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A two-phased study on the use of remote photoplethysmography (rPPG) in paediatric care

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Background: Advancements in medical technologies have led to the development of contact-free methods of haemodynamic monitoring such as remote photoplethysmography (rPPG). rPPG uses video cameras to interpret variations in skin colour related to blood flow, which are analysed to generate vital signs readings. rPPG potentially ameliorates problems like fretfulness and fragile skin contact associated with conventional probes in children. While rPPG has been validated in adults, no prior validation has been performed in children.

Methods: A two-phased prospective cross-sectional single-centre study was conducted from January to April 2023 to evaluate the feasibility, acceptability, and accuracy of obtaining heart rate (HR), respiratory rate (RR) and oxygen saturation (SpO_2) using rPPG in children, compared to the current standard of care. In Phase 1, we recruited patients ≤16 years from the neonatal and paediatric wards. We excluded preterm neonates with gestational age <35 weeks and newborns <24 hours old. The rPPG webcam was positioned 30 cm from the face. After 1 minute of facial scanning, readings generated were compared with pulse oximetry for HR and SpO_2, and manual counting for RR. Correlation and Bland-Altman analyses were performed. In Phase 2, we focused on the population in whom there was potential correlation between rPPG and the actual vital signs.

Results: Ten neonates and 28 children aged 5 to 16 years were recruited for Phase 1 (765 datapoints). All patients were haemodynamically stable and normothermic. Patients and caregivers showed high acceptability to rPPG. rPPG values were clinically discrepant for children <10 years. For those ≥10 years, moderate correlation was observed for HR, with Spearman's correlation coefficient (Rs) of 0.50 [95% confidence intervals (CI): 0.42, 0.57]. We performed Phase 2 on 23 patients aged 12 to 16 years (559 datapoints). Strong correlation was observed for HR with Rs=0.82 (95% CI: 0.78, 0.85). There was weak correlation for SpO_2 and RR (Rs=–0.25 and –0.02, respectively).

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Conclusions: Our study showed that rPPG is acceptable and feasible for neonates and children aged 5 to 16 years, and HR values in older children aged 12 to 16 years correlated well with the current standard. The rPPG algorithms need to be further refined for younger children, and for obtaining RR and SpO_2 in all children. If successful, rPPG will provide a viable contact-free alternative for assessing paediatric vital signs, with potential use in remote monitoring and telemedicine.

Keywords: Children; paediatric; remote photoplethysmography (rPPG); heart rate (HR); vital signs

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Introduction

Advancements in the field of medical innovation and technology have resulted in the development of various methods of haemodynamic monitoring to allow for increased accessibility and convenience (1). The coronavirus disease 2019 (COVID-19) pandemic pushed us into a new era of digital medicine, with telemedicine and remote consultation with increased utility of home monitoring devices or wearables (2). Many of these devices require precise placement of a specialised monitor on a particular body surface. Remote photoplethysmography (rPPG) is an innovation which directly addresses this problem through contactless monitoring.

Highlight box

Key findings

- Use of remote photoplethysmography (rPPG) to measure paediatric vital signs of heart rate (HR), respiratory rate (RR) and oxygen saturation (SpO2) is feasible and acceptable to children of varying ages and their caregivers.
- For children aged 12 to 16 years, HR values obtained by rPPG strongly correlated with the current standard of care.

What is known and what is new?

- rPPG has been well validated for assessment of vital signs such as HR and SpO2 in the adult population, but there is a lack of studies on the use of rPPG in children.
- Our study is the first to assess the feasibility and accuracy of rPPG in the paediatric population across varying ages, including neonates up to 28 days old, and children aged 5 to 16 years.

What is the implication, and what should change now?

- Our study supports the potential use of rPPG as a novel method of contactless vital signs monitoring for adolescents.
- Refinement of rPPG algorithms is required to accurately assess all paediatric vital signs for children <12 years old, and for RR and SpO2 across all ages.

rPPG works by adapting conventional photoplethysmography to detect changes in blood volume through the use of a video camera rather than contact photosensor (3). As blood absorbs more light compared to its surrounding tissues, changes within the microvasculature are detected as changes in reflection of light from the surface of the skin (4,5). A video camera captures these light reflections and generates pixel values. These are then processed through complex computer algorithms and converted into physiological data (6,7). These data can potentially be used to extrapolate parameters such as heart rate (HR), heart rate variability (HRV), respiratory rate (RR), oxygen saturation (SpO_2) and blood pressure (BP) (8,9). Since the introduction of rPPG around the mid-2000s (10), this technology has been validated for use in adults for assessment of vital signs (11,12). To date, however, there is a lack of paediatric studies on the use of rPPG for haemodynamic monitoring.

