Cardiovascular Engineering and Technology, Vol. 7, No. 3, September 2016 (© 2016) pp. 305–307
DOI: 10.1007/s13239-016-0272-z

Erratum

Erratum to: Continuous and Pulsatile Pediatric Ventricular Assist Device Hemodynamics with a Viscoelastic Blood Model

BRYAN C. GOOD,[1] STEVEN DEUTSCH,[1] and KEEFE B. MANNING[1,2]

[1]Department of Biomedical Engineering, The Pennsylvania State University, 205 Hallowell Building, University Park, PA 16802, USA; and [2]Department of Surgery, Penn State Hershey Medical Center, Hershey, PA 17033, USA

Erratum to: Cardiovascular Engineering and Technology, VOL. 7, NO. 1, MARCH 2016, PP. 23–43 DOI 10.1007/S13239-015-0252-8

In follow up research we recently discovered that several of the surplus hemodynamic energy (SHE) values used in our manuscript "Continuous and Pulsatile Pediatric Ventricular Assist Device Hemodynamics with a Viscoelastic Blood Model" were not correctly calculated. SHE (ergs/cm^2) (Eq. 1) is the extra energy generated from a flow pulsation and is defined as the difference between the energy equivalent pressure (EEP, mmHg) (Eq. 2) and the time-averaged pressure (TAP, mmHg) (Eq. 3):

$$SHE = 1332(EEP - TAP) \tag{1}$$

$$EEP = \frac{\int_0^T p \cdot Q \cdot dt}{\int_0^T Q \cdot dt} \tag{2}$$

$$TAP = \int_0^T p \cdot dt \tag{3}$$

where Q is the flow rate (L/min), p is the boundary pressure (mmHg) and T is the length of the cardiac cycle (s). While the correct boundary pressures and TAPs were used in all simulations, the flow rate used in the calculation of EEP for the pulsatile (Case 2) and continuous (Case 3) flow cases at all three pediatric hematocrits (20, 40 and 60%), however, was incorrect and overestimated the true EEP and resultant SHE for these simulations. With respect to the healthy flow (Case 1), all TAP, EEP, and SHE values were calculated correctly.

To assess the impact of this error, the authors recalculated the EEP and SHE, for Cases 2 and 3 for all three blood hematocrits (Table 1). The new pulsatile SHE values are all 15.8% lower than the original values and the new continuous SHE values are all 50.2% lower than the original values reported. Figure 1 compares the original and corrected percent differences in SHE from the healthy aortic flow (Case 1) due to pulsatile and continuous bypass. Originally, for pulsatile PVAD flow, the decreases in SHE were 4, 9, 9, and 6% at the great vessels and aortic outlet, but are corrected to 21, 26, 26, and 22%, respectively. For continuous PVAD flow, the decreases in SHE were 84, 85, 84, and 82%, at the great vessels and aortic outlet, but are corrected to 133, 133, 132, and 131%, respectively. Additionally, since all of the original pulsatile and continuous flow SHE values were calculated using the same incorrect flowrate, the percent differences between the 20 and 60% hematocrit models (original Fig. 6), remained unchanged when using the corrected flowrate.

All SHE values originally reported were on the same order of magnitude as a previous study by Yang *et al.*[1] in a pediatric aorta with a Newtonian blood model. The pulsatile SHEs ranged from 1% lower at the brachiocephalic artery to 18% lower at the descending aorta compared to Yang *et al.*,[1] while the continuous

Address correspondence to Keefe B. Manning, Department of Biomedical Engineering, The Pennsylvania State University, 205 Hallowell Building, University Park, PA 16802, USA. Electronic mail: kbm10@psu.edu

The online version of the original article can be found under doi: 10.1007/s13239-015-0252-8.

1869-408X/16/0900-0305/0 © 2016 Biomedical Engineering Society

TABLE 1. Original and corrected SHE (ergs/cm^3) results for both pulsatile (Case 2) and continuous (Case 3) PVAD flow for all three pediatric hematocrit models.

Blood hematocrit (%)	Flow mode		Aortic inlet	Cannula outlet	Brachiocephalic	Left common carotid	Left subclavian	Aortic outlet
20	Pulsatile	Original	20,389.83	24,914.23	18,683.26	17,600.68	16,172.54	4815.17
		Corrected	17,167.82	20,834.70	15,826.95	14,887.00	13,670.63	3858.57
20	Continuous	Original	8831.94	8879.60	7914.37	7744.88	7250.05	1997.94
		Corrected	4401.49	4425.24	3944.21	3859.74	3613.14	995.70
40	Pulsatile	Original	21,858.00	27,099.62	18,996.86	17,756.90	16,260.37	4453.38
		Corrected	18,361.55	22,613.96	16,096.81	15,026.35	13,749.57	3810.51
40	Continuous	Original	9390.76	9407.34	8045.16	7811.15	7276.15	1975.23
		Corrected	4679.99	4688.25	4009.40	3892.77	3626.15	984.37
60	Pulsatile	Original	24,005.20	30,343.15	19,411.02	17,942.34	16,445.42	4374.41
		Corrected	20,175.16	25,347.65	16,452.62	15,189.98	13,915.32	3741.66
60	Continuous	Original	10,305.29	10,283.56	8237.95	7900.18	7331.52	1940.68
		Corrected	5135.75	5124.92	4105.47	3937.14	3653.74	967.16

