American Journal of Pediatrics
2023; 9(2): 79-84
http://www.sciencepublishinggroup.com/j/ajp
doi: 10.11648/j.ajp.20230902.15
ISSN: 2472-0887 (Print); ISSN: 2472-0909 (Online)

Validity Study Comparing Polar Ignite's® Estimated VO2max to Traditional Cardiopulmonary Exercise Testing in Normal Cardiac Anatomy & Fontan Pediatric Patients

Brian Hernandez[1], Bayley Roberts[1], Erica Jamro-Comer[2], Anusha Kodidhi[2], Lisa Roelle[1], Nathan Miller[3], Lauren Littell[1], Aecha Ybarra[1], Jonathan Silva[4], Jennifer Silva[1, 4], William Orr[1, *]

[1]Division of Pediatric Cardiology, Department of Pediatrics, Washington University School of Medicine, St Louis, MO, USA

[2]Department of Pediatrics, St. Louis Children's Hospital, St. Louis, MO, USA

[3]Electrophysiology Laboratory, St Louis Children's Hospital, St Louis, MO, USA

[4]Department of Biomedical Engineering, Washington University McKelvey School of Engineering, St Louis, MO, USA

Email address:

worr@wustl.edu (William Orr)

[*]Corresponding author

To cite this article:

Brian Hernandez, Bayley Roberts, Erica Jamro-Comer, Anusha Kodidhi, Lisa Roelle, Nathan Miller, Lauren Littell, Aecha Ybarra, Jonathan Silva, Jennifer Silva, William Orr. Validity Study Comparing Polar Ignite's® Estimated VO2max to Traditional Cardiopulmonary Exercise Testing in Normal Cardiac Anatomy & Fontan Pediatric Patients. *American Journal of Pediatrics*. Vol. 9, No. 2, 2023, pp. 79-84.
doi: 10.11648/j.ajp.20230902.15

Received: April 19, 2023; **Accepted**: May 17, 2023; **Published**: May 29, 2023

Abstract: Cardiorespiratory fitness as represented by maximum oxygen uptake, VO2max, is considered the best indicator for overall cardiovascular health. Fitness technology such as wrist worn devices, now allows for an easy method to monitor an individual's VO2max. This study sought to compare the estimated VO2max measurements from the Polar Ignite (Polar Electro Oy, Kempele, Finland) fitness watch (Polar Ignite) against the gold standard, cardiopulmonary exercise testing (CPET) in normal cardiac anatomy and Fontan pediatric patients. This single-center, prospective study enrolled patients with normal cardiac anatomy and single ventricle patients with Fontan palliation (Fontan) between 13-21 years. The Polar Ignite was fastened on the patient's right or left wrist while supine and estimated VO2max was generated based on a non-exercise test (Polar Fitness Test). A maximal voluntary CPET using the standard Bruce Treadmill Protocol was then completed. Measurements from the two tests were compared using the intraclass correlation coefficient (ICC), Pearson correlation coefficient and Bland-Altman method. Forty-seven patients were enrolled, including n=36 (77%) normal cardiac patients and n=11 (23%) Fontan patients. The majority of participants were white (n=41, 87%) and female (n=36, 66%). Patients were 15.3±1.9 years old, weighed 65.7±16.6 kg, and were 168.0±10.4 cm tall on average. The mean estimated Polar Ignite VO2max and peak CPET VO2 was 43.9±6.1 ml/kg/min vs 37.7±8.2 ml/kg/min, respectively in the normal cardiac group, and 42.6±3.9 ml/kg/min vs 22.6±5.6 ml/kg/min, respectively in the Fontan group. We found poor validity (ICC=0.21) and a weak correlation (r=0.31, p=0.07) between VO2max measured by the Polar Ignite and CPET in the normal cardiac group and poor validity (ICC=0.08) and strong correlation (r=0.84, p=0.001) in the Fontan group. In Bland-Altman analyses, the mean bias between VO2max as measured by the Polar Ignite and CPET was 6.85 ml/kg/min among the normal cardiac group and 20.05 ml/kg/min among the Fontan group. The Polar Ignite overestimated VO2max compared to CPET in both the normal cardiac and Fontan groups and cannot replace formal testing.

