Cardiology in the Young

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Oxygen saturation measurement in cyanotic heart disease with the Apple watch

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Original Article

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Abstract

Background: Accurate measurement of transcutaneous oxygen saturation is important for the assessment of cyanosis in CHD. Aim of this study was the evaluation of a supplementary transcutaneous oxygen saturation measurement with an Apple watch® in children with cyanotic heart disease. *Material and methods:* During a six-minute walk test, measurement of transcutaneous oxygen saturation was performed simultaneously with an Oximeter (Nellcor, Medtronic, USA) and an Apple watch® Series 7 (Apple inc, USA) in 36 children with cyanotic heart disease. *Results:* Median age was 9.2 (IQR 5.7–13.8) years. Transcutaneous oxygen saturation measurement with the Apple watch® was possible in 35/36 and 34/36 subjects before and after six-minute walk test. Children, in whom Apple watch® measurement was not possible, had a transcutaneous oxygen saturation < 85% on oximeter. Before six-minute walk test, median transcutaneous oxygen saturation was 93 (IQR 91–97) % measured by oximeter and 95 (IQR 93–96) % by the Apple watch®. After a median walking distance of 437 (IQR 360–487) m, transcutaneous oxygen saturation dropped to 92 (IQR 88–95, $p < 0.001$) % by oximeter and to 94 (IQR 90–96, $p = 0.013$) % measured with the Apple watch®. *Conclusion:* In children with mild cyanosis measurement of transcutaneous oxygen saturation with an Apple watch® showed only valid results if transcutaneous oxygen saturation was > 85%, with higher values being measured with the smart watch. In children with moderate or severe cyanosis transcutaneous oxygen saturation, measurement with the Apple watch® was not reliable and cannot be recommended to monitor oxygen saturation at home.

In cyanotic heart disease, measurement of transcutaneous oxygen saturation is a cornerstone in scheduling interventional or surgical procedures. In patients with univentricular palliation, this assessment of transcutaneous oxygen saturation is essential prior to the third surgical step (establishment of total cavopulmonary connection) or could indicate presence of veno-venous collaterals bypassing the lung in subjects with completed Fontan circulation. As standard of care, measurement of transcutaneous oxygen saturation is performed as plethysmography: certified medical devices emit light at two distinct wavelengths as oxygenated and deoxygenated haemoglobin have different absorption spectra based on the Beer–Lambert law. Signals of these lights could be used to calculate transcutaneous oxygen saturation and heart rate.[1]

With Moore's law, size of these devices is nowadays tiny and enabled manufactures to integrate this technology in different smart watches to offer consumers health data. An optical sensor at the backside of the watch emits light at the wrist and detects the reflection. It is of note that these watches are not certified medical devices and did not pass any official approval process. In adult patients, these watches have been successfully used for the detection of arrhythmias[2–4] and oxygen saturation.[5] A recent study suggested that O_2 measurement in children with a smart watch is not practical due to a high number unsuccessful measurements.[6] Aim of this study was to re-evaluate value and the accuracy of smart watch based transcutaneous oxygen saturation measurement in children with cyanotic heart disease;[6] here especially during the 6-minute walk test.

Material and methods

Patients with cyanotic heart disease who visited our outpatient department between 04/2022 and 07/2023 were asked for participation in this study. Inclusion in this study required written consent, mental and physical ability to perform a six-minute walk and a wrist suitable for wearing an Apple watch® Series 7 with 41 mm case size (Apple, CA, USA). Subjects > 18 years and those with baseline transcutaneous oxygen saturation > 98% were excluded from this study.

Participants performed a six-minute walk test as part of our routine follow-up care. During six-minute walk test, continuous measurement of transcutaneous oxygen saturation was performed using a Nellcor N-65 OxiMax oximeter (Medtronic, USA) with a disposable DS 100A

Table 1. Baseline characteristics of the study cohort (n = 36). Data is given as median and inter-quartile-range or number and percentage if appropriate

		all Patients n = 36
Female gender	n (%)	16 (44%)
Body weight	kg	30 (18–45)
Body length	cm	137 (113–168)
Diagnosis		
Hypoplastic left heart syndrome	n (%)	15 (42%)
Tricuspid atresia	n (%)	5 (14%)
Pulmonal atresia	n (%)	4 (11%)
Double-outlet right ventricle	n (%)	4 (11%)
Congenitally corrected transposition of the great arteries	n (%)	3 (8%)
Miscellaneous	n (%)	5 (14%)
s/p surgical therapy		
Total cavopulmonary connection without fenestration	n (%)	21 (58%)
Total cavopulmonary connection with fenestration	n (%)	7 (20%)
Glenn anastomosis / comprehensive stage II	n (%)	3 (8%)
Central AP shunt	n (%)	2 (6%)
None	n (%)	3 (8%)

sensor (Medtronic, USA) being attached to the index finger of the right hand. The measurement of transcutaneous oxygen saturation could be done continuously while moving. In addition, an Apple watch® Series 7 was attached to the right wrist and transcutaneous oxygen saturation measurement was done before and after the six-minute walk test. This measurement of transcutaneous oxygen saturation with the Apple watch® required 10 s while the wrist was kept still.

