The impact of total lumbar disc replacement on segmental and total lumbar lordosis

Balkan Cakir *, Marcus Richter, Wolfram Käfer, Wolfhart Puhl, René Schmidt

Department of Orthopaedics and Spinal Cord Injuries, University Hospital Ulm, c/o Rehabilitationskrankenhaus Ulm (RKU), Oberer Eselsberg 45, 89081 Ulm, Germany

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Abstract

Background. One of the goals of total lumbar disc replacement is restoration of the physiological sagittal alignment. There is little evidence if this goal is reached in vivo and further affects the clinical outcome.

Methods. In 29 patients segmental lordosis and total lumbar lordosis were measured on X-rays pre- and postoperatively. The functional outcome was evaluated prospectively with the Visuell Analgoue Scale, Oswestry Low Back Pain Disability Questionnaire and Short Form 36 Health Survey Questionnaire.

Findings. Total disc replacement increased segmental lordosis significantly while total lumbar lordosis remained unchanged. Preoperative segmental/total lumbar lordosis was physiological in 52%/91% of the patients. Postoperatively these values changed to 72% for segmental- and 94% for total lumbar lordosis. No difference could be observed in clinical outcome measures in patients with physiological and unphysiological segmental lordosis.

Interpretation. Monosegmental total disc replacement increases the segmental lordosis in most of the cases while preserving the total lumbar lordosis which produces a decrease of lordotic angle in the adjacent segment(s). Although short term clinical results are not affected, the segmental lordosis increase and adjacent segment(s) alteration may influence long term outcome.

Keywords: Intervertebral disc replacement; Arthroplasty; Lumbar lordosis; Sagittal alignment

1. Introduction

There has been an increasing recognition of the importance of sagittal plane contour in the normal function of the lumbar spine in various disease states. Von-Lackum (1924) postulated an increase in the shearing strain at the lumbo-sacral junction due to an increase in the lordotic angle with concomitant poor posture and back strain. Splithoff (1953) comparing patients with and without back pain, concluded that those with pain had a decreased angle. Magora and Schwartz (1980) found that loss of lumbar lordosis is a good indicator of low back pain. With regard to the literature both extremes, hypo- and hyperlordosis, seem to be more often associated with low back pain than physiological lumbar lordosis. Therefore one of the main goals of spinal surgery is to restore or maintain a physiological alignment of the spine. Several studies dealt with the subject of coronar or sagittal alignment of the spine after different operative procedures (La Grone, 1988; Shufflebarger and Clark, 1992). An exception are “non-fusion procedures”, which are one of the last developments in spinal surgery. “Non-fusion technology” includes, beside other devices, the total disc replacement (TDR). There is little evidence if the goal of physiological sagittal alignment is achieved by TDR and if it further affects the clinical outcome.

* Corresponding author.
E-mail address: balkan.cakir@rku.de (B. Cakir).
The aims of this study were therefore (1) to evaluate the segmental and total lumbar lordosis before and after total disc replacement (2) to analyze the relevance of the measured values for the clinical outcome.

2. Methods

2.1. Patients selection

Patients were treated with TDR for symptomatic degenerative disc disease (DDD) or postdiscectomy syndrome (PDS). The inclusion criteria were as follows:

1. Low back pain for at least 12 months
2. Minimum 6 months of conservative therapy
3. Absence of facet joint arthrosis confirmed by CT
4. No pain relief after facet joint infiltration
5. Disc degeneration (black disc) confirmed by MRI
6. Absence of intraspinal scar tissue in MRI after PDS
7. Discography with positive “Memory pain”
8. Monosegmental degenerative disc disease

2.2. Implant design

The implant (ProDisc®, Synthes–Spine Solutions, NY, USA) consist of three implant components (2 plates, 1 polyethylene inlay) with a ball-and-socket joint principle. The forged cobalt–chrome plates, coated with pure titanium, are anchored with keel and spikes to the endplates. The inlay consists of ultra-high molecular weight polyethylene with three different heights (10 mm, 12 mm and 14 mm). Two different plate sizes (M: L) with two different angulations (6°, 11°) are available. The implant allows 13° of flexion and 7° of extension from the neutral position.

2.3. Operative technique

Surgery is performed through a retroperitoneal approach using a pararectal incision for level L3–L4 and L4–L5 or a horizontal incision for level L5–S1. After access to the anterior part of the disc space (Fig. 1A) the anterior longitudinal ligament and the anterior and posterior part of the anulus fibrosus is excised while preserving the lateral anulus (Fig. 1B). The TDR is inserted after preparation of the endplates to ensure a proper alignment of the prosthesis endplates on the vertebral endplates (Fig. 1C).

