Ann Vasc Dis Vol.4, No.3; 2011; pp 209–217

doi:10.3400/avd.oa.11.00002

Original Article

Indicators of Survival after Open Repair of Ruptured Abdominal Aortic Aneurysms and an Index for Predicting Aneurysmal Rupture Potential

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Background: **The aims of this study were to assess variables associated with survival in patients undergoing ruptured abdominal aortic aneurysm (RAAA) repair and to develop an index other than the aneurysmal diameter to predict rupture potential.**
Methods: **This study included 43 consecutive patients who underwent open surgery for RAAAs.**
Results: **The mortality rate was 18.6% (8/43). The ratio between the maximum aneurysmal diameter and the length (along the central axis) from the aneurysmal neck to the point at which the diameter was three-fourth of the maximum aneurysmal diameter was used as an index to predict aneurysmal rupture potential. The index score was 2.7 ± 1.2 in the RAAA and 1.9 ± 0.9 in the EAAA ($p = 0.018$). For aneurysms of $\leq$ 6-cm diameter, the index score was 3.0 ± 1.0 in the RAAA and 1.8 ± 0.9 in the EAAA ($p = 0.03$). All patients in the EAAA except one had an index score of < 2.3 and 6 of the 7 patients with RAAA had a score of > 3.**
Conclusions: **The results suggest that patients with AAA having scores of > 3 are at high risk of rupture. This index would be useful for decision making regarding repair of AAA, especially in the borderline cases.**

Key words: ruptured abdominal aortic aneurysm, emergency open repair; novel index score of rupture potential

Introduction

Despite the increased number of cases of elective abdominal aortic aneurysm (EAAA) repair, the number of patients with ruptured AAA (RAAA) has not significantly reduced in the past decade.[1] Further, although the mortality rate following EAAA repair has steadily improved by about 1%–6%,[2] the mortality rate after RAAA repair has not significantly changed in the last three decades and is still in the 30%–70% range.[3, 4] Many factors, including age, comorbidity, medical condition, preoperative shock or hypotension, increased creatinine level, low hemoglobin or hematocrit level, and technical and postoperative complications, are considered predictors of death, but none of these correctly predict the outcome of patients with RAAA.[5–7]

The maximum transverse aneurysmal diameter has been the only criterion used to predict aneurysmal rupture potential in the last 40 years.[8] According to this criterion, aneurysms reaching 5–5.5 cm in diameter are generally recommended for repair.[9] However, there are many reports of rupture of aneurysms smaller than 5.5 cm in diameter; the estimated rupture rate of small aneurysms varies between 4.6% and 23%.[10] On the other hand, the incidental presentation of extremely large asymptom-

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Received: December 31, 2010; Accepted: April 8, 2011
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atic aneurysms demonstrates the potential for indolent rupture-free growth of some large aneurysms. Aneurysms of similar size are likely to have disparate growth rates; therefore, measurement of the maximum transverse aneurysmal diameter as the sole predictor of rupture potential is insufficient. Although this measure is the most reliable, another reliable clinical predictor of AAA rupture risk is necessary.[11–16]

Recent studies have focused on AAA volume and vessel shape and tortuosity as potentially better predictors of AAA rupture risk,[17–21] and the estimated maximum wall stress has received considerable attention in this regard.[11, 12, 14, 15, 22] However, these criteria are not universally applicable because the imaging capabilities for quantifying these characteristics are still not available clinically. In addition, there are often cases of steep inclinational initiation of aneurysmal rise encountered during RAAA repair. In contrast, the maximum diameter criterion is widely applicable and currently used for decision-making purposes, importantly because the AAA size is the dominant consideration in the decision to intervene in asymptomatic patients. Therefore, another morphologic predictor that is suitable for practical application and which supports aneurysmal diameter for the estimation of AAA risk is required.

The aims of this study were to assess significant variables associated with survival in patients undergoing emergent RAAA repair and develop a predictive index of aneurysmal rupture potential.

