Thermal imaging as a method to study the effect of induced ischemia on vasomotion activity

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Abstract

Vasomotion is an auto-regulation mechanism that optimizes blood distribution within the microcirculatory system. Thermal imaging is an interesting approach to measure this phenomena. Previous studies have detected that vasomotric blood flow is quantifiable as temperature micro oscillations in the frequency range of 0,005 - 0,15 Hz. Four healthy subject was recruited to investigate the possibilities of measuring changes in vasomotric blood flow caused by partial occlusion of blood supply by using thermal imaging. The temperature oscillations in the skin were measured with an infrared camera. Measurement were done under normal conditions and with 50% restriction of hands blood supply by brachial cuff. Data processing involved correction of artifacts seen in the temperature recording. An investigation seeking reasons for these artifacts led to findings of limitations in the thermal camera used for recording. Morlet continuous wavelet transform was used on the corrected temperature recording to find the frequency content in the micro temperature oscillations. Statistical analysis of the mean amplitude values within the frequency bands showed no significant difference between the magnitudes of uncuffed and cuffed. Results show thermal imaging might not be sensitive enough to detect vasomotion and clear limitations in the experimental setup.

I. Introduction

Vasomotion is the phenomena of oscillating changes in the capillary vessel diameter enforced by smooth muscle cells. This phenomena occurs in the microcirculatory system as an autoregulatory mechanism that optimizes blood distribution within the microcirculatory system.[1-4] Although there have been several studies, which have dealt with the occurrences of vasomotion within the capillary network, this area is not completely investigated.[5,6,7] However with a better knowledge of vasomotion it might be possible to add new parameters in the monitoring of intensive care patients. Particularly patients in danger of developing hypoxia due to shock as this affects alterations in the microcirculatory system and interferes with the perfusion.[8,9] New methods for studying vasomotric activity arise and thermal imaging presents advantages in larger sample area and by being non invasive. Previous studies detected that the vasomotric blood flow is quantifiable as temperature micro oscillations within three frequency bands of endothelial ($0,005 - 0,02Hz$), neurogenic ($0,02 - 0,05Hz$) and myogenic ($0,05 - 0,15Hz$) origin. [1,5,6,10] Therefore the interest of this study is to investigate thermal imaging's ability to detect, if there are vasomotric changes in the micro temperature oscillations of skin depending on hypoxia in the observed area.

II. Methodology

i. Subjects

Four healthy subjects (3 males and 1 female, average age 30.5 years) were recruited. Subjects were recruited within the project group.

Two subject were right handed and two left handed. No subjects consumed caffeine, alcoholic beverages, or medicine before the experiment. All subject were aware of experiment procedure and were willing to participate. Subjects showed no signs of cardiac disease or tremors.

ii. Test setting

Subjects were placed in an upholstered adjustable chair for a comfortable sitting position. The hand was stabilized by a vacuum pillow covered with microfiber tissue, which was attached on the armrest. Xenics Gobi 640 $17m$ GigE infrared camera (Xenics NV, Belgium) was positioned with a tripod $37,5 \pm 1,0$ cm over subjects dominant hand and connected via Ethernet cable with a computer. The setup is shown in figure 1.

Figure 1: *Test setting at Region Hospital Nordjylland showing setup of chair, thermal camera and computer.*

iii. Software setting

Xeneth 2.6 software (Xenics NV, Belgium) installed on computer was used for data acquisition. The sampling rate was set to $6,25$ Hz, the file format to a raw data $.xvi\ file$ and both, room and ambient temperature, to $25°C$ and emissivity of observed object to 1.

iv. Experimental procedure

The experiment involved 2 x 20 min data acquisition periods. One under normal conditions without the presence of hypoxia in the targeted hand, and another where blood flow restriction enforces hypoxia. The camera was set to warm up for at least 15 min. Subjects. Meanwhile systolic blood pressure was measured to determine total occlusion pressure (TOP) of subjects dominant arm. Needed cuff pressure (p_{cuff}) for restricting 50% blood flow was calculated with $p_{cuff} = TOP \times 0.3$.[11] The subjects had at least 30 minutes to adjust to the room temperature.

