Covering the intercostal artery branching of the Adamkiewicz artery during endovascular aortic repair increases the risk of spinal cord ischemia

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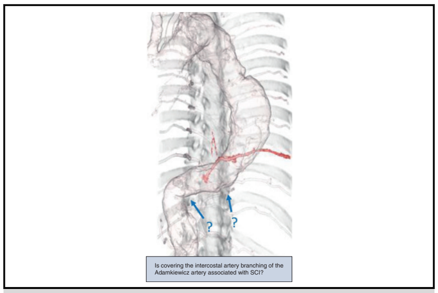
ABSTRACT

Objectives: This study aimed to determine the relationship between covering the intercostal artery branching of the Adamkiewicz artery (ICA-AKA) and spinal cord ischemia (SCI) during thoracic endovascular aortic repair (TEVAR).

Methods: Patients who underwent TEVAR from 2008 to 2022 were enrolled. Stent grafts covered the ICA-AKA in 108 patients (covered AKA group) and stent grafts didn't cover the ICA-AKA in 114 patients (uncovered AKA group). The characteristics of 58 patients from each group were matched based on propensity scores.

Results: No significant differences in SCI rates were detected between the covered AKA (10%; 11/108) and uncovered AKA (3.5%; 4/114) groups ($P = .061$). Shaggy aorta (odds ratio [OR], 5.16; 95% confidence interval [CI], 1.74-15.3, $P = .003$), iliac artery access (OR, 6.81; 95% CI, 2.22-20.9, $P = .001$), and procedural time (OR, 1.01; 95% CI, 1.00-1.02, $P = .003$) were risk factors for SCI in the entire cohort. Although covering the ICA-AKA (OR, 2.60; 95% CI, 0.86-7.88, $P = .058$) was not a significant risk factor, shaggy aorta (OR, 8.15; 95% CI, 2.07-32.1, $P = .003$), iliac artery access (OR, 9.09; 95% CI, 2.22-37.2, $P = .002$), and procedural time (OR, 1.01; 95% CI, 1.01-1.02, $P = .008$) were risk factors for SCI in the covered AKA group. No significant risk factors were detected in the uncovered AKA group.

Conclusions: Covering the ICA-AKA was not an independent risk for SCI in TEVAR. However, covering the ICA-AKA was indirectly associated with the risk of SCI in patients with shaggy aorta, iliac access, and procedural time. (JTCVS Open 2024;17:14-22)



Answer: Yes, but it depends on the situation.

CENTRAL MESSAGE

Covering the ICA-AKA was indirectly associated with the risk of SCI in patients with shaggy aorta, iliac access, and procedural time.

PERSPECTIVE

Covering the ICA-AKA was not an independent risk for SCI in TEVAR. However, covering the ICA-AKA was indirectly associated with the risk of SCI in patients with shaggy aorta, iliac access, and procedural time. Therefore, if possible, the ICA-AKA would be preserved in patients with high risk of SCI.

The collateral network concept by Griepp and colleagues[1] states that "the spinal cord has many incoming arteries and rich collateral blood channels inside and outside the spinal cord; therefore, it is important to maintain collateral blood flow and not depend on a single artery." However, this concept applies only when no anterior spinal artery stenosis occurs or when the collateral vessels are extraordinarily developed due to the presence of an additional radiculomedullary artery or previous surgical repair if stenosis of the anterior spinal artery occurs. In the remaining cases, spinal cord blood supply is dependent on thin-diameter vessels rather than a single thick vessel. Therefore, the segmental arteries would be preserved as much as possible to avoid spinal cord ischemia (SCI) during thoracic endovascular aortic repair (TEVAR).[2-5]

The arteria radicularis anterior magna, also known as the Adamkiewicz artery (AKA), has an important role as a

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Abbreviations and Acronyms

AKA	= Adamkiewicz artery
CI	= confidence interval
CSFD	= cerebrospinal fluid drainage
CT	= computed tomography
ICA-AKA	= intercostal artery branching of the Adamkiewicz artery
MEP	= motor-evoked potential
OR	= odds ratio
PSM	= propensity score matching
SCI	= spinal cord ischemia
TAA	= thoracic aortic aneurysm
TEVAR	= thoracic endovascular aortic repair

segmental artery feeding the spinal cord. Several papers from Japan highlight the clinical significance of the AKA during TEVAR for degenerative distal arch and/or descending thoracic aortic aneurysms (TAAs).[4,6-8] However, few reports originate from Western countries, and no guidelines have been established.[9] In Japan, preserving AKA flow during TEVAR is controversial. To address the insufficient evidence and determine the relationship between AKA and the risk of SCI, we investigated the effects of covering the intercostal artery branching of the Adamkiewicz artery (ICA-AKA) during TEVAR on SCI. This study aimed to reveal the relation covering the ICA-AKA and SCI during TEVAR for nondissecting distal arch and descending TAA by excluding aortic dissections that included malperfusion syndrome.[10]

METHODS

Ethical Statement

This observational study was approved by the institutional review board (August 8, 2018; M30-036). The need for individual oral and written informed consent was waived because of the retrospective design of the study.

