The Application of the Novel Grading Scale (Lawton-Young Grading System) to Predict the Outcome of Brain Arteriovenous Malformation

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BACKGROUND: A supplementary grading scale (Supplemented Spetzler-Martin grade, Supp-SM) was introduced in 2010 as a refinement of the SM system to improve preoperative risk prediction of brain arteriovenous malformations (AVMs).

OBJECTIVE: To determine the ability to predict surgical outcomes using the Supp-SM grading scale.

METHODS: This retrospective study was conducted on 200 patients admitted to the Helsinki University Hospital between 2000 and 2014. The validity of the Supp-SM and SM grading systems was compared using the area under the receiver operating characteristic (AUROC) curves, with respect to the change between preoperative and early (3-4 mo) as well as final postoperative modified Rankin Scale (mRS) scores.

RESULTS: The performance of the Supp-SM was superior to that of the SM grading scale in the early follow-up (3-4 mo): AUROC = 0.57 (95% confidence interval [CI]: 0.49-0.65) for SM and AUROC = 0.67 (95% CI: 0.60-0.75) for Supp-SM. The Supp-SM performance continued improving over SM at the late follow-up: AUROC = 0.63 (95% CI: 0.55-0.71) for SM and AUROC = 0.70 (95% CI: 0.62-0.77) for Supp-SM. The perforating artery supply, which is not part of either grading system, plays an important role in the early follow-up outcome ($P = .008$; odds ratio: 2.95; 95% CI: 1.32-6.55) and in the late follow-up outcome ($P < .001$; odds ratio: 5.89; 95% CI: 2.49-13.91).

CONCLUSION: The Supp-SM grading system improves the outcome prediction accuracy and is a feasible alternative to the SMS, even for series with higher proportion of high-grade AVMs. However, perforators play important role on the outcome.

KEY WORDS: Brain arteriovenous malformation, Spetzler-Martin grading system, Supplementary grading system, Modified Rankin Scale

T he Spetzler-Martin grading scale (SMS) has long been used to predict the surgical outcomes of patients with brain arteriovenous malformations (AVMs). SMS categorizes AVMs into 5 grades based on size (small: 0-3 cm; medium: 3-6 cm; large: over 6 cm), existence of deep venous drainage, and eloquence of location. While SMS is certainly useful in predicting surgical outcomes, it has its limitations and does not consider many factors that potentially influence outcome. In 2010, Lawton and colleagues proposed a new grading scale to improve patient selection and to more accurately predict surgical risk. The Supplemented Spetzler-Martin grade (Supp-SM) adds patient age, history of hemorrhage, and nidus type in addition to the classical SMS factors.

Since the Supp-SM’s introduction in 2010, few studies have compared the performance of SMS and Supp-SM in predicting surgical outcomes. We analyzed surgically treated patients with brain AVMs to compare the predictive value of Supp-SM to SMS alone.

ABBREVIATIONS: AUROC, area under the receiver operating characteristic; AVM, arteriovenous malformation; CI, confidence interval; mRS, modified Rankin Scale; OR, odds ratio; ROC, receiver operative characteristic; SM, Spetzler-Martin; SMS, Spetzler-Martin grading scale; Supp-SM, Supplemented Spetzler-Martin grade

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To evaluate the predicting power of the new grading scale, we compared their individual performance; each grading scale was individually added to a clinical prognostic model, based on the modified Rankin Scale (mRS). We hypothesized that the Supp-SM performance would be higher than that of the SMS alone in predicting the surgical outcomes of brain AVM.

RESULTS

Overall, 200 patients were included in this study. Patient demographics and AVM characteristics are summarized in Table 1. Of all patients, 38% had embolization and 3% had radiosurgery before microsurgical resection. Favorable outcomes after surgery were observed in 138 of the 200 patients (69% mRS scores 0–2). Unchanged or improved mRS scores were observed in 133 patients (67%). At the first (3–4 mo) follow-up, 7 patients (3%) had died, whereas at the final follow-up (2016) 23 (11%) had died, 16 from AVM-related causes. Nine of the patients who died had preoperative mRS scores of 5. Older patients, patients with unruptured AVMs, and patients with diffuse AVM nidi showed a higher tendency for unfavorable outcomes. However, deep perforating artery supply showed a significant relationship with unfavorable outcome (P < .001). There was no difference in the proportion of patients with large AVMs (P = .470).