2.4. Computer-based X-ray study

X-ray films were taken using standard radiographic technique with the subject standing with his or her hands resting on a bar in front of the subject at the shoulder level pre- and postoperatively. The distance between the radiographic tube and the film was 110 cm, with a known magnification of 1.15. The radiographs were stored by a video camera-based image capture system (DiagnostiX, Basis 2048, GE Medical, Germany) in digital format on a personal computer. The software allows the examiner to draw separate lines through the endplates of the superior and inferior vertebral body of the curve. After these lines are drawn, the software automatically displays the angle formed by the lines. Standard Cobb measurements were made of the segmental lordosis (SL) at the operated level and the total lumbar lordosis (LL) pre- and postoperatively. The LL was measured from the upper vertebral endplate of L1 to the superior endplate of S1. From L1 to L5 the SL was measured from the upper vertebral endplate of the cranial vertebra to the lower vertebral endplate of the caudal vertebrae (Fig. 2A and B). At L5–S1 the SL was measured from the upper vertebral endplate of L5 to the superior endplate of S1.

The classification of SL and LL with regard to the literature (Gelb et al., 1995; Jackson and McManus, 1994; Wood and Schendel, 1996) was as follows for SL/LL:

- Insufficient: <16°/<41°
- Normative: 16–30°/41–75°
- Excessive: >30°/>75°

Two independent orthopedic surgeons evaluated the X-rays for any evidence of loosening, subsidence/migration of the TDR endplates and spontaneous fusion of the operated segment.

2.5. Clinical follow up

All patients had a minimum follow up interval of 12 months. Only 6° angulated prosthesis were included in the study.

Fig. 1. Operative technique. Access to the anterior part of the segment (A). Excision of the anterior longitudinal ligament, anterior and posterior anulus of the disc by preserving the lateral anulus (B). Situs after insertion of the prosthesis (C).
the study group to eliminate a prosthesis related impact on the results. The clinical outcome was evaluated pre- and postoperatively with the Visual Analogue Scale (VAS), Oswestry Low Back Pain Disability Questionnaire (OQ) and the Short Form 36 Health Survey Questionnaire (SF-36).

2.6. Data analysis

Differences in LL, SL and in the clinical outcome measures before and after surgery were tested by Wilcoxon matched-pairs signed-ranks tests. A P-value of less than 0.05 was considered statistically significant.

3. Results

Twenty-nine patients (19 female, 10 male) fulfilled the inclusion criteria. The mean (SD) age was 40.8 (6.4) years (range: 29–56) with a mean follow up interval of 15.3 months (range: 12–35). The diagnosis was DDD in 21 patients and PDS in 8 patients. The distribution of the inlay height with regard to the operated levels was as follows: 26 patients with 10 mm inlay (1* L3–L4; 8* L4–L5 and 17* L5–S1); two patients with 12 mm inlay (1* L4–L5, 1* L5–S1) and one patient with 14 mm inlay (L4–L5).

At the time of the study no signs of loosening, subsidence, migration or spontaneous fusion could be detected in any patient by the two independent observers. No significant change could be observed in the mean LL (pre-/postoperatively: 53.7°/55.9°; P = 0.084), but in the mean SL (pre-/postoperatively: 17.9/26.3; P < 0.001) after TDR. A significant improvement was achieved in all clinical outcome measures (Table 1).

When angulation changes of 5° or more were considered as a distinct change, four of 29 patients had a distinct increase of LL postoperatively, 23 patients had no change and two patients had a distinct loss of LL. Twenty-five of 29 patients had a distinct increase of SL postoperatively, four showed no change and none had a distinct loss of SL (Fig. 3).

The longitudinal changes of SL and LL are shown in Table 2. According to the beforementioned classification (see Section 2.4) preoperatively 52% normative SL changed to 72% normative SL postoperatively. Most of the patients had a normative LL pre- (91%) and postoperatively (94%).

Neither preoperatively nor postoperatively patients with physiological SL vs unphysiological SL differed in pre- and postoperative outcome measures (Tables 3 and 4).

4. Discussion

Four main conclusions can be drawn as preliminary results of the current study. After monosegmental TDR
The total lumbar lordosis did not change significantly. The segmental lordosis increases significantly in most cases. The significant increase in SL while maintaining the LL postoperatively indicates a change in the adjacent segment(s). The short term clinical outcome is not influenced by segmental lordosis changes.

