SUPPLEMENTARY INFORMATION

1 Governing Equations

The equation of motion for the continuous phase (blood) are the Navier-Stokes equations:

$$\nabla \cdot \boldsymbol{u} = 0 \tag{1}$$

$$\rho \left(\frac{\partial \boldsymbol{u}}{\partial t} + \boldsymbol{u} \cdot \nabla \, \boldsymbol{u} \right) = -\nabla p + \mu \nabla^2 \boldsymbol{u} \tag{2}$$

Equation (1) and (2) represents the basic continuity and momentum equations for the fluid in dimensional form. Here, $\boldsymbol{u}$ is the velocity, p is pressure, ρ is the fluid density, and μ is the fluid dynamic viscosity. Blood was modeled as a homogeneous, incompressible, Newtonian fluid with density ρ = 1060 kg/m^3 and dynamic viscosity μ = 0.0035 Pa-s to solve the unsteady Navier-Stokes equations[24].

2 Particle Tracking

The equation of motion of a particle at location $\boldsymbol{X}(t)$ is at time instant t, is:

$$\frac{d}{dt}\boldsymbol{X}(t) = \boldsymbol{U}(\boldsymbol{X}(t), t) \tag{3}$$

Equation (3) represents the simplified particle dynamics, where the velocity is a function of location, equal to the velocity of the blood surrounding it. The particle location is updated by numerical integration of this equation with sufficiently small time step.

3 Model Boundary Conditions

The Windkessel model solves the following equation for time-varying pressure:

$$\frac{P(t)_i}{R_i} + C_i \frac{d\,P(t)_i}{dt} = Q(t)_i \tag{4}$$

Where i indicates an outlet (i.e. brachiocephalic, carotid, subclavian and descending aorta) $P(t)_i$ represents the time-varying pressure at outlet i, $Q(t)_i$ is the volume flow rate of blood through outlet i, C_i is the vascular capacitance in (m^3/Pa) and R is the vascular resistance in (Pa-s/m^3) for outlet i.The various R and C values used for the four outlets are shown in Table S1.

4 Results: Lagrangian Metrics

Over 100,000 particles were injected at the outflow graft for each simulation and were individually tracked. Lagrangian metrics were evaluated at multiple levels – all injected particles, particles remaining the interior of the domain and particles exiting through each of the four outlets. Particles that collectively exited through the great vessels are discussed in detail in the main manuscript, while the other categories are described here.

4.1 All injected particles

Figure -S 1(a) shows PDFs, boxplots and PO plots of particle RT. Particles had the lowest median RT (1.00 s) for the 45^0 configuration, whereas they remained longer in the domain (1.30 s) for the 60^0 configuration than those in the 90^0 configuration (1.21 s). PO plots indicate that particles for the 90^0 configuration have a $\sim 50\%$ higher risk of lingering in the vasculature between 1-2 seconds compared to the 45^0 configuration. While the maxima RT for any particle for all three configurations were the same (10 s, the length of the simulations), the % of outliers was largest for the 60^0 configuration (8.7%). Table -S 2 shows the median and outlier information of RT for all particles.

Figure -S 1(b) shows PDFs, boxplots and PO plots of SH for all particles. Particles had the lowest median SH (0.67 Pa-s) for the 60^0 configuration, whereas they accumulated higher stress histories (1.03 Pa-s) for the 90^0 configuration (with those in the 45^0 configuration being very close to the 60^0 case, 0.70 Pa-s). The PDF plot clearly indicates a significant shift to higher values of the particle SH distributions for the 90^0 configuration, indicating that a large % of particles accumulate ~50% higher SH compared to the other two configurations studied. PO plots indicate that particles for the 90^0 configuration have a ~ 75% higher risk of accumulating a SH between 1 and 2 Pa-s compared to the 45^0 configuration, and an overall higher risk of ~ 67% of accumulating a SH higher than 1 Pa-s. Moreover, the maximum SH attained by particles in the 90^0 configuration (155.03 Pa-s) was 30% higher than for particles in the 45^0 configuration. In addition, the % of outliers was the largest for the 90^0 configuration (12.84%). Table -S 2 shows the median and outlier information of SH for all injected particles.

