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Age-specific non-invasive transcutaneous Doppler ultrasound derived haemodynamic reference ranges in elderly Chinese adults

Cangel Pui-yee Chan [a,*], Nandini Agarwal [a], King-keung Sin [b], Sangeeta Narain [a], Brendan E. Smith [c], Colin A. Graham [a], Timothy H. Rainer [a,*]

[a] Accident and Emergency Medicine Academic Unit, Prince of Wales Hospital, The Chinese University of Hong Kong, Hong Kong Special Administrative Region
[b] Department of Chemistry, The Hong Kong University of Science and Technology, Hong Kong Special Administrative Region
[c] School of Biomedical Science, Charles Sturt University, Bathurst, New South Wales, Australia; Intensive Care Unit, Bathurst Base Hospital, Bathurst, New South Wales, Australia

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ABSTRACT

Background: Whilst there is a presumption in medicine that ageing adversely affects cardiovascular function, it is unknown if resting haemodynamics are compromised in the elderly, and if so, to what degree. This study was intended to answer several questions; whether age-related changes in haemodynamics occur; whether there was a difference between the haemodynamics of ageing subjects with and without mild chronic disease; whether there was a difference in haemodynamics as measured from either the aortic or the pulmonary valve; and to establish reference ranges for this population.

Methods: Chinese adults aged over 60 years were divided into three age bands of 61–70, 71–80 and over 80 years. The haemodynamic parameters were measured using a non-invasive Doppler ultrasound-based instrument, the Ultrasonic Cardiac Output Monitor (USCOM).

Results: One hundred and sixty-five subjects (48.5% males) were recruited. 78 (47.3%) had no known disease whilst 87 (52.7%) had mild chronic illness. A total of 21 individual haemodynamic parameters were measured or calculated for each subject. There were no significant differences in stroke volume (SV), cardiac output (CO), systemic vascular resistance (SVR) or in body surface area (BSA)-indexed parameters, SV index (SVI), cardiac index (CI) and SVR index (SVRI) across age groups, or in other indexed haemodynamic parameters. No significant differences in indexed haemodynamics were found between those subjects with and those without mild chronic disease. Small, statistically significant, but clinically insignificant, differences (<5%) were found between the aortic and pulmonary valve measurements for SV, SVI and heart rate.

Conclusions: Ageing does not have any significant effect on resting haemodynamics in the elderly population studied. Mild chronic disease does not adversely affect resting haemodynamics in this population.

General Significance: Reference ranges were established for 21 haemodynamic parameters, as measured by USCOM, for an elderly Chinese population but not for non-Chinese populations.

1. Introduction

Population ageing is widespread around the world. The ageing trend began in developed countries and is now accelerating, not only in the first world, but also in developing countries. The major drivers of population ageing are increasing longevity and declining fertility [5]. The Chinese population is ageing particularly rapidly due to a falling mortality rate and the one child policy. By 2050 more than one quarter of the population will be over 65 years old [1]. Whilst ageing is known to affect the cardiovascular system both structurally and functionally [21,25], it is still unclear how, or if, ageing affects the resting haemodynamic profiles of the elderly.

The Ultrasonic Cardiac Output Monitor (USCOM) is a non-invasive continuous wave Doppler ultrasound device derived from echocardiography, which measures haemodynamic parameters, accurately and reliably [8,10,23,27,32,37]. It allows the measurement of haemodynamics in normal conscious subjects in a totally non-invasive manner, by measuring transvalvular flow across either the aortic or the pulmonary valve. It has been shown to be more accurate and more sensitive to change than the pulmonary artery catheter [32], and at least as accurate as research quality echocardiography [16,30], with a much shorter learning curve than echocardiography [15,26,27]. As with all quantitative tests, it is essential to have a reference range to compare any given reading against. By definition,

* Corresponding author at: Accident and Emergency Medicine Academic Unit, 2/F, Main Clinical Block and Trauma Centre, Prince of Wales Hospital, Shatin, NT, Hong Kong Special Administrative Region. Tel.: +852 2632 1033; fax: +852 2648 1469.
E-mail addresses: cangelchan.cc@gmail.com (C.P. Chan), thrainer@cuhk.edu.hk (T.H. Rainer).

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values beyond the normal reference range are regarded as abnormal clinically. Equally, from a prognostic viewpoint, knowledge of the normal range is required to establish goals of therapy. Reference ranges for haemodynamic parameters as measured by USCOM have been established for Chinese full-term neonates [16,17], Chinese children aged 1 month–12 years [8], Chinese and Caucasian adolescents aged between 12 and18 years [18], and Chinese and Caucasian adults aged between 18 and 60 years (unpublished data). However, there are no reference ranges for the elderly, despite the increasing use of point of care haemodynamics in general, and the USCOM in particular, in clinical practice. It is also unknown to what degree mild chronic disease, prevalent in the elderly population, affects resting haemodynamics.

This study was undertaken to establish whether age-related changes in haemodynamics occur; to what degree the haemodynamics of ageing subjects are affected by mild chronic disease; whether there is any discrepancy in measurements between the aortic valve and the pulmonary valve in this age group; and to establish reference ranges for this population.

