THE EFFECT OF GRAVITY ON CINE X-RAY ANGIOGRAPHY

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INTRODUCTION

X-ray angiography – in which an iodinated contrast agent is injected arterially to opacify the vessel lumen during x-ray projection – has become an indispensable tool for diagnosing vascular diseases and guiding interventionists during endovascular treatment. Owing to the high temporal resolutions achievable via projection angiography, it is straightforward to dynamically image the contrast agent as it opacifies and then clears the lumen. This washin and washout of contrast agent provides what is thought to be a reasonable window into the otherwise inaccessible in vivo blood flow dynamics.

Since contrast agents are roughly 30% denser than blood, it is possible that gravity might perturb the contrast agent from passively mimicking the blood flow dynamics; however, it is assumed that the time over which the contrast agent is visualized combined with the rate of blood flow nullifies any gravitational effects. In the context of aneurysm hemodynamics, the validity of this assumption was recently questioned by Wang et al. [1], who showed that the orientation of an aneurysm model (and hence gravity) played a significant role in determining the contrast agent dynamics. Moreover, considerable differences were seen between washout curves of contrast agent versus an isobaric optical dye. In this study we used anthropomorphic basilar tip aneurysm models to test the effect of gravity on contrast agent dynamics under varying geometrical and flow conditions.

METHODS

The subjects of this study were two life-sized, anthropomorphic vertebrobasilar artery flow-through models with an aneurysm at the tip of the basilar artery (Figure 1, top). In one model the aneurysm was placed to preserve coronal and sagittal symmetry (Figure 1, bottom left). In the second model one of these symmetries was broken tilting the aneurysm bulb out of the coronal plane (Figure 1, bottom right); in this way rotating the model 180° about its axis would reverse the effect of gravity on the contrast agent relative to the aneurysm. Both models were rigid walled and made from silicone elastomer (Sylgard 184; Dow Corning), following the geometry and construction techniques described by Fahrig et al. [2].

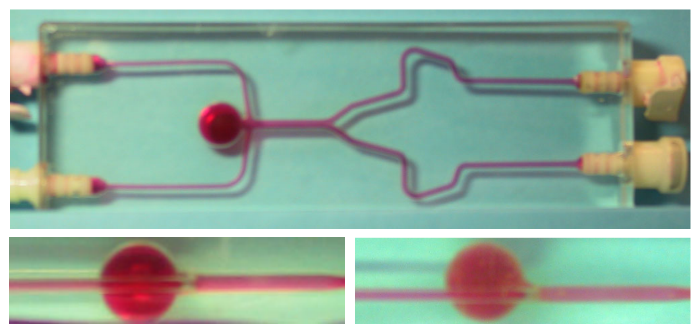

Figure 1: (Top) Coronal view of the basilar tip aneurysm model. (Bottom) Close up sagittal views of the symmetric (left) and asymmetric (right) versions of this model.

A computer controlled flow simulator (Compuflow 1000; Shelley Medical Imaging Technologies) was used to pump a 60:40 glycerol:water mixture under steady (3 & 4.5 ml/s) and physiologically pulsatile flow conditions (mean 4.5 ml/s; peak 6 ml/s) derived from cine phase contrast MRI measurements of flow in the basilar artery of an elderly volunteer. The actual flow waveform entering the model was measured using an electromagnetic flow meter (Model 322; Carolina Medical Electronics). To mimic clinical acquisitions, an iodinated contrast agent (Omnipaque 300; Amersham) was diluted to 200 mg/ml with 1/3 saline by volume and selectively injected for 1.3 seconds into one of the vertebral arteries via power injector at 7 ml/s for a blood mimic mean flow rate of 4.5 ml/s, and 4.5 ml/s for a mean blood mimic flow rate of 3 ml/s. Digital subtraction angiograms were collected using a Siemens Multistar Angiography system, with 15 Hz acquisitions beginning one second prior to injection of contrast agent, and ending after contrast washout from the aneurysm was complete or twenty seconds, whichever came first.

RESULTS

Visualization of the contrast agent dynamics in the symmetric aneurysm model demonstrates the effect that gravity can have under steady flow conditions. In particular, as shown in Figure 2, we see marked settling of the contrast agent in the symmetric aneurysm model, whereas once symmetry is broken the contrast distribution is much more uniform. Under pulsatile flow conditions (Figure 3) settling of the contrast agent is reduced in the symmetric model, and mostly absent in the asymmetric model. Finally, with the asymmetric model viewed in the sagittal plane and flipped to reverse the effect of gravity (Figure 4), contrast appears to be largely unaffected by gravity.

DISCUSSION

This study demonstrates that, under the conditions of physiological asymmetry and pulsatile flow, gravity has little effect on the contrast agent dynamics. Marked gravitational effects on the contrast agent did, however, occur when the model was doubly symmetric and/or when the imposed flow was steady; cases that are decidedly unphysiological.

