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IDEAS AND TECHNICAL INNOVATIONS

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Functional MRI of the spine: different patterns of positions of the forward flexed lumbar spine in healthy subjects

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Abstract Since the introduction of the technique of vertical open-configuration systems, efforts have been made to obtain functional lumbar spinal magnetic resonance (MR) images. The purpose of this study was to determine the relation between facet joint orientation and flexion patterns in the lower lumbar spine. Thirty-four normal subjects (18 women, 16 men) were examined in a vertical open 0.5-T MR scanner with T1-weighted gradient echo (GE) sequences. Flexion angles were digitally measured in the sagittal plane and facet joint orientation in the axial plane. The population showed three different functional flexion patterns: 17.6% (*n*=6) had kyphotic angles in all three lower lumbar levels during forward flexion (type 1), 50% (*n*=17) had a lordotic angle at L5/S1 but kyphotic angles at L4/L5 and L3/L4 (type 2), and 32.4% (*n*=11) showed lordotic angles at L5/S1 and L4/L5 but a kyphotic angle at L3/L4 (type 3). There were statistically significant differences between flexion patterns and mean facet joint orientation: at L4/L5 33.3° for type 1, 33.5° for type 2 and 46.2° for type 3; at L5/S1 27.2° for type 1, 46.4° for type 2 and 48.1° for type 3. There were no significant differences between the three groups at L3/L4. The three different flexion patterns in normal subjects and their relation to facet joint orientation have not been described previously. Knowledge of these patterns may lead to a better understanding of physiological spinal movement as a base for future investigations in low back pain patients.

Keywords Lumbar spine · Functional MRI · Flexion-extension · Functional types

Introduction

Imaging of the flexed and extended spine has been carried out since the first half of the 20th century using lateral radiographs [3, 8]. With this technique, the examined subject is exposed to ionizing radiation with no assessment of soft tissues or axial plane imaging. Magnetic resonance imaging (MRI) provides excellent anatomical details in all planes without exposure to ionizing radiation. In the past, restrictions existed for functional lumbar spinal imaging, because of the systems' configuration. With the development of open MR scanners this problem has been partly overcome [4, 6, 9]. Because of ongoing developments and improvements in image quality, it is possible to reduce motion artifacts by decreasing acquisition time. Although functional MRI of the lumbar spine is not yet a standard diagnostic procedure, in the future it is likely to be used for diagnostic entities such as discoligamentous instability or position-dependent spinal stenosis.

To assess pathological findings by a new diagnostic method, it is necessary first to investigate physiological conditions. The purpose of this study was to establish the best setup for MRI of the forward flexed lumbar spine, describe the findings in a group of asymptomatic subjects and correlate them with the orientation of the facet joints.

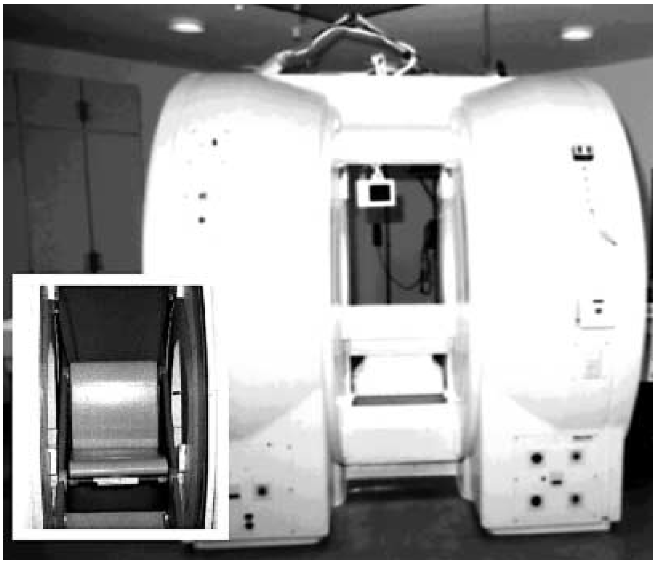

Fig. 1 Vertical open magnetic resonance imaging (MRI) system GEMS Signa SP.5T and amagnetic chair for the examination (inlet)

Materials and methods

Subjects

Thirty-four volunteers (18 women, 16 men), with no symptoms of low back pain, were recruited for this investigation. The mean age was 25.4 years (range 20–33 years). There were two physical limitations due to the scanner's configuration: only volunteers with a height less than 190 cm and waist width of less than 50 cm could be included. Exclusion criteria were: transitional lumbosacral vertebrae, significant degenerative changes and/or other anatomical abnormalities.