Methods

This study included 43 consecutive patients having RAAA without thoracic extension who presented at Shinshu University Hospital between January 2004 and June 2009. Data were collected retrospectively from the hospital information system, operating theater logbooks, and intensive care unit records. The diagnosis of rupture was confirmed by reviewing the preoperative axial computed tomography (CT) findings and description of intraoperative visualization of blood outside the aneurysmal wall, in the retroperitoneum, mesentery, or peritoneal cavity, for free rupture. The baseline characteristics of patients and intraoperative and postoperative variables were documented (**Table 1**). There were 35 (81%) men and 8 (19%) women (**Table 1**); the overall male-to-female ratio for all cases of RAAA was about 4 : 1. Most patients in the RAAA group were aged over 65 years (mean age = 75.5 ± 8.8 years), with the peak incidence at 75–80 years. There were 16 (37.2%) patients over the age of 80 years. Most patients (85%) were transferred from referring hospitals. Thirty-four patients had abdominal aortic aneurysmal rupture and nine had iliac arterial aneurysmal rupture.

The major operative complications were also recorded. Preoperative shock was defined as systolic blood pressure of < 80 mmHg. Postoperative renal insufficiency was defined as a serum creatinine level of > 2.0 mg/dl. Operative mortality was defined as death within 30 days of operation or in-hospital death if later than 30 days. Aneurysmal morphology, site, and type of rupture (open or closed), as well as intraoperative bleeding, were assessed. The aneurysms were classified into aortic aneurysmal rupture or iliac aneurysmal rupture. Further, extension of hematoma was grossly quantified with the Fitzgerald classification according to the anatomic compartments involved: type 1, the periaortic area; type 2, the retroperitoneal space but restricted to the caudal end of the renal artery; type 3, the retroperitoneal space and spread beyond the renal artery or into the intrapelvic space; type 4, intraperitoneal hemorrhage. The presence or absence of renal displacement and contrast agent extravasation were recorded as easily detectable indicators of hemorrhagic volume. To examine the statistical difference of the initial rising angle of the proximal side between RAAA and nonruptured AAA, patients with EAAA repair were randomly selected and matched to patients with RAAA according to the maximum aneurysmal diameter as the control group. All RAAA repairs were performed by open surgical procedure by cardiovascular surgeons.

To assess the initial rising angle of the proximal side of the aneurysm from horizontal centerline axis of the aorta as an index to estimate the aneurysmal expansion rate, the maximum transverse aneurysmal diameter (D) and the length along the central axis from the aneurysmal neck to the point at which the diameter was three-fourth of the maximum transverse aneurysmal diameter (L) were measured, using axial view of CT scan: the index is represented by (3/4xD)/L (**Fig. 1**). To measure the precise diameter and length, we used only available 2.5–5.0 mm sliced enhanced CT with DICOM data, not to include hematoma in its diameter or the length. 25 patients out of 43 had these data and were available in this study. This is the reason, 25 patients out of 43 were analyzed in this study.

Table 1 Baseline characteristics of patients who underwent open repair of ruptured abdominal aortic aneurysms

Variable	Value
Demographics	
Age (yr)	75.5 ± 8.8
Female gender	18.6 (8)
History of COPD	7.0 (3)
History of CVA	37.2 (16)
History of CAD	23.2 (10)
History of DM	18.6 (8)
History of PVD	7.0 (3)
History of hypertension	83.7 (36)
History of CRF	1.6 (5)
History of hyperlipidemia	27.9 (12)
History of hemodialysis	0.0 (0)
Current smoking	20.9 (9)
Preoperative characteristics	
Prior aortic reconstruction	9.3 (4)
Distance to hospital (km)	25.3 ± 24.0
Transfer by air	11.6 (5)
Iliac artery aneurysmal ruptur	20.9 (9)
Free rupture	14.0 (6)
SBP < 80 mmHg	79.1 (34)
SBP	90.8 ± 29.8
Shock index (HR/SBP)	1.16 ± 0.7
ER-to-OP start time (min)	96 ± 56
CPR	0.0 (0)
Blood chemistry	
Mean hemoglobin level (g/dl)	9.5 ± 3.5
Mean platelet count (× 10^4 cells)	14.3 ± 6.8
Intraoperative variables	
Proximal aortic clamp site	
Supraceliac	11.6 (5)
Suprarenal	27.9 (12)
Infrarenal	60.5 (26)
Intrathoracic	0.0 (0)
Clamp time (min)*	
Supraceliac	78.5 ± 58.7 (5)
Suprarenal	84.3 ± 24.8 (12)
Infrarenal	93 ± 16 (26)
Lowest BP (mmHg)	47.9 ± 17.4
IMA reconstruction	46.5 (20)
Postoperative variables	
Renal failure requiring hemodialysis	4.7 (2)
Renal failure (Cr level > 2 mg/dl)	34.9 (15)
Myocardial infarction	0.0 (0)
Tracheostomy	4.7 (2)
Stroke	2.3 (1)
Intestinal ischemia	0.0 (0)
Failure to close abdomen	11.6 (5)

