Effect of Hydration on Whole Blood Viscosity in Firefighters

Ralph E. Holsworth Jr, DO; Young I. Cho, PhD; Joseph Weidman, BS, PharmDc

ABSTRACT

Context • Cardiovascular disease (CVD) is the leading cause of on-duty death among firefighters, totaling 45% of on-duty fatalities. Heat stress and fluid losses can result in decreases in cardiac output of firefighters, despite sustained tachycardia and maximally elevated heart rate during emergencies. Measurements of whole blood viscosity (WBV) may serve as an independent biomarker of the hydration and dehydration states of on-duty firefighters.

Objective • The current pilot study investigates the effects of a strenuous firefighting simulation and subsequent rehydration on WBV and other biological metrics in nine healthy, nonsmoking firefighters to (1) determine whether dehydration and rehydration result in detectable changes in WBV and (2) compare WBV with the results from a range of conventional medical tests.

Design • The research team designed a single-center, unblinded pilot study.

Setting • Fire Training Division, 1900 Lind Ave SW, Renton, WA, 98057.

Participants • Participants were 9 healthy, nonsmoking firefighters who were volunteers.

Outcome Measure(s) • Vital signs, traditional medical blood tests, and WBV were measured for each firefighter (1) at baseline, (2) after exercise but before rehydration with alkaline water, and (3) postexercise and after rehydration. Hematocrit (HCT), hemoglobin (Hb), and WBV increased after exercise and before rehydration.

Results • Dehydration during the mock fire drill resulted in elevated WBV at both low- and high-shear rates. HCT and Hb increased due to dehydration and hemoconcentration. Hb and HCT returned to baseline values after exercise and rehydration, and while WBV improved, baseline values were not restored. After exercise but before rehydration, WBV changes were significantly larger than HCT and Hb changes, suggesting the profound influence of hydration states on WBV.

Conclusions • WBV measurements were better determinants of hydration states than HCT or Hb and should be performed to monitor the cardiovascular health of at-risk firefighters. (*Altern Ther Health Med*. 2013;19(4):44-49.)

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Cardiovascular disease (CVD) is the leading cause of on-duty death among firefighters—45% of on-duty fatalities—and a major cause of morbidity.[1] Proportionately, firefighters experience the highest rates of mortality while on duty due to CVD when compared to the rates of other occupational groups and other public safety officers.[2] As compared with the odds of death from coronary heart disease during nonemergency duties, the odds were 12 to 136 times higher during active fire suppression.[3] In fact, the most frequent cause of death among firefighters is heart disease rather than burns or smoke inhalation.[3] Firefighters are prone to certain behaviors, work under unique conditions, and face hazardous exposures that may increase their cardiovascular risks.[4] In general, these risks can be divided into acute and chronic stressors. Acute stressors include irregular physical exertion, smoke exposure, excessive heat and dehydration, and duty-specific hazards, whereas chronic stressors include long sedentary periods, shift work and partial sleep deprivation, firehouse dietary patterns, and occupational stress.[1]

A significantly higher prevalence of cardiovascular risk factors, such as current smoking, hypertension, diabetes mellitus, and hypercholesterolemia, was found among

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firefighters dying of on-duty CVD as compared to controls (ie, surviving firefighters).[2] Firefighting duties directly challenge the cardiovascular system, including the alarm bell's activation of the sympathetic nervous system, the physical workload of firefighting, and the associated heat stress and dehydration.[1] Heat stress and fluid losses can result in decreases in cardiac output despite sustained tachycardia and maximally elevated heart rate during emergencies.[1,5] For example, a 15% reduction in plasma volume was observed after three bouts of strenuous firefighting activity, which can have significant physiologic impacts, such as decreased stroke volume.[1] The reduced plasma volume caused by heat stress and dehydration can result in hemoconcentration.

