Featured Article

Impact of preoperative identification of the artery of Adamkiewicz on spinal cord injury after descending aortic and thoracoabdominal aortic repair

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Background: Some recent reports have demonstrated that preoperative Adamkiewicz artery (AKA) identification and its targeted reconstruction has provided satisfactory outcomes with respect to spinal cord protection. This paper investigates the impact of preoperative identification of the AKA on reducing the incidence of spinal cord injury (SCI) in open repair (OR) and endovascular repair (EVR) of descending thoracic aortic (dTA) and thoracoabdominal aortic aneurysm (TAA) repair.

Methods: The clinical data of patients with dTA and TAA treated between 2011 and 2022 were investigated. A total of 256 patients comprising of 201 males and 55 females, with a mean age of 72.1±10.0 years, were included. OR was used in 102 patients and EVR in 154 patients whose distal landing zone was below T8, all of which needed preoperative identification of the AKA.

Results: The AKA was identified in 207 (80.9%) patients, and was located in the level between T8 and T12 in 81.2%. In OR, the responsible arteries, including the identified AKA, were promptly reconstructed in 66 (64.7%) patients. In EVR, 65 (42.2%) patients had the AKA covered by an endovascular prosthesis. Deaths prior to 30 days occurred in seven (2.7%, four in OR and three in EVR) patients. In OR, SCI occurred in six (5.9%) patients including three (2.9%) with paraplegia and three (2.9%) with paraparesis, whereas in EVR ten (6.5%) patients had SCI, including two (1.3%) with paraplegia and eight (5.2%) with paraparesis. The incidence of SCI was significantly higher in patients with the AKA covered than those without it covered [13.8% (9 of 65) *vs.* 1.1% (1 of 89); P=0.002], whereas no significant differences were found between patients with or without the AKA reconstructed.

Conclusions: Preoperative identification of the AKA was useful enough to determine treatment strategies with less likelihood of SCI in both OR and EVR for dTA and TAA pathologies.

Keywords: Descending thoracic and thoracoabdominal aortic pathologies; open repair; endovascular repair (EVR); Adamkiewicz artery (AKA); spinal cord injury (SCI)

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Introduction

Surgical treatment for descending thoracic aortic (dTA) and thoracoabdominal aortic aneurysm (TAA) lesions remains challenging, with considerable mortality and high complication rates. Spinal cord injury (SCI) remains as one of the most serious sequelae (1-3). The artery of Adamkiewicz (AKA) is paramount in the anatomical and physiological setting for spinal cord perfusion and protection intraoperatively. However, few historical reports have supported the importance of identifying the AKA, because preoperative and intraoperative identification of the AKA is difficult (4,5). Some more recent reports have demonstrated that preoperative identification of AKA using computed tomography (CT) angiography and its targeted reconstruction have provided satisfactory outcomes in dTA and TAA repair, particularly for the endpoint of spinal cord protection (4,6). Based on a previous study, we have employed preoperative AKA identification using CT angiography and its targeted reconstruction in open repair (OR), and with the stent graft, especially the distal landing zone, placed so that it did not protrude into the AKA whenever possible in endovascular repair (EVR) (4-6). In this study, we conducted a retrospective investigation of the impact of preoperative AKA identification on reducing the incidence of SCI in OR and EVR of dTA and TAA pathologies.

Methods

We reviewed our institutional database, identifying 444 consecutive patients (102 in OR and 342 in EVR) who had undergone dTA or TAA surgical treatment between 2011 and 2022 at Tokyo Medical University Hospital. Of them, all OR patients, and 154 EVR patients whose distal landing zone was below T8, needed preoperative AKA identification and were included in this study. However, some patients who underwent an operation in an emergent setting did not undergo preoperative identification. Following this, 227 (88.7%) patients, 96 (94.1%) in OR, and 130 (84.4%) in EVR, underwent preoperative CT angiography to locate the AKA.

Data collection

The procedures followed were in accordance with Ethical Guidelines for Medical and Biological Research Involving Human Subjects (enacted on March 23, 2021, by the Japanese Government) and the Helsinki Declaration of 1975, as revised in 2008. This study was approved by the clinical research committee of Tokyo Medical University [institutional review board (IRB) approved No. T2020-0254]. Patient consent was waived by all IRBs due to the retrospective nature of the study. After IRB approval, the clinical data were collected from the hospital medical records.

