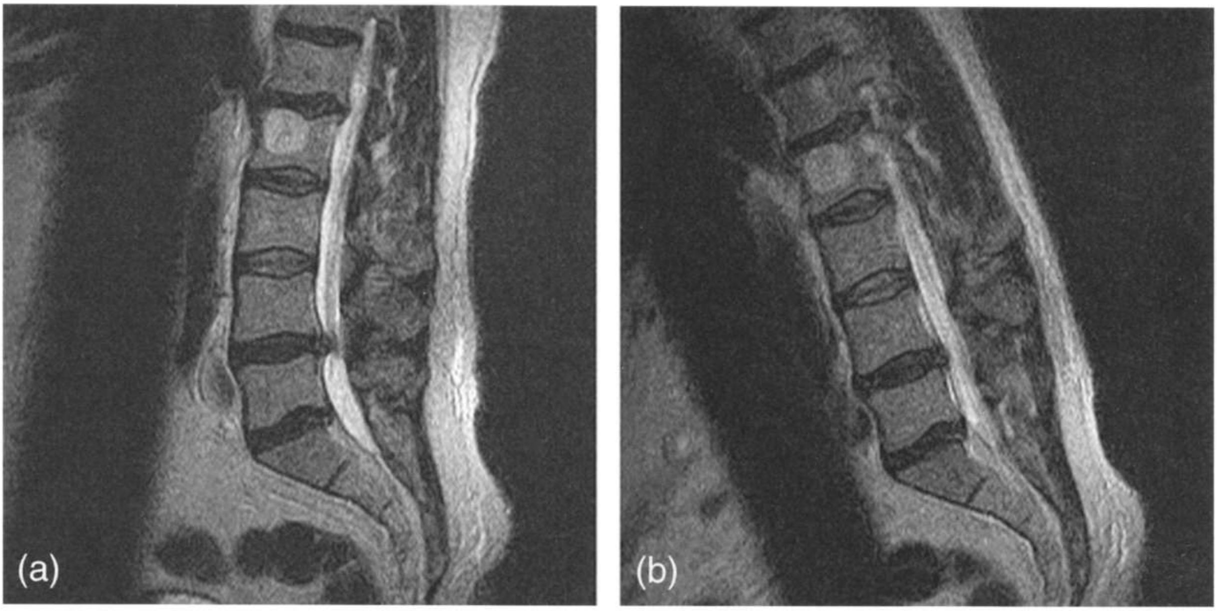

Figure 3. Reducing disc herniation. (a) Upright-neutral midline sagittal T2-weighted fast-spin echo MRI (pMRI) showing a focal midline posterior disc herniation at the L4–L5 level. (b) Upright-flexion midline sagittal T2-weighted fast-spin echo MRI (kMRI) revealing partial reduction of the posterior disc herniation at the L4–L5 level, as compared to the upright-neutral examination.

time of the MRI examination, a feature that was partially or completely lost on the neutral recumbent examination (rMRI). In other words, this relative postural sagittal spinal curvature correction phenomenon was manifested by a change from a straight or even reversed lordotic curvature or rMRI to a more lordotic one on pMRI. Increasing severity of focal posterior disc herniation on the neutral-pMRI compared to the rMRI was noted, and was yet worse in degree on extension-kMRI; these posterior disc herniations were less severe on flexion-kMRI maneuvers as compared to all other acquisitions. Absolute de novo appearance of disc herniation on neutral-pMRI was identified on extension-kMRI acquisitions in some cases as compared to rMRI. Increasing severity of central spinal canal stenosis was identified on neutral-pMRI and on extension-kMRI acquisitions, as compared to rMRI, and was overall most severe on extension and least severe on flexion-kMRI acquisitions. Similarly, increasing severity of spinal neural foramen stenosis was identified on neutral-pMRI and on extension-kMRI acquisitions, as compared to rMRI, and was overall most severe on extension and least severe on flexion-kMRI acquisitions. Increasing central spinal canal narrowing with spinal cord compression on extension-kMRI was identified in some cervical examinations as compared to recumbent rMRI, neutral-pMRI and flexion-kMRI maneuvers. No examination was uninterpretable based on patient motion during any portion of the MRI acquisitions. No patient was unable to complete the entire examination due to subjective feelings of claustrophobia (Figures 2–8).

