Iliac fixation inhibits migration of both suprarenal and infrarenal aortic endografts

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Objective: **To evaluate the role of iliac fixation in preventing migration of suprarenal and infrarenal aortic endografts.**
Methods: **Quantitative image analysis was performed in 92 patients with infrarenal aortic aneurysms (76 men and 16 women) treated with suprarenal (n = 36) or infrarenal (n = 56) aortic endografts from 2000 to 2004. The longitudinal centerline distance from the superior mesenteric artery to the top of the stent graft was measured on preoperative, postimplantation, and 1-year three-dimensional computed tomographic scans, with movement more than 5 mm considered to be significant. Aortic diameters were measured perpendicular to the centerline axis. Proximal and distal fixation lengths were defined as the lengths of stent-graft apposition to the aortic neck and the common iliac arteries, respectively.**
Results: **There were no significant differences in age, comorbidities, or preoperative aneurysm size (suprarenal, 6.0 cm; infrarenal, 5.7 cm) between the suprarenal and infrarenal groups. However, the suprarenal group had less favorable aortic necks with a shorter length (13 vs 25 mm; $P < .0001$), a larger diameter (27 vs 24 mm; $P < .0001$), and greater angulation (19° vs 11°; $P = .007$) compared with the infrarenal group. The proximal aortic fixation length was greater in the suprarenal than in the infrarenal group (22 vs 16 mm; $P < .0001$), with the top of the device closer to the superior mesenteric artery (8 vs 21 mm; $P < .0001$) as a result of the 15-mm uncovered suprarenal stent. There was no difference in iliac fixation length between the suprarenal and infrarenal groups (26 vs 25 mm; $P = .8$). Longitudinal centerline stent graft movement at 1 year was similar in the suprarenal and infrarenal groups (4.3 ± 4.4 mm vs 4.8 ± 4.3 mm; $P = .6$). Patients with longitudinal centerline movement of more than 5 mm at 1 year or clinical evidence of migration at any time during the follow-up period comprised the respective migrator groups. Suprarenal migrators had a shorter iliac fixation length (17 vs 29 mm; $P = .006$) and a similar aortic fixation length (23 vs 22 mm; $P > .999$) compared with suprarenal nonmigrators. Infrarenal migrators had a shorter iliac fixation length (18 vs 30 mm; $P < .0001$) and a similar aortic fixation length (14 vs 17 mm; $P = .1$) compared with infrarenal nonmigrators. Nonmigrators had closer device proximity to the hypogastric arteries in both the suprarenal (7 vs 17 mm; $P = .009$) and infrarenal (8 vs 24 mm; $P < .0001$) groups. No migration occurred in either group in patients with good iliac fixation. Multivariate logistic regression analysis revealed that iliac fixation, as evidenced by iliac fixation length ($P = .004$) and the device to hypogastric artery distance ($P = .002$), was a significant independent predictor of migration, whereas suprarenal or infrarenal treatment was not a significant predictor of migration. During a clinical follow-up period of 45 ± 22 months (range, 12-70 months), there have been no aneurysm ruptures, abdominal aortic aneurysm–related deaths, or surgical conversions in either group.**
Conclusions: **Distal iliac fixation is important in preventing migration of both suprarenal and infrarenal aortic endografts that have longitudinal columnar support. Secure iliac fixation minimizes the risk of migration despite suboptimal proximal aortic neck anatomy. Extension of both iliac limbs to cover the entire common iliac artery to the iliac bifurcation seems to prevent endograft migration. (J Vasc Surg 2007;45:250-7.)**

Endovascular repair of infrarenal aortic aneurysms (EVAR) has been shown to have favorable outcomes when compared with open aneurysm repair.[1-4] However, there are ongoing concerns regarding the long-term durability of EVAR due to device-related failure modes such as migration, endoleaks, aneurysm enlargement, and stent fractures.[5]

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Competition of interest: Ms Crabtree, Dr Bloch, and Dr Zarins are consultants to Medtronic Vascular, the manufacturer of the endovascular devices used in this study. Other authors have no competing interests.
Presented at the Sixtieth Annual Meeting of The Society for Vascular Surgery, Philadelphia, PA, June 1-4, 2006.
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0741-5214/$32.00

doi:10.1016/j.jvs.2006.09.061

The migration and positional stability of aortic stent grafts have been studied extensively,[5-10] with emphasis on patient selection; preoperative measurement of aortic neck diameter, length, angulation, thrombus, and calcification; intraoperative considerations of device sizing and positioning; and postoperative measurement of proximal fixation length.[11,12] A great deal of attention has been focused on proximal endograft fixation with currently available devices using a variety of fixation mechanisms, including infrarenal and/or suprarenal fixation with radial force, with or without penetrating hooks or barbs. However, device migration continues to be an issue for all currently available devices.[13-15] This may be explained, in part, by the failure of most studies to consider the role of distal iliac fixation in maintaining the positional stability of stent grafts.[6,7,11,12,16,17]

