Sideways displacement of the endograft within the aneurysm sac is associated with late adverse events after endovascular aneurysm repair

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Objective: Previous studies have shown the importance of proximal and distal endograft fixation. There is little information on the middle, unsupported section of endograft within the aneurysm sac. We quantified sideways movement of the endograft within the aneurysm sac and correlated it to late adverse events.

Method: Patients who underwent endovascular abdominal aortic aneurysm (AAA) repair with a suprarenal or infra-renal endograft between January 1997 and December 2007 were analyzed for sideways endograft movement. Patients were included if they had a digital preoperative computed tomography angiogram (CTA), a postoperative CTA within 3 months after the index procedure, and at least one follow-up CTA thereafter with a minimal time interval of 6 months.

The endograft position within the aneurysm sac was quantitated on cross-sectional images using a fixed vertebral body reference point. Patients with change in endograft position >5 mm were placed in the sideways displacement (SD) group and compared with patients with no displacement (ND; <5 mm change in position). The relationship between sideways endograft movement and endovascular aneurysm repair (EVAR)-related complications were noted for AAA rupture, AAA-related death, conversion, secondary procedures, AAA growth (>5 mm), proximal migration (>10 mm), and new onset of type I or III endoleaks.

Results: The study included 144 patients (mean age, 76 ± 7.6 years). Mean follow-up time was 43 ± 27 months. Fifty patients (35%) had sideways endograft movement ≥5 mm during follow-up. Baseline AAA diameter was larger (SD 60 ± 9 mm vs ND 57 ± 9 mm; P < .05) and proximal and iliac endograft fixation lengths were shorter (SD 18 ± 8 mm vs ND 24 ± 11 mm; P < .05 and SD 35 ± 14 vs ND 42 ± 16 mm; P < .05) in patients with sideways endograft displacement. There was no significant difference between the groups in AAA rupture and AAA-related death (one fatal AAA rupture, ND group). SD patients had a higher surgical conversion rate (10% vs 0%; P = .002), more secondary procedures (44% vs 6%; P < .001), more AAA sac enlargement (42% vs 10%; P < .001), more endograft migration (66% vs 5%; P < .001), and more type I or III endoleaks (36% vs 3%; P < .001).

Conclusions: Positional stability of the endograft within the aneurysm sac is critical for the long-term success of EVAR. Sideways movement of the endograft within the aneurysm sac is associated with an increased risk of late adverse events.


The goal of endovascular treatment of an abdominal aortic aneurysm (AAA) is to exclude the aneurysm from the bloodstream and thereby eliminate the risk of rupture.

Despite improvements in endograft design, implantation technique, patient selection, and early results, there are persistent concerns regarding the long-term durability of endovascular AAA repair (EVAR). Endograft migration leading to new-onset endoleaks is of particular concern and may result in AAA rupture, the need for secondary procedures, or surgical conversion during follow-up. Until recently, most studies of endograft stability after EVAR focused on the proximal anchoring site of the endograft. These studies have shown that secure proximal endograft fixation is needed to ensure long-term durability of the endograft.

Unfortunately, endograft instability, as evidenced by proximal endograft migration, is sometimes difficult to see on the sequential follow-up computed tomography (CT) scans due to tortuosity of the aneurysm neck and inadequate timing of the contrast infusion. Although sophisticated three-dimensional (3D) CT image reconstruction can overcome these difficulties, 3D imaging software is often not available, and these measurements are time-consuming and therefore are not very useful in clinical practice.

We recently described that in addition to proximal endograft fixation, distal (eg, iliac) endograft fixation plays a significant role in the long-term durability and clinical success of EVAR. CT imaging with 3D reconstructions is even more important in evaluating distal endograft fixation because iliac fixation lengths can only accurately be
measured using 3D reconstructions with central lumen line measurements.

