Laser Speckle Contrast Images
Processing of Data to Analyze Microvascular Variations in Hand Skin of Healthy Subjects

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Abstract: Diseases such as frostbite, Raynaud's phenomenon, carpal tunnel syndrome, systemic sclerosis, hand burns, hand flaps or hand wounds lead to microvascular dysfunctions. These diseases can affect only one hand and even sometimes only some fingers. Therefore, in order to quantify the microvascular alterations, it can be useful to compare microvascular perfusion of both hands (altered versus healthy hand). However, skin microvasculature presents spatial variations and the possibility to directly compare perfusion values of the two hands has not been studied yet. We therefore propose to quantify these spatial variations. For this purpose, perfusion values from laser speckle contrast images (LSCI) of the two hands (dorsal faces) from seven young healthy subjects are acquired simultaneously and then processed. The results show that the dorsal faces of the two hands in our young healthy subjects present close perfusion values (average coefficient of variation less than 9% for our subjects). These findings are preliminary observations to quantify the microvascular alterations in the above-mentioned diseases. The coefficient of variation in diseased states remains to be studied in order to see whether LSCI could be of interest to improve the diagnosis of hand skin pathologies.

1 INTRODUCTION

Microvascular dysfunction in hands is an early stage in several pathologies. Thus, for diseases such as frostbite (Foray, 1992), Raynaud's phenomenon (Brown, 2012; Gladue et al., 2013), carpal tunnel syndrome (Shannon and Rizzolo, 2012), systemic sclerosis (Wigley, 2009; Herrick, 2000), hand burns (Meier et al., 2011; Barachini et al., 2004), hand flaps (Du et al., 2011; Soderstrom et al., 1999) or hand wounds, hand skin microvasculature is specifically affected: morphological abnormalities of the capillaries (enlarged loops, giant capillaries, ramifications, capillary disorganization), microhemorrhages or lower density (capillary loss) (DeAngelis et al., 2009). Altered hand skin microvascular function could therefore be a surrogate marker for the above-mentioned diseases. In order to quantify such vascular dysfunctions, accurate and sensitive measurement techniques have become a key issue.

Recently, the laser speckle contrast imaging (LSCI) technique has been proposed for skin microcirculation monitoring (Humeau-Heurtier et al., 2013a; Rege et al., 2012; Mahe et al., 2012b; Mahe et al., 2012c; Miao et al., 2010; Draijer et al., 2009). LSCI gives a 2D map of the microvascular blood perfusion (see an example in Fig. 1). The principles of LSCI rely on the illumination of tissues (optically rough surface) by a laser light. Raw speckle reflectance images are collected with a CCD camera. Motions (e.g., blood flow) in the tissues alter the speckle pattern over time. A faster blood flow leads to more blurring in the captured image than slower flow or no flow. The degree of blurring is quantified as the local speckle contrast value, with zero contrast (no speckle pattern) corresponding to high blood flow, and unity contrast (fully developed speckle pattern) to no flow. The speckle contrast K is defined as the ratio of the standard deviation to the mean intensity $\langle I \rangle$, as (Briers and Webster, 1996)

$$K = \frac{\sigma_s}{\langle I \rangle}, \quad (1)$$

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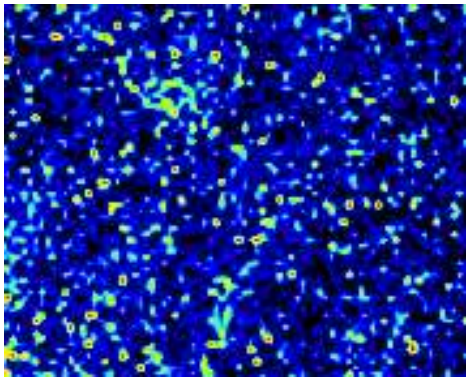

Figure 1: Laser speckle contrast image of a zone on the dorsal face of the hand from a healthy subject.

where σ_s refers to the spatial standard deviation of the speckle intensity. The speckle contrast K is a function of the exposure time T of the camera and is related to the autocovariance of the intensity fluctuations in a single speckle (Fercher and Briers, 1981)

$$K^2 = \frac{\sigma_s^2(T)}{\langle I \rangle^2} = \frac{1}{T\langle I \rangle^2} \int_0^T C_t(\tau) d\tau, \quad (2)$$

where $C_t(\tau)$ is the autocovariance of the intensity fluctuations in a single speckle. The contrast value is used to form the microvascular blood perfusion image (Draijer et al., 2009).

