Individual reference values for 2D echocardiographic measurements. The Stockholm – Umeå Study

Jan Svedenhag[1], Thomas P. Larsson[2], Per Lindqvist[3,4], Arne Olsson[5] and Eva Rythén Alder[2]

[1]Department of Clinical Physiology, Capio S:t Görans Hospital, Karolinska Institute, [2]Departments of Clinical Physiology and Nuclear Medicine, Danderyds Hospital, Karolinska Institute, Stockholm, [3]Department of Clinical Physiology, Heart Centre, Umeå University, [4]Department of Surgical and Perioperative Sciences, Umeå University, Umeå, and [5]Department of Clinical Physiology, Södersjukhuset, Karolinska Institute, Stockholm, Sweden

Correspondence
Jan Svedenhag, Department of Clinical Physiology, Karolinska Institute, Capio S:t Görans Hospital, SE-112 81 Stockholm, Sweden
E-mail: jan.svedenhag@capiostgoran.se

Accepted for publication
Received 30 January 2014;
accepted 14 April 2014

Key words
aortic root; atrium; chamber; dimensions; left ventricle; wall thickness

Summary

Objectives: Improved reference values for 2D echocardiographic measurements are required, even when more recent echocardiographic technology is employed. In addition, it may be preferable to individualize reference values from age, gender and body characteristics of any subject.

Design: A material of 180 healthy subjects was collected and investigated, aiming for an even distribution of sex and age (from 20 to 80 years of age; the Stockholm material). For atrial areas, material from another 216 healthy subjects with similar sex and age distribution was added (the Umeå material). The 2D measures determined were the left and right ventricular diameters in diastole, the left ventricular diameter in systole, the thickness of septum and posterior wall, the diameters of the aortic root (sinotubular junction) and the left atrium (all in parasternal view), together with the left and right ventricular diameters in diastole and left and right atrial areas in end-systole (apical four-chamber view). The width of the inferior vena cava (from subcostal view) was also determined.

Results: Confidence intervals for females and males are presented for each of these measures. Multiple linear regression analyses with age, sex and measures of body characteristics as predictors were also performed, and for eight of the 12 measurements, such equations are presented.

Conclusions: It is possible to obtain more highly individualized reference values for these cardiac dimensions, which may clinically be a better way of distinguishing pathological states from normal states.

Introduction

The use of ultrasound to study cardiac structures was first described by Edler and Hertz (1954). The use of echocardiography in a clinical setting has been expanding continuously since the 1970s, and is now one of the most widely used cardiac imaging techniques around the world.

Echocardiography is primarily used to differentiate abnormality from normality in patients. While this may be more or less obvious in some cases, the full investigative power of echocardiography is dependent on quantitative measurements, including that of cardiac dimensions. However, despite the widespread use of echocardiography, there is currently a considerable heterogeneity in reference values used for cardiac dimensions. Few reference studies are available, and these mainly use either older echocardiographic techniques or a limited number of subjects (Henry *et al*., 1980; Schnittger *et al*., 1983; Knutsen *et al*., 1989). More recently, recommendations for cardiac chamber quantification and reference values have been published by Lang *et al*. (2005, 2006) [Guidelines of the American Society of Echocardiography (ASE) in conjunction with the European Association of Echocardiography (ESC)]. Although accepted in principle, some of the proposed normal ranges in these guidelines have been difficult to implement in a clinical setting in our laboratories, for example the narrow upper limit of septum and posterior wall thickness (Lang *et al*., 2006).

As a result of this lack of useful reference values, the definition of cardiac dimension normality may differ from one echocardiographic centre to another, even when located in close proximity (such as in the Stockholm region).

The purpose of the present study was to define new reference values for 2D echocardiographic dimensions collected systematically in a uniform way. Cardiac dimensions can depend on a variety of factors including sex, age and body characteristics. Therefore, an additional objective of the study was to present individualized reference values which take these factors into account.

Material and methods

Five echocardiographic centres participated in the study: the Departments of Clinical Physiology at the four main hospitals in Stockholm (Karolinska Huddinge, Capio S:t Göran, Danderyd and Södersjukhuset), together with the Echocardiographic Unit of one private centre (FysiologLab, Stockholm). At each site, two of the most experienced echocardiographers, each with more than 10 years of echocardiographic practice (one physician and one sonographer), were recruited. Significant initial preparatory work was focused on ensuring that identical measurement techniques were used at all five sites.