Heikkinen et al[18] showed that the migration of an infrarenal endograft with longitudinal columnar support was closely related to the adequacy of iliac fixation. No stent-graft migration occurred in patients who had good iliac fixation, even in those who had suboptimal proximal aortic fixation. Multivariate analysis identified iliac fixation as the most important predictor of stent-graft migration or stability over a 2-year observation period. The single most important factor in preventing migration was close proximity of the distal end of the endograft to the origin of the internal iliac artery. This suggested that the bifurcation of the iliac arteries may provide a point of positional stability. The purpose of this study was to determine whether iliac fixation is uniquely important to a single stent-graft system or whether it may have broader implications for other infrarenal aortic endovascular devices. To this end, we have compared two modular stent graft systems that both rely on radial and frictional fixation forces and longitudinal columnar support without penetrating hooks or barbs. One has a suprarenal fixation stent, whereas the other is an infrarenal device. Sequential quantitative image analysis was used to determine proximal and distal fixation lengths and endograft positional stability at 1 year.

METHODS

Patients with infrarenal abdominal aortic aneurysms who were treated with EVAR at Stanford University Medical Center and enrolled in a prospective clinical and image-based follow-up protocol were considered for this study. Informed consent was obtained from each patient before surgery, and all patient follow-up protocols, including imaging protocols, were approved by the institutional review board. A total of 367 patients were treated with either a suprarenal endograft with longitudinal columnar support (Talent stent graft; Medtronic Vascular, Santa Rosa, Calif) or an infrarenal endograft with longitudinal columnar support (AneuRx stent graft; Medtronic Vascular) from 2000 to 2004. All patients with preoperative and sequential postoperative imaging studies performed at Stanford University Medical Center with online data sets available for workstation review and three-dimensional image analysis were selected for this study. A total of 92 patients met the inclusion criteria for this study: 36 patients treated with the suprarenal device and 56 patients treated with the infrarenal device.

Preoperative and postoperative spiral computed tomographic (CT) scans and 1-year follow-up spiral CT scans or magnetic resonance imaging studies were evaluated in each patient by using quantitative three-dimensional image analysis. Three-dimensional reconstructions and volume rendering were performed on a TeraRecon workstation (TeraRecon Inc, San Mateo, Calif) with maximum-intensity projection, centerline, and orthonormal views, thus allowing for measurement of angles and 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. Measurements were performed on images obtained before (range, 1-35 days), immediately after (range, 1-4 days), and 1 year after (range, 11-14 months) the endovascular procedure. All quantitative imaging measurements were obtained by a single investigator with special training in three-dimensional

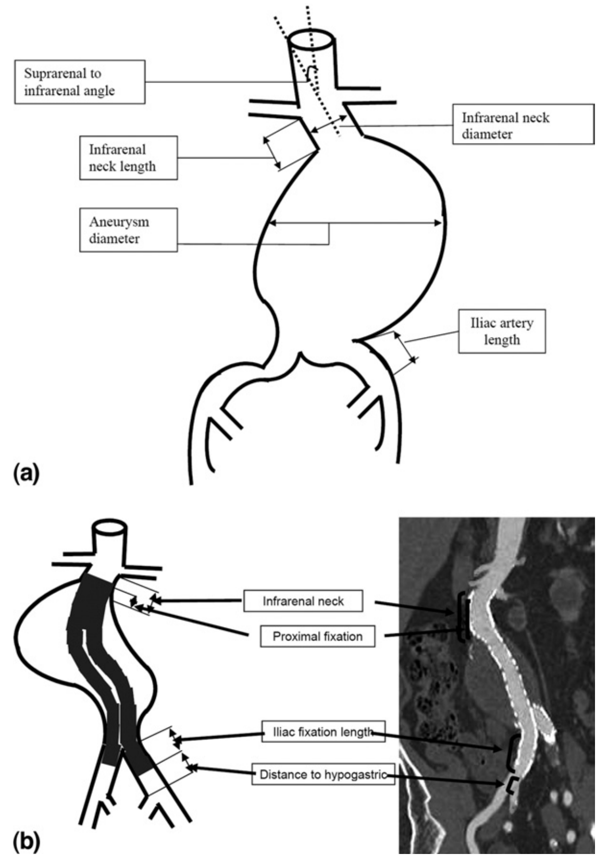

Fig 1. A, Measurement of preoperative aneurysm characteristics. **B,** Depiction of poststent image measurements.

image analysis who was not involved with the clinical care of the patients and was blinded to the clinical outcomes of the patients.

