Introduction: A detailed evaluation of the in vivo geometry and topology of skeletal muscle arteriolar networks is essential for understanding microvascular blood flow regulation. Beyond increasing the understanding of skeletal muscle hemodynamics, such data provides critical experimental inputs for theoretical blood flow simulation studies. The objective of this study was to comprehensively analyze the geometry and topology of complete arteriolar networks within the rat gluteus maximus (GM) muscle and to apply these experimental data in our computational blood flow model. Using outputs from theoretical simulations, we evaluated inter-network hemodynamic variability in an effort to describe the level of functional homology among skeletal muscle arteriolar networks.

Methods: The rat GM muscle provides the ideal experimental model to study locomotive skeletal muscle. Its planar geometry and uniform thinness enable access (within a single focal plane) to its entire microcirculation for microscopic imaging and perturbation. Using intravital videomicroscopy, the GM (n=8) was scanned under baseline conditions and photomontages were compiled (~500 images per network). Photomontages were registered to a MATLAB x-y coordinate system and scaled digital networks were generated. Approximately 1500 discrete nodes were used to mathematically model each network, with an average length of approximately 100 μm between each node, resulting in 179 to 239 vessel segments per network. A previously established two-phase blood flow model (MATLAB) was used to simulate and assess the hemodynamic properties of each arteriolar network including heterogeneity within each network and variability between networks.

Results: The relationships of arteriolar diameter and segment length as a function of vessel order were fitted with an exponential decay function and this resulted in significantly better “goodness of fit” values for diameters (R² = 0.62 to 0.75) than lengths (R² = 0.32 to 0.53), suggesting greater predictability and homology between arteriolar diameter and vessel order. Blood flow rate in each vessel segment decayed exponentially with increasing (1A to 9A) arteriolar order for each network (R² = 0.71 to 0.88). Log-log plots between blood flow and arteriolar diameter showed a strong correlation for each network (R² = 0.65 to 0.86) with similar slopes of regression lines (3.08 to 3.81).

Conclusion: This study provides the first comprehensive analysis of rat GM topology and geometry. Simulation results show strong homology in blood flow properties between all the networks considered. This analysis allows detailed comparison of the hemodynamic properties of the different arteriolar networks studied, including the extent to which observed topological and geometric homologies result in similar hemodynamic outcomes.