The potential benefits of rPPG in children are numerous, including being infection-control friendly—of great importance given the lessons learned from the global pandemic. The use of contactless technology also addresses an enduring issue of fretfulness in young children when placed on traditional contact monitors, affecting the accuracy of such readings and causing distress to the child and caregiver. In addition, contactless technology eliminates the risk of Medical Adhesive Related Skin Injuries (MARSI) in patients with delicate skin (e.g., premature neonates and children with chronic debilitating skin conditions) (13,14).

Given the potential application potential of rPPG, we aimed to study the feasibility, acceptability and validity of rPPG in assessing HR, RR and SpO_2 in children, compared to the current standard of care. We present this article in accordance with the STROBE reporting checklist (available

at https://atm.amegroups.com/article/view/10.21037/atm-23-1896/rc) (15).

Methods

We performed a 2-phased prospective cross-sectional study in KK Women's and Children's Hospital, a tertiary paediatric hospital in Singapore. The pilot study (Phase 1) was conducted in 2 clinical areas—the inpatient general paediatric wards, and the neonatal special care nursery (SCN). Neonates ≤28 days old and children ≤16 years old undergoing vital signs monitoring as per usual clinical protocol or as ordered by the attending physician, were identified and recruited.

We excluded preterm neonates <35 weeks, newborns <24 hours old, those admitted to the high dependency ward, oncology wards or intensive care unit, as well as those assessed to be clinically unstable, acutely unwell and/or requiring closer monitoring within the general paediatric wards. We also excluded neonates who were hypothermic with temperatures less than 36.5 ℃ (16).

The technology for rPPG was a prototype provided by Nervotec Pte. Ltd, a Singapore-based start-up company. This rPPG technology was developed based on well-validated methods described in existing literature (5,17,18), and is Nervotec's proprietary rPPG software for contactless vital signs monitoring. This software uses computer vision techniques to first identify and locate faces within incoming video frames. Regions of interest (ROIs) are then identified within the facial area. Facial data is further refined, eliminating non-informative regions such as the hair and eyes. Once ROIs are defined, the software takes a spatial and temporal average of ROI pixels in each frame to corresponding Red, Green, Blue (RGB) values. Signal pre-processing techniques are then applied to remove noise, and further refine the raw signal. Following the tracking of color changes within the video stream over a specific duration, the filtered RGB signals undergo processing to produce blood volume pulse (BVP) signals. HR, RR, and SpO_2 values are calculated by analysing BVP signals in either a time or frequency domain by using established mathematical formulae and peak detection techniques (18).

In our study, HR was primarily extracted by analysing the maximum frequency peaks in the BVP signal corresponding to heartbeats [the power spectral density (PSD) of the selected BVP signal]. The following equation was used to calculate HR: $HR = 60 \times f$ (highest peak in the frequency spectrum). RR was derived from the PSD of the BVP signal. Band pass filtering was applied to each component with the cut-off frequencies in the normal human breathing range. The component with the strongest peak would be the best candidate for the respiration signal. RR was calculated by identifying the peaks in the resultant signal and converting the frequency to breaths per minute. The equation used was: $RR = 60 \times f$ (peak frequency within the appropriate range). SpO_2 was determined by analyzing the ratio of the alternating current (AC) and direct current (DC) components of signals from the Red and Blue colour channels in the RGB images. The formula used for SpO_2 extraction was as follows: $SpO_2 = (\alpha - \beta) \times (AC_{red}/DC_{red} \div AC_{blue}/DC_{blue})$, where α and β are mathematical constants with values 1 and 0.02, respectively. This ratio was then converted into percentage SpO_2. The implementation of Band pass filtering allowed for more precise estimation of RR and SpO_2, especially within diverse skin tones and demographic variations.