The origin of the superior mesenteric artery (SMA) was used as the reference point to determine the luminal centerline distance to the proximal portion of the stent graft on postimplantation and 1-year CT scans. An increase in longitudinal centerline distance more than 5 mm at 1 year was considered to be significant. Proximal and distal (iliac) fixation lengths were defined as the length of the stent graft that was in full apposition to the aorta and common iliac arteries, respectively (Fig 1, *B*). The proximal fixation length for suprarenal devices included the suprarenal bare stent and the infrarenal covered apposition zones. Infrarenal neck length was defined as the length of aorta between the lowermost renal artery and the beginning of the most proximal portion of the aneurysm. The angle between the suprarenal and infrarenal aorta was determined by using centerline measurements (Fig 1, *A*).

Complete and current clinical follow-up data were available on all patients in the prospectively maintained clinical database. Patient characteristics and comorbidities were recorded along with follow-up information, complications, secondary procedures, and long-term outcomes.

Table I. Demographic data and comorbidities in patients with the suprarenal and infrarenal devices

Variable	*Suprarenal fixation (n = 36)*	*Infrarenal fixation (n = 56)*	P *value*
Age, y (mean ± SD)	76 ± 6	73 ± 7	.09
Female (%)	22%	14%	.3
Obesity (%)	25%	29%	.7
Hypertension (%)	75%	71%	.7
Smoking (%)	86%	77%	.3
Chronic obstructive pulmonary disease (%)	33%	25%	.4
Coronary artery disease (%)	58%	38%	.05
Congestive heart failure (%)	19%	14%	.5
Cancer (%)	36%	29%	.4
Diabetes (%)	28%	21%	.5
Chronic renal insufficiency, creatinine >1.5 mg/dL (%)	11%	16%	.5

Patients receiving the Talent and the AneuRx stent grafts were assigned to the suprarenal and infrarenal groups, respectively. For comparison, the cohort was further divided into the migrator and nonmigrator groups for both devices. Patients were placed in the migrator group if there was an increase in centerline distance from the origin of the SMA to the proximal edge of the stent graft of more than 5 mm at 1 year or if at any time during the clinical follow-up period there was radiographic evidence of migration more than 10 mm or if a secondary procedure (extender cuff placement or proximal neck balloon dilation/stenting) was performed.

Baseline demographics for the patients are expressed as the mean ± SD for continuous variables and as percentages of the cohort for binary variables. Statistical analysis was performed by using SAS version 9.1 (SAS Institute, Cary, NC). Comparisons between groups were made by using the Student *t* test or Wilcoxon rank sum test for continuous variables and the χ^2 or Fisher exact test for binary variables, as appropriate. Predictors of migration were analyzed by using multivariate logistic regression. *P* values <.05 were considered significant.

RESULTS

Among the 92 patients included in this study, 36 (39%) were treated with the suprarenal device, and 56 (61%) were treated with the infrarenal device. The demographics of the patients in the suprarenal and infrarenal group are shown in Table I. The suprarenal and infrarenal groups did not differ significantly in age, sex distribution, or comorbidities. Preoperative aneurysm size was similar in the two groups (suprarenal, 6.0 ± 0.1 cm; infrarenal, 5.7 ± 0.1 cm; *P* = .2). However, the suprarenal group had less favorable aortic necks, as evidenced by shorter neck length (13 vs 25 mm; *P* < .0001), larger neck diameter (27 vs 24 mm; *P* < .0001), and greater neck angulation (19° vs 11°; *P* = .007) compared with the infrarenal group. Despite a shorter aortic neck length, the suprarenal group had a longer proximal fixation length (22 vs 16 mm; *P* < .0001), and the top of the device was closer to the SMA (8 vs 21 mm; *P* < .0001) as a result of the 15-mm-long uncovered suprarenal stent (Table II).