The behavior of the midportion of the endograft within the aneurysm sac has received little attention until recently, when Rafii et al. reported that lateral or sideways movement of the endograft was an indicator of endograft instability. This study showed that 5-mm lateral movement of the endograft within the aneurysm sac at 1 year was associated with an increased risk of late adverse events. Endograft movement could be detected on simple cross-sectional CT images without the need for 3D imaging and without the need of contrast injection. This initial study described a small group of patients with one endograft and relatively short follow-up. The purpose of our investigation was to determine whether sideways movement of the endograft within the aneurysm sac is related to endograft migration and late clinical adverse events in a large patient population with long-term follow-up.

METHODS

Patients with asymptomatic infrarenal AAA who underwent elective EVAR with a bifurcation graft at Stanford University Medical Center between January 1997 and December 2007 and who were entered into a prospective, Institutional Review Board-approved, image-based follow-up protocol were reviewed. The follow-up protocol consisted of clinical examination and CT scanning at regular time intervals, including postprocedure baseline, at 6 months, 12 months, and yearly thereafter. Patients were treated with a suprarenal or infrarenal endograft (Talent or AneuRx stent graft system; Medtronic Vascular, Santa Rosa, Calif). Patients were included in this study if the following digital contrast CT scans were available: preoperative computed tomography angiography (CTA), a postoperative CTA within 3 months of the index procedure, and at least one follow-up CTA with a minimum interval of 6 months from the first postoperative CT scan. Patients were excluded from the study if digital images were unavailable or of insufficient quality for 3D image processing and quantitation measurements. Follow-up CT scans performed at other institutions were included, if available, and uploaded into our workstation for analysis. The follow-up CT scan used to quantitate sideways displacement was either the latest digital CT scan available or the last CT scan before a secondary procedure was done to resolve endograft- or AAA-related complications. Clinical records and follow-up information of all selected patients were retrospectively reviewed.

Secondary procedures with an influence on endograft configuration were classified as any combination of proximal, distal, or interposition endograft extenders or implantation of a new bifurcated or aortouni-iliac endograft within the former endoprosthesis. Partial or total explantation of the endoprosthesis and aortic neck plication were classified as conversion procedures and were noted separately in addition to secondary endovascular procedures. Patients who had an indication for a secondary procedure and who were advised to undergo a secondary procedure, but refused, were counted as having had a secondary procedure for statistical analysis.

Baseline patient characteristics and comorbidities, American Society of Anesthesiologists (ASA) score, and aneurysm morphology were documented. Maximal AAA diameter was measured on the preoperative and direct postprocedural CT scan. When the postprocedural AAA diameter was increased compared with the preoperative size, the largest AAA diameter was taken as the baseline measurement. Aortic neck diameter was measured on the preoperative CT scan halfway between the caudal portion of the lowermost renal artery and the beginning of the AAA. Aortic neck length was the distance from the caudal portion of the lowermost renal artery to the beginning of the AAA.

CT scans included images with and without intravenous nonionic contrast that were performed on a multidetector-row CT scanner with a slice thickness of 1.5 mm. Delayed imaging was used to detect endoleaks.

The 3D image analyses were performed on a workstation (TeraRecon Inc, San Mateo, Calif) with maximum-intensity projection, centerline, and orthonormal views, thus allowing for measurement of curvilinear distances. All reported diameters were measured perpendicular to the centerline axis, and the reported lengths were curvilinear distances measured along the centerline of vessels.

The inferior border of the superior mesenteric artery was used as a reference point in determining endograft migration when the postprocedural and the follow-up CT scans were compared. The distance from the superior mesenteric artery to the beginning of the first 360° appearance of the endograft was used to measure endograft migration. Endograft migration was defined as a distal migration of ≥10 mm during follow-up and any migration that needed a secondary intervention (migration of <10 mm with proximal type 1 endoleak or <10 mm migration in patients who had a short proximal aortic neck length of <10 mm).