Keywords: Wearable Devices, Cardiopulmonary Exercise Testing, VO2max, Fontan

1. Introduction

Cardiorespiratory fitness (CRF), or exercise capacity, is a focus for athletes and exercise enthusiasts as a measurable metric that can be tracked over time. Exercise capacity is the ability to deliver oxygenated blood to the exercising skeletal muscles, requiring optimally functioning respiratory, cardiovascular and skeletal muscle systems and therefore can

be used as a representation of overall total body health and cardiovascular risk [1-3]. This coupling of external to cellular respiration is represented as the maximum oxygen uptake (VO2max) and refers to the greatest amount of oxygen taken in from inspired air while performing dynamic exercise [4]. Currently, the gold standard method for measuring a VO2max is through formal cardiopulmonary exercise testing (CPET), involving rigorous physical activity, sophisticated equipment and expert supervision [5-7]. However, with the advancement of technology, continuous monitoring of health parameters including exercise activity, performance and physiological data has become more widely available to the general public [8].

Fitness technologies now are available directly to consider as apps, software, smart equipment and wearable devices [9]. This has created an easy and cost-effective method of monitoring fitness and health, gaining popularity worldwide among adults and children [10]. One such wearable is the Polar Ignite (Polar Electro Oy, Kempele, Finland) fitness watch (Polar Ignite), which estimates a user's VO2max based on non-exercise conditions including resting heart rate (HR) and heart rate variability (HRV) [11]. To date, scientific validation studies to evaluate the accuracy of wrist worn wearables have been predominately completed in adult patients [11-14] demonstrating moderate-strong correlation, however there is little data to support its use in the pediatric population [15, 16].

The primary aim of this study is to determine the validity of the Polar Ignite's Fitness Test VO2max estimation compared to the VO2peak obtained with a formal CPET in pediatric patients with both normal cardiac anatomy and in those with single ventricle anatomy who have completed Fontan palliation (Fontan). We hypothesize that the Polar Ignite will provide an accurate estimate of the VO2max as compared to the CPET in the normal cardiac group, but will be inaccurate in the Fontan group.

2. Methods

A prospective study was undertaken enrolling patients between January 1, 2022 and October 31, 2022. A convenience sampling identified eligible participants by reviewing the weekly scheduled and clinically indicated CPET at the St. Louis Children's Hospital Exercise Physiology Lab. Inclusion criteria were: 1) patients between the ages of 13 and 21 scheduled for a CPET, and 2) either normal cardiac anatomy or Fontan palliation. Patients were excluded for 1) significant structural cardiac abnormalities on transthoracic echocardiogram except for a single ventricle with Fontan palliation, 2) hemodynamically significant dysrhythmias diagnosed before or during the CPET, 3) evidence of submaximal effort which was defined by a peak respiratory exchange ratio (RER) <1.05 and peak HR <85% predicted for age, 4) any heart rate lowering medications, or 5) if consent or assent was not obtained from both the parent/guardian and patient, respectively. Due to baseline chronotropic incompetence often seen in Fontan patients [17], they were not excluded for a HR <85% predicted for age. Study approval was obtained from the Institutional Review Board (IRB#:202109035) at Washington University School of Medicine in St. Louis, Missouri.

2.1. Demographic Data

Demographic data obtained included age, date of birth, height, weight, sex, race, and indication for CPET.

2.2. Polar Ignite Fitness Test

The non-exercise based Polar Ignite Fitness Test was completed according to the manufacturer's protocol. First, a patient's baseline demographics were entered manually into the Polar Ignite settings followed by proper fastening of the device to the patient's right or left wrist. While in the supine position, the patient remained free of movement and speech for approximately 1 minute prior to and during the Polar Fitness Test. After completion, the VO2max was displayed as VO2 mL/kg/min, and subsequently recorded. Finally, the watch was removed and a factory reset was performed.

