TH Rainer 譚偉恩
GN Cattermole
CA Graham
SSW Chan 陳兆華

Anthropometric and physiological measurements in healthy children

Key Messages

1. Normal ranges for Ultrasonic Cardiac Output Monitor–derived cardiovascular indices are derived for Chinese children aged 1 to 12 years in Hong Kong.
2. A simple formula for calculating stroke volume is constructed, but the error varies from 8 to 40%.
3. Stroke volume index and, to a lesser extent, the cardiac index generally increase from ages 1 to 5 years, but plateau or fall slightly thereafter.

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Accident & Emergency Medicine Academic Unit, The Chinese University of Hong Kong Trauma & Emergency Centre, Prince of Wales Hospital
TH Rainer, GN Cattermole, CA Graham, SSW Chan

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Principal applicant and corresponding author:
Prof TH Rainer
Accident and Emergency Medicine Academic Unit, Chinese University of Hong Kong, Room 02C44, Main Clinical Block and Trauma Centre, Prince of Wales Hospital, Shatin, NT, Hong Kong SAR, China
Tel: (852) 2632 1033
Fax: (852) 2648 1469
Email: thrainer@cuhk.edu.hk

Introduction

Measurement of cardiovascular parameters is important in the management of critically ill patients. Assessment of cardiac output (CO), stroke volume (SV), systemic vascular resistance (SVR), and their indices enables differentiation between shock states and monitoring illness progression and responses to therapy. The Ultrasonic Cardiac Output Monitor (USCOM1A; USCOM, Coffs Harbor, NSW, Australia) was introduced for clinical use in 2001. It measures cardiac function in a rapid, safe, and non-invasive means. The USCOM uses Doppler ultrasound to measure blood flow velocity through the aortic or pulmonary valve. Haemodynamic variables are generated after entering various patient parameters such as age, gender, height, and weight, as well as algorithms into the device.[1,2]

Normal paediatric values relating age to peak aortic flow measured with a suprasternal ultrasonic device have been published, but this device did not produce values for SV, CO, or SVR.[3] This study aimed to use the USCOM to determine the range of values for these vital signs and the derived cardiovascular indices, adjusted for age and gender, in Hong Kong Chinese children aged 1 month to 12 years, and to construct formulae relating to age, weight, other anthropometric measurements, vital signs, and cardiovascular indices.

Methods

This observational study was part of a prospective cross-sectional study titled "Healthy children's vital signs and USCOM values" conducted between October 2010 and July 2011. The study was approved by the Clinical Research Ethics Committee of the Chinese University of Hong Kong. Healthy Chinese children aged 1 to 12 years were recruited through kindergartens and schools in the Shatin district of Hong Kong. Eight kindergartens and six primary schools agreed to participate. Exclusion criteria were lack of consent, non-Chinese children, current symptoms of illness (eg respiratory tract infection, gastroenteritis), congenital or long-term conditions (eg diabetes, asthma, congenital heart disease), and current use of medication (whether over-the-counter or prescribed by a physician or Chinese medical practitioner).

Three operators were trained to use the USCOM. Standing height was measured to the nearest 0.1 cm using a stadiometer (Harpenden Portable Stadiometer, Holtain, UK). Children too young to stand were measured supine on a flat surface with a tape measure. Body weight was measured to the nearest 0.2 kg in school uniform (shorts and T-shirt) using electronic scales. Blood pressure (BP) and heart rate (HR) were measured in the right arm with an appropriately sized cuff using a standard emergency department oscillometric device (Patient Monitor BX-10ne; Omron Healthcare Co Ltd, Kyoto, Japan). Measurements were made supine at rest. To assess variation, a convenience sample of at least 10% of subjects had repeat measurements of BP and HR within 5 minutes of the first measurement. The first USCOM operator entered the subject's weight, height, and BP using a new account for each child. Scans were obtained using the aortic access area (suprasternal notch), because it was deemed not appropriate to require children to remove their clothing to obtain the pulmonary view. Each scan attempted to obtain at least three good-quality consecutive cycles.

Means and standard deviations (SDs) for cardiovascular indices were stratified according to age groups. Unpaired Student's *t* tests were used and statistical significance was set at $P<0.05$. LMS Chartmaker Pro version 2.3 software (Cole and Pan, Medical Research Council, London, UK) was used to describe the data in percentile curves (2.5th, 10th, 50th, 90th, 97.5th). The relationship between age and USCOM-derived cardiovascular indices was modelled by the (lambda-mu-sigma) LMS method of Cole and Green.[4] MedCalc version 10.4 was used to determine inter-observer reliability for measurement of SV, BP, and HR.[5] Intraclass correlation used the one-way random effects model for absolute agreement of single paired observations with raters selected at random. Bland-Altman limits of agreement were calculated for the percentage difference between observations. Coefficients of variation were calculated as percentage ratios of the SD of the differences between the two measurements and the overall mean. From the results of our pilot study, the mean and SD for SV were used to calculate a sample size of 105 subjects in each year group to achieve 95% confidence that the true mean lies within 5% of that observed.