Dehydration is also an important issue in the general population as it is one of the major health problems in the 21st century. It has been well-established that consumption of soft drinks, which have an osmolality of ~700 mOsm/kg, and beer, which has an osmolality of ~1000 mOsm/kg, causes dehydration in both young and old people.[6] Also, the overall increasing trends in US life expectancy from about 50 years in 1900 to greater than 75 years today have amplified the importance of the effects of dehydration on seniors, because dysfunction of thirst sensors worsens with age.[7] A number of clinical symptoms common in many senior citizens, such as arthritis joint pains, knee problems, lower-back pains, and constipation, among others, may be manifestations of severe and chronic dehydration.[8] However, currently no well-accepted standard methodology or instrumentation exist that can be used in a clinical setting to monitor dehydration status.

In recent years, clinical interest has increased in the role of whole blood viscosity (WBV) in the pathogenesis of cardiovascular and cerebrovascular diseases.[9-11] This attention, however, has been hindered by the lack of an uncomplicated and clinically practical method to measure WBV. Since the circulatory system is a closed system, the viscosity or thickness of blood that the heart is pumping can play a crucial role in determining tissue perfusion as well as the workload of the heart. An increase in blood viscosity (BV) will require the heart to work harder to provide the same level of perfusion to the tissues and organs of the body. An overworked heart may be more likely to become hypertrophic and ultimately result in congestive heart failure.

HYPOTHESIS AND OBJECTIVES OF THE STUDY

It is hypothesized that hemoconcentration caused by dehydration is an independent cardiac risk factor in general. The maintenance of hydration is based upon hypothetical calculations of fluid losses, metabolic requirements, losses of respiratory water vapor, and replenishment of those losses. Restoration of fluids in the medical community is largely empirical and not typically based upon quantitative feedback regarding the restoration of the proper intravasculature blood volumes or establishing normal blood volume. WBV

may serve as an independent biomarker of euvolumina and provide an accurate depiction of firefighters' hydration statuses, their ability to maintain appropriate and safe core body temperatures, and their CVD risk.

Therefore, the objectives of the present study were to (1) determine whether dehydration during a mock fire drill and oral rehydration resulted in detectable changes in WBV in active firefighters and (2) compare WBV with the results from a range of conventional medical tests, including complete blood counts (CBC) and blood urea nitrogen (BUN)/creatinine (Cr) ratios, that would allow the research team to evaluate hydration/dehydration states further.

METHODS
Participants

The present study is a single-center, unblinded pilot study of 15 healthy, nonsmoking firefighters who were volunteers and who were not on any concomitant medications. The mean age of the eight male firefighters was 42.3 ± 6.8 years, while the one female firefighter was 37 years of age. At screening, the participants recruited for the study answered questions relating to eligibility criteria. Male and female firefighters 18 to 75 years of age, who were apparently healthy and not currently taking medications, were eligible. Based on eligibility, nine qualifying participants, eight males and one female, were enrolled and signed the informed consent for participation in the study.

Outcome Measures

Previously, in a clinical study of 24 apparently healthy males, WBV had been shown to be generally stable longitudinally over a 2-week period without intervention, with small, nonsignificant, diurnal increases in the morning and after meals.[12]

In the current study, 2 weeks prior to the mock fire drill, measurements were performed at baseline, time point T1. Participants fasted overnight, starting at midnight (NPO), and the research team measured each participant's height, weight, and vital signs, also recording prior and concomitant medications and the time of their last food intake. Blood specimens from the antecubital vein were obtained with a standard venipuncture and placed in vacutainers (Becton, Dickinson and Company, Franklin Lakes, NJ, USA) with ethylenediaminetetraacetic acid (EDTA) anticoagulant for clinical laboratory tests and WBV measurements. A 21-gauge, butterfly needle was used to obtain the blood samples for the viscosity and CBC measurements. Results of clinical laboratory tests were obtained and confirmed to be normal before continuing with the study's procedures.