Statistical analysis was done with SPSS 28 (IBM, NY, USA).

Results

Patient cohort

A total of 36 children were included in this study. Median age was 9.2 (IQR 5.7–13.8) years, median body weight was 30.3 (IQR 18.2–45) kg, and median body height was 137 (113–160) cm (see Table 1).

Results of the six-minute walk test

During six-minute walk test, a median walking distance of 437 (IQR 360–487) m was obtained. Measured by the certified oximeter, median transcutaneous oxygen saturation was 93 (IQR 91–97) % at the beginning of the six-minute walk test and dropped to 92 (IQR 88–95) % at the end of walking ($p < 0.001$). Transcutaneous oxygen saturation measurement with the Apple watch® was possible in 35/36 subjects at the beginning of six-minute walk test and was 95 (IQR 93–96) %. The boy (5.7 years) in whom the Apple watch® failed transcutaneous oxygen saturation measurement before walking had s/p total cavopulmonary connection procedure for hypoplastic left heart syndrome with a large Fontan fenestration and a transcutaneous oxygen saturation of 77% on oximeter. Median difference between transcutaneous oxygen saturation measurement by oximeter and Apple watch® was 0% (IQR −4–1%, $p = 0.057$). In 3 (8%) subjects, transcutaneous oxygen saturation values on oximeter were > 3 basis (%) points compared to Apple watch® while transcutaneous oxygen saturation was < 3% basis points on oximeter in 11 (31%) patients, respectively.

After the six-minute walk test, transcutaneous oxygen saturation measurement with the Apple watch® was possible in 34/36 children and had dropped to 94 % (IQR 90–96 %, $p = 0.013$). In addition to the boy in whom the first measurement already failed, the watch refused measurement in another boy (4.2 years) with s/p Glenn procedure for hypoplastic left heart syndrome who had a simultaneous transcutaneous oxygen saturation of 85% on oximeter. After the six-minute walk test, median difference between transcutaneous oxygen saturation measurement by oximeter and Apple watch® was -1% (IQR −3–1%; $p = 0.041$) with higher values being measured with the smart watch. Measurements yield a transcutaneous oxygen saturation > 3% basis points on oximeter in only one (3%) subject while lower transcutaneous oxygen saturation < 3% basis points on oximeter were present in 7 (19 %) patients, respectively.

Data did not differ if comparing the pre-/post-six-minute walk test measurements in children aged < 10 years (n = 18) with those > 10 years (n = 18).

Discussion

In adult patients, smart watches have been successfully used for the detection of oxygen saturation, while O2 measurement in children with a smart watch was reported not to be practical due to a high number unsuccessful measurements.[6] The aim of this study was to re-evaluate value and accuracy of smart watch based transcutaneous oxygen saturation measurement in children with cyanotic heart disease. Changes in oxygen saturation may help in scheduling new doctor's appointments.

We therefore compared the transcutaneous oxygen saturation measurement of a certified oximeter with the performance of an Apple watch® during rest and after a six-minute walk test as a model of exercise. It is of note that the Apple watch® required for transcutaneous oxygen saturation measurement at an interval of 10 s with a wrist kept still and measurement with the watch therefore represent not the maximum of cyanosis.

In a recent study on 270 children, transcutaneous oxygen saturation measurement with the Apple watch® showed no satisfying results due to a high number of unsuccessful measurements.[6]

In our study, results of the oximeter and the smart watch did not differ statistically before six-minute walk test and were by trend slightly higher for the smart watch. During the six-minute walk test, transcutaneous oxygen saturation measurement dropped significantly in our patients. Although we recorded oximeter transcutaneous oxygen saturation at the same time, the Apple watch® transcutaneous oxygen saturation results were slightly, but significantly higher and therefore tend to underestimate cyanosis systemically. In addition, the Apple watch® did not show any transcutaneous oxygen saturation result lower 82% which limits

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the usability of the watch to subjects with mild cyanosis like in previous observations on subjects with lung disease.[5] It could be assumed that the watch facilitates detection of a slow transcutaneous oxygen saturation drop in selected subjects with CHD and a moderate cyanosis (e.g. patients after total cavopulmonary connection without fenestration and growing veno-venous collaterals), but the watch cannot be recommended for monitoring cyanosis at home in children with cyanotic heart disease.

Author contribution. Stefan Rupp and David Backhoff contributed equally.

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Competing interests. None.

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