Title

A dataset of speed-resolved blood perfusion and oxygen saturation in human skin response to thermal stimulation

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Abstract

The functional status of vessels can be determined by assessing blood perfusion. By integrating diffuse reflectance spectroscopy (DRS) and laser Doppler Flowmetry (LDF), the speed-resolved blood perfusion and blood oxygen saturation can be measured simultaneously by Enhanced Perfusion and Oxygen Saturation (EPOS). The dataset presented in this descriptor contains EPOS data recorded from a forearm point exposed to different levels of thermal stimulation, the classical LDF at control points, the R-R time series and data regarding characteristics of subjects. All data were recorded from 60 recruited healthy subjects. Half of the subjects received different levels of thermal stimulation, and half of them were blank controls. We believe that this dataset will lead to the development of local blood perfusion methods that can be used to index vessel function assessments. This publicly available dataset will be beneficial to the microcirculation evaluation.

Background & Summary

There is increasing evidence that microcirculation can be used to evaluate vascular disorders at the systemic level[1, 2], and there is a close relationship between cardiac function and vessel function[3, 4]. In general, the functional status of vessels can be assessed by laser Doppler flowmetry (LDF). However, differentiating between different vascular compartments using the classical LDF approach is difficult. Recently, a multiparameter model based on the Monte Carlo algorithm has provided the possibility of further distinguishing the different velocity components in microcirculation perfusion[5-7]. This new method may provide further insight into evaluating vascular dysfunction at the systemic level[8, 9].

According to previous studies, blood perfusion signals recorded by LDF can be separated into different frequency bands in the frequency domain[10-13]; these frequency bands might reflect different physiological rhythms[14]. From another perspective, microcirculation perfusion can also be distinguished by the speed distribution, and the speed of red blood cells (RBCs) is closely related to the total cross-sectional area of different types of blood vessels. Therefore, different velocity components have potential value for distinguishing different types of blood vessels, thereby exploring the regulatory mechanisms of local microcirculation. By applying computational models, the Enhanced Perfusion and Oxygen Saturation (EPOS) system enables absolute measures of speed resolved perfusion. Dividing the flow in different speeds enables some differentiation of the flow into different vessel structures, such as capillaries, venules and arterioles, although one cannot expect a one-to-one correlation between flow speed and vessel type. By separating perfusion into speed regions, the different

vascular effects that result from thermal stimulation can be studied separately. Therefore, our results provide an opportunity for deeper insight into endothelial and neurovascular function and for a better understanding of how microcirculation responds to different levels of thermal stimulation in human skin microcirculation.

On the other hand, oxygen saturation represents a dynamic balance between the O₂ supply and O₂ consumption in the capillary, arteriolar, and venular beds. It is generally believed that local oxygen saturation is closely related to blood flow perfusion. Previous studies have shown an exponential correlation between oxygen saturation and blood flow. When the flow speed increases, the capillary transit time decreases, resulting in an instantaneously lowered oxygen extraction and an increased overall blood saturation level[15]. However, because blood flow components can be divided into different speed-resolved components, there is still no evidence of the relationship between oxygen saturation and speed-resolved blood perfusion.

This data descriptor outlines a dataset of speed-resolved blood perfusion and oxygen saturation signals recorded locally at the stimulating point before and after stimulation with different levels of thermal stimulation, as well as classical LDF data of the control points and RR interval data of the subjects. It was compiled for our related work[16] with parts of the dataset used in study on complexity changes of local speed-resolved blood perfusion and the relationship between local speed-resolved blood perfusion and the heart rate. The results[16] indicated that different thermal stimulation resulted in different changes in the complexity area index of speed-resolved blood perfusion. Overall, this dataset can be used to study the relationship between local oxygen saturation and speed-resolved blood flux in response to different levels of thermal stimulation. In addition, our present dataset is useful as a reference dataset for various studies on normal or abnormal blood perfusion signal patterns that are common. Because both DRS and LDF have limited penetration depth, the measurements shown here will be restricted to only the superficial regions of the skin.

Methods

These methods are expanded versions of descriptions in our related work[16, 17].