MR imaging

A superconducting open-configuration MR system (Signa SP.5T by General Electric Medical Systems, Milwaukee, Wisc.) was used to acquire images (Fig. 1). The unit consists of two vertical donut-shaped cryostats with a distance between them of 58 cm. Between the cryostats a chair was installed. The subject's lumbar spine was placed within the center of the magnetic field by adjusting the height of the chair. A flexible rectangular transmit-receive surface coil was fixed onto the volunteer's back. To keep a stable position during the scans in flexion (Fig. 2) a rod was installed in front of the chair at the height level of the seat. The subjects had to put their feet on it to reach rectangular bending in hip and knee joints. The arms were placed under the hollow of the knee, while each hand held the opposite elbow. In this position flexion was actively supported.

Images in different positions (sitting neutral, sitting with flexion, sitting with extension, sitting with axial rotation) were obtained to determine range of motion (these results are presented in a forthcoming study). For this study, we analyzed flexion images. Motion artifacts were reduced by using a T1-weighted gradient echo sequence (TR=150 ms, TE=3.4 ms, flip angle 90°, FOV 24×18 cm, slice thickness 10 mm, matrix 256×192, NEX 2) with an acquisition time of 44 s. Images were obtained in the sagittal plane as well as in the axial plane to display the facet joints.

Measurements

The computer work station of the MR scanner was used to measure angles digitally. The amount of flexion of two adjacent vertebrae was obtained from the angle between their cranial endplates (Fig. 4A, 5A, 6A) as suggested by White and Panjabi [7]. For mathematical differentiation between flexion and extension we used positive values for kyphotic angles and negative values for lordotic angles. The orientation of the facet joints was gained as shown in Fig. 3 using the method of Grobler et al. [1].

Results

All subjects accepted the sitting position and were able to maintain it during the scan.

