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Prediction of outcome after abdominal aortic aneurysm rupture

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Background: **Most vascular surgeons practice a selective policy of operative intervention for patients with ruptured abdominal aortic aneurysm (AAA). The evidence on which to justify operative selection remains uncertain. This review examines the prediction of outcome after attempted open repair of ruptured AAA.**

Methods: **The Medline and EMBASE databases and Cochrane Database of Systematic Reviews were searched for clinical studies relating to the prediction of outcome after ruptured AAA. Reference lists of relevant articles were also reviewed.**

Results: **The last 20 years has seen >60 publications considering variables predictive of outcome after AAA rupture. Four predictive scoring systems are reported: Hardman Index, Glasgow Aneurysm Score, Physiological and Operative Severity Score for Enumeration of Mortality and Morbidity (POSSUM), and the Vancouver Scoring System. No scoring system has been shown to have consistent or absolute validity. Of the remaining data, there are no individual or combination of variables that can accurately and consistently predict outcome.**

Conclusions: **Little robust evidence is available on which to base preoperative outcome prediction in patients with ruptured AAA. Experienced clinical judgement will remain of foremost importance in the selection of patients for ruptured AAA repair. (J Vasc Surg 2008;47:222-30.)**

Most surgeons practice a selective policy of operative intervention for patients with ruptured abdominal aortic aneurysm (AAA).[1] This approach is underpinned by the rapid assessment of the patient's current clinical condition, premorbid health, and functional status to determine if attempted operation is appropriate and associated with a realistic chance of survival. It aims to ensure health care resources are used appropriately and avoid futile attempts at intervention in patients with prohibitive risk. In clinical practice, this patient selection is largely based upon subjective criteria. However, to ensure that selection is objective, a system that can accurately predict outcome in patients with ruptured AAA is crucial.

Many authors have attempted to identify variables capable of predicting death in patients with ruptured AAA. There is much heterogeneity in the nature and quality of results and the methods used for reporting. A few series have gone further and have performed statistical modelling on predictive variables to design scoring systems that can forecast outcome. In many systems, however, sound methodology has not been used in the design; furthermore, only a few have undergone robust audit, let alone prospective validation. A previous review has recognized that these limitations would render meta-analytical techniques unsuitable.[2] The following systematic review considers existing scoring systems and existing literature on variables predictive of outcome in patients with ruptured AAA.

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METHOD

The Medline, EMBASE, and Cochrane Systematic Reviews (January 1985 to June 2006) electronic databases were searched. The search strategy used the MeSH headings "Aortic aneurysm, abdominal" and "aortic rupture or rupture.mp," with the Boolean operator "and." The OVID search engine 10.3.2 (Ovid Technologies, New York, NY) was used. Criteria for inclusion were studies assessing variables predictive of outcome in patients before attempted open repair of ruptured AAA. Studies that examined outcome in a subgroup of patients alone and those that only assessed selected variables were excluded. Manual searching was also done of reference lists from articles retrieved by electronic searching. Articles retrieved were restricted to those published in English. All identified articles were obtained through local library collections and The British Library.

RESULTS

Hardman index. The Hardman scoring system is probably the most well known of scoring systems for use in patients with ruptured AAA. Originally described in 1996, this retrospective series reviewed 154 nonconsecutive patients who underwent operation for ruptured AAA between 1985 and 1993 at a single Australian tertiary vascular center.[3] Univariate analysis was done on 67 preoperative variables in 136 patients for their association with death in-hospital or ≤30 days of surgery. Continuous variables significantly associated with death were categorized into quartiles, and the mortality rate of each category examined. All variables related to postoperative death were further analyzed alongside data from another 18 patients to develop a multivariate model. The significant multivariate risk factors were then assessed for their cumulative effect when weighted equally.

Table I. Operative mortality (%) according to number of Hardman variables

First author	*Year*	*Patients, No.*	*No. of Hardman variables*			
			0	*1*	*2*	*≥3*
Hardman[3]	1996	154	16%	37%	72%	100%
Prance[4]	1999	69	18%	28%	48%	100%
Neary[5]	2003	188	35%	55%	74%	90%
Boyle[6]	2003	79	8%	24%	55%	100%
Calderwood[7]	2004	137	40%	46%	77%	92%*
Tambyraja[8]	2005	85	15%	55%	38%	33%

*Mortality for 3 risk factors only. For 4 risk factors, mortality was 100%.