The experimental setup comprised of a Logitech C920 High Definition Pro Webcam connected to a standard laptop which ran the rPPG application. This device was registered as a Clinical Research Material (Notification number CRM2200314) with Singapore's Health Sciences Authority. Eligible patients had their vital signs recorded using the current standard of care and the novel rPPG device during their hospital stay. In our institution, we routinely use pulse oximetry for obtaining HR and SpO_2, and manual counting for obtaining RR values. For the purpose of standardization, we used the same Masimo Radical-7® Pulse CO-Oximeter® device for all participants. The pulse oximetry probe was applied on the participant's thumb (for paediatric patients) or dorsum of the hand (neonatal patients). The rPPG webcam was positioned 30 centimeters from the participant's face, either on a table stand if the patient was able to sit up or clamped to an extension rod above the patient if lying supine.

The rPPG webcam would scan the patient's face for 1 minute. Concurrently, the research personnel would manually count the patient's RR over this 1-minute duration. At the end of 1 minute, HR, SpO_2 and RR readings were automatically generated on the computer software. The corresponding HR and SpO_2 observed on the pulse oximeter at this point were manually recorded, together with the RR obtained by manual counting. If the patient cried or moved excessively such that this process was interrupted, attempts were made to calm the child down and try again. For the pilot study, we did not set a limit to the number of measurements of vital signs taken over the course of the patient's inpatient stay, and this depended on

Table 1 Regulatory standards

Parameters	Standards
Heart rate range	30–250 BPM
Heart rate accuracy	An allowable readout error of no greater than ±10% of the input rate or ±5 BPM, whichever is greater
Oxygen saturation range	84–100%
Oxygen saturation accuracy	2% RMSE
Respiratory rate range	6–45 RPM
Respiratory rate accuracy	±4% or ±1.5 RPM, whichever is greater

BPM, beats per minute; RMSE, root mean square error; RPM, respirations per minute.

whether the patient was cooperative and willing to continue. There was a gap of at least 2 minutes between each measurement. Each different time point was considered as a unique episode or data point.

The research personnel recorded if the patient was awake, asleep, crying or agitated as these states would affect the clinical accuracy of vital signs obtained. Data on other clinical parameters collected were age, gender, height, weight, ethnicity and temperature. We assessed skin tone using the Fitzpatrick skin phototype scale (19,20). Relevant medical history was collected from the patient's medical notes, including diagnoses and use of chronic medications.

We first performed the pilot study (Phase 1) to assess the feasibility and acceptability of using the experimental equipment on all age groups of patients. This was assessed based on direct feedback from the child (if verbal) and/or the parent on the experimental setup, observations from the research personnel on the child's level of comfort, as well as the drop-out rate (patients who withdrew from the study) and reasons for doing so. We also looked at the accuracy of rPPG-derived vital signs for the different ages using the standards specified in *Table 1*. We referenced regulatory standards from the American Standards National Institute ANSI/AAMI EC13-2002 (21) to assess the clinical accuracy of rPPG for HR (22). The decision to use ANSI/AAMI EC13-2002 was made in the context of comparing our rPPG estimates with established standards for electrocardiograph (ECG) devices. As there are no widely recognized regulatory standards for measurements of RR, we referenced clinical guidelines (23) to derive a conservative range of ±4 respirations per minute (RPM). For accuracy metrics for HR and RR, we used mean absolute error (MAE) to ensure consistency and alignment with established standards. For SpO_2, we used the BS EN International Standard for Organization (ISO) 80601-2-61:2019 standard which states that the root mean square error (RMSE) must not exceed 2% of the SpO_2 range (24).

Statistical analysis

The Spearman's correlation coefficient (Rs) was used to identify possible correlations between rPPG-derived HR, SpO_2 and RR values and the corresponding standards of care (25), with 95% confidence intervals (CI) reported. Bland-Altman analyses were also performed (26).

For the subsequent Phase 2, we focused on a target age group that the technology was most accurate for, based on the data from the pilot study. We performed a sample size analysis to derive a target sample size for validation of rPPG specific to this age group. A sample size was determined to allow for sufficient number of data points to produce a two-sided 90% CI with a distance from the regression slope to the limits of <0.1, when the sample regression slope was assumed to be 1 (27). The standard deviation of the primary endpoints was estimated using their theoretical range. The correlation between the two approaches was assumed to be 0.8. Power calculation was performed using the CIs for Linear Regression Slope approach and conducted on PASS software (version 14 Power Analysis and Sample Size Software (2015) (NCSS, LLC. Kaysville, Utah, USA, ncss.com/software/pass). We performed correlation and Bland-Altman analyses to compare rPPG-derived vital signs with the standards of care.