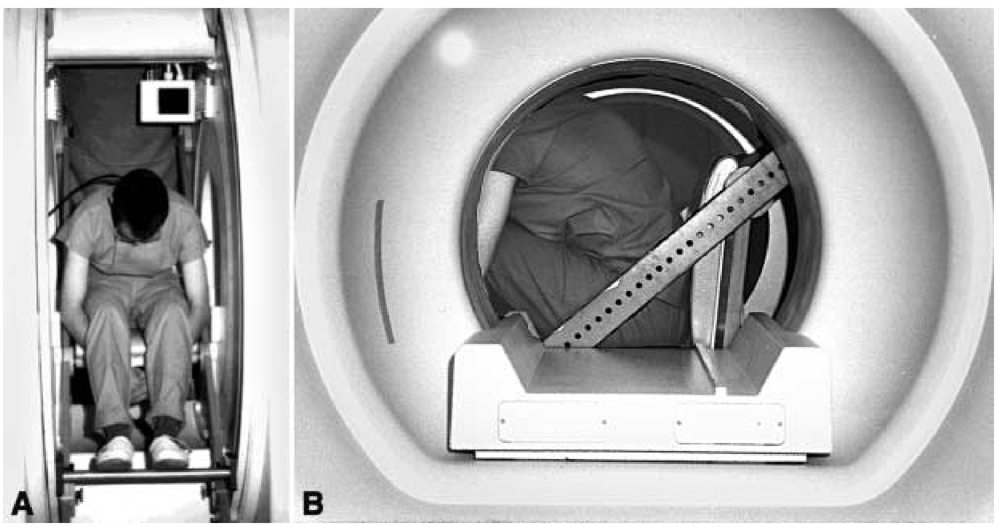

Fig. 2 Frontal (**A**) and lateral (**B**) view during the scan

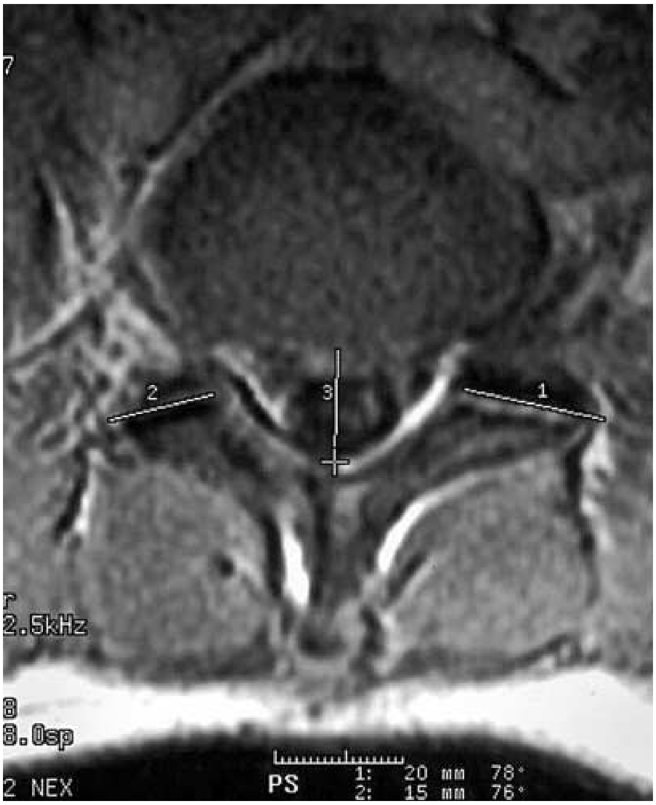

Fig. 3 Measurement of facet joint orientation. These are the facet joints at L5/S1 of a subject from the type 1 group

Functional types of flexion

We classified three different patterns of position of the lower lumbar spine in forward flexion.

Type 1 (Fig. 4). In all lower lumbar motion segments (L3–S1) the angle between cranial endplates is positive (kyphotic) or at least 0° (parallel endplates). Type 1 occurred in six subjects (17.6% of all cases, 5.9% of the men, 11.8% of the women).

Type 2 (Fig. 5). In the segments L3/L4 and L4/L5 the angle between cranial endplates is positive (kyphotic) or at least 0° (parallel endplates) and there is a negative (lordotic) angle between cranial endplates of L5/S1. Type 2 occurred in 17 subjects (50% of all cases, 29.4% of the men, 20.6% of the women).

Type 3 (Fig. 6). In the L3/L4 segment, the angle between cranial endplates is positive (kyphotic) or at least 0° (parallel endplates), and there is a negative (lordotic) angle between cranial endplates of L4/L5 and L5/S1. Type 3 occurred in 11 subjects (32.4% of all cases, 11.8% of the men, 20.6% of the women).

With these different patterns of positions, we subdivided the subjects into three groups and analyzed the orientation of the facet joints separately for each group.

Analysis of facet joint angles

At the L3/L4 level, where all functional types reached kyphosis, there was no significant difference (*t*-test for equal variances) between the three types in facet joint orientation. Mean values of the measured facet joint angles were: 50.5° for type 1, 46.7° for type 2 and 51.4° for type 3 (related to the frontal plane).

At L4/L5, where types 1 and 2 in flexion reached kyphotic angles and type 3 had a lordotic configuration, there were significant differences between types 1 and 3

