Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Objective determination of capillary refill time by OLED-on-CMOS technology: a prospective observational proof of principle clinically study

Torsten Richter

torsten.richter@ukdd.de

Faculty of Medicine and University Hospital Carl Gustav Carus Dresden, TUD Dresden University of Technology

Judith Baumgarten

Fraunhofer Institute for Photonic Microsystems IPMS

Uwe Vogel

Fraunhofer Institute for Photonic Microsystems IPMS

Konrad Schubert

Faculty of Medicine Carl Gustav Carus, TUD Dresden University of Technology Dresden

Anja Schulz

Faculty of Medicine and University Hospital Carl Gustav Carus Dresden, TUD Dresden University of Technology

Thea Koch

Faculty of Medicine and University Hospital Carl Gustav Carus Dresden, TUD Dresden University of Technology

Rosa Nickl

Faculty of Medicine and University Hospital Carl Gustav Carus Dresden, TUD Dresden University of Technology

---

Article

Keywords: capillary refill time, objective measurement, bidirectional OLED-Display, optical sensor, microcirculation, monitoring, physiologic

Posted Date: September 21st, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10821371/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Capillary refill time (CRT) is a quick and simple method of obtaining information about human microcirculation. However, this method is highly dependent on the examiner, among other things. We have therefore incorporated the key principles of clinical measurement into a technical device designed to enable objective CRT assessment.

Organic light emitting diode (OLED) - on - complementary metal-oxide-semiconductor (CMOS) technology was used to construct a handy device with which a constant pressure could be applied to the skin surface with pressure control and precise timing. This device allows for independent determination of CRT, free from the influence of ambient light or the examiner's time assessment. This method of CRT measurement was compared with the standard clinical CRT measurement method measured on the skin of each patients sternum (n = 20).

CRT device determined values were 1.2 [± 0.4] seconds. Whereas CRT measured by the conventional method was 1.5 [± 0.4] seconds. Physiological parameters did not change between before and after CRT measurement. In 13 of 20 patients, a slightly shorter CRT was observed compared to conventional measurement. Using the OLED-on-CMOS based CRT measuring holds promise for monitoring objective bedside determination of regional microcirculation and give new questions for further studies.

Introduction

Monitoring microcirculation in clinical praxis would be highly desirable, as restriction of oxygen delivery promotes cellular dysfunction, which may subsequently lead to tissue dysfunction or organ failure and increased infection rates.[1,2] Previous measuring methods which allows conclusions about the microcirculatory situation of patients are global laboratory parameters as blood lactate,[3] as well as more regional techniques, including video-microscopic devices[4], laser Doppler flowmetry[5], near infrared spectroscopy (NIRS)[6] and vascular occlusion test. [7,8] However, these measurement methods are depended on a laboratory analyses or plugged devices and require a considerable technical effort.

Capillary refill time (CRT) is a widely used, non-invasive clinical test for monitoring tissue perfusion. It is used to monitor patients of all ages, from newborns to the elderly. [9] [10,11] There is evidence that the use of CRT monitoring in cases of septic shock may lead to a faster recovery from organ dysfunction.[12-14] Measuring the CRT is quick and easy: The examiner presses his own finger a defined time of 2 – 10 seconds on the skin of the patient to produce a blanching of the skin.[14,15] Afterwards, the time is measured in which this bloodless skin area has filled up with blood again, visible as regaining the original coloration (Figure 1). It is easy to learn and quick to perform at the bedside in a point-of-care-manner. Another advantage is the possibility of limitless repeating and no requirement of any technical devices. This simplicity makes this approach very attractive for monitoring regional micro-perfusion.

With an applied pressure for 5 seconds it is suggested that a CRT of more than 2 seconds being indicative for shock.[16] Others defined CRT more than 3 seconds as indicator for abnormalities, including children. [14,17]

However, the applied pressure and the examiner´s finger may vary and may therefore lead to different results. Moreover, the CRT assessment is susceptible to several factors that can substantially influence the results, including skin and core temperatures, age, ambient light and the duration -, amount -, surface - and site of pressure application. Owing to the highly subjective nature of the measurement and changing environmental conditions, inter- and intraobserver variability can be considerable.[18,19]

Clinical findings derived from CRT may therefore vary, for example, because of differences in the selected measurement sites, pressure application, and timing. Furthermore, studies based on CRT become more accurate when the timing is recorded precisely, for example by using a stopwatch.[20]

To make clinical monitoring of microcirculation more objective and less user-dependent, a new quantitative method for CRT measurement based on a bidirectional micro – organic light emitting diode (OLED) – display[21,22] was developed. In the present proof-of-principle study, this OLED-on-complementary metal-oxide-semiconductor (CMOS) sensor tool was tested on patients´ skin to measure CRT.

Methods

This study is a prospective observational proof of principle clinically study and was registered at the German Clinical Trials Register (DRKS00025098 https://www.drks.de/search/de/trial/DRKS00025098/details) on 13/10/2021. The study protocol is according to the CONSORT Guidelines 2010. Positive ethic votum was approved by the Institutional Review Board of the Technische Universität Dresden (BO-EK-37012021). All methods were performed in accordance with the relevant guidelines and the declaration of Helsinki. Patients from the general wards at the University Hospital Dresden were enrolled as study participants. The participants were enrolled after written informed consent was obtained. All voluntary patients without any relevant medical history, contraindications and exclusion criteria received monitoring of physiological data. Patient recruitment took place from 01/12/2021 to 14/09/2022.

The following were considered as exclusion criteria: the presence of vascular diseases like peripheral arterial occlusive disease, varicosis, chronic venous insufficiency, acute thrombosis or thrombosis in anamnesis of a patient and stroke and patients with rheumatic disorders, raynaud syndrome, edema, skin diseases, burn injuries, scars, or those taking vasoactive medications, as were patients below 18 years of age.

