Variable life adjusted display methodology for continuous performance monitoring of carotid endarterectomy

G Kuhan¹, DP McCollum², PM Renwick², IC Chetter², PT McCollum²

¹Department of Vascular Surgery, Royal Bournemouth and Christchurch Hospitals, Bournemouth, UK

²Academic Vascular Unit, Hull Royal Infirmary, Hull, UK

ABSTRACT

INTRODUCTION The aim of this study was to use variable life-adjusted display (VLAD) methodology to monitor performance of six vascular surgeons undertaking carotid endarterectomy in a single institution.

MATERIALS AND METHODS This was a prospective study with continuous analysis. A risk score model to predict 30-day stroke or death for individual patients was developed from data collected from 839 patients from 1992 to 1999. The model was used to monitor performance of six surgeons from 2000 to 2009. Individual risk factors and 30-day outcomes were analysed and VLAD plots were created for the whole unit and for each surgeon.

RESULTS Among the 941 carotid endarterectomies in the performance analysis, 28 adverse events were recorded, giving an overall stroke or death rate of 3.06%. The risk model predicted there would be 33 adverse events. There was no statistical difference between the predicted and the observed adverse events ($P > 0.2$, χ^2 value 1.25, 4 degrees of freedom). The VLAD plot for the whole unit shows an overall net gain in operative performance, although this could have been chance variation. The individual VLAD plot showed that surgeons 1, 2, 3 and 6 to have an overall net gain in the number of successful operations. The changes observed between the surgeons was not significant ($P > 0.05$) suggesting chance variation only.

CONCLUSIONS Performance of carotid endarterectomy can be continuously assessed using VLAD methodology for units and individual surgeons. Early identification and correction of performance variation could facilitate improved quality of care.

KEYWORDS

Carotid endarterectomy – Risk – Outcome – Performance – Audit

Accepted 20 July 2017

CORRESPONDENCE TO

G Kuhan, E: gkuhan@nhs.net

Introduction

There is growing pressure for more widespread introduction of methods for monitoring outcomes.¹ The 30-day stroke or death rate for carotid endarterectomy varies from 2% to 20% for individual surgeons.² A high stroke or death rate can be from chance variation or because of high patient risk factors. Any reasonable comparison between surgeons and units should adjust for these factors. Early identification of substandard performance might aid surgical units to implement necessary steps to reduce stroke or death rates.³ Measures to monitor performance continuously, as opposed to yearly or quarterly auditing of outcomes, can provide instant feedback.

The most simple form of continuous performance monitoring is the cumulative sum plot (CUSUM).⁴ Cumulative mortality is plotted against number of operations and the slope of the curve reflects performance. CUSUM does not adjust for case mix; to compensate for this factor, the difference between the expected mortality (calculated using a risk

model) and the observed mortality is plotted against the number of operations. This plot gives a jagged curve that ascends for each surviving patient and descends for each death. The size of the rise or fall depends on the individual risk factors: the higher patient risk the less the curve descends if there is a death. Equally, the curve rises higher if the patient survives. This method of analysis, known as variable life adjusted display (VLAD),⁵ has been used widely for quality control purposes.⁶ VLAD methodology has been recently improved to allow the likelihood that a departure from the norm could have occurred by chance.⁷ The aim of this study was to use VLAD methodology to monitor performance for carotid endarterectomy in a single institution.

Material and Methods

A model to predict the risk of adverse events for individual patients was developed from data collected for 839 patients undergoing carotid endarterectomy from 1992 to 1999 inclusive. A postoperative adverse event was defined as death or

non-fatal stroke within 30 days of carotid endarterectomy. Surgery was performed by one of five surgeons at two units. A risk model was devised in a previous study based on 67 possible risk factors and outcomes.⁸ Multivariate logistic regression analysis was carried out to develop a risk factor model, which was later converted to the risk score model.

The risk model was used to monitor performance of surgeons on prospectively collected data. For this exercise, data from consecutive carotid endarterectomies performed by six surgeons from 2000 to 2009 were available, including the appropriate risk factors and 30-day outcomes. VLAD plots were created for each surgeon and for the whole unit. The expected values were derived from the risk score and actual outcomes were given a value of 1 if there was a postoperative adverse event and 0 otherwise. The VLAD thus gives an indication as to the net gain (a positive score) or loss (a negative score) in sequential procedures.

The cumulative value of predicted – actual risk for each successive patient was superimposed on the VLAD plot for the entire series and the 95% prediction interval for the whole unit calculated. The prediction intervals were calculated by assuming that under the null hypothesis the distribution of the VLAD would be approximately normal, with mean zero.

