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Grey Relational Analysis of Benefit of Surgical Management for Abdominal Aortic Aneurysm

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Grey relational analysis was used to compare the long-term outcomes of endovascular repair (EVAR) versus open repair for patients with abdominal aortic aneurysm (AAA). Patients with AAA undergoing open repair (n = 133) or EVAR (n = 88) from July 1995 to January 2009 were studied retrospectively. Compared with EVAR, longer periods of postoperative intubation and hospital stay ($P < 0.001$) were required for open repair. The operation time was significantly longer in open surgery than in EVAR ($P < 0.001$). Patients in the open repair group required larger volumes of intraoperative blood transfusion than those in EVAR ($P < 0.001$), and they had more of a trend of cardiac failure after surgery than those in the EVAR group. The operative mortality was similar in both groups. On follow-up, the all-cause mortality and the rates of ischemic legs within 5 years had no significant differences between the 2 procedures ($P > 0.05$). The grey relational grades in EVAR and open repair were 0.673 and 0.936, respectively. Compared with open repair, patients with AAAs undergoing EVAR had fewer complications in the short term and had a similar all-cause mortality in the long term.

Key words: Grey relational analysis – Abdominal aortic aneurysm – Endovascular repair – Open repair

Aortic aneurysm can be treated with open repair surgery or endovascular repair (EVAR). Several studies, including the EVAR1 and EVAR2 studies, have reported the outcomes of EVAR versus open repair.[1–7] These trials showed that EVAR is superior to open surgery in terms of operative mortality in the short term, and there were no differences in mortality or aneurysm-related mortality in the long term. However, any possible long-term benefit from EVAR versus open surgical repair for abdominal aortic aneurysm (AAA) has not been proven,[2] and the data of long-term mortality rate after repair surgery are limited. It is necessary to study this issue to get a clear answer.

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Table 1 Demographics and comorbidity of patients with AAAs undergoing EVAR or open repair

Variable	All groups, No. (%)	EVAR, No. (%)	Open repair, No. (%)
No. of patients	221	88	133
k = 1 male	171 (77.38)	71 (80.68)	100 (75.19)
k = 2 coronary artery disease	60 (27.15)	27 (30.68)	33 (24.81)
k = 3 recent angina	5 (2.26)	2 (2.27)	3 (2.26)
k = 4 recent CABG	31 (14.03)	12 (13.64)	19 (14.29)
k = 5 history of PTCA	17 (7.69)	6 (6.82)	11 (8.27)
k = 6 recent MI	7 (3.17)	4 (4.55)	3 (2.26)
k = 7 CHF within 30 d	3 (1.36)	1 (1.14)	2 (1.50)
k = 8 hypertension	108 (48.86)	40 (45.45)	71 (51.88)
k = 9 cerebrovascular disease	23 (10.41)	12 (13.64)	11 (8.27)
k = 10 history of PVD	11 (4.98)	8 (9.09)	3 (2.26)
k = 11 diabetes	18 (8.14)	6 (6.82)	12 (9.02)
k = 12 smoker	58 (26.24)	24 (27.27)	34 (25.56)
k = 13 unilateral IAA	42 (19.00)	19 (21.59)	23 (17.29)
k = 14 bilateral IAA	17 (7.69)	8 (9.09)	9 (6.77)
k = 15 DAA	3 (1.36)	1 (1.14)	2 (1.50)
k = 16 5.5–8 cm in diameter	173 (78.28)	74 (85.23)	99 (74.44)
k = 17 diameter >8 cm	48 (21.72)	14 (15.91)	34 (25.56)
k = 18 Abdominal pulsatile mass	96 (43.44)	33 (38.64)	63 (47.37)
k = 19 Abdominal and back pain	69 (31.22)	27 (30.68)	42 (31.58)

CABG, coronary artery bypass grafting; CHF, chronic heart failure; DAA, descending aorta aneurysm; IAA, iliac artery aneurysm; MI, myocardial infarction; PTCA, percutaneous coronary angiography; PVD, peripheral artery disease.

Grey analysis defines situations with no information as black, and those with perfect information as white.[8] Yet, neither of these idealized conditions occurs in real world. In fact, situations between these extremes are described as being grey. Therefore, a grey system means a system in which some of the information is known and some of the information is unknown. Grey analysis provides techniques for determining a good solution, an appropriate solution for practical problems, it has been used in clinical studies.[9–11] In order to investigate the long-term effects of EVAR versus open surgery for AAA, we retrospectively evaluated the outcomes of patients with AAA who underwent EVAR versus open repair by grey relational analysis.

