Reply:

We greatly appreciate the comments by Dr Kallmes regarding our article on the differences in computational fluid dynamics (CFD) simulations of aneurysmal blood flow due to the choice of imaging technique between CT angiography and 3D rotational angiography (3DRA).[1] We found large quantitative differences in the estimation of hemodynamic variables, but qualitative variables that describe the main flow characteristics were reproduced across imaging modalities.

In our population, the estimated mean wall shear stress on the aneurysm differed on average 44.2%. Although this result indeed encourages us to be prudent when analyzing quantitative data, we think that Dr Kallmes' doubt about the utility of CFD-derived hemodynamic variables is not fully justified. The main flow characteristics that reproduced well in our study have also been found to compare well with in vivo data,[2,3] and they seem to provide valuable information regarding aneurysm development. Last year, the *American Journal of Neuroradiology* published 2 articles by Cebral et al[4,5] demonstrating the potential of CFD simulations in a study of 200 cases imaged with 3DRA. The authors found associations between aneurysmal rupture risk and both qualitative and normalized quantitative variables, suggesting that despite inaccuracies in the estimated magnitude of hemodynamic forces, valuable information can be derived from flow patterns alone.

We never set out to answer the question "Which imaging technique is the standard of reference?" in our study. With its higher spatial resolution and lower visibility of bone, we can expect 3DRA to provide superior anatomic accuracy in comparison with CTA and, therefore, superior accuracy in the CFD simulation. However, without data on the true geometry of the vasculature and the true hemodynamics, we were not in the position to support statements about which of the imaging modalities in our patient data produced estimations closer to the "truth." As mentioned before, other studies did make comparisons with in vivo data and found the main flow characteristics of CFD simulations to agree well.

We thank Dr Kallmes for providing new images related to the study by Brinjikji et al[6] that argued in favor of 2D digital subtraction angiography over 3DRA in performing anatomic measurements. 2D imaging techniques are not an option when constructing 3D vascular models for CFD simulations, but the findings of Brinjikji et al illustrate clearly that better spatial resolution will naturally lead to improved neck characterizations[7] and, more generally, that advances in imaging techniques will naturally lead to more accurate vascular models. However, we would like to emphasize that the vascular models we used were not threshold segmentations that depend strongly on the choice of threshold value (in the way that the size of vascular structures in the visualization of 3DRA images depends on window/level settings). The vascular models were instead obtained by using a completely automatic geodesic active region segmentation algorithm. More details on this method and its accuracy are provided by Hernandez and Frangi.[8]

We hope that we have shed some light on the reproducibility of CFD simulations across imaging modalities. Despite the inaccuracies in quantitative hemodynamic variables, we genuinely believe that CFD simulations have proved and will continue to prove useful in understanding the initiation, growth, and rupture of aneurysms and will 1 day find their way into clinical practice to provide the clinician with patient-specific accurate information on the hemodynamic condition of an aneurysm.

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