Table II. Aneurysm characteristics for patients with suprarenal versus infrarenal fixation

Variable	*Suprarenal fixation (n = 36)*	*Infrarenal fixation (n = 56)*	P *value*
Preoperative aneurysm diameter (mm)	60 ± 11	57 ± 11	.2
Preoperative infrarenal neck diameter (mm)	27 ± 3	24 ± 2	<.0001
Preoperative neck length (mm)	13 ± 8	25 ± 9	<.0001
Proximal fixation length (mm)	22 ± 8	16 ± 6	<.0001
Angulation, suprarenal to infrarenal aorta (°)	19 ± 10	11 ± 10	.007
SMA to top of stent graft (mm)	8 ± 7	21 ± 8	<.0001
Iliac fixation length (mm)*	26 ± 11	25 ± 10	.8
Device to hypogastric artery distance (mm)*	9.5 ± 10	14 ± 11	.06
Migration distance at 1 y (mm)	4.3 ± 4.4	4.8 ± 4.3	.6
Type I endoleak (%)	6%	9%	.7
Type II endoleak (%)	31%	18%	.2
Secondary interventions at 1 y (%)	17%	23%	.4

Data are mean ± SD or percentages, as indicated.
SMA, Superior mesenteric artery.
*The average value of the right and left sides is given.

Longitudinal (caudal) centerline movement of the device at 1 year was detected in both the suprarenal and infrarenal groups. There was no difference in the mean caudal centerline movement distance between the suprarenal (4.3 ± 4.4 mm) and infrarenal (4.8 ± 4.3; *P* = .6) groups. Ten patients (28%) in the suprarenal group and 20 patients (36%) in the infrarenal group had caudal movement of more than 5 mm at 1 year or evidence of clinical migration during the follow-up period and comprised the respective migrator groups. There was no significant difference in mean follow-up time between the migrator and nonmigrator groups (*P* = .6). In the suprarenal cohort, the migrator and nonmigrator groups did not differ significantly in preoperative aneurysm diameter, infrarenal neck diameter, proximal fixation length, or comorbidities. There was no difference in proximal fixation length between the migrator and nonmigrator groups (23 vs 22 mm; *P* > .999). However, the migrator group had a significantly shorter iliac fixation length (17 ± 6 mm) compared with the nonmigrator group (29 ± 11 mm; *P* = .006). In addition, the migrator group had a twofold greater distance between the end of the iliac limb and the hypogastric artery (17 ± 9 mm) compared with the nonmigrator group (7 ± 9 mm; *P* = .009; Table III).

In patients with infrarenal fixation, the migrator and nonmigrator groups were similar in preoperative aneurysm diameter (60 vs 55 mm; *P* = .07) and infrarenal neck

Table III. Preoperative and postoperative imaging characteristics in relation to longitudinal centerline movement greater than 5 mm at 1 year

	Suprarenal fixation (n = 36)			*Infrarenal fixation (n = 56)*		
Variable	*Migrator (n = 10)*	*Nonmigrator (n = 26)*	P *value*	*Migrator (n = 20)*	*Nonmigrator (n = 36)*	P *value*
Preoperative aneurysm diameter (mm)	60 ± 9	60 ± 12	.9	60 ± 10	55 ± 11	.07
Preoperative infrarenal neck diameter (mm)	26 ± 2	27 ± 3	.3	25 ± 2	23 ± 2	.07
Preoperative infrarenal neck length (mm)	10 ± 9	14 ± 8	.2	23 ± 10	26 ± 9	.06
Proximal fixation length (mm)	23 ± 9	22 ± 7	>.999	14 ± 4	17 ± 6	.1
Angulation, suprarenal to infrarenal aorta (°)	31 ± 22	14 ± 11	.05	10 ± 10	12 ± 10	.7
Iliac fixation length (mm)*	17 ± 6	29 ± 11	.006	18 ± 7	30 ± 9	<.0001
Device to hypogastric artery distance (mm)*	17 ± 9	7 ± 9	.009	24 ± 10	8 ± 5	<.0001
Migration distance at 1 y (mm)	10 ± 4	2 ± 2	<.0001	10 ± 3	2 ± 2	<.0001
Endoleak rate (%)	40%	35%	.8	40%	19%	.1
Secondary intervention rate (%)	30%	12%	.3	55%	6%	<.0001

Data are mean ± SD or percentages, as indicated.
*The average value of the right and left sides is given.

diameter (25 vs 23 mm; $P = .07$). There was no difference in proximal fixation length between the migrator and nonmigrator groups (14 vs 17 mm; $P = .1$). However, the migrator group had a significantly shorter iliac fixation length (18 ± 7 mm) compared with the nonmigrator group (30 ± 9 mm; $P < .001$). In addition, the migrator group had a threefold greater distance from the iliac limb to the hypogastric artery (24 ± 10 mm) compared with the nonmigrator group (8 ± 5 mm; $P < .001$; Table III).