Ethical statement

This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study received ethical approval from the SingHealth Institutional Review Board (No. 2022/2192). KK Women's and Children's Hospital is part of SingHealth (Singapore Health Services). Informed consent from each patient's parent or legal guardian was obtained prior to participation. Additionally, children aged 6 years and older were asked to give their assent for participation.

Results

A total of 38 patients were recruited for Phase 1, of whom

Table 2 Baseline characteristics of participants in Phase 1 (N=38)

Variables	Values
Number of recordings	765
Number of recordings per subject, mean ± SD	21.6±16
Age, mean ± SD	
Neonates	6.3±6.5 days of life
Children	12.4±3.1 years
Weight (kg), mean ± SD	
Neonates	3.0±0.6
Children	45.9±22.6
Height (cm), mean ± SD	
Neonates	49.1±4.1
Children	148.1±19.9
Male gender, n (%)	16 (45.7)
Race/ethnicity, n (%)	
Chinese	16 (42.1)
Malay	11 (28.9)
Indian	9 (23.7)
Others	2 (5.3)
Skin tone, n (%)	
Fitzpatrick types I & II	0 (0)
Fitzpatrick type III	12 (31.6)
Fitzpatrick type IV	16 (42.1)
Fitzpatrick type V	10 (26.3)
Fitzpatrick type VI	0 (0.0)

10 (26.3%) were neonates, and 28 (73.7%) were aged 5 to 16 years (*Table 2*). From this population, 765 data points were obtained (mean number of recordings per subject of 21.6±16, range of 0 to 51 measurements per patient). As we performed the pilot study in the neonatal ward first, we found that results were significantly discrepant compared to the ground truth. Test runs in two children aged above 28 days and below 5 years were also discrepant. As there seemed to be minimal benefit in continuing to run the device on children below 5 years, we continued the rest of Phase 1 on children above 5 years in the paediatric wards. A breakdown of the number of recordings per age group is provided in Table S1. The 2 test recordings were not included in the analysis in *Table 2*.

Patients and their caregivers were accepting of the experimental setup and equipment, with many enthusiastic about the potential benefits of such a technology for children. Some parental concerns included any risk of the video images being used for unintended purposes, or whether there was any infra-red radiation that could potentially harm the child. These concerns were readily alleviated with reassurance that the web camera was offline (not connected to the internet and therefore no risk of susceptibility to hacking), that the child's images would not need to be captured or stored for this technology to work, and that there was no increased risk of any form of radiation to the child. The older participants were comfortable with the rPPG setup as it allowed them to continue doing activities such as reading and writing, or watching their own devices, as long as there was minimal active movement. There were no drop-outs during the pilot study.

Further results from the pilot study showed that rPPG-derived vital signs values were clinically discrepant from the actual vital signs even for children aged between 5 to 10 years, despite accounting for movement and lighting. For example, HR values differed by as much as 30 to 50 beats per minute compared to pulse oximetry readings, with values being more discrepant the younger the child. A decision was made not to perform formal data analysis for all children below 10 years in view of the above finding, and to focus on the older children. For patients aged 10 to 16 years (21 patients, 524 data points), the Rs value obtained for HR was 0.50 (95% CI: 0.42, 0.57). Rs improved to 0.56 (95% CI: 0.47, 0.64) at HR values below 100. Values for RR and SpO_2 were 0.07 (95% CI: −0.02, 0.16) and −0.03 (95% CI: −0.12, 0.05) respectively.

For Phase 2, we further narrowed our focus to older children aged 12 to 16 years, assuming their baseline HRs would mainly fall below 100 at rest. A minimum sample size of 20 patients with at least 20 data points collected each (resulting in approximately 400 time point data) was required to adequately validate rPPG HR in this age group, based on the results of the pilot study. We tested the hypothesis used under the sample size calculation and the regression slope for HR (beta) was 0.92 (90% CI: 0.80, 1.04).