In the case of symmetric and especially doubly symmetric aneurysm models under steady flow conditions, slowly counter-rotating vortices are formed within the aneurysm bulb, which serve to reduce transport between the aneurysm and parent vessel. This effectively traps the contrast agent within the bulb, where the slow velocities within the aneurysm allow it to settle out. This dependence on velocity and contrast agent volume was demonstrated in additional studies (not shown) in which the steady flow rate and/or volume of contrast agent was increased. Breaking symmetry serves to increases transport between the aneurysm and parent vessel, which more rapidly dissipates the volume of contrast agent in the aneurysm but also increases the aneurysmal velocity that further discourages settling. Physiological pulsatility introduces periodically higher velocities within the bulb, and also periodically collapses aneurysmal recirculation zones to further promote transport between the aneurysm and parent vessel. We have recently demonstrated the presence of such flow dynamic features in a physiologically realistic giant aneurysm model [3].

It is of course possible that a patient's particular geometry and/or pulsatility could conspire to promote stasis within the aneurysm bulb and thus enhance the effect of gravity on contrast agent dynamics. Such stasis would also ideally occur following the introduction of a stent and/or coils. In those cases that have not already self-thrombosed, however, the marked settling of contrast agent within the aneurysm bulb, while not necessarily representative of the detailed flow dynamics, still provides an indirect clue to the static nature of the blood flow dynamics within.

CONCLUSION

Owing to the limited effect of gravity under physiologically realistic conditions, contrast agent dynamics are a reasonable representation of the blood flow dynamics. When it does occur, pronounced settling of contrast agent in vivo is likely an accurate reflection of profound flow stasis.

REFERENCES

[1] Z. Wang et al., 2002, "Differences in flow characteristics between contrast media and blood during x-ray angiography," *Med Phys,* 29, p. 1354.

[2] R. Fahrig et al., 1999, "A three-dimensional cerebrovascular flow phantom," *Med Phys*, 26, pp. 1589-1599.

[3] D. A. Steinman et al., "Image-based computational simulation of flow dynamics in a giant intracranial aneurysm," *AJNR*, In Press.

ACKNOWLEDGMENTS

Supported by grants from the Canadian Institute of Health Research (GR-14937 and MPO-53185) and the Whitaker Foundation (RG-01-0219). DWH and DAS were supported by, respectively, Career Investigator and New Investigator awards from the Heart and Stroke Foundation of Canada. MDF was supported by the CHIR Strategic Training Program in Vascular Research.

In all figures gravity is acting in the downwards direction, Images are shown 5 seconds after contrast injection.

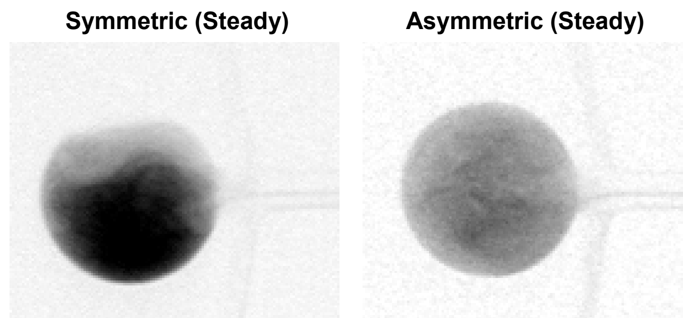

Figure 2: Pronounced gravitational effects are seen in coronal projections of the symmetric model placed on its side, and under steady flow conditions (left), whereas for the asymmetric model under the same flow conditions gravitational effects are modest (right).

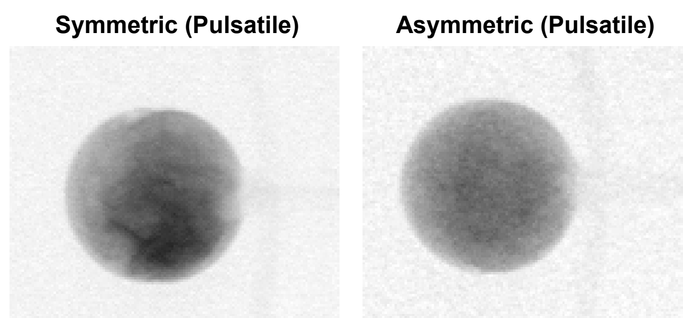

Figure 3: Under pulsatile flow conditions gravitational effects are reduced in the symmetric model (left), and mostly eliminated in the asymmetric model (right).

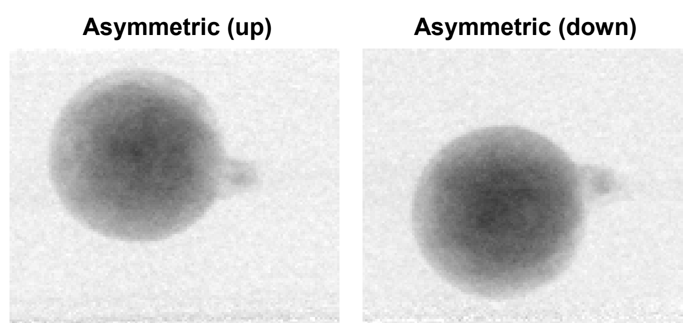

Figure 4: Sagittal projections show the minor effect of gravity on the asymmetric model placed flat with the aneurysm pointing up (left) and down (right).