Proximal and distal endograft fixation and the distance from the distal part of the endograft to the iliac bifurcation were measured on the postprocedural CTA. Proximal and distal endograft fixation was defined as the part of the proximal (covered and uncovered portion) and distal portion of the endograft that was in full 360° apposition with the aortic neck or iliac arteries, respectively. The endograft-iliac bifurcation distance was the distance from the distal portion of the endograft to the origin of the hypogastric artery. In patients treated by bifurcation devices, mean distances were taken. In patients treated by means of aortouni-iliac endografts, the total length of the monolateral limb was taken.

Sideways displacement was defined as any horizontal change in position of the midportion of the endograft within the AAA sac; sideways displacement could occur in the anterior, posterior, lateral, or oblique direction but was always perpendicular to the axial plane. Sideways endograft displacement was measured on the axial CT images on the same TeraRecon workstation, which also allows for simple 2D linear measurements. A fixed reference point was se-
lected on a lumbar vertebra close to the point of the maximal AAA diameter and the linear distance to the endograft was measured. The first postoperative CT scan was used as the baseline vertebra-endograft measurement, and the follow-up CT scans were measured at the same axial fixed point on the same lumbar vertebra (Fig 1). The distance from the anterior middle portion of the vertebral spine and the point between both endograft legs was measured on the postoperative and follow-up CT scans and analyzed for differences in path lengths (Fig 1).

The measurements were done by an investigator who was blinded for the clinical outcome. To analyze interobserver variability for sideways endograft movement, 25 randomly selected patients were measured by a second investigator in a blinded fashion. To assess intraobserver variability, 25 randomly selected patients were measured by the primary investigator twice in a randomly selected sequence. The interval between the first and second measurements was at least 2 weeks.

For comparison of groups, patients were divided in a no displacement (ND) group and a sideways displacement (SD) group, depending on the distance of sideways endograft movement. Patients were placed in the SD group if there was sideways endograft displacement of \( \geq 5 \) mm on the follow-up CT scan compared with the first postoperative CT scan. The selection for this specific threshold was based on previous work of the study group.\(^9\) Apart from the previously mentioned latest digital available CTA scan, we tried to collect earlier follow-up CTA scans after EVAR for the SD group.

To analyze the association of the sideways endograft displacement with clinical and radiologic outcomes, the following outcomes were noted: AAA rupture, surgical conversion, secondary procedures as mentioned earlier in

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**Fig 1.** Two-dimensional sideways displacement of 15 mm (in this patient most displacement is in anterior direction) of the endograft during follow-up (fixed axial vertebra level). Picture in the upper right (first postoperative computed tomography [CT] scan): vertebra-stent graft distance of 24 mm. Picture in the lower right (CT scan during follow-up): vertebra-stent graft distance of 39 mm.
this section, and AAA-related death. The radiologic parameters that were noted were AAA growth, defined as a growth of ≥5 mm during follow-up, and new onset of type I or III endoleaks, or both. Stable AAA diameter was defined as an AAA diameter with <5 mm decrease and <5 mm increase. AAA shrinkage was defined as a decrease in AAA diameter of ≥5 mm during follow-up.

Because sideways endograft movement will be related to proximal endograft migration (≥10 mm compared with the postoperative CT scan) in these investigated stiff endografts, proximal migration was investigated but not defined as a study end point. The correlation between sideways endograft movement and proximal migration was investigated.

**Statistical analysis.** Continuous data are presented as the mean ± standard deviation and range. Discrete variables are given as counts and percentages. For comparison of values between groups, t tests were used for continuous variables and the χ² test for binary variables. Differences between the ND and SD groups in clinical and radiologic end points were analyzed using χ² tests and the Kaplan-Meier method. The interobserver and intraobserver variability for sideways endograft movement were analyzed by calculating the Pearson correlation coefficient of the different measurements. Significance was assumed at P < .05. All statistical analyses were performed with SPSS 15.0 software (SPSS Inc, Chicago, Ill).