Figure 2. Sagittal spinal curvature correction; unmasking of central spinal stenosis; occult herniated intervertebral disc. (a) Recumbent midline sagittal T2-weighted fast-spin echo MRI (rMRI) shows straightening and partial reversal of the sagittal spinal curvature of the cervical spine. Posterior disc bulges/protrusions are present at multiple levels. (b) Upright-neutral midline sagittal T2-weighted fast-spin echo MRI (pMRI) shows restoration of the true sagittal postural cervical curvature upon neutral standing. (c) Upright-extension midline sagittal T2-weighted fast-spin echo MRI (extension kMRI) further posterior protrusion of the intervertebral discs at multiple levels, and anterior infolding of the posterior spinal ligaments, resulting in overall worsening of the stenosis of the central spinal canal. Note the impingement of the underlying spinal cord by these encroaching spinal soft tissue elements. (d) Recumbent axial T2*-weighted gradient recalled echo MRI (rMRI) at the C5–C6 disc level shows posterior paradiscal osteophyte formation extending into the anterior aspect of the central spinal canal. (e) Upright-extension axial T2*-weighted gradient recalled echo MRI (extension kMRI) revealing focal posterior disc herniation indenting and compressing the underlying cervical spinal cord. Note the overall stenosis of the central spinal canal.