The VLAD plots for each individual surgeon were compared on the same chart. On such a comparison, a single set of prediction intervals would not be appropriate, since they depend on case mix and size of series. Instead, *P* values were calculated to indicate the probabilities of the VLAD having the observed or more extreme values if the overall performances of the surgeons were as expected from the risk model. Given the model formulation, 6% of the total variance in the VLAD was found to be due to errors in the coefficients of the risk model and the remaining 94% was from random variation in the number of recorded adverse events. For this reason, the coefficient variability was ignored when determining the position of the prediction intervals and the *P* values.

Results

In the 839 carotid endarterectomies used to generate the initial model, there were 33 adverse events, giving an overall rate of 3.9%. The outcomes of the logistic regression

analysis to generate the risk model are shown in Table 1. Analysis led to a model with three risk factors: the presence of heart disease, a previous stroke and diabetes. A simplified model was tested by defining a risk score equivalent to the numbers of these factors present in each patient. This simplification resulted in no significant loss in goodness of fit (χ^2 0.575, *P* > 0.2 with 2 degrees of freedom). The shrinkage factor⁹ was calculated as 0.917, which was used as a multiplier for the risk score coefficient of 0.9044 to produce a final model:

$$\text{Logit (Risk)} = -4.27 + 0.85 \text{ (Risk score)}$$

A total of 914 carotid endarterectomies were included in the present performance analysis; 28 adverse events were recorded, giving an overall rate of 3.06%. The risk model predicted that there would be 33 adverse events. There was no statistical difference between the predicted and the observed adverse events (*P* > 0.2, χ^2 1.25, 4 degrees of freedom). Comparison of predicted and actual outcome rates by risk score are shown in Table 2 for both sets of patients.

The VLAD plot for the whole unit is displayed in Figure 1. Oscillating about the horizontal axis, overall performance appeared to be as expected for the first 400 procedures. Thereafter, the graph climbs upwards, indicating a gradual net gain in operative success. The VLAD plot for all six surgeons is illustrated in Figure 2.

Surgeons 1, 2, 3 and 6 showed an overall net gain in the number of successful operations while surgeons 4 and 5 had a net loss. The *P* values were equivalent to the probabilities of the VLAD having the observed or more extreme values if the overall performance of each surgeon was as expected from the risk model. None of the *P* values was significant at a 5% level, which suggests that these outcomes could be attributed to chance as opposed to any real change in performance.

Discussion

Performance monitoring and early detection of variance is necessary to improve standards of care. The benefit of carotid endarterectomy for asymptomatic and symptomatic patients with significant internal carotid artery stenosis has been proven by large randomised controlled trials.^{10,11} The number of operations performed in each vascular unit is

Table 1 Risk model			
Variable	Regression coefficient	Standard error	P value
First model:			
Diabetes	0.9083	0.4183	0.03
Heart disease	1.1066	0.3645	0.002
Stroke	0.7407	0.3544	0.04
Reduced model:			
Risk score	0.856	0.2045	< 0.0001

Table 2 Predicted and observed rates for risk scores						
Risk group	Pre 2000 data used for model		Post January 2002 data used for performance monitoring			
	Event rate (%)		Observed outcomes		Observed event rate (%)	Predicted events (n)
	Predicted	Observed	(n)	(N)		
0	1.4	1.6	3	313	0.9	4
1	3.2	3.1	13	409	3.1	13
2	7.2	8.9	9	169	5.3	12
3	15.3	18.1	3	23	13.1	4

likely to increase with centralisation of vascular services and the increasingly aged population. Measures should be in place to monitor surgeon and unit performance to deliver

the highest quality of care. Performance monitoring tools should adjust for patient level risk factors and should allow for chance variation. The VLAD method provides the necessary features and a graphical display that is easy to interpret.

There are some limitations with VLAD methodology. VLAD should not be used repeatedly to identify significant variations. VLAD is not a formal statistical testing procedure; rather, it is a method that assists in processing complex patterns of outcome. VLAD should be analysed with common sense to avoid over interpretation. For example, it might be considered that surgeons 3 and 4 (Figure 2) were performing suboptimally but this was only for transient period. The transient effect was not statistically significant in the overall analysis, so there was no cause for concern.

VLAD plots are generally useful for units that perform large number of carotid endarterectomies. The risk model used for calculating prediction intervals was derived locally and has been internally validated. Ideally, risk models need external validation. A risk model derived from national data – such as the UK national vascular database – could aid in comparative audit using similar techniques to those described in the current study. A dynamic risk model that encompasses changes in current practice will be needed. In the current study, the risk model was developed from data gathered in 1992–1999. Medical management and the urgency of surgery, for example, have changed over this period. Regular checks on the risk model for predictive accuracy will be necessary for future risk models.