On the day of the study, firefighters participated in a mock fire drill. The exercise involved each firefighter using a self-contained breathing apparatus for two 30-minute sessions of strenuous firefighting activity. This activity occurred in a building that contained live fire, after which the firefighters conducted physical rehabilitation.

After the exercise, two separate blood draws from each

firefighter were completed: (1) the first sample was drawn postexercise but prior to rehydration, time point T2, and (2) the second sample was drawn postexercise and 45 minutes after rehydration of the firefighter, time point T3.

At each time point, vital signs were recorded, and blood was collected for WBV and CBC measurements. For the rehydration procedure, each firefighter received half of his or her body weight in ounces of the therapeutic agent. For example, a firefighter weighing 200 pounds (90.7 kg) was provided 100 fluid ounces (2.96 L) of fluids for rehydration. Oral intake amounts for each firefighter were recorded from the beginning of the exercise to the end of the event.

All measurements—including WBV, CBC, blood urea nitrogen (BUN), and creatinine (Cr) measurements—were carried out at Meridian Valley Lab in Renton, Washington. Rehydration water with a pH level of 9.5 was provided by Essentia Water, Inc (Bothell, WA, USA). Prior to bottling, Essentia water is electrolyzed and reduced to increase its ability to scavenge reactive oxygen species. The antioxidant properties of electrolyzed, reduced water were previously shown to reduce reactive oxygen species during hemodialysis of end-stage, renal-disease patients.[13]

WBV was measured with the Hemathix viscometer (Health Onvector, Pennsauken, NJ, USA) at 37°C. Regarding the operating principle of the viscometer, viscosity μ is mathematically defined as the ratio of wall shear stress to wall shear rate,

$$\mu = \frac{\tau_w}{\dot{\gamma}_w}$$

and therefore, one needs to determine both wall shear stress and wall shear rate experimentally.

In the present study, the wall shear stress τ_w was determined from the pressure drop across a capillary tube that was positioned between the two vertical tubes of the U-tube section in the viscometer.[14] The pressure drop was obtained from the height difference of fluid levels between the two vertical tubes. Since the wall shear rate

$$\dot{\gamma}_w$$

is proportional to the ratio of blood velocity to tube diameter, the height variation, h(t), at the vertical tube was differentiated to render velocity[14]:

$$V(t) = dh(t)/dt.$$

A detailed description on the mathematical procedure to calculate both the wall shear stress and wall shear rate was given elsewhere.[14] The blood samples required for the viscosity tests were approximately 3 mL of whole blood with EDTA for anticoagulation. WBV was measured over a wide range of shear rates from 1 to 1000 s^{-1}. However, the present study reports WBV at two shear rates: 5 and 300 s^{-1}. The current study has referred to the WBV measured at 5 s^{-1} as low-shear BV and WBV measured at 300 s^{-1} as high-shear BV.

Statistical Analyses

Physiological parameters were evaluated and compared between baseline, postexercise/prehydration, and postexercise/posthydration states. Standard F tests and t tests were performed. Estimates with a P value < .05 were considered statistically significant. Analyses were conducted in Microsoft Excel using QI Macros 2012 (KnowWare International, Inc, DBA LifeStar, Denver, CO, USA).

RESULTS

Table 1 shows results of both the WBV and the CBC tests as well as BUN and Cr tests at three time points: (1) baseline—T1, (2) postexercise/prehydration—T2, and (3) postexercise/posthydration—T3. High-shear and low-shear BV significantly increased from T1 to T2, by 9.5% and 17.2%, respectively, while low-shear and high-shear BV also significantly decreased from T2 to T3, by 9.1% and 11.2%, respectively.

Hematocrit (HCT) is an important variable that indicates the states of hydration/dehydration as well as hemoconcentration. The values of the HCT at T1, T2, and T3 were 43.7, 46.1, and 44.0, respectively. The changes from T1 to T2 and from T2 to T3 were statistically significant. The Cr values that can be used to estimate the glomerular filtration rate (GFR) as a measure of renal function[15] were 0.88, 1.06, and 0.94 mg/dL at T1, T2, and T3, respectively.

