The impact of implantation technique on frontal and sagittal alignment in total lumbar disc replacement: a comparison of anterior versus oblique implantation

René Schmidt · U. Obertacke · J. Nothwang ·
C. Ulrich · J. Nowicki · H. Reichel ·
B. Cakir

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Abstract The concept of total lumbar disc replacement (TDR) is gaining acceptance due to good clinical short-term outcome. Standard implantation is strict anterior, which poses especially above the segment L5/S1 sometimes difficulties due to the vessel configuration. Therefore, oblique implantable TDR have been invented. In oblique implantation the anterior longitudinal ligament (ALL) is only partially resected, with additional partial resection of lateral annulus fibers. This could have an impact on biomechanical properties, which has not been evaluated until now. We therefore compared the standing ap and lateral X-rays pre- and postoperative after anterior and oblique implantation of TDR in segment L4/5. Significant differences between the groups were not found. In both the anterior and oblique group, segmental lordosis showed a significant increase, whereas total lordosis as well as ap balance were unchanged. The absolute segmental lordosis increase was nearly double in the anterior group. In conclusion, both anterior and oblique implanted TDR significantly increase segmental lordosis while retaining total lordosis and ap balance. The segmental increase is lower in the oblique implanted group which is probably due to the

remaining ALL. Further studies should evaluate whether this finding has any implication for the long-term outcome.

Keywords Total lumbar disc replacement · Anterior implantation · Oblique implantation · Sagittal alignment · Ap balance

Introduction

The concept of total disc replacement (TDR) is gaining acceptance due to good clinical outcome in several studies for different prosthesis types [1–6]. Despite good clinical results the *in vivo* biomechanics are only recently evaluated, with the main focus on range of motion [7, 8]. This is based on the hypothesis of a prevention of adjacent segment disease by motion preservation, which is the main concept of TDR.

Another parameter potentially affecting outcome is the sagittal alignment of the lumbar spine. In fusion patients changes of segmental and total lumbar lordosis seem to be more often associated with low back pain and possible enhanced rate of adjacent segment disease [9–13]. Le Huec et al. [14] postulated that lumbar disc replacement enables the spine to maintain its sagittal balance. But in the context of the ambition to determine the *in vivo* biomechanics of TDR, the sagittal balance of the lumbar spine has only lately attracted interest. Summarizing the current available evidence, the spine seems to be able to maintain total lumbar lordosis whereas the segmental lordosis of the implanted level increases after TDR [14–18]. One possible explanation is that in a strict anterior implanted TDR the resection of the anterior longitudinal ligament (ALL) and the anterior annulus as counterpart for posterior ligament forces is missing [17]. Recently, oblique implantable TDRs

R. Schmidt (✉) · U. Obertacke
Department of Orthopedics and Traumatology,
University Medical Center Mannheim, Mannheim, Germany
e-mail: rene.schmidt@gmx.de

R. Schmidt · J. Nothwang · C. Ulrich · J. Nowicki
Department of Orthopedics and Traumatology,
Klinik am Eichert, Göppingen, Germany

H. Reichel · B. Cakir
Department of Orthopedic Surgery, University of Ulm,
Ulm, Germany

have been invented primarily to ease the implantation of TDR, especially in the segment L4/5 due to the vessel configuration. The oblique implantation technique could affect total and segmental lordosis, as the ALL is only resected partially with additional resection of lateral annulus fibers on the side of the surgical approach. Having these facts in mind and based on the perception that alignment of the spine after lumbar TDR is of clinical relevance, it seems reasonable to evaluate the impact of implantation technique of the TDR (anterior vs. oblique) on sagittal and frontal balance of the spine. To our knowledge this potential correlation has not been evaluated until now.

Materials and methods

We evaluated retrospectively the patients with strict anterior implanted TDR (Prodisc-L, Synthes, Paoli, USA) and oblique implanted TDR (oblique Maverick, Medtronic Sofamor Danek, Memphis, USA). Inclusion criteria were implantation only in the segment L4/5, as well as no previous TDR or fusion of the lumbar spine. Implantation was performed with a left-sided standard retroperitoneal approach in supine position. The implantation of the TDR followed the manufacturer's recommendations. Pre- and postoperative standing antero-posterior (ap) and lateral X-rays were evaluated. Measurements were performed digitally with a specialized software (DiagnostiX, Basis 2048, Gemed, Freiburg, Germany). The following angles were determined pre- and postoperatively:

- total sagittal lumbar lordosis (TSL): from the upper endplate L1 to the sacral plateau,
- segmental sagittal lumbar lordosis (SSL): from the upper endplate L4 to the lower endplate L5,
- total antero-posterior lumbar balance (TALB): from upper endplate L1 to lower endplate L5,
- segmental antero-posterior lumbar balance (SALB): from the upper endplate L4 to the lower endplate L5.