**RESULTS**

**Baseline measures.** Among a total of 400 registered patients, 144 met the inclusion criteria and were included in the study. Of excluded patients, 15% had no follow-up period that met the criteria of inclusion or missed one of the necessary CT scans (38%). Moreover, CT scans could not be collected in 16% of patients, CT scans were not digitally recorded in 24% of patients, and the inferior quality of the CT scans precluded image analyses in 9% of patients. Patient demographics and aneurysm morphology are summarized in Table I. Age at the time of operation was 76.2 ± 7.6 years (range, 56-94 years). All patients had an asymptomatic infrarenal aortic aneurysm. Maximal diameter of the AAA was 58.5 ± 9.7 mm (range, 36-105 mm), aortic neck diameter was 26.7 ± 4.0 mm (range, 15-34 mm), and aortic neck length was 22.5 ± 13.0 mm (range, 5-64 mm).

Postoperative endograft fixation measurements are summarized in Table I. Proximal endograft fixation length was 22.2 ± 10.3 mm (range, 2-51 mm), and distal iliac fixation length was 39.5 ± 15.6 mm (range, 2-102 mm). CT scans precluded image analyses in 9% of patients. Patients in the ND group had larger baseline AAA diameter (60.2 ± 9.0 vs 57.0 ± 8.7 mm; P = .04). Sideways displacement occurred during follow-up in 11 of 54 patients (20%) with a small AAA (<55 mm). The incidence rose to 39% in patients with larger AAAs (≥60 mm). Mean follow-up time for patients in the SD group was 53.0 ± 30.1 months compared with 38.3 ± 24.3 months for patients in the ND group (P = .002). There were no

### Table I. Patient demographics, preoperative aneurysm morphology, and post-implantation measurements

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total group (n = 144)</th>
<th>SD group ≥5 mm (n = 50)</th>
<th>ND group &lt;5 mm (n = 94)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>76.2 ± 7.6</td>
<td>74.9 ± 7.7</td>
<td>77.2 ± 7.3</td>
<td>.15</td>
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<tr>
<td>Women, no. (%)</td>
<td>13 (9.0)</td>
<td>5 (10)</td>
<td>8 (8.5)</td>
<td>.18</td>
</tr>
<tr>
<td>Cardiac comorbidity, no. (%)</td>
<td>85 (59)</td>
<td>31 (62)</td>
<td>54 (57)</td>
<td>.50</td>
</tr>
<tr>
<td>Respiratory comorbidity, no. (%)</td>
<td>55 (38)</td>
<td>20 (40)</td>
<td>35 (37)</td>
<td>.23</td>
</tr>
<tr>
<td>Follow-up time (months)</td>
<td>4.3 ± 27.2</td>
<td>53.0 ± 30.1</td>
<td>38.3 ± 24.3</td>
<td>.002</td>
</tr>
<tr>
<td>ASA score ≥2, no. (%)</td>
<td>68 (47.2)</td>
<td>23 (46)</td>
<td>45 (47.9)</td>
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</tr>
<tr>
<td>Preimplantation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAA size (mm)</td>
<td>58.5 ± 9.7</td>
<td>60.2 ± 9.0</td>
<td>57.0 ± 8.7</td>
<td>.04</td>
</tr>
<tr>
<td>AAA-neck length (mm)</td>
<td>22.5 ± 13.0</td>
<td>22.7 ± 13.6</td>
<td>22.4 ± 12.8</td>
<td>.90</td>
</tr>
<tr>
<td>AAA-neck diameter (mm)</td>
<td>26.7 ± 4.0</td>
<td>25.9 ± 3.9</td>
<td>27.0 ± 4.1</td>
<td>.10</td>
</tr>
<tr>
<td>Postimplantation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximal fixation length (mm)</td>
<td>22.2 ± 10.3</td>
<td>17.9 ± 8.0</td>
<td>24.6 ± 10.7</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Iliac fixation length (mm)</td>
<td>39.5 ± 15.6</td>
<td>34.8 ± 14.5</td>
<td>42.2 ± 15.7</td>
<td>.008</td>
</tr>
<tr>
<td>Distance to hypogastric art (mm)</td>
<td>13.0 ± 12.0</td>
<td>15.4 ± 11.4</td>
<td>11.7 ± 12.2</td>
<td>.09</td>
</tr>
<tr>
<td>Transrenal graft (Talent), no. (%)</td>
<td>96</td>
<td>24 (25)</td>
<td>72 (75)</td>
<td>.001</td>
</tr>
<tr>
<td>Infrarenal graft (AneuRx), no. (%)</td>
<td>48</td>
<td>26 (54)</td>
<td>22 (46)</td>
<td>.001</td>
</tr>
<tr>
<td>Proximal graft diameter (mm)</td>
<td>31.8 ± 3.1</td>
<td>31.1 ± 3.4</td>
<td>32.4 ± 3.0</td>
<td>.17</td>
</tr>
</tbody>
</table>


