Thermal Infrared Imaging for Investigating Changes of Vasomotion in Peripheral Circulation

Asger E Knudsen[1], Emil Korsgaard[1], Jeppe Færgemand B[1], Nikolaj Justesen[1], Samuel E Schmidt[1], Andrei Ciubotariu[2]

[1] Dept. of Health Science and Technology Aalborg University, Aalborg, Denmark
[2] Dept. of Anaesthesia and Intensive Care, North Denmark Region Hospital, Hjoerring, Denmark

Abstract

Background & aim: In 2017, WHO estimated 48.9 million incident cases of sepsis worldwide, with 11 million sepsis related deaths. In early stages of sepsis microcirculatory function is impaired.An expression for general microcirculatory function is vasomotion, which is possible to measure on the dorsal side of the hand using an infrared camera. Thus, the objective of this study is to assess if sympathetic stimulation changes vasomotion in the peripheral circulation. Method: To investigate changes in vasomotion, infrared recordings of the hand were obtained. A cold pressor test was conducted on 10 healthy subjects. From the infrared recordings, four areas of interest were selected on the thumb muscle, index, middle and ring finger, which were converted to signals, and decomposed using discrete wavelet transform. Specific details from the discrete wavelet transform were reconstructed to assess changes in vasomotion. Results: During the cold pressor test changes in vasomotion were observed. However, there were no significant changes in vasomotion (thumb P=.237, index P=.219, middle P=.253 and ring P=.066). Conclusion: The sympathetic stimulation resulted in change in microcirculatory activity in the hand, however it did not result in significant change in temperature oscillations in vasomotion frequency bands.

1. Introduction

In 2017, WHO estimated 48.9 million yearly incident cases of sepsis worldwide, with 11 million sepsis related deaths corresponding to an incidence of 677.5 sepsis cases per 100,000 population [1]. Patients recovering from sepsis experience post-complications such as reduced physical and mental quality of life in the following years, while 43% of the surviving patients in Denmark are rehospitalised within 90 days [2]. Sepsis is defined as a life-threatening organ dysfunction caused by a dysregulated host response to infection in the blood, while septic shock is a subset of sepsis where profound circulatory, cellular, and metabolic abnormalities result in increased risk of mortality [3]. The global burden of sepsis has decreased through the past 30 years, however, the mortality rate remains at a high level [1].

An evaluation of the microcirculatory function in patients with sepsis and septic shock might contribute to predict outcome [4],[5]. An expression for microcirculatory function in the peripheral circulation is vasomotion. Vasomotion is low frequency rhythmic oscillations in the small resistance vessels generated by the smooth muscles causing rhythmically dilation and constricting of the vessels [6]. Sepsis and septic shock frequently causes impairments in vasomotion and vasomotor control due to injury in the endothelial cells (EC), which might be one of the underlying reasons for dysfunction of the microcirculation [7].

The impairment in vasomotion, is possible to measure with an infrared (IR) camera and has been applied in investigating the blood flow oscillations over time [8], [9]. Also, it is possible to investigate larger areas of interest (AOIs) in order to obtain a more representative picture of the overall microcirculatory function. However, before investigating vasomotion in sepsis patients, it is necessary to validate a general method for assessing vasomotion. Therefore, the objective of this study is to assess changes in vasomotion during sympathetic stimulation in the peripheral circulation

2. Method

To investigate vasomotion an experiment with the purpose of provoking changes in vasomotion was conducted. The experiment consisted of a cold pressor test (CPT) in order to provoke a sympathetic stimulation. The CPT was induced by placing the subject's right hand in a bucket of circulating ice water at 0 °C, while the left hand was recorded by an IR camera. The sympathetic stimulation causes a constriction of the blood vessels increasing the blood pressure, which results in decreased blood flow in the peripheral part of the body, since the blood is priori-

tised to the large skeletal muscles, the heart, the lungs etc. Furthermore, the ECs are affected by a sympathetic stimulation, and thereby affecting vasomotion. Thus, it was hypothesised that vasomotion changes due to the CPT.