The cuff for enforcing blood flow restriction in the second acquisition period was affixed on subjects dominant arm without tightening it. Subject is placed in the chair and its dominant hand is stabled with the vacuum pillow. Lens focus was adjusted for a sharp image of the hand.

After the first measurement under normal conditions, pressure in the cuff was set to enforce 50 % blood flow restriction. The subject did not move the hand while cuff tightening. To minimize any possible movement bias the subject was not allowed to move or speak during the whole procedure.

v. Data processing

v.1 Preparation of data

The acquired xvi. files were read and processed in MATLAB R2017b. The header in the beginning of each file and frame was removed. Afterwards the raw uint 16 pixel intensities was divided into frames.

v.2 Regions of interest

Regions of interest (ROIs) were selected on behalf of getting full representation of the hand. As shown in figure 2 originating from the fingertips elongating down the hand to the beginning of the wrist. 28 ROIs were chosen. Each region represent one pixel intensity in the 480 x 640 image matrix.

This pixel represents an area of the hand with a diameter of $417\mu m$.

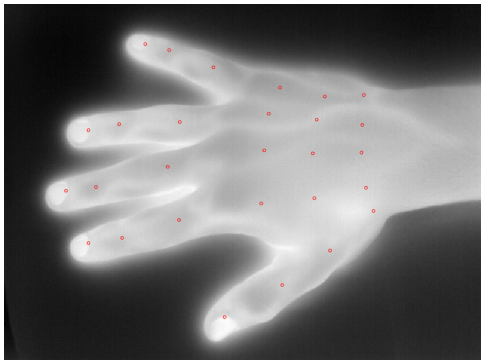

Figure 2: *Frame from thermal image of subject 1. Red dots showing the 28 ROIs.*

v.3 Artifacts

Under visual inspection of the temperature trace over time, some unexplainable jumps were present. These jumps were characterized as artifacts made by the camera. From the raw data of all regions four types of artifacts were characterized. A noise component is observed during the whole recording. Adjustments of the shutter from non-uniformity correction due to the internal temperature. The intervals between two jumps contain a drift component. An overall drift component can also be observed. Figure 4 shows the signal of one ROI to present the occurring artifacts.

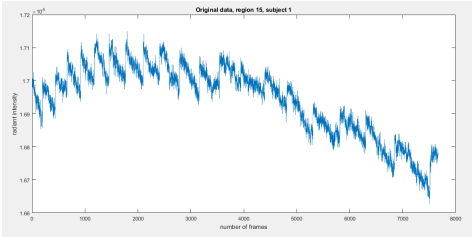

Figure 3: *The original data of region 15 in the uncuffed recording of subject 1 used as an example to outline the artifacts. The intensity is shown over time.*

v.4 Correction method

The shutter adjustments and the drift between these adjustments seen in figure 4 corrupted the original the most. Therefore a correction method based on linear regression was implemented. A linear regression is made on each drift between shutter adjustments. The found regression lines er are put together at the middle point of an adjustment forming a new temperature recording base. The residual are then projected on to the newly corrected base forming a new temperature trace.

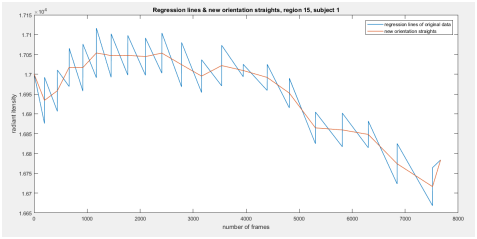

Figure 4: *Connected regression line of the original data of region 15 in the uncuffed recording of subject 1 in blue. New created orientation line of the same recording in the same region shown in red.*

v.5 Continuous wavelet transformation

Analysis of the corrected data is done in time frequency domain by the use of the Morlet continues wavelet transform (CWT). The CWT present higher resolution of frequency content in low frequency signals, compared the usually used frequency analysis method of Fourier transforms.[5,6] A scalogram showing the time-frequency analysis content of the signal given as output of the CWT can be seen in figure 5.

