Here are currently 2 established surgical treatments for DDD: arthroplasty and spinal arthrodesis. Although arthrodesis benefits from a longer clinical history, clinical and preclinical studies on spinal arthroplasty have now been reported in >100 publications. The first artificial disc—the SB Charité I (Depuy Spine, Inc.)—was created in 1984, and clinical results with this device were reported as early as 1987.

This prosthesis undertook 2 major design changes and, in its final configuration, was investigated in a US FDA IDE randomized, controlled clinical trial. Based on the 2-year results of this IDE study, SB Charité III was granted approval by the FDA. The results of the 2-year trial were published in 2005, and additional clinical case reports soon followed.

Although patients > 45 years of age may have comorbidities or contraindications for arthroplasty for a number of reasons, particularly osteopenia, this analysis demonstrates that patients who are indicated for 1-level arthroplasty experience similar clinical outcome, satisfaction, or adverse events compared with their younger counterparts. (DOI: 10.3171/SPI/2008/8/2/101)

**Object.** Lumbar arthroplasty is approved in the US for the treatment of degenerative disc disease at 1 level in skeletally mature patients. However, a bias toward older patients (> 45 years of age) who are otherwise indicated for the procedure may exist. In this study, the clinical outcomes of patients from the Charité Investigational Device Exemption (IDE) study were analyzed on the basis of patient age.

**Methods.** There were 276 patients enrolled in the IDE study of the Charité Artificial Disc who underwent 1-level arthroplasty at either L4–5 or L5–S1, including 71 nonrandomized and 205 randomized individuals. Patient data were analyzed based on age (18–45 years [217 patients, Group 1] compared with 46–60 years [59 patients, Group 2]). Statistical analyses were performed based on 2-year postoperative improvements in Oswestry Disability Index (ODI), 36-item Short Form Health Survey (SF-36), and visual analog scale (VAS) scores (clinical outcome), as well as range of motion (radiographic outcome), and adverse events.

**Results.** There was no significant difference between the groups with respect to level implanted, operative time, blood loss, changes in ODI and VAS scores or any of the 8 component scores of the SF-36, compared with baseline, at all time points throughout the 24-month follow-up period (p > 0.10). Patient satisfaction was equivalent at 24 months, with 87% satisfaction in Group 1 and 85% satisfaction in Group 2 (no statistical difference). In addition, no significant differences were identified with respect to adverse events including approach related, neurological, technique related, or reoperation.

**Conclusions.** Although patients > 45 years of age may have comorbidities or contraindications for arthroplasty for a number of reasons, particularly osteopenia, this analysis demonstrates that patients who are indicated for 1-level arthroplasty experience similar clinical outcome, satisfaction, or adverse events compared with their younger counterparts. (DOI: 10.3171/SPI/2008/8/2/101)
on this particular topic resulted in a limited number of publications.\textsuperscript{7,10,13-16} Raffo and Lauerman\textsuperscript{14} investigated patients with spine-related conditions in their ninth decade of life and reported an increased risk of comorbid conditions and hence death for this particular patient subset. Similarly, Naderi et al.\textsuperscript{13} showed less postoperative neurological improvement following cervical fusion in older patients than in younger ones. Although an overall age effect is accepted within the surgical community, some reports have shown contradictory findings in which no risk improvement was noted with age,\textsuperscript{15} or more surprisingly, in which younger patients were shown to be more prone to inferior results.\textsuperscript{7} These combined data points further highlight the lack of understanding related to the effect of age on spinal surgery outcomes.

In this study, the effect of age on clinical outcome was evaluated within the patient population included in the Charité IDE study. More specifically, clinical outcomes were evaluated for patients $\leq$ 45 years of age (Group 1) compared with those $> 45$ years (Group 2), who had undergone implantation of the Charité device. Results were then evaluated statistically to determine whether clinical outcomes would differ as a function of age.

**Clinical Material and Methods**

**Study Design and Surgical Technique**

Between May 2000 and April 2002, 276 patients were implanted with the Charité device as part of a prospective, randomized, nonblinded, FDA-approved IDE study conducted at 14 investigational sites across the US. The details of the institutional review board approval process, the patient randomization, the inclusion/exclusion criteria, and the surgical technique were previously described by Blumenthal et al.\textsuperscript{1} Of importance for this analysis is that all patients at risk for osteopenia or osteoporosis were subject- ed to a densitometry scan prior to inclusion in the study; specifically, all patients $> 50$ years and all patients at risk for osteoporosis, as defined by the National Osteoporosis Foundation, were screened. Patients with densitometry scores $< -1.0$ and $-2.5$ were defined as osteopenic and osteoporotic, respectively, and excluded from the study. Of the 276 patients, 205 were part of a randomized cohort against fusion with BAK cages (Zimmer Spine) and autograft, whereas 71 were treated as part of a training population and, therefore, were nonrandomized.