A total of 180 subjects were recruited, mainly via poster campaigns and among hospital staff. Each unit aimed for an evenly distributed subject population by sex and by six age deciles from 20 up to 80 years. The subjects were all regarded as healthy and asymptomatic. Each subject completed a questionnaire detailing current and previous medical conditions, smoking habits, current medication and exercise habits before entering the study. Individuals were not included in the study if they had a history of previous or current cardiovascular or lung disease, hypertension, epilepsy or any systemic disease known to affect the cardiovascular system. None were using any kind of medication for the cardiovascular system. Subjects with psychiatric disease were not included if they used psychotropic medication with potential cardiovascular influence. Individuals participating in physical exercise above moderate levels (>6 h per week or jogging/running >70 km per week) and clearly obese subjects ($BMI > 31{\cdot}6$ kg m^{-2}) were excluded. Normal ECG was required, with resting heart rate between 40–100 beats min^{-1}, and blood pressure after 10 min of rest (supine or sitting) not above 145/90 mmHg. Participating females of reproductive age all reported menstruation during the preceding 8 weeks. If any structural disease was found in the subsequent echocardiographic examination (including valve insufficiency above grade 1/4 or indications of an increased right ventricular systolic pressure), the subject was excluded from the study. Two patients originally included were omitted from the study following the echocardiographic examination: one due to poor image quality and the other due to mitral valve pathology. Most participants received a small recompense for their effort (either a movie ticket or a flower voucher). The study was approved by the Ethical Committee in Stockholm.

The equipment used for the investigations was the Siemens Sequoia (Siemens Healthcare, Erlangen, Germany) and GE Vivid 7 (GE Healthcare, Buckinghamshire, UK). The clinical setting of these machines (including second harmonics) was used.

The 2D measures that were performed were:

1 *In the parasternal view* (and the subject in left lateral position): the right and left ventricle diameters, the thickness of septum and posterior wall, and the aortic root at the sinotubular junction (all in end-diastole, see Fig. 1) together with the left ventricular and atrial diameters (in end-systole). The left ventricle was measured slightly apical to the tips of the mitral valve, and with a 90-degree angle to the length axis of the left ventricle. The right ventricle was measured using an extension of the left ventricular diameter line.

2 *In the apical four-chamber view* (and the subject in left lateral position): the diameters of the left and right ventricle were determined (in end-diastole, 1/3 of the ventricle length from the AV-plane, Fig. 2) together with the area of both left and right atrium (in end-systole, see below).

3 *In the subcostal view* (and the subject lying on his/her back with legs bent): the diameter of the inferior vena cava was measured in the long axis (1 cm from the cava entrance in the right atrium, in end-diastole and end-expiratory).

The echocardiographic image was optimized for each measurement with regard to image contrast and depth, and when required also for sector size. The measurements of heart dimensions were all performed in triplicate according to the principle 'trailing edge to leading edge' and the recommendations of the American Society of Echocardiography (Lang *et al.*, 2005).

In addition, the AV-plane displacement of the left ventricle (septal, lateral in apical four-chamber view and inferior, anterior in apical two-chamber view) was included, as was the

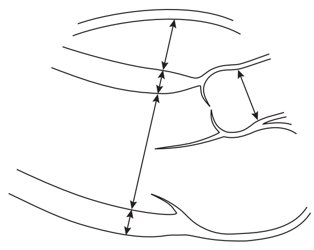

Figure 1 Two-dimensional guided measurements in the parasternal long-axis view. The right and left ventricle diameters, the thickness of septum and posterior wall, and the aortic root at the sinotubular junction are shown (all in end-diastole).

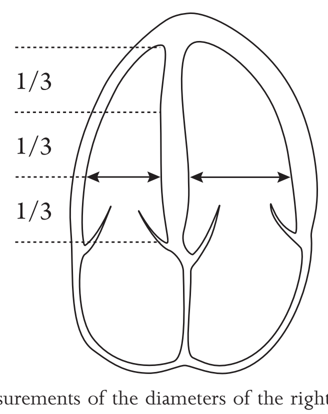

Figure 2 Measurements of the diameters of the right and left ventricle in the apical four-chamber view (in end-diastole).

