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Application Conditions of Laser Speckle Contrast Imaging Analyzer Based on Dynamic Scattering Material

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Abstract
Objective: To find out the factors that affect the measurement results of laser speckle contrast imaging (LSCI) by simulating using conditions. Methods: Using fresh animal blood as dynamic scattering material, the practical conditions and parameters were simulated to explore the application conditions of laser speckle imaging analyzer. The LSCI device we used was a commercial product (Laser Speckle Blood Flow Imager Ⅱ, SIM BFI WF, SIM Opto-Technology Co., Ltd, Wuhan, China.). First, in a certain range of blood flow velocity experiments, we aimed to get the corresponding blood flow velocity detection range of the laser speckle contrast imaging analyzer. Then, we explored the changes of laser speckle contrast imaging analyzer results under five conditions : different surface colors ; different exposure times (1-15ms), different light conditions (shading, lamplight and no light), different distances between the probe and the object (15, 20, 25, 35, 35, 40, 45, 50cm), and different angles between the probe laser beam and the object (90°, 85°, 80°, 75°, 70°, 65°). Results: 1. Within a certain range of blood flow velocity, the laser speckle contrast imaging analyzer could relatively and accurately reflect the changes in blood flow velocity. 2. The surface color of the object, exposure time, the distance between the probe and the object, and the angle between the probe laser beam and the object all had an influence on the results. Conclusion: The color of the object, the set of exposure time, the light condition, the probe distance and the angle between probe laser beam and object are all LSCI influence factors.

Keywords: *Laser speckle contrast imaging (LSCI), application conditions, affecting factors, blood flow velocity*

I. Introduction

Laser speckle contrast imaging (LSCI) is a novel technique for analyzing the micromotion of objects [1, 2]. When the coherent laser irradiates on the rough surface of the object, it will produce a particle-like image between the bright and dark phases. It is vague, known as the laser speckle phenomenon, and has been considered as a noise that interferes with the resolution of laser imaging [3-5]. When the scattering particles in the object move, the corresponding speckle intensity fluctuation also changes, hence the dynamic speckle contains the information of the velocity change of the object [6, 7].

The metabolism of the human body is carried out every second, and the change of blood perfusion affects the function of various tissues and cells at all times. LSCI makes microcirculation blood perfusion assessment feasible [1, 2]. LSCI has advantages over other blood flow detectors: in a way of no contact, no tracer medium, no multi-point scanning, it can monitor regional blood flow changes with a temporal resolution of tens of milliseconds and a spatial resolution of tens of microns [8]. It has been widely used in clinical practices [9]: intraoperative monitoring of microcirculation and organ blood perfusion [10-14], evaluation of the prognosis of wound surfaces in burn patients [15], evaluation of fingertip microcirculation in patients with Reynolds syndrome [16, 17], and the evaluation of local block anesthesia effects [18].

Few previous studies reported the response range of LSCI [19], and the application conditions: effects of setting of exposure time [20], light conditions [15], the distance between the probe and the object [15, 21], and the angle between the probe laser beam and the object [22]. However, different research teams have different hardware

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configurations such as data processing algorithms [23], laser transmitters [24], and acquisition cameras [25]. The conclusions of these studies are not exactly consistent with the results observed by the instrument we used. And it is worth mentioning that we observed that the surface color of the object also affected the results, which has not been reported in previous studies. In order to obtain stable and reliable blood perfusion results, we need to simulate the actual conditions and parameters in the study to find out the factors affecting the results of the laser speckle imaging instrument.

II. Materials and Methods

A commercial laser speckle blood flow imaging analyzer (Laser Speckle Blood Flow Imager II, SIM BFI WF, SIM Opto-Technology Co., Ltd., Wuhan, China) was used in application experiments. Fresh arterial blood was applied to explore the blood flow velocity detection range of the laser speckle imager and the factors that affect the measurement results in practical use.