Results

Data were collected from 1353 Chinese children (55% boys) aged 1 to 12 years from eight kindergartens and six primary schools in Hong Kong. Of them, 1197 healthy Chinese children (55% boys) were scanned with USCOM, and formulae were constructed. The reference ranges for HR, systolic BP, and respiratory rate are shown in Table 1, whereas the normal ranges for cardiovascular indices are shown in Table 2.

For inter-observer variation, a second operator independently scanned 1059 (88%) children, and 183 (15%) of them had a second BP and HR measurement. Coefficients of variation, intraclass correlations, and Bland-Altman limits of agreement for SV, BP, and HR are shown in Table 3. By any measure, USCOM yielded less inter-observer variation for BP or HR than the standard automated oscillometric device.

Regarding normal ranges for clinical use in resuscitation, the Figure shows that the SV index and, to a lesser extent, the cardiac index generally increase from ages 1 to 5 years but plateau or fall slightly thereafter.

The most accurate and user-friendly method of presenting the data was by graphs (Fig). The formulae to calculate the lower limit, median, and upper limit of SV were: 10 + (4 x age), 15 + (6 x age), and 20 + (8 x age), respectively, with 13% to 8%, 20% to 12%, and 40% to 9% error as age increased, respectively.

Discussion

This is the largest study to present normal ranges for cardiovascular indices measured using USCOM, and the first study to present USCOM data for a Chinese population. We used 2.5th and 97.5th percentiles to define the expected range of 95% of the population. Thus, there was a probability of 0.05 that a healthy child had USCOM measurements outside this range. Our results were consistent with those in a study using USCOM in 100 children aged 1 to 16 years and in a study using the earlier suprasternal ultrasonic device.[3] In previous studies, normal paediatric ranges for SV measured with echocardiography were based on weight and height (but not age), which prevented direct comparison with our results. It is likely that the normal values for children depended to some extent on extrapolation from values

Table 1. Reference ranges (2.5 to 97.5 centile) measured using the Ultrasonic Cardiac Output Monitor (Adapted with permission from Lippincott Williams and Wilkins/Wolters Kluwer Health: Critical Care Medicine, copyright 2010)

Age group	Heart rate (beats per minute)	Systolic blood pressure (mm Hg)	Respiratory rate (breaths per minute)
Small Toddler (12-23 months)	99-155	75-110	20-45
Pre-school (24-59 months)	80-130	80-120	15-30
School (60-143 months)	65-115	90-135	15-30

Table 2. Normal ranges for Ultrasonic Cardiac Output Monitor–derived cardiovascular indices (Adapted with permission from Lippincott Williams and Wilkins/Wolters Kluwer Health: Critical Care Medicine, copyright 2010)

Age (years)	Systemic vascular resistance (ml.m-2)	Cardiac index (l.min-1.m-2)	Systemic vascular resistance index (d.s.cm-5.m2)	Mean arterial pressure (mm Hg)	Heart rate (min-1)
1-2	31-55	3.5-6.5	750-1600	48-83	93-140
3-4	37-67	3.6-7.1	750-1700	52-86	78-130
5-12	42-76	3.3-6.9	910-2000	61-94	62-110

Table 3. Interobserver variation (Adapted with permission from Lippincott Williams and Wilkins/Wolters Kluwer Health: Critical Care Medicine, copyright 2010)

Parameter	Stroke volume	Systolic blood pressure	Heart rate
Coefficient of variation (%)	11.3	13.0	11.5
Intraclass correlation (95% CI)	0.94 (0.93 to 0.94)	0.50 (0.38 to 0.60)	0.76 (0.69 to 0.82)
Bland-Altman limits of agreement (%)			
Upper limit (95% CI)	22.3 (21.2 to 23.4)	26.1 (22.8 to 29.3)	22.3 (19.5 to 25.1)
Lower limit (95% CI)	-20.5 (-19.3 to -21.6)	-24.5 (-21.3 to -27.8)	-21.9 (-19.1 to -24.7)

