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**Intracranial Aneurysms, Cancer, X-Rays,
and Computational Fluid Dynamics**

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AJNR Am J Neuroradiol published online 3 May 2012

<http://www.ajnr.org/content/early/2012/05/03/ajnr.A3163.citation>

This information is current as
of April 19, 2024.

EDITORIAL

Intracranial Aneurysms, Cancer, X-Rays, and Computational Fluid Dynamics

Recent editorials by Kallmes, Cebral, and Meng, along with a current commentary by Robertson and Watton, have addressed the limitations, capabilities, and potentials of using computational techniques as aids to better understanding both the natural history and the impact of endovascular interventions as they relate to intracranial aneurysms (IAs). We would like to add to this discussion the perspective of 2 colleagues, one an engineer and computational scientist and the other a clinician and interventional neuroradiologist, who have worked together using and developing these techniques over the last 6 years.

Intracranial Aneurysm: A Single Disease?

As recently as the mid-1970s, it was common for physicians deeply involved in oncology research to speak and write about finding both a “cause and a cure for cancer.” Today, such a notion is archaic. We now find ourselves speaking and writing about IAs using almost identical jargon. Why is it that IAs are considered a single disease and not a spectrum or continuum of a disease, or even multiple diseases having, as their common target, the arterial wall of intracranial arteries? Perhaps it is because, until recently, clinicians have largely thought of the arteries from which aneurysms arise as being “pipes” and of aneurysms as representing a weak spot on an arterial wall, similar to a weak spot on a balloon or inner tube, that is, unable to remodel or repair itself. Only 15 years ago, a review paper in the *New England Journal of Medicine* considered vascular remodeling to be an “emerging concept,”¹ and only in the last several years has the dynamic and rapid responsiveness of vascular remodeling and arterial homeostasis become generally apparent. Perhaps another reason is that, on angiograms, IAs look remarkably similar, hence the moniker “berry aneurysms.” Further contributing to this lack of insight is that the infrequency of patients having serial angiograms has severely limited the ability of practitioners to observe this phenomenon in their patients. Finally, the near absence of naturally occurring IAs in creatures other than humans and the difficulties associated with obtaining suitable tissue at the time of necropsy or surgery have served to severely restrict the study of the sequential biologic changes that occur as IAs form, grow, and rupture.

Computational Fluid Dynamics (CFD): A Virtual Instrument After All

Simply put, CFD produces results of mathematic models (ie, Navier-Stokes equations) that researchers postulate capture the basic laws governing the physics of fluid flows. Only in the late 1950s and early 1960s did it become possible to perform realistic simulations related to air flow over a blunt object, such as a space capsule heat shield, and only in the mid-1990s did it become realistic to perform simulations of blood flow using computational resources, then available only at a limited

number of facilities. In the last 5–10 years, research has shown that we can be successful at simulating/predicting how blood flows in and around IAs. In other words, CFD is capable of providing new data with information about the in vivo patterns of blood flow in IAs; these are difficult or even impossible to investigate with imaging modalities. With further experience and dissemination, it seems probable that insights from CFD will, over time, ascend the DIKW (data, information, knowledge, wisdom) ladder. Still, no matter how sophisticated the applications or the knowledge (or even wisdom) that should be derived from these applications, the results will inescapably provide only one, albeit significant, element of the information required to elucidate the natural history of IAs.

Too Many CFD Parameters: Growing Pains or Is There Something Else Predictive of the Natural History of IAs?

Just as we search for and expand the parameters used for measurement of brain perfusion, hoping for better and more reproducible results, we should likewise explore and expand the search for hemodynamic parameters that may correlate with the origin, growth, and rupture of IAs. Our study of the hemodynamic changes in IAs, which are associated with changes in heart rate, is one example of what we view as a potentially significant parameter that has yet to be fully evaluated.² New technologies develop and evolve so as to both optimize their capabilities and expand the applications to which they may be applied. Such it was with x-rays, and such it is with CFD. New technologies are most often overvalued when first described; then, as they become disseminated, they sink below their true value, finally reaching a state of realistic value only when they have been widely tested and optimized. Potential applications of CFD have not been fully explored, optimization of computational techniques for assessing blood flow in and around IAs is ongoing, and the definition of the most meaningful output parameters are not at a stage where there can be any broad consensus. Thus, in our opinion, it is not realistic to make a value judgment regarding the ultimate value of CFDs, either as a means for investigating basic hemodynamic phenomena or as a tool that may be useful in a clinical environment.

Next Step and Closing Remarks

To us, it seems implausible to expect that, in isolation, CFD studies may reveal singular keys to important questions about a biologic process such as the initiation, growth, and rupture of IAs. It does, however, seem quite plausible that the results from CFD studies on large populations could provide great help in categorizing aneurysms according any number of hemodynamic parameters. Perhaps, then, these categories, when correlated with other factors known to be important in vascular health—such as collagen mutations, smoking, family history, and so on—and then if further combined with information specific to individual patients—such as age, sex, and perianeurysmal environment—could give insights that might prove useful in predicting the risk of aneurysm rupture. We fully realize that correlations do not represent causation; however, in our experiences, as well as in those of others, they sometimes offer very significant hints.^{3,4} As the ability to perform CFD in clinical environments on large numbers of patients increases, as more insight is gained into the regulation of arterial health (homeostasis) and remodeling, as more under-

standing is gained about the mechanics of the vascular wall, as the ability to image not only the vascular lumen but also the arterial wall increases, this additional information may send computational scientists back to broaden and refine their mathematic models, thereby leading to methods that would allow investigation and integration of other important and potentially clinically relevant parameters, such as collagen turnover, cross-linking, and so on (eg, fluid-structure-growth modeling).

Believing in the great potential for the integration of observations and measurements made by clinicians with simulations, calculations, and models made by scientists, we feel that this is a time to be optimistic and proactive in collaborations that unite and optimize our ability to define just what value CFD adds to the ability to mitigate the death and misery currently associated with IAs.

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<http://dx.doi.org/10.3174/ajnr.A3163>