The data are the percentage (*n*) or the mean ± standard deviation of 43 patients.
*The values in parentheses are the number of cases.
COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; CAD, coronary artery disease; DM, diabetes mellitus; PVD, peripheral vascular disease; CRF, chronic renal failure; SBP, systolic blood pressure; HR, heart rate; ER, emergency room; OP, operation; CPR, cardiopulmonary resuscitation; IMA, inferior mesenteric artery

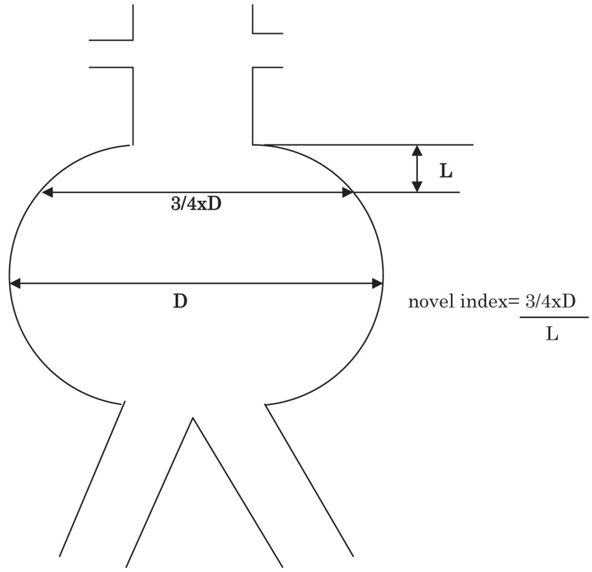

Fig. 1 Schematic of a representative abdominal aortic aneurysm (AAA) indicating the index for predicting aneurysmal rupture potential. The index is defined as (3/4xD)/L, where D is the maximum AAA diameter (transversally) and L is the length (measured along the central axis) of the AAA from the neck to the point at which the diameter is 3/4xD.

Statistical Analysis

Continuous variables are summarized as the mean and standard deviation (SD), and categorical variables are summarized as the number of cases and percentage. The Mann–Whitney *U*-test, unpaired Student's *t*-test, 2 × 2 chi-square test, Fisher exact probability test, and Yates chi-square test were used in the univariate analysis to identify demographic, clinical, and postoperative factors associated with operative mortality and determine differences in the index scores between RAAA and EAAA. All analyses were performed with SAS version 9.1 under the alpha level of 0.05 (SAS Institute, Inc., Cary, NC) and EXCEL (Microsoft Co. Ltd.).

Results

The mean diameter of the ruptured AAA was 7.24 ± 1.4. The mode of transportation was by air in five cases (11.6%) and by road in 39 cases (88.4%). Six patients (14%) presented with free rupture. All patients complained of transient or continuous pain. Aortoenteric fistulae were noted in two patients. Nine patients presented with ruptured iliac aneurysms. Systolic blood pressure

Table 2 Correlation between IMA reconstruction and IIA sacrifice

Procedure	*N*
Unilateral IIA sacrificed	7
IMA reconstruction	5 (71.4%)
Bilateral IIAs sacrificed	5
IMA reconstruction	4 (80.0%)
Bilateral IIAs preserved	31
IMA reconstruction	12 (38.7%)