Study Design and Population

This observational, retrospective, cohort study complies with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines. Between October 2008 and July 2022, 611 patients in our center underwent TEVAR with proximal landing at zones 3 or 4 for TAA.[11] Patients with aortic dissections (n = 174), redo TEVAR due to any type of endoleak (n = 85), pseudoaneurysms (n = 45), aortic ruptures (n = 36), thoracoabdominal aortic aneurysms (n = 30), or no ICA-AKA identification (n = 19) were excluded (Figure 1).

TEVAR Techniques

Stent grafts were chosen based on sizing and surgeons' preferences. The following devices were used in this study: Valiant Captivia/Navion (Medtronic, Inc), RELAY Plus/RELAY pro (Bolton Medical Inc), Zenith TX2/Zenith Alpha (Cook Inc), and Gore TAG or cTAG (W. L. Gore & Associates, Inc). Stent graft sizing was based on the manufacturers' instructions for each device.

TEVAR procedures were performed with the patients under general anesthesia. Vascular access was via direct surgical femoral exposure for most patients. Iliac artery access was used if a patient had a significantly

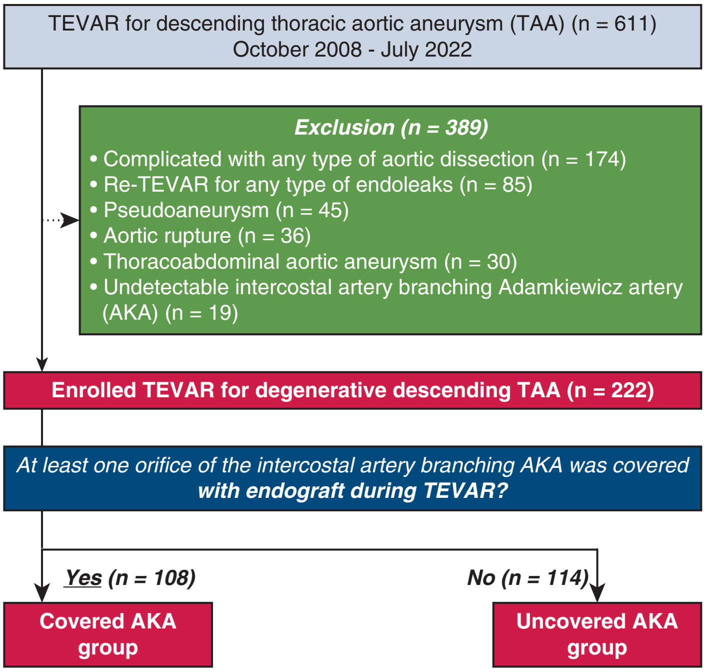

FIGURE 1. Flowchart of study population. *TEVAR*, Thoracic endovascular aortic repair.

thinner common femoral artery or external iliac artery compared with the device's outer diameter or a patient was post-bifurcated graft replacement of the abdominal aorta. To reach the appropriate distal landing zone and prevent endoleaks, the celiac artery was closed by the interventional radiologists with/without an embolization device if necessary. Motor-evoked potentials (MEPs) were monitored to detect SCI.[12]

Preventative Procedures for SCI

The following preoperative, intraoperative, and postoperative procedures were conducted to prevent SCI. The AKA was mainly detected using magnetic resonance angiography until August 2011. Since September 2011, radiologists at this center routinely applied computed tomography (CT) angiography with a 64- or 128-channel multidetector-row helical CT scanner to locate the AKA. The scan covered the area from the seventh thoracic vertebra to the third lumbar vertebra (the location was determined using a scout digital radiograph).[13] Figure 2 shows the characteristic CT angiography identifying the AKA and collateral vessels.

During the intraoperative period, prophylactic cerebrospinal fluid drainage (CSFD) was initiated, with a draining pressure of less than 12 cmH2O in patients with prearranged covering the ICA-AKA, shaggy aorta, extensive coverage of the aorta, occluded hypogastric artery, and/or occluded left subclavian artery. If the covering the ICA-AKA might be avoidable to obtain adequate landing zone, the ICA-AKA was preserved as far as possible. Since 2018, carbon dioxide flushing through the side port of the flushing chamber was performed before the heparinized saline flush to minimalize the volume of air released during deployment of a stent graft when performing TEVAR using a stent graft system with a sheath delivery system other than cTAG.[14] In patients with significant MEP changes (baseline MEP $\leq$25%), mean blood pressure was augmented to over 90 mm Hg (or systolic pressure over 150 mm Hg) with aggressive use of catecholamines for 48 hours after deployment of the endograft under direct arterial blood pressure monitoring. However, if there was no lower-extremity motor impairment, no additional CSFD insertion was considered.