2.1 Acquisition of animal arterial blood

Adult male New Zealand rabbit was anesthetized by intraperitoneal injection of 10% chloral hydrate solution at a dose of 3-5ml/kg. After the full onset of anesthesia, the heart blood was taken, 25-30ml each time. The pre-configured heparin sodium reagent (1mg/ml) was fully mixed with the arterial blood and then kept in an icebox for use.

2.2 Detection of the response range

The collection of fresh anticoagulant arterial blood was put into a 50ml syringe, the blood flows through a fixed one-time used sterile extension tube which inner diameter is 3mm, with the LSCI probe overed it. Through careful calculation, the infusion range of the micro-infusion pump was controlled in 0-900ml/h (simulated pipeline actual blood flow rate in the range of 0-35mm/s) for laser speckle contrast imaging analysis.

The experimental exposure time was set to 10ms, the probe distance between the laser probe and the object was 25cm, the angle between the probe laser beam and the object was 90°.

2.3 Results acquisition of different exposure time

After the transparent sterile extension tube was fixed, the surface was marked with blue, red, yellow, and black ink of about 1cm each. In this study, an unmarked segment was selected as the blank control segment. The different exposure time conditions were tested with a 75ml/h pump flow rate, and 1-15ms was selected as the exposure time range.
Experiments were done in the outpatient room with no light environment, the distance between the laser probe and the object was 35cm, and the angle between the probe laser beam and the object was 90°.

2.4 Results acquisition under different light conditions

When the distance between the laser probe and the object was 35cm, the angle between the probe laser beam and the object was 90°, and the pump flow rate was 75ml/h, the light condition was tested.

Light conditions were: 1. shading condition, shading curtains cover the window. 2. Lamplight condition, clinic room with white lamplight on at night. 3. No light condition, no light at night in the clinic room.

2.5 Results acquisition of the distance between the probe and the object

In a no light environment, and the angle between the probe laser beam and the object was 90°, the distances between the probe and the object were tested at the pump flow rate of 75mL/h. The selected test distances were 15cm, 20cm,

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25cm, 35cm, 35cm, 40cm, 45cm and 50cm.

2.6 Result acquisition of the angle between the probe laser beam and the object

When there was no light and the distance between the probe and the object was 30cm, the angle conditions between the laser probe and the object were tested at the pump flow rate of 75mL/h. The angles between the probe laser beam and the object were 90°, 85°, 80°, 75°, 70°, and 65°.

2.7 Statistical analysis

Under each simulation condition, 3-5 speckle images were collected and processed using IBM SPSS Statistic 27.0 statistical software package. Measurement data were expressed as mean ± standard deviation ($\bar{x} \pm s$), normal distribution data were statistically analyzed by variance analysis, and non-normal distribution data were statistically analyzed by Kruskal-Wallis nonparametric test. $P < 0.05$ indicated that the difference was statistically significant.

III. Results

3.1 The response range of LSCI over the actual blood flow velocity

LSCI could reflect the corresponding blood flow index (BFI) at the blood flow rate range of 0-35mm/s, and the BFI was about 75PU (per unit) at the flow rate of 0mm/s (Fig.1 A). With the increasing of the actual blood flow velocity, BFI also increased. When the blood flow velocity was within 5 mm/s, the actual blood flow velocity had a good linear correlation with BFI (Fig.1 B). But when the blood flow velocity exceeded 5mm/s, the trend of BFI increment gradually decreased. After the actual blood flow velocity was over 15mm/s, the BFI increment trend was approximately stopped. Collectively, the actual blood flow rate presented a linear response relationship with BFI in a range.