Figure 1 shows the individual variations of low-shear BV for nine firefighters (FF), eight males and one female (FF6). The maximum and minimum variations in the low-shear BV from T1 to T2 were +31.3% and +8.2%, respectively. The maximum and minimum variations in the low-shear BV from T2 to T3 were -21.5% and +0.3%, respectively.

Figure 2 shows the low-shear BV as a function of HCT at 3 time points—T1, T2, and T3. As a reference, the data for low-shear BV obtained at T1 is indicated by a solid line. As expected, the low-shear BV increased with increasing HCT.

Figure 3 shows the tissue oxygen delivery index (TODI) as a function of HCT, where TODI is defined as the ratio of HCT (%) to the low-shear BV. Again, the TODI data obtained at T1 is indicated by a solid line as a reference.

Figure 4 gives individual variations of estimated glomerular filtration rate (e-GFR) as a function of the low-shear BV. An arrow in each curve indicates the baseline time point T1, whereas the point in the middle of each curve indicates T2 with the other end of the curve representing T3. All curves have a V-shape with different apex angles. From T1 to T2, the value of e-GFR generally decreased as the low-shear BV increased, except for FF8, where the e-GFR remained unchanged during the periods between T1, T2, and T3. Note that a dramatic drop in the e-GFR occurred for the female firefighter, with a moderate increase in the low-shear BV from T1 to T2.

Figure 5 shows the results of e-GFR vs TODI for 3 time points—T1, T2, and T3. As a reference, the e-GFR data obtained at T1 is indicated by a solid line. In general, the e-GFR increased with increasing TODI, indicating that the

Table 1. WBV, CBC, BUN, and Cr at T1, T2, and T3

	T1		T2			T3				Serial Differences			
	Mean	SD	Mean	SD	*P* Value vs T1	Mean	SD	*P* Value vs T1	*P* Value vs T2	Diff T1-T2	Diff T2-T3	% Change T1-T2	% Change T2-T3
SBP (mm Hg)			136.1	10.2		126.6	10.4		.0542				
DBP (mm Hg)			87.2	5.3		85.3	7.0		.2060				
HR			97.9	18.2		72.4	13.2		.000001				
WBV @ 300 s⁻¹ (mP), high-shear BV	39.0	2.6	42.7	5.4	.0053	38.8	3.3	.3570	.0030	3.7	-3.9	9.5%	-9.1%
WBV @ 5 s⁻¹ (mP), low-shear BV	105.5	10.9	123.6	18.4	.0001	109.8	14.2	.1308	.0030	18.1	-13.8	17.2%	-11.2%
Complete Blood Count													
WBC (× 10³/μL)	5.9	1.3	8.2	2.6	.0222	7.6	1.3	.0122	.1186	2.3	-0.6	39.2%	-7.5%
RBC (× 10³/μL)	5.0	0.4	5.2	0.3	.0008	5.0	0.4	.3886	.0001	0.2	-0.2	4.4%	-4.3%
Hb	14.8	1.2	15.4	0.9	.0057	14.5	0.9	.1542	.0001	0.6	-0.9	3.8%	-5.6%
HCT	43.7	3.1	46.1	2.3	.0014	44.0	2.7	.3319	.0003	2.4	-2.1	5.4%	-4.5%
MCV (fL)	87.8	2.7	88.3	2.8	.0993	88.2	2.6	.2533	.4246	0.5	-0.1	0.5%	-0.1%
MCH (pg)	29.8	0.9	29.4	0.9	.0214	29.1	0.8	.0049	.0125	-0.4	-0.3	-1.2%	-1.1%
MCHC (g/dL)	33.9	0.7	33.3	0.7	.0047	33.0	0.5	.0001	.0283	-0.6	-0.3	-1.8%	-0.8%
RDW (fL)	12.3	0.5	12.4	0.5	.2427	12.6	0.5	.0023	.0012	0.1	0.2	0.5%	1.9%
PLT (× 10³/μL)	236.7	42.8	298.4	67.1	.0002	245.7	43.2	.0458	.0001	61.7	-52.7	26.1%	-17.7%
BUN/Creatinine													
BUN (mg/dL)	15.6	3.0	16.7	3.2	.1927	15.9	3.1	.3952	.0016	1.1	-0.8	7.1%	-4.8%
Cr (mg/dL)	0.88	0.13	1.06	0.18	.0026	0.94	0.14	.0406	.0406	0.2	-0.1	20.5%	-11.3%
BUN/CR ratio	17.7	2.5	16.3	4.5	.1828	17.3	4.7	.3990	.0068	-1.4	1.0	-8.1%	6.4%