For the first 24 to 48 hours after TEVAR, all patients were admitted to the intensive care unit for hemodynamic and neurologic one-to-one care. Arterial blood pressure was continuously monitored. Neurologic examinations were conducted every 2 hours. In patients without neurologic symptoms of SCI, CSFD was sustained for 6 to 24 hours after stent graft deployment, and CSFD tubes were routinely removed 48 hours after TEVAR. No remarkable changes in the postoperative management were offered during the study period.

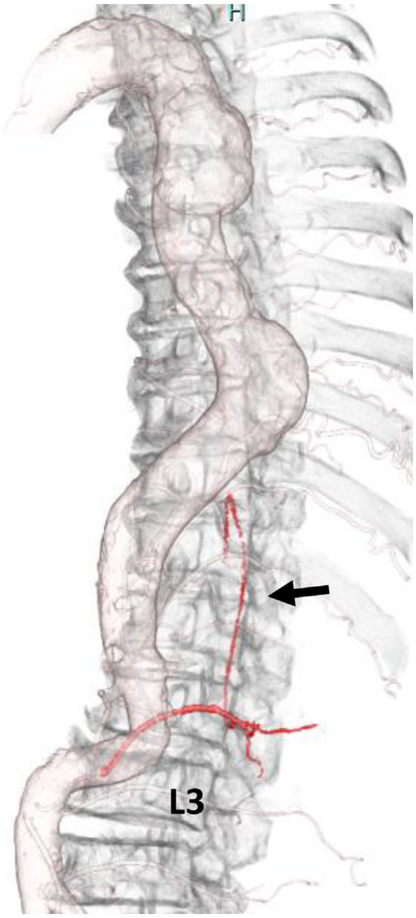

FIGURE 2. Identification of the Adamkiewicz artery. The Adamkiewicz artery (*black arrow*) and collateral vessels arising from the third lumbar artery were identified using computed tomography angiography.

Definitions and Outcomes

A shaggy aorta was defined as an aortic intimal irregularity with an atheroma thickness of $\geq$5 mm protruding into the aortic lumen based on CT findings (Figure 3). This assessment was performed by both a radiologist and a cardiovascular surgeon using the arterial phases, at 2 segments (including aortic arch to descending aorta and renal-mesenteric aorta). SCI was defined as any transient or permanent neurological dysfunction in the lower extremities with or without bladder and bowel dysfunction.

The primary outcome was the occurrence of SCI. The secondary outcomes included the incidence of hospital mortality and major complications.

Statistical Analysis

Categorical variables were compared using Fisher exact tests. After checking for normality with the Shapiro–Wilk test, continuous variables were compared and expressed as means with standard deviations. The non-normally distributed continuous variables were expressed as medians and compared by Mann–Whitney *U* tests. Univariable analysis was performed using a logistic regression model for identifying risk factors associated with SCI. The primary and secondary outcomes were reevaluated after propensity score matching (PSM). A logistic regression analysis was conducted to calculate propensity scores for patients with embolic events using their baseline features. Then, a 1:1 PSM based on the nearest neighbor matching algorithm with replacements was performed. The caliper width was set at 20% of the standard deviation of the propensity scores. Statistical analyses were performed using SPSS Statistics for Windows, version 24.0 (SPSS Inc).

RESULTS

Patients, Baseline Demographics, and Clinical Characteristics

Of the 222 patients enrolled in the study, the ICA-AKA was identified in all cases (100%), and at least one orifice of the ICA-AKA was covered with a stent graft during TEVAR in 108 patients, who were assigned to the covered AKA group (24 female patients; mean age 77 years [73-82 years]). The ICA-AKAs were not covered by stent grafts in 114 patients, who were assigned to the uncovered AKA group (28 female patients; mean age 76 years [71-81 years]) (Figure 1). Table 1 shows the patient characteristics of each group. Patients in the covered AKA group