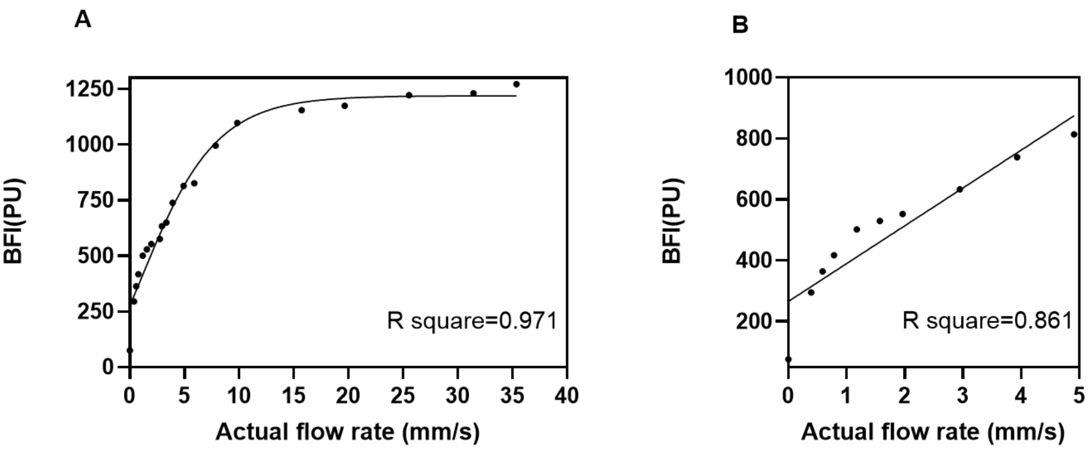

Fig 1: BFI of different blood flow rates. A: BFI at the blood flow rate of 0-35 mm/s. B: BFI at 0-5 mm/s blood flow rate

3.2 Influences of the exposure time and the surface color

The unmarked segment was set as the blank control. BFI of all five segments decreased with the increase of exposure time, but the changing trend was not constant (Fig. 2). The blank control, blue, red, yellow segments showed the same changing trend, the BFI reduction amplitude was sharper when the exposure time was less than 10ms than the exposure time was greater than 10ms.

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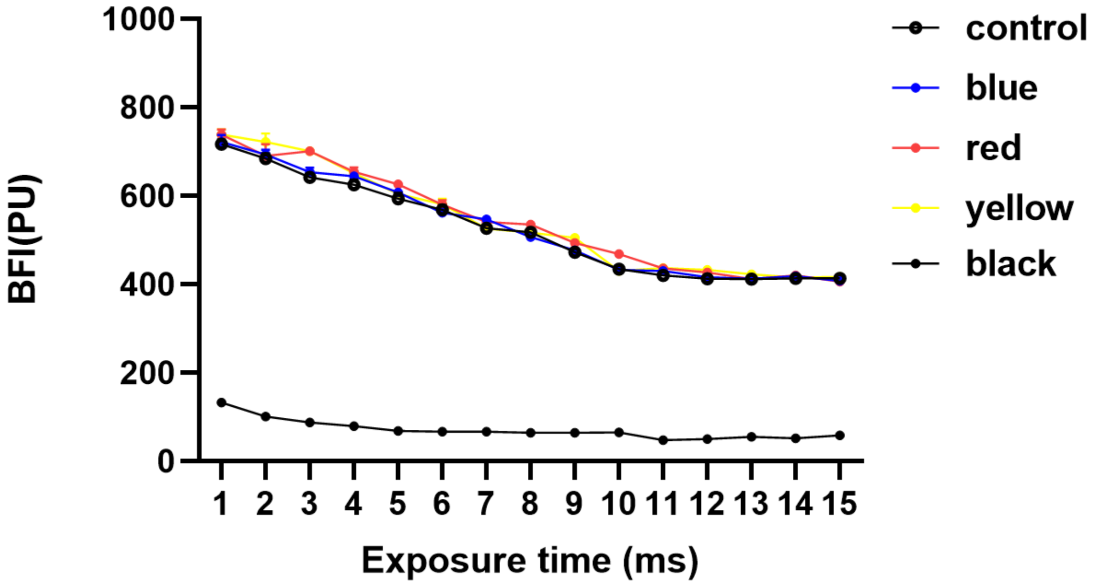

Fig 2: Changes of different color blood flow segments in different exposure times

The BFI of the black marker segment was inconsistent with that of the other color segments. After the exposure time exceeded 5ms, the BFI of this segment was slightly decreased and was significantly lower than that of the blank control and other color regions.