Examples of migration in relation to iliac fixation are shown in Figure 2. During a mean clinical follow-up time of 45 ± 22 months (range, 12-70 months), there have been no aneurysm ruptures, no abdominal aortic aneurysm–related deaths, and no surgical conversions to open surgical repair. Type I endoleaks have been documented in 6% of patients with a suprarenal device and 9% of patients with an infrarenal device at some time during the study period, with no difference between the groups ($P = .7$). Type II endoleaks have been documented in 31% of patients in the suprarenal group and 18% in the infrarenal group ($P = .2$). There have been no major adverse clinical events related to migration or the endovascular device in either group. During the follow-up period, secondary treatments have been performed in 6 (17%) of 36 patients with suprarenal and 10 (23%) of 56 patients with infrarenal devices, with no difference between groups ($P = .4$). Secondary treatments included interventions to treat migration and type I endoleaks, extender modules to increase proximal or distal fixation without migration or endoleak, and coil embolization or aneurysm sac injections for type II endoleaks. The most common secondary procedure was placement of modular iliac extender cuffs to the level of the hypogastric artery (42% of secondary procedures), with no evidence of subsequent stent graft movement in either the suprarenal or infrarenal group.

Multivariate logistic regression models were used to identify predictors of migration and their respective predictive values (Table IV). Surprisingly, neither proximal fixation length nor device type (suprarenal vs infrarenal) was a significant predictor of migration in the presence of other variables in the model. Conversely, iliac fixation length ($P = .004$) and the device to hypogastric artery distance ($P = .002$) were highly significant predictors of stent-graft migration. The odds ratio for iliac fixation length was 0.589, thus indicating that for each millimeter increase in iliac fixation length, the odds of migration are reduced by 41% if all other factors in the model are held constant. The odds ratio for the device to hypogastric distance was 1.533, thus indicating that for each millimeter increase in distance from the hypogastric artery, the odds of migration increase by 53% if all other factors are held constant. The odds ratios were similar when the suprarenal and infrarenal groups were analyzed individually. Other factors, such as age, sex, medical comorbidities, maximum aneurysm diameter, preoperative neck angulation, and neck diameter or neck length, did not have a significant effect on risk of migration.

DISCUSSION

The importance of proximal aortic fixation in maintaining the positional stability of aortic endografts is well recognized.[6-12] An analysis of migration among 1119 patients enrolled in the multicenter AneuRx clinical trial from 1996 to 1999 showed that the proximal stent-graft fixation length was significantly shorter in patients with migration compared with patients without migration (16 vs 23 mm; $P = .005$).[11] Multivariate analysis of AneuRx Core Laboratory CT imaging data revealed that proximal fixation length ($P = .005$) and renal to stent graft distance ($P = .001$) were significant predictors of migration. There was significant variation in migration rates among clinical sites ($P < .001$), ranging from 0% to 30%, and the differences were not well explained by differences in proximal fixation lengths among sites or the use of proximal extender cuffs at the time of implantation.[11] There was no information on iliac fixation because this was not evaluated by the Core Laboratory, and the only data related to iliac fixation were a determination of whether an iliac type I endoleak was present. In fact, the role of distal iliac fixation has only