Five independent variables were identified on multivariate analysis: preoperative hemoglobin level <9 g/L, serum creatinine level >90 μmol/L, electrocardiographic ischemia, in-hospital loss of consciousness, and age >76 years. No single risk factor had a predictive value in isolation, but the cumulative predictive value of the risk factors is summarized in Table I. Three or more of the five risk factors were associated with a 100% mortality rate.

After its conception, the Hardman score was commended for its simplicity and practicality in the acute setting. Validation of the system has been performed at various levels. To date, six studies have assessed the performance of the Hardman system.[4-8] These are summarized in Table I.

On initial inspection, these results seem to support the original data of Hardman and colleagues. Of the five series, three or more positive variables are uniformly associated with perioperative death in three studies. However, it is concerning that three of the reports contain patients with three or more variables who survived operative repair. Although it has been widely concluded that the presence of more than three Hardman variables is a good predictor of death, this would seem not to be universally true.

More critical analysis of these data reveals that all but one review is retrospective in nature and the only prospective data are compiled from two centers. These data add some credence to the validity of the Hardman score system but also highlight that the instrument is not as precise as initially reported. This emphasizes the need for further prospective validation before its use in clinical practice can be unanimously supported.

Glasgow aneurysm score. The Glasgow Aneurysm Score (GAS) was first reported in 1994.[9] This instrument was originally developed as a tool for prognostic scoring in patients undergoing repair of intact or ruptured AAA. A retrospective, multicentered, nonconsecutive sample of 500 patients undergoing AAA repair at general surgical units in Glasgow between 1980 and 1990 was examined for risk factors associated with death. Multivariate analysis identified the independent risk factors of age, shock, myocardial disease, cerebrovascular disease, and renal disease. Myocardial disease is typified by documented myocardial infarction or on-going angina, or both. Cerebrovascular disease refers to all grade of stroke, including transient ischemic attacks. Renal disease is any combination of history of chronic or acute renal failure, urea level >20 mmol/L, or creatinine level >150 μmol/L at presentation.

Rounding of the regression coefficients created a simple risk score: risk score = age in years + 17 (for shock) + 7 (for myocardial disease) + 10 (for cerebrovascular disease) + 14 (for renal disease). Appraisal of the scoring system showed that mortality rate increased in proportion to score. The same authors prospectively evaluated their system in a subsequent multicentered study.[10] Again, they reported similar results to the original analysis used in developing the score. Mortality was found to correlate well with GAS, and scores of >95 were related to a mortality rate of >80%.

This generic scoring system for patients undergoing AAA repair has had little further validation. Given its simplicity, ease of use, and apparent predictive power, this seems surprising. However, a Finnish group recently examined the performance of the GAS in a retrospective review of 836 patients with ruptured AAA admitted to 21 hospitals and included in a large national vascular registry.[11] These data confirmed that the GAS was independently associated with postoperative death. This series did not have a cutoff score that predicted a postoperative mortality rate of 100%, although a score of >98 was associated with a mortality rate of about 80%.

We have previously reported the results of our own retrospective audit of the GAS.[8] A surprising finding was that the GAS performed poorly as a predictive tool. Indeed, it was impossible to identify any score that conferred extreme risk, and even in 14 patients with scores of ≥110, operative mortality was <50%. Despite its apparent merits, further attempts at validation have yielded conflicting results. Until further data are available, its use in outcome prediction and as a risk-stratification tool for comparative audit must be questioned.