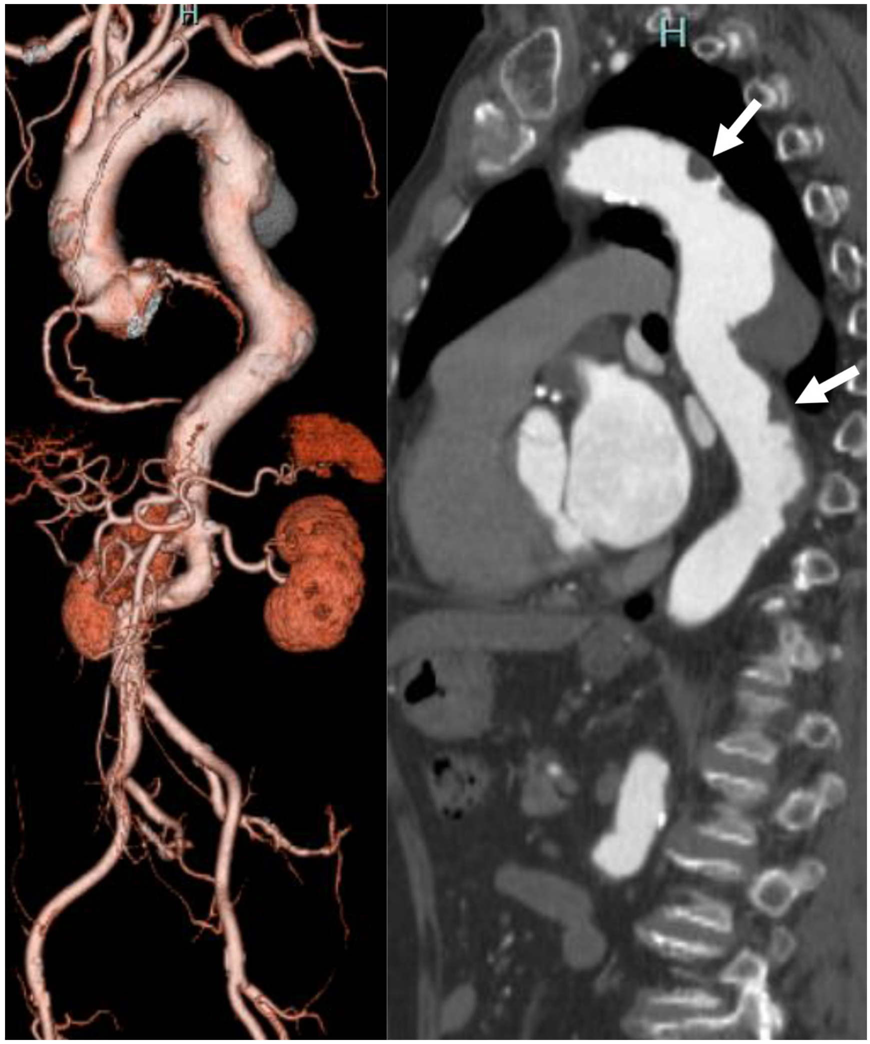

FIGURE 3. Computed tomography angiography findings of the shaggy aorta. The 3-dimensional and sagittal aortic computed tomography angiography images show a shaggy aorta. *White arrows* indicate an intimal irregularity with atheroma thickness.

had a significantly greater rate of preoperative CSFD tube insertion than the uncovered AKA group ($P < .001$). The proximal landing zone ($P < .001$) and distal landing zone ($P < .001$) were significantly more distal in the covered AKA group compared with the landings in the uncovered AKA group. Significantly more zones were covered by the stent grafts in the covered AKA group compared with the uncovered AKA group ($P = .017$) (Table 1).

TEVAR Outcomes and Endoleaks

All TEVARs were performed electively. No differences in procedural times ($P = .906$), amount of bleeding ($P = .387$), and the use of blood transfusion ($P = .438$) were detected between the 2 groups. No differences in immediate type I endoleaks (5/108; 4.6% vs 6/114; 5.3%, $P = 1.000$) or type III endoleaks (1/108; 0.9% vs 1/114; 0.9%, $P = 1.000$) were detected on the CT scans (Table 2).

Early Clinical Outcomes Including Spinal Cord-Related Findings

Early mortality and complications during hospitalization in each group are listed in Table 2. No 30-day mortality was observed in either group, and no differences in hospital mortality were detected between the 2 groups (1.9% [2/108] for the covered AKA versus 2.6% [3/114] for the uncovered AKA, $P = 1.000$). The causes of hospital mortality included aspiration pneumonia (n = 2) in the covered AKA group and suffocation due to aspiration (n = 1), infective endocarditis (n = 1), and peritonitis (n = 1) in the uncovered AKA group. No differences in postoperative complications were detected between the 2 groups (Table 2).

TABLE 1. Patients' characteristics (entire and matched cohorts)

