Dynamic examination of the lumbar spine by using vertical, open magnetic resonance imaging

HANS-EKKEHART VITZTHUM, M.D., PH.D., ALEXANDER KÖNIG, AND VOLKER SEIFERT, M.D., PH.D.

Klinik und Poliklinik für Neurochirurgie der Universität Leipzig, Leipzig, Germany

Object. The aim of this study was to determine the relationship of different structures of the lower lumbar spine during interventional movement examination.

Methods. Clinically healthy volunteers and patients suffering from degenerative disorders of the lumbar spine underwent vertical, open magnetic resonance (MR) imaging (0.5 tesla). Three functional patterns of lumbar spine motion were identified in 50 healthy volunteers, (average age 25 years). The authors identified characteristic angles of the facet joints, as measured in the frontal plane. In 50 patients with degenerative disorders of the lumbar spine (41 with disc herniation, five with osteogenic spinal stenosis, and four with degenerative spondylolisthesis) the range of rotation was increased in the relevant spinal segments. Signs of neural compression were increased under motion.

Conclusions. Dynamic examination in which vertical, open MR imaging is used demonstrated that the extent of neural compression as well as the increasing range of rotation are important signs of segmental instability.

Abbreviation used in this paper: MR = magnetic resonance.
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Clinical Material and Methods

A specially designed chair fitting inside the magnets of a 0.5 tesla, open MR imaging unit (Signa SP; General Electric Medical Systems, Milwaukee, WI) permits dynamic examination of the lumbar spine (Fig. 1). The pulse sequences are T₁-weighted fast multiplanar gradient–echo sequences (TR 150 msec, TE 3.4 msec, flip angle 90°, field of view 24 × 28 cm, slice thickness 10 mm, matrix 256 × 192).

The best imaging quality is obtained by using a short acquisition time (44 seconds), although a short acquisition time does restrict image quality. To compare the measurement between volunteers and patients, standardization of the path and range of motion is essential (Figs. 2 and 3). The range and path of motion must be controlled and maintained for more than a minute; therefore, a standard range of motion defined for this purpose cannot attain the maximum individual range of motion.

The mobility of the lumbar vertebral bodies during extension–flexion within the sagittal plane is assessed according to the parameters described by White and Panjabi.9 Kyphotic variations are characterized by positive degrees of angle and lordotic variations by negative values (Fig. 4).

Axial rotation is described as the degree of rotation of the median cross section relative to the adjacent vertebrae (Fig. 5). We evaluated the axial MR images by measuring the articular facet angles separately for the left and right side, relative to the frontal plane (Fig. 6).

Healthy Volunteers

Fifty healthy volunteers were examined. There were 22 women and 28 men between 22 and 28 years of age (average 25 years; Table 1). No volunteer had a history of lumbar spine disease or complained of lumbar spine–related complications at the time of examination. The MR images were acquired in the lower part of the lumbar spine between the L-3 and S-1 vertebral bodies, as this is the most relevant region for degenerative conditions of the vertebral column.

Patient Population

Fifty patients were examined. There were 20 women and 30 men between 34 and 71 years of age (average 53 years); the mean body weight was 69 kg (range 58–96 kg) and body length averaged 1.72 m (1.64–1.89 m). All patients suffered from monosegmental clinical symptoms that were correlated with the MR imaging finding, indicating that decompression of the lumbar nerve roots was required.

In eight patients the affected segment was at the L3–4 level, in 28 at L4–5, and in 14 at L5–S1. Classified in terms of preoperative diagnosis, there were 41 cases of lumbar disc herniation, five cases of lateral osteogenic recess stenosis, and four cases of degenerative spondylolisthesis (Wiltse Type III).

Statistical Analysis

The statistical analysis was performed with the Kolmogoroff–Smirnov test, Kruskal–Wallis test, Mann–Whitney U-test, t-test, Spearmann rank test, and Pearson test by using the system SPSS 7.0.

Results

Healthy Volunteers

Fifty healthy volunteers were examined using the aforementioned procedure. During anteflexion, three clearly distinct functional patterns could be distinguished, which were always reproducible and not correlated to sex, body length, or body weight (not significant).

The Type I pattern was a harmonic kyphotic pattern of the lumbar spine that was demonstrated following anteflexion. In only eight volunteers (approximately one of six volunteers) anteflexion resulted in a harmonic kyphotic change of each of the three intervertebral spaces with segmental angles between +3° and +8°, with a mean total flexion of +15° (Fig. 7 upper). The Type II pattern was an anteflexion-induced lordotic compensatory shift at L5–S1. In half of all volunteers (25 cases) anteflexion yielded angles in the range of 0 to 9° at the L5–S1 level, which indicated a lordotic compensatory shift of this segment. Accordingly, we found positive angles between +3° and +9° above L5–S1 (Fig. 7 center). The Type III pattern was an anteflexion-induced lordotic compensatory shift of the last two lumbar segments.
In one third of volunteers (17 cases) a kyphotic segmental change was demonstrated during anteflexion exclusively in the L3–4 level with positive angles in the range of +6° and +10°, whereas the L4–5 and L5–S1 segments presented negative angles as a result of a lordotic compensating motion (Fig. 7 lower).