Abbreviations: T1 = time point 1; T2 = time point 2; T3 = time point 3; SD = standard deviation; SBP = systolic blood pressure; DBP = diastolic blood pressure; HR = heart rate; PaO₂ Sat (mm HG) = oxygen pressure in blood; WBV = whole blood viscosity; BV = blood viscosity; WBC = white blood cell count; RBC = red blood cell count; Hb = hemoglobin; HCT = hematocrit; MCV = mean corpuscular volume; MCH = mean corpuscular hemoglobin; MCHC = mean corpuscular hemoglobin concentration; RDW = red cell distribution width; PLT = platelet count; BUN = blood urea nitrogen; Cr = creatinine; diff = difference.

GFR improved with improved tissue perfusion based on the low-shear BV. Note that the e-GFR values at T2 and T3 were significantly below the baseline values at T1. However, TODI was relatively high, probably due to small HCT.

DISCUSSION

The present study was conducted to examine the effect of heat stress/dehydration on both WBV and CBC as well as BUN and Cr, and the effect of rehydration on these properties of blood through use of Essentia water of pH of 9.5. As expected, the changes in percentages for hemoglobin (Hb) and HCT from T1 to T2 were 4.1% and 5.5%, respectively, indicating significant hemoconcentration due to the heat stress/dehydration. After rehydration, the changes in Hb and HCT from T2 to T3 were -5.8% and -4.6%, respectively, suggesting that the rehydration with Essentia water effectively restored the baseline state. Mean levels of BUN were not significantly changed from T1 to T2; however from T2 to T3, a significant reduction in mean BUN levels was observed. At T3, the reduction of BUN, which is a recognized biomarker for kidney function and hydration status, was suggestive of a rehydration effect by Essentia water. It could not be determined by this study's design and sample size whether WBV may be able to serve as a more sensitive hydration biomarker than BUN. This question should be addressed in future clinical studies.

Compared to the changes in the Hb and HCT, the changes in the WBV at both high and low shear rates from T1 to T2 were much greater (ie, 9.5% and 17.2% respectively), indicating that the hemoconcentration due to the heat stress/dehydration affected WBV more than the Hb and HCT. After rehydration, the changes in the WBV at both high- and low-shear rates from T2 to T3 were -9.1% and -11.2%, respectively, indicating that the rehydration with Essentia water improved WBV but did not fully restore it to the baseline state at T3.

This study used each participant as his or her own control and demonstrated time-dependent changes. An additional arm of the study, comprised of firefighters who would undergo a similar protocol without rehydration, would have been helpful for investigating a causal link between rehydration by Essentia water and the restoration of the various rheologic and hematologic markers. That arm could be a control group that is age- and gender-matched or randomized, and the research team expects the control to be implemented in future research.