2. Methods

2.1. Study design

This was a prospective cross-sectional study conducted between February and October 2012 in the Emergency Department of the Prince of Wales Hospital, Hong Kong. All aspects of the study were approved by the Joint Chinese University of Hong Kong–New Territories East Cluster Clinical Research Ethics Committee (reference number CRE-2009.482). Chinese adults aged over 60 years were recruited through Ma On Shan Neighbourhood Elderly Centre, the Department of Otorhinolaryngology, Head and Neck Surgery of Prince of Wales Hospital, and volunteers' referrals from other districts in Hong Kong. Exclusion criteria included age under 61 years, lack of consent, non-Chinese adults, and acute illness within the past four weeks. Following a detailed explanation of the study, written consent was obtained from all recruited subjects. Each subject was requested to complete a health questionnaire to identify current and past health status, and current medication use. Clinical management systems were also used to cross reference data from the subjects' medical records, where available.

Subjects were divided into two groups. Group 1 included those with no known acute or chronic illness, and who had taken no medication in the previous four weeks, and would be classed as ASA 1 (a normal healthy subject) according to the classification of the American Society of Anesthesiology [2]. Group 2 included subjects categorized as ASA 2, a patient with mild systemic disease. Subjects with more severe chronic disease, corresponding to ASA 3 and above, were excluded.

Physical characteristics of all subjects were recorded. Standing height was measured barefoot to the nearest 0.1 cm using a measuring tape. Body weight was measured to the nearest 0.1 kg using an electronic scale (Compact Precision Scale C200H, Conair Far East Ltd., Hong Kong). Arterial pressure was measured in the right arm in the supine position with an appropriately sized cuff using an oscillometric device (Omron HEM-7200 Automatic Blood Pressure Monitor, Omron Healthcare Co., Ltd, Japan), followed immediately by the USCOM measurement. Haemoglobin concentration was measured with a capillary blood sample collected by finger prick using HemoCue® B-Hemoglobin system (HemoCue® AB, Ängelholm, Sweden).

2.2. USCOM measurements

The USCOM device (USCOM Ltd, Sydney, Australia) calculates stroke volume (SV) by measuring the ejection velocity of blood flow across the aortic or pulmonary valves and multiplying the velocity time integral (VTI) of the trace of the Doppler flow profile by the cross-sectional area (CSA) of the minimum outflow tract diameter (OTD), which is derived from the subject's weight and height using a proprietary algorithm. Heart rate (HR) is also measured from the periodicity of the Doppler waveform, and cardiac output calculated as $CO = SV \times HR$. The mean arterial pressure (MAP) is calculated from the inputted systolic and diastolic blood pressures as $MAP = DBP + [(SBP - DBP) / 3]$ and systemic vascular resistance (SVR) from CO, MAP and central venous pressure (CVP) as $SVR = (MAP - CVP) \times 80 / CO$. CVP was assumed to be zero [20].

The USCOM uses measured oxygen saturation (SpO_2) from an integral pulse oximeter probe and inputted haemoglobin concentration [Hb] to calculate oxygen delivery (DO_2). Smith–Madigan inotropy index (SMII) and potential to kinetic energy ratio (PKR) are calculated using the method of Smith and Madigan [35]. The 21 haemodynamic parameters are explained further in Appendix 1 [19,35].

All USCOM measurements were performed by a senior researcher with experience of over 1000 USCOM examinations in a wide variety of patients and research subjects. To achieve acceptable proficiency in the use of the USCOM, trainees must achieve a level of inter- and intra-observer variability which is within the limits of physiological variation of patients, i.e. less than 10%, and typically the values are around 5–8% [9,14,16]. Measurements were performed with the subject in the supine position, following a period of rest of at least 5 min, and immediately following blood pressure measurement. The suprasternal insonation window was used for aortic measurements, which was performed first, whilst the left parasternal insonation window was used for pulmonary valve measurements. A minimum of three consecutive diagnostic quality Doppler ejection profiles were required for each measurement, and three measurements were made for each subject on each of the two valves. This generated a minimum of 18 diagnostic quality ejection waveforms for each subject, nine for each valve. This leads to a threefold improvement in measurement accuracy, as the standard error of the measurement is directly proportional to the standard deviation of SV and inversely proportional to the square root of the number of measurements, in this case $\sqrt{9} = 3$. This provides a greater degree of measurement accuracy than the single waveform examination often employed in echocardiography.

2.3. Sample size calculation

Based on published values [6], the mean SV for subjects aged 65 and 73 years were 69.5 ± 4.9 mL and 63.0 ± 4.7 mL respectively. Therefore, a minimum sample size of 9 subjects in each group would be required to achieve a power of 80% with a 2-sided significance level of $\alpha = 0.05$. In order to investigate the difference in haemodynamic parameters between the three age groups, the two ASA groups and the two aortic and pulmonary windows, the minimum sample size required for this study is 108 subjects (9×3 age groups $\times$ 2 ASA groups $\times$ 2 valves = 108). From previous experience with this population, we estimated that up to 25% of subjects might yield sub-optimal quality images. The minimum sample size was therefore set at 135.

2.4. Statistical analysis

Continuous variables were analyzed using the Mann–Whitney U test or Wilcoxon Rank Sum test. Multiple comparisons of different age groups were performed using the Kruskal–Wallis test. Categorical variables were analyzed using the Chi-square test or Fisher's exact test. As the data showed a normal distribution, the