Operative techniques

In the OR group, some adjuncts for organ protection were routinely used to prevent SCI, renal failure, mesenteric ischemia, and other malperfusion syndromes. During both OR and EVR, transcranial motor-evoked potentials (MEPs) showing muscle action potentials elicited by transcranial brain stimulation were used to monitor spinal cord ischemia. The limit for critical change in MEP was determined to be any reduction of the signal (amplitude) more than 50%, which is thought to reflect an increased risk of spinal cord ischemia. In cases with deep hypothermia, the MEP disappeared completely. The assessment of MEP monitoring was then done before core-cooling and during/after systemic rewarming (7). In the OR group, one or two selected intercostal arteries (ICAs) or lumbar arteries (LAs) including the identified AKAs in preoperatively were reconstructed using 8- or 10-mm side grafts and/or preserved with a beveling technique at moderate-to-deep hypothermia with total cardiopulmonary bypass (CPB) or mild hypothermia with partial CPB. However, reconstruction and/or preservation of AKA was not performed if there was no intraoperative MEP reduction, and if the ICA had been reconstructed in a previous operation, or if the preoperative CT showed a feeding artery to the anterior spinal artery other than AKA. At the beginning of 2015, the current muscle-sparing approach (MSA) through a left antero-axillary incision was adopted to preserve the collateral network circulation to the spinal cord in the posterolateral thoracic muscles (PLTMs) (8). On the other hand, in cases where the distal landing zone was below T8, we identified AKAs preoperatively, and as much as possible, the landing zone was placed so that it did not extend into the AKA in EVR. Cerebrospinal fluid drainage (CSFD) was performed in elective patients with a high risk of SCI, such as involvement of the AKA in the surgical site.

Statistical analyses

Statistical analysis was performed using SPSS 27.0 (IBM SPSS Inc., Chicago, IL, USA). $P<0.05$ was considered statistically significant. Continuous values were expressed as the median [interquartile range (IQR)], and categorical data were expressed as numbers (n), with percentages in parentheses. Intergroup comparison was made using Student's *t*-test for normally distributed data, and the Mann-Whitney *U* Test for all other data. Multivariable logistic regression analyses were performed using the forward selection (Wald) method (input $P<0.05$, exclusion $P>0.1$) to estimate the risk factors for MEP amplitude reduction and SCI.

Table 1 Patient characteristics

Variables	All, n (%)	OR, n (%)	EVR, n (%)
Patient number between 2011 and 2022	256	102	154
Male	201 (78.5)	84 (82.4)	117 (76.0)
Age (years), mean ± SD	72.1±10.0	60.6±13.9	72.6±9.6
Aortic pathology			
Aneurysm	116 (45.3)	28 (27.5)	88 (57.1)
Dissection	121 (47.3)	74 (72.5)	47 (30.5)
EL or SINE	8 (3.1)	0	8 (5.2)
Others	11 (4.3)	0	11 (7.1)
Emergent	41 (16.0)	6 (5.9)	35 (22.7)
Other coexisting conditions			
Hypertension	213 (83.2)	88 (86.3)	125 (81.2)
Hyperlipidemia	72 (28.1)	28 (27.5)	44 (28.6)
Diabetes mellitus	35 (13.7)	9 (8.8)	26 (16.9)
CKD (Cr ≥2.0 mg/dL)	31 (12.1)	8 (7.8)	23 (14.9)
COPD	47 (18.4)	9 (8.8)	38 (24.7)
CAD	72 (28.1)	21 (20.6)	51 (33.1)
CVD	43 (16.8)	14 (13.7)	29 (18.8)
Connective tissue disorder	27 (10.5)	26 (25.5)	1 (0.6)
Prior aortic surgery			
Aortic root-arch	90 (35.2)	50 (49.0)	40 (26.0)
Descending aorta	54 (21.1)	29 (28.4)	25 (16.2)
Graft replacement	12 (4.7)	9 (8.8)	3 (1.9)
TEVAR	42 (16.4)	20 (19.6)	22 (14.3)
Thoracoabdominal aorta	1 (0.4)	0	1 (0.6)
Abdominal aorta	35 (13.7)	15 (14.7)	20 (13.0)
Preoperative identification of the AKA	207 (80.9)	86 (84.3)	121 (78.6)
T8–T12	168 (65.6)	76 (74.5)	92 (59.7)

OR, open repair; EVR, endovascular repair; SD, standard deviation; EL, endoleak; SINE, Stentgraft Induced New Entry; CKD, chronic kidney disease; Cr, creatinine value; COPD, chronic obstructive pulmonary disease; CAD, coronary artery disease; CVD, cerebrovascular disease; TEVAR, thoracic endovascular aortic repair; AKA, Adamkiewicz artery.