The WBV versus HCT results at 3 time points—T1, T2, and T3—provide interesting physiological responses to the heat stress/dehydration (Figure 2). Assuming that the firefighters in the study were mostly healthy, the acute

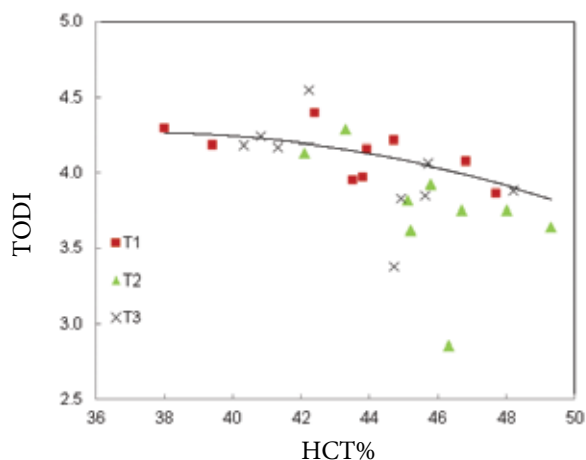**Figure 1.** Variations in Individual, Low-shear BV at T1, T2, and T3
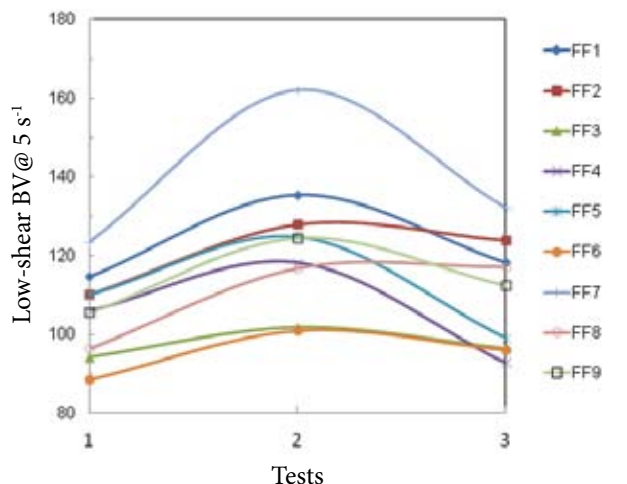
Abbreviations: BV = blood viscosity; FF1-FF9 = firefighters 1-9; T1 = time point 1; T2 = time point 2; T3 = time point 3.

Figure 2. Low-shear BV as a Function of Hematocrit at T1, T2, and T3
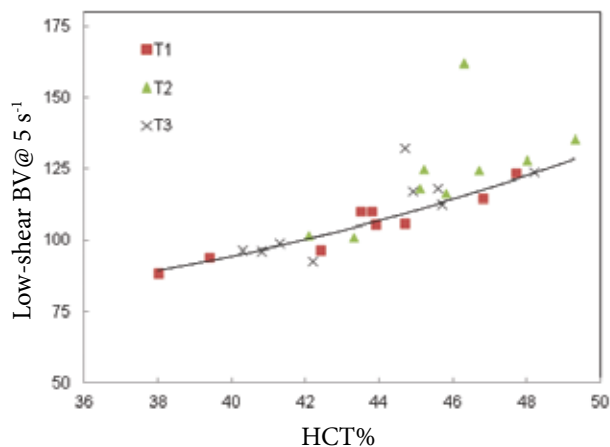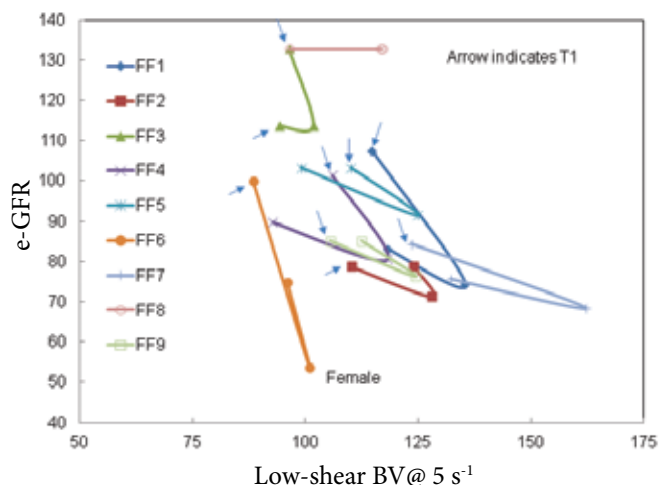

Abbreviations: BV = blood viscosity; HCT = hematocrit; T1 = time point 1; T2 = time point 2; T3 = time point 3.