To obtain IR video recordings, a thermal camera with a temperature sensitivity of 0.05°C was used (Gobi-640-GigE, Xenics, Belgium). The camera was placed 0.40 m above the left hand of the subject, directed towards the dorsal side of the hand. Subjects were placed in a relaxed supine position with the left hand placed on a table at the level of the heart. Double sided tape were used to prevent hand movement. The videos were recorded with a frame rate of 50.50 Hz. Before starting the recordings, the subjects acclimated for 10 minutes to the room temperature and to obtain regular blood flow.

2.1. Subjects

10 male subjects aged 22-36 (25.3 $\pm$3.92) gave informed consent to participate. As suggested in [10], the subjects were non smokers, and had not consumed alcohol or caffeine-containing products within at least four hours prior to the experiment. Furthermore, the subjects fasted at least two hours prior to the experiment. Exclusion criterion for subject enrollment was known cardiovascular diseases.

2.2. Pre-processing

The recorded IR videos were downsampled to 5.05 Hz, and consisted of frames containing raw values that were converted to temperature using a conversion table from the camera's calibration file. To assess the temperature oscillations in the hand, specific AOIs were selected. The mean temperature of each AOI was calculated for each frame, thus creating a signal representing the vasomotion. The AOIs were on the thumb muscle on the first dorsal interosseous muscle, and between the distal interphalangeal joint and the proximal interphalangeal joint of the index finger, middle finger, and ring finger as illustrated in figure 1.

The signals were arranged into four windows; pre-intervention window (Pre-CPT), intervention window (CPT), delayed intervention window (D-CPT), and post-intervention window (Post-CPT). The vasomotion signals were investigated in Pre-CPT, D-CPT, and Post-CPT using wavelet decompositon to assess the effect of the intervention. The windows are illustrated in figure 2

2.3. Extracting the Vasomotion Signal

To investigate vasomotion changes the discrete wavelet transform (DWT) was utilised in order to derive signals within the measurable frequency range of vasomotion (5-50 mHz) [11].

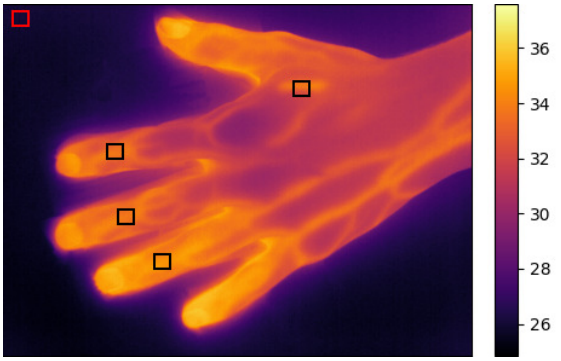

Figure 1. One frame from one of the subject's recording. The black squares indicate the four AOIs on the fingers. The red square in upper left corner indicates the reference area used to correct the signals for noise and unintentional camera calibrations.

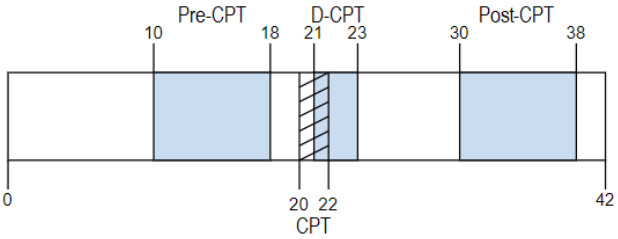

Figure 2. The timing of the windows during the recording. The Pre-CPT from minute 10-18, the CPT from minute 20-22, the D-CPT minute 21-23, and the Post-CPT from minute 30-38.

From the DWT, detail level 7, 8, and 9 with center frequencies of 9.867 mHz, 19.734 mHz, and 39.467 mHz, respectively, were derived. The derived detail levels were reconstructed to a new signal, thus containing all frequency components related to vasomotion. To investigate the changes in vasomotion in the reconstructed signal, the mean standard deviations (STD) in Pre-CPT, D-CPT and Post-CPT were calculated.