4.2 Interior particles: Particles remaining in the computational domain after the duration of the simulation

Upon completion of the simulations (10 cardiac cycles), ~ 45% of the particles that were injected remained in the computational domain for each configuration. Analyzing the particle metrics for these interior particles provides valuable insights into particles that have not yet been ejected into either the upper (brachiocephalic, carotid, subclavian) or lower (descending aorta) circulation.

Interestingly, interior particles had the least median RT of 0.99 second for the 90^0 configuration, while they remained longer in the domain (1.45 seconds) for the 60^0 configuration than those in the 45^0 configuration (1.1 seconds). PO plots indicate that particles for the 60^0 configuration have a ~ 40% higher risk of lingering in the vasculature longer than 1 second compared to the other configurations. While the maximum RT for any particle for all three configurations were the same (10 cardiac cycles), the % of outliers were the largest for the 60^0 configuration (17.05%). Table -S 3 shows the median and outlier information for all particles in the Interior category.

Figure -S 2(b) shows PDFs, boxplots and PO plots of SH for interior particles. Particles had the least median SH of 0.50 Pa-s for the 60^0 configuration, whereas they accumulated higher stress histories (0.95 Pa-s) for the 90^0 configuration than those in the 45^0 configuration (0.62 Pa-s). The PDF plot clearly indicates a significant right-shift of particle SH distributions for the 90^0 configuration, indicating that a large % of particles accumulate ~90% higher SH compared to the other configurations. PO plots indicate that particles for the 90^0 configuration have a ~ 300% higher risk of accumulating a SH between 1 and 2 Pa-s compared to the 60^0 configuration, and an overall higher risk of ~ 70% of accumulating a SH higher than 1 Pa-s. Interestingly, maximum SH was attained by particles in the 45^0 configuration (93.31 Pa-s) which was ~45% higher than particles in the 90^0 configuration. However, the % of outliers was the largest for the 60^0 configuration (18.16%), followed by the 90^0 configuration (16.49%). Table -S 3 shows the median and outlier information of SH for all particles in the Interior category.

4.3 Exterior particles: Particles exiting the computational domain by any of the four outlets during the simulation

Upon completion of the simulations (10 cardiac cycles), ~ 55% of the particles that were injected had exited the computational domain for each configuration. Analyzing the particle metrics for these exterior particles provides valuable insights into particles that were ejected into the upper (brachiocephalic, carotid, subclavian) and lower (descending aorta) circulation.

Exterior particles had the least median RT of 0.9 seconds for the 45^0 configuration, while they remained longer in the domain (1.41 seconds) for the 90^0 configuration than those in the 60^0 configuration (1.22 seconds). The PDF plot (Figure -S 3(a)) indicates a clearly defined secondary peak of ~1.5 seconds for the 60^0 and 90^0configurations PO plots indicate that particles for the 90^0 configuration have a ~ 120% higher risk of lingering in the vasculature longer than 1 second compared to the other configurations, and an overall higher risk of ~ 52% of lingering longer than 1 second. The maximum RT for any particle leaving the 45^0 configuration was the lowest (8.95 seconds), while the % of outliers were the largest for the 45^0 configuration (3.90%). Table -S 4 shows the median and outlier information for all particles in the Exterior category.

Figure -S 3(b) shows PDFs, boxplots and PO plots of SH for particles exiting the region of interest. Exiting particles had the least median SH of 0.77 Pa-s for the 45^0 configuration, whereas they accumulated higher stress histories (1.09 Pa-s) for the 90^0 configuration than those in the 60^0 configuration (0.80 Pa-s). The PDF plot clearly indicates a significant right-shift of particle SH distributions for the 90^0 configuration, indicating that a large % of particles accumulate ~40% higher SH compared to the other configurations. PO plots indicate that particles for the 90^0 configuration have a ~ 60% higher risk of accumulating a SH between 1 and 2 Pa-s compared to the 45^0 configuration, and an overall higher risk of ~ 51% of accumulating a SH higher than 1 Pa-s. The maximum SH was attained by particles in the 90^0 configuration (155.03 Pa-s) which was ~30% higher than particles in the 45^0 configuration. The % of outliers was the largest for the 90^0 configuration (9.39%), followed by the 60^0 configuration (8.58%). Table -S 4shows the median and outlier information of SH for all particles in the Exterior category.

