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Editorial for "Evaluating a Phase-Specific Approach to Aortic Flow: A 4D Flow MRI Study"

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Four dimensional flow magnetic resonance imaging (4D flow MRI) has been used to measure in vivo blood flow from small, cerebral vessels to the aorta. It can capture the complex flow patterns of the aorta in three dimensions throughout the cardiac cycle. This ability enables in depth characterization of blood flow in various aortopathies.[1] Because it is an emerging technique with limited clinical implementation, studies to find the best post-processing and analysis techniques are ongoing.[2]

The vessel wall of the aorta can deform more than 7% during the cardiac cycle in addition to undergoing translation from heart motion and surrounding structures.[3,4] The aortic wall boundary is typically determined from a maximum intensity projection or at peak systole of the magnitude MR image,[5] while others have registered computed tomography data with the 4D flow datasets.[6] However, accounting for aortic motion in the segmentation of 4D flow data may improve the accuracy of flow-derived metrics, particularly metrics directly relating to the aortic wall such as wall shear stress (WSS) and oscillatory shear index (OSI).[7]

In this study, the authors seek to evaluate how phase-specific segmentation of the aorta affects flow characterization from 4D flow MRI.[8] 4D flow MRI was acquired for 40 non-disease subjects and 10 subjects with dilated aortas. Segmentations of the magnitude image were performed at seven time points during the systolic phase of the cardiac cycle in the aortic root and the ascending aorta, while the remainder of the aorta was segmented at peak systole. They evaluated various flow metrics in both multi-phase and single-phase models which included velocity, vorticity, helicity, kinetic energy, and viscous energy loss. They found that time-averaged values were comparable between the two segmentation methods, but flow metrics at peak systole varied between multi- and single-phase approaches. In addition, they compared time-averaged flow parameters to peak values and found a

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correlation between the two, suggesting that measuring peak values may be sufficient for 4D flow MRI analysis. This finding could be important for reducing analysis time but should not replace time-averaged or diastolic flow analysis in diseases where diastolic flow differences may be significant such as false lumen flow in aortic dissections.

The main advantage of 4D flow MRI compared with computational fluid dynamics or 2D flow imaging, is that it can directly capture the complete time-resolved blood velocity field of the aorta in 3D. The analysis presented in this study show what errors are by inaccurately defined aortic wall boundaries. Use of phase-specific segmentation could lead to better characterization of disease states, particularly those causing changes in WSS and WSS-derived metrics. The main disadvantage of this phase-specific approach is the increased post-processing time from additional aortic segmentations. However, as automatic and AI-based segmentation methods emerge, the processing time could be significantly reduced.[5,9]

Deep learning is already being applied to time-resolved segmentation in some cardiovascular 4D flow MRI applications.[10] Bustamante et al, used deep learning-based segmentation to automatically segment the heart and thoracic aorta throughout the cardiac cycle. As opposed to atlas-based segmentation, deep learning allowed them to segment the cardiac chambers and aorta from subjects with varying morphologies. However, some cases did require manual correction so there is still a need for larger training datasets. Until AI approaches become more robust, using the manual, phase-specific method presented here can sufficiently provide better flow characterization.

There are a few limitations of this method that should be highlighted. Flow metrics that are calculated using the velocity gradient near the wall are most affected by the segmentation of wall boundaries. Velocity spatial resolution and segmentation can introduce errors into the calculation of these metrics, so comparing WSS calculated using the multi-phase segmentation vs. the single-phase would reveal the significance of time-resolved segmentation for this metric. It would also be helpful to quantify the time difference between the multi-phase and single-phase approach. Time is important to consider when developing clinically translatable methods so comparing the time needed for multiple segmentations vs. the benefits of the outcome must also be weighed.

In conclusion, Ramaekers et al demonstrated how in vivo flow metrics change based on how the aortic wall boundary is defined throughout the cardiac cycle. While the specific metrics evaluated did not reveal significant changes, it is important for metrics derived from or near the wall such as WSS, OSI, and relative residence time to be further investigated. A future study using a larger subject cohort investigating these metrics is needed to increase the significance of these findings.

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