3. Results

Due to non-physiological interruptions in the IR recordings, one subject was excluded from this study. The detail levels 7, 8 and 9, with center frequencies of 39.467 mHz, 19.734 mHz, and 9.86 mHz and the reconstructed signal levels for subject 01 are illustrated in figure 3. The oscillations in vasomotion were not as profound in D-CPT compared to Pre-CPT and Post-CPT. This pattern was followed by most subjects in the index, middle, and ring finger as illustrated in figure 4.

The mean STDs in the thumb muscle and the three fingers were between 0.045 °C and 0.046 °C Pre-CPT,

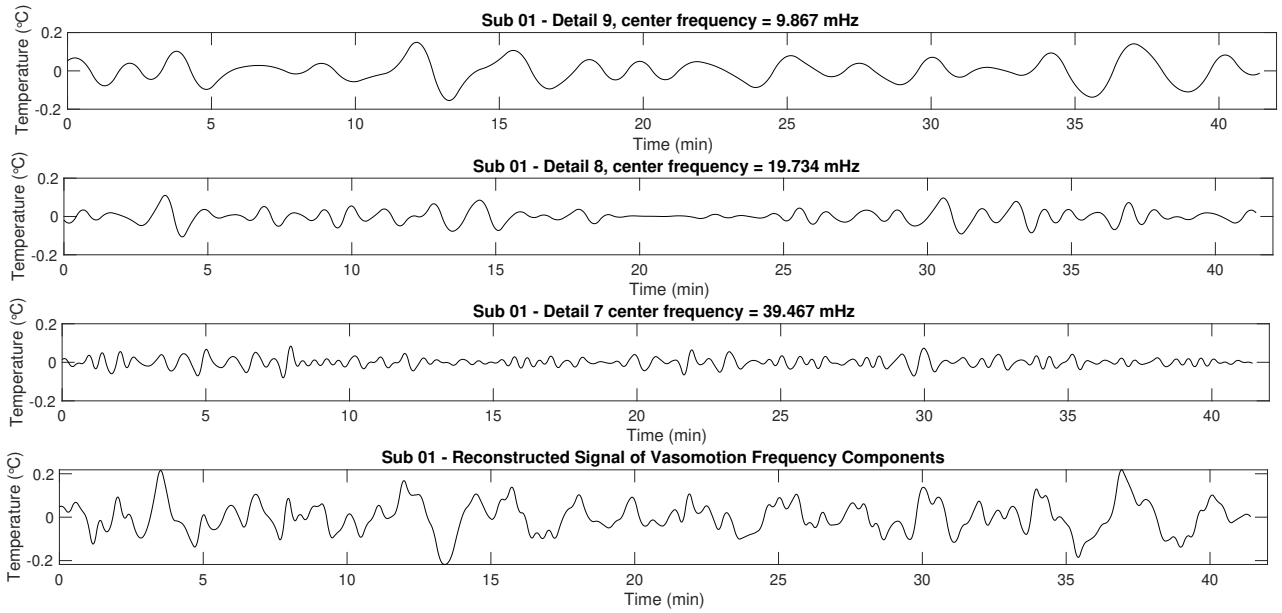

Figure 3. The detail levels 7, 8 and 9 and the reconstructed vasomotion signal based on these detail levels for subject 01.

between 0.028 °C and 0.035 °C D-CPT, and between 0.030 °C and 0.040 °C Post-CPT. The changes in STD of the thumb (P=.237), index finger (P=.219), middle finger (P=.253), and ring finger (P=.066) was not significant between Pre-CPT, D-CPT, and Post-CPT.

