Introduction: Development of the lumbar fusion technique has resulted in fusion rates approaching 95%, but this has not correlated with a comparable increase in successful clinical outcomes. Some of the recent literature questioned the efficacy of spinal fusion as the choice of operation of low back pain and lumbar spinal degeneration. Additionally, adjacent segment disease following spinal fusion in the long-term continues to be a concern. Lumbar spinal dynamic stabilization systems have been developed as the alternative to lumbar fusion to preserve the kinematics of the surgical segments and allow stabilization without bone grafting. Clinical outcomes of dynamic stabilization have been variable in the literature. Schnake et al. [1] reported similar clinical results as seen in fusion cases with pedicle screws, whereas Grob et al. [2] did not show better clinical outcomes when comparing dynamic stabilization to fusion. Range of motion of the dynamically stabilized segments has been reported to be less than that of intact level of the spine [3] and was controllable by the length of spacer used in the operation [4]. However, few studies have evaluated the kinematics of dynamic stabilization in vivo.

Radiostereometric Analysis (RSA) is an accurate in vivo measurement technique and has been used to examine spinal kinematics. The purpose of this study was to examine the kinematics of a dynamically stabilized segment over time using RSA. Two questions were examined with this study. (1) Would there be any changes in the kinematics over time? (2) How would the kinematics compare to other common lumbar procedures such as lumbar discectomy or posterior lumbar fusion?

Materials and Methods: Informed consent was obtained by each subject following approval by the Institutional Review Board. Four patients (2 males & 2 females, ages: 63.5 ± 11.3 yrs) with lumbar spondylosis with/without instability were enrolled to undergo dynamic stabilization (Dynesys® Dynamic Stabilization System, Zimmer Spine) with decompression at L3/L4, L4/L5 and/or L5/S1 (DYS group). Another four patients (2 males & 2 females, 64.8 ± 8.3 yrs) with the same diagnostic criteria were enrolled to undergo posterior lumbar fusion and pedicle screw fixation with decompression at L2/3, L3/4 and/or L4/5 (PLF group). Eight patients (4 males & 4 females, 49.2 ± 5.7 yrs) with lumbar disc herniation at either L4/5 or L5/S1 were enrolled to undergo lumbar discectomy (LD group). The patients were followed post-operatively at 1 month, 1 year and 2 years. Five levels from DYS, five levels from PLF and eight levels from LD were analyzed for this study.

Standard surgical technique was followed in this study population by four spine surgeons. During surgery, 3-5 tantalum beads (0.8 or 1.0 mm diameter) were implanted into the adjacent vertebra at the operated levels. At each post-operative follow-up, biplanar standing neutral (ST), forward bending (FB) and backward bending (BB) radiographs were obtained and segmental motions were calculated based on the relative motion of the superior vertebra to the inferior vertebra. Sagittal rotation (ROT), superior/inferior (SIT) and anterior/posterior (APT) translations were calculated for flexion (ST to FB), extension (ST to BB) and sagittal ROM (BB to FB). To address the first question of interest, each dependent variable (ROT, SIT and APT) for the three movements was submitted to a one-way MANOVA with time as a factor (1 month, 1 year, 2 years). For the second question, each dependent variable was submitted to a MANCOVA with type-of-operation (DYS, PLF and LD) as a testing factor and time as a covariate.

Results: Relating to the kinematic changes of a dynamically stabilized segment over time, there were no significant changes in any motions for any movements. Concerning the differences based on type of operation, there were significant main effects for type of operation in flexion (p=0.013), extension (p=0.021) and sagittal ROM (p=0.001). However, there were not any significant covariate effects in any tests. The post-hoc analyses revealed ROT and SIT of DYS were significantly smaller than those of LD in flexion (p=0.017, p=0.017) and sagittal ROM (p=0.002, p=0.004). SIT of DYS was significantly smaller than that of LD in extension (p=0.012). APT of flexion (p=0.01) and ROT of sagittal ROM (p=0.039) in PLF were significantly smaller than those of LD. Table 1 summarizes the differences in motion based on type of procedure.

Discussion: The segmental motions were significantly smaller than those of lumbar discectomy during sagittal movements. Previous studies demonstrated that Dynesys stabilization significantly decreased the magnitude of ROM after implantation in all directions in vitro [4] and in sagittal movements in vivo [5]. Additionally, the current study suggests that the decreased sagittal kinematics of a dynamically stabilized segment remains up to 2 years without significant changes over time. In comparison to fusion, there were no significant differences in sagittal kinematics with dynamic stabilization. The most distinctive motion preserved after dynamic stabilization was APT in sagittal movements. The premise behind dynamic stabilization is to control the abnormal motions and to restore physiologic load transmission to relieve pain and prevent adjacent segment disease. Injury to the spinal segment has increased the neutral zone in vitro and dynamic stabilization has been shown to restore the neutral zone to a magnitude less than that of the intact spine [4]. In the current study, the decreased ROT and SIT following dynamic stabilization during the sagittal movements may support the premise of controlling abnormal motions, although future studies would have to confirm this in comparison to unsymptomatic motion.


Table 1. Sagittal range of motion (in deg) of surgical segments based on type of lumbar surgery

<table>
<thead>
<tr>
<th>Type of Operation</th>
<th>DYS</th>
<th>PLF</th>
<th>LD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROT (deg)</td>
<td>5.5 (1.3)</td>
<td>5.8 (2.7)</td>
<td>5.9 (4.5)*</td>
</tr>
<tr>
<td>SIT (mm)</td>
<td>2.71 (1.49)</td>
<td>3.61 (1.76)</td>
<td>3.36 (2.04)*</td>
</tr>
<tr>
<td>APT (mm)</td>
<td>-0.05 (0.36)*</td>
<td>-0.42 (0.69)</td>
<td>-0.17 (0.16)</td>
</tr>
<tr>
<td>Extension</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROT (deg)</td>
<td>-3.1 (1.4)</td>
<td>-2.2 (1.6)</td>
<td>-1.3 (1.3)</td>
</tr>
<tr>
<td>SIT (mm)</td>
<td>-1.38 (0.53)</td>
<td>-1.91 (0.92)</td>
<td>-0.29 (0.25)*</td>
</tr>
<tr>
<td>APT (mm)</td>
<td>-0.48 (0.76)</td>
<td>-0.52 (0.48)</td>
<td>-0.26 (0.32)</td>
</tr>
<tr>
<td>Sagittal ROM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROT (deg)</td>
<td>2.6 (1.3)*</td>
<td>5.6 (2.6)</td>
<td>2.1 (1.3)*</td>
</tr>
<tr>
<td>SIT (mm)</td>
<td>1.73 (1.49)</td>
<td>2.68 (1.83)</td>
<td>-0.39 (0.84)*</td>
</tr>
<tr>
<td>APT (mm)</td>
<td>1.78 (0.79)</td>
<td>0.40 (0.62)</td>
<td>0.15 (0.31)</td>
</tr>
</tbody>
</table>

Note: * significantly different with LD