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Relationship between the blood perfusion values determined by laser speckle imaging and laser Doppler imaging in normal skin and port wine stains

Defu Chen [a], Jie Ren [b], Ying Wang [b], Hongyou Zhao [b], Buhong Li [c], Ying Gu [b,*]

[a] School of Information and Electronics, Beijing Institute of Technology, Beijing 100081, China
[b] Department of Laser Medicine, Chinese People's Liberation Army General Hospital, Beijing 100853, China
[c] Key Laboratory of Optoelectronic Science and Technology for Medicine of Ministry of Education, Fujian Provincial Key Laboratory for Photonics Technology, Fujian Normal University, Fujian 350007, China

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ABSTRACT

Objective: Laser Doppler imaging (LDI) and laser speckle imaging (LSI) are two major optical techniques aiming at non-invasively imaging the skin blood perfusion. However, the relationship between perfusion values determined by LDI and LSI has not been fully explored.
Methods: 8 healthy volunteers and 13 PWS patients were recruited. The perfusions in normal skin on the forearm of 8 healthy volunteers were simultaneously measured by both LDI and LSI during post-occlusive reactive hyperemia (PORH). Furthermore, the perfusions of port wine stains (PWS) lesions and contralateral normal skin of 10 PWS patients were also determined. In addition, the perfusions for PWS lesions from 3 PWS patients were successively monitored at 0, 10 and 20 min during vascular-targeted photodynamic therapy (V-PDT). The average perfusion values determined by LSI were compared with those of LDI for each subject.
Results: In the normal skin during PORH, power function provided better fits of perfusion values than linear function: powers for individual subjects go from 1.312 to 1.942 (R^2 = 0.8967–0.9951). There was a linear relationship between perfusion values determined by LDI and LSI in PWS and contralateral normal skin (R^2 = 0.7308–0.9623), and in PWS during V-PDT (R^2 = 0.8037–0.9968).
Conclusion: The perfusion values determined by LDI and LSI correlate closely in normal skin and PWS over a broad range of skin perfusion. However, it still suggests that perfusion range and characteristics of the measured skin should be carefully considered if LDI and LSI measures are compared.

1. Introduction

The human cutaneous microcirculation has been considered as a crucial surrogate marker of systemic microvascular function in a variety of injuries and diseases [1–3]. Over recent years, several laser-based techniques have been developed for assessing the microcirculatory blood perfusion [1,2,4,5]. Among these techniques, laser Doppler and laser speckle contrast techniques play a preponderant role in the clinical and experimental studies [3]. Both these two techniques can be used to obtain the microcirculatory blood perfusion values, but the analytical methods applied to the two techniques are different [6,7].

Laser Doppler technique analyze beat frequencies that are related to the mixing of Doppler-shift light scattered from the moving red blood cells, with the non-shift light scattered from the stationary tissue components [8,9]. Laser Doppler flowmetry (LDF) is the initially developed laser Doppler technique and has been used for nearly 40 years. Single-point LDF provides good temporal resolution but poor reproducibility due to the regional heterogeneity of skin perfusion (especially in low capillary density skin area) [10]. This drawback was addressed by laser Doppler imaging (LDI). The conventional LDI obtain a two-dimensional image of tissue perfusion by rastering of a laser beam horizontally and vertically across the tissue surface, which may take several minutes [11]. In order to reduce the acquisition time, a new generation of commercial LDI technique called laser Doppler line scanner (LDLS), which raster a line of pixels in parallel at a single time step, was developed [8,12]. The LDLS technique allows for a series of perfusion measurements that performed in parallel [2]. The improvement significantly

* Corresponding author. Fax: +86 10 6822 2584.
E-mail address: guyinglaser301@163.com (Y. Gu).

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reduces the acquisition time and thus it brings LDI technique one step closer to real time imaging [2]. Recently, a high-speed LDI using an integrating CMOS sensor for full-field scanning has been also developed, but the instrument can only measure the area of about 50 cm^2 in size [13].

Laser speckle contrast imaging (LSCI) is based on the spatial and/or temporal statistics of the speckle pattern [14,15]. The traditional LSCI is a non-contact, full-field, real-time technique by calculating the spatial speckle contrast, which is defined as the ratio of the standard deviation of the intensity to the mean intensity over a square of 5×5 or 7×7 pixels window sliding in one image [16]. Consequently, LSCI has the disadvantage of a lack of spatial resolution. In order to overcome this limitation, a new form of LSCI called laser speckle imaging (LSI) based on the speckle temporal contrast, which is determined in 1 pixel over a sequence of images, has been developed [17–19]. As compared with the conventional LSCI, LSI maintains the full spatial resolution of CCD camera but with a lower temporal resolution [19].