**Clinical Outcome Measurements**

Clinical assessments were completed before surgery and after surgery at 6 weeks and 3, 6, 12, and 24 months following surgery. Clinical outcomes were assessed using a VAS for pain (range 0–100), the ODI questionnaire, the SF-36, neurological status, and patient satisfaction questionnaires. Radiographic assessments were completed at the same time points as the clinical assessments.

**Radiographic Scanning and Measurement Technique**

The detail of the radiographic scanning and measurement technique was previously discussed for the full IDE patient population by McAfee et al.\textsuperscript{12} Briefly, the radiographic scanning technique was based on that reported by Kuslich et al.\textsuperscript{6} All radiographs were scanned, digitized, and analyzed by a software program designed to measure differences between flexion/extension angles and translations of the operative motion segment using a technique described by Lenke et al.\textsuperscript{8} and McAfee et al.\textsuperscript{11} Sagittal plane rotation was measured by establishing the difference between the Cobb measurements taken in flexion and extension. Flexion/extension at the operated level was calculated from lines drawn on the vertebral endplate surfaces. These lines could include either the operative or adjacent endplates, depending on radiographic clarity. Two angle measurements were obtained from the operative level endplates and subtracted to obtain the flexion/extension angle. To ensure reproducibility, a calibration scale containing known angles and distances was scanned, and the digital angles/distances was calculated and compared to actual values.

**Statistical Analysis**

Data were analyzed using the SAS statistical software package (version 8.2, SAS Institute). For categorical variables, probability values were generated using the Fisher exact test. A t-test was used to test means. The primary effectiveness evaluation for the study was an assessment of the equivalence of the 2 age groups in terms of the proportion of patients in each treatment group classified as a responder. The success status of patients was summarized by treatment group using counts and percentages.

**Results**

**Enrollment in the IDE**

The overall age distribution is shown in Fig. 1. There was no significant difference between the 2 groups with respect to treatment level, mean surgical time, or estimated blood loss (Table 1). The prosthesis was placed at L4–5 in 64 (29%) of 217 patients in Group 1 (that is, patients between the ages of 18 and 45 years) and 16 (27%) of 59 patients in Group 2 (that is, those between the ages of 46 and 60 years). The device was placed at L5–S1 in 153 (70%) of 217 patients in Group 1 and 43 (73%) of 59 patients in Group 2. The mean operative time for patients in Group 1 was 117.1 minutes, and it was 125.1 minutes for patients in Group 2. The mean blood loss was 200.9 and 249.1 ml for Groups 1 and 2, respectively.

**Clinical Outcomes**

**Oswestry Disability Index and VAS Scores**

The ODI questionnaire, VAS pain surveys, and SF-36 questionnaires were administered before surgery and at each follow-up visit. The overall mean preoperative ODI, VAS, and SF-36 PCS and MCS scores were equivalent between groups. At all follow-up time points, patients in both groups demonstrated significant improvement in ODI (Fig. 2 left), VAS (Fig. 2 right), SF-36 PCS (Fig. 3 left), and SF-36 MCS (Fig. 3 right) scores compared with preoperative scores ($p < 0.05$). At 24 months, the reduction in mean postoperative ODI scores compared with preoperative scores in Group 1 was 53.6%, and in Group 2, 49.9% ($p = 0.5717$). The reduction in VAS scores at 24 months versus preoperative scores was 44.0 in Group 1 and 43.1
in Group 2 (p = 0.8436). Similarly, SF-36 scores were not statistically different between the groups. The mean SF-36 PCS score change from preoperative evaluations was 7.1 in Group 1 and 5.6 in Group 2 (p = 0.9722). The mean SF-36 MCS score change from preoperative evaluations was exactly 14.0 for both groups (p = 0.5219).

Patient Satisfaction

As part of this survey, patients were asked to rate their satisfaction level as satisfied, somewhat satisfied, somewhat dissatisfied, or dissatisfied (Fig. 4). A trend toward increased satisfaction levels was noticed in Group 2: whereas 69% of patients in Group 1 were satisfied, 75% of patients in Group 2 reported being satisfied. This slight trend disappeared when combining the results for satisfied and somewhat satisfied. In Group 1, 87% of patients rated their satisfaction as either satisfied or somewhat satisfied. In Group 2, 85% of patients rated their satisfaction level as satisfied or somewhat satisfied.