For the consideration of the CRT-tool functions, the measurement was divided into the following steps as illustrated in Figure 1: compression of the skin area until it fades and maintaining the pressure for 5

seconds, releasing the pressure and measuring the time until the original skin colour is regained. The measurements were provided by one person without changes. Measurements were obtained at a singular measurement manually and with the CRT-device from the sternum. Basic monitoring (heart rate, blood pressure, oxygen saturation, body temperature) and room temperature were obtained before and after the measurements.

CRT-measuring-tool

In order to achieve an objective measurement of CRT, ideally - the following factors have to be taken into account: The pressure exerted on the skin should be standardized. The pressure contact area to the skin should be the same. The light used for measurement should be constant and should not be affected by external light influences. It should be possible to measure the time until the skin returns to its original colour automatically and independently of the examiner.

With the use of the prototype, the standardized contact surface serves both as a light source and as a detection area. This is achieved with the help of the OLED-on-CMOS technology in which emitted light can be recaptured via the same chip, as illustrated in Figure 2. An outer protective layer enables hygienic cleaning of the contact surface after use. The white light (ranging from 450 nm to 700 nm) shines on the skin and thus enables the initial colouration to be recorded on an area of 12,8 mm × 9,6 mm by 800 × 600 pixels. The data is converted to a mean brightness value and buffered for later on comparison.

The pressure is applied manually by the examiner and measured by a FX29 load cell from TE connectivity. A software timer starts to run for 5 seconds if the load is within the range of 15 N to 25 N. After the pressure is released, the time until the original skin colour returns is measured by a comparison of the current mean brightness value with the one buffered at the beginning of the procedure. The time is displayed on the monitor and stored together with a timestamp, proband ID and the maximum load in a data file. The CRT measuring prototype and the measurement unit is shown in figure 3.

A pressure sensor behind the OLED-sensor unit controlled the pressure applied to the skin during the phase of pressure. A connected computer indicates whether the force exerted is within the specified target range and counts down until, after five seconds, complete pressure relief can be achieved without losing contact with the skin. The time measurement, which starts automatically after pressure relief, records the duration until the blanching has ended and the skin has returned to its original colour. The measurements were taken on the basis that the maximum allowable skin contact force is less than 2 N.

Data measurements

Room temperature was taken before and after measurements, body temperature was obtained by ear thermometer and skin temperature was taken before and after all measurements using taped temperature sensors. Physiological parameters (noninvasive blood pressure), heartrate, pulse, skin temperature) were recorded by IntelliVue MX 800 (PHILIPS healthcare, Germany). CRT measurement was performed manually and one measurement with the device at the sternum. The harm was assessed.

This was done systematically. It was performed at the end of the measurements. Complications were defined as persistent skin redness, rashes or other local changes at the measurement site, or significant changes in physiological parameters towards pathological values by the end of the measurements.

Statistical analysis

R statistical software (R Core Team 2025, R Foundation for Statistical Computing, Vienna, Austria) wasused for data analyses. Bland-Altman plot for analyzing the agreement between manual (m) and digital (d) measurements of capillary refill time was determined.[23] The limits of agreement (LOAs) define the estimated 95% reference range assuming independent and identical normal distribution of the differences (m-d). The sample size was assumed to be n = 20 in order to evaluate the quality of the proof of concept.

Results

A total of 20 patients at the University Hospital Carl Gustav Carus Dresdenin the mean age of forty years were enrolled in the study. There are 11 females among them. No patient was excluded from the study, nor did any patient suffer any harm. The measurements were carried out as planned and were always performed by the same researcher, without the study interfering with the patients' hospital care. Neither conventional nor digital CRT measurement in the patients studied caused skin irritation or any other abnormalities or damage.

All patients were categorized as ASA I classified. Patients physiological data are presented in Table 1. Skin colour classified according to the Fitz Patrick Scale were mainly 3 (n = 8) and 2 (n = 7) and less 1 (n = 4) and 4 (n = 1).

Table 1

Demographic baseline data from patients (n = 20). Values are given in mean [standard deviation] or number (percentage), as appropriate. ASA I: physical status defined after American Society of Anesthesiology category I, BMI: Body mass index, HR: Heart Rate, MAP: Mean Arterial Blood Pressure, SpO_2-blood oxygen saturation by pulse oximetric measurement.

Variables	**Values**
Age (years)	40 [± 11]
Female (%)	55
BMI (kg/m^2)	25.5 [± 2.5]
ASA I (%)	100
HR before measurement	70 [± 9]
HR after measurement	70 [± 8]
Sinus rhythm %	100
MAP (mmHg) right arm before measurement	94.4 [± 8.8]
MAP (mmHg) right arm after measurement	93.3 [± 8.5]
MAP (mmHg) left arm before measurement	94.3 [± 9.2}
MAP (mmHg) left arm after measurement	93.4 [± 7.9]
SpO_2 (%) before measurement	99 [± 1]
SpO_2 (%) after measurement	99 [± 1]
Body temperature (°C)	36.4 [± 0.3]
Cutaneous temperature (°C)	31.4 [± 1.1]
Room temperature (°C)	24.0 [± 1.3]

Table 1
Demographic baseline data from patients (n = 20). Values are given in mean [standard deviation] or number (percentage), as appropiate. ASA I: physical status defined after American Society of Anesthesiology categorie I, BMI: Body mass index, HR: Heart Rate, MAP: Mean Arterial Blood Pressure, SpO_2-blood oxygen saturation by pulse oxymetric measurement.