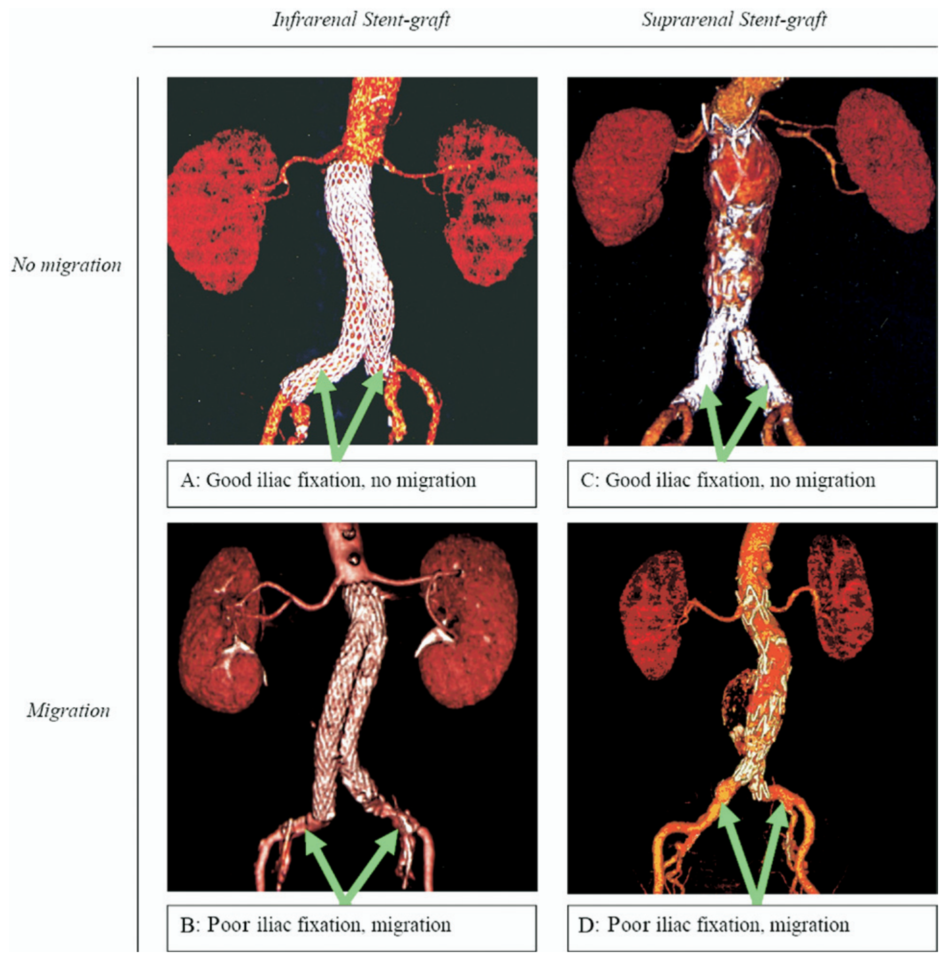

Fig 2. Examples of good and bad iliac fixation. **A,** Infrarenal stent graft with good iliac fixation and no migration. **B,** Infrarenal stent graft with poor iliac fixation; migration was treated with iliac extender cuff placement, with no further migration. **C,** Suprarenal stent graft with good proximal and distal fixation and no migration. **D,** Suprarenal stent graft with good proximal and poor distal fixation; migration was treated with iliac extender cuff placement, with no subsequent migration.

Table IV. Multivariate logistic regression for migration greater than 5 mm

Factor	*Estimate*	*Standard error*	P *value*	*Odds ratio*
Angulation (°)	0.07	0.05	.2	1.185
Infrarenal neck length (mm)	−0.05	0.07	.5	0.953
Infrarenal neck diameter (mm)	−0.14	0.26	.6	0.874
Proximal fixation length (mm)	−0.11	0.09	.2	0.893
Maximum preoperative aneurysm diameter (mm)	0.04	0.07	.5	1.046
Iliac fixation length (mm)*	−0.53	0.18	.004	0.589
Distance to hypogastric artery (mm)*	0.43	0.14	.002	1.533
Suprarenal fixation (vs infrarenal)	−0.16	0.01	.9	0.853

*The average value of the right and left sides is given.

recently been identified as an important factor in preventing stent-graft migration. Despite numerous clinical studies seeking to identify factors that may contribute to migration, iliac fixation was not taken into consideration until the report by Heikkinen et al[18] in 2006. Among 173 patients treated with the AneuRx stent graft from 1996 to 2003, Heikkinen et al found that 17 patients (10%) had migration during a mean follow-up period of 23 months and that all 17 patients had evidence of suboptimal iliac fixation on the postimplantation CT scan. Proximal and distal fixation were classified as good, bad, or intermediate according to CT measurement of fixation lengths. Good iliac fixation was defined as an iliac fixation length of at least 25 mm, with the distal end of the stent graft within 10 mm of the iliac bifurcation. Patients with good iliac fixation experienced no stent graft migration even in the face of bad or intermediate proximal aortic fixation. Migration occurred only in patients with bad or intermediate iliac fixation, and many of the migration patients also had bad proximal aortic fixation. Both proximal and distal fixation were independent predictors of migration, and the proximity of the distal end of the stent graft to the iliac bifurcation seemed to be the single most important factor in preventing migration.[18]