Detailed distribution of the patient characteristics and the AVM-related factors were connected to the outcomes (Table 2). Neurological outcomes were arranged by SM and Supp-SM grades. Unfavorable outcome level increases with higher grades in both SM and Supp-SM grading systems, particularly at the long-term outcome. However, the high percentage (28%) of SM grades IV and V in our series (Table 1) led to an average correlation between the grades and the outcomes.

Univariate analysis identified age (P < .001), perforating artery supply (P = .030), and associated aneurysm (.046) as significant predictors for unfavorable mRS at the early outcome (3–4 mo follow-up). Eloquence of location was borderline significant (P = .063).

For late outcome, univariate analysis identified age (mean > 40; P = .001), eloquence (P = .006), diffuse nidus (P = .001), perforator supply (P < .001), deep venous drainage (P = .014), and nonhemorrhage presentation (P = .049) as significant predictors for unfavorable outcome (Table 3).

To identify independent predictors of dichotomized outcomes (favorable vs unfavorable), defined as improvement or no change vs worsening in mRS scores between mRS before surgery and early mRS (<4 mo), as well as mRS before surgery and late mRS outcome, a binary logistic regression model was constructed using the Wald method (first entering variables into the model and then using stepwise backward elimination). For early unfavorable outcome, the significant factors were age >40 (P < .001; odds ratio [OR] = 5.9) and perforator supply (P = .008; OR = 2.9; Table 4). For unfavorable late outcome, the significant factors were age >40 (P = .002; OR = 3.2), AVM size >30 mm (P = .047; OR = 0.4), diffuseness of the nidus (P = .001; OR = 5.7), deep perforator supply (P < .001; OR = 5.9), and nonhemorrhagic presentation (P = .045; OR = 0.4; Table 5).

The area under the ROC curve, indicating the predictive accuracy of the SMS and Supp-SM models for early outcome, was higher for the Supp-SM compared to SMS (0.67 and
TABLE 1. Patient Demographics, AVM Characteristics, and Outcomes.

| No. | %   | P Value |
|-----|-----|---------|
| Age, yr |     |         |
| <20  | 33  | 17%     |
| 20-40| 64  | 32%     |
| >40  | 103 | 51%     |
| AVM size (cm) |     |         |
| <3   | 108 | 54%     |
| 3-6  | 78  | 39%     |
| >6   | 14  | 7%      |
| Eloquence |     |         |
| 127 | 63% |         |
| Deep venous draining |     |         |
| 84  | 42% |         |
| Diffuse nidus |     |         |
| 33  | 16% |         |
| Hemorrhagic presentation |     |         |
| 125 | 63% |         |
| Perforating artery supply |     |         |
| 44  | 22% |         |
| Spetzler-Martin grade |     |         |
| 1   | 47  | 23%     |
| 2   | 55  | 28%     |
| 3   | 42  | 21%     |
| 4   | 46  | 23%     |
| 5   | 10  | 5%      |
| Supplemented Spetzler-Martin grade |     |         |
| 2   | 3   | 2%      |
| 3   | 22  | 11%     |
| 4   | 33  | 17%     |
| 5   | 54  | 27%     |
| 6   | 35  | 18%     |
| 7   | 27  | 14%     |
| 8   | 15  | 7%      |
| 9   | 10  | 5%      |
| 10  | 1   | 1%      |
| Preop mRS |     |         |
| 0   | 21  | 11%     |
| 1   | 80  | 40%     |
| 2   | 36  | 18%     |
| 3   | 28  | 14%     |
| 4   | 2   | 1%      |
| 5   | 33  | 16%     |
| 4-mo mRS |     |         |
| 0   | 4   | 2%      |
| 1   | 81  | 41%     |
| 2   | 31  | 15%     |
| 3   | 43  | 22%     |
| 4   | 14  | 7%      |
| 5   | 18  | 9%      |
| 6 (dead) |     |         |
| 7   | 3   | 3%      |
| missing |     |         |
| 2   | 1%  |         |
| Last follow-up mRS |     |         |
| 0   | 42  | 21%     |
| 1   | 52  | 26%     |
| 2   | 44  | 22%     |
| 3   | 17  | 9%      |
| 4   | 18  | 9%      |
| 5   | 4   | 2%      |
| 6 (dead) |     |         |
| 23  | 11% |         |
| Interval (surgery to last follow-up) years | 6.02 ± 4.95 |

*P correlation with last mRS (2016). P-values are derived from a Chi-square test or ANOVA.