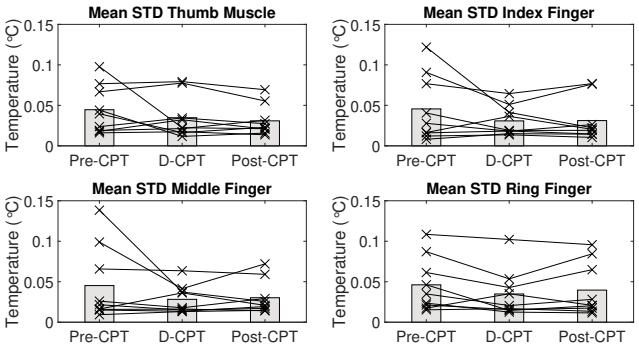

Figure 4. The mean STD across subjects for the thumb muscle, index, middle, and ring finger

4. Discussion

To assess changes in vasomotion, detail level 7, 8, and 9 from the DWT decomposing were derived from and reconstructed to a signal representing vasomotion, and the STD was calculated in Pre-CPT, D-CPT, and Post-CPT. There was no significant change in the STD of the vasomotion signal obtained from the thumb muscle, index, middle, and ring finger due to the CPT. However, in several subjects, it was possible to detect changes in STD due to the CPT, but the results were not statistically significant.

4.1. Investigating the Frequency Bands Individually

The investigated frequencies in vasomotion are in a range of 5 mHz to 50 mHz corresponding to approximately 200 to 20 seconds for one oscillation. Therefore, the period of sympathetic stimulation might be too short in order to find changes in these low frequent oscillations, indicating that the intervention might last for an extended period than the two minutes. The CPT is not possible to extend due to ethical considerations, however, the CPT could be prolonged by placing the hand in the ice buckets in intervals possibly extending the sympathetic stimulation. Moreover, another longer lasting stimulation could be considered to assess the changes in the lowest frequencies.

The reconstructed signals of detail level with center frequencies of 39.467 mHz, 19.734 mHz, and 9.86 mHz were used to investigate the vasomotion. However, it might be relevant to investigate the detail levels separately in order to investigate the different components of vasomotion. The frequency band from 5 mHz to 20 mHz is endothelial dependent, while the frequency band from 20 mHz to 50 mHz is sympathetic dependent [11],[12]. By separating the detail levels to fit into these bands, it is possible to esti-

mate the effect of the CPT on the sympathetic and endothelial dependent vasomotion separately, which might give a better understating of which frequencies are changed.

4.2. Microcirculation as a Parameter for Assessing Sepsis Patients

The microcirculatory function is impaired in sepsis patients [4],[5], which might be valuable in the early stages of sepsis [13]. Therefore, assessing the microcirculatory blood flow from IR recordings and DWT might be a possible supplementary parameter to the macrocirculatory parameters, in the early stages of sepsis. The alterations in the microcirculatory perfusion result in organ dysfunction [14]. Therefore, by evaluating the patient's microcirculatory blood flow with IR recordings through the course of sepsis, it might be possible to assess the general oxygen perfusion in the body, possibly preventing organ dysfunction and other consequential damages to the body. However, it is currently challenging to apply an assessment of microcirculatory function, since there is a lack of standardised targets and a generalised therapeutic methods targeting to restore the microcirculatory parameters. [15]

5. Conclusion

The sympathetic stimulation induced by the CPT resulted in changes in microcirculatory activity in the hand, however there was no significant changes in vasomotion. The non-significant change in vasomotion was found, which could be investigated further with an IR camera with a higher sensitivity. The change in microcirculatory activity from the sympathetic stimulation might be a useful finding for assessing dysfunction in microcirculation as a predictor in patients with sepsis in early stages.

References

[1] Rudd KE, Johnson SC, Agesa KM, Shackelford KA, Tsoi D, Kievlan DR, Colombara DV, Ikuta KS, Kissoon N, Finfer S, Fleischmann-Struzek C, Machado FR, Reinhart KK, Rowan K, Seymour CW, Watson RS. Global, regional, and national sepsis incidence and mortality, 1990–2017: analysis for the Global Burden of Disease Study. The Lancet 2020;395(10219):200–211. ISSN 1474547X.