Participants and design

Sixty healthy subjects aged 18 to 60 years were included in this study. Please refer to Data 4 for more details[18]. None of the participants reported neurological, psychiatric, or other brain-related diseases. None of the subjects were taking any medication that would affect cardiovascular or autonomic regulation. Alcohol, tea and coffee intake were prohibited for at least 24 hours prior to measurements. This study was conducted according to the Helsinki declaration, all participants were informed of the experimental procedure, and all patients provided written consent prior to the experiment. Written consent was approved by the Institutional Research Ethics Boards of Acupuncture & Moxibustion of the China Academy of Chinese Medical Sciences.

All recruited participants completed the measurements between 9 a.m. and 5 p.m. Subjects in the thermal stimulation group received a total of 4 different levels of stimulation corresponding to 38°C, 40°C, 42°C and 44°C. The order of thermal stimulation was randomly determined for each patient. The experimental protocol was as follows: All experiments were carried out in a quiet, temperature-controlled (24-26°C) laboratory. After a period of cardiovascular stability (30 min), a baseline recording was made for 30 min. Then, the test subjects were stimulated using a thermal stimulation EPOS (Perimed AB, Stockholm, Sweden) for 30 min followed by a 30-min rest period. For the blank control group (BC group), the measurement process was the

same as that for the temperature stimulation group (TS group), except that the probe was not heated to keep the subjects in a resting state so that the blood flow parameters of the subjects could be obtained in a resting state. The thermal stimulation point was located on the anterior aspect of the forearm, between the tendons of the palmaris longus and the flexor carpi radialis, 5 B-cun proximal to the palmar wrist crease. Control point 1 was located 2 B-cun proximal to the palmar wrist crease, and control point 2 was located 8 B-cun proximal to the palmar wrist crease [19]. The recording points are shown in Figure 1.

Figure 1. The thermal stimulation point and control point in the right forearm. The thermal stimulation point was located on the anterior aspect of the forearm, between the tendons of the palmaris longus and the flexor carpi radialis, 5 B-cun proximal to the palmar wrist crease. Control point 1 was located 2 B-cun proximal to the palmar wrist crease, and control point 2 was located 8 B-cun proximal to the palmar wrist crease. The figure is modified from our related work.

Protocol for the blood perfusion and oxygen saturation measurements

During the recording session, subjects were placed in a supine position, and their forearms were fixed with a vacuum pillow (AB Germa, Kristianstad, Sweden). Microcirculation was measured by a PeriFlux 6000 Enhanced Perfusion and Oxygen Saturation (EPOS; Perimed AB, Stockholm, Sweden) system with a 3-Hz sampling rate according to the previously described recording protocol [8, 20]. All of the measurement processes were set up in the EPOS management system. During measurements, the EPOS flat probe was fixated using double-sided adhesive tape (PF 105-1, Perimed AB, Stockholm, Sweden). The EPOS system was used for a multimodal assessment of the microcirculation using diffuse reflectance spectroscopy (DRS) and LDF. Using the EPOS system, data for both speed-resolved blood perfusion and oxygen saturation signals were obtained simultaneously. The blood perfusion of the stimulated point was evaluated for three speeds (V1, <1 mm/s; V2, 1-10 mm/s; and V3, >10 mm/s). The probe combined both a laser Doppler probe and a thermostatic probe at the stimulated point, which allowed for controlled, consistent heating of the skin area under the probe surface.

The control points are also located on the midline of forearm, which is collinear with the stimulus point and equidistant from the stimulus point. The classic LDFs of both control points (points 1 and 2) were recorded by a PeriFlux 5000 (Perimed AB, Stockholm, Sweden) system with a 64-Hz sampling rate. The method used to record the blood perfusion flux signal is described in our previous studies [21-23]. Thus in the control points, just conventional blood perfusion was recorded and without any stimulation

Both the thermal stimulation point and control points are shown in Figure 1. The temperature recordings, oxygen saturation recordings, speed-resolved perfusion and classic LDF of the control points for one case subject are shown in Figure 2. For the speed-resolved perfusion results recorded by PF6000, the data were exported directly from the EPOS system in MATLAB

format; for the control point results, which were recorded by PF5000, the data were opened with PeriSoft for Windows (version 2.5.5, Perimed, Sweden) and then exported in the txt format. Finally, the data were saved in MATLAB (2015b, MathWorks, Natick, Massachusetts, USA) and Excel format.