Results

Patient characteristics

Table 1 presents the preoperative characteristics of this patient cohort. Forty-one (16.0%) patients underwent an operation in an emergent setting. We were able to locate the AKA for 207 (80.9%) patients, in the range of T8–T12 in 81.2% (168/207) of cases.

Operative results

Table 2 presents the operative results in OR group. Fifty-

Table 2 Operative results in OR

Variables	N (%) or median [IQR] (n=102)
Procedure status	
Elective	96 (94.1)
Urgent	2 (2.0)
Emergent	4 (3.9)
MSA	61 (59.8)
Graft replacement	
Descending	50 (49.0)
Thoracoabdominal	52 (51.0)
Ex I	1 (1.0)
Ex II	11 (10.8)
Ex III	15 (14.7)
Ex IV	12 (11.8)
Ex V	13 (12.7)
CSFD	63 (61.8)
Concomitant abdominal grafting	11 (10.8)
AKA in the operative site	82 (80.4)
Surgery for targeted AKA	66 (64.7)
Reconstruction of ICAs/LAs	43 (42.2)
One branch	23 (22.5)
Two branches	13 (12.7)
≥three branches	7 (6.9)
Preservation of ICAs/LAs with beveling tech.	39 (38.2)
Body temperature	
Deep hypothermia w. CPB	42 (41.2)
Mild hypothermia w. pCPB	60 (58.8)
Surgical duration (min)	
Operation time	573.5 [267–1,691]
CPB time	211 [91–588]
ACC time	112 [40–250]
DHCA time	32 [18–103]
Reduction of MEP amplitude to under 50%	23 (22.5)

OR, open repair; IQR, interquartile range; MSA, muscle-sparing approach; Ex, extent (Safi classification); CSFD, cerebrospinal fluid drainage; AKA, Adamkiewicz artery; ICAs/LAs, intercostal arteries/lumber arteries; tech., technique; w., with; CPB, cardiopulmonary bypass; pCPB, partial CPB; ACC, aortic cross-clamp; DHCA, deep hypothermia circulatory arrest; MEP, motor-evoked potentials.

two (51.0%) patients had descending aortic repair and 50 (49.0%) patients had TAA repair. The AKA was located at the operative site in 82 (80.4%) patients. Of those patients, reconstruction or preservation of targeted AKA was performed in 66 (64.7%) patients, including reconstruction in 43 (42.2%) patients. Preservation of intended ICAs/LAs was performed in 39 (38.2%) patients, and both were performed in 19 (18.6%) patients. The significant reduction of MEP amplitude to less than 50% was observed in 23 (22.5%) patients; four (17.4%) were in those undergoing surgery under deep hypothermia with CPB, and 19 (82.6%) were in those surgery under mild hypothermia with partial-CPB. Connective tissue disease (CTD) [odds ratio, 0.050; 95% confidence interval (CI): 0.004–0.596; P=0.018] and partial-CPB (odds ratio, 7.158; 95% CI: 1.260–40.644; P=0.026) were independently associated factors of MEP reduction in the multivariate analysis (*Table 3*). In EVR, 35 patients (22.7%) underwent surgery urgently or emergently. Sixty-five (42.2%) patients had the AKA covered by an endovascular prosthesis. The significant reduction of MEP amplitude was observed in 18 (11.7%) patients. The incidence of reduction of MEP amplitude was significantly higher in patients with the AKA covered than those without the AKA covered [26.2% (17 of 65) *vs.* 1.1% (1 of 89); P<0.001].