2.3. Cardiopulmonary Exercise Test

Following the Polar Fitness Test, subjects performed their scheduled CPET. All patients underwent a symptom-limited maximal CPET performed on a treadmill ergometer using the standard Bruce Treadmill Protocol. Patients were equipped with a neoprene face mask connected to an Ultima™ CardiO2 (MGC Diagnostics, St Paul, MN) metabolic cart. Expired gases were measured at rest and throughout the exercise protocol. Metabolic measurements including oxygen consumption (VO2), and carbon dioxide production (VCO2) were measured on a breath-by-breath basis to calculate an RER. The RER and HR were measured continuously. Peak oxygen consumption (VO2peak) was recorded.

2.4. Statistical Analysis

The distribution of demographic and clinical characteristics of the study sample were examined overall and stratified by cardiac anatomy. Continuous variables were examined as mean±SD and t-tests were utilized to assess differences between the cardiac anatomy groups. Categorical variables were examined as N (%) and Chi-Square tests were utilized to assess differences between the cardiac anatomy groups. The intraclass correlation coefficient (ICC; calculated using single rater/measurement, absolute-agreement, 2-way random-effects model), Pearson correlation coefficient, and Bland-Altman analyses were conducted, stratified by cardiac anatomy, to assess the relationship between the VO2max as estimated by the Polar Ignite and the VO2peak as measured by CPET. P-values < 0.05 were considered statistically significant. SAS v9.4 was used for analyses.

3. Results

A total of 56 patients met the inclusion criteria and were enrolled in this study. Four patients were excluded from analyses for inability to generate a VO2max on the Polar

Ignite and five were excluded for a submaximal effort on the CPET leaving a final cohort of 47 patients. Of the 47 patients, the average age was 15.3±1.9 years, average height was 168.0±10.4 cm, average weight was 65.7±16.6 kg, n=31 (66%) were female and n=41 (87%) were white. CPET indications included chest pain (n=12, 26%), syncope (n=11, 23%), shortness of breath (n=6, 13%), tachycardia/palpitations (n=5, 11%), others (n=2, 4%), and Fontan (n=11, 23%) (Table 1). Thirty-six (77%) patients had normal cardiac anatomy and n=11 (23%) patients had Fontan anatomy. No statistical differences in demographic characteristics were detected between the two groups. While there was no statistically significant difference in the resting HR (77.9±15.1 bpm in the normal cardiac anatomy and 77.4±15.3 bpm in the Fontan group), there was a statistically significant difference found in the mean peak HR (191±9.1 bpm in the normal cardiac anatomy and 160.2±16.5 in the Fontan group; p <0.001).

Among the normal cardiac patients, the Polar Ignite mean estimated VO2max was 43.9±6.1 mL/kg/min compared to the CPET mean VO2peak was 37.0±8.2 mL/kg/min. Furthermore, the intraclass correlation coefficient was 0.20 and the Pearson correlation coefficient was r=0.31 (p=0.07). Similarly, in the Fontan group, the Polar Ignite estimated mean VO2max was 42.6±3.9 mL/kg/min, and the mean VO2peak was 22.6±5.6 mL/kg/min as measured by CPET. The intraclass correlation coefficient was 0.08 and the Pearson correlation coefficient was r=0.84 (p=0.001) among the Fontan group. Bland-Altman Plots were used to visualize the limits of agreement between the estimated VO2max of the Polar Ignite and VO2peak of the CPET in both groups of patients. The Bland-Altman plot for the normal cardiac group shows a mean bias of 6.85 ml/kg/min with the 95% limits of agreement ranging from -10.28 to 23.97 ml/kg/min (Figure 1). The Bland-Altman plot for the Fontan anatomy group shows a mean bias of 20.05 ml/kg/min with the 95% limits of agreement ranging from 13.65 to 26.44 ml/kg/min. (Figure 2).

