Global and Focal Effects of Radiation Therapy on the Cerebral Vasculature in Pediatric Brain Tumor Survivors using simultaneous MRA-SWI at 7T

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Purpose

Although radiation therapy (RT) is a common treatment for pediatric brain tumors, it can have detrimental long-term effects such as impaired cognition and heightened risk for ischemic stroke. RT-induced endothelial damage can lead to vascular injury manifesting as cerebral microbleeds (CMBs). As survival improves in these children, understanding the evolution of CMBs and the effect of their presence on surrounding vasculature could serve as a risk factor for evaluating the severity of radiation related injury whose cognitive impairment persists into adulthood. The goal of this study was to explore the effects of uniform whole brain RT on arterial structure 1)globally throughout the brain, 2)surrounding CMBs, and 3)as a function of CMB volume.

Methods

Patients and Data Acquisition: 15 patients(ages 10-24) treated with whole-brain(WB) or whole-ventricular(WV) RT for a pediatric brain tumor 2 months to 16 years prior to imaging were scanned on a 7-Tesla MRI scanner using a simultaneous MRA-SWI acquisition that enables the visualization of arteries, veins, and CMBs all on one image. Five patients had repeat scans ~1 year after their baseline scan. Two patients with juvenile pilocytic astrocytomas (ages 14-16) who did not receive RT as part of their treatment were included as controls.

Calculation of Vascular Metrics: The arteries from MRA were automatically segmented using an adaptive Frangi filter to retain the radii of vessels in the original image. A Euclidean Distance Transform was then applied for calculating the vessel radii map from non-overlapping 8mm projections through the entire brain. Total vessel volume and the proportion of small vessels normalized by brain volume were compared with time since RT and number of CMBs for each gender and type of RT. Serial changes were evaluated in those patients with repeat scans. Veins from SWI were segmented similarly as arteries and a semi-automated algorithm that included a user-guided GUI to remove CMB mimics was used for segmenting CMBs from SWI. The nearest end points of artery and vein with respect to each CMB were automatically determined to calculate respective distance measures that were plotted as a function of CMB volume.

Results & Discussion

Global normalized arterial volume was significantly reduced with increasing RT treatment volume ($p<0.02$ Kruskal Wallis test). Whole brain arterial volume also decreased with increasing number of CMBs and at follow-up scan compared to baseline for 4/5 patients imaged serially [Figure1]. The proportion of small arteries (0.23-0.46 mm) increased with respect to time since RT for both males and females, suggesting gradual luminal narrowing for years following RT. Although initially, larger CMBs were farther from the nearest vein, over time, CMBs far from surrounding vasculature tended to decrease in size, suggesting that after a CMB forms, the surrounding vasculature narrows and eventually recedes. Overall, CMBs were located closer to veins than arteries.

Conclusion

Our findings demonstrate the feasibility of our approach for quantifying subtle vascular changes in arterial structure and CMB properties due to RT. We anticipate that the methods developed here will enable future analyses that assess radiation-induced vascular injury in larger cohorts.

Highlights:

This study explores the effects of radiation therapy on vascular structure using a combined MRA-SWI sequence at 7T and a new method for arterial segmentation and quantification. Normalized arterial volume was significantly reduced with increasing RT treatment volume, number of CMBs, and at followup. CMBs were larger when further away.

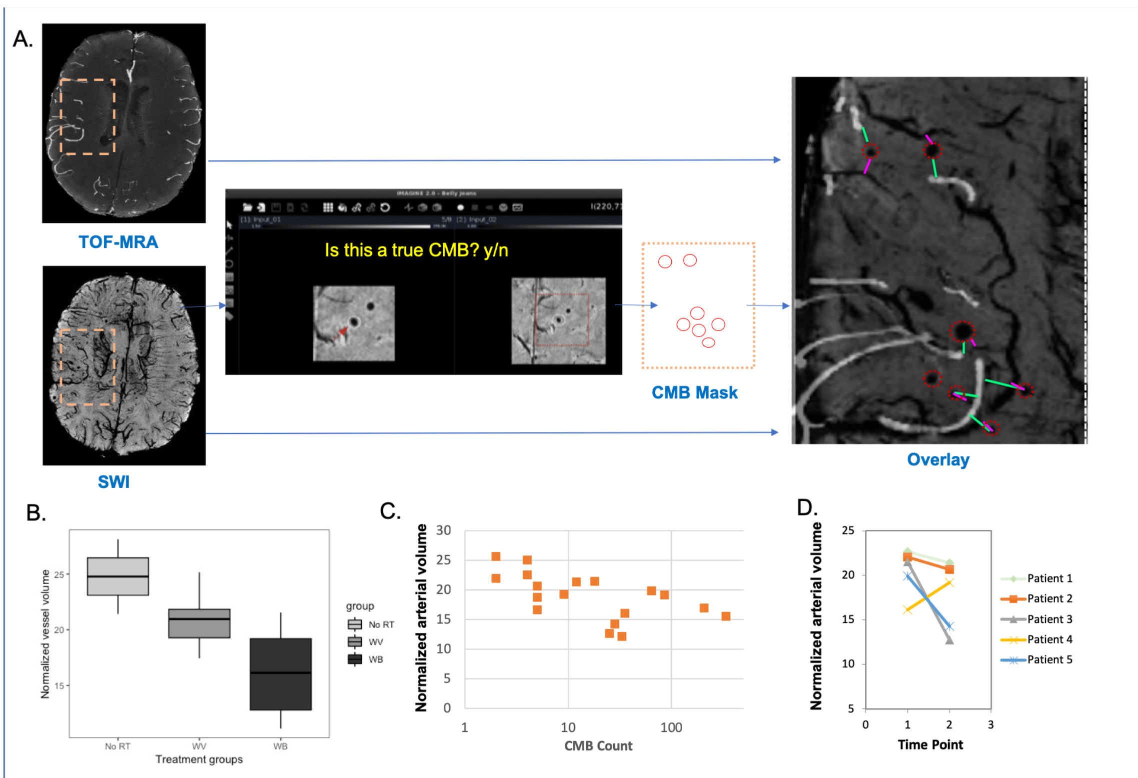

Figure 1. A. Arteries, veins and CMBs overlaid for a single 8mm projected slice. B. Normalized arterial volume for different treatment groups: no RT, whole ventricular RT (WV) and whole brain RT (WB). C. Vessel volume as a function CMB count plotted on a logarithmic scale. D. serial changes decreases in vessel volume at follow-up compared to baseline for patients imaged serially.