Electrocardiogram measurement protocol

The ECG was measured by the NeurOne system (NeurOne, MEGA electronics Ltd, Finland). Subjects were directed to lie down on a comfortable bed, and 3 adhesive Ag/AgCl electrodes (3M, Shanghai, China) were applied to the chest for ECG recording at a sampling rate of 1000 Hz[21, 24-26]. The raw data were saved as Data 5 in EDF format, the files were imported into Kubio HRV software (Kubios HRV Premium 3.0.0, Kubios oy, Kuopio, Finland) in EDF format, and then, the 50-min RR interval time series were extracted and saved in mat format.

Figure 2. Example of raw dataset. (a) The temperature under different temperature. (b) The oxygen saturation under different temperature. (c) The speed-resolved blood perfusion at the stimulation and recording point under different temperature. (d) The classical blood perfusion at control points under different temperature. V1, low speed, <1 %RBC $\times$ mm/s; V2, mid-speed, $1-10$ %RBC $\times$ mm/s; and V3, high speed, >10 %RBC $\times$ mm/s. BP1, blank control point 1; BP2, blank control point 2.

Data records

The dataset can be found on the figshare[18]. Data 1, Data 2 and Data 3 folders contain both matlab and excel format files each. Data 5 contains ECG raw data in EDF format (the data structure is shown in Figure 3). The names of the files under each folder are shown in Table 1, Table 2 and Table 3. The mat file in the Data 1 folder contains 4 matrix elements: oxygen, perfusion, temperature and time. The matrix perfusion element is made up of three columns: v1(<1 %RBC $\times$ mm/s), v2 ($1-10$ %RBC $\times$ mm/s) and v3(>10 %RBC $\times$ mm/s). The oxygen, perfusion and temperature elements are synchronized in time with a 3-Hz sampling rate and are shown in Figure 2a, b, and c. The mat file in the Data 2 folder contains 2 matrix elements, namely, BP_1 and BP_2, from classical LDF recorded at control points with a 64-Hz sampling rate, and these data are shown in Figure 3d. The mat file in the Data 3 folder contains 2 matrix elements: RRs and T_RRs. The RRs represent the R-R time series of the ECG, and the T_RRs represent the time index. The samples were extracted from ECG recordings with a NeurOne

system with a 1000-Hz sampling rate. Data 4, comprising data pertaining to the subjects' characteristics, is presented in CSV format.