4.3.1 Particles exiting through the brachiocephalic branch

Particles had a 70% higher chance of staying in the aortic arch for longer (median RT 0.77 seconds) before exiting through the brachiocephalic branch for the 90^0 configuration compared to the 60^0 configuration (median RT 0.24 seconds). Consequently, median SH was also highest (0.77 Pa-s) for 90^0 configuration, indicating a 68% increased risk for accumulating high SH. For RT, PO plots indicate that particles for the 90^0 configuration have a ~ 800% higher risk of lingering in the vasculature longer than 1 second compared to the other configurations, and an overall higher risk of ~ 1000% of lingering longer than 1 second. For SH, PO plots indicate that particles for the 90^0 configuration have a ~ 150% higher risk of accumulating a SH between 1 and 2 Pa-s compared to the 45^0 configuration, and an overall higher risk of ~ 200% of accumulating a SH higher than 1 Pa-s. While the % outliers of particle RT were highest for 90^0 configuration (43.94%), the 60^0 configuration led to the longest particle RT (8.24 seconds). The % outliers of particle SH were highest (25.41%) for the 90^0 configuration and the maximum SH was attained by particles also in the 90^0 configuration (133.95 Pa-s).

4.3.2 Particles exiting through the left common carotid branch

Particles had a 20% higher chance of staying in the aortic arch for longer (median RT 0.60 seconds) before exiting through the carotid branch for the 90^0 configuration compared to the 45^0 configuration (median RT 0.50 seconds). Consequently, median SH was also highest (0.94 Pa-s) for 90^0 configuration, indicating a 25% increased risk for accumulating high SH. For RT, PO plots indicate that particles for the 90^0 configuration have a ~ 50% higher risk of lingering in the vasculature longer than 1 second compared to the other configurations, and an overall higher risk of ~ 20% of lingering longer than 1 second. For SH, PO plots indicate that particles for the 90^0 configuration have a ~ 22% higher risk of accumulating a SH between 1 and 2 Pa-s compared to the 45^0 configuration, and an overall higher risk of ~ 27% of accumulating a SH higher than 1 Pa-s. Interestingly, the % outliers of particle RT were highest for 45^0 configuration (13.68%), while the 60^0 configuration led to the longest particle RT (9.19 seconds). The % outliers of particle SH were highest (9.50%) for the 45^0 configuration and the maximum SH was attained by particles also in the 45^0 configuration (119.54 Pa-s).

4.3.3 Particles exiting through the left subclavian branch

Particles had a 65% higher chance of staying in the aortic arch for longer (median RT 0.91 seconds) before exiting through the subclavian branch for the 90^0 configuration compared to the 45^0 configuration (median RT 0.55 seconds). Consequently, median SH was also highest (1.09 Pa-s) for 90^0 configuration, indicating a 85% increased risk for accumulating high SH. For RT, PO plots indicate that particles for the 90^0 configuration have a ~ 175% higher risk of lingering in the vasculature longer than 1 second compared to the other configurations, and an overall higher risk of ~ 110% of lingering longer than 1 second. For SH, PO plots indicate that particles for the 90^0 configuration have a ~ 120% higher risk of accumulating a SH between 1 and 2 Pa-s compared to the 45^0 configuration, and an overall higher risk of ~ 125% of accumulating a SH higher than 1 Pa-s. The % outliers of particle RT were highest for the 90^0 configuration (17.34%), while the 60^0 configuration led to the longest particle RT (9.14 seconds). The % outliers of particle SH were highest (18.14%) for the 90^0 configuration while the maximum SH was attained by particles in the 60^0 configuration (120.84 Pa-s).

Boxplots, particle statistics and PO plots are shown inFigure -S 4, Figure -S 5, Figure -S 6 and Figure -S 7 for particles exiting through the brachiocephalic, carotid and subclavian branches.