Twenty-three participants aged 12 to 16 years (mean age 14±1.1 years) were subsequently recruited for Phase 2 (validation study), with a total of 559 data points obtained (mean number of recordings per subject of 24.3±2.5, range of 20 to 28 measurements per patient). Thirteen (56.5%) were male, and 20 (87%) were of Fitzpatrick skin types III

Table 3 Baseline characteristics of participants in Phase 2 (N=23)

Variables	Values
Number of recordings	559
Number of recordings per subject, mean ± SD	24.3±2.5
Age (years), mean ± SD	14±1.1
Weight (kg), mean ± SD	59.5±17.4
Height (cm), mean ± SD	159.9±8.8
Male gender, n (%)	13 (56.5)
Race/ethnicity, n (%)	
Chinese	8 (34.8)
Malay	11 (47.8)
Indian	3 (13.0)
Others	1 (4.3)
Skin tone, n (%)	
Fitzpatrick types I & II	0 (0)
Fitzpatrick type III	10 (43.5)
Fitzpatrick type IV	10 (43.5)
Fitzpatrick type V	2 (8.7)
Fitzpatrick type VI	1 (4.3)

SD, standard deviation.

and IV (*Table 3*). All patients were normothermic (between 36.5 to 37.5 ℃). None had any chronic cardiorespiratory conditions or were on any chronic medications.

Figure 1 presents Bland-Altman plots of rPPG HR, SpO_2 and RR values compared to the corresponding standards of care, for children aged 12 to 16 years (Phase 2). The Bland-Altman plots for rPPG HR and oximetry HR showed a mean difference of 0. In *Figure 2*, we present the scatterplots for rPPG HR, SpO_2 and RR values compared to the corresponding standards of care. The strength of the associations is reflected in *Figure 2*, with Rs=0.82 (95% CI: 0.78, 0.85) for rPPG HR and oximetry HR. For rPPG SpO_2 and oximetry SpO_2, the Rs value was –0.25 (95% CI: –0.32, 0.18), while for rPPG RR and manually counted RR, the Rs value was –0.02 (95% CI: –0.10, 0.06).

Discussion

Our study found that the use of rPPG technology is feasible and acceptable across varying age groups of paediatric patients, from neonates (up to 28 days old) to children aged 5 to 16 years. For older children aged 12 to 16 years, we found good agreement between the rPPG technique and standard of care when used to measure HR. In addition, a strongly positive and statistically significant Spearman's correlation coefficient (28) was observed for rPPG HR and oximetry HR. However, correlation was weak (although statistically significant) for rPPG SpO_2, and poor with no statistical significance for rPPG RR in this age group. For younger children below 12 years, results were clinically discrepant for all 3 parameters.

To our best knowledge, this is the first study to evaluate the use of rPPG in obtaining paediatric vital signs across varying age groups. Bautista *et al.* published a systematic review and meta-analysis of rPPG in children in May 2023 (29). 14 of the 15 studies included in the review were performed solely in the neonatal population. As early as 2013, Aarts *et al.* (30) first demonstrated the use of rPPG to obtain heart beat induced photoplethysmographic signals strong enough to be measured in 19 patients in the neonatal intensive care unit (NICU). This was followed by several other studies assessing HR using rPPG in infants in the NICU (31-33), primarily focused on clinical feasibility. For older children, only one study performed by Bal recruited patients aged 2 months to 14 years, but the patient population was small with 7 participants from the paediatric intensive care unit (34).

Many of these studies reported good feasibility of rPPG technology in their patients (30-33). This mirrors our current study's findings, and additionally our patients displayed very high acceptability to this technology. With regards to accuracy of rPPG in children, surprisingly Bautista *et al.* concluded that contactless PPG accurately measures neonatal HR and RR without the need for a skin probe, which is contrary to our findings. The differences in findings from prior studies and the current one can be due to several factors. Many of the prior studies involved small numbers of patients (range, 2 to 28), with 11 of 14 studies on HR and RR having ten patients or less. Sample size analysis showed that our study was adequately powered to assess rPPG HR (based on the test of hypothesis of slope =1, as the 90% CI of the regression slope included 1). Among the limitations of their study, Bautista *et al.* specified that on individual review, most had a risk of bias often related to unclear image processing methods. In addition, one study was conducted under very specific conditions (in near darkness in the NICU) (33). In contrast, our study was conducted on clinically stable children of varying ages using available ambient lighting, and as such, we propose that our