Figure 3. TODI as a Function of Hematocrit

Abbreviations: TODI = tissue oxygen delivery index; HCT = hematocrit; T1 = time point 1; T2 = time point 2; T3 = time point 3.

Figure 4. Variations in Individual e-GFR as a Function of Low-shear BV

Abbreviations: e-GFR = estimated glomerular filtration rate; BV = blood viscosity; FF1-FF9 = firefighters 1-9.

dehydration resulted in a swing toward to the right side along the solid line from T1 to T2, except for the FF7 case, where the acute dehydration resulted in hemodilution. In spite of the hemodilution for the FF7 case, low-shear BV at T2 increased by 31.3% from the value at T1 due to the dehydration. Subsequently, the low-shear BV at T3 dropped by 18.6% after rehydration, still significantly greater than the baseline BV at T1.

This study identified an abnormality in the case of FF7 that merits further discussion with reference to Figure 3, where TODI versus HCT is shown. If the body's fluid-balance system behaved normally, the TODI data would be expected to swing to the right side with heat stress/dehydration and swing back to the left side with rehydration. Since the FF7 case had hemodilution instead of hemoconcentration after heat stress/dehydration, the TODI dramatically dropped at T2, suggesting the possibility of impaired perfusion at the tissue level, including at the myocardium and kidneys for instance. Further research in this area is merited. Even after rehydration, the TODI was well below the subject's own initial baseline value.

The data shown in Figure 4 provides individual variations between the estimated GFR and low-shear BV. The mean low-shear BV at T2 was 123.6 ± 18.4 mP while the value for FF7 was 162.1 mP, a value significantly greater than the mean value after dehydration in spite of hemodilution. The e-GFR for FF7 had the lowest value at T2 among male firefighters, possibly due to increased plasma concentration, which would highlight the prospect of future risk of renal complications. The results in Figure 5 shows that the decrease

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Figure 5. e-GFR as a Function of TODI at T1, T2, and T3
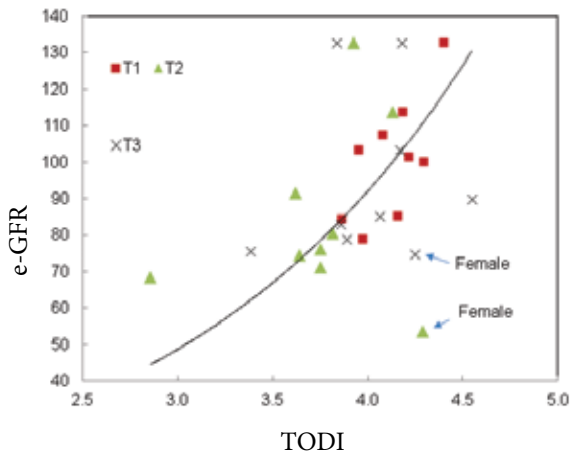
Abbreviations: e-GFR = estimated glomerular filtration rate; TODI = tissue oxygen delivery index; T1 = time point 1; T2 = time point 2; T3 = time point 3.

in the e-GFR in the case of FF7 was accompanied with a significant drop in the TODI, as expected. In the female firefighter, in spite of a major drop in the e-GFR after the heat stress/dehydration, the TODI value remained at the maximal level, suggesting that the tissue perfusion was not compromised by the dehydration.

