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CAPILLARY REFILL TIME MEASUREMENT DEVICE

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Abstract

Capillary refill time (CRT) can be defined as a rapid clinical test for assessing blood flow through peripheral tissues. Importance of the monitarisation of the CRT is emphasized in diagnosis and treatment guideleness for shock. The capillary refill test is currently conducted manually and its implementation varies according to medical personnel. There isn't any commercial device that standardizes both the magnitude and the duration of the force applied for sensing the perfusion of the capillaries. A microcontroller based device is designed to measure the capillary refill time. An infrared led is used as a light source. Also a linear actuator is used to able to apply a constant force during a constant time to the fingertip. We evaluated our design on one healthy volunteer and one thalassemia carrier by performing 30 measurements. It is known that thalassemia carriers may have prolonged capillary refill time which is consistent with our measurements obtained by the proposed design.

Keywords: Capillary refill time, Shock, Optical sensors

KILCAL DAMAR DOLUM SÜRESİ ÖLÇÜM CİHAZI

Öz

Kapiler dolum zamanı, çevresel dokulardaki kan akışını değerlediren hızlı klinik bir test olarak tanımlanabilir. Şokun tanı ve tedavi rehberlerinde kapiller geri dolum zamanı (Capillary Refill Time, CRT) monitorizasyonunun önemi belirtilmektedir. Hâlihazırda CRT manuel olarak ölçülmekte ve uygulanması ölçüm yapan personele göre değişmektedir. Kılcal damarlardaki kanlanmayı tespit etmek için uygulanan kuvveti ve baskı süresini standardize eden ticari cihaz mevcut değildir. Kapiler dolum zamanını ölçmek için mikroişlemci tabanlı bir cihaz tasarlanmıştır. Işık kaynağı olarak kızılötesi bir LED kullanılmıştır. Ayrıca parmak ucuna belirli bir süre bilinen bir kuvvet uygulamak için bir lineer aktüatör kullanılmıştır. Tasarımımızı, bir sağlıklı ve bir talesemi taşıyıcısı gönüllü üzerinde 30 ölçüm gerçekleştirmek suretiyle değerlendirdik. Talesemi taşıyıcılarının daha uzun CRT'ye sahip olduğu bilinmektedir. Önerilen tasarımla yapılan ölçümler de bu durumu doğrulamıştır.

Anahtar Kelimeler: Kılcal Damar Dolum Süresi, Şok, Optik sensörler

Cite

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1. Introduction

Shock is a major mortality factor for both for children and adults. It is estimated that 8,000 children under five years die every day from hypovolemic shock. The mortality rate among children with septic shock is approximately %25. Importance of the monitarisation of the Capillary Refill Time (CRT) is emphasized in diagnosis and treatment guidelines for shock. It is included in the World Health Organization (WHO) emergency triage assessment and treatment (ETAT) guidelines.

Manually CRT is measured by applying a short pressure on nail beds which prevents blood flow to capillaries and causes blanching. If there is good blood flow to the nail bed, a pink color should be observed less than 2 seconds after pressure is released. More than 2-3 seconds means poor circulation. CRT can be especially important for evaluation of clinical conditions such as cardiovascular disorders and shock. For example, for a patient suspected of having infection, tachycardia and abnormal CRT together are considered as septic shock.

Different approaches exist in the literature on the evaluation of CRT (Table 1). So it is necessary to standardize CRT measurements. By evaluating current literature on CRT, we may conclude that the main parameters affecting the capillary refill time are: magnitude and duration of the force applied, ambient temperature and extremity surface temperature. There isn't any commercial device that standardizes both the magnitude and the duration of the force applied for sensing the perfusion of the capillaries. Experimental ones use a mechanical spring system and does not consider the duration of the force applied [1].

The designed device standardizes both the magnitude and the duration of the force applied. We evaluated the device on two volunteers: one healthy and one thalassemia carrier.

Table 1: Summary of different approaches, for performing and evaluating CRT, that exist in the literature.