Patients and Methods

The study was approved by our hospital's ethics committee. All patients undergoing surgery provided written consent. All patients with AAAs treated surgically from July 1995 to January 2009 were identified from a medical database. Open repair had been performed to repair AAAs before 2004, and since then EVAR has been introduced and performed for AAAs. The patients included in the study had infrarenal AAA with diameter of 5 cm or more, adequate infrarenal neck, and aortic-iliac anatomic configuration suitable for EVAR. Patients were excluded from the study if they had one of the following conditions: a maximum aneurysm diameter less than 5 cm, ruptured AAA, suprarenal AAA, infrarenal neck unsuitable for endovascular fixation, presence of active infection, or urgent surgery for AAA. The population that met the above inclusion criteria consisted of 133 patients undergoing open repair surgery (open group) and 88 patients undergoing EVAR (EVAR group; Table 1).

Myocardial infarction (MI) was defined as previously documented MI; recent MI was defined as MI within the past 6 months. Recent angina referred to ongoing angina or angina within 30 days. Cerebrovascular disease included all grades of stroke, including transient ischemic attacks. The diagnosis was confirmed with computed tomography angiography or magnetic resonance imaging preoperatively. Patients were followed up 6 months to 5 years through outpatient visit, telephone, or e-mail.

Grey relational analysis

The basic steps and formulae are illustrated as follows[9–11]:

- To define data series

  Usually, we let x_0 (0 = reference parameter) serve as the reference series and x_i ($i = 1, 2, n$; $n \geq 2$, i is the comparative parameter) as the comparative series; x_0 and x_i are named data series. Data in all groups are assigned as the reference series;

Table 2 Grey relational coefficient and grey relational grade of demographics and comorbidity of patients with AAAs who underwent EVAR or open repair

	Difference series		GRC	
Variable	x_1	x_2	r01(k)	r02(k)
k = 1	0.0424	0.0117	0.9218	0.9771
k = 2	0.0160	0.019	0.9690	0.9634
k = 3	0.0017	0.0014	0.9966	0.9972
k = 4	0.0160	0.0089	0.9690	0.9825
k = 5	0.0148	0.0096	0.9713	0.9812
k = 6	0.0171	0.0132	0.9669	0.9743
k = 7	0.0000	0	1.0000	1.0000
k = 8	0.0906	0.0662	0.8466	0.8831
k = 9	0.0310	0.0258	0.9416	0.9509
k = 10	0.0474	0.0368	0.9134	0.9314
k = 11	0.0206	0.0139	0.9604	0.9730
k = 12	0.0128	0.003	0.9750	0.9940
k = 13	0.0139	0.015	0.9730	0.9709
k = 14	0.0122	0.0108	0.9762	0.9789
k = 15	0.0000	0	1.0000	1.0000
k = 16	0.0000	0.0102	1.0000	0.9800
k = 17	0.0891	0.0618	0.8488	0.8900
k = 18	0.1011	0.0754	0.8318	0.8690
k = 19	0.0369	0.0200	0.9313	0.9615
GRG			0.2045	0.1373

GRC, grey relational coefficient; GRG, grey relational grade

for the comparative series x_i ($i = 1, 2$), $x1$ and $x2$ refer to the EVRA and open repair groups, respectively. The related variables are represented by k (Table 1).

- Calculation of dis-dimension for data series

$$x_i(k)' = \frac{x_i(k)}{\frac{1}{n}\sum_{k=1}^{n} x_i(k)} \tag{1}$$

The dis-dimension series are obtained by averaging. The formula is illustrated as (1), $k = 1, 2, n$; $n \geq 3$; k is an observing point. The $x_i(k)$ and $x_i(k)'$ are the values of the observing points in the EVRA and open repair groups, respectively.

- To find difference series $\Delta 0_i$

$$\Delta 0_i(k) = |x_0(k) - x_i(k)| \tag{2}$$

From $\Delta 0_i(k)$, there are $_{\max_i \max_k}|x_0(k) - x_i(k)|$ and $_{\min_i \min_k}|x_0(k) - x_i(k)|$, which are the maximum and minimum values of $\Delta 0_i$, respectively (Table 2). Variables x_1 and x_2 represent the proportion of the grey relational coefficient of demographics and comorbidities of patients in EVAR and open repair groups, respectively.

