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Rule-Based Prediction Analysis for 30-Days Neurological Recovery Status Post Stent-Assisted Coiling of Brain Aneurysms

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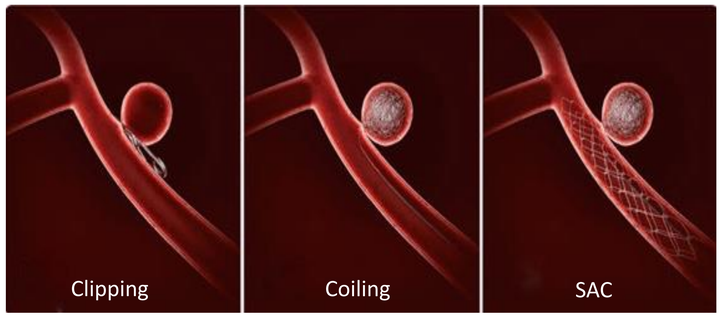
Problem

- Brain aneurysm, one of the most serious cerebral disorders, often results in brain functional damages and diseases
- Complete obliteration and neurological recovery remain the benchmark to evaluate the success of brain aneurysm treatment



- Recently, an increasing trend of the use of stent-assisted coiling (SAC) treatment resulting in a short recovery period, asymptomatic outcome and stable obliteration was observed
- However, accurate prediction, along with key risk factors, of the outcomes after SAC treatment is yet unrecognized

Research Object

- Identify potential preoperative risk factors
- Develop a rule-based model using a mathematical programming technique to identify key rules that are used for predicting the clinical outcomes 30-Days post-SAC treatment
- Provide transparent "if-then" relationships between preoperative clinical info (i.e., risk factors) and outcomes

Data Collection

- Two neurosurgeons supervised standardized data collection sessions
- Eighteen risk factors (a mixture of continuous, integer, and categorical risk factors) are considered
- A total of 65 patients as training set and 21 patients as validation set
- Patients are divided into a symptomatic (positive) group $p \in I^+$ and an asymptomatic (negative) group $n \in I^-$ according to their 30-Days post-SAC recovery status

Solution Approach

Logical Analysis of Data

- **Data Binarization**

Patient	Class	Aneurysm size	GOS
S1	+	3.8	3
S2	+	1.6	5
S3	+	2.1	4
S4	-	1.6	4
S5	-	2.1	1

Patient	1.85≤f1<2.95	3.3≤f2<5
S1	No	No
S2	No	No
S3	Yes	Yes
S4	No	Yes
S5	Yes	No

- **Feature Selection**

$$\min \sum_{k \in I_k(p,n)} z_k$$

$$s.t. \sum_{k \in I_k(p,n)} z_k \geq 1 \quad \forall n \in I^+, p \in I^-$$

$$z_k \in \{0,1\}$$

- **Model Construction**

$$\Delta(i) = \sum_{j \in L} \alpha_j P_j(i) - \sum_{j \in M} \beta_j N_j(i)$$

WMCP

$$\max \sum_{i \in i^+} \frac{1}{\theta^{n_i}} x_i - C_1 \sum_{i \in i^-} \varepsilon_i$$

$$s.t. (1 - b_{ik}^+) y_k \leq 1 - x_i \quad \forall i \in I^+, k \in K$$

$$\sum_{k \in K} (1 - b_{ik}^-) y_k \geq 1 - \varepsilon_i \quad \forall i \in I^-$$

$$\sum_{k \in K} y_k \geq 1$$

$$x_i, y_k, \varepsilon_i \in \{0,1\}$$

Impact/Results

Decision Model

	Rules for Symptomatic Recovery (Positive)	Positive Prevalence	Negative Prevalence	Positive Homogeneity	Negative Homogeneity
P1	[BR>1] + [Location=Posterior]	31%	0%	100%	0%
P2	[Age≥60]	31%	0%	100%	0%
P3	[Lobes=1] + [BR>1]	34%	0%	100%	0%
P4	[Location=Posterior] + [Size=Medium-Large] + [Lobes=1]	17%	7%	75%	25%
P5	[Alcoholic=Yes] + [BR>1]	23%	0%	100%	0%
P6	[Size=Medium-Large] + [BR>1]	63%	3%	96%	4%
P7	[Gender=Female] + [Location=Posterior] + [Lobes>1] + [Hyperlipidemia=Yes] + [Alcholic=Yes]	9%	0%	100%	0%

	Rules for Asymptomatic Recovery (Negative)	Positive Prevalence	Negative Prevalence	Positive Homogeneity	Negative Homogeneity
N1	[Age<60] + [Size=Small] + [BR≤1]	0%	13%	0%	100%
N2	[Age<60] + [Alcoholic=No] + [BR≤1]	0%	10%	0%	100%
N3	[Age<60] + [Gender=Male] + [BR≤1]	0%	13%	0%	100%
N4	[Age<60] + [Gender=Male] + [Size=Small]	0%	10%	0%	100%
N5	[Age<60] + [Location=Anterior] + [BR≤1]	0%	60%	0%	100%
N6	[Age<60] + [Lobes=1] + [BR≤1]	3%	20%	15%	85%
N7	[Age<60] + [Alcoholic=No] + [BR≤1]	0%	34%	0%	100%
N8	[Age<60] + [Location=Anterior] + [Alcoholic=No] + [Lobes>1]	10%	47%	20%	80%

Pattern Analysis Example

- SAC for aneurysms in the posterior circulation is more likely to cause neurological symptoms within 30-Days of the procedure than SAC for aneurysms in the anterior circulation (P1, P4, P7, N5 and N8)

Prediction Performance

	5-fold CV on Training Dataset			Training Dataset (65 patients)			Testing Dataset (21 patients)		
Method	Accuracy	Sensitivity	Specificity	Accuracy	Sensitivity	Specificity	Accuracy	Sensitivity	Specificity
WMCP-LAD	90.48%	94.29%	86.67%	95.00%	100.00%	90.00%	75.00%	100.00%	50.00%
WEKA-LAD	87.69%	91.43%	83.33%	95.38%	100.00%	90.00%	95.24%	88.90%	100.00%
SVM	86.15%	82.86%	90.00%	90.77%	88.56%	94.12%	90.47%	100.00%	83.33%
DT	83.08%	82.86%	83.33%	90.77%	88.57%	93.33%	90.47%	100.00%	83.33%
LR	90.77%	91.43%	90.00%	95.38%	100.00%	90.00%	95.23%	100.00%	91.67%

Conclusion

- Preoperative patient information are significant in predicting the 30-Days post-SAC neurological recovery status
- Interpretable decision model for better SAC outcomes

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