Ischemia and functional status of the left arm and quality of life after left subclavian artery coverage during stent grafting of thoracic aortic diseases

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Background: **The objective of this study was to report on the incidence of left arm ischemia, left arm function, and quality of life after thoracic endovascular aortic repair (TEVAR) by stent grafting with and without coverage of the left subclavian artery (LSA).**

Methods: **All patients who underwent TEVAR since 1996 in our institution were included. Basic demographic parameters, underlying disease, details of TEVAR, long-term left arm function (Disabilities of the Arm, Shoulder, and Hand [DASH] questionnaire), and quality of life (12-Item Short Form Health Survey) were analyzed. End points were left arm ischemia, need for LSA revascularization (before or after TEVAR), long-term functional impairment, and quality of life.**

Results: **A total of 138 patients underwent TEVAR for degenerative aneurysm (n = 64), traumatic aortic injury (TAI; n = 38), or Stanford type B dissection (n = 36). Seventy-three patients (52.9%) had LSA coverage, which led to partial or complete LSA occlusion in 49 (35.5%). Selectively, nine patients (6.5%) had primary LSA revascularization. After TEVAR, left arm ischemia was observed in only one patient, who consecutively needed a left carotid to subclavian bypass. During a mean follow-up period of 4.1 ± 3.7 years, no additional patient needed secondary LSA revascularization. In comparing patients with occluded vs patent LSA, the Physical Component Summary (PCS) and Mental Component Summary (MCS) health scores (12-Item Short Form Health Survey) as well as DASH scores were similar. However, subgroup analysis showed better PCS scores for TAI patients with patent LSA, whereas MCS and DASH scores were similar in TAI patients, and scores were indifferent within thoracic aortic aneurysm and Stanford type B dissection subgroups. In comparing different subgroups, TAI patients had significantly better PCS, MCS, and DASH scores.**

Conclusions: **TEVAR is associated with a low risk of peri-interventional left arm ischemia. During long-term follow-up, secondary LSA revascularization is uncommon. Coverage of the LSA has no impact on left arm function and quality of life, probably with the exception of physical health scores in patients with TAI. (J Vasc Surg 2014;60:64-9.)**

Thoracic endovascular aortic repair (TEVAR) by stent grafting is an established treatment modality that frequently requires complete or partial coverage of the left subclavian artery (LSA) origin for an adequate proximal landing zone to be achieved. As a consequence of LSA coverage, downstream ischemic complications, such as posterior circulation stroke, spinal cord ischemia, and left arm ischemia, may occur. In contrast to multiple papers dealing with neurologic complications after LSA coverage,[1-6] up to now, fewer data on incidence, clinical management, and long-term outcome of left arm malperfusion were published. Moreover, there are no data on long-term functional impairment after LSA coverage by standardized questionnaires dealing with left arm function and the patient's quality of life.

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We therefore analyzed our patients who underwent TEVAR to report on the incidence of left arm ischemia and secondary LSA revascularization as well as left arm function and quality of life during long-term follow-up after TEVAR with and without LSA coverage. This is a single-center experience of an institution using a policy of selective primary LSA revascularization, basically depending on bilateral vertebrobasilar anatomy.

METHODS

All patients who underwent stent grafting for TEVAR since January 1996 in our institution were included. Basic demographic parameters, underlying disease, details of stent graft implantation, and LSA revascularization were analyzed. End points were incidence of left arm ischemia, need for LSA revascularization (before or after stent graft deployment), long-term left arm functional impairment, and quality of life.

Left arm acute ischemia was defined by signs and symptoms that are characterized by the six *p*'s: pulselessness, pallor, pain, poikilothermia, paresthesia, and paralysis. Severity of acute ischemia was classified according to the categories I to III published by Rutherford et al.[7] In addition, in the chronic phase after TEVAR, exercise-induced limb pain, symptomatic subclavian artery steal syndrome, and ulceration or gangrene at the level of the hand or fingers were documented.

For analysis of long-term left arm functional disability, all patients were asked to answer the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire. The DASH questionnaire conceptualizes the upper extremities as a single functional unit and refers to the patient's everyday activities, which are assessed by 30 questions.[8-11] For statistical analysis and comparison of subgroups, DASH answers were summarized and, by a conversion formula, led to a score between 0 (no deficit) and 100 (severe disability). Long-term quality of life was assessed by the 12-Item Short Form Health Survey (SF-12) questionnaire.