Table 3 Perioperative events within 30 days

Events	EVAR (n = 88)	Open repair (n = 133)	P
Age, y	66.77 ± 8.77	68.71 ± 9.50	0.127
Operation time, h	1.79 ± 0.79	3.40 ± 0.98	0.0001
Hospital stay, d	6.76 ± 0.89	11.9 ± 0.99	0.0001
Blood infusion, mL	158 ± 35	610 ± 24	0.0001
Reoperation	0 (0)	9 (6.76)	0.012
Perioperative mortality	1 (1.12)	5 (3.76)	0.452

- To calculate the grey relational coefficients $\gamma 0_i(k)$

$$\gamma 0_i(k) = \left[\min_i \min_k |x_0(k) - x_i(k)| + \zeta \cdot \max_i \max_k |x_0(k) - x_i(k)|\right] \div \left[\Delta 0_i(k) + \zeta \cdot \max_i \max_k |x_0(k) - x_i(k)|\right] \tag{3}$$

Equation (3) can be used in the analysis of multifactorial single series. The ζ is named the distinguishing coefficient. The value of ζ is usually defined on different information. In any case, there is $1 > \zeta > 0$. The coefficient ζ is usually defined as 0.5.

- The grey relational grade is defined as the average of all grey relational coefficients. To find grey relational grade different aged material:

$$\gamma 0_i = \frac{1}{n}\sum_{k=1}^{n} \gamma 0_i(k) \tag{4}$$

Equation (4) can be used in the analysis of multifactorial single series. Therefore, the sequence of the affecting factors in the system can be studied based on the value of the grey relational grade.

- To construct the grey relational order based on the size of $\gamma 0_i$ (Tables 1 and 2)

In addition to grey relational analysis, data were also analyzed using SPSS statistical software (Chicago, Illinois). Demographics, comorbidities, perioperative events, and outcomes in both groups were compared. Categoric variables were computerized using χ^2 or Fisher's exact tests; continuous variables were analyzed using Student t tests for parametric data. $P < 0.05$ was considered as statistically significant (Tables 3 and 4).

Table 4 Complications on long-term postoperative follow-up

	EVAR (n)	EVAR, %	Open repair (n)	Open repair, %	P
All-cause mortality	26 (79)	32.90	30 (103)	29.10	0.583
Graft stenosis	5 (74)	6.76	0 (103)	0.00	0.012
Stent migration, 4-y	2 (81)	2.46	0 (103)	0.00	0.192
Stent migration, 5-y	3 (74)	4.10	0 (103)	0.00	0.071

Results

Patents were followed up from 7 to 68 months, with a median follow-up of 37 months. The follow-up rates were 83% (73/88) in the EVAR group and 77.44% (103/133) in the open repair group.

Tables 1 and 2 show the results of grey relational grade in EVAR and open repair groups were 0.7177 and 0.7728, respectively, indicating the identical basic conditions in both groups. Perioperative mortalities were 1.12% (1/88) in EVAR and 3.76% (5/133) in open repair; all-cause mortalities within a median follow-up of 37 months were 32.9% (26/79) in the EVAR group and 29.1% (30/103) in the open repair group ($\chi^2 = 0.301$, $P = 0.583$; Tables 3 and 4).

Table 5 shows the postoperative complications; 3 factors—X0, X1, and X2—represent the proportion of patients in both groups, the EVAR group, and the open repair group, respectively. Nine events were included for instigation. Data were standardized by converting into dis-dimension series (Table 6). The coefficient ζ was selected as 0.5 with the values in Table 6 for $\max_i \max_k |x_0(k) - x_i(k)|$ and $\min_i \min_k |x_0(k) - x_i(k)|$. Equations (2) and (3) can be calculated for the difference series and grey relational coefficient as listed in Table 7. Hence, grey relational grade can be obtained according to Equation (4) in the following: $r01 = 0.673$ and $r02 = 0.936$, which implies that the EVAR procedure has fewer complications than open repair.

Tables 3 and 4 demonstrate that longer periods of postoperative intubation and hospital stay were required in the open repair group. The surgical time was significantly longer in open surgery than in EVAR ($P = 0.001$).The percentage of patients requiring transfusion and the volume of intraoperative blood transfusion were 8 and 3 times higher than those of the open group, respectively. Patients in the open repair group had more of a trend toward cardiac failure after surgery than those in the EVAR group (Table 5).

Overall operative mortality was comparable, without significant differences (Table 3). Reoperation was required in the open repair group (9/133; 67.6%). Morbidity referred to all complications following surgical procedures. Overall morbidity was higher in patients in the open repair group, including prolonged intubation and pneumonia, followed by hemorrhage, wound infection, renal failure, and shock (Table 5).

On follow-up, stent migration rates were 2.46% (2/81) and 4.10% (3/74) in patients treated with EVAR within 4 and 5 years, respectively. Graft stenosis was observed in the EVAR group; in contrast, no graft migration or graft stenosis occurred in the open repair group (Table 4). In follow-up, no blood flow was found inside of aneurysm on computed tomography angiography. Incidences of wound infections, pneumonia, and renal failure were higher in the open repair group versus the EVAR group (Table 5).