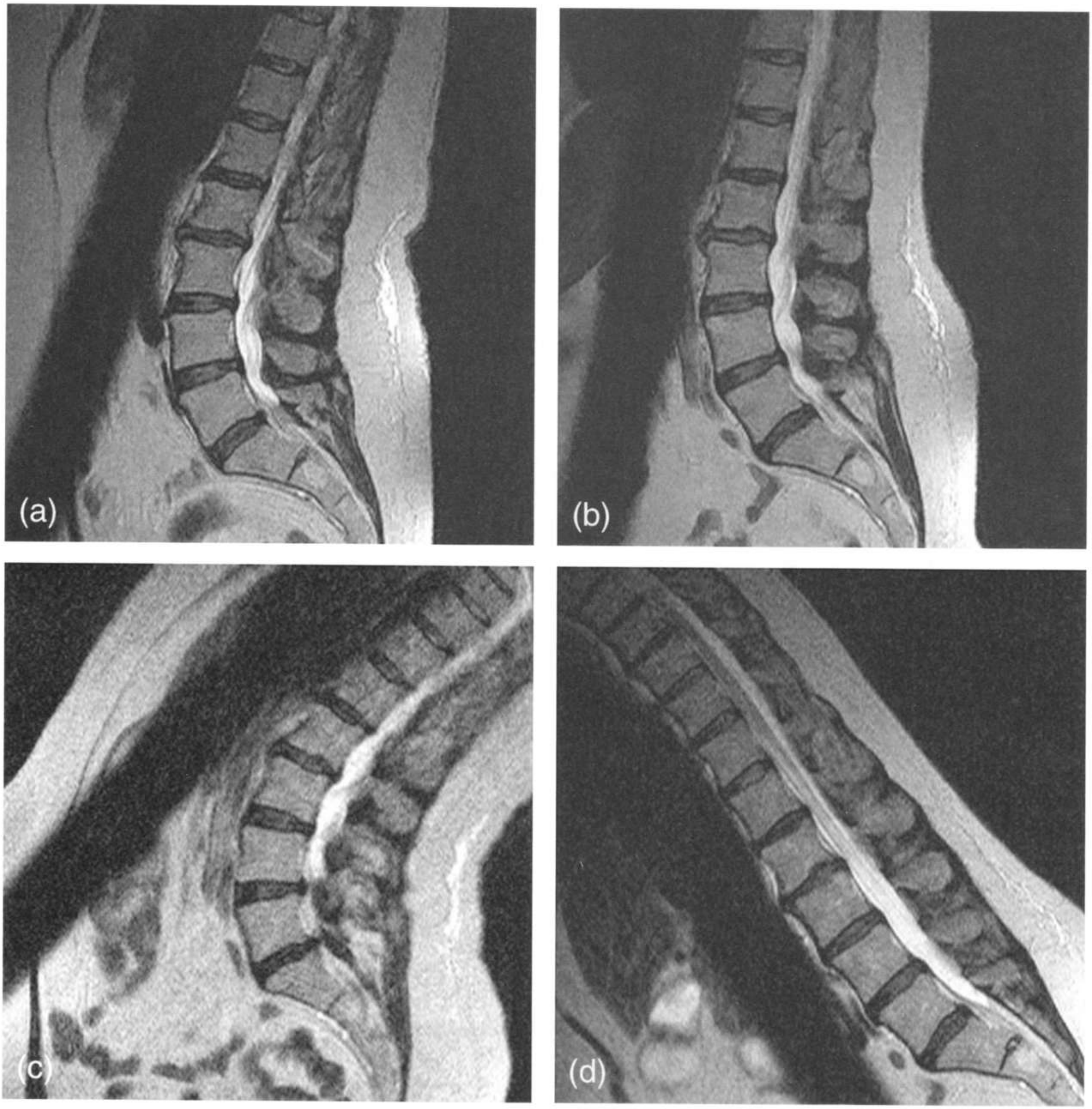

Figure 4. Worsening-reducing spinal stenosis. (a) Recumbent midline sagittal T2-weighted fast-spin echo MRI (rMRI) shows mild, generalized spondylosis and minor narrowing of the central spinal canal inferiorly. (b) Upright-neutral midline sagittal T2-weighted fast-spin echo MRI (pMRI) shows mild worsening of the central spinal canal stenosis inferiorly. Note the assumption by the patient of the true postural sagittal curvature of the lumbosacral spine as compared to the recumbent examination. (c) Upright-extension midline sagittal T2-weighted fast-spin echo MRI (kMRI) reveals severe worsening of the central spinal canal in the lower lumbar area (L4–L5, L5/S1). (d) Upright-flexion midline sagittal T2-weighted fast-spin echo MRI (kMRI) demonstrates complete reduction of the central spinal canal stenosis at every lumbar level.

4. DISCUSSION

Conventional recumbent MRI, or rMRI, is obviously inadequate theoretically for a complete evaluation of the spinal column. The human condition includes both weight-bearing body positioning, or pMRI, as well as complex kinetic maneuvers, or kMRI. The present MRI unit was intended to address these considerations. Both occult weight-bearing disease (e.g. focal intervertebral disc herniations, spinal stenosis), and kinetic-dependent disease (e.g. disc herniations, spinal stenosis, hypermobile instability) of a degen-