5 Figures and Tables

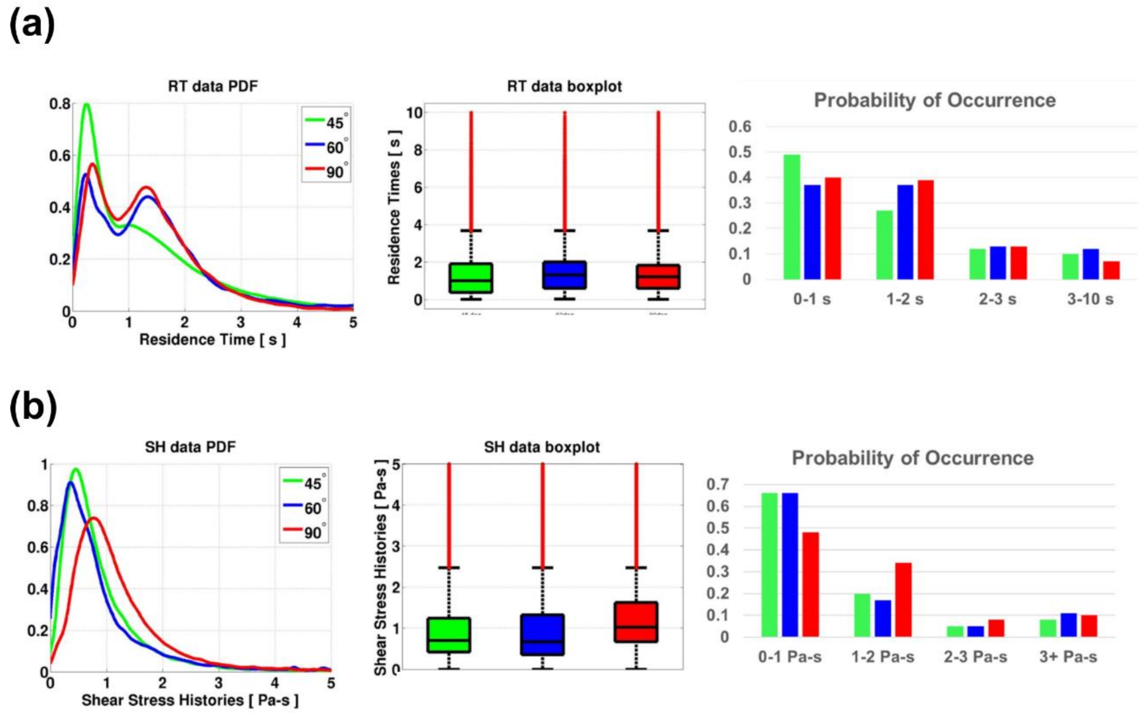


Figure -S 1: PDF, boxplot and PO plots of (a) RT and (b) SH for all particles in the studyC1 category