[2] Perner A, Lassen AT, Schierbeck J, Storgaard M, Reiter N, Benfield T. Sygdomsbyrde og definitioner af sepsis hos voksne. Videnskab 2018;180(11):2–6.

[3] Singer M, Deutschman CS, Seymour C, Shankar-Hari M, Annane D, Bauer M, Bellomo R, Bernard GR, Chiche JD, Coopersmith CM, Hotchkiss RS, Levy MM, Marshall JC, Martin GS, Opal SM, Rubenfeld GD, Poll TD, Vincent JL, Angus DC. The third international consensus definitions for sepsis and septic shock (sepsis-3). JAMA Journal of the American Medical Association 2016;315(8):801–810. ISSN 15383598.

[4] Trzeciak S, Dellinger RP, Parrillo JE, Guglielmi M, Bajaj J, Abate NL, Arnold RC, Colilla S, Zanotti S, Hollenberg SM. Early microcirculatory perfusion derangements in patients with severe sepsis and septic shock: Relationship to hemodynamics, oxygen transport, and survival. Annals of Emergency Medicine 2007;49(1). ISSN 01960644.

[5] De Backer D, Donadello K, Sakr Y, Ospina-Tascon G, Salgado D, Scolletta S, Vincent JL. Microcirculatory alterations in patients with severe sepsis: Impact of time of assessment and relationship with outcome. Critical Care Medicine 2013;41(3):791–799. ISSN 00903493.

[6] Pradhan RK, Chakravarthy VS. Informational dynamics of vasomotion in microvascular networks: A review. Acta Physiologica 2011;201(2):193–218. ISSN 17481708.

[7] Lundy DJ, Trzeciak S. Microcirculatory dysfunction in sepsis. Critical care nursing clinics of North America 3 2011; 23(1):67–77. ISSN 1558-3481.

[8] Sagaidachnyi A, Usanov D, Skripal A, Fomin A. Restoration of finger blood flow oscillations by means of thermal imaging 2012;.

[9] Ciubotariu A, Ribergaard NE. Vasomotion in Peripheral Circulation of Healthy Subjects and Patients with Septic Shock: A Thermal Infrared Imaging Study, 2019.

[10] Kvandal P, Stefanovska A, Veber M, Kvermmo HD, Kirkebøen KA. Regulation of human cutaneous circulation evaluated by laser Doppler flowmetry, iontophoresis, and spectral analysis: Importance of nitric oxide and prostaglandines. Microvascular Research 2003;65(3):160–171. ISSN 00262862.

[11] Sagaidachnyi AA, Volkov IU, Fomin AV. Influence of temporal noise on the skin blood flow measurements performed by cooled thermal imaging camera: limit possibilities within each physiological frequency range. Saratov Fall Meeting 2015 Third International Symposium on Optics and Biophotonics and Seventh Finnish Russian Photonics and Laser Symposium PALS 2016;9917(May):99170N. ISSN 16057422.

[12] Kvandal P, Landsverk SA, Bernjak A, Stefanovska A, Kvernmo HD, Kirkebøen KA. Low-frequency oscillations of the laser Doppler perfusion signal in human skin. Microvascular Research 2006;72(3):120–127. ISSN 0026-2862.

[13] Mignemi NA, McClatchey PM, Kilchrist KV, Williams IM, Millis BA, Syring KE, Duvall CL, Wasserman DH, McGuinness OP. Rapid changes in the microvascular circulation of skeletal muscle impair insulin delivery during sepsis. American journal of physiology Endocrinology and metabolism 2019;316(6):1012–1023. ISSN 15221555.

[14] Spronk PE, Zandstra DF, Ince C. Bench-to-bedside review: Sepsis is a disease of the microcirculation. Critical Care 2004;8(6):462–468. ISSN 13648535.

[15] De Backer D. Is microcirculatory assessment ready for regular use in clinical practice? Current Opinion in Critical Care 2019;25(3):280–284. ISSN 15317072.

Address for Correspondence: asgerek@hst.aau.dk
Selma Lagerløfs Vej 249, 9000 Aalborg, Denmark