If the endplates were not exactly visible ap, alternatively the pedicle eyes were used as reference points. The intra-observer reliability was measured in the oblique implanted TDRs with a time delay of 6 weeks, separated for the above mentioned angles.

Statistical analysis was performed with a specific software (SPSS, 16.0, Chicago, USA). Non-parametrical tests were used and the significance level was set at $p < 0.05$. Statistical analysis was done for the comparison of the above mentioned angles between pre- and postoperative values with the Wilcoxon signed-rank test. The Mann-Whitney test was used to compare the anterior and oblique group for distinctions. For that purpose the differences

between pre- and postoperative angles (postoperative–preoperative) were used.

Results

In the anterior implanted group 12 patients fulfilled the inclusion criteria and in the oblique implanted group 13 patients. Average age and standard deviation (STD) of the anterior and oblique group were 38.4 ± 7.9 years (10 females and 2 males) versus 44.7 ± 7.7 years (7 females and 6 males).

The 95% confidence interval (95% CI) for the intra-observer reliability was for the TSL measurement $\pm 3.8^\circ$, SSL $\pm 3.6^\circ$, TALB $\pm 2.8^\circ$ and the SALB $\pm 2.8^\circ$. For a descriptive presentation of clinically significant changes, which account for the measurement error, the differences between pre- and postoperative angle measurements were determined. Consequently, according to the 95% CI, an increase of e.g. postoperative TSL $> 3.8^\circ$ was defined as a veritable increase of TSL and a decrease of postoperative TSL $< -3.8^\circ$ as a veritable decrease of TSL. A change of postoperative TSL between these values was defined as no veritable change in TSL. The results of this categorical assessment are graphically presented for the anterior implanted group in Fig. 1 and the oblique implanted group in Fig. 2.

The average values for the angle measurements and the p value are shown in Tables 1 and 2. A statistically significant difference within the groups was only found for the comparison of the segmental sagittal lumbar lordosis in both groups (Tables 1, 2). When comparing the anterior and the oblique group no statistical differences were found for none of the measured parameters (Table 3).

Fig. 1 Postoperative change of sagittal and frontal alignment in the anterior implanted group (TSL total sagittal lumbar lordosis, SSL segmental sagittal lumbar lordosis, TALB total antero-posterior lumbar balance, SALB segmental antero-posterior lumbar balance)

Fig. 2 Postoperative change of sagittal and frontal alignment in the oblique implanted group (*TSLL* total sagittal lumbar lordosis, *SSLL* segmental sagittal lumbar lordosis, *TALB* total antero-posterior lumbar balance, *SALB* segmental antero-posterior lumbar balance)

Discussion

The anterior implantation technique is the standard approach for the insertion of total lumbar disc prosthesis. As this approach inevitably sacrifices the ALL and the insertion of the prosthesis above the level L5–S1 is

Table 3 Statistical comparison of postoperative changes in sagittal and frontal alignment parameters between anterior and oblique implantation group

	TSLL	SSLL	TALB	SALB
<i>p</i> value*	0.384	0.192	0.463	0.253

TSLL total sagittal lumbar lordosis, *SSLL* segmental sagittal lumbar lordosis, *TALB* total antero-posterior lumbar balance, *SALB* segmental antero-posterior lumbar balance

* Mann–Whitney test

complicated by the need for mobilization of the overlying vessels, oblique implantable TDR was developed to ameliorate these shortcomings of the anterior approach. Studies on alignment after TDR include only anterior implantation. Tournier et al. [15] found some changes of sagittal balance depending on the level implanted with an overall significant increase of the mean total lumbar lordosis. No evaluation of segmental lordosis was performed. Chung et al. [16] showed a significant increase in total lumbar lordosis and also in the lordosis of the segment implanted. Le Huec et al. [14] found no change of total lumbar lordosis, although a significant increase of lordosis in the implanted level was reported. Cakir et al. [17, 18] had similar results with significant segmental increase of lordosis and

Table 1 Pre- and postoperative average absolute values for sagittal and frontal alignment parameters in the anterior implanted group