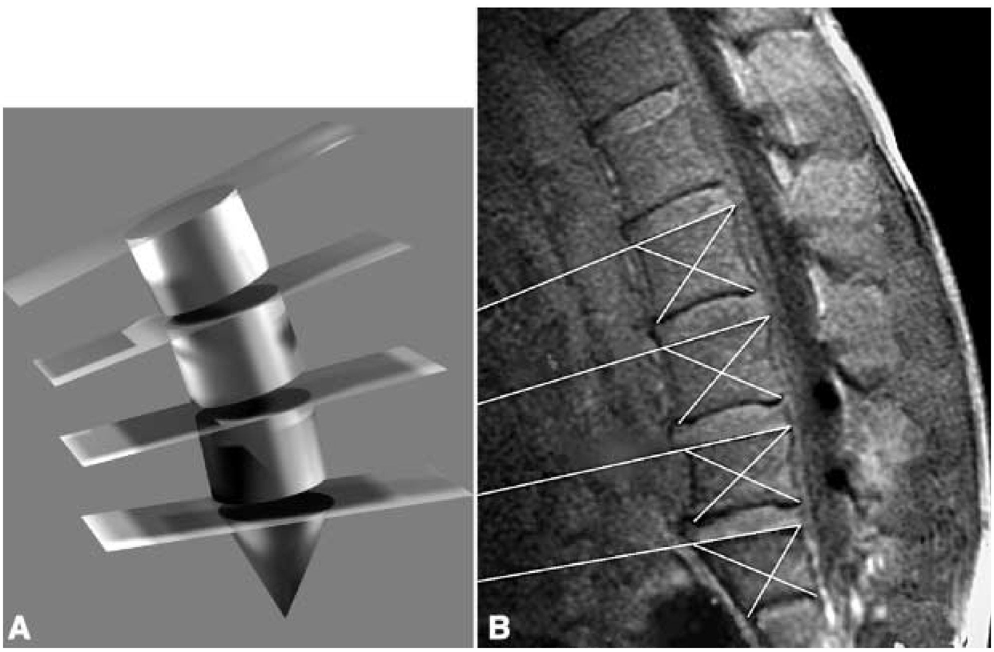

Fig. 4 A, B Flexion type 1: kyphosis at L3/L4, L4/L5 and L5/S1 (converging of the endplate planes at all three levels). **A** Schematic and **B** MR image

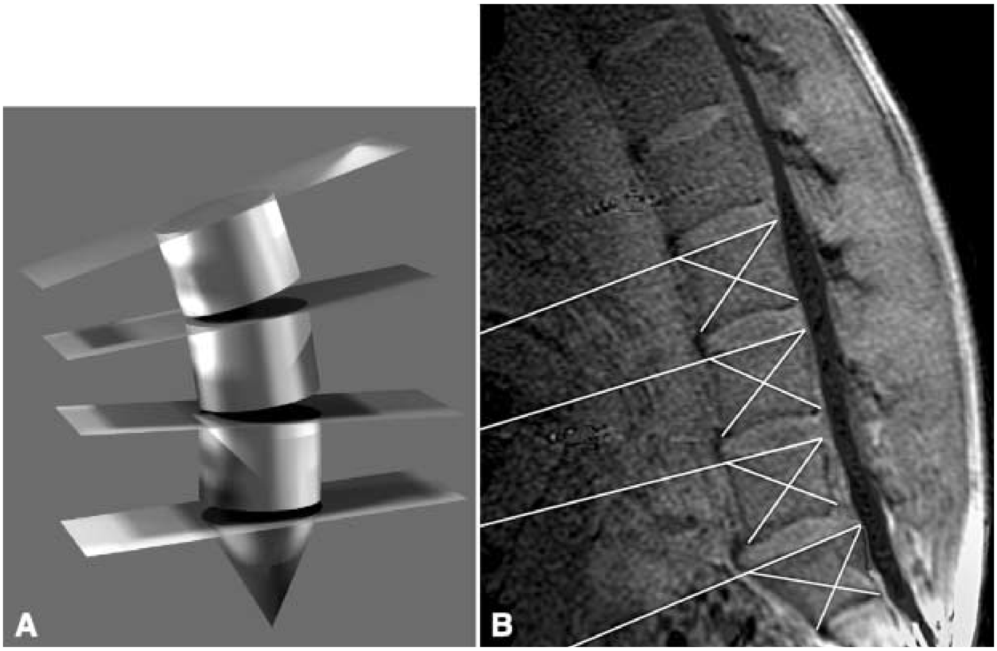

Fig. 5 A, B Flexion type 2: kyphosis at L3/L4 and L4/L5, but lordosis at L5/S1 (converging planes at L3/L4 and L4/L5, diverging planes at L5/S1). **A** Schematic and **B** MR image