TS dataset name					BC dataset name	
ID	38°C	40°C	42°C	44°C	ID	Dataset
T_070	T6_070_38.mat	T6_070_40.mat	T6_070_42.mat	T6_070_44.mat	T_100	T6_100.mat
T_071	T6_071_38.mat	T6_071_40.mat	T6_071_42.mat	T6_071_44.mat	T_101	T6_101.mat
T_072	T6_072_38.mat	T6_072_40.mat	T6_072_42.mat	T6_072_44.mat	T_102	T6_102.mat
T_073	T6_073_38.mat	T6_073_40.mat	T6_073_42.mat	T6_073_44.mat	T_103	T6_103.mat
T_074	T6_074_38.mat	T6_074_40.mat	T6_074_42.mat	T6_074_44.mat	T_104	T6_104.mat
T_075**	T6_075_38.mat	T6_075_40.mat	T6_075_42.mat	T6_075_44.mat	T_105	T6_105.mat
T_076	T6_076_38.mat	T6_076_40.mat	T6_076_42.mat	T6_076_44.mat	T_106	T6_106.mat
T_077	T6_077_38.mat	T6_077_40.mat	T6_077_42.mat	T6_077_44.mat	T_107	T6_107.mat
T_078	T6_078_38.mat	T6_078_40.mat	T6_078_42.mat	T6_078_44.mat	T_108	T6_108.mat
T_079	T6_079_38.mat	T6_079_40.mat	T6_079_42.mat	T6_079_44.mat	T_109	T6_109.mat
T_080	T6_080_38.mat	T6_080_40.mat	T6_080_42.mat	T6_080_44.mat	T_110	T6_110.mat
T_081	T6_081_38.mat	T6_081_40.mat	T6_081_42.mat	T6_081_44.mat	T_111	T6_111.mat
T_082	T6_082_38.mat	T6_082_40.mat	T6_082_42.mat	T6_082_44.mat	T_112	T6_112.mat
T_083	T6_083_38.mat	T6_083_40.mat	T6_083_42.mat	T6_083_44.mat	T_113	T6_113.mat
T_084	T6_084_38.mat	T6_084_40.mat	T6_084_42.mat	T6_084_44.mat	T_114	T6_114.mat
T_085	T6_085_38.mat	T6_085_40.mat	T6_085_42.mat	T6_085_44.mat	T_115	T6_115.mat
T_086	T6_086_38.mat	T6_086_40.mat	T6_086_42.mat	T6_086_44.mat	T_116	T6_116.mat
T_087	T6_087_38.mat	T6_087_40.mat	T6_087_42.mat	T6_087_44.mat	T_117	T6_117.mat
T_088	T6_088_38.mat	T6_088_40.mat	T6_088_42.mat	T6_088_44.mat	T_118	T6_118.mat
T_089	T6_089_38.mat	T6_089_40.mat	T6_089_42.mat	T6_089_44.mat	T_119	T6_119.mat
T_090	T6_090_38.mat	T6_090_40.mat	T6_090_42.mat	T6_090_44.mat	T_120	T6_120.mat
T_091	T6_091_38.mat	T6_091_40.mat	T6_091_42.mat	T6_091_44.mat	T_121	T6_121.mat
T_092	T6_092_38.mat	T6_092_40.mat	T6_092_42.mat	T6_092_44.mat	T_122	T6_122.mat
T_093	T6_093_38.mat	T6_093_40.mat	T6_093_42.mat	T6_093_44.mat	T_123	T6_123.mat
T_094	T6_094_38.mat	T6_094_40.mat	T6_094_42.mat	T6_094_44.mat	T_124	T6_124.mat
T_095	T6_095_38.mat	T6_095_40.mat	T6_095_42.mat	T6_095_44.mat	T_125	T6_125.mat
T_096	T6_096_38.mat	T6_096_40.mat	T6_096_42.mat	T6_096_44.mat	T_126	T6_126.mat
T_097	T6_097_38.mat	T6_097_40.mat	T6_097_42.mat	T6_097_44.mat	T_127	T6_127.mat
T_098	T6_098_38.mat	T6_098_40.mat	T6_098_42.mat	T6_098_44.mat	T_128	T6_128.mat
T_099	T6_099_38.mat	T6_099_40.mat	T6_099_42.mat	T6_099_44.mat	T_129	T6_129.mat

Table 1. The file names of Data 1 (recorded by EPOS). TS, thermal stimulation; BC, blank control.