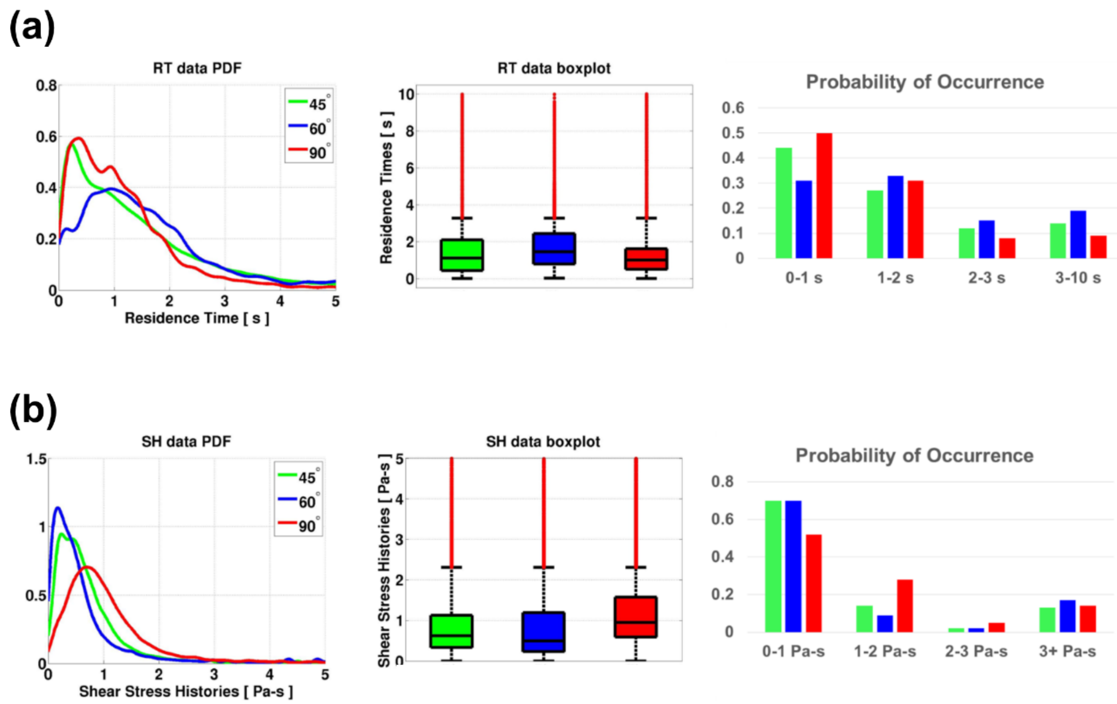


Figure -S 2: PDF, Boxplots and PO plots of (a) particle RT and (b) particle SH for all particles in the C2-Interior category

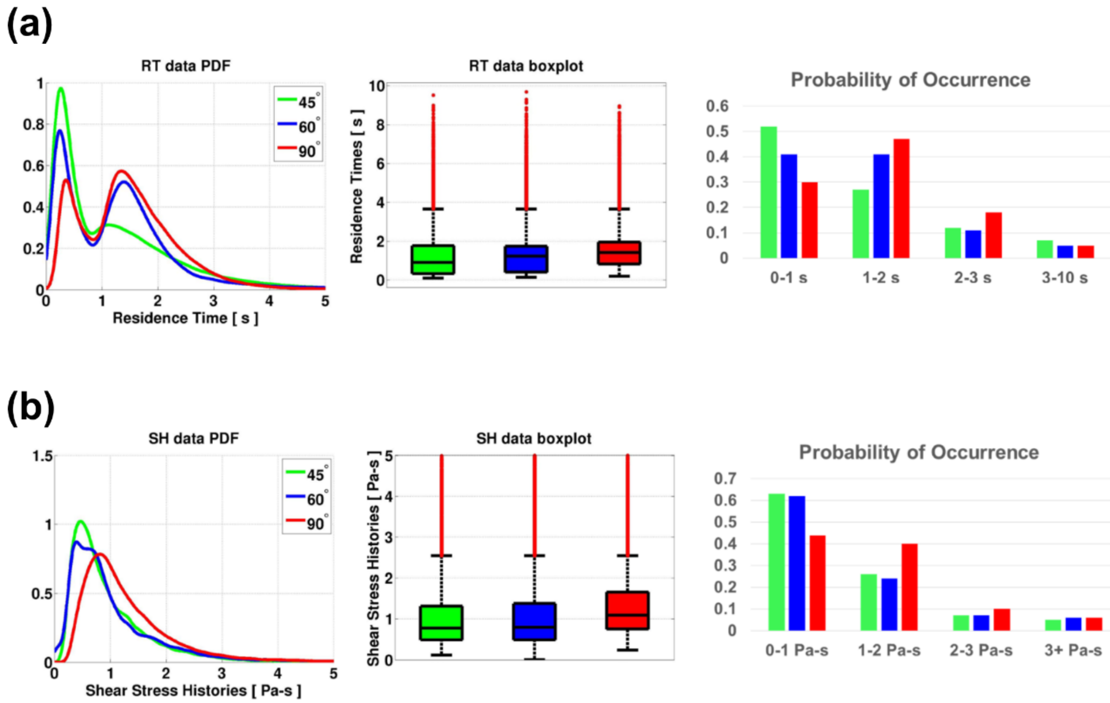


Figure -S 3: PDF, Boxplots and PO plots of (a) particle RT and (b) particle SH for all particles in the C2-Exterior category