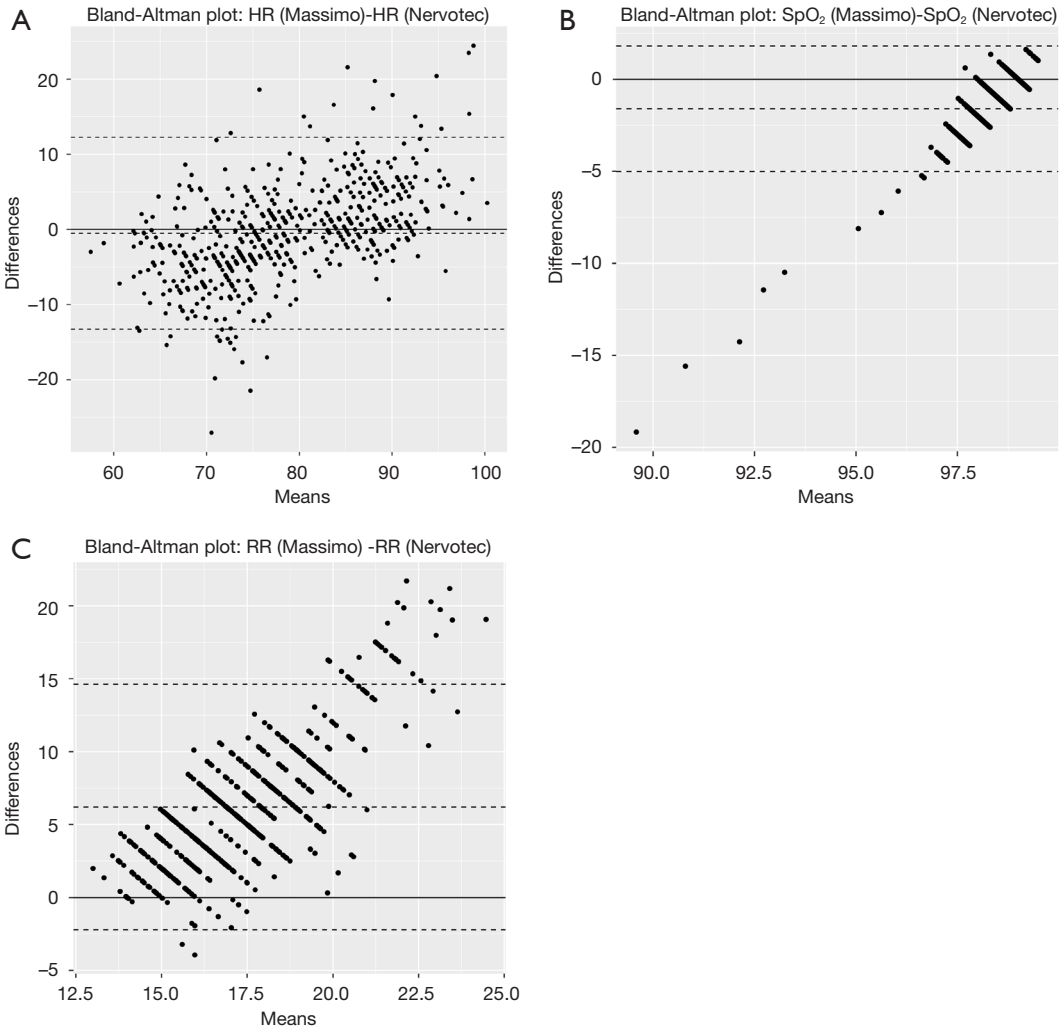

Figure 1 Bland-Altman plots showing the differences of measurements of HR, SpO2 and RR by rPPG and standards of care (Y-axis) and means of measurements of HR, SpO2 and RR by rPPG and standards of care (X-axis), in children aged 12 to 16 years (Phase 2). The dotted lines indicate the upper and lower agreement limits, and the continuous lines indicate the difference in the means. (A) Bland-Altman plot: HR (standard) – HR (rPPG). (B) Bland-Altman plot: SpO2 (standard) – SpO2 (rPPG). (C) Bland-Altman plot: RR (standard) – RR (rPPG). HR, heart rate; SpO2, oxygen saturation; RR, respiratory rate; rPPG, remote photoplethysmography.

findings may be more generalizable, but require further validation by other investigators.