**, abnormal value of oxygen saturation.

TS dataset name					BC dataset name	
ID	38°C	40°C	42°C	44°C	ID	Dataset
T_070	T5_070_38.mat	T5_070_40.mat	T5_070_42.mat	T5_070_44.mat	T_100	T5_100.mat
T_071	T5_071_38.mat	T5_071_40.mat	T5_071_42.mat	T5_071_44.mat	T_101	T5_101.mat
T_072	T5_072_38.mat	T5_072_40.mat	T5_072_42.mat	T5_072_44.mat	T_102	T5_102.mat
T_073	T5_073_38.mat	T5_073_40.mat	T5_073_42.mat	T5_073_44.mat	T_103	T5_103.mat
T_074	T5_074_38.mat	T5_074_40.mat	T5_074_42.mat	T5_074_44.mat	T_104	T5_104.mat
T_075	T5_075_38.mat	T5_075_40.mat	T5_075_42.mat	T5_075_44.mat	T_105	T5_105.mat
T_076	T5_076_38.mat	T5_076_40.mat	T5_076_42.mat	T5_076_44.mat	T_106	T5_106.mat
T_077	T5_077_38.mat	T5_077_40.mat	T5_077_42.mat	T5_077_44.mat	T_107	T5_107.mat
T_078	T5_078_38.mat	T5_078_40.mat	T5_078_42.mat	T5_078_44.mat	T_108	T5_108.mat
T_079	T5_079_38.mat	T5_079_40.mat	T5_079_42.mat	T5_079_44.mat	T_109	T5_109.mat
T_080	T5_080_38.mat	T5_080_40.mat	T5_080_42.mat	T5_080_44.mat	T_110	T5_110.mat
T_081	T5_081_38.mat	T5_081_40.mat	T5_081_42.mat	T5_081_44.mat	T_111	T5_111.mat
T_082	T5_082_38.mat	T5_082_40.mat	T5_082_42.mat	T5_082_44.mat	T_112	T5_112.mat
T_083	T5_083_38.mat	T5_083_40.mat	T5_083_42.mat	T5_083_44.mat	T_113	T5_113.mat
T_084	T5_084_38.mat	T5_084_40.mat	T5_084_42.mat	T5_084_44.mat	T_114	T5_114.mat
T_085	T5_085_38.mat	T5_085_40.mat	T5_085_42.mat	T5_085_44.mat	T_115	T5_115.mat
T_086	T5_086_38.mat	T5_086_40.mat	T5_086_42.mat	T5_086_44.mat	T_116	T5_116.mat
T_087	T5_087_38.mat	T5_087_40.mat	T5_087_42.mat	T5_087_44.mat	T_117	T5_117.mat
T_088	T5_088_38.mat	T5_088_40.mat	T5_088_42.mat	T5_088_44.mat	T_118	T5_118.mat
T_089	T5_089_38.mat	T5_089_40.mat	T5_089_42.mat	T5_089_44.mat	T_119	T5_119.mat
T_090	T5_090_38.mat	T5_090_40.mat	T5_090_42.mat	T5_090_44.mat	T_120	T5_120.mat
T_091	T5_091_38.mat	T5_091_40.mat	T5_091_42.mat	T5_091_44.mat	T_121	T5_121.mat
T_092	T5_092_38.mat	T5_092_40.mat	T5_092_42.mat	T5_092_44.mat	T_122	T5_122.mat
T_093	T5_093_38.mat	T5_093_40.mat	T5_093_42.mat	T5_093_44.mat	T_123	T5_123.mat
T_094	T5_094_38.mat	T5_094_40.mat	T5_094_42.mat	T5_094_44.mat	T_124	T5_124.mat
T_095	T5_095_38.mat	T5_095_40.mat	T5_095_42.mat	T5_095_44.mat	T_125	T5_125.mat
T_096	T5_096_38.mat	T5_096_40.mat	T5_096_42.mat	T5_096_44.mat	T_126	T5_126.mat
T_097	T5_097_38.mat	T5_097_40.mat	T5_097_42.mat	T5_097_44.mat	T_127	T5_127.mat
T_098	T5_098_38.mat	T5_098_40.mat	T5_098_42.mat	T5_098_44.mat	T_128	T5_128.mat
T_099	T5_099_38.mat	T5_099_40.mat	T5_099_42.mat	T5_099_44.mat	T_129	T5_129.mat

Table 2. The file names of Data2 (recorded by PF5000). TS, thermal stimulation; BC, blank control