Although laser Doppler and laser speckle contrast techniques were widely used for microvascular blood perfusion measurement, the relationship between perfusion values determined by the two techniques has not been fully explored [3,17,20–26]. Recently, more and more studies have been focused on elucidating the relationship [17,20–26]. Since the laser Doppler and laser speckle techniques cannot provide perfusion values in absolute units, most recent studies tried to analyze the relationship between perfusion values determined by single-point/integrating-probe LDF and LSCI coupled with specific reactivity tests [3,20–23]. Among the tests, the increase in blood perfusion of normal skin on the forearm above baseline levels following release from brief arterial occlusion, commonly known as post-occlusive reactive hyperemia (PORH), is one of the most commonly used [3,20–22]. The perfusion values are rapidly changing after the release of occlusion during PORH. The obtained results showed that the relationship between perfusion values determined by single-point/integrating-probe LDF and LSCI is non-linear in normal skin on the forearm during PORH. Nevertheless, the works only compared data from single-point/integrating-probe LDF with full-field LSCI. Comparing data from LDI with those of LSCI would have made more sense, as LDI are 'regional' and not single-point as LDF [27]. However, the acquisition of an image for the conventional LDI requires a few minutes when they depend on the scanning of the tissues, which make PORH difficult to measure with the LDI. As a result, the relationship between perfusion values determined by LDI and LSCI in normal skin during PORH has never been investigated.

Port wine stains (PWS) birthmarks are congenital and progressive vascular malformations histologically characterized by ecstatic capillaries predominantly in the upper dermis of human skin [28]. The incidence of PWS is estimated to be approximately 0.3–0.5%. Vascular-targeted photodynamic therapy (V-PDT) is widely considered to be an effective method for the treatment of PWS [28,29]. The perfusion in PWS can be assessed objectively and noninvasively by LSI [29–31] and LDI [32–34], and significant changes in PWS perfusion was observed during V-PDT [31,32]. However, the perfusion values of PWS as assessed by LDI and LSI have never been directly compared.

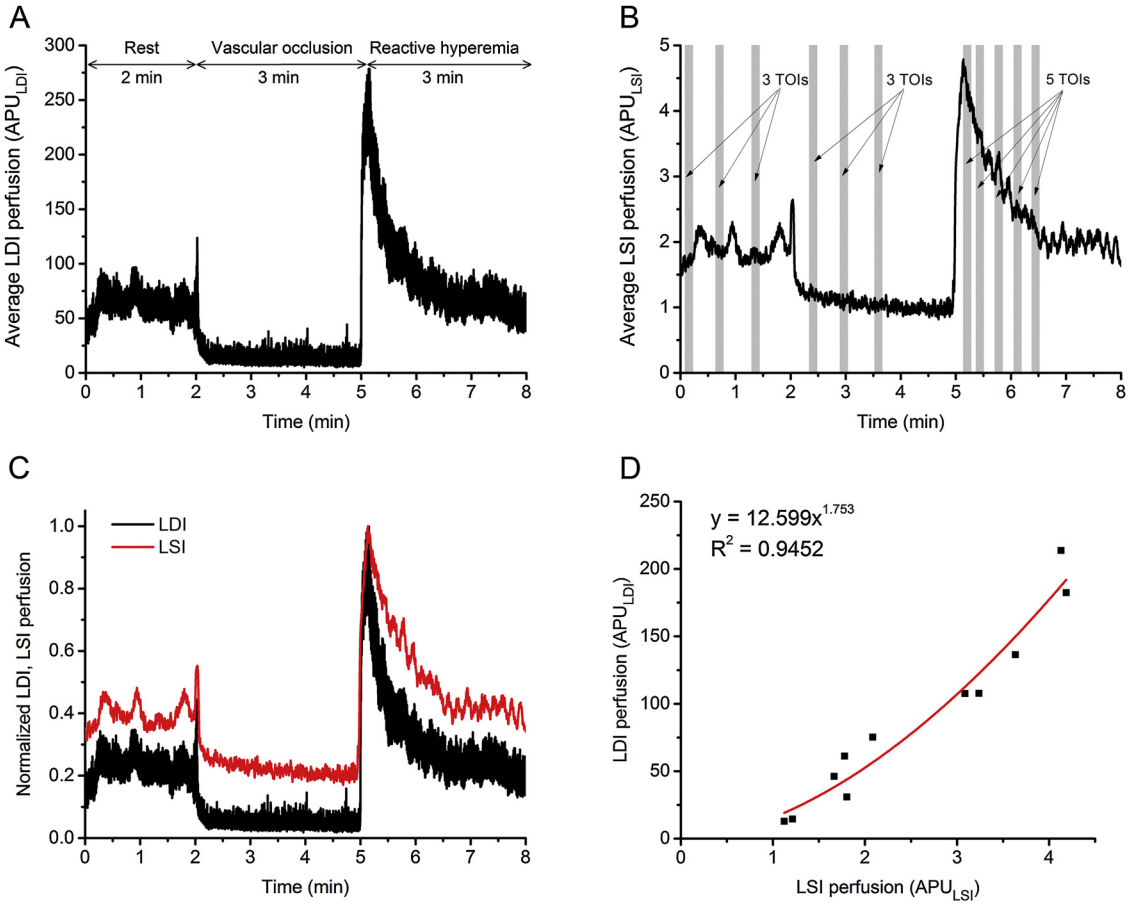

Fig. 1. Typical normal skin perfusion (male, 28 years, non-smoker) measured by (A) LDI and (B) LSI as a function of time during a rest (2 min), vascular occlusion (3 min) and reactive hyperemia (3 min) sequence, for a typical subject. (C) Normalized skin perfusion values determined by LDI (black line) and LSI (red line), respectively. (D) The LSI perfusion data plotted against LDI perfusion data for the subject.(For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)