Statistical analysis was performed by descriptive statistics. Means and standard deviations of the DASH and SF-12 scores were calculated, and subgroup analysis and comparison of scores were performed by two-tailed t test, which was considered significant if $P < .05$.

RESULTS

A total of 138 patients underwent TEVAR for degenerative thoracic aortic aneurysm (TAA; n = 64), traumatic aortic injury (TAI; n = 38), or Stanford type B dissection (TBD; n = 36) during the study period. LSA coverage was performed in 73 patients (52.9%) and led to partial or complete LSA occlusion in 49 (35.5%). Nine patients (6.5%) underwent primary LSA revascularization before TEVAR. Indications for primary LSA revascularization were planned proximal extension of the stent graft to landing zone 0 and 1 (n = 4), dominant left vertebral artery or hypoplastic right vertebral artery (n = 2), previous or simultaneous AAA repair (n = 2), and a patient with type B aortic dissection presenting with paraplegia. A total of 129 patients (93.5%) did not undergo LSA revascularization before thoracic stent graft implantation.

After TEVAR, four of the patients who did not undergo primary LSA revascularization (3.1%; 4 of 129) developed stroke, and two patients (1.6%) had paraplegia. All but one patient with neurologic complications had patent LSAs. Location of stroke was diffuse (n = 2; both patients with TAA; presumably embolic), posterior (n = 1; patient with TAA with patent LSA and history of AAA repair), or anterior (n = 1; patient with TAA; LSA occlusion after TEVAR; underwent secondary revascularization due to stroke, spinal cord ischemia, and left arm ischemia).

Left arm ischemia was observed in one patient only (0.8%: 1 of 129 patients who underwent TEVAR; 2.0%: 1 of 49 with complete or partial LSA occlusion after TEVAR); a 67-year-old patient presented with left arm ischemia (Rutherford grade I) in combination with paraplegia and anterior circulation minor stroke after TEVAR plus LSA coverage for exclusion of a degenerative TAA. This patient consecutively underwent a left carotid to subclavian bypass procedure. Preinterventional imaging (computed tomography scan) as well as angiography of the supraaortic arteries during TEVAR in this particular patient showed patent carotid and vertebral arteries on both sides. Therefore, neurologic complications were considered to result presumably from embolisms during stent graft implantation and not as a direct consequence of LSA coverage alone. After secondary LSA revascularization, the patient's left arm ischemia resolved without long-term impairment and neurologic symptoms improved. Finally, after an individual follow-up period of more than 9 years, neurologic deficits resolved apart from urinary incontinence, which was treated with implantation of an artificial urinary sphincter 1 year after TEVAR.

During follow-up, after a mean period of 4.1 ± 3.7 years after TEVAR, no additional patient required secondary revascularization for left upper extremity symptoms (ischemia, effort fatigue, or subclavian steal syndrome). DASH and SF-12 questionnaires were answered by 49 patients, that is, 63% of the survivors (n = 78). Responders included patients with TAI (n = 24), TAA (n = 11), and TBD (n = 14). Basic demographic parameters (age and gender) of responders are summarized in Table I and show significant differences in terms of age; patients who underwent TEVAR for TAI were youngest, and patients with TAA were oldest. In addition, functional and quality of life scores varied between different aortic diseases. As shown in Table II, TEVAR for TAI was associated with better long-term function (DASH score, 14.4 ± 17.1) and quality of life (Physical Component Summary [PCS] score, 45.6 ± 10.4; Mental Component Summary [MCS]

Table I. Demographic parameters of patients with long-term follow-up data who answered DASH and SF-12 questionnaires

	Patients	*Median age, years (range)*	*Gender, M:F*
TAI	24	40.3 (14.9-62.3)	18:6
vs TBD		$P < .001$	NS
vs TAA		$P < .001$	NS
TBD	14	57.2 (45.0-76.4)	12:2
vs TAA		$P = .021$	NS
TAA	11	67.4 (58.2-80.8)	9:2

DASH, Disabilities of the Arm, Shoulder, and Hand; *NS,* not significant; *SF-12,* 12-Item Short Form Health Survey; *TAA,* thoracic aortic aneurysm; *TAI,* traumatic aortic injury; *TBD,* Stanford type B dissection.