TS dataset name					BC dataset name	
ID	38°C	40°C	42°C	44°C	ID	Dataset
T_070	T_070_38.mat	T_070_40.mat	T_070_42.mat	T_070_44.mat	T_100	T_100.mat
T_071	T_071_38.mat	T_071_40.mat	T_071_42.mat	T_071_44.mat	T_101	T_101.mat
T_072	T_072_38.mat	T_072_40.mat	T_072_42.mat	T_072_44.mat	T_102	T_102.mat
T_073	T_073_38.mat	T_073_40.mat	T_073_42.mat	T_073_44.mat	T_103	T_103.mat
T_074	T_074_38.mat	T_074_40.mat	T_074_42.mat	T_074_44.mat	T_104	T_104.mat
T_075	T_075_38.mat	T_075_40.mat	T_075_42.mat	T_075_44.mat	T_105	T_105.mat
T_076	T_076_38.mat	T_076_40.mat	T_076_42.mat	T_076_44.mat	T_106	T_106.mat
T_077	T_077_38.mat	T_077_40.mat	T_077_42.mat	T_077_44.mat	T_107	T_107.mat
T_078	T_078_38.mat	T_078_40.mat	T_078_42.mat	T_078_44.mat	T_108	T_108.mat
T_079	T_079_38.mat	T_079_40.mat	T_079_42.mat	T_079_44.mat	T_109	T_109.mat
T_080	T_080_38.mat	T_080_40.mat	T_080_42.mat	T_080_44.mat	T_110	T_110.mat
T_081	T_081_38.mat	T_081_40.mat	T_081_42.mat	T_081_44.mat	T_111	T_111.mat
T_082	T_082_38.mat	T_082_40.mat	T_082_42.mat	T_082_44.mat	T_112	T_112.mat
T_083	T_083_38.mat	T_083_40.mat	T_083_42.mat	T_083_44.mat	T_113	T_113.mat
T_084	T_084_38.mat	T_084_40.mat	T_084_42.mat	T_084_44.mat	T_114	T_114.mat
T_085	T_085_38.mat	T_085_40.mat	T_085_42.mat	T_085_44.mat	T_115	T_115.mat
T_086	T_086_38.mat	T_086_40.mat	T_086_42.mat	T_086_44.mat	T_116	T_116.mat
T_087	T_087_38.mat	T_087_40.mat	T_087_42.mat	T_087_44.mat	T_117	T_117.mat
T_088	T_088_38.mat	T_088_40.mat	T_088_42.mat	T_088_44.mat	T_118	T_118.mat
T_089	T_089_38.mat	T_089_40.mat	T_089_42.mat	T_089_44.mat	T_119	T_119.mat
T_090	T_090_38.mat	T_090_40.mat	T_090_42.mat	T_090_44.mat	T_120	T_120.mat
T_091	T_091_38.mat	T_091_40.mat	T_091_42.mat	T_091_44.mat	T_121	T_121.mat
T_092	T_092_38.mat	T_092_40.mat	T_092_42.mat	T_092_44.mat	T_122	T_122.mat
T_093	T_093_38.mat	T_093_40.mat	T_093_42.mat	T_093_44.mat	T_123	T_123.mat
T_094	T_094_38.mat	T_094_40.mat	T_094_42.mat	T_094_44.mat	T_124	T_124.mat
T_095	T_095_38.mat	T_095_40.mat	T_095_42.mat	T_095_44.mat	T_125	T_125.mat
T_096	T_096_38.mat	T_096_40.mat	T_096_42.mat	T_096_44.mat	T_126	T_126.mat
T_097	T_097_38.mat	T_097_40.mat	T_097_42.mat	T_097_44.mat	T_127	T_127.mat
T_098	T_098_38.mat	T_098_40.mat	T_098_42.mat	T_098_44.mat	T_128	T_128.mat
T_099	T_099_38.mat	T_099_40.mat	T_099_42.mat	T_099_44.mat	T_129	T_129.mat

Table 3. The file names of Data 3 (50-min RR interval extracted from Data 5) and Data 5 (ECG signal recorded by NeurOne system). TS, thermal stimulation; BC, blank control.

Figure 3. The structure of the database. Data 1, Data 2, Data 3, Data 4 and Data 5 can be found in figshare (<https://doi.org/10.6084/m9.figshare.8299343.v4>).

