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Sarah Schneider*, Klaus Affeld, Claudia Kopic and Ulrich Kertzscher

Blood pressure measurement on the cheek

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Abstract: In a large group of patients, it is impossible to measure blood pressure using an upper arm cuff. An alternative, non-invasive method of blood pressure measurement is required for patients with severe limb deformities or obesity, for amputees, and in the emergency medicine. The device proposed here measures blood pressure in the cheek using a small pressure pad and a pump to occlude the cheek artery – arteria facialis – and assesses blood flow with an infrared light source and a detector. The infrared light signal is analysed to assess the systolic and diastolic blood pressure of the patient. Manual evaluation of the light intensity signal showed a good agreement between cheek blood pressure measurement and a reference measurement using an upper arm cuff.

Keywords: arteria facialis; blood pressure measurement; photoplethysmography; thalidomide.

1 Objective

Blood pressure is one of the most important factors for the diagnosis of cardiovascular disease [1]. In 2014, 39% of all deaths in Germany were associated with diseases of the cardiovascular system [2]. High blood pressure (hypertension) often goes unnoticed by the patient, and becomes apparent only when serious events such as heart attack, stroke or kidney failure occur. These complications can be prevented or at least delayed by an early treatment of hypertension. Therefore, blood pressure measurement is an important routine examination and should be performed at home on a daily basis.

In a large group of patients, it is not possible to administer the customary, non-invasive blood pressure measurement using an upper arm or wrist cuff. These are patients with severe limb deformities, such as people damaged by the drug thalidomide ("Contergan"), but also obese patients and amputees. Additionally, in emergency medicine, there is often limited access to the upper arm or wrist as required to measure blood pressure.

A new blood pressure measurement device is presented here which does not depend on a patient's limbs; instead, a small pressure pad is applied to the cheek and blood flow is detected using a photoplethysmographic sensor.

2 Material and methods

The measurement device consists of a U-shaped frame which is to be placed in the corner of the mouth as in Figure 1. The first leg of the frame is situated in the oral cavity, holding an infrared light detector at the inner cheek. An infrared light-emitting diode is located on the second leg of the frame at the outer cheek. A pressure pad is situated between the frame and the light diode at the outer cheek.

Principle: Infrared light travels through the pressure pad, cheek tissue and the facial artery (Arteria facialis), and a fraction of the light is detected by the photo-detector at the inner cheek. The transmitted light intensity changes according to the cheek's blood content. This intensity signal is used to detect the blood pulse in the facial artery.

The light intensity signal demonstrates a specific behavior during the inflation and deflation of pad pressure, as seen in Figure 2. Blood flow in the facial artery will decrease with increasing pad pressure, reaching a global maximum at the diastolic blood pressure.

Eventually, the facial artery will be completely emptied of blood when the systolic pressure is reached in the pad. The situation is reversed with decreasing pad pressure: blood flow will return to the facial artery, resulting in a recurring light intensity signal when systolic pressure is reached. The two global maxima of the intensity signal indicate the location of the diastolic pressure in the pad.

Evaluation: Light intensity signals (LI signals) were examined manually by practiced investigators. Data was processed using MATLAB R2013b (The MathWorks, Inc.,

***Corresponding author: Sarah Schneider,** Biofluid Mechanics Lab, Charité – Universitätsmedizin Berlin, Augustenburger Platz 1, 13353 Berlin, Germany, E-mail: sarah.schneider@charite.de
Klaus Affeld, Claudia Kopic and Ulrich Kertzscher: Biofluid Mechanics Lab, Charité – Universitätsmedizin Berlin, Augustenburger Platz 1, 13353 Berlin, Germany, E-mail: klaus.affeld@charite.de (K. Affeld)

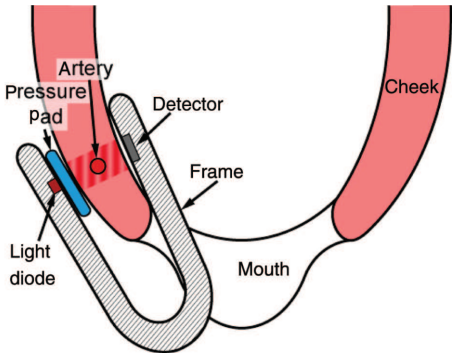

Figure 1: Schematic of the measurement device. A light diode, a light detector, and the pressure pad are mounted on a frame which is placed in the corner of the mouth.