Table II. Analysis and comparison of PCS and MCS health scores and DASH scores in patients during long-term follow-up after TEVAR

	Patients	*PCS score*	*MCS score*	*DASH score*
TAI	24	45.6 ± 10.4	53.4 ± 9.8	14.6 ± 17.1
vs TBD		$P = .156$	$P = .046$	$P = .066$
vs TAA		$P = .013$	$P = .013$	$P = .001$
TBD	14	40.3 ± 9.7	45.9 ± 10.7	27.3 ± 22.8
vs TAA		$P = .198$	$P = .506$	$P = .138$
TAA	11	34.0 ± 11.2	42.6 ± 10.2	43.4 ± 27.0

DASH, Disabilities of the Arm, Shoulder, and Hand; *MCS,* Mental Component Summary; *PCS,* Physical Component Summary; *TAA,* thoracic aortic aneurysm; *TAI,* traumatic aortic injury; *TBD,* Stanford type B dissection; *TEVAR,* thoracic endovascular aortic repair.
Results are shown as mean ± standard deviation.

Table III. Analysis of PCS and MCS health scores and DASH scores in patients during long-term follow-up after TEVAR with patent vs occluded LSA

	Patients	*PCS score*	*MCS score*	*DASH score*
All, LSA occluded	20	41.0 ± 10.3	49.9 ± 11.8	26.6 ± 27.8
All, LSA patent	29	42.5 ± 11.6	48.7 ± 10.5	22.6 ± 20.1
		$P = .68$	$P = .72$	$P = .58$
TAI, LSA occluded	12	40.8 ± 10.7	54.2 ± 10.1	19.0 ± 20.1
TAI, LSA patent	12	49.7 ± 8.4	52.8 ± 9.9	10.2 ± 12.8
		$P = .04$	$P = .75$	$P = .23$
TBD, LSA occluded	7	43.5 ± 9.9	45.9 ± 12.0	30.2 ± 31.2
TBD, LSA patent	7	37.2 ± 9.1	45.9 ± 10.4	24.3 ± 11.5
		$P = .28$	$P = .99$	$P = .64$
TAA, LSA occluded	1	NA	NA	NA
TAA, LSA patent	10	34.7 ± 11.9	44.2 ± 10.0	38.3 ± 23.8
		NA	NA	NA

DASH, Disabilities of the Arm, Shoulder, and Hand; *LSA,* left subclavian artery; *MCS,* Mental Component Summary; *NA,* not applicable; *PCS,* Physical Component Summary; *TAA,* thoracic aortic aneurysm; *TAI,* traumatic aortic injury; *TBD,* Stanford type B dissection; *TEVAR*, thoracic endovascular aortic repair.
All results are shown as mean ± standard deviation.

score, 53.4 ± 9.8) compared with patients with TBD ($P = .046$ for MCS) and, most strikingly, compared with patients with TAA ($P = .013$ for PCS and MCS scores; $P = .001$ for DASH scores).

Serial computed tomography scans performed during follow-up of patients after TEVAR showed patent LSA (n = 29) and partially (n = 3) or completely (n = 17) occluded LSA. For further analysis, patients with partial and complete occlusion of the LSA (n = 20) were added and assessed together. In looking at left arm perfusion in patients with occluded LSA, only two individuals had palpable pulses. After complete LSA occlusion, all patients' left arm systolic blood pressure was ≥95 mm Hg, and pressure indices comparing left and right arms were between 0.6 and 0.8. In comparing patients with partially and completely occluded vs patent LSA, the PCS and MCS health scores (SF-12 questionnaire) were similar in both groups (PCS score, 41.0 ± 10.3 vs 42.5 ± 11.6; MCS score, 49.9 ± 12.2 vs 48.7 ± 10.5; not significant). In addition, functional arm status showed similar DASH scores (26.6 ± 27.8 vs 22.6 ± 20.1; not significant). Data and subgroup analysis of PCS and MCS health scores as well as DASH scores are shown in Table III. Subgroup analysis was limited by the small number of patients within different groups, especially in patients with TAA. Subgroup analysis did not find any difference in patients with TAI, TAA, or TBD in terms of DASH scores as well as PCS and MCS scores, except for patients with TAI; LSA occlusion led to worse physical health scores compared with the group with patent LSA (PCS score, 40.8 ± 10.7 vs 49.7 ± 8.4; $P = .04$). However, there was no difference between both TAI groups with respect to left arm function as measured by the DASH scores (10.2 ± 12.8 vs 19.0 ± 20.1; $P = .23$).