Technical validation

To exclude motion artefacts, the subjects' forearms were fixed with a vacuum pillow (AB Germa, Kristianstad, Sweden). During the recording, if the haemoglobin signature in the DRS spectra was too weak, the RBC oxygen saturation estimation became unstable. The oxygen saturation estimate was hence discarded for haemoglobin areas that were too small and if the estimated RBC tissue concentration was below 0.1 % [20]. During data preprocessing, any outliers were replaced using the linear interpolation method. By default, an outlier is a value that is more than three scaled median absolute deviations (MADs) away from the median.

In the current dataset, data for oxygen saturation and speed-resolved blood perfusion were obtained simultaneously, and coherence analysis was performed between oxygen saturation and speed-resolved blood perfusion. To calculate the coherence between oxygen saturation and speed-resolved blood perfusion, the coherence value was estimated by the following equation [27]:

$$C_{xy}(f) = \frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)}$$

where $P_{xy}(f) = \int_{-\infty}^{\infty} R_{xy}(t)e^{-jft} dt$, and thus, $P_{xy}(f)$ is the Fourier transform of the R_{xy} (R_{xy} is the cross-correlation of x and y). This equation obtains the magnitude squared coherence estimate $C_{xy}(f)$ of the input signals x and y using Welch's averaged, modified periodogram

method. The value of $C_{xy}(f)$ is between 0 and 1 and indicates how well x corresponds to y at each frequency. The results (Figure 4) showed that the coherence value between blood flux and oxygen saturation was stable both before and after thermal stimulation.

In general, the flow with speeds below 1 mm/s are associated with capillary flow, although some venular flow may also fall into that category. The speeds 1-10 mm/s is foremost constituted by flow in venules, small arterioles and, under some circumstances, veins. The flow speeds above 10 mm/s are primarily related to flow in larger arterioles and other larger vessels situated in the sampling volume. It should be noted, however, that these relationships between flow speed and vessel type may be altered during for example heating provocations

or when pressure is applied. Under some conditions, capillaries may act as shunting vessels and then likely contain flow speeds above 1 mm/s, but in that situation those capillaries do not contribute to the nutritive flow. Therefore, when interpreting the data, we should pay attention to the following points: First, the data we get are distinguished by speed, not by blood vessel type; Second, under the condition of thermal stimulation, the standard value of speed to distinguish blood flow may change, no longer 1mm/s and 10 mm/s, and it should be increased appropriately; Third, oxygen saturation are different in different vessel types. It is a potential method to correct speed-resolved blood flow through relationship between oxygen saturation and speed-resolved blood flow.

Figure 4. Coherence analysis results between oxygen saturation and speed-resolved blood perfusion. (a) The coherence value between oxygen saturation and V1 blood perfusion before thermal stimulation. (b) The coherence value between oxygen saturation and V2 blood perfusion before thermal stimulation. (c) The coherence value between oxygen saturation and V3 blood perfusion before thermal stimulation. (d) The coherence value between oxygen saturation and V1 blood perfusion after thermal stimulation. (e) The coherence value between oxygen saturation and V2 blood perfusion after thermal stimulation. (f) The coherence value between oxygen saturation and V3 blood perfusion after thermal stimulation. V1, low speed, $<1\% \text{RBC} \times \text{mm/s}$; V2, mid-speed, $1-10\% \text{RBC} \times \text{mm/s}$; and V3, high speed, $>10\% \text{RBC} \times \text{mm/s}$. Oxy, oxygen saturation. Data are presented as the mean $\pm$ sem.

Data availability

Guangjun, W., Shuyong, J., Xiaojing, S., Weibo, Z. (2019): A dataset of speed-resolved blood perfusion and oxygen saturation after different thermal stimulation. figshare <https://doi.org/10.6084/m9.figshare.8299343.v4>. Readers can access codes in our datasets at figshare.com. Among these codes, MATLAB codes named "Code for Data 1.zip" for extract data from raw datasets can be found.

Competing interests

The authors declare that they have no competing interests.

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Author contributions

Wang Guangjun designed and performed the experiment.

Wang Guangjun, Jia Shuyong, Song Xiaojing and Zhang Weibo collected and checked the data.

Wang Guangjun analysed the data.

Wang Guangjun wrote the paper.

All of the authors read, revised and approved the final manuscript

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