Although rPPG SpO_2 did not have strongly positive correlation with oximetry SpO_2 in the older children, it was observed that above a threshold of 97% (based on oximetry), the agreement between the two sets of readings improved. When the Bland-Altman plot was regenerated for SpO_2 readings of 97% and above, the standard deviation of the differences was smaller and closer to the acceptable range of ±2%. This observation may not be clinically impactful since SpO_2 levels of 95% and above are considered normal (35). Nevertheless, with improved algorithms, rPPG could potentially be more robust in detecting accurate SpO_2 results below 95%. For RR however, the standard for routine care remains to be manual counting (36), as conventionally, even pulse oximetry is not able to accurately capture this vital sign (37,38).

For younger children below 12 years of age with baseline HRs above 100 beats per minute (BPM), the current algorithm used in our study would require more work and refinement to accurately assess HR and SpO_2. Even at complete rest states (sleeping) with the same lighting

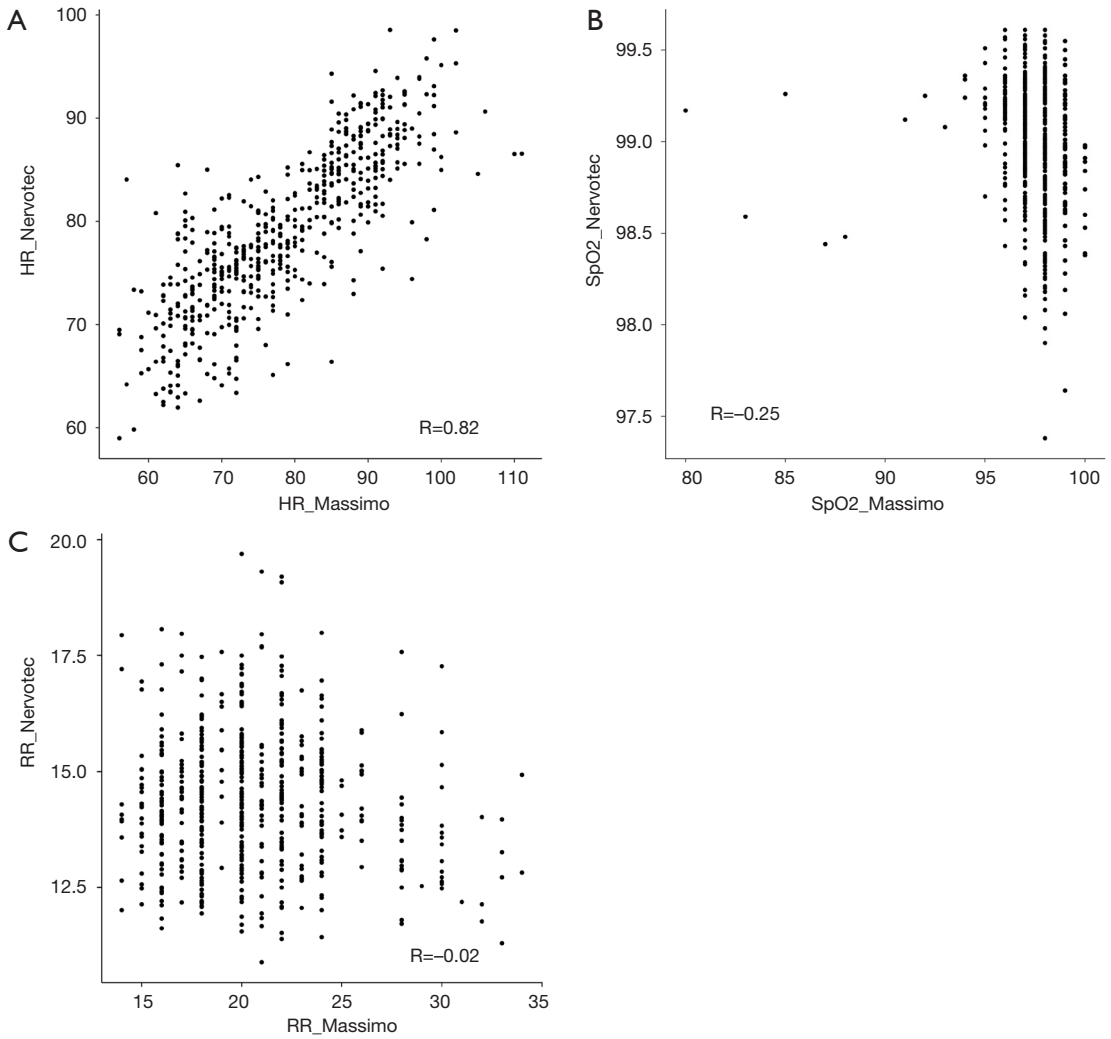

Figure 2 Correlation scatterplots for rPPG-derived HR, SpO2 and RR (Y-axis) and HR, SpO2 and RR by standards of care (X-axis) with corresponding Spearman's correlation coefficient (Rs) values, in children aged 12 to 16 years (Phase 2). (A) Scatterplot for HR (rPPG) – HR (standard). (B) Scatterplot for SpO2 (rPPG) – SpO2 (standard). (C) Scatterplot for RR (SpO2) – RR (standard). rPPG, remote photoplethysmography; HR, heart rate; SpO2, oxygen saturation; RR, respiratory rate.

conditions as the older participants, readings for younger children remained clinically discrepant from the ground truth. There is a lack of studies thus far on why this may be so. We postulate that refinement of the algorithms to account for smaller faces and differential proportions in the younger patients can potentially lead to improvement in this technology. To further evaluate this technology in younger children, subsequent ethical approval and informed consent was obtained for video images to be recorded, and these were sent to our collaborator for analysis. These video images were taken from seven children ranging in age from 3 days to 6 years.

We also observed that the rPPG device in our study tended to under-report high measurements and over-report low measurements. One contributing factor to the observed systematic bias is that our algorithms were primarily trained on adult populations, where lower HRs and RRs are more prevalent compared to the paediatric population. The specific signal processing techniques employed, including screening filters, were initially designed to extract information within a certain range. This design posed a challenge when applied to paediatric subjects. Subsequent adjustments will be made by our collaborator, including the use of different screening filters to mitigate this bias and

further improve accuracy results (39).