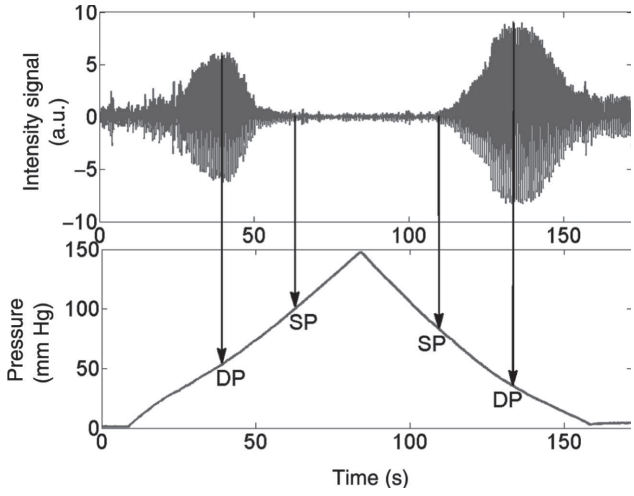

Figure 2: Light intensity signal (top) and pad pressure signal (bottom) on the cheek of a subject during a measurement. Systolic (SP) and diastolic blood pressure (DP) can be determined from the characteristic progression of the light intensity signal. The height-adjusted blood pressure from this measurement was 130/83 mm Hg during inflation and 112/64 mm Hg during deflation of the pressure pad.

Natick, MA, USA). The evaluation is based on the following assumptions:

1. Systolic pressure is detected where LI signals disappear and no clear pulsations are found any longer in the LI signal, and
2. Diastolic pressure is detected at the global maxima of the LI signal.

For the evaluation, the upper and lower envelopes of the LI signal were computed. The lower envelope is used to generate a positive corrected intensity signal, as shown in Figure 3.

Implementation: The measurement starts by inflating the pressure pad with a piston pump (PHD ULTRA™,

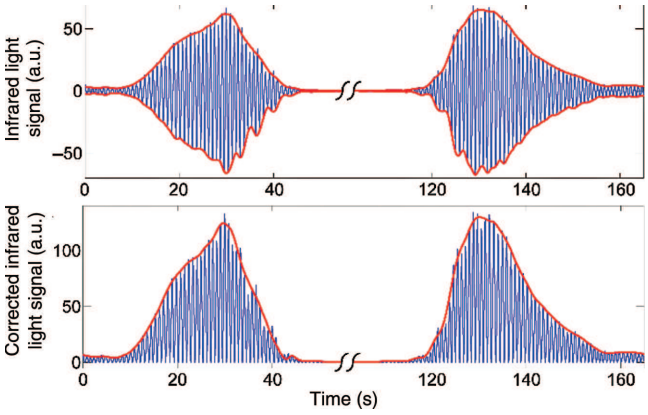

Figure 3: Light intensity signal with envelopes (top) and corrected intensity signal with upper envelope (bottom).

Figure 4: Prototype of the new blood pressure measurement device.

Harvard Apparatus, Holliston, MA, USA) to a suprasystolic pressure. Once the peak pressure is reached, the pressure pad is slowly deflated. Pad pressure and transmitted infrared light signals were recorded using LabVIEW (National Instruments™, Austin, TX, USA).

A prototype of the device is shown in Figure 4. The frame is made from polylactic acid (PLA) and printed using a 3D printer (Ultimaker 2, Geldermalsen, The Netherlands). The pressure pad is made from polyurethane foil (100 µm thickness). The diode emits infrared light with a wavelength of 940 nm.

The device was tested on 10 voluntary, healthy subjects in comparison with an M500 automatic blood pressure monitor (Omron Healthcare, Kyoto, Japan). The inner cheek area of the cheek device was covered with a protective sleeve (Premium Plus Dental Supplies Inc., NY, USA). Both devices were positioned correctly on the cheek and upper arm, and subjects remained seated during the measurement. The height difference between cheek and upper arm was measured for a correct calibration of the pressure results. The arm cuff measurement was activated manually during the inflation and deflation phases of the cheek measurement. Measurements were performed both at rest and after light physical activity.