DISCUSSION

Our practice of selective LSA revascularization before TEVAR was associated with a low risk of peri-interventional left arm ischemia; only one patient of 49 individuals (2.0%) with partially or completely occluded LSA after TEVAR was affected. In the literature, especially in looking at published reviews on complications after LSA coverage during TEVAR, the incidence of left arm ischemia after TEVAR was reported to be significantly higher,[12-16] namely, between 4.1% and 10.2%. In their systematic review, which was one of the basic papers of the Society for Vascular Surgery practice guidelines for the management of the LSA during TEVAR,[17] Rizvi et al[15] summarized data from 19 publications between 1996 and 2008. After LSA coverage, 38 of 399 patients with LSA coverage (9.5%) had reported malperfusion of the left arm (ischemia, claudication, subclavian steal syndrome), in contrast to two of 908 patients without LSA occlusion. Noteworthy, their review excluded single-cohort studies in which all patients received LSA coverage without a concurrent comparison group, some of them showing 0% left arm complication rates.[18,19] In addition, in looking at Rizvi's data, there was a substantial discrepancy in the outcomes of different studies included, leading to a "very-low-quality evidence suggesting that coverage increased the risk of arm ischemia."[15]

In general, in looking at publications dealing with left upper limb symptoms after LSA coverage during TEVAR, only a few papers included more than three patients with arm symptoms.[20-27] Papers on "left limb symptoms" after TEVAR frequently summarize patients with ischemia, claudication, steal syndrome, and other symptoms like transient skin discoloration of the fingers or hand, without clear description of the clinical course in the subgroups. Therefore, overall complication rates as well as treatment strategies and results are inconsistent. However, in analysis of the published data, true ischemia seems rare and is less frequently seen than claudication or steal syndromes (Table IV).

In our series, only one patient presented with left upper extremity ischemia after TEVAR. As this particular patient

Table IV. Analysis of papers dealing with "left upper arm symptoms" after LSA coverage during TEVAR

Author (year)	*Patients with symptoms*	*Ischemia*	*Claudication*	*Steal*	*Secondary revascularization*
Rehders et al (2004)[27]	7	-	-	7	0
Ferreira et al (2007)[25]	4	-	-	4	3
Reece et al (2007)[26]	4	-	3	1	3
Peterson et al (2008)[23]	5	-	5	-	2
Woo et al (2008)[24]	5	1	1	-	2
Kotelis et al (2009)[22]	5	-	3	2	4
Antonello et al (2013)[20]	9	-	9	-	1
Lee et al (2013)[21]	5	-	3	-	0
Total	44	1	24	14	15

Only papers with more than three cases were included. Two papers (Lee et al, 2013[21]; Woo et al, 2008[24]) included patients with atypical symptoms that are not listed, and adding numbers of subgroups does not correspond to the total number of patients with "left arm symptoms."

had concomitant stroke and spinal cord ischemia, the patient underwent immediate left carotid to subclavian bypass operation. Noteworthy, our patient with arm ischemia had patent carotid and vertebral arteries on both sides. Therefore, this patient did not undergo selective LSA revascularization before TEVAR. However, left arm ischemia could have been avoided by prophylactic revascularization in this case. After secondary LSA revascularization, the patient's left arm ischemia resolved completely, and no long-term left arm impairment was observed. In our series, there was no additional secondary LSA revascularization after TEVAR for left arm symptoms such as claudication or subclavian steal syndrome.

Whereas left arm ischemia represents an absolute indication for secondary revascularization in most cases, patients with claudication or steal syndrome are frequently treated conservatively, as shown in Table IV. Recently, Antonello et al[20] published their experience including nine patients with severe arm claudication after TEVAR; over time, after a mean follow-up period of 36 months, symptoms improved significantly, and only one of the nine patients needed secondary LSA revascularization. Earlier, Rehders et al[27] described seven patients with symptoms of subclavian steal syndrome; all patients were treated conservatively, and no secondary LSA revascularization was indicated during a mean follow-up period of 24 months.