Variables	Values
Age (years)	40 [± 11]
Female (%)	55
BMI (kg/m^2)	25.5 [± 2.5]
ASA I (%)	100
HR before measurement	70 [± 9]
HR after measurement	70 [± 8]
Sinus rhythm %	100
MAP (mmHg) right arm before measurement	94.4 [± 8.8]
MAP (mmHg) right arm after measurement	93.3 [± 8.5]
MAP (mmHg) left arm before measurement	94.3 [± 9.2}
MAP (mmHg) left arm after measurement	93.4 [± 7.9]
SpO_2 (%) before measurement	99 [± 1]
SpO_2 (%) after measurement	99 [± 1]
Body temperature (°C)	36.4 [± 0.3]
Cutaneous temperature (°C)	31.4 [± 1.1]
Room temperature (°C)	24.0 [± 1.3]

Digital CRT-data could be determined using the prototype.The results, expressed as means and differences, are shown in Fig. 4. The range of values for the device determined digital CRT values where 0.6–2.3 seconds. The conventional manually measured CRT ranged from 0.7 to 2.1 seconds. Digital measurement revealed a slightly shorter CRT than conventional measurement in 13 out of 20 patients. This resulted in an overall digitally measured CRT of 1.2 [± 0.4] seconds, compared to a conventional measured CRT of 1.5 [± 0.4] seconds. However, this majority occurrence of shorter device measured CRT values remained less than one second.

Discussion

In this proof-of-principle-study, non-invasively objective CRT values were determined in patients using a new device based on OLED-on-CMOS sensor technology. There are difficulties in comparing the standard subjective method with all the uncertainties with a new non evaluated digital method.[24] However, with the device, we measured a slightly shorter CRT in the majority of patients. This may be explained by the fact that measurement with the prototype began immediately after pressure release, since the finger did not need to be removed before timing began.

Standardized performance of the measurement using a stopwatch (as in this study) may improve the reliability of conventionally determined CRT values. [20,25] In this study, conventionally measured CRT values in the range of 100 ms were considered. However, since the standard clinical unit for CRT is seconds, the values are quite similar and fall within the range of 1 second.

Numerous patient-related and external factors can influence the measurement. Taking into account the exclusion criteria for the patients measured here, hemodynamic coherence can be assumed, meaning that normal microcirculatory parameters can also be assumed in the presence of normal macrocirculatory parameters.[1] The physiological parameters before and after the measurement showed no significant changes and, like the microcirculatory parameters, fell within the normal ranges.

Even whilst attempts were being made to stabilize the conditions for conventional CRT measuring, daylight and lighting conditions varied. Light conditions were continuously the same with the digital measurement. Further research is needed to determine to what extent changes in the light spectrum represent an improvement on the white light used here for CRT measurement. Whilst this study took into account the influence of light absorption due to the degree of skin pigmentation, further research is required to provide a representative answer to this question.

Temperatures below 20 and above 25°C can affect the CRT.[26] The ambient temperature measured here was between 23 and 25°C. The measured body temperature was within the normal range and, like the skin temperature, showed only minor inter-individual variations of approximately 1°C. The extent to which the temperature of the fingertip or the OLED-on-CMOS sensor influenced the measurement is unknown. As this was a single measurement with a skin contact time of 5 s (manual) or approx. 7 s (digital), it is unlikely that this brief contact time was sufficient to transmit temperature changes to the deeper capillaries.

Temperature is a major influencing factor in fingertip measurements; this is particularly true when the region is supplied by terminal peripheral arteries, and such measurements can be difficult to interpret when blood flow is centralised.[26] For measurements during shock, a CRT measurement site close to the trunk is recommended, as it is assumed that measurements taken on the extremities no longer reflect the actual blood flow situation due to the centralization of blood supply, since these areas may be significantly under-perfused. For this reason, the prototype was not exclusively designed for measurements on the finger but also allowed measurements on the skin surface. In this study

measurements were taken at the sternum. The applicability of the prototype at different measurement sites is the subject of current investigations.

In CRT examinations of the fingertip, a pressure force of between 3 and 7 N proved to be optimal.[15] We selected an application force of 15 N for the location on the sternum in order to achieve a reliable blanching of the skin.

In tests involving different durations of pressure (ranging from 2 to 6 seconds) to the fingertip, a duration of 2 seconds was already deemed optimal.[15] In this proof-of-principle study, we opted for 5 seconds in accordance with the widely used standard clinical method.[27]

Previous attempts to standardize the measurement of CRT have been based on a pressure system with an optical analysis unit. For example, a semi-automated system developed by Blaxter et al. applies pneumatic pressure to the skin surface, the effects of which are detected using multispectral optical measurement and recorded electronically. This involved combining six LEDs and a photodiode, as well as a high-resolution camera, in such a way that skin discolouration could be recorded before, during and after pressure was applied. [27]

A pneumatic pressure system applied to the fingertip was used to detect blood flow-dependent changes using an infrared light signal (940 nm) from a pulse oximetry sensor. The values obtained were termed ‘Blood Refill Time’ (BRT) and compared with the manual CRT. The manual CRT was determined here using a software-based video analysis method. Both the BRT measured in this way and the CRT showed a strong correlation, with the BRT showing longer refill times and a wider range than the standardised CRT.[28]

Another device used polarised light and controlled compression proximal to the wrist crease on the forearm for a video-based measurement of the CRT, referred to here by the authors as ‘polarised CRT’. The skin was illuminated within a cylinder using an LED light source with coaxial polarising filters, which allowed specular reflections to be suppressed. The CRT measurements proved to be robust and independent of skin colour.[29]

Using an electromagnetic piston mechanism, the DiCARTTM system applies standardised pressure for 5 seconds, and the skin changes following piston withdrawal are analysed via video for 6 seconds. One advantage of this device is its flexibility due to its portability. Significant hemodynamic changes induced by arterial and venous occlusion tests could thus be recorded as standardised CRT. However, the prototype used demonstrated limited precision and, according to the authors, a level of agreement with the clinical reference method that was not yet satisfactory.[30–32]

Using the prototype employed in this study, we were able to demonstrate that the sensor is capable of determining the CRT by functioning simultaneously as a pressure, illumination and detection unit. Using the bidirectional OLED sensor, we were able to improve CRT determination to such an extent that certain

subjective factors—such as varying pressure forces, changing light conditions and different contact areas on the skin's surface—could be ruled out.