3 Results

Fifty eight measurements were performed on 10 subjects (five male, five female, average age: 26.2 ± 5.1 years). Forty seven measurements were performed at rest and 11 measurements were performed after the subject performed light physical activity. Each measurement resulted in two analyzable parts (inflation and deflation phases of pressure) and two upper arm measurements to compare with the cheek measurements. Slopes of the pressure curve were 2.73 ± 0.04 mm Hg ascending and 2.53 ± 0.05 mm Hg descending.

Manual detection: The manual detection was performed using the raw light intensity signal as shown in Figure 3 (top) and at the corrected LI signal, shown in Figure 3 (bottom).

The differences between the manual detection and the reference measurement at the upper arm using the raw LI signal were systolic -15.93 ± 8.88 mm Hg for inflation and -19 ± 6.43 mm Hg for deflation and diastolic -1.28 ± 7.19 mm Hg for inflation and -11.4 ± 12.39 mm Hg for deflation. Bland-Altman plots are shown in Figure 5.

The differences between the manual detection and the reference measurement at the upper arm using the corrected LI signal were systolic -3.62 ± 16.24 mm Hg during inflation and -10.09 ± 9.66 mm Hg during deflation and diastolic -0.33 ± 13.33 mm Hg during inflation and -12.85 ± 13.03 mm Hg during deflation. Bland-Altman plots are shown in Figure 6.

4 Discussion

The results of the manual detection show a good agreement between manual detection and reference measurement for systole and diastole during the inflation phase. Deviations are assessed as acceptable if they meet the criteria of the American Association for the Advancement of Medical Instrumentation (AAMI), [3]: the test device must not differ from the reference method (mercury standard in the AAMI protocol) by a mean difference >5 mm Hg or a standard deviation >8 mm Hg. This is true for all of the manual detection methods during inflation except for the systolic inflation using raw light intensity signal.

During the deflation phase, a systemic error occurs for both systole and diastole: lower absolute pressures show a higher difference from reference measurements than high absolute pressure. The standard deviation is high in all measurements.

There are various reasons for the pressure differences:

1. Measurement errors in height difference result in pressure difference errors of 0.73 mm Hg/cm,
2. The initial or final pulse of the LI signal could not be clearly differentiated from noisy signals during occlusion, resulting in temporal allocation errors of approximately 2.63 mm Hg/s,
3. Cheek blood pressure is actually lower than upper arm blood pressure because the vessel is smaller,
4. The sensor was not positioned correctly and the facial artery was not in the center of infrared light.

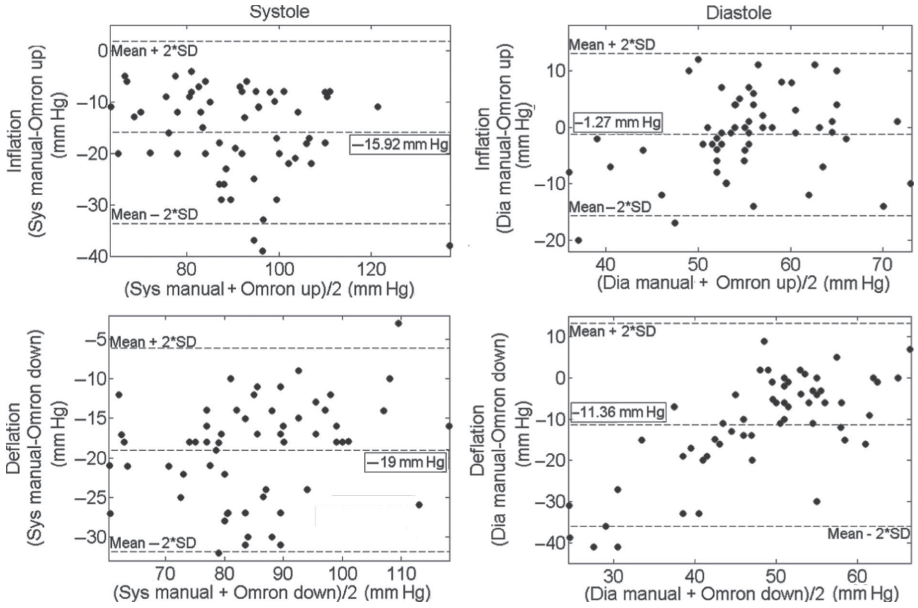

Figure 5: Bland-Altman plots of manual detection (based on raw LI signal) vs. reference blood pressure measurement with upper arm cuff (Omron) for systolic and diastolic inflation and deflation phases.