The results of LL measurement of the current study are consistent with the reported data of Tropiano et al. (2003) who also could not observe a significant difference in LL postoperatively. After implantation of a ProDisc®-TDR in 53 patients (40 mono-, 11 bi-, 2 threesegmental) the average increase of LL was 5.2° (preOP[range]: 30–72°; postOP[range]: 46–72°). On the other hand Hopf et al. (2002) reported about an increase of 20.2% (7°) in LL in 25 patients after implantation of the Charité®-TDR (7 bi-, 18 monosegmental; preOP: 35.6°; postOP: 42.6°). It is noteworthy that the X-rays were taken in supine position which would account for the rather unphysiological low LL preoperatively and would make the data uncomparable to the current study.

Data regarding segmental lordosis after TDR was only reported by Hopf et al. (2002) with an average increase of 7° in 25 patients after implantation of the Charité®-TDR (7 bi-, 18 monosegmental; preOP: 35.6°; postOP: 42.6°). It is noteworthy that the X-rays were taken in supine position which would account for the rather unphysiological low LL preoperatively and would make the data uncomparable to the current study.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Preoperatively mean (SD)</th>
<th>Postoperatively mean (SD)</th>
<th>P-value</th>
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<tbody>
<tr>
<td>LL (°)</td>
<td>53.7 (11.7)</td>
<td>55.9 (10.2)</td>
<td>0.084</td>
</tr>
<tr>
<td>SL (°)</td>
<td>17.9 (7.4)</td>
<td>26.3 (7.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ΔLL (°)</td>
<td>2.2 (5.6)</td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ΔSL (°)</td>
<td>8.4 (4.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VAS</td>
<td>68.8 (11.3)</td>
<td>22.7 (21.7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>OQ</td>
<td>49.8 (14.0)</td>
<td>22.5 (20.1)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PCS-SF36</td>
<td>27.3</td>
<td>41.6</td>
<td></td>
</tr>
<tr>
<td>MCS-SF36</td>
<td>39.0</td>
<td>49.9</td>
<td></td>
</tr>
</tbody>
</table>

Values are mean ± SD. Wilcoxon matched-pairs signed-ranks tests.

LL = Cobb-angle of lumbar lordosis (L1–S1), SL = Cobb-angle of operated segment, Δ = values postoperatively – values preoperatively, VAS = Visuell analogue scale, OQ = Oswestry disability questionnaire, PCS-SF36/MCS-SF36 = Physical/mental component summary of SF 36.

Table 2

<table>
<thead>
<tr>
<th></th>
<th>Preoperatively</th>
<th>Postoperatively</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Insufficient*</td>
<td>Normative**</td>
</tr>
<tr>
<td>Insufficient*</td>
<td>1 [1]</td>
<td>11 [1]</td>
</tr>
<tr>
<td>Normative**</td>
<td>0 [0]</td>
<td>10 [26]</td>
</tr>
<tr>
<td>Excessive***</td>
<td>0 [0]</td>
<td>0 [0]</td>
</tr>
<tr>
<td>Σ</td>
<td>1 (3%)</td>
<td>21 (72%)</td>
</tr>
</tbody>
</table>


Total lumbar lordosis: Insufficient * <41°, normative ** 41–74°, excessive ***>74°.
crease of 11° after implantation of the unconstrained Charité–TDR. Comparison of our data (average increase of 8.4°) with the data reported by Hopf et al. (2002) are suggestive of prosthesis design related changes in SL. An unconstrained prosthesis like the Charité–TDR which allows a pure posterior translation seems to increase SL more than a constrained prosthesis like the ProDisc®. Huang et al. (2003) mentioned that the facet joints are loaded in extension and hypothesised that physiological posterior translation during extension has a facet-protective effect by decreasing facet loads. Therefore they conclude that a relative reduction of posterior translation in extension by a constrained TDR with a small radius of curvature would cause increased facet joint loads with extension. On the other hand, an unconstrained prosthesis that is free to translate during extension may find an equilibrium point between facet joint compression and capsuloligamentous tension. This may be a probable explanation that constrained prosthesis do not increase SL as much as unconstrained prosthesis due to early impingement in facet joints compared to unconstrained prosthesis. But this rather theoretical consideration is not proven yet and on the other hand the difference in SL may also be explained by different implant positions.