In diseases such as frostbite, Raynaud's phenomenon, carpal tunnel syndrome, systemic sclerosis, burns, flaps and wounds, skin microvascular alterations and vascular dysfunctions may affect only one hand (the diseased one). In order to quantify such alterations and dysfunctions, it can be useful to compare skin perfusion values of the diseased hand to skin perfusion values of the healthy hand. However, due to spatial variations of perfusion in skin, the question relative to the possibility to directly compare LSCI perfusion values of the two hands still has to be answered. Thus, in the case of no disease, are perfusion values of both hands similar? Are there variations from one hand to the other? If yes, is it possible to quantify them?

In order to quantify spatial variations between the perfusion values of two hands from healthy subjects, we herein propose to process laser speckle contrast images acquired simultaneously in the two hands of voluntary subjects.

2 MATERIALS AND METHODS

2.1 Measurement Procedure

Seven Caucasian healthy subjects participated in the study (six men, one woman; 22.6 $\pm$5 years old). All the subjects provided written, informed consent prior to participation and the study was carried out in accordance with the Declaration of Helsinki. Each subject was sitted confortably in a quiet room with controlled temperature and without any air movements (Mahe et al., 2012a). They were asked to position the ventral face of each hand on a table. LSCI data of both hands were acquired in laser speckle perfusion units (LSPU) with a PeriCam PSI System (Perimed, Sweden) having a laser wavelength of 785 nm and an exposure time of 6 ms. The distance between the laser head to skin was set around 24 cm (Mahe et al., 2011), which gave an average image resolution of 0.6 mm. Laser speckle contrast images were acquired and stored for 5 min with a sampling frequency of 18 Hz on a computer and analyzed off-line.

2.2 Image Processing Procedure

After the acquisitions, five pixels on each hand were randomly chosen on the first image of the LSCI sequence. These pixels are thereafter noted as P_i, with i varying between 1 and 5. Then, for each pixel P_i, the amplitude value was followed with time on the image sequence (5 min) to obtain a time-evolution signal, noted thereafter as $sP_i(t)$. Around each of these five pixels P_i, five square regions of interest (ROI), each of different size, were also determined: 3.2 mm^2 (3 pixels$\times$3 pixels), 29.1 mm^2 (9 pixels$\times$9 pixels), 81.0 mm^2 (15 pixels$\times$15 pixels), 190.4 mm^2 (23 pixels$\times$23 pixels), 345.9 mm^2 (31 pixels$\times$31 pixels) (see (Humeau-Heurtier et al., 2013b)). Pixel values inside each ROI were averaged and followed with time on the image sequence (5 min) to obtain time-evolution signals, noted thereafter as $sROI_jP_i(t)$ for the ROI j around the pixel P_i, j corresponding to the size of the square value (3, 9, 15, 23, or 31). Then, for each hand, the five time-evolution signals $sP_i(t)$ were averaged in time to obtain five LSCI perfusion values which were averaged together. The same was performed for the five time-evolution signals $sROI_jP_i(t)$. For each hand and for each of the seven subjects, we therefore had one LSCI perfusion value corresponding to the five pixels and one LSCI perfusion value corresponding to each of the five ROI sizes (see Fig. 2).

The coefficient of variation (CV) was computed to compare the LSCI perfusion values between each hand. The CV was calculated according to the procedure proposed by Hopkins (Hopkins, 2000). For this purpose, the perfusion value from the five pixels P_i of one hand was compared to the perfusion value from the five pixels P_i of the other hand. The same was

Table 1: Average perfusion values in LSPU for the 7 subjects for each ROI size and for the two hands. ROI sizes are in pixels × pixels (see text for details).

Size of ROI	Pixel	3×3	9×9	15×15	23×23	31×31
Left hand	65.0	64.6	64.0	63.8	64.3	65.9
Right hand	67.6	67.4	67.1	67.5	67.8	69.1
Average	66.3	66.0	65.6	65.6	66.1	67.5

Table 2: Coefficient of variation (CV, in percentage) between the perfusion values of the two hands of healthy subjects. ROI sizes are in pixels × pixels (see text for details).