Measurements of segmental rotation of the three lowermost lumbar segments again indicated characteristic differences among the three functional patterns. The total angle of rotation between S-1 and L-3 increased from 7 to 10°. However, a correlated harmonic rotational displacement of each of the three lumbar segments was observed only in volunteers with the Type I pattern. The average rotation per spinal segment was 3°. Although it reaches the same total angle of rotation, the L5–S1 segment in volunteers with the Type II pattern adds only 1° to the total rotation, whereas L4–5 and L3–4 contribute 3° and 4°, respectively. In the Type III pattern, a decreased rotational capacity in the L4–5 and L5–S1 segments was found with a mean value of only 1° in contrast to the L3–4 segment, which exhibited a mean range of rotation of 5°.

Measurement of the articular facet angles within the examined area provided characteristic correlations to the three functional patterns (Table 2). Articular facet angles in volunteers with Type I patterns were found to be situated in rather frontal positions. At L5–S1 an average angle of 20° was observed. At L4–5 and L3–4 we found angles of 36° and 45°, respectively. The corresponding mean angles for volunteers with Type II patterns were 40° at L5–S1, 42° at L4–5, and 48° at L3–4. In volunteers with Type II patterns the facets are shifted to a more sagittal position: 45° at L5–S1, 47° at L4–5 and 53° at L3–4. There proved to be no significant differences between left and right sides.

The difference between the three types of flexion and the facet angles is significant (Kruskal–Wallis test p < 0.01); the correlation between the different types (except the facet angle at L3–4 in volunteers with Type I as compared with Type III patterns) is significant (Mann–Whitney U-test).
**Patient Population**

The dynamic open MR examination in patients suffering from monosegmental clinical symptoms was performed before surgical treatment. In 32 patients (with herniations of the intervertebral disc and degenerative spondylolisthesis exclusively) dynamic examination of flexion–extension contributed important additional information to the preliminary diagnosis (Fig. 8). Data important to determining a preliminary diagnosis were also provided by dynamic rotation examination performed in five patients with herniations of the intervertebral disc (Fig. 9).

Measurement of the angular position of the facet joints in 41 patients with herniation of the intervertebral disc (eight cases of L3–4, 21 cases of L4–5, and 12 cases of L5–S1) resulted in the following mean values: L3–4, 42° (range 40–46°); L4–5, 32° (range 30–40°); and L5–S1, 25° (range 20–32°) (Table 3).

In 36 patients (88%) with nerve root syndrome (herniations of the intervertebral disc) the facet joint of the affected segment was shifted to a more frontal position compared with that of the opposite side (Fig. 10).

In the five patients with lateral recess stenosis (L4–5 in four cases and L5–S1 in one case) the facet angles averaged 30° (range 28–32°) in two cases with L4–5 stenosis and 21° in the case with L5–S1 stenosis. A clear difference between the left and right side was evident only in the latter case (6° in favor of the affected side).

In the four patients with degenerative spondylolisthesis (L4–5 in three cases and L5–S1 in one case) the mean facet angles were 30° (range 28–32°) at L4–5 and 17° at L5–S1. Clear lateral differences could not be observed. Based on a comparison with the results obtained in healthy volunteers,
the latter functional patterns were classified as Type I. The smaller the facet angles (that is, the facet joints positioned more frontally), the bigger is the disposition for grave degenerative malfunction of the affected segment. In cases of dorsolateral prolapse, even the affected side is characterized by a more frontal position of the joint.

During flexion–extension examination, severe deficiencies were demonstrated in all patients with regard to flexibility of the affected segment (range 0–1°) independent of the affected vertebral level and degenerative changes. In five cases with osteogenic lateral recess stenosis and four cases with degenerative spondylolisthesis, rotation angles of 3 to 4° were measured in the affected region, whereas in patients with disc herniation increased angles of 5° were observed. Of the patients with disc herniation, the maximum attainable rotation of L4–5 was found to be 11° in one patient (Fig. 11).

It is concluded that in patients with degenerative disease of the spine an increased range of rotation in the affected segment with simultaneous deficiency in flexion–extension capacity is demonstrated and the characteristics of a Type I functional pattern are observed.