*Proximal fixation length longer than the preimplantation neck length due to the uncovered portion of the proximal graft in the patients treated with a transrenal fixating endograft.
Table II. Clinical and radiologic outcomes

<table>
<thead>
<tr>
<th>Variable</th>
<th>SD group (n = 50)</th>
<th>ND group (n = 94)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute prox migration (mm)</td>
<td>15.1 ± 13.5</td>
<td>3.2 ± 3.7</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Prox migration ≥ 10 mm, no. (%)</td>
<td>33 (66)</td>
<td>5 (5.3)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Absolute lateral displacement (mm)</td>
<td>9.6 ± 7.0</td>
<td>1.9 ± 1.7</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>AAA diameter change (mm)</td>
<td>+2.6 ± 10.4</td>
<td>-2.7 ± 8.1</td>
<td>.001</td>
</tr>
<tr>
<td>AAA growth ≥ 5 mm, no. (%)</td>
<td>21 (42)</td>
<td>9 (9.6)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>New-onset endoleak type I/III, no. (%)</td>
<td>18 (36)</td>
<td>3 (3.2)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Clinical

- AAA ruptures, no. (%) 0 (0) 1 (1.1) .47
- Secondary procedures, no. (%) 22 (44) 6 (6.4) <.001
- Conversions, no. (%) 5 (10) 0 .002
- AAA-related death, no. (%) 0 1 (1.1) .47

AAA, Abdominal aortic aneurysm; ND, no displacement; SD, sideways displacement.

Differences between the SD and ND groups in aortic neck length (22.7 ± 13.6 vs 22.4 ± 12.8 mm) or diameter (25.9 ± 3.9 vs 27.0 ± 4.1 mm).

Patients treated by infrarenal fixating stent grafts had significantly more sideways displacement than patients with transrenal fixation of the stent graft (54% vs 25%; P = .001), and had more proximal stent graft migration (41% vs 19%; P = .003). Patients with an infrarenal fixating stent graft had a significantly shorter proximal fixation than patients treated with a transrenal fixating endograft (24 ± 10.8 mm vs 19 ± 8.2 mm; P = .002).

SD group had significantly shorter postoperative proximal (17.9 ± 8.0 vs 24.6 ± 10.7 mm; P < .001) and distal endograft fixation lengths (34.8 ± 14.5 vs 42.2 ± 15.7 mm; P = .008). One of the possible explanations for the shorter proximal fixation in the SD group is the larger number of patients treated by means of an infrarenal fixating endograft. The distance from the end of the endograft to the origin of the hypogastric arteries was not different between the two groups (15.4 ± 11.4 vs 11.7 ± 12.2 mm).

We successfully collected earlier follow-up CTA scans in 33 of 50 patients in the SD group, and in 25, sideways endograft movement ≥ 5 mm had already been documented on an earlier CTA scan after EVAR. However, eight patients in the SD group had < 5 mm sideways movement of the endograft earlier on in the follow-up after EVAR.

Clinical end points. The clinical end points for both groups are summarized in Table II. AAA rupture was rare and occurred in only one patient. This patient was in the ND group, had a persisting type I endoleak with aneurysm enlargement, and refused recommended secondary treatment. This was the only AAA-related death in this study.