In this study, we provide further evidence for the predictive power of the Supp-SM. After the introduction of the Supp-SM in 2010,2 few published articles have shown its superiority over classical SMS.3,4,6

DISCUSSION

In this study, we provide further evidence for the predictive power of the Supp-SM. After the introduction of the Supp-SM in 2010,2 few published articles have shown its superiority over classical SMS.3,4,6

To minimize the risk of surgical resection, we need to study preoperative relative factors. With the wide spectrum of AVM pathology, individual context, the team’s surgical ability and technical support, and finally and most importantly, patient selection for surgery is the key for a good outcome.

Previous AVM grading systems are familiar to neurosurgeons, and these systems helped in predicting the surgical risk and in developing the management decision process. The SM grading system is the most known, practical system, and it has the following variables: size of the AVM (<3, 3-6, and >6 cm), venous draining (deep or superficial), and whether there is eloquence of location. We receive 5 different grades from that collection of variables. Recently, the SM grade system has been modified and renamed the Spetzler-Ponce grading system,7 which is simplified as three difference classes. Class A includes SM grades I and II, class B includes SM grade III, and class C includes SM grades IV and V. This classification is aimed at improving the treatment decision process.

Surgery is recommended for grades I and II, and no treatment is recommended for grades IV and V. However, there is a high degree of ambiguity in class B management recommendation,8-11 and multimodal treatment is often recommended for cases deemed eligible for treatment. Multimodality could mean embolization.
### TABLE 2. Detailed Distribution of Factors and Neurological Outcomes Associated With Spetzler-Martin Grades and Supplemented Spetzler-Martin Grades.

| Neurological outcomes (200 patients) | Outcome (4-mo follow-up) | Outcome (last follow-up) |
|-------------------------------------|--------------------------|--------------------------|
|                                     | Favorable (n | %) | Unfavorable (n | %) | Favorable (n | %) | Unfavorable (n | %) |
| Sex                                 | Female | 56 | 62% | 34 | 38% | 64 | 70% | 28 | 30% |
|                                     | Male | 57 | 53% | 51 | 47% | 69 | 64% | 39 | 36% |
| Age group                           | 0-20 | 23 | 70% | 10 | 30% | 27 | 82% | 6 | 18% |
|                                     | 20-40 | 39 | 62% | 24 | 38% | 47 | 73% | 17 | 27% |
|                                     | >40 | 51 | 50% | 51 | 50% | 59 | 57% | 44 | 43% |
| AVM size (cm)                       | <3 | 65 | 61% | 42 | 39% | 77 | 71% | 31 | 29% |
|                                     | 3-6 | 42 | 54% | 36 | 46% | 49 | 63% | 29 | 37% |
|                                     | >6 | 6 | 46% | 7 | 54% | 7 | 50% | 7 | 50% |
| Elocuence location                  | Non-E | 48 | 66% | 25 | 34% | 60 | 82% | 13 | 18% |
|                                     | E | 65 | 52% | 60 | 48% | 73 | 58% | 54 | 42% |
| Nidus                               | Compact | 98 | 59% | 68 | 41% | 118 | 72% | 49 | 29% |
|                                     | Diffuse | 15 | 47% | 17 | 53% | 15 | 45% | 18 | 55% |
| Perforating artery supply           | No | 92 | 59% | 63 | 41% | 112 | 72% | 44 | 28% |
|                                     | Yes | 21 | 49% | 22 | 51% | 21 | 48% | 23 | 52% |
| Deep venous draining                | No | 69 | 60% | 46 | 40% | 83 | 72% | 33 | 28% |
|                                     | Yes | 44 | 53% | 39 | 47% | 50 | 60% | 34 | 40% |
| Rupture                             | Yes | 90 | 73% | 33 | 27% | 86 | 69% | 39 | 31% |
|                                     | No | 23 | 31% | 52 | 69% | 47 | 63% | 28 | 37% |
| Embolization before surgery         | No | 73 | 59% | 51 | 41% | 86 | 69% | 38 | 31% |
|                                     | Yes | 40 | 54% | 34 | 46% | 47 | 62% | 29 | 38% |
| Spetzler-Martin grade               | I | 31 | 66% | 16 | 34% | 40 | 85% | 7 | 15% |
|                                     | II | 31 | 57% | 23 | 43% | 37 | 67% | 18 | 33% |
|                                     | III | 25 | 60% | 17 | 40% | 25 | 60% | 17 | 40% |
|                                     | IV | 22 | 48% | 24 | 52% | 25 | 54% | 21 | 46% |
|                                     | V | 4 | 44% | 5 | 56% | 6 | 60% | 4 | 40% |
| Supplemented Spetzler-Martin grade  | 2 | 3 | 100% | 0 | 0% | 3 | 100% | 0 | 0% |
|                                     | 3 | 17 | 77% | 5 | 23% | 19 | 86% | 3 | 14% |
|                                     | 4 | 24 | 73% | 9 | 27% | 29 | 88% | 4 | 12% |
|                                     | 5 | 31 | 59% | 22 | 41% | 37 | 69% | 17 | 31% |
|                                     | 6 | 20 | 57% | 15 | 43% | 21 | 60% | 14 | 40% |
|                                     | 7 | 10 | 37% | 17 | 63% | 13 | 48% | 14 | 52% |
|                                     | 8 | 5 | 36% | 9 | 64% | 4 | 27% | 11 | 73% |
|                                     | 9 | 2 | 20% | 8 | 80% | 6 | 60% | 4 | 40% |
|                                     | 10 | 1 | 100% | 0 | 0% | 1 | 100% | 0 | 0% |