Range of Motion

Although not statistically different, the mean preoperative ROM as measured on lateral flexion/extension films showed greater trends toward increased motion in Group 1 than Group 2 (p = 0.0723); ROM decreased in both groups at 3 months by 20.3 and 25.4% in Groups 1 and 2, respectively, but remained nonstatistically different between both groups. The ROM increased by 0.8° in both groups between the preoperative and 24-month postoperative measurements to reach 7.7 and 6.3° in Groups 1 and 2, respectively (p = 0.0704). This difference from the preoperative to 24-month postoperative time points was not statistically different (Fig. 5). In addition, maintenance of disc height (anterior, middle, and posterior) as well as foraminal height was achieved in both groups. Although statistically significant differences were noted for these variables between the preoperative and the immediate postoperative time points, no statistical difference between groups was observed between the immediate postoperative and 2-year postoperative time points (Fig. 6).

Key Adverse Events

There were noted adverse events in this study. In Group 1, 11 patients (5.1% of enrolled patients) experienced a major neurological event; in Group 2, only 2 patients (3.4% of enrolled patients) experienced this type of event (p = 0.7415). Approach-related adverse effects were reported in 21 patients (9.7%) in Group 1 and in 7 patients (11.9%) in Group 2 (p = 0.6291). Technique/sizing-related adverse effects were reported in 9 patients (4.1%) in Group 1 and in
3 patients (5.1%) in Group 2 (p = 0.7237). Adjacent-level disease was reported in 1 patient (0.5%) in Group 1 and in 1 patient (1.7%) in Group 2 (p = 0.3825). Thirteen patients (6.0%) in Group 1 required reoperation at the index level, whereas 3 patients (5.1%) in Group 2 required a similar re-operation (p = 1.0000).

Major neurological adverse events were also noted. Burning/dysthetic leg pain affected 7 patients (3.2%) in Group 1 and 1 patient (1.7%) in Group 2. A motor deficit at the index level affected 3 patients (1.4%) in Group 1 and 1 patient (1.7%) in Group 2. Nerve root injury was reported in 1 patient (0.5%) in Group 1 and in no patient in Group 2.

Approach-related injuries were also reported. Twelve patients (5.5%) in Group 1 and 7 patients (11.9%) in Group 2 experienced venous injuries. Two patients (0.9%) in Group 1 and 4 (6.8%) in Group 2 were afflicted with retrograde ejaculation. Injuries to the ileus were observed in 1 patient (0.5%) in Group 1 and 4 patients (6.8%) in Group 2. Perioperative vein thrombosis occurred in no patient in Group 1 but occurred in 2 patients (3.4%) in Group 2. Blood loss > 1500 ml was reported in 1 patient (0.5%) in Group 1 and in no patient in Group 2. In Group 1, incisional hernia occurred in 3 patients (1.4%), epidural hematoma and dural tear occurred in 1 patient (0.5%) each; these injuries were not reported in patients in Group 2.

Technique/sizing-related injuries were reported: subsidence in 4 patients (1.8%) in Group 1 and in 3 patients (5.1%) in Group 2; and migration in 5 patients (2.3%) in Group 1 and in no patient in Group 2. Adjacent-level disease was reported for 1 patient in each age group (0.5% of Group 1 and 1.7% of Group 2). Reoperation at the index level was reported in 13 patients (6.0%) in Group 1 and 3 patients (5.1%) in Group 2. Table 2 summarizes these key adverse events.

**Discussion**

Controlled, randomized IDE trials designed to select a
homogeneous patient group provide a unique opportunity to evaluate effects such as age on surgical outcome. In this study, 2 patient groups were considered: those ranging in age from 18 to 45 years (Group 1) and those from 46 to 60 years of age (Group 2). This age criterion was chosen to divide the patient population into 2 subpopulations while maintaining statistical power. The same operative approach, indications for surgery, and exclusion/inclusion criteria were applied for both groups. Thereby, the groups were truly comparable with only 1 variable.

As indicated by Blumenthal et al., patients were only included in the study following a positive response to a provocative discogram. This measure was confirmatory of pain and disability, along with radiographic and treatment history, and thus ensured inclusion in the study specific to patients with severe debilitating pains. Therefore, although age groups differed, there was no clinical difference between the age groups preoperatively, as shown by the VAS, ODI, and SF-36 scores.

Total disc replacement was effective in correcting pain and disability in both patient groups. Interestingly, there was no difference in the rate or effectiveness of pain and disability between the groups at the investigated time points. Patients in both groups recovered at the same pace and intensity.

Range of motion was similarly maintained across groups. Patients in Group 2 presented with a smaller ROM preoperatively and maintained that flexion/extension capability throughout the entire study. Similarly, patients in Group 1 were characterized by a slightly greater ROM (not statistically different) at the preoperative evaluation, and maintained that slight increase in range throughout the study, compared with the older group.

With respect to complications and adverse events, no differences could be found across groups, further reinforcing the notion that patients in both groups have a similar probability of success when undergoing total disc replacement.