Discussion

Grey relational analysis can be used to represent the grade of correlation between 2 related events in order to measure their differences, and it is an effective and practical tool to compare outcomes of surgical procedures.[9–11] In the current study, grey relational analysis was used to compare the patient's characteristics and the long-term postoperative outcomes between EVAR and open repair. Our grey

Table 5 Complications of patients following EVAR or open repair for AAAs

Series	Total, No.	χ0, %	EVAR, No.	χ1, %	Open, No.	Repair χ2, %
Intubation >24 h (k = 1)	24	10.86	2	2.27	22	16.79
Pneumonia (k = 2)	34	15.38	7	7.95	27	20.61
Cardiac failure (k = 3)	22	9.95	5	5.68	16	12.21
Acute renal failure (k = 4)	32	14.48	7	7.95	24	18.32
Bleeding requiring transfusion (k = 5)	34	15.38	3	3.41	31	23.66
Wound infection (k = 6)	28	12.67	2	2.27	26	19.85
Shock (k = 7)	33	14.93	9	10.23	24	18.32
Lower limb ischemia (k = 8)	5	2.26	2	2.27	3	2.29
Mortality (k = 9)	6	2.71	1	1.14	5	3.82

Table 6 Dis-dimension data from Table 5

Series	χ0 total	χ1 EVAR	χ2 open
Intubation >24 h (k = 1)	0.655	0.124	0.679
Pneumonia (k = 2)	1.000	0.749	0.857
Cardiac failure (k = 3)	0.586	0.499	0.464
Acute renal failure (k = 4)	0.931	0.749	0.750
Bleeding requiring transfusion (k = 5)	1.000	0.250	1.000
Wound infection (k = 6)	0.793	0.124	0.822
Shock (k = 7)	0.966	1.000	0.750
Lower limb ischemia (k = 8)	0.000	0.124	0.000
Mortality (k = 9)	0.034	0.000	0.072

Table 7 Grey relational coefficient of complications after EVAR or open repair for AAAs from Table 6

	Difference series		Grey relational coefficients	
	x_1 (EVAR)	x_2 (open)	r01(k) (EVAR)	r02(k) (open)
k = 1	0.531	0.024	0.4850	0.5076
k = 2	0.251	0.143	0.6658	0.4289
k = 3	0.087	0.122	0.8518	0.3699
k = 4	0.182	0.181	0.7331	0.4055
k = 5	0.750	0.000	0.4000	0.5556
k = 6	0.669	0.029	0.4277	0.5390
k = 7	0.034	0.216	0.9363	0.3481
k = 8	0.124	0.000	0.8013	0.3842
k = 9	0.034	0.038	0.9363	0.3481

relational analysis results revealed that the postoperative complications were fewer in EVAR than in open repair, yet the operative mortality and long-term all-cause mortality were equivalent in both groups. EVAR can demonstrate the less invasive benefits in the short term rather than the long term. This could be explained by the fact that EVAR is a minimally invasive procedure with less trauma to patients, and open repair may precipitate risk of fatal complications or even death in the short term. After passing the perioperative period, open repair gradually demonstrates its durability.[1–7,12]

The short-term mortality had varied definitions among studies.[1–7,12,13] Dangas *et al*[12] reported 30-day mortality data and did not include in-hospital mortality, whereas two large scale studies of RCT, DREAM and OVER[12,13], used a combination of 30-day and in-hospital mortality. Contrary to previous study results, our present study showed similar short-term mortality between EVAR and open repair; the disparity from DREAM trial[6,12] could be due to the limited number of patients we studied.

There is still a debate regarding which procedure for AAA treatment is optimal in the long term.[1–7] The results of the present study are in agreement with those of meta-analyses[2,7] comparing outcomes of patients undergoing EVAR and open repair for AAA. These data have not demonstrated the long-term survival benefit of EVAR over open repair for AAA.

Reoperation rates vary in different studies because of different follow-up times. One study showed a 9.8% reoperation rate among 543 EVAR cases, compared with 5.8% of 539 open repairs during 4 years.[4] Another study compared 444 EVAR with 437 open repair outcomes during a mean 1.8-year follow-up and found essentially equivalent rates of reintervention.[13] The reoperation rate for patients undergoing open repair in our study was 6.8% (9/133), and no patients in EVAR group underwent reoperation, which was in line with the literature[3,13]; thus, the long-term benefit of EVAR for AAA was questioned.

We have to recognize that our study was limited by a retrospective review of medical files and a historical comparison of 2 surgical procedures for AAA, which could cause the bias of the conclusion of this study.

In conclusion, grey relational analysis results showed that endovascular repair of AAA causes fewer complications than open repair in the short term, and both procedures are equivalent with respect to all-cause mortality rate in the long term. A randomized study is warranted to elucidate the long-term benefit of repair procedures for AAA.

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