Size of ROI	Pixel	3×3	9×9	15×15	23×23	31×31
CV for subject 1	7.9	8.2	6.9	7.1	7.2	7.9
CV for subject 2	6.7	5.4	4.0	6.7	6.8	5.0
CV for subject 3	10.3	10.3	6.7	3.9	2.4	2.2
CV for subject 4	5.9	5.1	5.8	5.1	5.4	6.6
CV for subject 5	8.2	8.4	8.8	7.1	4.6	3.8
CV for subject 6	5.4	5.2	3.5	3.9	4.1	5.1
CV for subject 7	16.2	16.2	11.4	10.1	10.1	9.7
Average CV	8.7	8.4	6.7	6.3	5.8	5.8

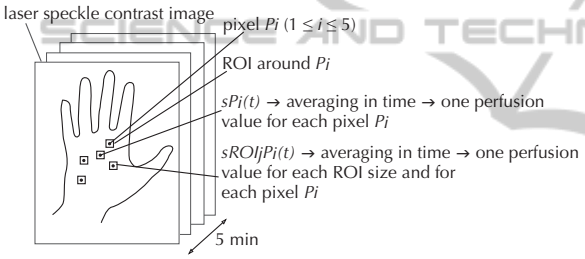

Figure 2: Schematic representation of the signals processed. Only one hand is represented here. On our recordings, the two hands were present on each image.

performed for each ROI size.

3 RESULTS AND DISCUSSION

The results obtained for the analysis of the spatial variations are shown in Tables 1 and 2. From Table 1 we observe that the average perfusion value is 66.1 LSPU when the two hands are considered together (average perfusion value between 65.6 LSPU and 67.5 LSPU). When the two hands are considered separately, we observe that the average perfusion values are very similar for both hands but that the average perfusion value is slightly higher for the right hand than for the left hand, whatever the ROI size (see Table 1). In that case, the standard deviation varies from 11.5 LSPU and 15.4 LSPU. The slightly higher value for the perfusion in the right hand compared to the one of the left hand may be due to the fact that all our subjects were right-hander. To analyze these results, we computed the standard deviation of the perfusion values obtained on a white surface (same measurement procedure as for the hands). For the same ROI sizes as for the hands, we obtain standard deviation values of the difference between the points in the white surface between 0.7 LSPU and 4.3 LSPU (0.7 LSPU for a ROI of 31×31 pixels and 4.3 LSPU for a ROI of the size of the pixel). For the white surface, the standard deviation decreases for larger ROI sizes since we have less noise in the perfusion values when more data points are used for the analysis. These standard deviations on the white surface are much lower than the ones found for the hands.

Moreover, from Table 2 we note that the CV between the perfusion values of the two hands varies between subjects but is always lower than 16.2% for a ROI of the size of a pixel for a subject, and lower than 9.7% for a ROI size of 31 pixels×31 pixels for a subject. The average CV for the 7 subjects is low ($< 9\%$) for each size of ROI analyzed (see Table 2). Furthermore, the larger the ROI size (between 3.2 mm^2 and 345.9 mm^2), the lower the average CV value.

All these results show that, despite the spatial variations in skin microcirculation, the dorsal face of the two hands in healthy subjects present close perfusion values (average CV $< 9\%$). These findings lead to the suggestion that, for patients with diseases affecting one hand (e.g., frostbite, Raynaud's phenomenon, carpal tunnel syndrome, systemic sclerosis, hand burns, hand flaps or hand wounds), it may be possible to quantify skin microvascular alterations and vascular dysfunctions by comparing laser speckle contrast images perfusion of the two hands.

4 CONCLUSIONS

Spatial variations in perfusion values from the two hands of healthy subjects are herein studied from laser speckle contrast images. We show that the dorsal face of the two hands in healthy subjects present close perfusion values (CV $<$ 9.7% for a ROI size of 31 pixels$\times$31 pixels). The possible increase of CV in diseased states remains to be studied in order to see whether LSCI could be of interest to improve the diagnosis of diseases such as frostbite, Raynaud's phenomenon, carpal tunnel syndrome, systemic sclerosis, hand burns, hand flaps or hand wounds.

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