Limitations

The handheld prototype allows for freedom of movement and measurements to be taken at various locations, however it is connected to a computer (laptop) via USB to transfer data and create log files. Consequently, the device's mobility is limited by this connection. Even though the pressure applied is regulated, it cannot be ruled out that certain areas beneath the sensor may be subjected to greater stress than others, e.g. due to tilting or inclination effects. The technology used here, which involves a measurement that begins within a specified pressure range and ends automatically upon a completely pressure release, should serve as a feedback mechanism to reduce intra-examiner variance in pressing force and time.[33]

There are still unanswered questions regarding how measurements taken with the prototype are affected by different skin types, skin colours, contact pressures, contact areas and measurement locations. Furthermore, opportunities for optimization regarding the colour spectrum used and the contact temperature would be the subject of further investigations. This would be particularly useful for carrying out repeated measurements at the same location.

Conclusion

Bidirectional OLED microdisplay technology opens up the possibility of standardized CRT measurement. The prototype used here on the torso yielded CRT values that were close to those obtained using conventional measurement methods. Further studies are required to evaluate the measurement techniques with regard to different test sites, appropriate lighting and forces applied.

Perspective

The use of OLED-on-CMOS technology allows the surface to be integrated with the light source and the observation unit, thereby offering opportunities for further space-saving optimization. This provides an advantage over other approaches involving light sources and camera technology. OLED-on-CMOS technology potentially enables miniaturisation, which in turn would facilitate integration into textile materials and enable repeatable measurements. Furthermore, the OLED-on-CMOS technology has the potential to detect temporal differences in the CRT with spatial resolution.

Abbreviations

ASA
American Society of Anesthesiologists
BRT
Blood Refill Time

C
Celsius
CMOS
complementary metal-oxide-semiconductor
CRT
capillary refill time
d
digital
LEDs
light-emitting diodes
LOAs
limits of agreement
m
manual
mm
millimeter
N
Newton
NIRS
near infrared spectroscopy
nm
nanometer
OLED
organic light emitting diode

Declarations

Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki and and positive approved by the responsible Ethics Committee of the Technical University of Dresden (BO-EK-37012021). Written informed consent was obtained from all patients prior to enrollment.

Conflicts of Interest:

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to

publish the results.

Funding:

The study was supported by Else Kröner Fresenius Center (EKFZ) for Digital Health, Faculty of Medicine Carl Gustav Carus, TUD Dresden University of Technology, Dresden, Germany for the project “CRT” and by the German Federal Ministry of Research, Technology and Space (SEMECO, 03ZU22104376). The project *SEMECO-B4: Mobile Erfassung der Mikroperfusion (MikroFlow; 100693914)* is co-funded by the European Union and co-financed from tax revenues on the basis of the budget adopted by the Saxon State Parliament and SAB.

Author Contribution

Conceptualization, TR and UV.; methodology, RN, JB, UV, TR; software, JB and UV; validation, RN, JB, AS and TR; formal analysis, KS, RN, JB, AS and TR; investigation, AS; resources, TK; data curation, TR, RN, JB, AS; writing—original draft preparation, TR and RN; writing—review and editing, TR, RN, JB, KS, UV and TK; visualization, TR, RN, JB; supervision, TR, TK; project administration, TR and UV; funding acquisition, RN, JB, TR and UV.

Acknowledgement

The authors would like to thank Dr. Annett Berthold and Sabine Marscholleck of the Else Kröner Fresenius Center for Digital Health at Dresden University of Technology for their exceptional administrative support

Data Availability

The original data presented in the study are included in the article. Further inquiries can be directed to the corresponding author.

References

1. Ince, C. Hemodynamic coherence and the rationale for monitoring the microcirculation. *Crit. Care*. **19** (Suppl 3). 10.1186/cc14726 (2015).