Method	Evaluation	Ref
The test should be performed on the fingertip or nail bed in a warm room. Light pressure is applied to blanch the fingernail bed, and the time is measured until color returns.	Delay of only 2-3 s indicates moderate dehydration, and a measurement of more than 3 s occurs with severe fluid losses.	[2]
Check CRT at the kneecap or forearm.	Normal CRT is less than 2-3s.	[3]
It is most accurate in a fingernail depressed with gentle pressure for at least 3 s and under warm ambient conditions.	Normal CRT for the pediatric patient is usually considered to be less than 2s.	[4]
Skin perfusion may be assessed by the temperature of the skin or by CRT (the time required for color to return to the skin after pressure blanching that part of the skin is released).	Normal CRT is 2s or less; however, low environmental temperature may cause peripheral vasoconstriction and lengthening of capillary refill.	[5]
Following cutaneous pressure on a digit held at the level of the heart or preferably on the center of the sternum for 5s, capillary refill should occur within 2s.	A slower refill than this indicates poor skin perfusion.	[6]
Method not described	Although CRT is a widely used clinical sign, there is little validation of its accuracy. A CRT of less than 3 s is traditionally accepted as normal.	[7]
To evaluate the CRT, lift the extremity slightly above the level of the heart, press on the skin, and rapidly release the pressure.	A CRT >2 s is a useful indicator of moderate dehydration when combined with decreased urine output, absent tears, dry mucous membranes, and a generally ill appearance.	[8]
To assess the child's capillary refill, grasp the child's thumb or big toe between finger and thumb. Look at the pink of the nail bed. Apply minimal pressure necessary for 3 s to produce blanching of the nail bed. Time the capillary refill from the moment of release until total return of the pink color.	CRT should be less than 3 s. If it is more than 3 s the child is in shock.	[9]

2. Materials and Methods

To be able to observe light intensity variations induced by blood volume changes, one infrared LED (940nm, Vishay, TSAL 6400) and appropriate photodiode (430-1100nm, Vishay, VBPW34S) are used. IR wavelength is chosen because it allows deep penetration in tissue and also decreases the effect of the ambient light.

The measurement principle of continuous wave(CW) light-tissue interactions are based on Beer-Lamber law presented in Figure 2 that describes light attenuation through a sample of homogenous non-scattering media. Mathematically law is expressed as

$$I = I_o e^{-\varepsilon_\lambda c l} \qquad (1)$$

where I is the transmitted intensity of the light, I_o is the incident intensity, ε_λ is the extinction coefficent or absorptivity of the absorbent at wavelength λ, c is the the concentration of the absorbent, and l is the optical path-length of the sample. In case where the sample consists of layers of absorbents, the total intensity of transmitted light is a linear superposition of intensities of each absorbent. The absorbance can be written in form;

$$A_\lambda = -\ln(T) = -\ln(\frac{I}{I_o}) = \sum_a \varepsilon_{a,\lambda} c_a l_a \qquad (2)$$

where a represents all tissue components such as arterial blood, venous blood, skin and bones in the sample, T represents a sample called transmission.

IR light is absorbed by hemoglobin in the blood (Figure 1) and according to Beer-Lambert law described above absorbed intensity is proportional to the concentration of hemoglobin. So decreasing the blood volume by applying pressure on finger causes less light absorption and more light reflection. Then releasing pressure on fingertip permit the flow of blood back into the capillaries and causes less light reflection.

The photodiode produces current as a function of the intensity of the reflected light from the finger. The current signal is converted to a voltage signal by using a transimpedance amplifier (opamp LM358). Then voltage signal, amplified by an inverting amplifier, is read by the ADC input pin of the microcontroller (Microchip, dspic33fj128gp802). We used dsPIC33F since it has built-in signal processing capabilities. Block diagram of the designed device is shown in Figure 3.