In this study, we sought to determine whether iliac fixation also played a role in preventing migration of endografts with suprarenal stent fixation and longitudinal columnar support. We used a more advanced quantitative image-analysis methodology (TeraRecon) to evaluate preimplantation and postimplantation CT scans of both suprarenal and infrarenal devices. Measurements were taken by a single observer, who was blinded to the clinical outcomes of the patients. Only patients with imaging studies performed at Stanford Medical Center and available in the hospital's electronic image storage system were included in this analysis. Because migration may be a time-dependent event, we sought to eliminate time as a variable in this study by evaluating stent-graft positional change at the same 1-year postprocedure time interval in all patients. Furthermore, we measured aortic and iliac fixation lengths directly on postimplantation CT scan curved planar reformations of the aorta and each iliac artery. This eliminated potential inaccuracies that may arise from calculating the iliac fixation lengths by subtracting the postprocedure distance to the hypogastric artery from the preoperative iliac length and proximal fixation lengths by subtracting the renal to stent graft distance from the preoperative aortic neck length measurements.[18] We used the same direct-measurement technique to determine the postoperative distance from the stent graft to the hypogastric artery. To address the question of whether iliac artery length changes significantly as a result of endovascular manipulation and straightening by the stiff guidewire and stent graft, we measured the iliac artery length before and after endovascular treatment and found no significant change in iliac artery length. The mean preoperative iliac artery length was 39 mm, and the mean postoperative iliac artery length was 38 mm ($P = .5$).

We found that both suprarenal and infrarenal stent grafts may rely to a significant extent on iliac fixation to maintain the positional stability of the device. Both the iliac fixation length and the proximity of the stent graft to the iliac bifurcation were associated with lower rates of longitudinal displacement of the stent graft at 1 year. Patients who experienced movement more than 5 mm in both the suprarenal and infrarenal groups had significantly shorter iliac fixation lengths and significantly greater distances to the iliac bifurcation, thus highlighting the importance of iliac fixation in preventing migration.

Although there was no difference in mean longitudinal centerline movement at 1 year between the suprarenal and infrarenal groups, a significant number of patients in both groups (28% in the suprarenal and 36% in the infrarenal group) exceeded the 5-mm movement threshold for migration in this study. Whereas most clinical reports of migration have used a greater than 10-mm movement criterion to define migration,[19-21] we chose to use a threshold of 5 mm of longitudinal movement in order to be able to more precisely determine the relationship between iliac fixation and endograft positional stability. The clinical significance of this degree of longitudinal centerline positional change is uncertain, and this measure may not be comparable to the more commonly used method of axial measurement of endograft position to evaluate migration. In cases of substantial aortic neck and stent graft angulation, significant changes in longitudinal centerline position may result in little or no axial stent-graft displacement. We found no clinical adverse events associated with greater than 5 mm of centerline movement, although many patients underwent secondary procedures as a result of or related to this movement. With a greater than 10-mm centerline movement threshold to define migration, there was no significant difference in migration rates between the suprarenal group (3/36; 8%) and infrarenal group (6/56; 11%).

Our findings are remarkable in that stent-graft migration occurred only in patients with poor iliac fixation. Despite the inclusion of patients with short, angulated, and large-diameter necks, no patient with good iliac fixation experienced migration even if the proximal fixation length was suboptimal. Therefore, secure iliac fixation, as documented by a long iliac fixation length and close proximity to the hypogastric arteries, prevented migration in the suprarenal group despite adverse neck anatomy. Similarly, there was no migration in infrarenal devices with good iliac fixation. These findings are similar to Heikkinen and colleages' observations[18] in a larger group of patients treated with the AneuRx device and suggest that longitudinal columnar support may be important in maintaining positional stability and preventing migration of both the Talent suprarenal and the AneuRx infrarenal devices. A notable difference between this study and that of Heikkinen et al is that proximal fixation length was not found to be a significant factor in migration. This does not discount the importance of proximal fixation and is likely due to the small number of patients and the fact that the multivariate analysis included both suprarenal and infrarenal devices, which have large differences in proximal fixation lengths as a result of the bare metal suprarenal stent. Whether iliac fixation plays an important role in devices with penetrating hook fixation mechanisms remains to be determined.

No significant adverse events occurred as a result of stent-graft movement; this may be because secondary procedures were performed in 17% of patients with the suprarenal device and 23% of patients with the infrarenal device. The most common secondary procedure was placement of iliac extender modules to extend the stent graft to the level of the hypogastric artery. There have been no instances of subsequent stent-graft movement among patients who have undergone secondary procedures to secure stent-graft fixation. This suggests that the stent graft should be extended to the level of the hypogastric artery at the time of the initial procedure in all patients, and this now is our current clinical practice for both suprarenal and infrarenal devices.