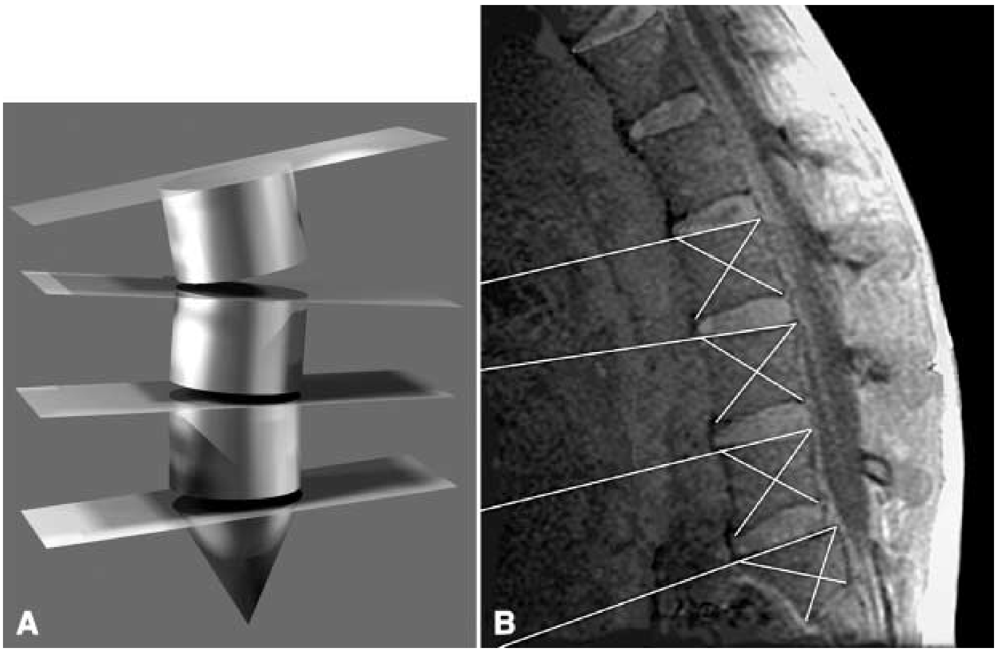

Fig. 6 A, B Flexion type 3: kyphosis at L3/L4, but lordosis at L4/L5 and at L5/S1 (converging planes at L3/L4, diverging planes at L4/L5 and at L5/S1). **A** Schematic and **B** MR image

($P<0.001$) as well as between types 2 and 3 ($P<0.001$), but not between types 1 and 2. Mean values of facet joint angles (related to the frontal plane) were: 33.3° for type 1, 33.5° for type 2, and 46.2° for type 3.

At the L5/S1 level, where only type 1 reached kyphosis, there were significant differences between types 1 and 2 ($P<0.001$) as well as between types 1 and 3 ($P<0.001$), but not between types 2 and 3. Mean values of facet joint angles (related to the frontal plane) were: 27.2° for type 1, 46.4° for type 2, and 48.1° for type 3.

The distribution of facet joint angles and flexion types of all subjects is shown in a three-dimensional scatter graph (Fig. 7).

In summary, it was established that in the two lowest lumbar levels under flexion stress, kyphosis was reached if the orientation of the facet joints had a more frontal orientation (i.e., the angle was less than 45°).