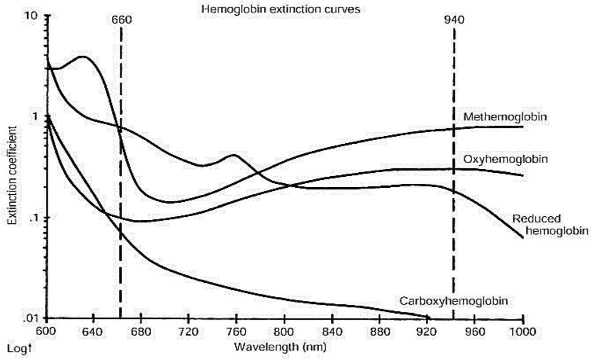

Figure 1 Absorption curve of hemoglobin with respect to wavelength (Courtesy of Susan Manson, Biox/Ohmeda, Boulder, Colorado, 1986).

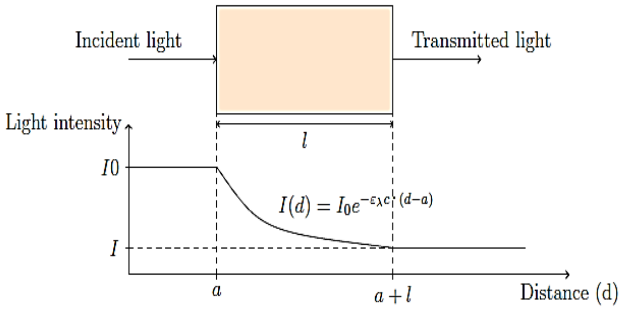

Figure 2 Beer-Lambert Law

A linear actuator is used to able to apply a constant force during a constant time to the fingertip. Briefly when the pressure is applied on fingertip by a Linear Actuator (Firgelli, PQ12S), measured voltage reaches at its peak value and when the pressure is released, voltage starts to decrease slowly. The duration between the instant that the pressure is released and the instant that the decreasing voltage curve reaches a constant slope is measured as CRT. Also temperature sensor (Maxim Integrated, DS18B20) is used to able to measure ambient temperature while we did not perform temperature calibration. Pressure is applied to the fingertip by the linear actuator which is driven by PWM (pulse width modulation) output of the microcontroller. A FSR (force sensing resistor, Interlink Electronics FSR-402) is attached to the tip of the actuator in order to detect pressure from the actuator. Actuator force is controlled by varying the PWM output according to the feedback signal from FSR (read by ADC input). A constant force is applied for 3 seconds. When the pressure is released, microcontroller starts to record the photodiode signal to an array for 5 seconds.

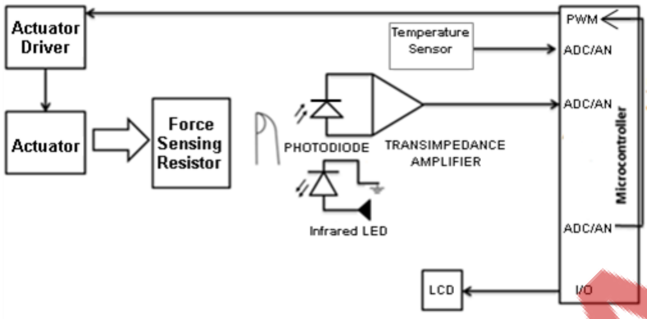

Figure 3 Simplified block diagram of the designed device.

3. Results

A sample measurement is recorded to the SD card and the obtained data is plotted by computer (Fig. 4). The duration between the instant that the pressure is released on the fingertip and the instant that the decreasing voltage curve reaches a constant slope is measured as CRT. When the curve reaches a constant value capillary refill is said to be completed. Device is evaluated by performing 30 experiments on two volunteers (Table 2). Some of the experiments are performed at different times which means different ambient temperature. And some of them performed in succession which results with the increase of the finger surface temperature.

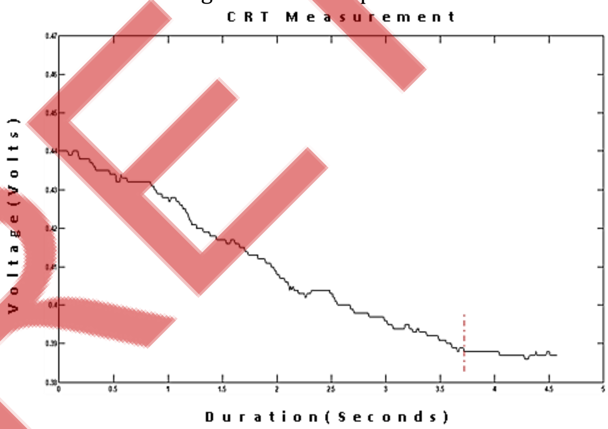

Figure 4 Photodiode signal measured at ADC input

Table 2: Results of the experiments performed on volunteers.