To acquire a better understanding of the compensatory functional changes, we examined adjoining vertebral segments. We observed articular facet angles of 30° (at L5–S1), 36° (at L4–5), and 45° (at L3–4) that corresponded to a functional pattern of the Type I class. There were no clear indications of angular differences between left and right sides. A mean positive angle of 3° (range 2–5°) was found for flexion–extension, whereas in three cases of L4–5 disc herniation negative angles of −2° were demonstrated at the adjoining lumbosacral junction. In the segments adjacent to the degeneratively changed segments in all 50 patients—dependent of the damaged re-

### Table 2

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<tr>
<th>Functional Pattern</th>
<th>Facet Angle (in degrees)</th>
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<tr>
<td></td>
<td>L3–4</td>
</tr>
<tr>
<td>Type I (8 volunteers)</td>
<td>44.62 ± 3.28</td>
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<tr>
<td>Type II (25 volunteers)</td>
<td>48.68 ± 3.35</td>
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<tr>
<td>Type III (17 volunteers)</td>
<td>53.00 ± 1.84</td>
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<tr>
<td>total (50 volunteers)</td>
<td>48.84 ± 2.85</td>
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* Values are presented as the mean ± standard deviation.
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Discussion

Our results of dynamic open MR examination in patients with degenerative conditions of the lumbar spinal column have to be considered as preliminary, because the number of cases is small with regard to patient variables.

To obtain objective and exact measurements of the various angles as well as to be able to compare the results, constant supervision and control of posture, movement, and position during the examination is essential. We gave preference to reproducibility and comparability over determination of the maximum range of motion. The measurements included flexion–extension capability within the sagittal plane and axial torsion; however, the present experimental design prevents examination of sideward flexion of the lumbar spinal column. Despite strict compliance to the same experimental procedure, a correlation of results between healthy volunteers and patients with

<table>
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<tr>
<th>Vertebral Level</th>
<th>Affected Segments</th>
<th>Flexion Rotation Facet Angle</th>
<th>Flexion Rotation Facet Angle</th>
<th>Flexion Rotation Facet Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>L3–4 (8 cases)</td>
<td>L3–4 (8 cases)</td>
<td>0.50 ± 0.53</td>
<td>4.88 ± 0.83</td>
<td>0.53 ± 0.83</td>
</tr>
<tr>
<td>L4–5 (21 cases)</td>
<td>L4–5 (21 cases)</td>
<td>0.39 ± 0.69</td>
<td>4.07 ± 0.49</td>
<td>0.27 ± 0.74</td>
</tr>
<tr>
<td>L5–S1 (12 cases)</td>
<td>L5–S1 (12 cases)</td>
<td>0.39 ± 0.69</td>
<td>4.07 ± 0.49</td>
<td>0.27 ± 0.74</td>
</tr>
</tbody>
</table>

* All values, except those shown in U-test columns, are presented as mean ± standard deviation.
† Statistically significant.
‡ Not statistically significant.

Fig. 9. Axial T1-weighted MR images obtained in a 38-year-old man with a clinically and radiologically confirmed dorsomedial L4–5 disc herniation before (left) and after rotation (right).

Fig. 10. Axial T2-weighted MR image demonstrating a typical case of L4–5 nerve root compression in a 50-year-old woman. The image demonstrates the asymmetrical facet joints and an accompanying shift in the ipsilateral facet joint to a more frontal position compared with the opposite side.
degenerative conditions is of limited significance because of the mean age difference between both groups.

Despite these restrictions and despite the attendant current high costs, we find these examinations with the open MR imaging attractive. For the first time, we can observe an individual live presentation of the morphological changes that occur during movements of the lumbar spine. Clearly this advantage leads to the improved ability to diagnose pathological/morphological conditions by using the precise documentation provided by the measured numerical data.

Conclusions

There exist three different functional patterns of lumbar spine motion (Types I, II, and III) that are based on measured articular facet angles, which are given by predisposition or morphological situation, and are independent of sex.

Individuals with a distinct frontal position of the facet joints are predisposed to degenerative malfunctions of the lumbar spinal column, especially if measurable differences are found between the facet angles at the left and right side. Degenerative malfunctions of the lumbar spine lead to a characteristic decrease of flexion–extension capability with a simultaneous increased range of rotation, which must be considered in any discussion of segmental instability. Examination of spinal segments adjacent to the affected level did not provide any indication of the often presumed hypermobility. A clear decrease of rotational capability is an indication of a compensatory functional reaction. Based on the preliminary experiences reported here, an improved definition of spinal segment instability and objective numerical data obtained on segmental mobility can be gained by conducting dynamic examinations in which open MR imaging is used.

References


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Address reprint requests to: Hans-Ekkehart Vitzthum, M.D., Ph.D., Klinik für Neurochirurgie der Universität Leipzig, Johannisallee 34, D-04103 Leipzig, Germany. email: vithe@server3.medizin.uni-leipzig.de.