SHEs ranged from 43% higher at the brachiocephalic artery to 75% higher at the descending aorta. Since this study was the first of its kind to examine PVAD flow pulsatility using a viscoelastic blood model, the expected differences in pulsatility compared to Yang's Newtonian blood model simulations were initially unclear. The corrected SHE values are still on the same order of magnitude but now range from 20% lower at the brachiocephalic artery to 18% lower at the descending aorta compared to Yang *et al.*,[1] while the continuous SHEs ranged from 34% lower at the brachiocephalic artery to 3% higher at the descending aorta.

Overall, the same trends are seen with greater pulsatility at all outlets with pulsatile support compared to continuous support but with both cases of PVAD support leading to significant reductions in pulsatility compared to the healthy case. However, with the corrected SHE values, the pulsatility losses are even more significant for both pulsatile and continuous PVAD support than previously reported. The same conclusions with regards to the benefits of pulsatile over

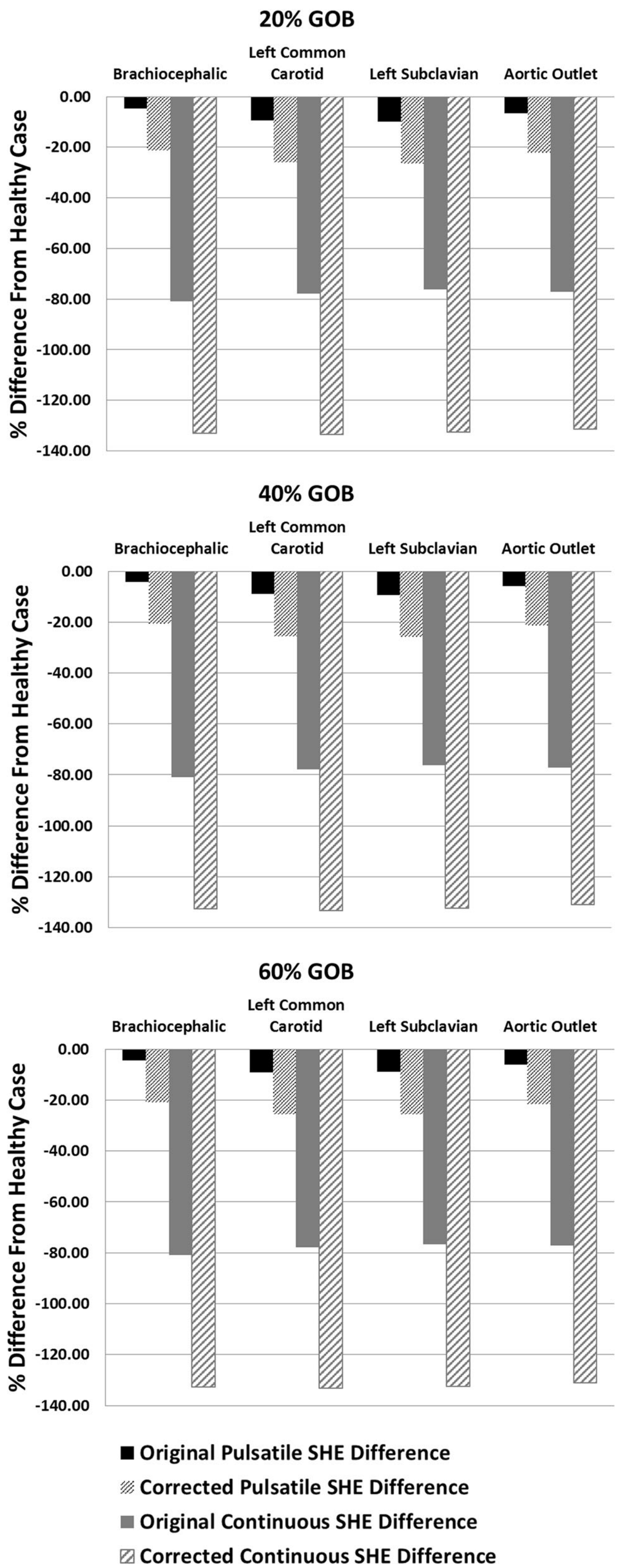

FIGURE 1. Original and corrected percent decrease in SHE at each outlet boundary from the healthy aortic flow to both pulsatile and continuous PVAD flows.

continuous circulatory support and the potential complications in pediatric organ development from a lack of pulsatility remain. The authors sincerely apologize for this error.

REFERENCE

[1]Yang, N., S. Deutsch, E. Paterson, and K. Manning. Comparative study of continuous and pulsatile left ventricular assist devices on hemodynamics of a pediatric end-to-side anastomotic graft. *Cardiovasc. Eng. Technol.* 1(1):88–103, 2010.