Abstract

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Transcranial Doppler-based modeling of hemodynamics using delay differential equations

Approximately 40,000 people suffer brain aneurysm rupture and 2.5 million suffer a traumatic brain injury (TBI) each year in the USA. Cerebral vasospasm (CV) occurs as a complication of brain hemorrhage resulting from cerebral aneurysm rupture and TBI. CV causes further cerebral injury and is the primary cause of death and disability in aneurysmal hemorrhage and TBI. Consequently, it is critical to design a model for diagnosing and analyzing the abnormal cerebral blood flow velocity hemodynamics associated with CV. By generating such a model, it would be possible to design machine learning mechanisms for earlier prediction of CV. In previous studies, cerebrovascular models of blood flow behavior for different disorders were established. Unfortunately, those models are disorder specific and have too many parameters to tune. We have established a model for the signal envelope of the cerebral blood flow velocity that was produced by transcranial Doppler (TCD). We have applied it to simulate CV behavior, and it is general enough to be applied to other cerebrovascular disorders. The model is based on the delay differential equation as a representative modeling equation for three diagnostic categories: control (no CV hyperemia), hyperemia, and CV. The model has only four tunable parameters and allows switching from one case to another by changing those parameters. After validation of the model, the generated envelope signals compared to spectrograms recorded by transcranial Doppler, demonstrated good concordance in all three categories between the model and signals acquired with TCD. This result could be used for modeling cerebral blood velocity abnormalities and lead to early detection of CV in TBI and aneurysmal hemorrhage.