The physiological and operative severity score for the enumeration of mortality and morbidity. The POSSUM score was described and prospectively validated by Copeland et al[12] in 1991. Its primary function was as a scoring system for general surgical audit to allow for the effects of case-mix rather than as an instrument to predict individual case outcome. POSSUM represents a risk-prediction model based on a physiology score derived from 12 preoperative variables, which are independently predictive of adverse postoperative outcome on multivariate analysis,

Table II. Physiological and Operative Severity Score for Enumeration of Mortality and Morbidity (POSSUM) physiologic and operative variables

Physiological score	*Operative score*
Age, y	Operation category (minor, intermediate, major, major+)
Cardiac signs	No. of procedures
Respiratory signs	Total blood loss, mL
Systolic blood pressure, mm Hg	Peritoneal soiling
Pulse rate, per min	Malignancy
Glasgow Coma Score	Timing of operation
Serum urea, mmol/L	
Serum sodium, mmol/L	
Serum potassium, mmol/L	
Hemoglobin, g/L	
White cell count, $\times 10^9$/L	
Electrocardiogram	

Mortality risk equations (R = risk of mortality):
POSSUM: $\ln(R/1-R) = -7.04 + (0.13 \times \text{physiological score}) + (0.16 \times \text{operative severity score})$.
Vascular (V)-POSSUM: $\ln(R/1-R) = -8.0616 + (0.1552 \times \text{physiological score}) + (0.1238 \times \text{operative severity score})$.
V-POSSUM (physiological score only): $\ln(R/1-R) = -6.0386 + (0.1539 \times \text{physiological score})$.
Ruptured abdominal aortic aneurysm (RAAA)-POSSUM: $\ln(R/1-R) = -4.9795 + (0.0913 \times \text{physiological score}) + (0.0958 \times \text{operative severity score})$.
RAAA-POSSUM (physiological score only): $\ln(R/1-R) = -2.7569 + (0.0968 \times \text{physiological score})$.

and an operative score derived from six further intraoperative variables (Table II). Each of the variables is graded and scored exponentially as 1, 2, 4, or 8.

The combined physiology and operative scores were subjected to logistic regression analysis to generate risk equations that convert the scores into a predicted percentage morbidity and mortality. However, attempted validation in both general and subspecialty surgery has reported a lack of calibration of the initial model and suggestions for remodelling of the regression equation have been proposed.[13-16] This led to the Vascular Surgical Society of Great Britain and Ireland developing a risk equation specific for patients undergoing vascular surgery, the V-POSSUM.[17] Specific evaluation of the POSSUM system in ruptured AAA repair demonstrated that the equation performed poorly in emergency aortic surgery.[18]

Subsequently, two further equations exclusively for ruptured AAA were derived from a retrospective series of 106 patients.[19] One equation incorporated both physiology and operative scores and the other only used the physiology score. Initial validation was performed by the authors on a further set of 107 patients with ruptured AAA. The physiology-only equation was effective but was found to have a lack of fit at a certain risk range. However, the ruptured AAA POSSUM (RAAA-POSSUM) equation that combined physiology and operative scores was more successful at accurately predicting outcome.

Two further series have examined the validity of both RAAA-POSSUM systems. Both equations were used to analyze retrospective data on 188 patients with ruptured AAA from Gloucester.[5] Both systems performed well, with no difference in observed and expected mortality results. A further nonconsecutive, retrospective series of 68 patients who survived >24 hours after repair of a ruptured AAA from Leicester also confirmed that although the two systems tended to slightly overpredict death, there was no statistically significant lack of fit. However, the limitations of the latter highly selected data set are obvious.[20]

To date, the RAAA-POSSUM systems have not been prospectively validated. Although the existing evidence suggests that they perform well, the utility of the POSSUM system in clinical decision making is questionable. It is paramount to reiterate that the POSSUM methodology is principally for comparative audit. The need for operative variables renders most POSSUM equations impractical for preoperative risk prediction.

Although the data required for the physiology RAAA-POSSUM tool are easily recorded, the need for complex mathematical equations can make its utility cumbersome in the clinical setting. The system allows for more precise risk stratification of patients than some of the other systems already described. This level of accuracy may introduce even more complexity to clinical decision making. In the Gloucester study, one of 16 patients with a predicted mortality risk of >80% survived, as did three of 21 with a risk of 70% to 80%. Using this system, the absolute prediction of operative futility would appear unfeasible.

Vancouver scoring system. Of scoring systems applicable to patients with ruptured AAA, the Vancouver system is probably the least well known and used.[21] Also reported in 1996, this retrospective series examined 147 patients who underwent repair of a ruptured AAA between 1984 and 1993. Perioperative demographic and physiologic variables significantly associated with death on univariate analysis underwent further multivariate analysis.