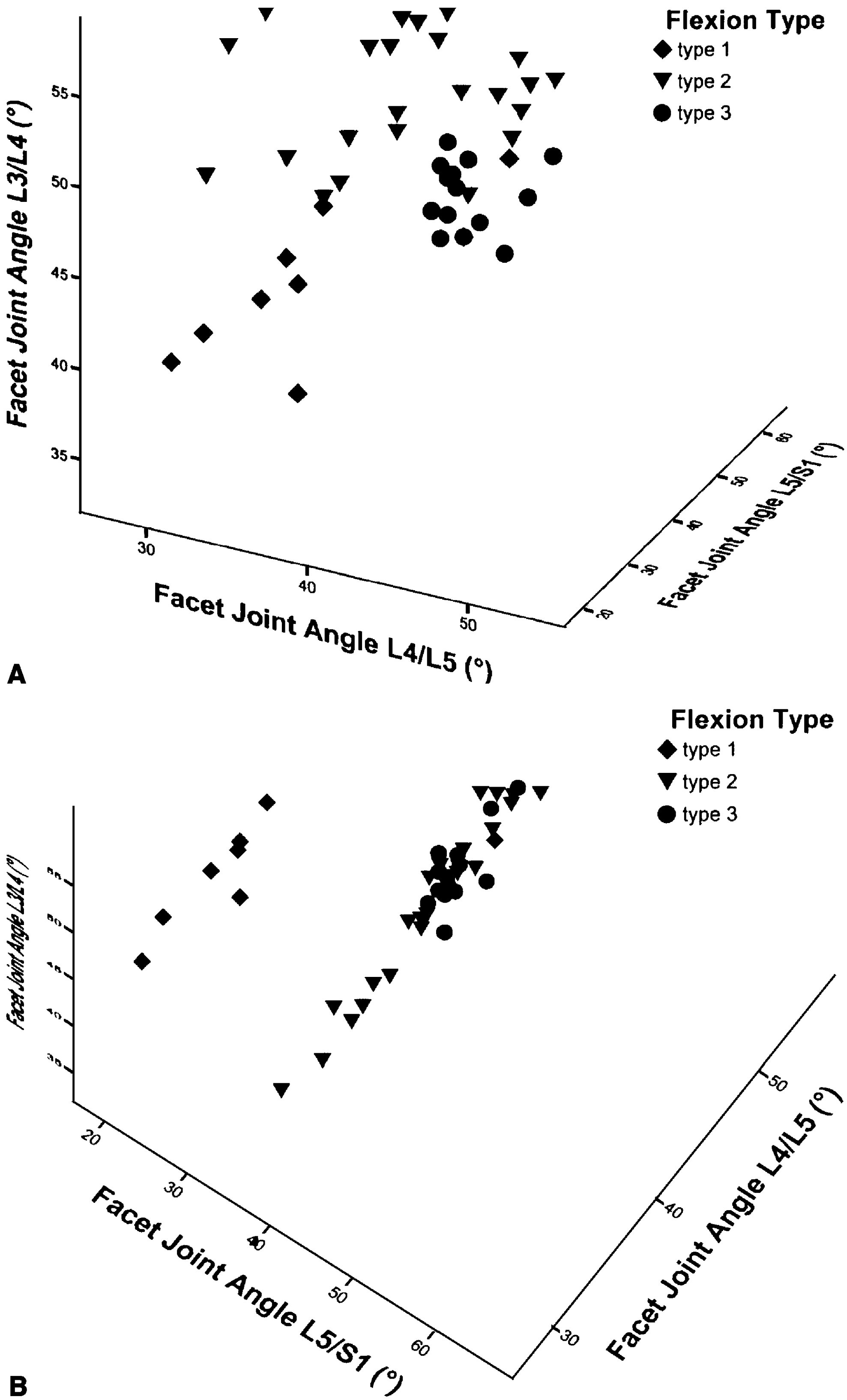

Fig. 7 A, B Three-dimensional analysis of the distribution of facet joint orientation. Type 1 is significantly separated from types 2 and 3 at L5/S1 (**A**). At L4/L5 there is a significant difference between types 1/2 and 3 (**B**)

Discussion

To our knowledge, the three different functional patterns of flexion of the lower lumbar segments have not been described previously in the literature. Although Harvey et al. [4] investigated functional flexion-extension MR images and described natural variation in the sagittal spine contour, they did not mention the special patterns of positions found in our study. These different types were reproducible in 100% of the ten subjects who were examined twice by one single examiner. Though we are aware of the poor test-retest reliability of lumbar spine motion measurements in general, as mentioned by Mayer et al. [5], the high level of reproducibility in the present study was due to the classification of results into three clearly defined types.

In our study we established the relationship between flexion pattern and facet joint orientation, measured in axial plane MR images. There was a statistically significant difference in mean facet joint angles for type 1 (27.2°) against types 2 (46.4°) and 3 (48.1°) at L5/S1 and for types 1 (33.3°) and 2 (33.5°) against type 3 (46.2°) at L4/L5, showing that a more frontal facet joint orientation (less than 45°) promotes flexion in the two lowest lumbar levels of the spine. Since one single examiner studied facet joint obliquity, we suppose there is sufficient reliability of the data, because Gunzburg et al. found no significant difference in repeated measurements from lumbar spine computed tomography (CT) scans [2].

The influence of facet joint angles linked to individual constitutional parameters for spinal curvatures and kyphotic/lordotic segmental changes during flexion/extension has not been sufficiently taken into account. In the presence of pathologic conditions, with associated functional deficits, this may be extremely useful in the planning of treatment. Another aspect that will be analyzed in a forthcoming study is the increased or decreased axial rotation present in a degenerated segment.

Conclusion

The knowledge of special flexion patterns described in this study may be important for the understanding of physiological spinal movement properties as a base for investigation of low back pain patients with functional MRI. Improved image quality together with reduced acquisition time may help to establish functional spine examinations in open-configuration MR scanners as the standard diagnostic procedure of the future, without the need for exposure to radiation.

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