Table 1. *Patient Demographics (N=47).*

	Total (n=47)	Normal Cardiac Anatomy (n=36)	Fontan Anatomy (n=11)	P-value[a]
Age (years)	15.3±1.9	15.0±1.6	16.3±2.5	0.14
Height (cm)	168.0±10.4	169.2±8.7	164.4±14.5	0.32
Weight (kg)	65.7±16.6	65.9±16.6	65.4±17.6	0.93
Sex, n (%)				
Male	16 (34.0%)	11 (30.6%)	5 (45.5%)	0.47
Female	31 (66.0%)	25 (69.4%)	6 (54.5%)	
Race, n (%)				
White	41 (87.3%)	33 (91.7%)	8 (72.7%)	
Black	4 (8.5%)	2 (5.6%)	2 (18.2%)	0.15
Asian	1 (2.1%)	0 (0.0%)	1 (9.1%)	
Declined	1 (2.1%)	1 (2.7%)	0 (0.0%)	
CPET Indication, n (%)				
Chest pain	12 (25.5%)	12 (33.3%)		
Syncope	11 (23.4%)	11 (30.6%)		
Shortness of breath	6 (12.8%)	6 (16.8%)		
Tachycardia/Palpitations	5 (10.6%)	5 (13.9%)		
Other	2 (4.3%)	2 (5.5%)		
Fontan	11 (23.4%)		11 (100%)	
Heart Rate (bpm)				
Resting	77.8±15.0	77.9±15.1	77.4±15.3	0.91
Peak	184.3±17.4	191±9.1	160.2±16.5	<0.0001

Note: numbers are presented as n (%) or mean ± standard deviation

[a]p-values from Chi-square tests and t-tests

Abbreviations: CPET-cardiopulmonary exercise stress test, BPM-beats per minute

Table 2. *Collected VO2 max (mL/kg/min).*

	N	Polar Ignite (est. max VO2)	CPET (peak VO2)	ICC	Pearson Corr. Coeff.
Normal Cardiac Anatomy	36	43.9±6.1	37.0±8.2	0.20	r= 0.31 (p=0.07)
Fontan Anatomy	11	42.6±3.9	22.6±5.6	0.08	r=0.84 (p=0.001)

Note: numbers are presented as mean ± standard deviation

r: Pearson correlation coefficient

Abbreviations: CPET, cardiopulmonary exercise stress test; ICC, intraclass correlation coefficient; VO2, maximum amount of oxygen consumption

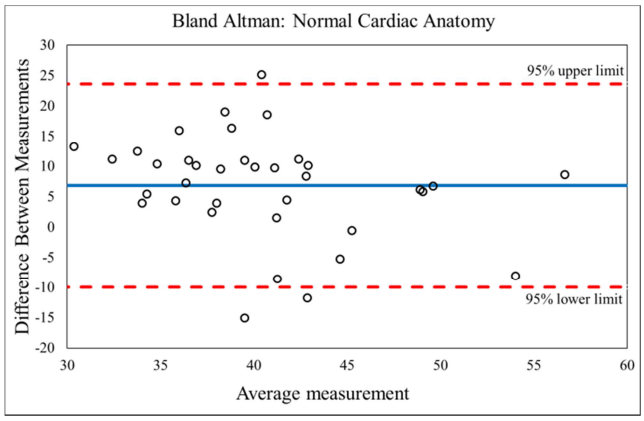

Figure 1. *Bland Altman analysis of Polar Ignite watch compared to the gold standard CPET among patients with normal cardiac anatomy. Solid horizontal line represents the mean difference of VO2max measurements between the Polar Ignite Watch and CPET. The upper and lower limits of agreement (LOA) indicated by dashed lines represent +1.96 and -1.96 standard deviations, respectively. Points may represent multiple patients.*