Univariate analysis identified age, reduced conscious level, preoperative cardiac arrest, history of myocardial infarction, and a history of collapse as being associated with postoperative death. After multivariate logistic regression analysis, age, reduced conscious level, and preoperative cardiac arrest remained as significant predictors of death. These variables could be entered into a predictive model equation on the basis of the coefficients from the logistic regression model. The probability of death is estimated using the equation $[e^x/(1 + e^x)]$, where e is the base of the natural logarithm and x is the constant (-3.44) + sum of coefficients for the significant variables (Table III).

The Vancouver group has also attempted to validate their statistical model. They evaluated the performance of the instrument on a prospective series of 134 patients drawn from two tertiary centers.[22] The authors argue that their system is accurate at predicting patients at extreme risk (patients with a predicted mortality >90%); however, the instrument seems to perform less well at lower levels of mortality risk (patients with a predicted mortality >80%). The group concluded that their tool was of use in informing clinical decisions in patients with ruptured AAA, although unable to identify a 100% mortality rate.

Table III. Risk factor coefficients from the Vancouver scoring system

Variable	*Category*	*Coefficient (Constant = −3.41)*
Age		0.062 × age
Loss of consciousness	Yes	1.14
	No	−1.14
Cardiac arrest	Yes	0.60
	No	−0.60

Table IV. Series failing to identify variables predictive of death after operation

First author	*Year*	*Patients, No.*	*Deaths, %*
Campbell [23]	1986	52	56
Vohra [24]	1988	92	39
Harris [25]	1991	113	64
Meesters [26]	1994	99	49
Barry [27]	1997	140	52
Hatori [28]	2000	33	39
Bown [20]	2003	139*	32
Sultan [29]	2004	42	60

*Excludes patients who died ≤24 hours of operation.

Despite their assertion, this scoring system does not seem to have gained support and been used by other centers. No further independent validation is identifiable in the literature. Reasons for this may be related to the nature of the model. Although the variables used are easily obtained, the need for coefficients and complex mathematical formula render it less practicable in the acute situation. The derivation of a percentage risk of death is similar to the GAS and POSSUM systems. This instrument may have a utility for risk stratification for the purposes of audit, although more robust validation is needed to assess its credentials. Its use in clinical decision making in the acute setting is hampered by its complexity.

Other predictive variables. Interest in the prediction of clinical outcome in patients with AAA rupture is highlighted by the publication of >60 independent series investigating the subject in the last 20 years alone. Although the preceding scoring systems are, perhaps, the most sophisticated and well cited of these articles, the others also offer potentially useful data to inform clinical judgement.

Eight of these further articles reported negative results and were unable to identify any preoperative variables predictive of death after aneurysm rupture (Table IV).[20,23-29] These studies on 710 patients from European and North American centers are all retrospective in design. The median sample size was 92 (range, 33 to 140) and mortality was 49% (range, 32% to 64%). These data provide compelling evidence for the argument that absolute prediction of outcome in this disease is impossible. It is argued that withholding an operation on the basis of any predictive variables is unsound and ethically unjustified.[25] Some of the most highly regarded authorities in vascular surgery have championed this thesis.[30] It may also be assumed that an even greater body of similar unpublished data exists owing to the nature of publication bias.

Examination of the available data generates some concerns, however. Of the three series that study >100 patients, one excluded patients who died ≤24 hours of operation,[20] and another shared a data set with a further publication that a year later reported female gender, preoperative hypotension, low hemoglobin level, and thrombocytopenia as predictors of death.[27] Critics also have questioned whether “cardiac arrest” in these series simply represented an inability to palpate pulses due to hypotension or arrhythmia rather than true loss of cardiac output. Nevertheless, irrespective of these deficiencies, such data cannot be ignored.