Variable	Covered AKA (108)	Uncovered AKA (114)	P value	Covered AKA (58)	Uncovered AKA (58)	P value
Median age, y	77 (73-82)	76 (71-81)	.188	78 (74-81)	77 (73-81)	.489
Female sex	24 (22%)	28 (25%)	.752	11 (19%)	11 (19%)	1.000
Stroke history	33 (30%)	35 (31%)	.588	15 (26%)	17 (29%)	.836
Chronic kidney disease (Cr > 1.5)	20 (19%)	30 (26%)	.151	13 (22%)	17 (29%)	.525
Coronary artery disease	41 (38%)	50 (44%)	.414	27 (47%)	21 (36%)	.346
COPD	15 (14%)	13 (11%)	.687	8 (14%)	6 (10%)	.777
Antiplatelet therapy	40 (37%)	53 (46%)	.174	25 (43%)	24 (41%)	1.000
Anticoagulant therapy	10 (9.6%)	15 (13%)	.401	8 (14%)	8 (14%)	1.000
Shaggy aorta	14 (13%)	23 (20%)	.207	12 (21%)	12 (21%)	1.000
Occluded left subclavian artery	1 (0.9%)	2 (1.8%)	1.000	0	0	N/A
Occluded hypogastric artery (unilateral)	11 (10%)	10 (8.8%)	.820	3 (5.2%)	5 (8.6%)	.717
Previous aortic arch surgery	32 (30%)	49 (43%)	.051	23 (40%)	20 (34%)	.701
Previous intervention on abdominal aorta	34 (31%)	27 (24%)	.229	17 (29%)	17 (29%)	1.000
Preoperative CSFD tube insertion	61 (56%)	30 (26%)	<.001	24 (41%)	28 (48%)	.576
Iliac artery access	30 (25%)	27 (24%)	.540	15 (26%)	19 (33%)	.541
Proximal landing zone of the stent grafts	5 (3-6)	3 (3-5)	<.001	5 (3-6)	3 (3-6)	.131
Distal landing zone of the stent grafts	11 (10-12)	10 (9-11)	<.001	11 (10-12)	11 (9-12)	.429
Aortic coverage by the stent grafts, zones	7 (6-9)	6 (5-8)	.017	7 (5-9)	7 (6-8)	.958
Covering of the celiac trunk	8 (7.4%)	3 (2.6%)	.127	4 (6.9%)	3 (5.2%)	1.000

AKA, Adamkiewicz artery; *Cr*, creatinine; *COPD*, chronic obstructive pulmonary disease; *N/A*, not applicable; *CSFD*, cerebrospinal fluid drainage.

The rates of SCI were not significantly different between the covered AKA (10%; 11/108) and the uncovered AKA (3.5%; 4/114) groups ($P = .061$). No differences in the rates of permanent SCI ($P = .162$), transit SCI ($P = .270$), and therapeutic CSFD ($P = 1.000$) were detected between the 2 groups (Table 2).

TABLE 2. Early outcomes and complications (entire and matched cohorts)

Variable	Covered AKA (108)	Uncovered AKA (114)	P value	Covered AKA (58)	Uncovered AKA (58)	P value
TEVAR outcomes						
Procedural time, min	107 (90-154)	111 (90-151)	.906	107 (92-151)	116 (92-161)	.518
Amount of bleeding, mL	70 (10-265)	100 (10-285)	.387	75 (10-200)	185 (80-385)	.003
Blood transfusion	24 (22%)	31 (27%)	.438	14 (24%)	14 (24%)	1.000
Early outcomes						
30-d mortality	0	0	N/A	0	0	N/A
Hospital mortality	2 (1.9%)	3 (2.6%)	1.000	2 (3.4%)	2 (3.4%)	1.000
Spinal cord–related findings						
Spinal cord ischemia	11 (10%)	4 (3.5%)	.061	7 (12%)	3 (5.2%)	.322
Permanent	6 (5.6%)	2 (1.8%)	.162	4 (6.9%)	1 (1.7%)	.364
Transit	5 (4.6%)	2 (1.8%)	.270	3 (5.2%)	2 (3.4%)	1.000
Therapeutic CSFD	2 (1.9%)	2 (1.8%)	1.000	1 (1.7%)	1 (1.7%)	1.000
Subdural hematoma after CSFD	1 (0.9%)	0	.486	1 (1.7%)	0	1.000
Other complications						
Stroke	0	1 (0.9%)	1.000	0	1 (1.7%)	1.000
Acute kidney injury required CHDF	0	2 (1.8%)	.498	0	1 (1.7%)	1.000
Ileus	2 (1.9%)	0	.236	2 (3.4%)	0	.496
Stent graft–induced new entry	0	0	N/A	0	0	N/A
Pneumonia	2 (1.9%)	3 (2.6%)	1.000	2 (3.4%)	2 (3.4%)	1.000
Access route injury	6 (5.6%)	2 (1.8%)	.162	3 (5.2%)	2 (3.4%)	1.000

AKA, Adamkiewicz artery; *TEVAR*, thoracic endovascular aortic repair; *N/A*, not applicable; *CSFD*, cerebrospinal fluid drainage; *CHDF*, continuous hemodiafiltration.