As in any IDE study, the indications for this particular clinical study were very narrow and limited to single-level DDD at either L4–5 or L5–S1. Although these results clearly confirmed lack of age effect on clinical outcome, this notion cannot be generalized to patients who do not...
meet these criteria. Thus, the importance of selecting the right patients for total disc replacement with the Charité artificial disc, or any artificial disc device, cannot be over-emphasized.

A potential benefit of total disc replacement is the reduction or elimination of adjacent-level DDD. The 2-year end point of this study, however, did not allow for a convincing comparison on adjacent-level DDD between groups, given that this condition may take longer to develop. Age-based analyses on longer follow-up periods are required to provide convincing arguments on the effect of age on adjacent-level DDD following total disc replacement.

**Conclusions**

This analysis demonstrated a lack of statistical difference in clinical outcomes based on patient age (18–45 years compared with 46–60 years). Adverse event rates were also strikingly similar between groups. Although osteopenia was an exclusion criterion in this study and could influence clinical outcomes, it remains a concern in older patients; preoperative screening for osteopenia should therefore be recommended for older patients. In absence of osteopenia or other comorbidities, patients in Group 2 were shown in this study to gain similar benefits for total disc replace-
Effect of age on the clinical outcomes of spinal arthroplasty

TABLE 2

<table>
<thead>
<tr>
<th>Key adverse events</th>
<th>No. of Patients (%)</th>
<th>p Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>Group 1</td>
<td>Group 2</td>
</tr>
<tr>
<td>no. of patients</td>
<td>217</td>
<td>59</td>
</tr>
<tr>
<td>major neurological event</td>
<td>11 (5.1)</td>
<td>2 (3.4)</td>
</tr>
<tr>
<td>burning/leg pain</td>
<td>7 (3.2)</td>
<td>1 (1.7)</td>
</tr>
<tr>
<td>motor deficit</td>
<td>3 (1.4)</td>
<td>1 (1.7)</td>
</tr>
<tr>
<td>nerve root injury</td>
<td>1 (0.5)</td>
<td>0</td>
</tr>
<tr>
<td>approach-related event</td>
<td>21 (9.7)</td>
<td>7 (11.9)</td>
</tr>
<tr>
<td>venous injuries</td>
<td>12 (5.5)</td>
<td>7 (11.9)</td>
</tr>
<tr>
<td>retrograde ejaculation</td>
<td>2 (0.9)</td>
<td>4 (6.8)</td>
</tr>
<tr>
<td>ileum</td>
<td>1 (0.5)</td>
<td>4 (6.8)</td>
</tr>
<tr>
<td>thrombosis</td>
<td>0</td>
<td>2 (3.4)</td>
</tr>
<tr>
<td>blood loss &gt;1500 ml</td>
<td>1 (0.5)</td>
<td>0</td>
</tr>
<tr>
<td>hernia</td>
<td>3 (1.4)</td>
<td>0</td>
</tr>
<tr>
<td>epidural hematoma</td>
<td>1 (0.5)</td>
<td>0</td>
</tr>
<tr>
<td>dural tear</td>
<td>1 (0.5)</td>
<td>0</td>
</tr>
<tr>
<td>technique-related event</td>
<td>9 (4.1)</td>
<td>3 (5.1)</td>
</tr>
<tr>
<td>subsidence</td>
<td>4 (1.8)</td>
<td>3 (5.1)</td>
</tr>
<tr>
<td>migration</td>
<td>5 (2.3)</td>
<td>0</td>
</tr>
<tr>
<td>adjacent-level disease</td>
<td>1 (0.5)</td>
<td>1 (1.7)</td>
</tr>
<tr>
<td>reoperation</td>
<td>13 (6.0)</td>
<td>3 (5.1)</td>
</tr>
</tbody>
</table>

* The Fisher exact test was used to test categorical variables, and t-test was used to test means.

Disclosure

All authors received research funding for the IDE and benefits for consulting work from DePuy Spine, Inc., the manufacturer of the Charité Artificial Disc. The following authors also received royalties from DePuy Spine, Inc.: Drs. Geisler, Guyer, McAfee, Blumenthal, Regan, and Cappuccino.

Acknowledgments

We thank Brian Hetzell and George DeMuth from Stat-Tech Services for statistical analyses, and Dr. Chantal Holy, Director of Scientific Affairs for DePuy Spine, Inc., for editorial support.

References


Manuscript submitted May 31, 2007. Accepted October 18, 2007. Source of Support: Corporate/industry funds were received in support of this work from DePuy Spine, Inc. Address correspondence to: Fred H. Geisler, M.D., Ph.D., Illinois Neuro-Spine Center, 1900 Ogden Avenue, Suite 335, Aurora, Illinois 60504. email: fgeisler@fredgeisler.com.

J. Neurosurg.: Spine / Volume 8 / February 2008

107