The results of the study suggest a possible net gain, particularly in the later interval; however, the improvement could just be chance variation. Similarly, as stated, the difference observed between surgeons could also be due to chance. Plots similar to these provide instant feedback to surgeons about their performance and can identify those with suboptimal results. In the current study, there was no evidence of suboptimal performance among the surgeons. The outcomes of surgeons should be compared with national data before valid conclusions are made about apparent outliers. There is a real need for robust, reliable, transparent and honest data collection in a vascular unit. The outcomes of index procedures should be collected and audited by various members of the team (such as vascular surgeons, data entry clerks, vascular technologists, junior doctors). External

members (for example, stroke physicians and those who care for the elderly) should be involved in validation of outcome data. This approach provides resilience and reliability for reporting of outcome data which is recommended to all units.

There is considerable debate on which data should be available in the public domain. Public perceptions of complex outcome data like these are often variable and can lead to misleading conclusions. Outcome data of individual surgeons should be treated confidentially and sensitively. The outcome data of vascular units should be available in the public domain. Individual surgeons' results, however, should be audited within the unit and nationally. The review process of outliers should identify methods for outlying surgeons to improve their outcomes. Operating in large volume units rather than isolated smaller units can improve outcome.¹² Decisions on the selection of patients for carotid endarterectomy should be taken within multidisciplinary team, involving stroke physicians, radiologists and anaesthetist. Carotid endarterectomies should be carried out as part of a regular vascular list with experienced vascular anaesthetists and staff. The operative technique of outlying surgeons is probably not the main issue for most surgeons but can be assessed by assigning an experienced mentor. Vascular society guidelines should be adhered for pre- and postoperative care of patients.

Risk adjusted assessment of outcome provides clinicians with a true measure of performance. It is possible to obtain good outcome results by merely operating on predominantly low-risk patients. The current study illustrates the use of a risk model for risk adjustment and VLAD plots to aid continuous monitoring of outcome of surgeons and unit. The technique can be used nationally to improve outcome following carotid endarterectomy.

Acknowledgement

Royal College of Surgeons of England research fellowship.

References

1. Aylin P, Alves B, Best N *et al.* Comparison of UK paediatric cardiac surgical performance by analysis of routinely collected data 1984–96: was Bristol an outlier? *Lancet* 2001; **358**(9277): 181–187.
2. Rothwell PM, Warlow CP. Interpretation of operative risks of individual surgeons. European Carotid Surgery Trialists' Collaborative Group. *Lancet* 1999; **353**(9161): 1325.
3. de Leval MR, Francois K, Bull C *et al.* Analysis of a cluster of surgical failures. Application to a series of neonatal arterial switch operations. *J Thorac Cardiovasc Surg* 1994; **107**(3): 914–924.
4. Williams SM, Parry BR, Schlup MM. Quality control: an application of the CUSUM. *BMJ* 1992; **304**(6838): 1359–1361.
5. Lovegrove J, Valencia O, Treasure T *et al.* Monitoring the results of cardiac surgery by variable life-adjusted display. *Lancet* 1997; **350**(9085): 1,128–1,130.
6. Lawrance RA, Dorsch MF, Sapsford RJ *et al.* Use of cumulative mortality data in patients with acute myocardial infarction for early detection of variation in clinical practice: observational study. *BMJ* 2001; **323**(7308): 324–327.
7. Sherlaw-Johnson C, Lovegrove J, Treasure T, Gallivan S. Likely variations in perioperative mortality associated with cardiac surgery: when does high mortality reflect bad practice? *Heart* 2000; **84**(1): 79–82.
8. Kuhan G, Gardiner ED, Abidia AF *et al.* Risk modelling study for carotid endarterectomy. *Br J Surg* 2001; **88**(12): 1,590–1,594.
9. Van Houwelingen JC, Le Cessie S. Predictive value of statistical models. *Stat Med* 1990; **9**(11): 1,303–1,325.
10. Rerkasem K, Rothwell PM. Carotid endarterectomy for symptomatic carotid stenosis. *Cochrane Database Syst Rev* 2011; **(4)**:CD001081.
11. Halliday A, Harrison M, Hayter E *et al.* 10-year stroke prevention after successful carotid endarterectomy for asymptomatic stenosis (ACST-1): a multicentre randomised trial. *Lancet* 2010; **376**(9746): 1,074–1,084.
12. Killeen SD, Andrews EJ, Redmond HP. Provider volume and outcomes for abdominal aortic aneurysm repair, carotid endarterectomy, and lower extremity revascularization procedures. *J Vasc Surg* 2007; **45**(3): 615–626.