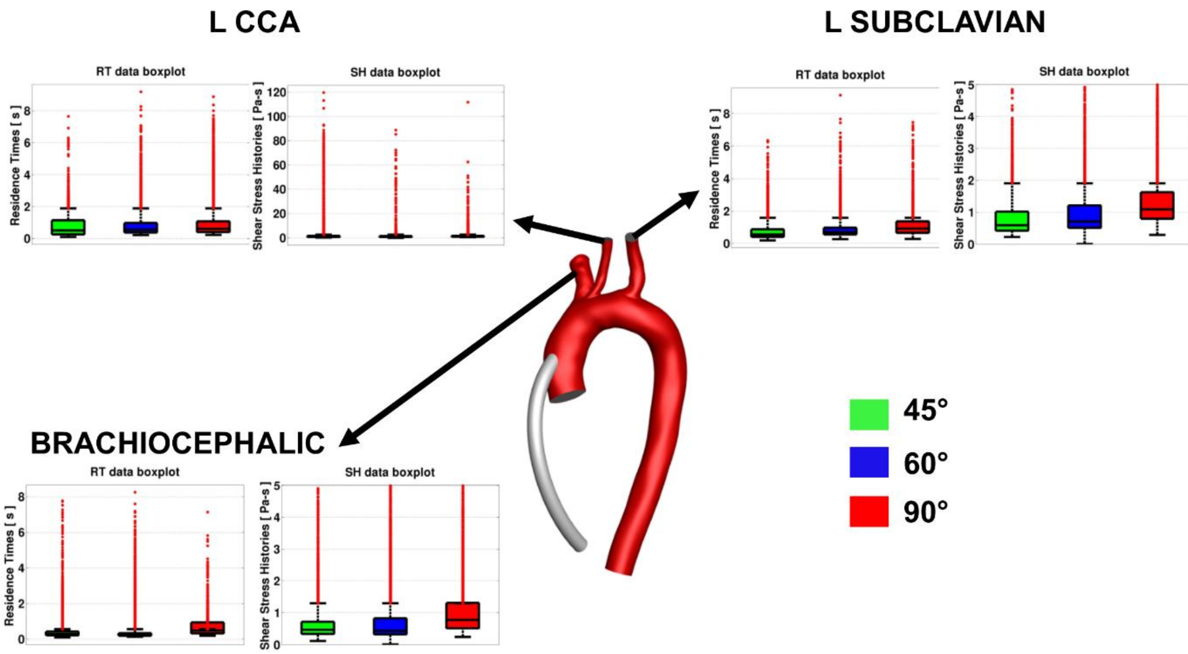


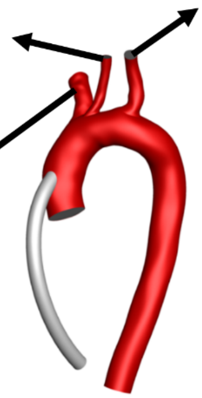
Figure -S 4: Boxplots of particle RT and SH for particles exiting through the brachiocephalic, left common carotid and left subclavian branches

L CCA

Case	Residence Time (s)	Stress Histories (Pa-s)
	Median	Median
45 ^{o}	0.50	0.84
60 ^{o}	0.55	0.75
90 ^{o}	0.60	0.94

L SUBCLAVIAN

Case	Residence Time (s)	Stress Histories (Pa-s)
	Median	Median
45 ^{o}	0.55	0.59
60 ^{o}	0.69	0.71
90 ^{o}	0.91	1.09



BRACHIOCEPHALIC

Case	Residence Time (s)	Stress Histories (Pa-s)
	Median	Median
45 ^{o}	0.28	0.46
60 ^{o}	0.24	0.43
90 ^{o}	0.48	0.77

Figure -S 5: Median particle RT and SH for particles exiting through the brachiocephalic, left common carotid and left subclavian branches