2. Kumar, A. An alternate pathophysiologic paradigm of sepsis and septic shock Implications for optimizing antimicrobial therapy. *Virulence* **5**, 80–97. 10.4161/viru.26913 (2014).
3. Londono, J. et al. Association of Clinical Hypoperfusion Variables With Lactate Clearance and Hospital Mortality. *Shock* 50, 286–292, (2018). 10.1097/SHK.0000000000001066
4. Bruno, R. R. et al. Sublingual microcirculation in prehospital critical care medicine: A proof-of-concept study. *Microcirculation* **27**, e12614. 10.1111/micc.12614 (2020).
5. Davida, L. et al. A prospective, longitudinal monocentric study on laser Doppler imaging of microcirculation: comparison with macrovascular pathophysiology and effect of adalimumab treatment in early rheumatoid arthritis. *Rheumatol. Int.* **40**, 415–424. 10.1007/s00296-019-04503-5 (2020).
6. Scheeren, T. W. L., Schober, P. & Schwarte, L. A. Monitoring tissue oxygenation by near infrared spectroscopy (NIRS): background and current applications. *J. Clin. Monit. Comput.* **26**, 279–287. 10.1007/s10877-012-9348-y (2012).
7. Kim, T. K. et al. Tissue microcirculation measured by vascular occlusion test during anesthesia induction. *J. Clin. Monit. Comput.* **30**, 41–50. 10.1007/s10877-015-9679-6 (2016).
8. Georger, J. F. et al. Could You Repeat Vascular Occlusion Test with near Infrared Spectroscopy to Determine a Modification of the Microcirculation and What Is the Minimal Significant Variation? *Intens Care Med.* **37**, S157–S157 (2011).
9. Lima, A. & Bakker, J. Clinical assessment of peripheral circulation. *Curr. Opin. Crit. Care*. **21**, 226–231. 10.1097/MCC.0000000000000194 (2015).
10. Huang, W. et al. Association of Sublingual Microcirculation Parameters and Capillary Refill Time in the Early Phase of ICU Admission. *Crit. Care Med.* **51**, 913–923. 10.1097/CCM.0000000000005851 (2023).
11. Monares Zepeda, E. et al. Capillary refill time as an additional triage criterion to decide ICU admission of deteriorating obstetric patients. *Crit. Care*. **29**, 231. 10.1186/s13054-025-05404-9 (2025).
12. Hernandez, G. & Bakker, J. Perspectives on perfusion monitoring in septic shock after the ANDROMEDA-SHOCK trial. *Med. Intensiva (Engl Ed)*. **43**, 578–581. 10.1016/j.medin.2019.09.009 (2019).
13. Zampieri, F. G. et al. Effects of a Resuscitation Strategy Targeting Peripheral Perfusion Status versus Serum Lactate Levels among Patients with Septic Shock. A Bayesian Reanalysis of the ANDROMEDA-SHOCK Trial. *Am. J. Respir Crit. Care Med.* **201**, 423–429. 10.1164/rccm.201905-0968OC (2020).
14. Andromeda-Shock-2 Investigators for the Andromeda Research Network & o., S. S. Personalized Hemodynamic Resuscitation Targeting Capillary Refill Time in Early Septic Shock: The ANDROMEDA-SHOCK-2 Randomized Clinical Trial. *JAMA* **334**, 1988–1999. 10.1001/jama.2025.20402 (2025).

15. Kawaguchi, R. et al. Optimal pressing strength and time for capillary refilling time. *Critical Care* 23, doi:ARTN 4 (2019). 10.1186/s13054-018-2295-3
16. Champion, H. R., Sacco, W. J., Carnazzo, A. J., Copes, W. & Fouty, W. J. Trauma score. *Crit. Care Med.* **9**, 672–676. 10.1097/00003246-198109000-00015 (1981).
17. Fleming, S. et al. Validity and reliability of measurement of capillary refill time in children: a systematic review. *Arch. Dis. Child.* **100**, 239–249. 10.1136/archdischild-2014-307079 (2015).
18. Pickard, A. et al. Intra-observer and inter-observer repeatability of capillary refill time. *Anaesthesia* **67**, 44–44 (2012).
19. Espinoza, E. D., Welsh, S. & Dubin, A. Lack of agreement between different observers and methods in the measurement of capillary refill time in healthy volunteers: an observational study. *Rev. Bras. Ter. Intensiva*. **26**, 269–276. 10.5935/0103-507x.20140038 (2014).
20. Jacquet-Lagrèze, M. et al. Prognostic value of capillary refill time in adult patients: a systematic review with meta-analysis. *Critical Care* 27, doi:ARTN 473 (2023). 10.1186/s13054-023-04751-9
21. Richter, B. V. et al. J. Bidirectional OLED microdisplay: Combining display and image sensor functionality into a monolithic CMOS chip. *IEEE International Solid-State Circuits Conference, San Francisco, CA, USA*, 314–316, (2011). 10.1109/ISSCC.2011.5746334
22. Vogel, U. et al. SVGA Bidirectional OLED Microdisplay for Near-to-Eye Projection. *SID Symposium Digest of Technical Papers* 46, 66–66, (2015). 10.1002/sdtp.10543
23. Bland, J. M. & Altman, D. G. Statistical Methods for Assessing Agreement between Two Methods of Clinical Measurement. *Lancet* **1**, 307–310. 10.1016/s0140-6736(86)90837-8 (1986).
24. Cui, Y., Yu, Q., Manatunga, A. & Jang, J. H. A model-free framework for evaluating the reliability of a new device with multiple imperfect reference standards. *Biometrics* 81, doi:ARTN ujaf (2025). 025 10.1093/biomtc/ujaf025
25. LeFlore, J. L. & Engle, W. D. Measurement of capillary refill time (CRT) in term neonates is not a reliable indicator of cardiovascular status. *Pediatr. Res.* **53**, 419a–419a (2003).
26. Shinozaki, K. et al. Low temperature increases capillary blood refill time following mechanical fingertip compression of healthy volunteers: prospective cohort study. *J. Clin. Monit. Comput.* **33**, 259–267. 10.1007/s10877-018-0159-7 (2019).
27. Blaxter, L. L. et al. An automated quasi-continuous capillary refill timing device. *Physiol. Meas.* **37**, 83–99. 10.1088/0967-3334/37/1/83 (2016).
28. Shinozaki, K. et al. Comparison of point-of-care peripheral perfusion assessment using pulse oximetry sensor with manual capillary refill time: clinical pilot study in the emergency department. *J Intensive Care* 7, doi:ARTN 52 (2019). 10.1186/s40560-019-0406-0
29. Bachour, R. P. D., Dias, E. L. & Cardoso, G. C. Skin-color-independent robust assessment of capillary refill time. *J. Biophotonics*. **16** 10.1002/jbio.202300063 (2023).
30. Ruste, M. et al. Measurement of capillary refill time with a handheld prototype device: a comparative validation study in healthy volunteers. *J. Clin. Monit. Comput.* **36**, 1271–1278. 10.1007/s10877-021-

00757-2 (2022).