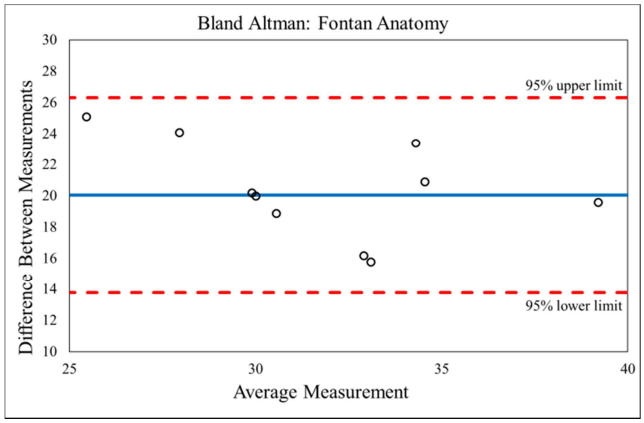

Figure 2. *Bland Altman analysis of the Polar Ignite watch compared to the gold standard CPET among patients with Fontan anatomy. Solid horizontal line represents the mean difference of VO2max measurements between the Polar Ignite Watch and CPET. The upper and lower limits of agreement (LOA) indicated by dashed lines represent +1.96 and -1.96 standard deviations, respectively. Points may represent multiple patients.*

4. Discussion

This is the first prospective study showing the use and validity of estimated VO2max measurements obtained from the Polar Ignite in pediatric patients with normal cardiac anatomy and single ventricle anatomy with Fontan palliation. As fitness technology continues to expand and gain popularity among athletes and fitness enthusiasts, clinicians and medical professions continue to explore the utility of this technology when evaluating and monitoring patients [18, 19]. The authors chose to study the Polar Ignite because of its non-exercise algorithm and the ability to perform testing in a single visit. The findings of this study showed poor validity and overestimation of VO2max in both normal cardiac and Fontan groups.

Previously, studies in the adult population between Polar wearable technologies and the CPET have demonstrated these to be valid tools for the estimation of VO2max. Cooper et al. [12], found no difference in absolute group mean VO2max and showed a moderate-strong relationship between the Polar A300 and CPET ($r=0.635$, $P<0.05$). Similar findings were shown in the Polar M52 by Crumpton et al. [20] who similarly found a strong relationship ($r=0.71$) and high accuracy. However, our findings were different then these reported adult studies showing weak correlation ($r=0.31$, $p=0.07$) and poor validity (ICC=0.21). It also showed overestimation (Bland Altman mean bias of 6.85 mL/kg/min) compared to the gold standard CPET. A VO2max difference of greater than 5 mL/kg/min between the two modalities was considered clinically relevant, as it is likely out of the margin of error. One potential explanation for the inaccurate estimations may be due to the technology's estimation algorithm. The Polar Ignite's Fitness Test estimates VO2max based on non-exercise conditions including resting HR, HRV and baseline user demographics [11]. Our results may differ compared to the reported adult studies due to the subtle differences in pediatric physiology regarding the relationship between HR and respiration. Prior studies assessing this relationship demonstrated the influence of the respiratory rate on the relationship between HRV and VO2max [21-23]. This was further described by Esco et al. [24], which suggested that by pacing a patient's breathing pattern, it may lead to the improvement in the accuracy of the Polar Fitness Test in estimating VO2max.

To our knowledge, this is the first study to analyze the estimated VO2max of a wrist-worn wearable in a group of pediatric patients with single ventricle anatomy who have undergone Fontan palliation. The VO2peak in this group, as measured by the CPET, was consistent with previous studies demonstrating that maximal exercise performance was lower than normal after Fontan surgery [25-29]. While the VO2max measured by the Polar Ignite and CPET were strongly correlated, our findings showed poor validity (ICC=0.08) and significant overestimation by 20.05 mL/kg/min by the Polar Ignite. Our data did not identify a significant difference in mean resting HR between the two groups, which may indicate that HRV and HR reserve in the Fontan group has a role in this discrepancy. It has been shown in studies of long-term complications in Fontan patients, sinus node dysfunction (SND) occurs in 11-45% of patients [17] and amongst these patients with SND, Fontan patients had a significantly higher HRV compared to normal cardiac anatomy controls without SND [17, 25, 30]. Furthermore, the Polar Ignite is likely unable to account for additional cofactors beyond the normal cardiac anatomy that are known to impact the overall cardiovascular health of Fontan patients. So while these algorithms continue to improve, they are not able or designed to replace current medical testing.