Mortality and morbidity

In OR, the overall 30-day mortality rate was 3.9% (n=4; *Table 4*). Median ventilation time, intensive care unit (ICU) stay, and hospital stay were 12 (IQR, 4–1,128) hours, 4.5 (IQR, 2–53) days, and 24 (IQR, 4–245) days, respectively. Eventually, six patients (5.9%) developed SCI; paraplegia occurred in three (2.9%) patients and paraparesis also occurred in three (2.9%) patients (*Table 4*). There were no significant differences between reconstruction or non-reconstruction of the AKA in the patients whose AKA was located at the operative site [6.8% (4/59) *vs.* 4.3% (1/23), P=1.000]. In multivariate analyses of the OR group, no independent risk factors for SCI were identified.

In EVR, the overall 30-day mortality rate was 1.9% (n=3). Two (1.3%) patients developed stroke. Ten (6.5%) patients developed SCI; paraplegia occurred in two (1.3%) patients and paraparesis occurred in eight (5.2%) patients. The incidence of SCI was significantly higher in patients with the AKA covered, than in those without the AKA covered [13.8% (9 of 65) *vs.* 1.1% (1 of 89); P=0.002].

Table 3 Univariate and multivariate analysis of reduction of MEP amplitude

Variables	Univariate		Multivariate	
	OR	P value	OR	P value
Male gender	2.667	0.215	–	–
Age (years)	1.028	0.137	–	–
Dissection	0.493	0.158	–	–
Emergency	1.786	0.520	–	–
Connective tissue disorder	0.098	0.027*	0.050	0.018*
HT	1.078	0.914	–	–
HL	1.208	0.716	–	–
Diabetes mellitus	1.825	0.423	–	–
CKD (Cr ≥2.0 mg/dL)	0.468	0.488	–	–
CAD	2.708	0.061	1.278	0.741
CVD	0.231	0.169	–	–
COPD	0.980	0.980	–	–
Previous aortic arch repair	1.041	0.941	–	–
Previous descending aortic repair	3.343	0.016*	1.086	0.909
Previous abdominal aortic repair	0.484	0.364	–	–
Ex I and II	0.314	0.282	–	–
Ex III	5.486	0.004*	4.691	0.052
Ex IV	1.167	0.829	–	–
Ex V	2.165	0.254	–	–
Concomitant abdominal grafting	2.165	0.254	–	–
Non-MSA	2.996	0.025*	3.741	0.06
Preoperative identification of AKA	1.313	0.693	–	–
Reconstruction of ICAs/LAs	1.670	0.285	–	–
Higher number of reconstructions of ICAs/LAs	1.624	0.029*	1.466	0.251
Preserved ICAs/LAs	2.101	0.122	–	–
Partial CPB	4.402	0.013*	7.158	0.026*
Operative time (min)	1.003	0.019*	1.004	0.065
CPB time (min)	1.004	0.100	–	–
ACC time (min)	0.998	0.822	–	–
AKA on the surgical site	1.828	0.373	–	–
Insertion of CSFD	1.556	0.384	–	–

*, statistically significant. MEP, motor-evoked potentials; OR, odds ratio; HT, hypertension; HL, hyperlipidemia; CKD, chronic kidney disease; Cr, creatinine value; CAD, coronary artery disease; CVD, cerebrovascular disease; COPD, chronic obstructive pulmonary disease; non-MSA, non-muscle sparing approach; AKA, Adamkiewicz artery; ICAs/LAs, intercostal arteries/lumber arteries; CPB, cardiopulmonary bypass; ACC, aortic cross-clamp; CSFD, cerebrospinal fluid drainage.

Table 4 Mortality and morbidity in OR

Variables	All (n=256), n (%)	OR (n=102), n (%)	EVR (n=154), n (%)
30-day mortality	7 (2.7)	4 (3.9)	3 (1.9)
Postoperative ECMO support	12 (4.7)	11 (10.8)	1 (0.6)*
Complications			
Stroke	2 (0.8)	0 (0)	2 (1.3)
Spinal cord injury	16 (6.3)	6 (5.9)	10 (6.5)
Paraplegia	5 (2.0)	3 (2.9)	2 (1.3)
Paraparesis	11 (4.3)	3 (2.9)	8 (5.2)
AKD (Cr ≥2.0 mg/dL)	42 (16.4)	19 (18.6)	23 (14.9)
CHDF	11 (4.3)	6 (5.9)	5 (3.2)
Coronary event	1 (0.4)	1 (1.0)	0 (0)
Pneumonia	7 (2.7)	5 (4.9)	2 (1.3)
Prolonged ventilation (≥72 h)	14 (5.5)	10 (9.8)	4 (2.6)

*, the patient converted to open repair. OR, open repair; EVR, endovascular repair; ECMO, extracorporeal membrane oxygenation; AKD, acute kidney disease; Cr, creatinine value; CHDF, continuous hemodiafiltration.