31. Jacquet-Lagrèze, M. et al. Reliability and reproducibility of the DICART device to assess capillary refill time: a bench and in-silico study. *J. Clin. Monit. Comput.* **37**, 1409–1412. 10.1007/s10877-023-01027-z (2023).
32. Descamps, A., Jacquet-Lagrèze, M., Aussal, T., Fellahi, J. L. & Ruste, M. DiCART™ device to measure capillary refill time: a validation study in patients with acute circulatory failure. *J. Clin. Monit. Comput.* **39**, 831–840. 10.1007/s10877-025-01271-5 (2025).
33. Shinozaki, M. et al. Feedback function for capillary refilling time measurement device. *Critical Care* 23, doi:ARTN 295 (2019). 10.1186/s13054-019-2570-y

Figures

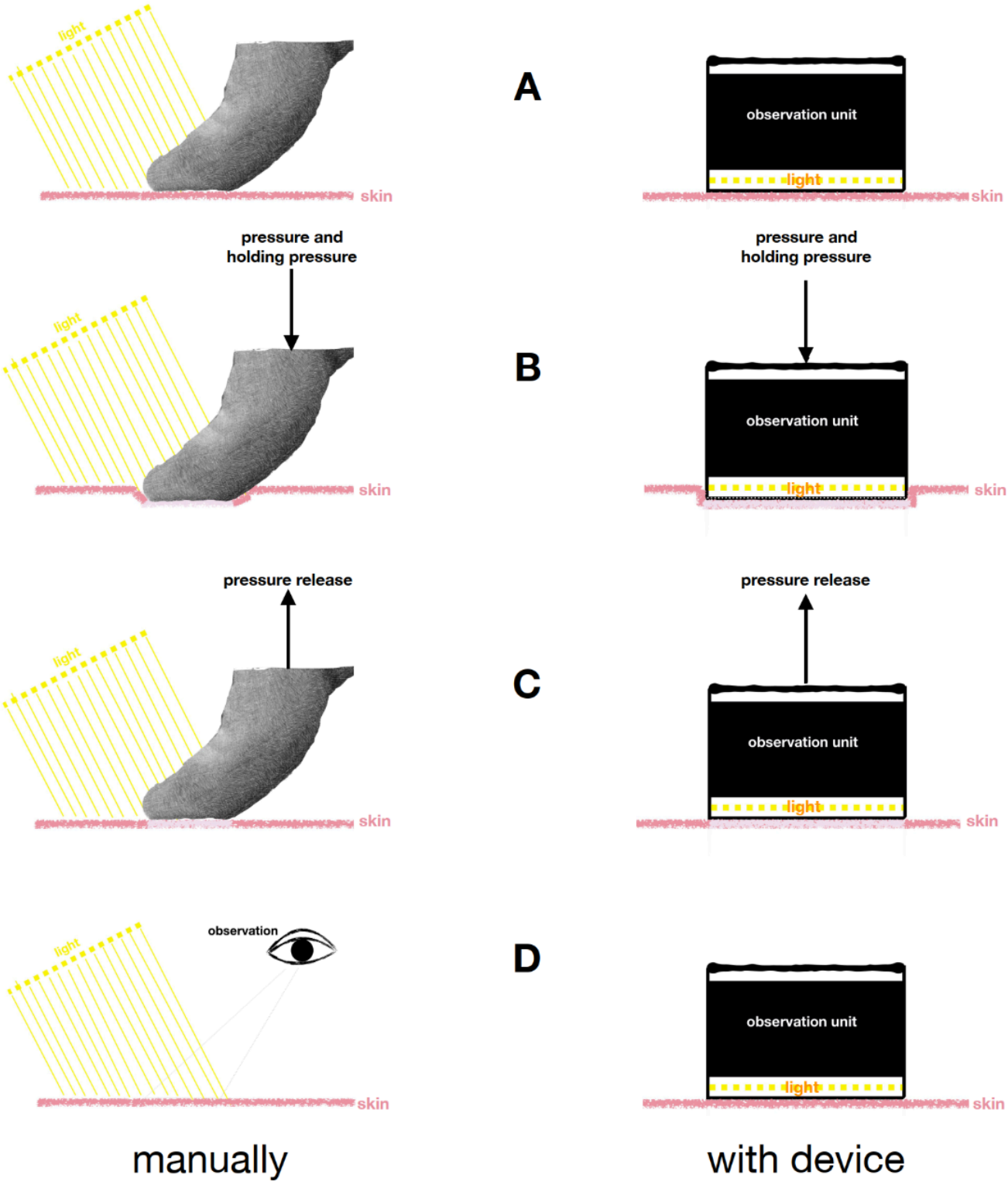
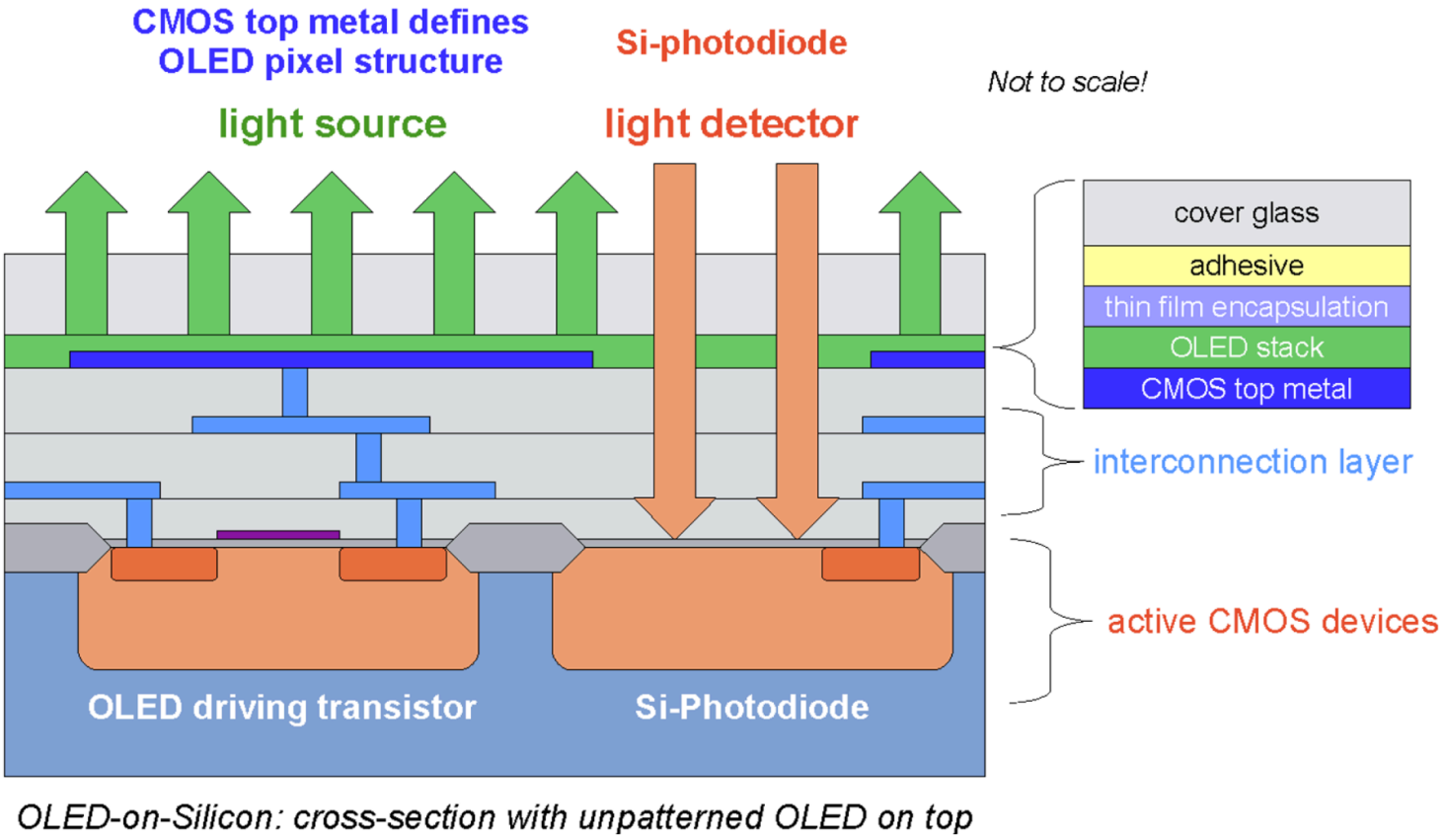