While our findings do not support the ability to replace formal CPET testing, the ability of this technology to assess for patient variation and change over time was also not assessed. Our findings of significant overestimation and a large error range on the Bland Altman in the normal cardiac group leads us to conclude that caution to the estimated VO2max of the Polar Ignite must be used on an individual

basis. This is similar to findings from Esco et al. [24], who investigated the validity of the Polar Fitness Test and likewise showed a large random error range on Bland Altman Plots. Despite the significant overestimation of the Polar Ignite in the Fontan group found in our study, the strong positive correlation (r=0.84, p=0.001) provides some evidence that further studies assessing trending of these estimations overtime could be used to monitor patients.

5. Limitations & Future Studies

This study has several limitations. Our ability to generalize these findings to a broader patient population is limited by the fact the majority of our participants were white and female; therefore further studies assessing a more diverse sample are needed. Additionally, a limited number of Fontan patients enrolled, which restricted the statistical power of this study and consequently made it difficult to draw definitive conclusions. Given the possible differences in the underlying anatomy of the patients who underwent Fontan palliation, this may have also impacted the findings in the estimated VO2max results of the Polar Ignite. Of note, wearable devices, including the Polar Ignite, are considered general wellness products. They therefore are not regulated by the United States Food and Drug Administration and as such are not marketed as medical devices.

6. Conclusion

With the widespread availability to consumers and rapid advancement of wearable technology in the continuous monitoring of health parameters, it is important to assess the accuracy of these devices. In our study we found that the estimated VO2max from the Polar Ignite had poor validity and overestimated the VO2max when compared to the CPET in pediatric patients with normal cardiac anatomy. Additionally, a significantly larger overestimation of the VO2max was found in the Fontan group, despite the finding of a strong correlation. These findings contend that the current technology of the Polar Ignite is not valid in estimating the VO2max in pediatric patients and therefore cannot replace formal CPET testing. As the technology continues to advance, there will likely be an improvement in accuracy, however further validation studies will be needed.

References

[1] Proudfoot, N. A., et al., Physical Activity and Trajectories of Cardiovascular Health Indicators During Early Childhood. Pediatrics, 2019. 144 (1).

[2] Ross, R., et al., Importance of Assessing Cardiorespiratory Fitness in Clinical Practice: A Case for Fitness as a Clinical Vital Sign: A Scientific Statement From the American Heart Association. Circulation, 2016. 134 (24): p. e653-e699.

[3] Raghuveer, G., et al., Cardiorespiratory Fitness in Youth: An Important Marker of Health: A Scientific Statement From the American Heart Association. Circulation, 2020. 142 (7): p. e101-e118.

[4] Fletcher, G. F., et al., Exercise standards for testing and training: a scientific statement from the American Heart Association. Circulation, 2013. 128 (8): p. 873-934.

[5] Takken, T., et al., Cardiopulmonary Exercise Testing in Pediatrics. Ann Am Thorac Soc, 2017. 14 (Supplement_1): p. S123-S128.

[6] Takken, T., et al., Cardiopulmonary exercise testing in congenital heart disease: (contra) indications and interpretation. Neth Heart J, 2009. 17 (10): p. 385-92.

[7] Mantegazza, V., A. Apostolo, and A. Hager, Cardiopulmonary Exercise Testing in Adult Congenital Heart Disease. Ann Am Thorac Soc, 2017. 14 (Supplement_1): p. S93-S101.

[8] Bayoumy, K., et al., Smart wearable devices in cardiovascular care: where we are and how to move forward. Nat Rev Cardiol, 2021. 18 (8): p. 581-599.

[9] Shei, R. J., et al., Wearable activity trackers-advanced technology or advanced marketing? Eur J Appl Physiol, 2022. 122 (9): p. 1975-1990.

[10] Kasparian, A. M. and S. M. Badawy, Utility of Fitbit devices among children and adolescents with chronic health conditions: a scoping review. Mhealth, 2022. 8: p. 26.