IMA, inferior mesenteric artery; IIA, internal iliac artery

Table 3 Univariate analysis of continuous variables

Variable	Survivors	Nonsurvivors	*p*
Age (yr)	75.3	76.5	0.481
Serum Cr level (mg/dl)	1.41	1.19	0.343
Preoperative Hb level (g/dl)	9.6	9.0	0.41
Preoperative platelet count (× 10^3 cells)	15.5	9.3	0.0089
Preoperative SBP (mmHg)	94.3	76.4	0.064
Preoperative shock index (HR/SBP)	1.1	1.5	0.013
Intraoperative lowest BP (mmHg)	50.8	36.3	0.018
Intraoperative blood loss (g)	3940	11050	0.035

Cr, creatinine; Hb, hemoglobin; SBP, systolic blood pressure; HR, heart rate

of < 80 mmHg (preoperative shock status) was registered in 34 cases (79%). Most surgeries were started within 96 ± 58 min from hospital arrival; especially, in the five cases of severe shock (systolic blood pressure < 60 mmHg), the operation was begun more quickly (62.6 ± 23 min). A midline transperitoneal approach was used in all patients. Proximal aorta clamping was achieved primarily at the infrarenal site in 26 patients (60.5%). In the case of 17 other patients (39.5%) with critical hypotension or difficult identification of the infrarenal aortic neck, the initial aortic clamp was placed above the renal arteries, mostly at the supraceliac aorta (5 cases, 11.6%). A supra celiac clamp was temporarily placed before the infrarenal control. Thoracotomy and descending aortic clamping were not performed to shorten the duration of supraceliac clamping.

The inferior mesenteric artery (IMA) was reconstructed in five of seven patients whose unilateral internal iliac arteries (IIAs) were sacrificed (**Table 2**). The IMA was reconstructed in four of five cases whose bilateral IIAs were sacrificed. Further, the IMA was reconstructed in 12 of 31 patients whose bilateral IIAs were preserved. The mean operative time was 282 ± 84 min.

The overall in-hospital mortality rate was 18.6% (8/43). The intraoperative mortality rate was 7.0% (3/43), and deaths mainly resulted from continued hemorrhage and irreversible shock in these cases.

The preoperative variables associated with death after RAAA repair are listed in **Table 3** and **Table 4**. Of the continuous variables, the preoperative platelet count, preoperative shock index, intraoperative blood loss, and intraoperative lowest systolic blood pressure were significantly associated with perioperative death. Further, of the categorical variables, the rupture type (free or closed), extension of hematoma (Fitzgerald classification), preoperative general condition (American Society of Anesthesiologists classification), and extravasation of contrast agent during CT scan were significantly associated with perioperative death.

The most common postoperative complications among the 40 patients who survived at least one day after surgery were respiratory failure requiring mechanical support over 72 h (7 patients, 17.5%), pneumonia (5 patients, 12%), and renal failure requiring dialysis (3 patients, 7%). Three patients died because of multiple organ failure within 15 postoperative days. One patient made satisfactory

Table 4 Univariate analysis of categoric variables

Variable	Survivors	Nonsurvivors	*p*
Open rupture	2	4	
Closed rupture	33	4	0.009
Fitzgerald classification			
Class 1	2	0	
Class 2	7	0	
Class 3	21	2	
Class 4	1	3	0.048
ASA classification			
Class 1	0	0	
Class 2	0	0	
Class 3	0	0	
Class 4	31	2	
Class 5	4	6	0.001
Extravasation of contrast agent in CT scan	4	2	
No extravasation	18	0	0.015
Renal dislocation in CT scan	17	3	
No renal dislocation	12	2	1.0
Preoperative catecholamine use	5	3	
No catecholamine	27	4	0.137
Preoperative shock status	24	8	
No shock	9	0	0.16
Supraceliac clamp	3	2	
Suprarenal clamp	8	4	
Infrarenal clamp	24	2	0.312
No IIA sacrificed	23	6	
Unilateral IIA sacrificed	5	2	
Bilateral IIAs sacrificed	5	0	0.856
AAA rupture	24	8	
Iliac artery aneurysmal rupture	9	0	0.164

ASA, American Society of Anesthesiologists; IIA, internal iliac artery; AAA, abdominal aortic aneurysm

progress after the operation but developed graft infection and underwent graft excursion and anti-anatomical reconstruction 2 months after the operation; he died of rupture of a thoracoabdominal aortic aneurysm. Three patients underwent a second laparotomy for intestinal ischemia, but there were no cases of severe intestinal ischemia requiring bowel resection. No patient developed postoperative spinal palsy.