None of the patients who had a secondary intervention or conversion died within 30 days after the secondary procedure. There was no difference in the rupture rate or AAA-related death rate between the two groups (P = .46).

Secondary procedures were more frequent in the SD group than in the ND group. A secondary procedure was required in 22 patients (44%) in the SD group and in six (6%) in the ND group to resolve endograft-related problems (P < .001). Kaplan-Meier estimates showed a freedom from secondary interventions of 97%, 97%, and 97% for the ND group and 96%, 86%, and 76% for the SD group at 12, 36, and 60 months (P = .01; Fig 2). The list of secondary interventions in each patient group is listed in Table III. Most secondary interventions were proximal extension cuffs for proximal type I endoleaks or migration.

Surgical conversion procedures were more frequent in the SD group than in the ND group. Five patients in the SD group (10%) compared with no patients in the ND group underwent conversion to open repair (P = .002). Kaplan-Meier estimates showed a freedom from conversion of 100% in the ND group and 100%, 98%, and 87% in the SD group at 12, 36, and 60 months (P = .015).

Radiologic end points. The radiologic end points are summarized in Table II. Of the 144 included patients, AAA diameter was stable in 73 patients (51%), AAA shrinkage was seen in 41 (28%), and AAA enlargement was seen in 30 (21%). AAA enlargement occurred in 21 SD patients (42%) versus 9 ND patients (10%; P < .001). Patients in the SD group had more new type I and III endoleaks compared with the ND group. New-onset type I or III endoleak was noted in 18 SD patients (36%) vs three ND patients (3.2%; P < .001). Kaplan-Meier estimates showed a freedom from new endoleaks of 98%, 97%, and 97% in the ND group and 98%, 79%, and 61% in the SD group at 12, 36, and 60 months (P < .001).

Proximal endograft migration was associated with sideways endograft movement. Of the 38 patients who had proximal migration > 10 mm, 33 (87%) had sideways movement of the endograft ≥ 5 mm. Of the 50 patients with sideways movement, only 33 (66%) had proximal migration of the endograft.

Interobserver and intraobserver variability. There was a highly significant association between the interobserver and intraobserver measurements regarding the sideways displacement of the endograft during follow-up. The interobserver and intraobserver Pearson correlation coefficients were 0.98 and 0.99, respectively (P < .001).

Discussion

The current study identified original data of 144 patients. Sideways displacement of the endograft during follow-up occurred in more than one in three patients. There was a strong association between sideways endograft displacement and most adverse events in the investigated patient population. To our knowledge, this study represents the largest cohort of patients to be systematically
studied for evidence of sideways movement of the midportion of the endograft in the AAA sac over time.

The role of the midportion of the endograft on the durability of EVAR has received little attention thus far. The midportion of the endograft, because of its unsupported position within the aneurysm sac, can have significant sideways movement during follow-up, particularly in large-diameter aneurysms and in endografts with an unsupported body.

Larger AAA diameters are associated with worse long-term outcome after EVAR, but the mechanism of this phenomenon has never been understood. Even after successful initial endovascular repair with good proximal endograft fixation and no endoleak, a large aneurysm diameter is a significant factor in long-term success after EVAR. In the current study, we showed that patients with sideways endograft movement had larger initial AAA diameter. The larger intrasac aneurysm space may facilitate sideways movement of the unsupported midportion of the endograft within the AAA sac. This may increase the fixation requirements of the endograft in the proximal or distal fixation zones and may help explain why patients with large AAA diameters have worse long-term outcomes after EVAR. However, we also found evidence in this study group of significant sideways displacement in patients with small aneurysms. Sideways displacement occurred during follow-up in 11 of 54 patients (20%) with a small AAA (<55 mm). The incidence rose to 39% in patients with larger AAAs (≥60 mm). While there is a clear association of sideways endograft movement and increasing AAA size, a small aneurysm size does not preclude sideways endograft movement.