There are several limitations to our study. First, the patients included in this study cohort represent a small segment of the patients undergoing EVAR at our institution and were selected on the basis of the availability of sequential online images for analysis, including preoperative imaging studies performed at Stanford. Patients referred to Stanford for evaluation and treatment of infrarenal aneurysms usually have had contrast CT scans at their local medical facility. Preoperative CT scans are repeated at Stanford only if outside studies are inadequate or if there are challenging anatomic features that require more detailed analysis. Similarly, 1-year CT studies are often performed at medical facilities closer to patients' homes and are performed at Stanford if there are particular concerns or abnormalities. Thus, patients in this study may represent a more difficult and challenging group of patients than those found in usual clinical practice. Nonetheless, the data are similar to and consistent with a larger study of all patients treated at our institution with the infrarenal device with imaging studies performed at outside institutions as well as at Stanford.[18] Second, the suprarenal and infrarenal patient groups were not comparable with respect to preoperative aortic neck anatomy; the suprarenal group had less favorable anatomy, with shorter neck lengths, larger neck diameters, and increased neck angulation. This is due to the fact that patients were usually selected for the suprarenal device because they had large-diameter, angulated necks and did not meet inclusion criteria for treatment with the commercially available infrarenal device. These patients were enrolled in a physician-sponsored Investigational Device Exemption with the suprarenal stent graft, which was available in device diameters up to 36 mm. It is well known that adverse neck anatomy increases the risk of migration,[6,10,12,17] and the suprarenal group was at a higher-than-expected risk of migration as a result of adverse anatomic patient selection bias. Nonetheless, no migration occurred in this group of patients with adverse anatomy if iliac fixation was secure. Finally, the technical aspects of EVAR have evolved and improved with time, and many of the infrarenal group were treated before we fully appreciated the importance of iliac fixation and incorporated routine extension to the iliac bifurcation into our practice.

Although the iliac artery diameter is carefully evaluated on preoperative imaging studies, iliac length is less often considered in selecting patients for EVAR. This may in part be because although axial CT images are usually adequate to evaluate the infrarenal aortic neck and iliac diameters, curvature and tortuosity of the iliac arteries makes iliac length measurement unreliable and difficult. Accurate iliac length measurements usually require three-dimensional reconstruction and centerline measurements, and these lengths may change during the implantation procedure because of the introduction of stiff guidewires and sheaths. Postimplantation determination of iliac fixation length is more complex and thus is rarely assessed in current clinical practice. The easiest and most reliable measure of adequacy of iliac fixation is the proximity of the distal end of the stent graft to the hypogastric artery, and this measure should be incorporated into routine postimplantation follow-up image assessments. Although this study demonstrates the importance of this measurement for the AneuRx and Talent devices, the findings may not be generalizable to other suprarenal and infrarenal devices, particularly those that include other fixation mechanisms such as hooks and barbs. Because migration may be seen with such devices, long-term studies of these devices should include data on iliac fixation to fully understand the dynamics of long-term endograft stability.

CONCLUSION

Iliac fixation plays an important role in preventing the migration of both suprarenal and infrarenal stent grafts with longitudinal columnar support. Iliac fixation length and the proximity of the stent graft to the iliac bifurcation are independent predictors of migration. Extension of both iliac limbs to the level of the iliac bifurcation seems to prevent endograft migration. Secure iliac fixation seems to minimize the risk of migration despite suboptimal proximal neck anatomy. Further studies are needed to determine whether iliac fixation is an important factor for endograft devices with penetrating hook mechanisms.

The authors thank Laura Pierce, Will Johnsen, and Mark Sofilos for facilitating image analysis and Kathleen Biederman for clinical data collection.

AUTHOR CONTRIBUTIONS

Conception and design: PB, JTL, CKZ
Analysis and interpretation: PB, JTL, OJA, CKZ
Data collection: PB, JTL, OJA
Writing the article: PB, JTL, OJA, CKZ
Critical revision of the article: PB, JTL, OJA, TC, DAB, CKZ
Final approval of the article: CKZ
Statistical analysis: PB, TC, DAB
Obtained funding: CKZ
Overall responsibility: PB, CKZ

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Submitted Jun 8, 2006; accepted Sep 30, 2006.