TABLE 3. Cox regression analysis (univariable): Predictors of SCI

Covariate	Overall (222)		Covered AKA (108)		Uncovered AKA (114)	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Covering the ICA-AKA	3.12 (0.96-10.1)	.058	N/A	N/A	N/A	N/A
Operative year			–	–	–	–
2008-2009	1.00	.943	–	–	–	–
2010-2011	1.31 (0.31-5.65)	.715	–	–	–	–
2012-2013	0.60 (0.10-3.47)	.568	–	–	–	–
2014-2015	0.68 (0.12-4.37)	.664	–	–	–	–
2016-2017	0.75 (0.13-4.37)	.749	–	–	–	–
2018-2019	0.40 (0.04-3.81)	.429	–	–	–	–
2020∼	0.70 (0.12-4.07)	.691	–	–	–	–
Median age	0.99 (0.93-1.08)	.950	0.99 (0.91-1.09)	.960	0.98 (0.85-1.13)	.734
Female sex	0.81 (0.22-2.97)	.746	0.76 (0.15-3.77)	.734	1.03 (0.10-10.3)	.983
Stroke history	0.78 (0.25-2.51)	.681	0.78 (0.20-2.99)	.713	0.75 (0.08-7.42)	.802
Chronic kidney disease (Cr > 1.5)	1.75 (0.57-5.38)	.328	1.77 (0.42-7.35)	.435	2.79 (0.83-20.7)	.315
Coronary artery disease	1.28 (0.45-3.67)	.664	1.41 (0.40-4.96)	.590	1.29 (0.18-9.51)	.802
COPD	1.82 (0.48-6.90)	.378	2.66 (0.62-11.4)	.189	0.00 (0.00-)	.999
Low ejection fraction (<50%)	0.00 (0.00-)	.999	0.00 (0.00-)	.999	0.00 (0.00-)	.999
Smoking history	1.43 (0.50-4.09)	.506	2.39 (0.66-8.71)	.186	0.39 (0.04-3.82)	.416
Statin therapy	0.70 (0.23-2.13)	.534	0.97 (0.27-3.54)	.961	0.40 (0.04-3.97)	.434
Antiplatelet therapy	0.68 (0.22-2.05)	.489	0.61 (0.15-2.44)	.483	1.16 (0.16-8.51)	.886
Anticoagulant therapy	1.23 (0.26-5.80)	.793	2.47 (0.45-13.5)	.295	0.00 (0.00-)	.999
Shaggy aorta	5.16 (1.74-15.3)	.003*	8.15 (2.07-32.1)	.003*	4.24 (0.56-31.8)	.160
Occluded left subclavian artery	0.00 (0.00-)	.999	0.00 (0.00-)	.999	0.00 (0.00-)	.999
Occluded hypogastric artery (unilateral)	1.52 (0.32-7.26)	.598	2.17 (0.41-11.6)	.365	0.00 (0.00-)	.999
Previous aortic arch surgery	1.57 (0.55-4.51)	.400	1.41 (0.38-5.19)	.607	4.17 (0.42-41.4)	.222
Previous intervention on abdominal aorta	0.39 (0.08-1.76)	.219	0.19 (0.02-1.58)	.125	1.08 (0.11-10.8)	.950
Preoperative CSFD	1.71 (0.60-4.89)	.319	0.92 (0.26-3.21)	.891	2.93 (0.39-21.8)	.294
Iliac artery access	6.81 (2.22-20.9)	.001*	9.09 (2.22-37.2)	.002*	3.40 (0.46-25.4)	.233
Proximal landing zone of the stent grafts	1.07 (0.80-1.42)	.658	1.06 (0.74-1.53)	.747	0.83 (0.39-1.76)	.627
Distal landing zone of the stent grafts	1.39 (0.97-1.99)	.077	1.19 (0.73-1.94)	.483	1.38 (0.73-2.59)	.323
Aortic coverage by the stent grafts, zones	1.19 (0.89-1.58)	.226	1.03 (0.74-1.44)	.842	1.49 (0.86-2.58)	.155
Covering of the celiac trunk	3.39 (0.66-17.3)	.143	3.37 (0.59-19.2)	.171	0.00 (0.00-)	.999
Procedural time	1.01 (1.00-1.02)	.003*	1.01 (1.00-1.02)	.008*	1.01 (0.99-1.02)	.267
Amount of bleeding	1.00 (1.00-1.01)	.388	1.00 (1.00-1.01)	.561	1.00 (0.99-1.00)	.578

AKA, Adamkiewicz artery; *OR*, odds ratio; *CI*, confidence interval; *ICA-AKA*, intercostal artery branching of the Adamkiewicz artery; *N/A*, not applicable; *Cr*, creatinine; *COPD*, chronic obstructive pulmonary disease; *CSFD*, cerebrospinal fluid drainage; *SCI*, spinal cord ischemia. **P* < .05.