Patients in the SD group had a significantly shorter proximal and distal endograft fixation length. As shown in this study, sideways endograft movement and migration was strongly correlated with the proximal end of the endograft. Prior studies have shown that a short proximal or short distal endograft fixation length, or both, is associated with an increased risk for proximal migration. Therefore, the association between sideways endograft movement and a shorter proximal and distal fixation lengths is no surprise. Downward movement of the proximal portion of the endograft is intimately associated with sideways movement of the midportion of the endograft if the distal fixation point does not move, because the length of the endograft does not change. In this study, we were not able to determine which is the primary event.

Proximal endograft migration was correlated with sideways endograft movement in this study. Of the 38 patients

Table III. Secondary interventions in the ND and SD groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>SD group (n = 50)</th>
<th>ND group (n = 94)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal extension cuff</td>
<td>11 (22)</td>
<td>3 (3)</td>
</tr>
<tr>
<td>Distal extension cuff</td>
<td>3 (6)</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Interposition cuff</td>
<td>1 (2)</td>
<td>0</td>
</tr>
<tr>
<td>Proximal and distal ext cuff</td>
<td>5 (10)</td>
<td>0</td>
</tr>
<tr>
<td>New endograft</td>
<td>1 (2)</td>
<td>0</td>
</tr>
<tr>
<td>Refuses secondary intervention</td>
<td>1 (2)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Aortic neck wrapping</td>
<td>4 (8)</td>
<td>0</td>
</tr>
<tr>
<td>Explantation*</td>
<td>1 (2)</td>
<td>0</td>
</tr>
</tbody>
</table>

ND, No displacement; SD, sideways displacement.

*Are considered as conversion operations.

Fig 2. Freedom from secondary procedures.
who had proximal migration >10 mm, 33 (87%) had sideways movement of the endograft.

Two patients with proximal migration did not have sideways movement of ≥5 mm, but the graft configuration was completely different at the same vertebra level on the follow-up CTA scan (Fig 3). Although sideways displacement was <5 mm at the same vertebral level, these endografts were displaced at another vertebral level lower in the AAA sac during follow-up. On the other hand, of the 50 patients with sideways movement, only 33 (66%) had proximal migration of the endograft. An explanation of why the endograft was not displaced in the proximal anchoring zone in 17 patients is that the graft could be displaced at the distal anchoring zone or that measuring sideways displacement is probably more accurate than the proximal migration measurements in these patients. It is very likely that if sideways movements are noticed without proximal migration, the endograft must have been displaced somewhere else. Unfortunately, we did not measure distal iliac stent graft movement in the study and therefore can only speculate that there was distal movement of the stent grafts.

As described in the Results, we successfully collected earlier CT scans of 33 of 50 patients in the SD group and determined that in 76% of these patients, sideways endograft movement (≥5 mm) had already occurred earlier on after EVAR. Owing to our study protocol, we think that with the current study we showed that sideways displacement is a very accurate measuring parameter, strongly correlated with adverse events. However, earlier follow-up CT scans could be collected in only 33 of 50 patients with SD, so the predictive value of sideways displacement could not be elucidated in the current study because numbers are too small.

The magnitude and direction of displacement forces acting on aortic endografts in vivo has been studied by Figueroa et al using 3D computational modeling techniques. These investigators found that pulsatile displacement force acting on an endograft is in a sideways direction with respect to the axis of the blood flow rather than in the downstream direction of blood flow. In these patient-specific models, 72% of the total displacement force on the endograft was directed sideways. Increased curvature of the endograft increases sideways displacement force, as does increased endograft diameter and increased blood pressure. These findings are consistent with our finding of sideways endograft movement in the aneurysm sac over time. The precise angulation of the sideways displacement (anterior–posterior or side-to-side) was not quantitated in our patient group and will be a subject for further study.