The novel index score was 2.7 ± 1.2 in the RAAA cases and 1.9 ± 0.9 in the EAAA cases (**Fig. 2**). Especially, for aneurysms of ≤ 6-cm diameter, the index score was 3.0 ± 1.0 in the RAAA cases and 1.8 ± 0.9 in the EAAA cases (**Fig. 3**). There were significant differences between the groups irrespective of the aneurysmal diameter. All patients with RAAA except one had index scores of > 3.0, and all patients in the EAAA group except one had scores of < 2.3. There was no significant difference between the groups in terms of aneurysmal diameter (**Fig. 4**).

Discussion

The mortality rate of ruptured aneurysms is remarkably high. With the exception of a few series,[23, 24] it has been reported as ranging from 30% to > 70%.[4] If patients who died at home or during transport to a hospital are included, the mortality rate approaches 90%.[25, 26] This excessively high operative mortality rate can be explained by the facts that patient selection is usually impossible, and the majority have already suffered the consequences of hypovolemic shock at admission. Johansen et al.[4] demonstrated a mortality rate of 70% in 186 patients with

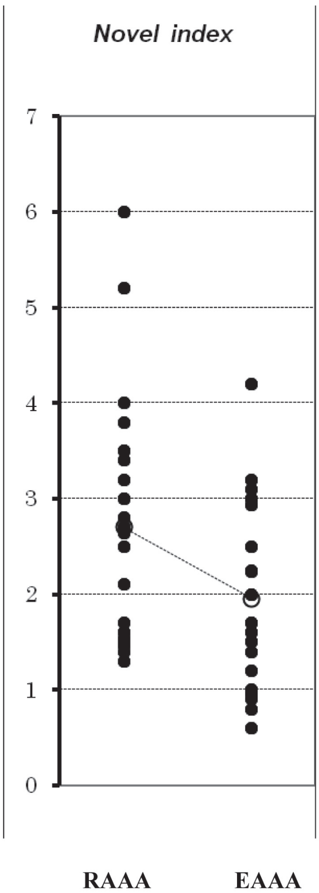

Fig. 2 Comparison of the index scores of the ruptured abdominal aortic aneurysm (RAAA) and elective abdominal aortic aneurysm (EAAA) groups. The index score was 2.7 ± 1.2 in the RAAA cases and 1.9 ± 0.9 in the EAAA cases. There were significant differences between the groups ($p = 0.018$).

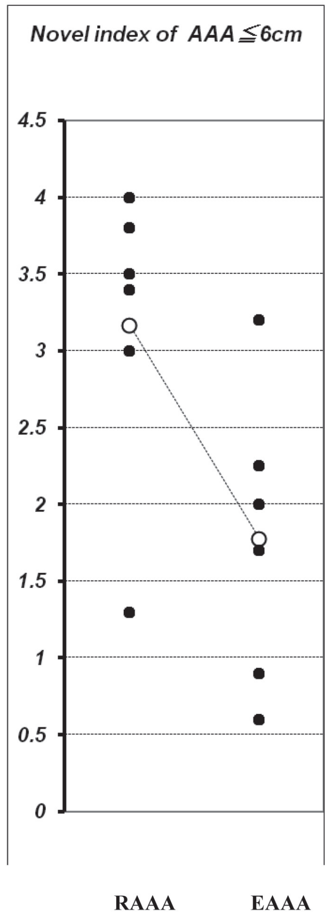

Fig. 3 Comparison of the index scores of the ruptured abdominal aortic aneurysm (RAAA) and elective abdominal aortic aneurysm (EAAA) groups for aneurysms of ≤ 6-cm diameter. The index score was 3.0 ± 1.0 in the RAAA cases and 1.8 ± 0.9 in the EAAA cases. There were significant differences in this series ($p = 0.03$).