3.3 Influence of the light condition

The BFI of the blank control segment was selected for comparison. When the exposure time was 5ms, the BFI of the colorless stage was compared, and there was no significant difference in the BFI under shading condition, lighting condition, and no light condition (Fig. 3, 5ms). When the exposure time was 10ms, there was no significant difference only in BFI under lighting condition and no light condition (Fig. 3, 10ms).

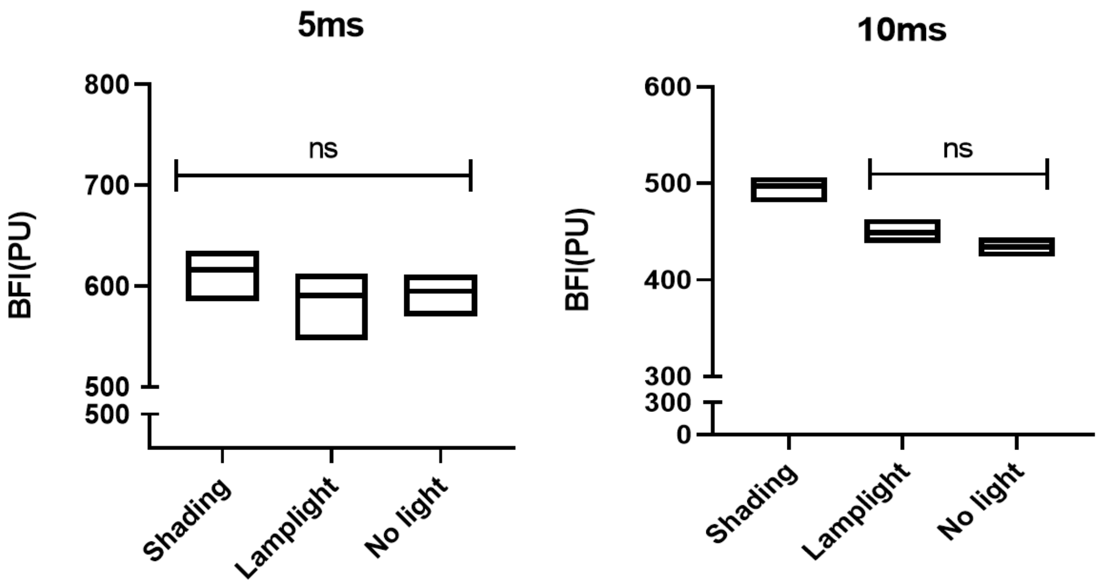

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Fig 3: BFI in different light conditions under two exposure times. Shading condition: shading curtains cover the window; lamplight condition: white lamplight on at night; no light condition: no lighting at night.

3.4 Influence of the distance between the probe and the object

The BFI of the blank control segment was selected for comparison. When the exposure time was 5ms, there was no significant difference in BFI between 20-35cm and 40-45cm distance ranges (Fig. 4, 5ms). When the exposure time was 10ms, there was no significant difference in BFI between the distance ranges of 30-35 cm and 40-50 cm (Fig. 4, 10ms).