Fig 3. Proximal endograft migration without sideways displacement. ND, No displacement; SD, sideways displacement.
Simple 2D measurements were done to document sideways movement of the endograft. The simple 2D sideways displacement measurement was a quick measurement that could be done within 60 seconds when comparing the postoperative endograft-vertebra distance with the follow-up distance and could be done on CT scans without the use of contrast media. We described a low interobserver and intraobserver variability with a highly significant correlation coefficient. Keeping in mind that 33 of 38 patients (87%) with proximal migration had sideways movement of the endograft and another two patients (5%) had a totally different endograft configuration at the same axial vertebra level, the simple and reproducible sideways movement measurement can possibly replace the time-consuming proximal endograft migration measurement during follow-up after EVAR. Since we have not analyzed comparisons, correlations, or predictive relations of sideways displacement versus other commonly used parameters, the use of this measurement technique for evaluating endograft positional stability should be further evaluated in prospective studies and with other endografts to increase our understanding of long-term durability of EVAR.

**Limitations.** Because we included a large number of patients, conclusion can be drawn with relatively high statistically validity. However, the study has some limitations.

First, we included only patients with at least 6 months of follow-up to be able to determine positional changes over time. Thus, the analyses excluded patients with postoperative events occurring within 6 months after the index procedure. This may have had an effect on measures such as overall AAA-related mortality. Because endograft migration and sideways displacement is a time-dependent event, we selected a standard time frame that coincides with the prospectively determined routine imaging follow-up protocol. Measuring sideways displacement during follow-up requires at least two CT scans to measure the difference in vertebra-endograft distance.

The second limitation is that almost half of the treated patients were tertiary referral patients, many with AAA anatomy not ideal for endovascular repair (AAA neck <15 mm, AAA neck angle >60°, extensive AAA neck thrombus/calcification, tortuosity of iliac arteries) but unfit for open repair. Since we did not document aortic neck angulation, we could not analyze this as a predictive factor for the aforementioned EVAR-related complications. This may have increased the risk of endograft movement and migration. In addition, some patients, particularly those with less complex anatomicies, were monitored with CT imaging done at the local referral center, with reports and images brought by the patient at follow-up visits. Some images were not suitable for quantitative image analysis for this study. Thus, missing comparative data may have introduced a selection bias for more complicated patients who underwent all follow-up imaging studies at our institution.

The third limitation is that we did not analyze the exact direction of the sideways endograft displacement in the horizontal plane (anterior–posterior or side-to-side displacement). One could imagine an endograft migrating to the side and posteriorly with no change in the absolute distance from a fixed point on one of the lumbar vertebrae to the endograft. This can introduce false negative results.

Another factor that could have influenced our results was that the CT scans were static scans. The measurements of all parameters occurred somewhere during the diastole and systole of the cardiac cycle. Although dynamic changes are investigated in the AAA neck, the dynamic changes of the sideways endograft movement at the point of maximal AAA diameter during the cardiac cycle has not been investigated so far. We set the threshold for sideways movement at ≥5 because we think some dynamic sideways displacement may occur during the cardiac cycle. This problem should be investigated on dynamic CT scans and will be an investigation goal for our study group.

Another limitation is that we only measured the vertebra-endograft position over time and did not determine the change of endograft position in the AAA sack. Asymmetric shrinkage or growth of the AAA during follow-up can therefore influence the vertebra-endograft position, without a change of the position of the endograft in the AAA sack.

**CONCLUSIONS**

This study highlights the importance of the midportion of the endograft, which is unsupported within the aneurysm sac. Significant sideways movement of the endograft is associated with endograft migration, whereas lack of movement indicates endograft stability. Sideways movement of the device within the aneurysm sac is associated with late adverse events; conversely, lack of movement is correlated with long-term success.

**AUTHOR CONTRIBUTIONS**

Conception and design: EW, CZ
Analysis and interpretation: EW, CZ
Data collection: EW, MG, BR
Writing the article: EW, CZ
Critical revision of the article: EW, JV, CZ
Final approval of the article: EW, CZ
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