	Average $\pm$ STD			<i>p</i> value*
	Preoperative	Postoperative	Difference (Postoperative – preoperative)	
TSLL	50.8 $\pm$ 12.6	54.8 $\pm$ 16.3	4.0 $\pm$ 5.9	0.060
SSLL	22.4 $\pm$ 8.6	29.2 $\pm$ 10.4	6.8 $\pm$ 5.1	0.004
TALB	2.5 $\pm$ 1.6	1.9 $\pm$ 1.2	–0.6 $\pm$ 1.8	0.432
SALB	1.5 $\pm$ 0.9	1.9 $\pm$ 1.7	0.4 $\pm$ 1.4	0.412

TSLL total sagittal lumbar lordosis, *SSLL* segmental sagittal lumbar lordosis, *TALB* total antero-posterior lumbar balance, *SALB* segmental antero-posterior lumbar balance, *STD* standard deviation

* Wilcoxon signed-rank test, values in degrees (°)

Table 2 Pre- and postoperative average absolute values for sagittal and frontal alignment parameters in the oblique implanted group

	Average $\pm$ STD			<i>p</i> value*
	Preoperative	Postoperative	Difference (Postoperative – preoperative)	
TSLL	41.6 $\pm$ 14.2	44.3 $\pm$ 12.4	2.7 $\pm$ 11.9	0.650
SSLL	17.7 $\pm$ 9.3	21.1 $\pm$ 8.4	3.4 $\pm$ 5.4	0.045
TALB	2.7 $\pm$ 2.2	2.9 $\pm$ 2.5	0.1 $\pm$ 2.2	0.875
SALB	2.3 $\pm$ 1.6	3.5 $\pm$ 2.5	1.2 $\pm$ 2.0	0.050

TSLL total sagittal lumbar lordosis, *SSLL* segmental sagittal lumbar lordosis, *TALB* total antero-posterior lumbar balance, *SALB* segmental antero-posterior lumbar balance, *STD* standard deviation

* Wilcoxon signed-rank test, values in degrees (°)

unaffected total lumbar lordosis. No study, however, has evaluated the *in vivo* consequences for the alignment of an oblique compared to the anterior approach. The present study, therefore, investigated the effect of anterior and oblique implantation technique of constrained lumbar disc prosthesis on frontal and sagittal alignment of the spine.

Although the general approach is identical in anterior and oblique implantation of a TDR, local resection of the ALL and annulus fibers differs. For a straight forward implantation, the whole ALL as well as the anterior annulus have to be removed. Cakir et al. [17] attributed the increase in segmental lordosis after lumbar TDR, beside other factors, to the scarification of the ALL during implantation. Dooris et al. [19] found in a finite element study that preserving the ALL could help in restoring the spinal stiffness in the sagittal plane and reduce facet loads.

In oblique implanted TDR (OTDR), the ALL is only resected up to the midline, leaving at least half of the ALL intact which could theoretically prevent significant increase of segmental lordosis. On the other hand, the lateral annulus fibers are partially resected in OTDR, which is not the case in anterior implanted TDR (ATDR). Rohlmann et al. [20] suggested that removing of lateral portions of the annulus increases mobility. In addition, the partial resection of the lateral annulus could result in an ap imbalance after OTDR. These possible consequences to our knowledge have not been evaluated up to date, which was the rationale for this study.

One major finding of the current study is that the segmental lordosis increased significantly in both groups. Theoretically, the distraction of the segment after TDR with increased height of the disc space, which was found in several studies [8, 15], enhances the ligament forces of the posterior elements which results in an extension bending moment [17]. The missing counterpart of this ligamental force, due to the excision of the ALL and anterior annulus in anterior implanted TDR, results in an increase of the segmental lordosis. This theory is partially denied by the fact that in this study both groups showed a significant increase in SSL. One explanation is that the remaining parts of ALL and annulus are not strong enough to counterweigh the extension bending moment. Another possibility is that the instantaneous axis of rotation (IAR) could be shifted anterior by the implantation of prosthesis, thereby enhancing the extension bending moment with consecutive increased segmental lordosis. As the determination of the IAR shows large individual, segmental and degeneration dependent variability, this is only a hypothesis requiring further investigation. Nevertheless, if looking at the amount of average segmental lordosis increase, we found double the increase with $6.8^\circ \pm 5.1^\circ$ for the anterior implanted TDR compared to the oblique group with $3.4^\circ \pm 5.4^\circ$, although this was not statistically significant.