Figure 1

Schematic representation of the measurement principle of CRT - conventional determination (left: manually) or with the aid of a device (right). A): Starting position, B): pressure with contact surface on the skin surface, maintaining the pressure for 5 seconds, resulting in reduced blood flow to the compressed skin area, C) pressure relief, D) measurement of the time until the pallor of the skin has completely regressed. It should be noted that with the conventional procedure, observation of the skin is

only possible after removal of the finger used. The device works with a pressure that can be controlled and a standardized surface area.



OLED-on-Silicon: cross-section with unpatterned OLED on top

Figure 2

Illustration of the principles of the organic light emitting diode (OLED) – sensor. CMOS: complementary metal-oxide-semiconductor, OLED: organic light emitting diode.

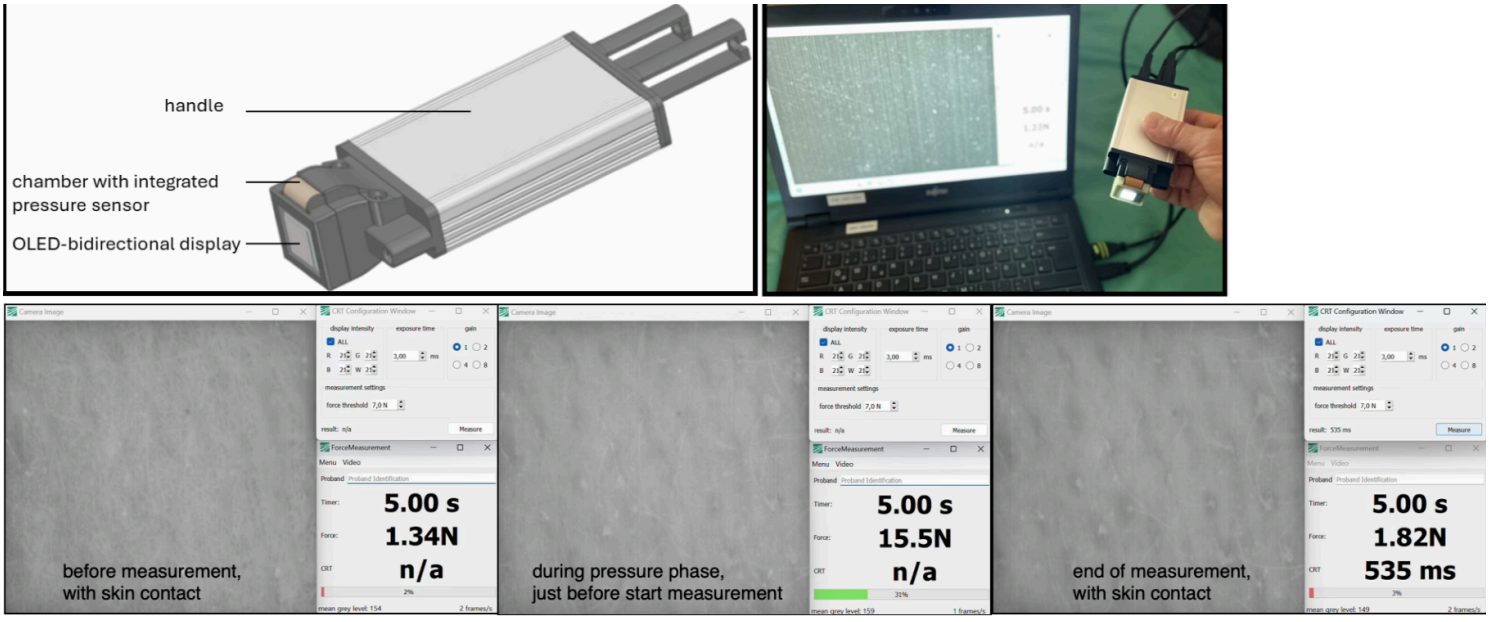


Figure 3

CRT measuring tool. Left: handheld Prototype, Right: measuring unit. Below: Measuring output on the Laptop-screen.

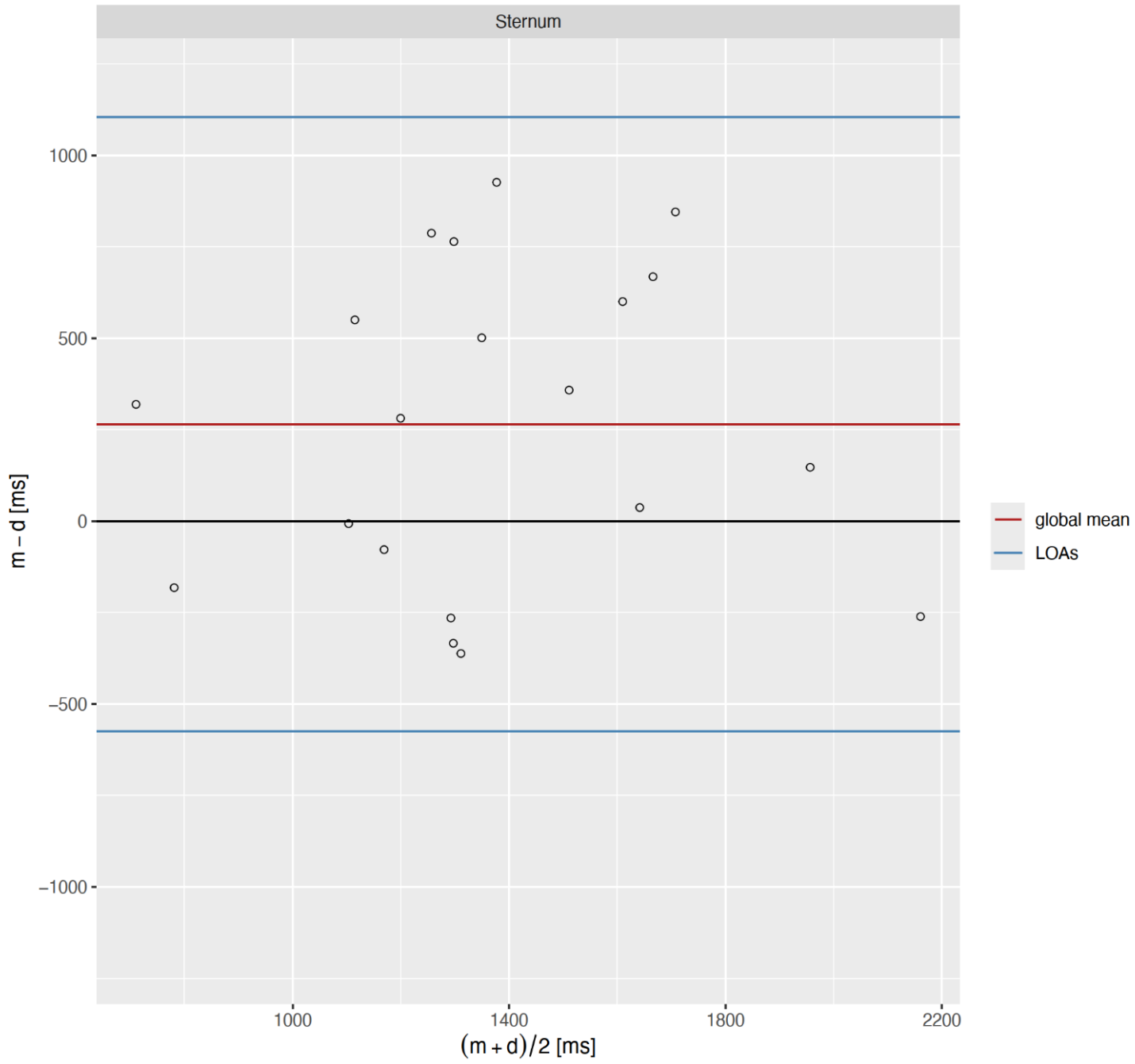


Figure 4

Bland-Altman plot for analysing the agreement between manual (m) and digital (d) measurements of recap time. If there is complete agreement, all points should lie on the horizontal zero line. Any deviation from the zero line should be small and non-systematic. The global mean shows such a deviation. The

limits of agreement (LOAs) define the estimated 95% reference range assuming a normal distribution of the differences (m-d).