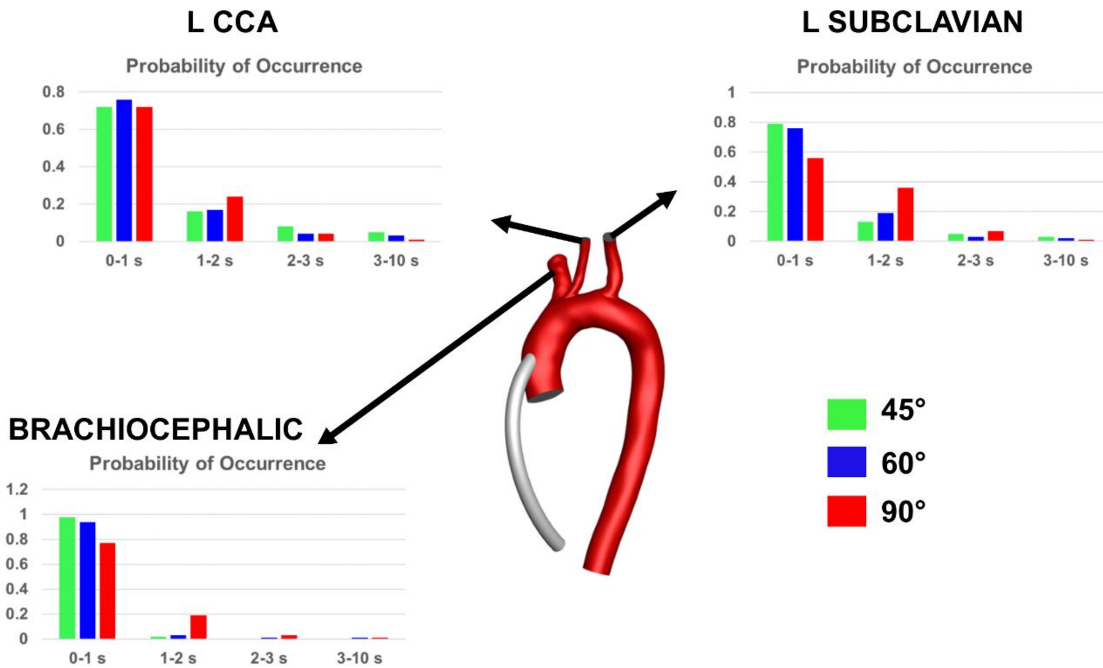


Figure -S 6: PO plots of particle RT for particles exiting through the brachiocephalic, left common carotid and left subclavian branches