Regardless of prosthesis type (constrained vs unconstrained) in most cases TDR increases the SL postoperatively. In our study group implantation of a TDR restored “normative” SL in case of “insufficient” SL preoperatively and often increased SL to “excessive” in case of “normative” SL preoperatively. In fact, 86% of patients had an increase of SL when 5° was considered a significant change and no one had a decrease of SL (Fig. 3). Furthermore 85% of patients with “insufficient” SL preoperatively changed to “normative” SL postoperatively and 33% of patients with “normative” SL preoperatively changed to “excessive” SL postoperatively (Table 2). One should notice that the rate of patients changing from normative to excessive segmental lordosis would be 53% if the definition of normative would cover 14–27° (current study: 16–30°) as proposed by Akamura et al. (2003).

Theoretical several factors are contributing to the markedly increase in the SL after TDR. (1) The transection of the anterior longitudinal ligament (ALL) and the anterior part of the annulus fibrosus. (2) The movement of the center of rotation anteriorly.

Table 3
Influence of the preoperative segmental lordosis (physiological vs unphysiological) on the pre- and postoperative clinical status

<table>
<thead>
<tr>
<th>SL physiological preoperatively</th>
<th>SL unphysiological preoperatively</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n = 15); mean (SD)</td>
<td>(n = 14); mean (SD)</td>
<td></td>
</tr>
<tr>
<td>VAS pre-OP 66.9 (8.6) P = 0.001*</td>
<td>70.8 (13.7) P = 0.002*</td>
<td>0.252**</td>
</tr>
<tr>
<td>VAS post-OP 22.0 (21.2)</td>
<td>23.4 (23.1)</td>
<td>0.880**</td>
</tr>
<tr>
<td>OQ pre-OP 46.4 (11.5) P = 0.001*</td>
<td>53.4 (16.0)</td>
<td>0.102**</td>
</tr>
<tr>
<td>OQ post-OP 22.5 (21.9)</td>
<td>22.4 (18.8)</td>
<td>&lt;0.847**</td>
</tr>
</tbody>
</table>

VAS = Visuell analagoue scale; OQ = Oswestry disability questionnaire, SL physiological = segmental lordosis 16–30°, SL unphysiological = segmental lordosis <16° or >30°.

* Wilcoxon matched-pairs signed-ranks tests. ** Mann–Whitney, non-parametric test for independent samples.

Table 4
Influence of the postoperative segmental lordosis (physiological vs unphysiological) on the pre- and postoperative clinical status

<table>
<thead>
<tr>
<th>SL physiological postoperatively</th>
<th>SL unphysiological postoperatively</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n = 21); mean (SD)</td>
<td>(n = 8); mean (SD)</td>
<td></td>
</tr>
<tr>
<td>VAS pre-OP 69.0 (12.3) P &lt; 0.001*</td>
<td>68.1 (8.6)</td>
<td>0.793***</td>
</tr>
<tr>
<td>VAS post-OP 23.7 (23.1)</td>
<td>20.0 (18.8)</td>
<td>0.830**</td>
</tr>
<tr>
<td>OQ pre-OP 51.6 (13.7) P &lt; 0.001*</td>
<td>45.0 (14.6)</td>
<td>0.429**</td>
</tr>
<tr>
<td>OQ post-OP 22.1 (20.0)</td>
<td>23.5 (21.7)</td>
<td>&lt;0.793**</td>
</tr>
</tbody>
</table>

VAS = Visuell analagoue scale; OQ = Oswestry disability questionnaire, SL physiological = segmental lordosis 16–30°; SL unphysiological = segmental lordosis <16° or >30°.

* Wilcoxon matched-pairs signed-ranks tests. ** Mann–Whitney, non-parametric test for independent samples.
The simplified, theoretical explanation is given in Fig. 4A and B with regard to White and Panjabi (1990) who define a static equilibrium of a body in resting or in uniform motion under a given set of forces and moments. Therefore the preoperative static equilibrium results in a given SL (Fig. 4A). Shifting of the instantaneous axis of rotation (IAR) anteriorly (like after TDR) increase the lever arms (L) of posterior located ligaments (Fig. 4B). The segmental distraction after TDR results in generation or increase in posterior ligamentous forces (F) postoperatively. The lack of a counterpart due to resection of the ALL and anterior anulus results in an additional imbalance towards an extension bending moment at that level. In this simplified model the muscle forces are considered to be uniformly pre- and postoperatively. These theoretical considerations are supported by different publications in the literature. White and Panjabi (1990) stated that a ligament with a larger lever arm provides greater stability to the spine than one with a shorter lever arm. Therefore they concluded that the function of a ligament is dependent upon the location of IAR. Although there is no final evidence of the location of the IAR in the lumbar intervertebral joint, it seems to be anterior to the facet joints, and in the region of the posterior nucleus and anulus. Gertzbein et al. (1984), Pearcy and Bogduk (1988) and Mimura (1990) identified a locus of IAR that is located in the posterior half of the intervertebral disc. Hafer et al. (1992) showed that in intact specimen the IAR was located posterior to the anulus and in the midline, however, anterior to the facet joint. Finally studies on functional biomechanics of spinal ligaments stresses the importance of the ALL in providing resistance to motion and stability to the spine (Myklebust et al., 1988; Panjabi et al., 1982; Schendel et al., 1993).