CONCLUSIONS

Dehydration during the mock fire drill resulted in elevated WBV at both low- and high-shear rates. HCT and Hb increased due to dehydration and hemoconcentration. Oral rehydration with Essentia water significantly lowered but did not quite return WBV to baseline values at both low- and high-shear rates. Hb and HCT were returned to baseline levels after rehydration. WBV measurements were better determinants of hydration states than HCT or Hb and should be performed to monitor the cardiovascular health of at-risk firefighters. It should be noted, however, that more studies with larger population sizes should be carried out to develop further evidence. Additionally, the case where hemodilution resulted from intense physical exercise should be studied to find reasoning behind this abnormality.

REFERENCES

1. Soteriades ES, Smith DL, Tsismenakis AJ, Baur DM, Kales SN. Cardiovascular disease in US firefighters: a systematic review. *Cardiol Rev.* 2011;19(4):202-215.
2. Kales SN, Soteriades ES, Christoudias SG, Christiani DC. Firefighters and on-duty deaths from coronary heart disease: a case control study. *Environ Health.* 2003;2(1):14.
3. Kales SN, Soteriades ES, Christophi CA, Christiani DC. Emergency duties and deaths from heart disease among firefighters in the United States. *N Engl J Med.* 2007;356(12):1207-1215.
4. Melius JM. Cardiovascular disease among firefighters. *Occup Med.* 1995;10(4):821-827.
5. Smith DL, Manning TS, Petruzzello SJ. Effect of strenuous live-fire drills on cardiovascular and psychological responses of recruit firefighters. *Ergonomics.* 2001;44(3):244-254.
6. Feldman M, Barnett C. Relationships between the acidity and osmolality of popular beverages and reported postprandial heartburn. *Gastroenterology.* 1995;108(1):125-131.
7. Lavizzo-Mourey R, Johnson J, Stolley P. Risk factors for dehydration among elderly nursing home residents. *J Am Geriatr Soc.* 1988;36(3):213-218.
8. Weinberg AD, Minaker KL. Dehydration: evaluation and management in older adults: Council on Scientific Affairs, American Medical Association. *JAMA.* 1995;274(19):1552-1556.
9. Lee AJ, Mowbray PI, Lowe GD, Rumley A, Fowkes FG, Allan PL. Blood viscosity and elevated carotid intima-media thickness in men and women: the Edinburgh Artery Study. *Circulation.* 1998;97(15):1467-1473.
10. Ciuffetti G, Schillaci G, Lombardini R, Pirro M, Vaudo G, Mannarino E. Prognostic impact of low-shear whole blood viscosity in hypertensive men. *Eur J Clin Invest.* 2005;35(2):93-98.
11. Cecchi E, Liotta AA, Gori AM, et al. Relationship between blood viscosity and infarct size in patients with ST-segment elevation myocardial infarction undergoing primary percutaneous coronary intervention. *Int J Cardiol.* 2009;134(2):189-194.
12. Wang S, Boss AH, Kensey KR, Rosenson RS. Variations of whole blood viscosity using Rheolog-a new scanning capillary viscometer. *Clin Chim Acta.* 2003;332(1-2):79-82.
13. Huang KC, Yang CC, Lee KT, Chien CT. Reduced hemodialysis-induced oxidative stress in end-stage renal disease patients by electrolyzed reduced water. *Kidney Int.* 2003;64(2):704-714.
14. Kim S, Cho YI, Hogenauer WN, Kensey KR. A method of isolating surface tension and yield stress effects in a U-shaped scanning capillary-tube viscometer using a Casson model. *J Nonnewton Fluid Mech.* 2002;103(2-3):205-219.
15. Brosius FC III, Hostetter TH, Kelepouris E, et al; American Heart Association Kidney and Cardiovascular Disease Council; Council on High Blood Pressure Research; Council on Cardiovascular Disease in the Young; Council on Epidemiology and Prevention; Quality of Care and Outcomes Research Interdisciplinary Working Group. Detection of chronic kidney disease in patients with or at increased risk of cardiovascular disease. *Circulation.* 2006;114(10):1083-1087.