RAAA treated at a single hospital; this survival rate was measured despite specialized prehospital management and transport, short emergency department diagnostic evaluation, aneurysmal repair by an operating vascular surgery team, and sophisticated postoperative care.

Considering the high mortality rate combined with the associated high hospital costs, Hardmann et al.[27] suggested that certain preoperative variables (preoperative cardiac arrest, age > 80 years, male gender, persistent preoperative hypotension despite aggressive crystalloid and blood replacement, admission hematocrit < 25, transfusion requirements exceeding 15 units) should be used to identify patients most likely to die, and would, therefore, be best treated without surgery. This approach may have some justification in this age of cost-effective therapy, but it also has significant ethical and legal implications. In the present study, there were no patients requiring cardiopulmonary resuscitation because the emergency staff administered the appropriate critical and intensive care, and anesthesiologists and the operating room staff coordinated to start the operation quickly. These factors were considered to be the reason for the good survival rate. Further, comparison of the mean age between survivors and nonsurvivors did not yield a statistically significant difference; surgical repair of RAAA was performed in all patients regardless of age. However, the number of preoperative deaths in the same area could not be confirmed. Aortic clamping under thoracotomy is

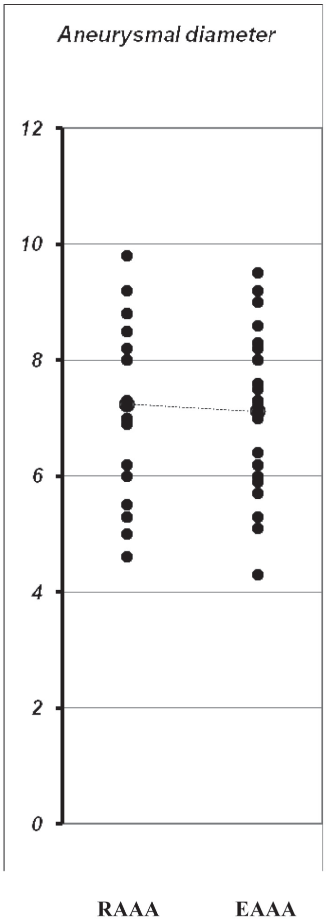

Fig. 4 Comparison of aneurysmal diameters in ruptured abdominal aortic aneurysm (RAAA) and elective abdominal aortic aneurysm (EAAA) groups. The diameter was 5.3 ± 05 in the RAAA cases and 5.4 ± 0.6 in the EAAA cases. There were no significant differences between the groups.

considered to be necessary especially in case of severe shock. However, supraceliac clamp under thoracotomy causes severe operative complications, intestinal ischemia, and paraplegia. Therefore, in this study, the supraceliac clamping time was maintained as short as possible, without thoracotomy.

Johansen et al.[4] suggested that the decision to deny operative treatment to a patient with RAAA should be made while considering each patient individually and can be justified only in those cases with poor quality of life due to a precarious general medical status or mental condition. Rather than using predictive variables to identify patients who will not survive, several studies, including this study, have been conducted to determine the surgical tactics and anesthesiological procedures that can improve the survival rate and identify patients in whom preoperative conditions and other clinical factors make conventional surgical repair inopportune. Although several authors noted higher mortality rates among elderly patients,[6, 25, 28, 29] advanced age was not found to be a significant predictor of survival in this study. Once elderly patients have survived the operation, they can enjoy a long life expectancy, similar to their contemporaries in the general population.[28, 29] Thus, it is reasonable to consider that physiologic age is more relevant than chronological age even if older patients are exposed to increased surgical risk in the case of aneurysmal rupture. Of the 43 patients who underwent open RAAA repair in this study, 35 (81.4%) survived surgery. The fact that 16 of the 43 patients (37.2%) were older than 80 years justifies our opinion regarding age. Age may be considered an indirect marker of physiologic status.