AV-plane displacement of the right ventricle (free wall in four-chamber view). A mean of three M-mode measurements of the distance from the AV-plane nadir during the latter part of the isovolumic relaxation phase (at/near the Q-wave on ECG) to the top during the systole (T-wave on ECG) was used (Fig. 3). If there was a second late peak, this was not taken into consideration. The measurements were made with an enlarged view of the AV-plane at hand.

For the measurement of left and right atrium area, a healthy subject material of 216 subjects from the Umeå University Hospital was added to the Stockholm material (otherwise the Umeå material was a M-mode dimension study and therefore not included in the present investigation). The number of measurements and exclusion criteria were similar to those used in the Stockholm material. The left and right atrial areas were defined as the area up to, but not above, the basal level of the mitral and tricuspid valve ring, respectively (in end-systole, just before the opening of the mitral or tricuspid valves). The entrance of pulmonary veins in the left atrium and the left atrial appendage was not included in the left atrial area (Fig. 4).

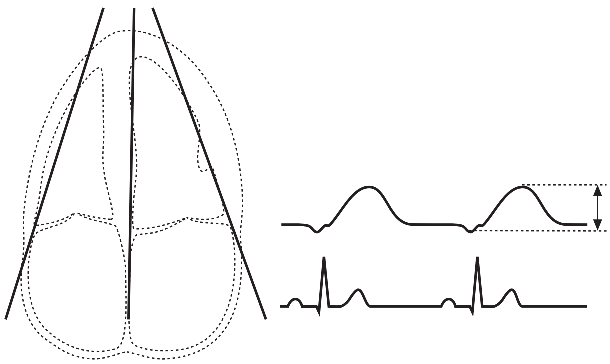

Figure 3 M-mode determinations of the AV-plane displacement of the left ventricle (septal and lateral) and of the AV-plane displacement of the right ventricle (free wall, TAPSE) in the apical four-chamber view. Measurements were made from the AV-plane nadir during the latter part of the isovolumic relaxation phase (at/near the Q-wave on ECG) to the top during the systole (T-wave on ECG). If there was a second late peak, this was not taken into consideration.

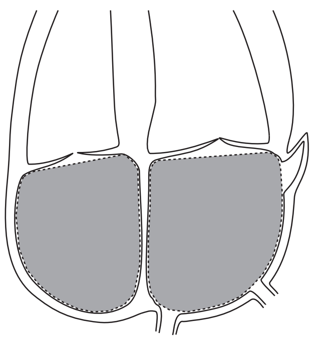

Figure 4 Measurements of the areas of the left and right atrium in the apical four-chamber view (in end-systole, just before the opening of the mitral or tricuspid valves).

For the evaluation, all data were compiled in a spreadsheet and analysed statistically using Statistica software (version 9.0; StatSoft, Tulsa, OK, USA). Statistical help from a StatSoft statistician was obtained. Basic characteristics of the subjects are presented as mean, SD and range. Confidence intervals for females and males were also calculated, as mean ±1·97–1·99*SD (depending on the number of observations).

Besides basal statistics, evaluation of multiple linear regression (best subsets with Mallow's CP) was performed for all parameters. In these statistical analyses, sex was tried as a categorical predictor and with the following as continuous predictors: age, $age^2/1000$, lnage, length, body mass, BMI, BSA, $BSA^{1/3}$, $BSA^{0·5}$ and $BSA^{1·5}$ (based both on earlier studies and on theoretical considerations). Multiple regression analyses then presented the best subset of predictors for each parameter. The analyses were considered to display a significant relation if r was >0·50 (for the larger material of left and right atrium if $r > 0·40$); it was also necessary to obtain a 'reasonable' intercept of the equation (LVd 4CH and RVd PLAX were omitted due to large negative intercept values). A 95% prediction interval was also calculated for each multiple linear regression evaluation.