Matched Cohort Analysis

After PSM, 58 patients from each group were selected to determine the risk factors for SCI. Variables related to SCI were analyzed, including preoperative CSFD, shaggy aorta, treatment length, and iliac access (Table 1). After PSM, no significant differences in the rates of SCI between the covered AKA (12%; 7/58) and uncovered AKA (5.2%; 3/58) groups were detected ($P = .322$). The bleeding volume was significantly lower in the covered AKA group (75 mL [10-200 mL]) compared with the bleeding volume in the uncovered AKA group (185 mL [80-385 mL]) ($P = .003$). No differences in other variables were detected (Table 2).

Risk Factors for SCI

Shaggy aorta (odds ratio [OR], 5.16; 95% confidence interval [CI], 1.74-15.3, $P = .003$), iliac artery access (OR, 6.81; 95% CI, 2.22-20.9, $P = .001$), and procedural

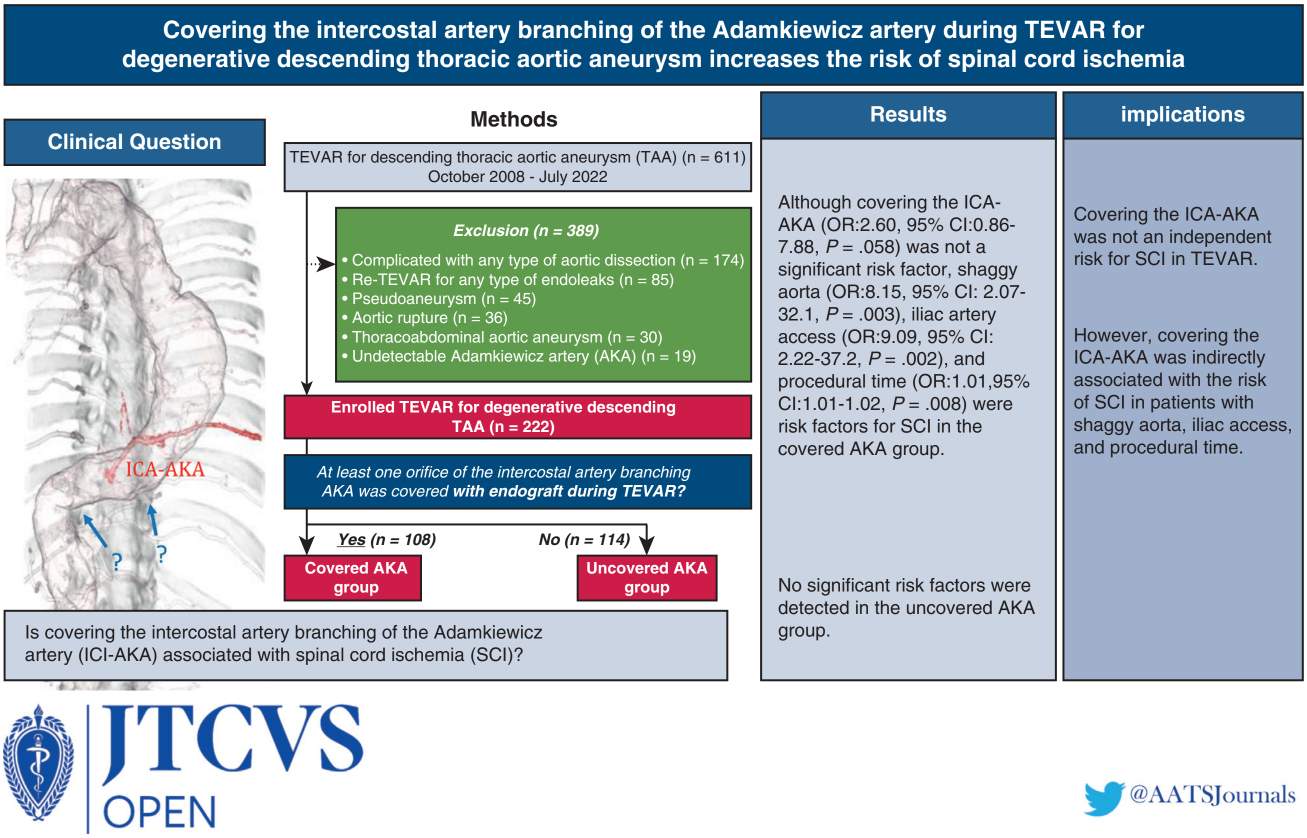

FIGURE 4. In this study, patients who underwent TEVAR from 2008 to 2022 were enrolled. Stent grafts covered the ICA-AKA in 108 patients and stent grafts didn't cover the ICA-AKA in 114 patients. Although covering the ICA-AKA was not a significant risk factor, shaggy aorta, iliac artery access, and procedural time were risk factors for SCI in the covered AKA group. No significant risk factors were detected in the uncovered AKA group. Covering the ICA-AKA was not an independent risk for SCI in TEVAR. However, covering the ICA-AKA was indirectly associated with the risk of SCI in patients with shaggy aorta, iliac access, and procedural time. *TEVAR*, Thoracic endovascular aortic repair; *ICA-AKA*, intercostal artery branching of the Adamkiewicz artery; *OR*, odds ratio; *CI*, confidence interval.