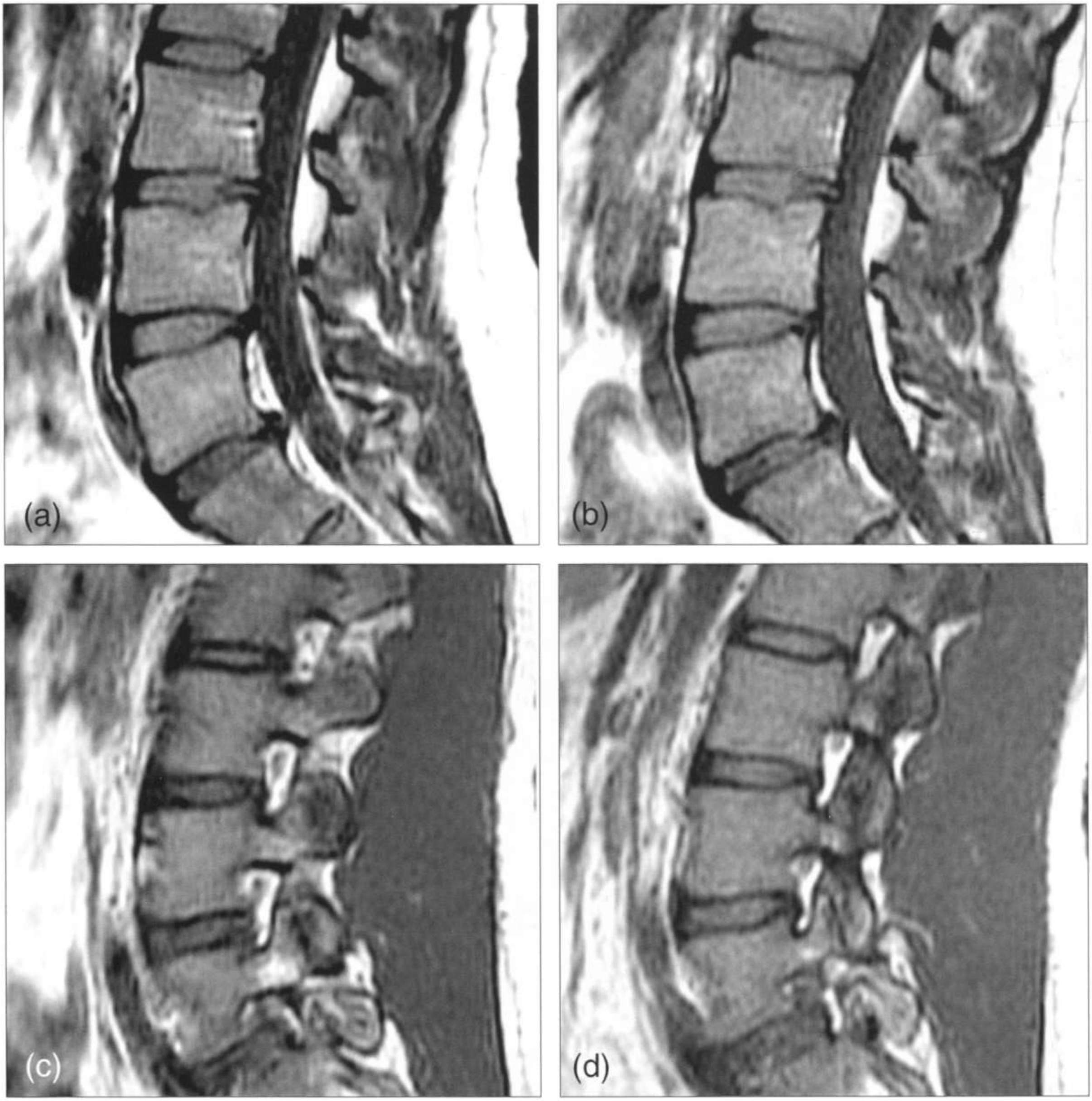

Figure 5. Effects of gravity on the intervertebral disc, thecal sac, and spinal neural foramina. (a) Recumbent midline sagittal T1-weighted fast-spin echo MRI (rMRI) shows a focal disc herniation at L5/S1 and mild narrowing of the superoinferior disc height at this level. (b) Upright-neutral midline sagittal T1-weighted fast-spin echo MRI (pMRI) shows minor further narrowing of the height of the L5/S1 intervertebral disc and further, minor posterior protrusion of the disc herniation at this level. Also note the generalized expansion of the thecal sac because of gravity-related hydrostatic CSF pressure increases and the consonant decrease in the dimensions of the anterior epidural space. (c) Recumbent midline sagittal T1-weighted fast-spin echo MRI (rMRI) on the patient's left side shows narrowing of the L5/S1 spinal neural foramen as a result of posterior disc protrusion, intervertebral disc space narrowing and paradiscal osteophyte formation. (d) Upright-neutral midline sagittal T1-weighted fast-spin echo MRI (pMRI) on the patient's left side reveals generalized narrowing of all of the spinal neural foramina, including the L5/S1 level, as compared to the recumbent examination.

erative nature were unmasked by the p/kMRI technique. In addition, a true assessment of the patient's sagittal spinal lordotic curvature was possible on neutral upright pMRI, thereby enabling better evaluation of whether the loss of curvature was due to patient positioning (i.e. rMRI) or as a probable result of somatic cervical muscular guarding or spasm.