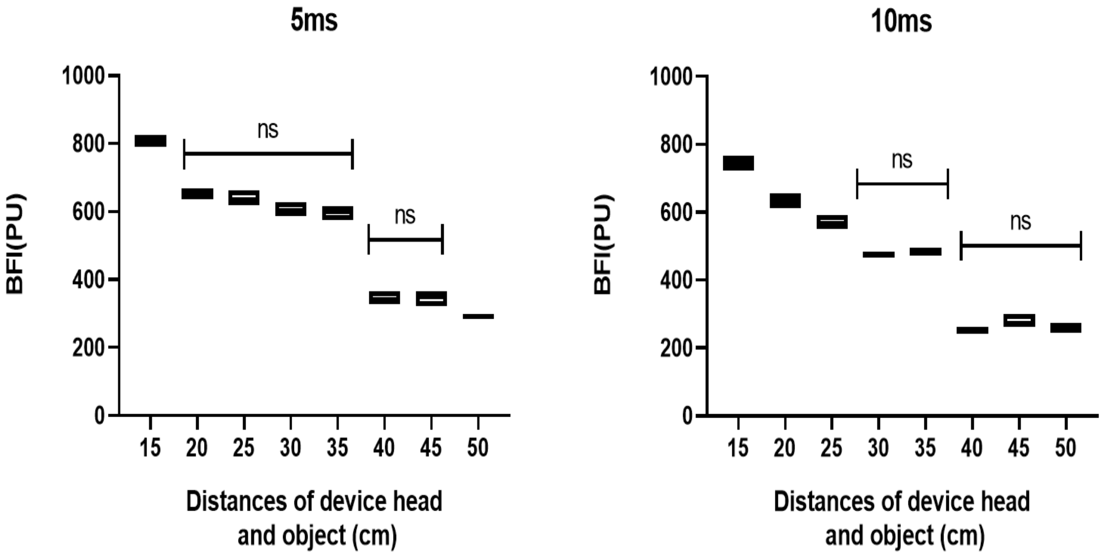

Fig 4: BFI of different distances between the probe and the object under two exposure times.

3.5 Influence of the angle between the probe laser beam and the object

The BFI of the blank control segment was selected for comparison. When the exposure time was 5ms, there was no significant difference in BFI between the probe laser beam and the object within the angle range of 90°-80° (Fig. 5, 5ms). When the exposure time was 10ms, there was no significant difference in BFI only within the angle range of 90 °-85 ° (Fig. 5, 5ms).

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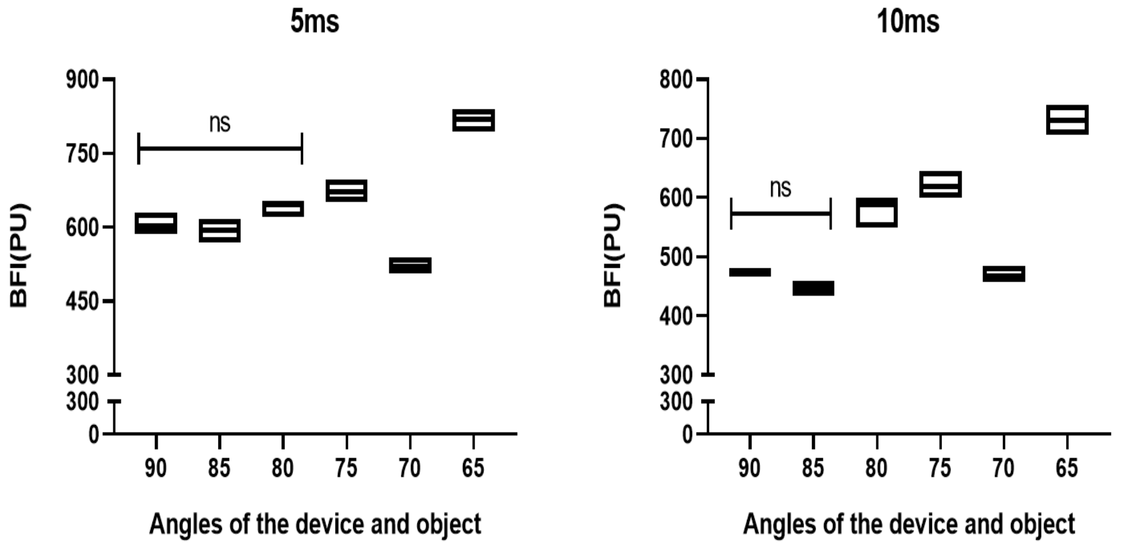

Fig 5: BFI of different angles between the probe laser beam and the object under two exposure times.