Discussion

Intraoperative identification and reimplantation of the responsible segmental arteries is a promising strategy for maintaining the spinal cord blood supply and may minimize the risk of SCI (4). However, in terms of AKA detection, the AKA was identified in 91.6% (86/96 in OR and 121/130 in EVR) of cases overall, and as in the Japanese multicenter study, the AKA was not clearly identified in around 10.0% of cases (4). Furthermore, the etiology of SCI is multifactorial, including reduced systemic or distal aortic perfusion, less reconstruction of the ICAs, embolism of the ICAs responsible for spinal cord circulation, edema of the spinal cord, and others (4). For those reasons, moderate to deep hypothermia with total CPB reduces oxygen consumption and protects the central nervous system (CNS), heart, and abdominal organs, with several previous reports having shown that moderate to deep hypothermia with total CPB has the advantage of spinal cord protection (4,9,10). Therefore, such integrated approaches to preoperative identification and reimplantation/preservation of the responsible segmental arteries do not always succeed in eliminating SCI (11).

The collateral network concept for spinal cord circulation was published in 2010, and various related papers of interest were published thereafter (12-14). Experimental evidence by Griepp *et al.* and Etz *et al.* established the concept of a collateral vascular network of spinal cord perfusion. An extensive collateral network of vessels supplies the spinal cord and adjacent paraspinal muscles (11,15,16). Since more than 80% of patients with dTA/TAA aneurysms in a recent study had collateral blood pathways to the AKA around the spinal column, collateral blood pathways within the PLTMs may be important collateral blood pathways to the AKA and spinal code. Therefore, at the beginning of 2015, the current MSA through a left antero-axillary incision was adopted to preserve the collateral network circulation to the spinal code in the PLTMs (8). Although dTA and TAA surgery remain challenging, despite technical improvements, we have achieved better results with preoperative identification of the AKA and its targeted reconstruction. The overall 30-day mortality rate was 3.9%, and the incidence of SCI was only 5.9%, including 2.9% of paraplegia and 2.9% of paraparesis, similar or better than previously reported figures (4,17). In our current surgical strategy, MSA patients had significantly lower incidence of SCI than non-MSA patients [1.7% (1/60) *vs.* 12.8% (5/39), P=0.037] and tended to decrease the MEP amplitude reduction (*Table 3*). The adoption of MSA may be more stable spinal code circulation with less MEP reduction and SCI.

On the other hand, in the EVR group, the incidence of SCI was only 6.4%, similar to previously reported figures (4,18,19). The incidence of SCI in patients undergoing EVR is generally lower than that in patients undergoing OR (18,19). The SCI was slightly higher in this study because only the patients whose distal landing zone was below T8 were included. In addition, previous reports have demonstrated that the AKA, which was identified preoperatively, and subsequently covered by an EVR prosthesis, had no correlation with the incidence of SCI. However, in this study, the stent graft was placed so that it did not protrude into the ICA/LA connecting to the AKA in EVR as much as possible. Moreover, 86 patients (55.8%) underwent previous proximal or distal aortic operations, which likely compromised such a collateral network. Hence, there might be significantly higher SCI rate in patients with the AKA covered than those without. With the advent of new EVR devices, more extensive and complicated EVR procedures, which likely result in higher risks of SCI, will emerge in the future. In these circumstances, identification of the AKA will be of greater importance for prevention of SCI.

There are several limitations to this study. This was a retrospective investigation at a single center with a small sample size, which potentially limits the application to other settings. Although randomized controlled trials are considered the highest level of evidence in clinical and surgical practice, they are less pertinent in the complex clinical and anatomical situation of diffuse aortic disease. Propensity score-matching analyses were also not suitable due to the small sample size. To elucidate the hypothesis that the AKA is an essential source of spinal code blood supply and investigate the effects of identification of the AKA, and reconstruction and/or preservation of the AKA on spinal code safety, an experimental animal model or extensive imaging studies in humans are required.

Conclusions

Before OR and EVR of dTA and TAA pathologies, identification of the AKA was useful in determining treatment strategies with less likelihood of SCI.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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