It was noted that all cases of fluctuating interverte-

Figure 6. Hypermobile spinal instability associated with degenerative anterior spondylolisthesis. (a) Recumbent midline sagittal T1-weighted fast-spin echo MRI (rMRI) shows minor, less that grade I, anterior spondylolisthesis at the L4–L5 level. The pars interarticularis was intact on both sides at this level. (b) Upright-neutral midline sagittal T1-weighted fast-spin echo MRI (pMRI) reveals minor worsening of the anterior slip of L4 on L5, as compared to the recumbent examination. (c) Upright-flexion midline sagittal T1-weighted fast-spin echo MRI (kMRI) demonstrates further anterior subluxation of L4 on L5 in flexion, as compared to a and b.

bral disc herniation had MRI signal loss compatible with desiccation as well as intervertebral disc space height reduction. These disc findings were also invariably true in cases of fluctuating central spinal canal and spinal neural foramen stenosis, and hypermobile spinal instability. It was possible to judge even minor degrees of hypermobile spinal instability grossly as well as by using region of interest measurements. This p/kMRI technique obviously does not suffer from the effects of magnification error potentially inherent in conventional radiographic dynamic flexion–extension studies traditionally used in these circumstances.

The images of the cervical and lumbar spine suffered very little from motion artifacts from either CSF or body origin; no study was degraded to the

Figure 7. Postoperative intersegmental fusion stability (4 years status-post clinically successful interbody bone graft fusion). (a) Upright-neutral midline sagittal T1-weighted fast-spin echo MRI (pMRI) shows the surgical fusion at C5–C6; autologous bony dowels were used for the original fusion performed 4 years prior to the current examination. Note the normal bony intersegmental alignment and postural sagittal lordotic curvature. Also note the posterior focal disc herniation at the T2–T3 level. (b) Upright-neutral midline sagittal T2-weighted fast-spin echo MRI (pMRI) again shows the intersegmental fusion. Note the good CSF spatial dimensions surrounding the spinal cord. The prominent disc herniation is again noted at the T2–T3 level. (c) Upright-flexion midline sagittal T2-weighted fast-spin echo MRI (kMRI) shows no intersegmental slippage at, suprajacent to, or subjacent to the surgically fused level. Note the maintenance of the anteroposterior dimension of the central spinal canal. Also note that the T2–T3 disc herniation is somewhat smaller on this flexion study as compared to b or d. (d) Upright-extension midline sagittal T2-weighted fast-spin echo MRI (kMRI) again reveals no intersegmental hypermobile instability or central spinal canal compromise at any level.

point of being uninterpretable. Patient motion was not a problem, this being overcome by simply placing the scan table at 5° posterior tilt enabling the patient to 'rest' against the table during the MRI acquisitions. The chemical shift artifact was minor on all images, this being directly related to field strength; this effect would be expected to be less than one-half that experienced at 1.5 T.

Figure 8. Lateral bending maneuver (example: normal case). Standing lateral-bending coronal T1-weighted fast-spin echo MRI (kMRI) shows normal right lateral bending of the spinal column in this volunteer.

To conclude, the potential relative beneficial aspects of upright, weight-bearing (pMRI), dynamic–kinetic (kMRI) spinal imaging on this system over that of recumbent MRI (rMRI) include: clarification of true sagittal upright neutral spinal curvature unaffected by patient positioning, revelation of occult degenerative spinal disease dependent on true axial loading (i.e. weight-bearing), unmasking of kinetic-dependent degenerative spinal disease (i.e. flexion–extension), and the potential ability to scan the patient in the position of clinically relevant pain. This MRI unit also demonstrated low claustrophobic potential and yielded high-resolution images with little motion/chemical artifact.

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