Considering the measurement error, 67% of the anterior implanted TDRs showed an increase for segmental lordosis versus 38% of the oblique group (Fig. 3). This means that despite the significant increase of segmental lordosis in both groups, the restraining moment of the ALL is probably the reason for a lower increase in the oblique group. This lower increase could be of clinical relevance. Akamaru et al. [21] found *in vitro* an increase of motion in adjacent levels after hypo- and hyperlordotic monosegmental fusion. Schlegel et al. [11] hypothesized that incorrect sagittal alignment of a lumbar fusion could cause degeneration at the adjacent level by inducing too much motion at that level. Moreover, van Ooij et al. [22] reported of a group of patients with unsatisfactory results after TDR and addressed the recurrent or persistent back and leg pain among others to the hyperlordosis in the operated segment. An opening of the facet joint in the superior part and a compression in the inferior part of the facet joint due to hyperlordosis were assumed as the possible causes of later facet joint arthrosis. Future investigations should assess, whether the overall lower increase of segmental lordosis in oblique implanted TDRs is of any benefit for the long-term outcome, especially by means of less symptomatic facet joint arthrosis at the implanted level.

Another major finding of the current study is that in contrast to the segmental lordosis, the TSLL showed neither in the anterior nor oblique group a statistical difference between pre- and postoperative values. Also the comparison of both groups concerning the TSLL was not statistically different. These findings are in line with other studies, where mainly total lumbar lordosis is unchanged after TDR [14, 17, 18]. The unchanged TSLL is not very surprising. Lumbar lordosis is closely linked to the shape of the pelvis

Fig. 3 Increased segmental lordosis after anterior implanted TDR with unchanged total lumbar lordosis. **a** Preoperative, **b** postoperative

[23]. The pelvic shape itself is mainly determined by the pelvic incidence which was, among others, studied by During et al. [24], Duval-Beaupère et al. [25] and Rous-souly et al. [26]. The pelvic incidence is an individual unchangeable parameter, which comprises two positional parameters, the sacral slope and pelvic tilt. The individual patient tries to maintain his own spino–pelvic alignment, including lumbar lordosis. However, as the segmental lordosis increased significantly in both groups, the unchanged total lumbar lordosis indicates an adaptation in the adjacent segments after TDR. Although the short-term clinical outcome seems to be unaffected by these changes as multiple studies have reported good to excellent short-term results after TDR [1–4, 6], potential implications by the hypolordotic segments for long-term clinical outcome and especially for adjacent segment degeneration cannot be ruled out as long-term results, considering these parameters are missing.

The total and segmental ap balance did not show significant differences neither within the groups nor when comparing the ATDR and OTDR. When considering the measurement error, the total ap balance was maintained at 83% in the anterior and 85% in the oblique group, resembling the ability for the spine to maintain the pre-operative ap balance. The segmental ap balance increased in the anterior group in one patient (8%) and in the oblique group in two (15%). When reviewing the X-rays, only one patient in the oblique group showed the proposed increase of a left lateral tilt due to the partial resection of the left lateral annulus (Fig. 4). Despite the partial resection of the lateral annulus, the spine seems to be able to maintain its global ap balance. This could be due to the fact that the restraining annulus is sufficient to prevent a lateral tilt or

the muscle forces can overcome this effect and stabilize the spine so that the ap balance is kept.

One major limitation of this study is clearly the low patient number, for which reason studies with larger patient numbers should re-evaluate the presented data. Nevertheless, it is important to mention these findings in small series to rule out severe negative effects, before large number series are performed. Furthermore, two different types of prosthesis have been used which could have an impact on the results. This effect is potentially lowered as both prostheses have a constrained ball and socket joint articulation and in addition the geometry of the oblique implantable TDR with triangular footplate is different from all anterior implantable TDRs so that a full analogy is not feasible. There is also 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 SSLL while maintaining TSSL postoperatively, before definitive statements can be made. Especially, due to the fact that increase of segmental lordosis did not affect short-term outcome and excellent or good short-term results have already been reported. Nevertheless, the importance of sagittal alignment after different operative procedures has also been documented in clinical studies and this topic therefore warrants further investigations.

In conclusion, anterior and oblique implantable TDRs enhance significantly the segmental lordosis while retaining total lumbar lordosis. The overall increase is nearly double in the anterior group compared to the oblique group. Both implantation techniques seem to be able to maintain segmental and total ap balance in most of the cases. These variations should be considered in future studies on the long-term clinical outcome after TDR.

Fig. 4 Increased left lateral tilt after oblique implanted TDR via left-sided approach with maintained total ap balance. **a** Preoperative, **b** postoperative

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