The remaining 55 series all describe one or more preoperative variables that were predictive of outcome in 81,350 patients (Table V).[31-80] It must be noted that two series have similar characteristics and are likely to represent duplicate publication of an extended data set.[77,80] The median number of patients studied was 119 (range, 18 to 67,751), and median mortality was 47% (range, 13% to 75%). It is noteworthy that only two studies were prospective in design.[48,56] Most data have been subjected to multivariate statistical tests, where appropriate, although some large series have only undertaken univariate analysis. Apart from the Hardman data, no other group has robustly identified preoperative variables, individually or combined, that are capable of defining a group with such a prohibitive risk of death that intervention is precluded. Even patients with preoperative cardiac arrest, a group that is intuitively at an extreme risk of mortality, are reported to have survival rates of up to 33% in certain series.[59]

Nevertheless, 10 variables regularly appear as significant predictors of death. If one takes hematocrit and serum hemoglobin as analogous variables, six of these appear more frequently than others. These six include hypotension, advanced age, cardiac arrest, raised serum creatinine level, low hemoglobin/hematocrit, and a history of ischemic heart disease. Of interest is that these variables or their correlates are all represented in the established scoring systems described earlier.

The risk factors of hypotension, cardiac arrest, raised creatinine level, low hemoglobin level, loss of consciousness, and electrocardiographic ischemia have retained independent statistical significance on multivariate analysis, and they are all implicated in the development or a manifestation of systemic shock. Furthermore, more than half of these 54 publications identify hypotension as a predictor of mortality. Of the reported risk factors, female gender is, perhaps, the most difficult to interpret. Four of the five data sets that describe this finding are North American and have considerable sample sizes. The over-representation of women in elective and emergency AAA mortality statistics is well described, but the reasoning remains uncertain.[81]

Table V. Series identifying preoperative variables predictive for death after attempted repair of ruptured abdominal aortic aneurysm

First author	*Year*	*Patients, No.*	*Deaths, %*	*BP, mm Hg*	*Age, y*	*Cardiac arrest*	*Creatinine, μmol/l*
Donaldson[31]	1985	81	43		• (>76)*		
Lambert[32]	1986	180	75	• (<80)			
Morishita[33]	1986	20	45	•*			
Nachbur[34]	1987	116	47		•*		
Shackleton[35]	1987	106	40				
Martin[36]	1988	58	26	• (<90)			
Amundsen[37]	1989	103	59	• (<92)	• (>71)		
Ouriel[38]	1990	243	55	• (<70)			• (>300)
Murphy[39]	1990	172	49	• (<90)*		•*	
Johansen[40]	1991	186	70		• (>80)*	•*	
AbuRahma[41]	1991	73	62	• (<90)			
Gloviczki[42]	1992	231	42	•			
Rosenthal[43]	1992	47	43	• (<90)*	• (>75)*	•*	
Scott[44]	1992	66	30		•‡		
Bauer[45]	1993	314	29	• (<90)			
McCready[46]	1993	208	50	• (<90)	• (>70)		
Katz[47]	1994	99	57		•		
Johnston[48]	1994†	147	49				• (>130)
Katz[49]	1994	1829	50	•			
Panneton[50]	1995	112	49	• (<90)		•	
Browning[51]	1995	54	44	• (<85)			
Marty-Ane[52]	1995	61	13		•		
Farooq[53]	1996	122	56	• (<80)		•	
Jaakkola[54]	1996	48	65	• (<90)			
Rutledge[55]	1996	1480	54		•*		
Chen[21]	1996	157	46		•	•	
Hardman[3]	1996	154	39		• (>76)		• (>190)
Koskas[56]	1997†	158	47	•	•		•
Martinez[57]	1997	84	57	• (<90)	•		
Lazarides[18]	1997	40	55				
Halpern[58]	1997	96	60	• (<90)			• (>150)
Satta[59]	1997	51	47	•*			
Subramaniam[60]	1998	18*	67	•*			
Barry[61]	1998	150	48	•*			
Dardik[62]	1998	527	47		•		
Van Dongen[63]	1998	309	25		• (>70)		
Sasaki[64]	1998	27	22	• (<80)	•		
Urwin[65]	1999	135*	63		•	•	
Ho[66]	1999	40	48		•		
Kniemeyer[67]	2000	57	32	• (<80)			
Turton[68]	2000	102	53	• (≤90)		•	
Heller[69]	2000	67751	46		• (>70)		•
Lovricevic[70]	2000	54	30	•‡		•‡	
Merlo[71]	2001	123	45		•*		
Noel[72]	2001	413	37			•	
Alonso-Perez[73]	2001	144	47	• (<80)	•		
Gutierrez–Morlote[74]	2002	106	49	• (<90)			
Hans[75]	2003	101	48		•		
Piper[76]	2003	147	35				
Markovic[77]	2004	229	54	• (<95)*		•*	• (>180)*
Lo[78]	2004	41	41				•
Dueck[79]	2004	2601	41		•		
Calderwood[7]	2004	137	56	• (<100)	• (>76)		• (>190)
Korhonen[11]	2004	836	47	•			
Davidovic[80]	2005	406	48	•*		•*	• (>180)*