time (OR, 1.01; 95% CI, 1.00-1.02, *P* = .003) were identified as risk factors for SCI in the entire cohort. Covering the ICA-AKA (OR, 2.60; 95% CI, 0.86-7.88, *P* = .058) was not statistically significant. In the covered AKA group, shaggy aorta (OR, 8.15; 95% CI, 2.07-32.1, *P* = .003), iliac artery access (OR, 9.09; 95% CI, 2.22-37.2, *P* = .002), and procedural time (OR, 1.01; 95% CI, 1.01-1.02, *P* = .008) were risk factors for SCI. In the uncovered AKA group, no significant risk factors for SCI were identified (Table 3).

DISCUSSION

Several prophylactic measures for preventing SCI during TEVAR have been reported.[12,15-17] We analyzed >200 patients with degenerative descending TAAs who underwent TEVARs after establishing prophylactic SCI measures; the incidence of both transient and permanent was 6.8%. No significant differences in the occurrence of SCI between the periods of TEVAR performed were detected, although we observed a slight importance.

Only a few reports regarding AKA and SCI have been published, and fewer studies have been published from Europe and the United States than from Japan.[4,6-9,18] Furthermore, no consensus has been reached on the significance of preserving the ICA-AKA during TEVAR. Kamada and colleagues[6] highlighted the importance of both careful identification of the AKA and preservation of potential collateral circulation. In their study, none of the 51 patients experienced permanent SCI after the authors identified the AKA and planned the stent graft deployment while considering the AKA location and potential collateral circulation pathways. In contrast, Mousa and colleagues[19] identified risk factors for SCI after TEVAR, including advanced age, smoking, longer stent graft length, and the American Society of Anesthesiologists class, but the AKA was not evaluated in their study.

The lack of awareness about the importance of the AKA may be due to the multifactorial pathogenesis of SCI after TEVAR and the complex, dynamic process of spinal cord perfusion, which is dependent on both collateral circulation and specific segmental arteries, including the AKA.[1-3] In addition, degenerative TAA may be associated with an increased risk for SCI because these patients tend to have fewer patent ICAs compared with patients with dissecting TAAs,[20] and the development of SCI depends not only on the patient's anatomy but also on the aortic disease. These factors contribute to the complex clinical importance of the AKA. For that reason, we excluded the effects of aortic dissection, including malperfusion syndrome,[18] to understand the influence of covering the ICA-AKA. Thus, our results are specific for TEVAR for nondissecting descending TAA and exclude the effects of debranching procedures related to left subclavian artery reconstruction.[19] This patient selection is one of the strengths of this study.

The rate of SCI tended to be greater in the covered AKA group (10%) compared with the rate in the uncovered AKA group (3.5%) but the difference was not significant. After PSM, our results indicate that covering the ICA-AKA plays an important role in increasing SCI, but covering the ICA-AKA alone is not directly related to the development of SCI. Thus, decreased blood supply to the spinal cord is associated with other factors, and covering the ICA-AKA may have an additional effect on SCI. To identify the additional factors, we performed univariable regression analysis for the entire cohort and the covered AKA and uncovered AKA groups. Shaggy aorta, iliac artery access, and procedural time were identified as risk factors for SCI in the entire cohort, in agreement with several previous studies.[4,20-22] The most important finding of our study was that shaggy aorta, iliac artery access,[23] and procedural time were similarly identified (with greater ORs) as risk factors for SCI in the covered AKA group, whereas no risk factors for SCI were identified in the uncovered AKA group. These results indicate that covering the ICA-AKA increases the risk of SCI, but the risk of SCI is low if the ICA-AKA is not covered by stent grafts. In addition, these results indicate that the ICA-AKA should not be covered by stent grafts, and selecting an appropriate landing site that preserve as much as possible is important, especially in patients having risk factors of SCI during TEVAR (Figure 4). Further investigation using prospective randomized controlled trials is needed to validate these results, but this is not easy due to ethical issues.

Our study has several limitations. First, this was a single-center, retrospective, observational study in a specific cohort of patients with a restricted sample size including the number of adverse events of SCI, especially in the uncovered AKA group with SCI. Second, improved TEVAR techniques, including new devices and improved SCI prevention measures may have affected the outcomes. Finally, diagnoses of SCI were made based only on clinical features, without visualization using spinal cord MRI.

CONCLUSIONS

Covering the ICA-AKA was not an independent risk for SCI in TEVAR. However, covering the ICA-AKA was indirectly associated with the risk of SCI in patients with shaggy aorta, iliac access, and procedural time.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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