There is no doubt that the results of this study have to be compared to long term clinical outcome measurements to verify the clinical relevance of an increase in SL while maintaining LL postoperatively. Especially due to the fact that unphysiological segmental lordosis did not affect short term outcome and excellent or good short term results have already been reported with constrained and unconstrained TDR (Bertagnoli and Kumar, 2002; Hopf et al., 2002). Nevertheless the importance of sagittal realignment after different operative procedures has been documented in clinical studies. A decrease of the sagittal spinal curvature indexes after fusion surgery was reported to increase the probability of segmental breakdown above and below the fusion level (Bridwell, 1996). Wedge-shaped cages (WSC) were introduced for different fusion operations and the impact of WSC geometry on segmental lordosis has already been demonstrated for anterior-lumbar-interbody-fusion (Weiner and Fraser, 1998) and postero-lateral-interbody-fusion cages (Gödde et al., 2003). In vitro biomechanical studies showed an increase in flexion–extension in adjacent segments.

![Figure 4](image-url)

Fig. 4. (A) In a simplified biomechanical model of “static equilibrium”, with uniformly muscle forces pre- and postoperatively, flexion bending moments [(W × LFBM) + anterior ligamentous resistance (FALL × LALL)] are equal to extension bending moments [(EBMMUS) + posterior ligamentous resistance (FPLL × LPLL + FCL × LCL + FISL × LISL)] (B) Situation after implantation of TDR. Decrease in the lever arm LFBM with decrease in flexion bending moments due to shifting of IAR anteriorly. Generation or increase of forces in the posterior ligamentous structures due to distraction (FPLL, FCL, FISL) which are directly proportional to the postoperatively increased lever arms (LPLL, LCL, LISL). Loss of anterior ligamentous forces (FALL) due to resection of anterior longitudinal ligament. Postoperatively an imbalance of flexion/extension bending moment towards extension will occur. Theoretically a new static equilibrium with increase in segmental lordosis will result (W = body weight; FBM = flexion bending moment; EBM = extension bending moment; MUS = extensor muscles; ALL = anterior longitudinal ligament; AF = anterior portion of anulus fibrosus; PLL = posterior longitudinal ligament; CL = capsular ligament of facet joint; ISL = interspinous ligament; SSL = supraspinous ligament; F = forces; L = lever arm; IAR = instantaneous axis of rotation).
322 unsatisfactory results after insertion of a Charité disc. Schlegel et al. (1996) hypothesized that incorrect sagittal alignment of a lumbar fusion probably causes degeneration at the adjacent level by inducing too much motion at that level. Umehara et al. (2000) recognized that the strain at the L3 lamina increased when lordosis was decreased in the instrumented segments L4–S1. Moreover van Ooij and McManus (1994) and Wood et al. (1996). The later would suffer from change in anatomic landmarks due to preparation of the endplates during surgery with change in endplate structure, which is still the case for L5–S1 in this paper.

With regard to the literature the definition of normative for SL and LL have a wide range. Therefore the classification system of SL and LL which was used in the current paper for further analysis was within the 95% confidence interval of values reported by those authors in the literature who used the same measurement technique.

5. Conclusions

Monosegmental TDR with the current prostheses design increases the segmental lordosis in most of the cases while preserving the total lumbar lordosis which produces a decrease of segmental lordosis in one ore more adjacent level(s). Although short term clinical results are not affected by unphysiological increase in SL, the unphysiological SL and adjacent segment(s) alteration may influence long term outcome. A prosthesis design with posterior center of rotation and preservation of the anterior structures could possibly lead to a more physiological sagittal alignment.

References


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