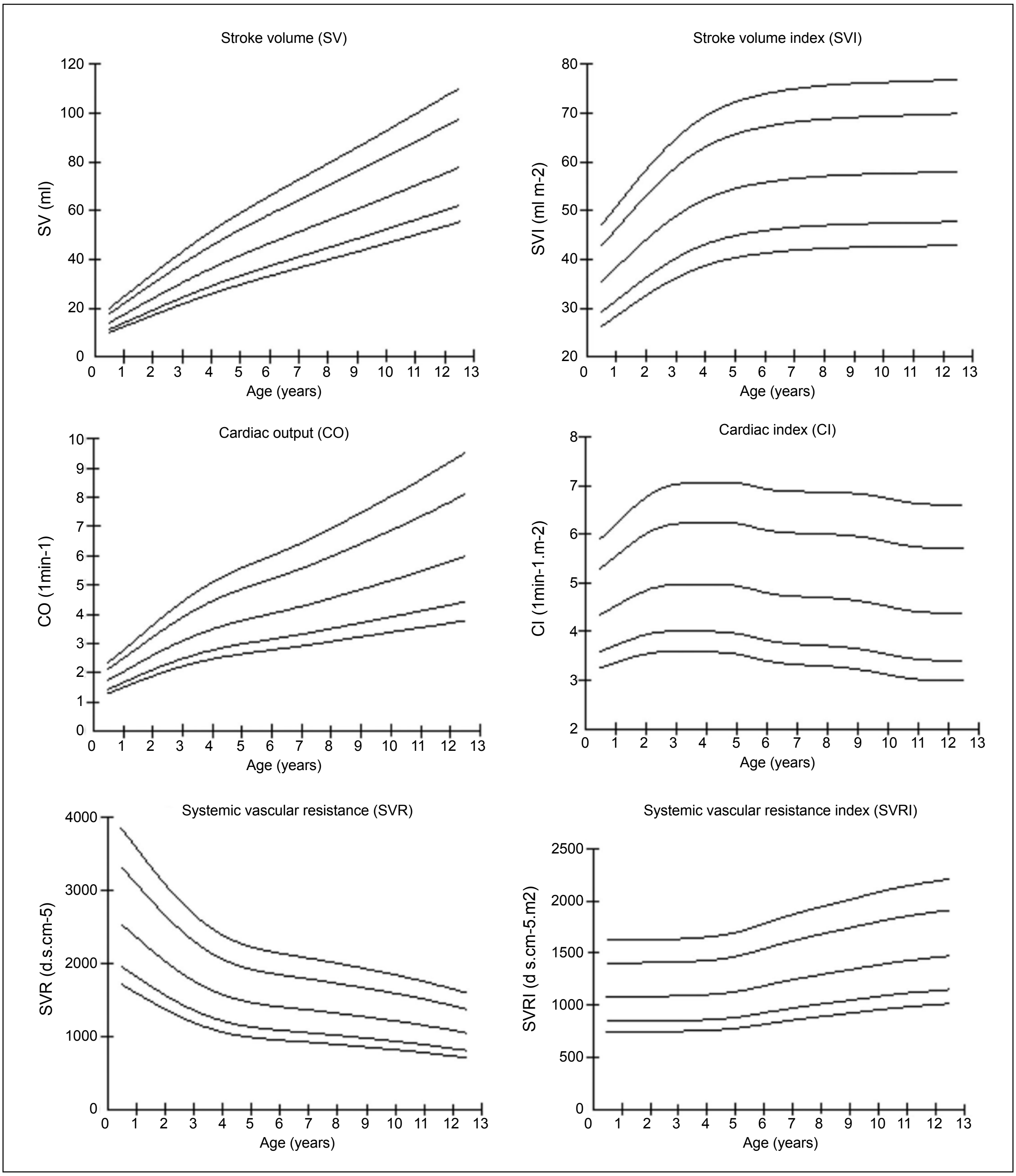

Fig. Ultrasonic Cardiac Output Monitor–derived cardiovascular indices: percentile curves of 2.5th, 10th, 50th, 90th, 97.5th. (Adapted with permission from Lippincott Williams and Wilkins/Wolters Kluwer Health: Critical Care Medicine, copyright 2010)

in adults and critically ill children. The USCOM is non-invasive and can obtain estimates of normal cardiovascular indices in children. However, compared with the gold standard, it may overestimate SV (from which the software derives the other indices).

The inter-rater reliability was good based on three measures: coefficient of variation, Bland-Altman limits of agreement, and intraclass correlation. There was less variability in BP and HR measurements with USCOM than with standard oscillometric devices used in the emergency department.

All scans by the first operator, regardless of quality, were analysed. The quality of each trace was assessed using a scoring system. After approximately 30 scans, each operator reached a steady state in his cumulative average scan quality.[6] All the scans were conducted after the end of this learning curve, but even highly experienced operators still sometimes failed to obtain a good-quality trace. This may have been due to the compliance or morphology of the subject. The second scans were not used to derive the normal values. In the resuscitation room, it is likely that just one operator uses the USCOM to obtain several views. In our study, each operator obtained three separate screenshots, which represents realistic practice. Sensitivity was determined by averaging values among subjects with two very good-quality scans. Median SVs obtained with better quality, averaged scans were approximately 4% greater than presented. In view of the wide range of normality, this difference was not considered clinically relevant.

This study was limited by the time allocated in the schools and kindergartens. We were unable to obtain two USCOM scans in all children. Nonetheless, children not scanned twice were unlikely to be different from those who were, and therefore we do not consider this a source of bias. Another limitation was that the numbers of children failed to reach the required sample size. Nonetheless, the numbers were more than that in previous studies, and the observed ranges for BP, HR, weight, and height were as expected, which suggests that our sample was representative. We aim to repeat the study in 0 to 2 year olds and in adolescents.

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