Exp. No	Healthy CRT(sn)	Thalassemia Carrier CRT(sn)
1	1.19	2.91
2	1.19	1.05
3	1.26	2.90
4	1.30	3.28
5	1.36	1.77
6	1.36	2.44
7	1.37	1.54
8	1.50	2.33
9	1.68	2.90
10	1.70	1.83
11	1.81	2.10
12	1.84	2.90
13	1.88	3.28
14	1.90	4.96
15	1.92	3.47
16	1.95	2.92
17	1.95	4.05
18	1.98	3.68
19	2.07	2.49
20	2.15	2.85
21	2.15	4.74
22	2.21	2.33
23	2.26	3.26
24	2.34	2.83
25	2.43	3.30
26	2.52	1.40
27	2.56	3.87
28	2.59	2.91
29	2.68	1.59
30	2.90	3.48

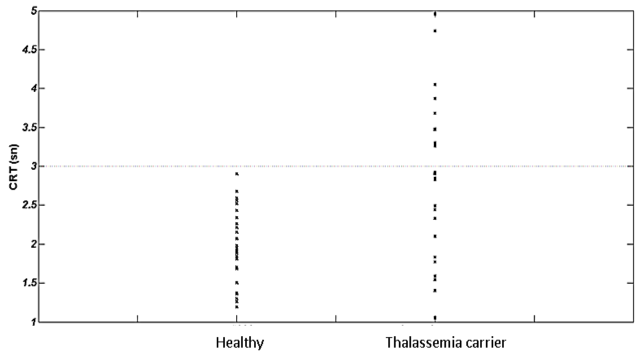

Figure 5 Comparison of the CRT.

The CRT values of the two volunteers were compared with the Wilcoxon rank sum test. The Wilcoxon rank sum test is a nonparametric test used to determine whether two independent samples taken from the population have the same distribution. The null hypothesis was established as the median values of the measurements taken from two volunteers are equal. The alternative hypothesis is that the median of the measurements taken from the healthy individual is less than the thalassemia carrier. Based on the test results, the null hypothesis is rejected in the 95% confidence and we can conclude that the values obtained from the healthy individual are lower. In addition, as can be seen from Fig.5, the results obtained for healthy individual are less than 3 seconds. According to current guidelines a CRT of less than 3 s is traditionally accepted as normal.

4. Conclusion

The capillary refill test is currently conducted manually and its implementation varies according to medical personnel. To the best of our knowledge this is the first study that standardizes both the magnitude and the duration of the force applied for sensing the perfusion of the capillaries by using a linear actuator and a microcontroller.

It is known that thalassemia carriers may have prolonged capillary refill time which is consistent with our measurements performed by using the designed device. Based on the results we may conclude that the device can perform automatic CRT measurements. But, with the permission of the ethics committee, the study should be expanded by performing more experiments on the child patients and healthy volunteers to able to use in a clinical environment.

All measurements taken from healthy subjects were below 3 seconds and this finding is consistent with the existing literature. But the CRT interval of the thalassemia carrier varies within a wide range. We performed some of the measurements at different times which means different ambient temperature. And some of them performed in succession which results with the increase of the finger surface temperature. Variability in measurements can be explained by the lack of temperature calibration.

Also the proposed design needs further improvements. Using a narrow band photodiode to detect IR light and a better mechanical design can reduce the effect of the ambient light. With a better PCB design, the noise can be minimized. Also using a high speed op-amp with low bias current for amplifying and filtering photodiode signal may give more accurate measure of CRT. Further denoising (filtering) can be performed by using dsPIC33F's built-in signal processing capabilities.

5. Acknowledgment

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