IV. Discussion

The results show that the surface color of the object, exposure time, the distance between the probe and the object, and the angle between the probe laser beam and the object all have an influence on the output results. The extent of influence of each factor is not completely consistent with the results reported in previous literature.

LSCI can provide the blood perfusion information of biological tissues in a non-invasive manner, but its feedback to the actual blood flow does not seem to be completely linear correlation. Choi et al. [19] used the in-vitro phantom to explore the response range of the LSCI instrument over the actual flow rate. Only when the blood flow velocity is 0.5-17mm/s, the LSCI instrument can sensitively reflect the changes of blood flow velocity in a linear response. This is consistent with the results of arterial blood simulation experiments in our study: when the blood flow velocity is over 10mm/s, the increasing trend of the result value decreases and does not increase with the increase of the proportion of blood flow velocity, suggesting that the actual blood flow rate over 10mm/s cannot be accurately represented by BFI. Such characteristics may be determined by the data algorithm of the device. Wang et al. [6] obtained a wider linear corresponding velocity range after improving the contrast calculation algorithm of speckle contrast data, in which the response range is wider as 0-40mm/s.

In our study, when the surface color of the object was black, the results of all exposure times are significantly lower than those in other color segments including blank control, which suggests that the results of the black segment cannot truly reflect blood perfusion change. The distribution of melanin cells in the skin is determined by heredity and environment. When LSCI is used in patients of complexion and patients with uneven skin colors, the BFI can’t reflect the group difference and the change of the real blood perfusion value, which is worth further researching in the clinical environment.
With the increase of exposure time, the BFI gradually decreases, which is the manifestation of the theoretical basis of LSCI [26]. However, the variation rules are different because of the hardware and data algorithm that the device used. In the exposure time range of 1-10ms, the reduction trend is sharper than the exposure time exceeds 10ms. This suggests that the influence level of the exposure time is in a dynamic decrease rule. However, when applied to the human body, excessive exposure will occur when the exposure time is too large, which has a great impact on the results. The setting of exposure time should be carefully selected after weighing the advantages and disadvantages.

Lindahl [15] and Mahé [21] have both described the influence of the distance between the probe and the object on

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the output results. The laser speckle imaging analyzer they used are the same (PeriCam PSI System, Perimed AB, Järfälla, Sweden). Lindahl et al. concluded that when the distance between the probe and the object was 15-36cm, the output results had no statistical difference. Mahé's results are not statistically significant in the 10-30cm distance range. Although the results of these two studies are inconsistent in specific values, the conclusions all suggest that the distance between the probe and the object has an effect on the speckle results except the distance is within a certain distance range. This is consistent with the experimental result of our study.

In addition, Lindahl [15] has also explored the illumination conditions and the influence of the angle between the probe laser beam and the object. The conclusion is that there is no statistical difference the incident angle range of 90°-45°under four different room light conditions. The results are similar to the results of ours, except the result of the 10ms exposure time situation which the results measured under shading conditions are higher than the results under light and lightless conditions. The possible interpretation is that under the shading condition, there is still sun light in a similar wavelength to the laser emission wavelength that is received by the optical sensor, resulting in experimental error. In the experiment of the angle between the probe laser beam and the object, the results of our study are not consistent with the conclusions of Lindahl's result. The angle ranges (90°-80°) under the exposure time of 5ms is larger than that (90°-85°) under the exposure time of 10ms. Considering the different data processing and optimization algorithms used by the research team, the influence of light and laser incident angle may be inconsistent.

V. Conclusion

LSCI is a promising technique for monitoring the blood flow changes of patients, which can relatively and accurately reflects the changes in a non-contact way, but the color of the object, the set of exposure time, the light condition, the probe distance and the angle between probe laser beam and object are all influence factors. Further studies are needed before applying in a specific kind of patients, for the linear response of LSCI is limited, but the actual blood flow velocity remains unknown in a sick status.

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