One limitation of our study was the use of Spearman's correlation coefficient to quantify the level of association or agreement between rPPG readings and the standard of care. There are several pitfalls to using the correlation coefficient alone to conclude agreement between two variables, and a high degree of correlation may not necessarily equate to true agreement (40). As such, we concurrently performed Bland-Altman analyses to further assess the strengths of the agreements and provide some conclusion on the overall accuracy of rPPG in comparison to the current standard of care.

A possible confounding factor in accuracy of rPPG technology is skin tone (41) and thus another limitation of our study in Phase 2 was that we were not able to recruit any patients with Fiztpatrick skin phototypes I and II, typically seen in the Caucasian population (42). In addition, we only had 1 patient with Fitzpatrick skin phototype VI, which is the most pigmented skin type. This was somewhat expected since our study was conducted in a Southeast Asian country with the main ethnicities of Chinese, Malay and Indian (43). Although light or dark skin tones can theoretically affect rPPG devices as melanin absorbs green light, a large study by Heiden *et al.* (44) on 8,585 adult participants (17,233 measurements) showed that Fitzpatrick skin phototypes did not affect the accuracy of rPPG for measuring HR, RR and BP. In this study, the authors compared rPPG RR to manual counting over 60 secs, and HR & BP with a standard clinical automatic sphygmomanometer on one arm.

A further limitation was the exclusion of unwell or unstable patients. These states result in decreased skin and soft tissue perfusion (45,46), and therefore may directly affect the accuracy of rPPG readings. As such, this early validation of rPPG as a tool for accurate assessment of HR only applies for well older children and limits its clinical applicability. Future studies on rPPG in children should aim to expand the patient population to include patients with haemodynamic instability and hypoxia. It is essential that the technology be able to pick up HR or SpO_2 readings outside of the range of normal for age, for the product to have clinical relevance as a screening tool.

Conclusions

This 2-phased study demonstrated that rPPG was an acceptable and feasible method of obtaining contactless vital signs in paediatric patients. For measurement of HR, values obtained by rPPG correlated well with the current standard of care in children aged 12 to 16 years. This result is promising, and future studies should expand further on the clinical accuracy of this technology for assessment of HR in older children. However, more work is required to refine the rPPG algorithms for younger children, and for obtaining RR and SpO_2 in all children. If proven successful, rPPG will provide a viable contact-free alternative for assessing paediatric vital signs, with vast potential uses in remote monitoring and telemedicine.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://atm.amegroups.com/article/view/10.21037/atm-23-1896/rc

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-23-1896/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the SingHealth Institutional Review Board (No. 2022/2192). KK Women's and Children's Hospital is part of SingHealth (Singapore Health Services). Informed consent was taken from all the

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