The jumps within the signal are shown as high bright spikes in the scalogram. In figure 5 those spikes are marked with red arrows.

The signals of some ROIs contain still jumps after application of the correction method. Therefore each signal and its scalogram has been submitted a visual control. Five ROI which showed in all measurements good response to the correction method were selected for further data processing. All five ROI are located in the back of the hand.

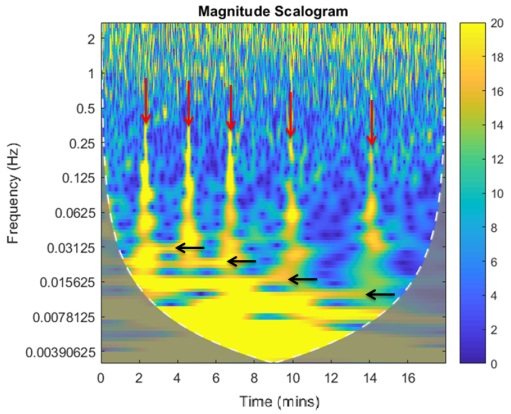

Figure 5: *Scalogram showing the time-frequency content of subject 3's uncuffed recording in ROI 8.*

vi. Statistical approach

To test the statistical significance of the difference between both condition a paired t-test with a significance level of $\alpha = 0,005$ is applied regarding the null-hypothesis $h_0 =$ "there is a difference in both conditions". Therefore the outcome data of each subject's scalograms are all frequency bands considered down to the total mean magnitude.

III. Results

The box-plots shown in figure display the mean magnitude for each subject ordered by color in both conditions. The line connecting uncuffed and cuffed condition indicates if magnitude increased or decreased. With the values visualized by the box-plots in figure a paired t-test provides the following p-values (table 1). These

	P-endo	P-myo	P-neuro
ROI 10	0.7116	0.8454	0.9389
ROI 14	0.6254	0.9237	0.6955
ROI 20	0.4141	0.9237	0.8004
ROI 21	0.4062	0.9564	0.8452
ROI 22	0.3826	0.9323	0.1552

Table 1: *Table showing the p-values corresponding to specific ROI in correlation with frequency band.*

p-values result in rejecting the null-hypothesis $h_0 =$ "there is a difference in both conditions".

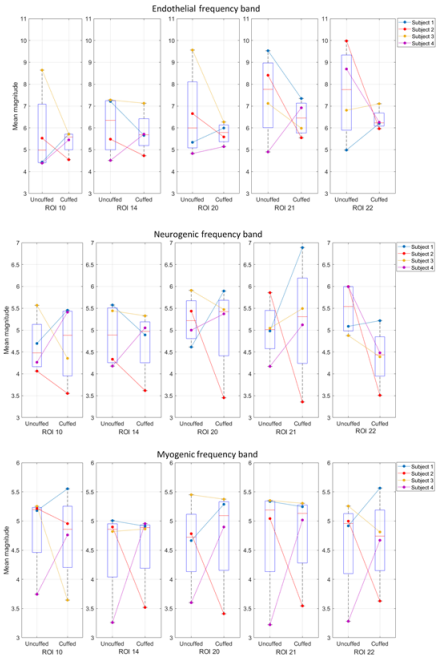

Figure 6: *Box-plot showing the mean magnitudes for each subject within endothelial, neurogenic and myogenic frequency bands.*

IV. Discussion

This study investigates the thesis, if thermal imaging is sensitive enough to measure the effects of vasomotion activity, and thereby investigate if changes in the microcirculatory system caused by a 50 % restriction of blood flow occur.