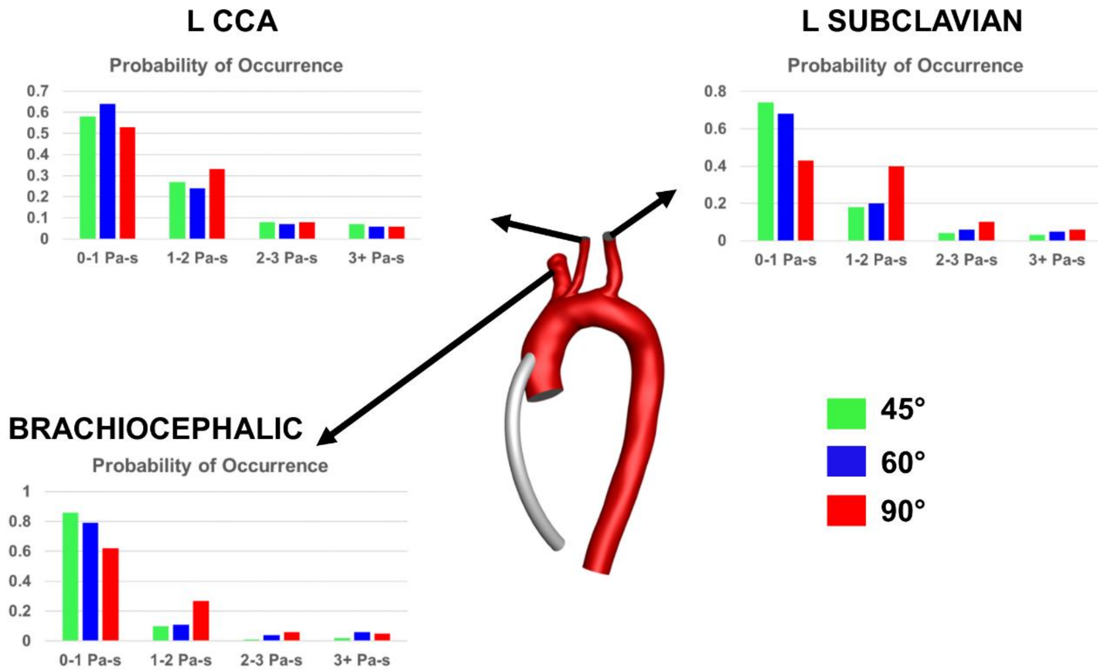


Figure -S 7: PO plots of particle SH for particles exiting through the brachiocephalic, left common carotid and left subclavian branches

Table -S 1: Parameters used in Winkessel model for vascular resistances

Outlet	Resistance R (Pa-s/m^3)	Capacitance C (m^3/Pa)
Brachiocephalic	1.852×10^8	5.401×10^{-11}
Common Carotid	3.901×10^8	2.563×10^{-11}
Left Subclavian	3.955×10^8	2.528×10^{-11}
Descending Aorta	5.368×10^7	1.863×10^{-10}

Table -S 2: : Median and outlier information of RT and SH for all particles. (Note: * indicates a statistically significant (*$p < 0.05$*) result in comparison with 45 ^{0} configuration, † indicates a statistically significant (*$p < 0.05$*) result in comparison with 60^0 configuration and ‡ indicates a statistically significant (*$p < 0.05$*) result in comparison with 90^0 configuration.)

Case	**Residence Time (s)**		**Stress Histories (Pa-s)**	
	Median	Outliers (Max, %)	Median	Outliers (Max, %)
45 ^{0}	1.00†‡	10.00, 6.25%	0.70†‡	119.54, 10.00%
60 ^{0}	1.30*‡	9.99, 8.67%	0.67*‡	129.20, 13.21%
90 ^{0}	1.21*†	9.99, 4.35%	1.03*†	155.03, 12.84%

Table -S 3: Median and outlier information of RT and SH for particles in the Interior of the domain at the completion of the simulation (have not left the domain yet) . (Note: * indicates a statistically significant ($p < 0.05$) result in comparison with 45 ^{0} configuration, † indicates a statistically significant ($p < 0.05$) result in comparison with 60^0 configuration and ‡ indicates a statistically significant ($p < 0.05$) result in comparison with 90^0 configuration.)

Case	**Residence Time (s)**		**Stress Histories (Pa-s)**	
	Median	Outliers (Max, %)	Median	Outliers (Max, %)
45 ^{0}	1.10†‡	10.00, 11.74%	0.62†‡	93.31, 13.98%
60 ^{0}	1.45*‡	9.99, 17.05%	0.50*‡	85.16, 18.16%
90 ^{0}	0.99*†	9.99, 8.11 %	0.95*†	63.84, 16.49%

Table -S 4: Median and outlier information of RT and SH for particles in the Exterior category (have left the domain through any one of the four outlets over the duration of the simulation). (Note: * indicates a statistically significant (*p < 0.05*) result in comparison with 45 ^{0} configuration, † indicates a statistically significant (*p < 0.05*) result in comparison with 60^0 configuration and ‡ indicates a statistically significant (*p < 0.05*) result in comparison with 90^0 configuration.)

Case	**Residence Time (s)**		**Stress Histories (Pa-s)**	
	Median	Outliers (Max, %)	Median	Outliers (Max, %)
45 ^{0}	0.90†‡	8.95, 3.90%	0.77†‡	119.54, 6.69%
60 ^{0}	1.22*‡	9.67, 3.16%	0.80*‡	129.20, 8.58%
90 ^{0}	1.41*†	9.50, 1.91 %	1.09*†	155.03, 9.39%