*a: Two missing cases from early follow-up.*
and surgery, surgery and radiosurgery, embolization and radiosurgery, or even a combination of all 3 modalities.

To enhance the grading system for AVM treatment, the Toronto group’s grading system added a new factor. This factor is the compactness of the AVM nidus. This system has replaced the size of the AVM with the nidus type. Deep venous drainage scores 2 points, the diffuseness of the nidus scores 3 points, and the eloquent location scores 4 points. The system did not achieve the popularity of the SM system. However, the diffuseness concept proved to be an important factor from a surgical point of view and significantly impacts the outcome.

Hemorrhagic presentation of the AVM is an important predictor risk for the natural history. The highest risk of bleeding is in those who had previously bled. However, hemorrhage widens the dead space around the AVM and facilitates surgical resection, particularly in low-grade AVM. At the same time, patients with unruptured AVMs typically do not have pretreatment neurological deficits, and are therefore more susceptible to develop new deficits after surgery, compared to patient with ruptured lesions presenting already with neurological deficits due to hemorrhagic stroke. Lawton et al put together 3 new factors: age, bleeding, and compactness. The new system has an analogous property with the SM system. Age

has 3 groups: less than 20 achieves 1 point, between 20 and 40 achieves 2 points, and over 40 yr achieve 3 points. There is 1 point for unruptured presentation, and 1 point for diffuseness of the nidus.

The Supp-SM grading system has 9 different grades (2-10). In this system, grade 6 is considered the cutoff point for acceptable surgical risk.

The new system has the flexibility of changing over time. Age and bleeding status are changeable factors. Furthermore, nidus shape and AVM size could be changed by radiotherapy and embolization. For that reason, Supp-SM proved to be a dynamic scale system and may be modified by other treatment modalities, particularly endovascular treatment.

Within SM grade III, there are different subtypes with varying mortality and morbidity, depending on the AVM subtype. Therefore, Lawton et al have subdivided it to grade III+, grade III, grade III−, and grade III*, which is a rare case of large AVM with a superficial draining vein and a noneloquent location, like the right frontal pole. Eloquent location advances grade III to III+, which was also proven in our experience.

Age, which scores 1 to 3 in the supplementary scale, has a certain propriety. High-risk AVM features (aneurysm association and venous abnormalities) are found more often in adults. Furthermore, children are more likely to a hemorrhage. Therefore, young age, which has a lower scoring by itself, is often combined with hemorrhagic presentation, which has a null score in the supplementary scale, further explaining the better outcome in young cohorts.

Deep perforator arterial supply proved to have a significant influence on the outcome in our study but not in the Lawton et al study. The increased risk caused by deep perforators is quite easy to understand. While resecting the AVM, these fragile small vessels are notoriously difficult to coagulate, and often retract deeper into white matter—containing potentially eloquent long fiber tracts. The deep perforating supply is also more common in large, complex AVMs which by themselves are associated with higher risk of surgery. One possible explanation for this factor being significant in our series is that we have a higher percentage of SM grades IV and V in this study (28%), whereas in Lawton et al it was 11%. This means that we have more cases with

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**TABLE 4. Factors Significantly Associated With Worse Early Outcome in Multiple Logistic Regression Model (Wald Stepwise Backward Model).**

| Factor                          | P value | OR  | 95% CI       |
|--------------------------------|---------|-----|--------------|
| Age > 40 yr                    | .000    | 3.25| 1.54-6.86    |
| Perforating arterial supply    | .008    | 2.99| 1.32-6.65    |

OR = odds ratio, CI = confidence interval.