i. Results

The obvious assumption, based on the presented p-values, that there are no changes in the microcirculatory system or rather in vasomotion by 50% restriction of blood flow can be substantiated by two reasons. Firstly independence of the microcirculatory system in terms of vasomotion activity. The available amount of blood in the microcirculatory system is dependent on the amount of blood the macrocirculatory system provides which means that the microcirculatory system is not independent. Consequently this explanation can be excluded. Another explanation for the insignificant result

could be by incorrect brachial occlusion. Incorrect occlusion would yield insufficient restriction for affecting the microcirculatory system. A wrong occlusion pressure could be the cause of this. The blood pressure measurements of three subjects delivered high values around 140 mmHg and 150 mmHg. Since those three subject were in different age and shape, a suspicion for incorrect values arise. Even if the blood pressure monitor delivered wrongly high values, the outcome of the second measurement would not have been influenced negatively. This would only lead to a calculated occlusion pressure higher than the one needed to reach the intended restriction, which would just lead to a larger difference between both conditions. It would be more problematic with a occlusion level to low. All blood pressure measurements were conduced and verified by a professional anesthesiologist.

ii. Critique of study design

The small sample size of four subjects applied to the statistical methods are not sufficiently meaningful. With a larger amount of subjects this study would get a more meaningful result. A larger amount of subjects might therefore have provided a significant difference between both conditions. An even gender distribution might also have been preferable.

Other limitations might be that the subjects hands had to be stabilized by a vacuum pillow with the assumption the subjects were still, but this does not give sufficient support to inhibit every movements of the subject. A mechanism for better stabilization of the hands should be included. An approach to compensate for instability of the hand during the experiment could have been to include image alignment in the data processing to limit the drawbacks of possible movements in the recordings. Furthermore with the used setup exact same conditions for each subject cannot be granted. For instance the room temperature should have been measured beforehand and taken into consideration before the start of each experiment to create the same conditions for all subjects. The presetting of the room temperature might have affected the data. This suspicion is enhanced by regarding subject 1*s* hand temperature which was 38°C. Also by regarding the hand temperature of 26°C of subjects 2 and 3, who had cold hands during the measurement, this suspicion is enhanced. The software settings should be verified and if necessary changed beforehand of the experiment. An optimization of the test setting would require a more controlled setup of the experiment and a thermal camera of higher quality preferable of a cooled type.

iii. Limitations in using thermal camera

Due to the corrupted temperature reading the correction method was implemented, which clearly affects parts of the signal in specific ROIs. The pixel drift increases with increasing distance to the center of the thermal image why pixel drift of ROIs located in the outer areas of the thermal image cannot be completely compensated for with the implemented correction method. The explanation for this is likely that the correction method is based on the assumption that the drift component in every interval is linear. This assumption might be wrong and a correction method that uses another regression method or combines different regression methods might adjust the artifacts in a better way. As a result the ROIs located in the outer area of the thermal image were excluded from the data analysis. Another camera might also be preferable to reduce the risks of technical artifacts like these.

Furthermore the smaller the observed area the closer the thermal camera has to be to this area. Thus the area represented by one pixel gets smaller. Within this study one pixel represents an area with a diameter around 417tm. Whereas previous studies observed smaller areas which means that the pixel represent a smaller area. With the use of a larger ROI, it might be that the amount of inverse dilating capillaries is equal and thereby canceling each other out. Due to inverse dilating capillaries there might be no changes over time

measurable because the frequency contents are occurring alternating in the different capillaries. In addition, it is obvious that the artifacts content in the signal is significantly higher than in the temperature signals detected in previous studies. Comparing the signals the question arises if the artifacts overlaps or suppresses the frequency content of vasomotric activity. Even though temperature changes over time in the skin were detected, it is uncertain, if this signal just represents the general skin temperature or also vasomotric activity.

V. Conclusion

The results of this study indicate that thermal imaging is not sensitive enough for detecting vasomotion activity. There have been no findings of a statistical significant difference in the dataset between the two conditions investigated, indicated by the high p-values in table 1. Despite no findings, this study provides information about key points that should be considered when with thermal imaging, for instance that the regions that is of most interest should be placed in the center of the thermal image. Further investigation in this field is needed, to show thermal imaging as a promising technique for detecting vasomotion activity.

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