2021 43rd Annual International Conference of the
IEEE Engineering in Medicine & Biology Society (EMBC)
Oct 31 - Nov 4, 2021. Virtual Conference

Accuracy Verification of a Rupture Prediction Equation for Unruptured Cerebral Aneurysms

Shota Sunami, Hiroyuki Takao, Soichiro Fujimura, Yuya Uchiyama,
Yuma Yamanaka, Toshihiro Ishibashi, Koji Fukudome, Yuichi Murayama, and Makoto Yamamoto

***Abstract*— We proposed a cerebral aneurysm rupture prediction equation including hemodynamic and morphological parameters and clinical information using statistical analysis and confirmed its validity on a different patient dataset. The calculated rupture prediction equation (*RPE*) considering *NWSS*max, *AR* and presence of aneurysmal bleb showed good accuracy when it was applied on a different patient dataset.**

***Clinical Relevance*—It may be able to predict the rupture of cerebral aneurysms in advance using the rupture prediction equation proposed in this study.**

I. INTRODUCTION

Hemodynamic, morphological, and clinical factors have been reported to be involved in the rupture of cerebral aneurysms. In previous studies, rupture prediction models which contained these three factors have been suggested using statistical methods [1]. However, the prediction models have not been validated for its accuracy in a different patient dataset from the one that was used to derive the prediction model. In this study, we calculated the *RPE* by conducting statistical analysis methods with hemodynamic parameters calculated from computational fluid dynamics (CFD) simulations, morphological parameters of each aneurysm and clinical information. The *RPE* was applied to the other patient dataset, and we verified the prediction accuracy of the *RPE* to confirm its practicality.

II. METHODS

We selected 330 aneurysms (ruptured: 29, unruptured: 301) diagnosed with clinical imaging before 2018 as the training data. We selected 36 aneurysm cases (ruptured: 8, unruptured: 28) diagnosed with clinical imaging between 2018 and 2020 as the test data. We used 3-dimensional arterial geometries that reconstructed from computed tomography angiography images for conducting CFD simulations and morphological measurements. The ruptured case was defined as an aneurysm that ruptured during the follow-up term and the image acquired before the rupture was used to conduct CFD analysis. The unruptured case was defined as an aneurysm that remained stable during the follow-up for more than 2 years. We obtained 23 hemodynamic parameters, 9 morphological parameters and 7 clinical information. Multivariable logistic regression was performed with each parameter from the training data. Sensitivity and specificity of the *RPE* were calculated by conducting receiver operating characteristic (ROC) analysis. Then, we introduced the *RPE* for the test data, and its sensitivity and specificity were also calculated.

*S. Sunami, Y. Uchiyama, and Y. Yamanaka are with the Graduate School of Mechanical Engineering, Tokyo University of Science. Katsushika-ku, Tokyo, 125-8585, Japan (e-mail: 4521535@ed.tus.ac.jp). H. Takao, T. Ishibashi, and Y. Murayama are with the Department of Neurosurgery, The Jikei University School of Medicine, Minato-ku, Tokyo, 105-8471, Japan (e-mail: takao@jikei.ac.jp). S. Fujimura, K. Fukudome, and M. Yamamoto are with the Department of Mechanical Engineering, Tokyo University of Science, Katsushika-ku, Tokyo, 125-8585, Japan (e-mail: yamamoto@rs.tus.ac.jp).

III. RESULTS

Multivariable logistic regression yielded the following *RPE*:

$$RPE = \frac{1}{1+\exp(6.67\text{-}0.365NWSS_{max}\text{-}3.06AR\text{-}1.97bleb)} \quad (1)$$

The *RPE* indicated high spatial maximum of *Normalized Wall Shear Stress* ($NWSS_{max}$) ($P < 0.05$), high *Aspect Ratio* (*AR*) ($P < 0.01$), and presence of aneurysmal *bleb* ($P < 0.01$), as risks of rupture. The threshold of the *RPE* was 0.124. When the *RPE* is more than 0.124, a case is predicted to rupture. ROC analysis showed that the sensitivity and specificity of *RPE* for the training data were 82.8 % and 89.0 %, respectively. On the other hand, the sensitivity and specificity for the test data, as the validation of the prediction accuracy, were 87.5 % and 89.3 %, respectively.

IV. DISCUSSION & CONCLUSION

The *RPE* showed $NWSS_{max}$ tends to be higher in the ruptured aneurysms. It is reported that damage of endothelial cells because of high *WSS* involved in aneurysm rupture [2]. In the high *NWSS* region, the force acting on the arterial wall in the shear direction caused by the blood flow may damage endothelial cells, leading to the rupture. The *RPE* also showed aneurysms owning high *AR* and *bleb* tend to rupture. In ruptured aneurysms with longitudinal shape, blood tended to flow inside the aneurysmal sac with vortices and the flow structure was unstable, compared to that of unruptured aneurysms. Thus, it is considered that both the damage of endothelial cells caused by high *NWSS* and the instability of the blood structure caused by *AR* or *bleb* involved in aneurysm rupture. When applied the *RPE* to the test data, 7 out of 8 ruptured aneurysms were predicted correctly. Most of ruptured aneurysms in the test data also tended to be high *WSS*, high *AR* or the presence of *bleb* as shown in the *RPE*. Therefore, The *RPE* may predict the aneurysm rupture in advance.

REFERENCES

[1] Takashi Suzuki, *et al*.," Rupture Risk of Small Unruptured Intracranial Aneurysms in Japanese Adults", *Stroke*, 51(2),2020, pp.641-643.

[2] J. R. Cebral, *et al*., "Quantitative characterization of the hemodynamic environment in ruptured and unruptured brain aneurysms", *AJNR*, 32(1), 2011, pp. 145-151.

978-1-7281-1178-0/21/$31.00 ©2021 IEEE