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**TABLE 5. Factors Significantly Associated With Worse Late Outcome in Multiple Logistic Regression Model (Wald Stepwise Backward Model).**

| Factor                          | P value | OR  | 95% CI       |
|--------------------------------|---------|-----|--------------|
| Age > 40 yr                    | .002    | 3.25| 1.54-6.86    |
| Size > 30 mm                   | .047    | 0.41| 0.17-0.99    |
| Nidus diffuseness              | .001    | 5.74| 1.98-16.66   |
| Perforating arterial supply    | .000    | 5.89| 2.49-13.91   |
| Nonhemorrhagic                 | .045    | 0.44| 0.20-0.98    |

OR = odds ratio, CI = confidence interval.
large and deeply drained AVMs, which hold a higher possibility of having perforators as supply feeders. The rather high portion of SM grades IV and V reflects both the population responsibility of our center (all AVM patients within the catchment area are treated by us) and the treatment policies of the study period—today, we prefer a more conservative approach for grades IV and V AVMs, particularly in cases of unruptured lesions.

**Study Limitations**

Our strategy with the results of this study could empower the validation of the Supp-SM grading scale, as we included a reasonable number of all grades, and the new scale achieves the same result shown by the scale’s inventors.

Judging the diffuseness of the nidus is still somewhat subjective. However, advanced radiological technologies allowed discriminating the many subtypes of diffuse nidus.

There are many other factors that could play important roles in the surgical outcome, such as associated aneurysm, time elapsed before surgery for ruptured cases, and perforators.

Eleven of the cases with rupture before surgery had received some other treatment modality (embolization in 10 cases, stereotactic radiosurgery in 1 case) than microsurgery for their originally unruptured AVM. Since the surgery was performed after the rupture, these cases were classified as being ruptured for the purpose of Supp-SM grading, even though they might have somewhat different properties than AVM cases experiencing rupture without any prior treatment. However, this should not affect the comparison of these 2 scales. Moreover, since multimodal treatment is so common nowadays, we believe that including also these cases to our series for completeness adds certain “real-life” value.

**CONCLUSION**

The new grading system helps in understanding and predicting surgical outcomes. Selection according to the available optimal scale is the key for success in AVM surgery, and most importantly, the Supp-SM grading scale helps decide when not to operate. Other scales could be invented in the future that include extra factors such deep perforators, according to the development of treatment modalities and available knowledge. With a challenging pathology like AVM, the surgeon’s judgment and skill are critical.

**Disclosures**

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barriers impeding the development of neurosurgery in the hands of young generations.

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This is a very thoughtful retrospective study that aims to validate the ability of the Lawton-Young Grading System (also known as the Supplementary Spetzler-Martin Grading Scale) to predict outcomes in patients with brain AVM who undergo surgical treatment. While the methodology is similar to those outlined by Lawton et al in 2010,¹ this study does provide a meaningful validation of the value of the Lawton-Young Grading System, particularly in a relatively even distribution of cases from Spetzler-Martin Grade 1 through 5 in the cohort.

In addition to factors such as age at surgery, diffuseness of nidus, and hemorrhagic presentation as suggested by Lawton et al 2010,¹ the one significant factor influencing surgical outcome found in this study is the presence of deep perforating arterial feeders. Many experienced surgeons would agree with the technical importance of these arterial feeders. Older age may imply higher overall surgical risk and lower ability for recovery. A diffuse nidus makes identification of the AVM margin challenging, thus increasing the likelihood of injury to adjacent eloquent brain tissue. Because patients without a history of hemorrhage are typically intact functionally, neurological deficits become more apparent if they occur postoperatively. Deep perforating feeders are often not accessible for preoperative embolization given their tiny size and tortuous anatomy. They are not only routinely found in the deep part of surgical field and often the last to be visualized during the operation, but they are also difficult to be coagulated. The outcome is often additional injury to deep white matter, as the authors mention.

The challenges of conducting a prospective randomized trial in cases of brain AVM therapy are apparent. This retrospective study offers insights into which supplemental factors should be considered in addition to the original Spetzler-Martin predicting factors to guide decision making during AVM surgical treatment. Thus, I strongly support the authors’ view that these supplemental factors be used in addition to the original Spetzler-Martin predicting factors during AVM surgery to achieve the best outcome.

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