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PREDILECTIONS OF CARDIOAORTIC EMBOLIC TRANSPORT

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Background. Stroke often occurs when a blood clot or other particle (embolus) forms in the heart or aorta and travels to the brain to block blood flow. A long-standing question has been what causes a cardiogenic or aortogenic embolus to travel to the brain versus other less dangerous parts of the body? Is this process random? Or do certain properties of the embolus, or of a person's vascular anatomy, significantly increase the risk of brain stroke? These relationships are difficult to observe or physically model and therefore to better understand predilections of embolic stoke, we developed computer models to track cardioaortic emboli to the cerebral and peripheral arteries.

Methods. Anatomically accurate models of the human aorta and branch arteries to the head were reconstructed from computed tomography (CT) angiography of 10 patients. Blood flow was modeled by the Navier-Stokes equations using a well-validated finite element flow solver with physiologic inflow and outflow boundary conditions. Embolic particulate was released from the aortic root, and aortic wall, over space and time and tracked through the common carotid and vertebral arteries to the brain for a range of particle sizes. A one way fluid-particle coupling was used based on the Maxey-Riley equations. Particle-artery wall impacts were based on a linear visco-elastoplastic model [1] using measured material properties of thromboemboli and the aorta. Further details are provided in [2].

Results and Discussion. Cardiogenic emboli reaching the carotid and vertebral arteries appeared to have a strong size-destination relationship that varied markedly from expectations based on blood distribution. The results indicate strong predilection of medium-sized (≈1 mm diameter) cardiogenic emboli to the major aortic arch branch arteries and subsequently the arteries to the head. Only particles reaching relatively larger diameters tended to prefer the descending aorta in excess of expectations based on volumetric flow. The increased transport of small to medium-sized particles to the upper branch arteries was consistent across all patient models considered. While this trend held for all patients, there was significant variation in degree of predilection between patients– indicating some patients may have vascular anatomy that places them at an inherently higher risk of cardiogenic particles being transported to the arteries supplying the head. Distributions were robust to large changes in modeling parameters that may be considered uncertain, including cardiac output, heart rate, strategy by which the particles were released, blood rheology, material properties of the embolus/vessel wall, and direction of the gravity vector.

Aorto-ostial cerebral branch configuration appears a leading factor for right vs left hemisphere stroke propensity. Seven of ten patients had innominate and left common carotid (LCC) ostia that were separated along the aortic arch, while three of ten had bovine arch anatomy; this distribution roughly matches prevalence in the general population. Bovine arch was associated with 26 ± 6% emboli to the right hemisphere, while separate ostia had 67 ± 14% right hemispheric embolization, highly significant despite the small sample size ($p<0.01$). The observed propensities based on aorto-ostial cerebral branch configuration may occur since the innominate artery is the first-in-line cerebral pathway in the prevailing anatomy, whereas the LCC origin is colocated in bovine arch diminishing this preference. Moreover, particulate incidence angle is more closely aligned with LCC takeoff in bovine arch, and LCC provides more direct path to the brain vs the innominate. The right vs left preferences observed were strongest for particle sizes that were most preferentially embolic to the brain. These trends persisted even when factoring for differences in artery sizes/volumetric flow rate.

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