LOC, Loss of consciousness; IHD, ischemic heart disease; *BP,* blood pressure; *Hb,* hemoglobin; *Hct,* hematocrit; *APACHE II,* Acute Physiology and Chronic Health Evaluation II; *TIA,* transient ischemic attack; *AAA,* abdominal aortic aneurysm; *COPD,* chronic obstructive pulmonary disease.

•This variable was predictive of death.

*Univariate analysis only.

†Prospective studies.

‡No statistical analysis.

Table V. Continued

Hb, g/L)	*Hct, %*	*IHD*	*LOC*	*Sex (M/F)*	*ECG changes*	*Platelets* ($\times 10^9/l$)	*Other*
	• (<30)*				•*		
		•					Hypertension
							Duration of symptoms,* associated disease,* duration of AAA
							Duration of symptoms <6 h*
			•				Cardiac failure, anion gap
							Collapse*
				• (F)*			
							Collapse
	•						APACHE II score
							Treatment delay*
		•					
	•						
				• (F)			Chronic renal failure
		•					
		•					
				• (F)*			
			•				
• (<9)			•		•		
							Stroke/TIA
						•	
• (<10)			•				
•*							
• (<10)*							COPD*
•*				• (F)*		•*	
		•					COPD
• (<9)					•	• (<100)	
				• (F)			Afro-Caribbean race
			•‡				
						• (<100)*	Hypertension*
	•						APACHE II
					•		
	• (<35)						Treatment delay
							Core temp
• (<10)*	• (<29)*	•*	•*				Low urine output,* leucocytes >14×10^9 /L,* urea >11 mmol/L*
				• (F)			
					•		
• (<10)*	• (<29)*		•*				Low urine output*, Leucocytes > 14 ×10^9/L,* urea >11 mmol/L*

DISCUSSION

The existing literature suggests that certain patient-related preoperative variables are associated with perioperative death after AAA rupture. Of note, however is that surgeon- and hospital-related variables are also known to have a profound impact on outcome.[79] Recent data have confirmed that outcome in terms of death after ruptured AAA repair is better in high-volume centers.[82] This factor may be implicated in the poor comparative performance of existing scoring systems that were derived from low-volume or non-specialist institutions. With the introduction of endovascular repair of ruptured AAA and the potential improvements in patient survival, risk scoring instruments may require further remodelling or recalibration.[83,84]

Predictive scoring systems are derived from a combination of demographic, physiologic, and therapeutic variables. It is ideal to try to generate the most accurate value of risk scoring from the least number of predictors by excluding variables that do not influence outcome. The selection of these variables is performed by a combination of statistical modelling and expert opinion. After an analysis on a development data set, validation should be performed on a separate data set from the same institution before being applied to data from other centers and compared with the performance of other predictive tools.[85]

There is much to be desired in terms of the quality and level of available evidence. In the past 20 years, no more than two prospective attempts to investigate risk factors associated with death after AAA rupture have been published. Furthermore, the measure and reporting of significant perioperative morbidity in this group of patients continues to lack accuracy and focus.[86]

CONCLUSION

At present, no scoring system or variable, in combination or on its own, can be persuasively recommended as being predictive of perioperative death and be used to influence treatment decisions. The existing scoring systems have not been adequately validated to be of use in dictating therapy or justifying clinical decision making. At best, they are useful to risk stratify patients for the purposes of audit and act as an adjunct to supplement clinical intuition. Until a scoring system that uses sound methodology and robust validation is available, experienced clinical judgement will remain of foremost importance in the selection of patients for ruptured AAA repair.

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AUTHOR CONTRIBUTIONS

Conception and design: AT, JM, RC
Analysis and interpretation: AT, JM, RC
Data collection: AT
Writing the article: AT, JM, RC
Critical revision of the article: AT, JM, RC
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