To date, upper extremity functional impairment in patients with and without coverage of the LSA after TEVAR was never evaluated and compared by standardized tools, such as the DASH questionnaire. The DASH questionnaire is an instrument extensively validated[8-11] and frequently used to assess wrist and hand function in patients with different diseases and injuries. Use of the DASH questionnaire was advised for assessing outcome in any upper limb disease irrespective of the etiology and site.[28]

Our analysis of the DASH scores in our cohort indicates that LSA coverage during TEVAR does not deteriorate arm function during daily activities. Noteworthy, our data reflect long-term results that are obtained after a mean follow-up period of more than 4 years. It is unclear whether functional outcome is different if it is measured early or late after LSA coverage. There might be a potential for functional improvement or adaptation to functional impairment during follow-up, for example, if a patient with a dominant left hand learns to use the right extremity for everyday activities. As a consequence, long-term functional outcome is potentially better than results evaluated immediately after LSA coverage. Further studies are needed to analyze arm function over time after LSA coverage during TEVAR.

Similar to limited data on upper limb function, studies dealing with quality of life after TEVAR are scarce. To our knowledge, our data are the first to compare quality of life in patients with and without LSA coverage after TEVAR. In the absence of comparable studies, our data indicate that long-term quality of life does not depend on LSA patency, except for physical health scores in patients with TAI. Significant differences within subgroups (TAI, TBD, and TAA) presumably depend on patients' age; as shown in Table I, patients with TAI are significantly younger, and therefore those patients are possibly more active, which potentially leads to problems in case of LSA occlusion. As a consequence, decision-making for secondary LSA revascularization after TEVAR should be less restrictive in younger individuals, such as patients with TAI.

Again, as already stated with regard to left arm function, it is unclear whether comparison of patients with and without LSA coverage immediately after TEVAR would lead to different results. There is certainly a need for future studies dealing with quality of life after TEVAR, and those assessments should be performed at predefined time intervals rather than at highly variable times after treatment, as in our analysis.

Interestingly, our analysis showed significant variations in DASH scores between different subgroups. Both DASH scores and quality of life scores were best in patients who underwent TEVAR for traumatic aortic injuries and worst for patients who had TEVAR for repair of thoracic aneurysms, whereas patients with aortic dissection type B are somewhere in between. It is unclear whether those differences are essentially due to different pathologic processes. However, more likely, the differences are due to significant disparities with regard to age. As shown in Table I, patients with traumatic aortic injuries are significantly younger and therefore do significantly better in terms of long-term limb function and quality of life. This hypothesis should be evaluated by more widespread implementation of standardized questionnaires for assessment of function and quality of life in the treatment of thoracic aortic diseases.

There are several limitations in analyzing our data. Our data reflect long-term results that are obtained after a mean follow-up period of more than 4 years. As mentioned earlier, it is unclear whether incidence and severity of arm ischemia as well as functional outcome and quality of life are different if measured early or late after LSA coverage. Similar to other published series, patients presenting with true ischemia after LSA coverage are rarely seen; therefore, our outcome analysis could not include a comparison of asymptomatic and symptomatic patients in terms of function and quality of life. Subgroup analysis in patients with different aortic diseases was limited by small numbers of patients and included more patients with better long-term prognosis, such as TAI, compared with other entities. LSA coverage during TEVAR might have more severe effects in patients with dominant left hand. We did not evaluate the dominant hand side of patients; therefore, we were unable to compare the subgroups. LSA revascularization before TEVAR cannot be discussed with respect to the fate of the left arm alone but has to be considered as a procedure preventing neurologic complications such as stroke and spinal cord ischemia.

CONCLUSIONS

Our data indicate that TEVAR is associated with a low risk of left arm ischemia as a consequence of LSA coverage. During long-term follow-up, secondary LSA revascularization is uncommon. Coverage of the LSA has no impact on left arm function and quality of life, probably with the exception of physical activity and associated quality of life in young patients with TAI.

AUTHOR CONTRIBUTIONS

Conception and design: JK, GF
Analysis and interpretation: JK, AK, ME, GG
Data collection: JK, AK, ME
Writing the article: JK
Critical revision of the article: WJ, GF
Final approval of the article: GF
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