[11] Technology, P. R. a., Polar Fitness Test. 2019. p. 6.

[12] Cooper, K. D. and A. B. Shafer, Validity and Reliability of the Polar A300's Fitness Test Feature to Predict VO2max. Int J Exerc Sci, 2019. 12 (4): p. 393-401.

[13] Snyder, N. C., C. A. Willoughby, and B. K. Smith, Comparison of the Polar V800 and the Garmin Forerunner 230 to Predict V̇o2max. J Strength Cond Res, 2021. 35 (5): p. 1403-1409.

[14] Kraft, G. L. and M. Dow, Validation of the Garmin Forerunner 920XT VO2max Estimation and the Polar RS300X Fitness Test. International Journal for Innovation Education and Research, 2019. 7 (9): p. 22-28.

[15] Bian, J., et al., Exploring the Association Between Self-Reported Asthma Impact and Fitbit-Derived Sleep Quality and Physical Activity Measures in Adolescents. JMIR Mhealth Uhealth, 2017. 5 (7): p. e105.

[16] Voss, C., et al., Validity of Commercial Activity Trackers in Children With Congenital Heart Disease. Can J Cardiol, 2017. 33 (6): p. 799-805.

[17] Dahlqvist, J. A., et al., Sinus node dysfunction in patients with Fontan circulation: could heart rate variability be a predictor for pacemaker implantation? Pediatr Cardiol, 2019. 40 (4): p. 685-693.

[18] Dunn, J., R. Runge, and M. Snyder, Wearables and the medical revolution. Per Med, 2018. 15 (5): p. 429-448.

[19] Smuck, M., et al., The emerging clinical role of wearables: factors for successful implementation in healthcare. NPJ Digit Med, 2021. 4 (1): p. 45.

[20] Crumpton, S., Validity of the Polar M52 Heart Rate Monitor in Predicting VO2max Medicine & Science in Sports & Exercise, 2003. 35 (5).

[21] Hayano, J., et al., Effects of respiratory interval on vagal modulation of heart rate. Am J Physiol, 1994. 267 (1 Pt 2): p. H33-40.

[22] Loimaala, A., et al., Controlled 5-mo aerobic training improves heart rate but not heart rate variability or baroreflex sensitivity. J Appl Physiol (1985), 2000. 89 (5): p. 1825-9.

[23] Melanson, E. L. and P. S. Freedson, The effect of endurance training on resting heart rate variability in sedentary adult males. Eur J Appl Physiol, 2001. 85 (5): p. 442-9.

[24] Michael R. Esco, E. M. M., Henry N. Williford, Aindrea N., McHugh, Barbara E. Bloomquist, Cross-Validation of the Polar Fitness TestTM vai the Polar F11 Heart Rate Monitor in Predicting VO2max. Journal of Exercise Physiology Online, 2011. 14.

[25] Anderson, P. A., et al., Contemporary outcomes after the Fontan procedure: a Pediatric Heart Network multicenter study. J Am Coll Cardiol, 2008. 52 (2): p. 85-98.

[26] McCrindle, B. W., et al., Physical activity levels in children and adolescents are reduced after the Fontan procedure, independent of exercise capacity, and are associated with lower perceived general health. Arch Dis Child, 2007. 92 (6): p. 509-14.

[27] Udholm, S., et al., Prognostic power of cardiopulmonary exercise testing in Fontan patients: a systematic review. Open Heart, 2018. 5 (1): p. e000812.

[28] Giardini, A., et al., Natural history of exercise capacity after the Fontan operation: a longitudinal study. Ann Thorac Surg, 2008. 85 (3): p. 818-21.

[29] Cade, W. T., et al., Peak oxygen uptake (VO2peak) across childhood, adolescence and young adulthood in Barth syndrome: Data from cross-sectional and longitudinal studies. PLoS One, 2018. 13 (5): p. e0197776.

[30] Bergfeldt, L. and Y. Haga, Power spectral and Poincare plot characteristics in sinus node dysfunction. J Appl Physiol (1985), 2003. 94 (6): p. 2217-24.