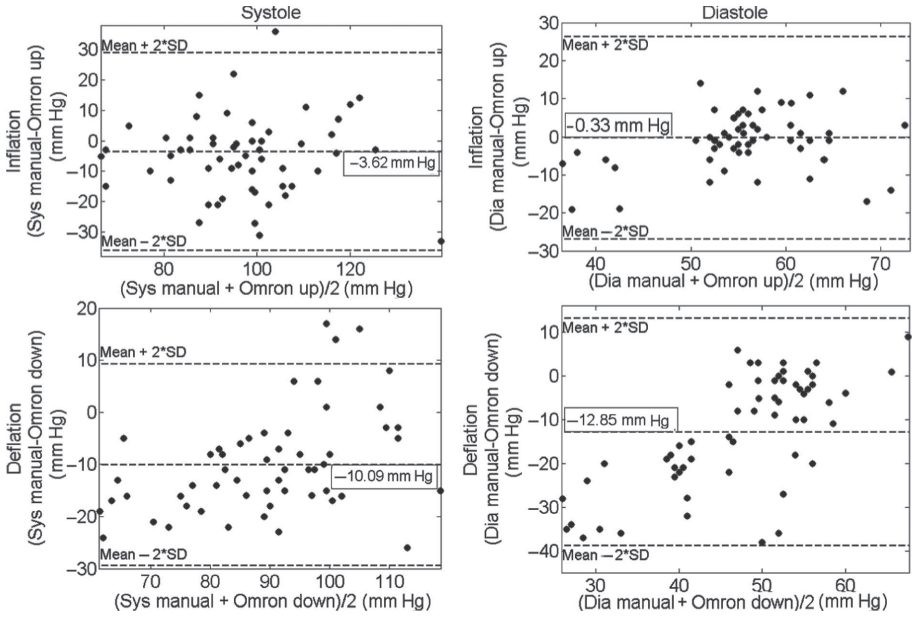

Figure 6: Bland-Altman plots of manual detection (based on corrected LI signal) vs. reference blood pressure measurement with upper arm cuff (Omron) for systolic and diastolic inflation and deflation phases.

5. The reference measurement using the upper arm cuff has an error which should be below 5 ± 8 mm Hg (to meet the criteria of the American Association for the Advancement of Medical Instrumentation, [3]).

There are differences between the manual detection methods (raw LI signal vs. corrected LI signal) of 12.30 ± 13.33 mm Hg for systole during inflation, 8.91 ± 9.95 mm Hg for systole during deflation, 0.95 ± 9.22 mm Hg for diastole during inflation, and -1.49 ± 5.64 mm Hg for diastole during deflation. This shows that systolic values are better detected using the corrected LI signal.

5 Conclusion

A new technique was developed to measure blood pressure in patients with severe limb deformation. Pressure and infrared light signals could be measured on the cheek using the device.

The manual detection of systolic and diastolic blood pressure from light intensity signals is possible, and sufficiently comparable to measurements on the upper arm. The system has been evaluated in normotensive subjects. The performance of the device will be tested for hyper- and hypotensive subjects and thalidomide patients in the future.

Currently, algorithms are being evaluated for the automatic detection of blood pressure values from infrared light signals.

Author's Statement

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References

[1] Hypertonie – Gesundheitsberichterstattung des Bundes. Robert-Koch-Institut; 2008.
[2] Gesundheit – Todesursachen in Deutschland 2014, Statistisches Bundesamt, Wiesbaden.
[3] O'Brien E, Waeber B, Parati G, Staessen J, Myers MG. Blood pressure measuring devices: recommendations of the European Society of Hypertension. Br Med J. 2001;322:531–6.