In this study, eight significant risk factors were identified in the univariate analysis. Of the continuous variables, preoperative shock index, preoperative platelet count, intraoperative lowest systolic blood pressure, and intraoperative blood loss were predictive of perioperative death. The change in these variables was affected by the amount of bleeding. Of all the categorical variables, rupture type (free or closed), extension of hematoma, preoperative general condition, and extravasation of contrast agent during CT scan were significantly associated with perioperative death. The presence or absence of contrast agent extravasation is an easily detectable indicator of hemorrhagic volume. The significant categorical variables except the preoperative general condition also reflect the amount of bleeding.

As a general rule, the IMA was reconstructed to prevent intestinal ischemia unless IMA good pulsation was confirmed. With this operative policy, no severe intestinal ischemia requiring bowel resection or spinal palsy was observed postoperatively. A previous paper reported that about 3%–15% of patients develop intestinal ischemia requiring intestinal resection as a complication of RAAA repair. Some patients have intestinal ischemia after RAAA repair in spite of IMA reconstruction. In this series, a second exploratory laparotomy was performed in the three IMA-reconstructed cases to examine intestinal ischemia. Fortunately, there was no case of intestinal ischemia requiring resection. In addition, among patients with aortoenteric fistula, one was saved, by surgical repair with extra-anatomical bypass, and discharged as ambulatory on postoperative day 42. Another patient with aortoenteric fistula was operated with anatomic reconstruction, but he died on postoperative day 1 because of shock.

In this study, we designed an easy and useful predictor for rupture suitable for practical, clinical use. Giannoglou et al.[30] suggested that the mean AAA curvature may be a better predictor of AAA rupture risk, although they implemented linearly elastic material properties. We often experience such cases which have a steep, inclinational initial rise of aneurysms in RAAA surgical repair.

We attempted to quantify the rising angle of proximal AAA, ruptured AAA, and elective repaired AAA (EAAA), and examined the correlation between rupture potential and novel quantitative rising angle novel index. In order to assess the rising angle of proximal aneurism arising from horizontal centerline axis of the aorta, we measured maximum transverse diameter of AAA (D) and the length of centerline axis from aneurismal neck to the maximum point of AAA using axial view of CTscan, because only an axial view of CT date from reference hospitals were available in many cases. Next, we calculated 3/4xD and measured the length of centerline axis from aneurismal neck to the point of diameter of 3/4xD (L) (**Fig. 1**). The novel index of RAAA potential was defined (3/4xD)/L. AAA consists of a steeply sloped portion and a gently sloped portion. If only the maximum transverse diameter is used in this index, both gently and steeply sloped portion will be assessed. Therefore, to include only steeply sloped portion, the length to three-fourth of the maximum diameter was included. So it was considered that estimation of (3/4xD)/L might be able to assess steeply sloped portion more than estimation of D/L, and we could get these results in this report. We calculated these indexes of 25 RAAA cases and 24 elective AAA cases (EAAA) as a control group. Diameter between RAAA and EAAA has no difference (**Fig. 4**). The index was 2.7 ± 1.2 in RAAA cases, 1.9 ± 0.9 in EAAA cases. Especially, in smaller AAA cases under 6-cm diameter, the index was 3.0 ± 1.0 in RAAA cases and 1.8 ± 0.9 in EAAA cases (**Figs. 2** and **3**). There was a significant difference between the index of RAAA and EAAA, statistically. There was more remarkable difference in smaller AAA cases under 6 cm (**Fig. 3**). In this figure, all RAAA cases despite one case revealed more than 3 index. Additionally, all EAAA cases despite one revealed less than 2.3 index. These results suggest that the AAA cases whose novel indexes were revealed as over 3 may be a high risk group for rupture even if its diameter is under 6-cm diameter. On the other hand, in cases whose indexes were less than 2, a traditional maximum diameter of AAA may be a more reliable criterion with those aneurysms that reach 5–5.5 cm diameter, generally recommended for repair.

In conclusion, index scores of > 3 may be good predictors of the risk of AAA rupture and patients with these scores should be considered at high risk. This index would be useful to clinicians for decision making regarding surgical repair of AAA, especially in the case of borderline lesions (≤ 6-cm diameter).

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