Results

Subject characteristics

The mean (range) age, length, body mass, BSA and BMI of the Stockholm material are presented in Table 1, together with systolic and diastolic blood pressures. The distribution of males and females in the different age classes was quite even (Table 2), with the exception of slightly fewer males in the highest age deciles, primarily 70–80 years. Healthy subjects were in fact harder to find in these oldest male deciles.

For the Umeå material (added to the Stockholm material for the atrial area reference values), the age, length and BSA distributions were very similar to the Stockholm material, although the body mass and the BMI were slightly higher (Table 1). For those subjects for whom the systolic pressure

Table 1 Subject characteristics (mean ± SD, range) in the study materials.

	Stockholm (*n* = 180) (main material)	**Umeå (*n* = 216) (added for atrial areas)**
Sex	Females: 95; Males: 85	Females: 108; Males: 108
Age (years)	48·6 ± 16·7 (19–81)	49·0 ± 17·6 (22–89)
Length (cm)	173 ± 9 (153–195)	172 ± 9 (146–196)
Body mass (kg)	70·3 ± 12·4 (43–116)	73·1 ± 13·6 (44–110)
BSA (m^2)	1·83 ± 0·20 (1·38–2·45)	1·85 ± 0·20 (1·40–2·32)
BMI ($kg\ m^{-2}$)	23·4 ± 2·8 (17·2–31·6)	24·7 ± 2·8 (17·2–35·8)
SBP (mmHg)	123 ± 11 (100–145)	123 ± 12 (90–144)
DBP (mmHg)	75 ± 8 (60–90)	75 ± 8 (55–96)

Table 2 Age distribution of female and male subjects in the Stockholm material.

	20–30 years	30–40 years	40–50 years	50–60 years	60–70 years	70–80 years
Females	15	15	17	16	18	14
Males	15	15	16	15	15	9

of the right ventricle could be calculated, it was found to be normal in both study populations (Stockholm: $n = 84$, mean 24·7 mmHg; Umeå: $n = 164$, mean 22·3 mmHg).

Confidence intervals

Table 3 presents the 95% confidence intervals for all cardiac dimensions, and for females and males separately. The confidence intervals of atrial areas, as shown in Table 3, were derived from the combined Stockholm and Umeå materials, but were also calculated separately for the Stockholm material (left atrial area: females 11·1–20·6, males 12·5–23·2 cm^2; right atrial area: females 9·6–17·5, males 10·6–20·3 cm^2). The AV-plane displacement of the left ventricle (septal, and mean of septal, lateral, inferior and anterior) and of the right ventricle (free wall) are also presented (Table 3).

Table 3 Confidence intervals for females and males of the different echocardiographic 2D measures together with AV-plane displacement of the left and right ventricles.

	Females	Males
LVd PLAX (2D)	3·61–5·05	3·88–5·70
LVs PLAX (2D)	2·04–3·57	2·29–4·07
LVd 4CH (2D)	3·42–5·01	3·72–5·65
Septum PLAX (2D)	0·64–1·18	0·77–1·31
Posterior wall (2D) (i.e. inferior-lateral wall)	0·62–1·09	0·67–1·21
AV-plane displacement LV septum (mm)	9·2–16·5	9·2–17·6
AV-plane displacement LV mean (sept, lat, inf, ant; mm)	10·2–17·6	10·7–18·0
RVd PLAX (2D)	2·14–3·56	2·26–3·99
RVd 4CH (RVD1, 2D)	2·16–3·56	2·23–4·17
AV-plane displacement RV free wall (TAPSE) (mm)	17·2–31·1	16·5–31·4
Aortic root PLAX (sinotubular junction, d, 2D)	1·91–3·13	2·11–3·49
Left atrium PLAX (s) (2D)	2·44–3·85	2·64–4·23
Left atrial area (s) 4CH[a]	8·9–20·7	10·3–22·8
Right atrial area (s) 4CH[a]	8·6–18·2	9·9–22·6
Inferior vena cava (d) (2D)	1·00–2·37	1·10–2·47

Stockholm study alone ($n = 180$).
[a]For left and right atrial areas, the combined studies of Stockholm and Umeå were used ($n = 392/394$). 2D measures were performed according to the measuring principle 'trailing edge to leading edge'. Values are presented or calculated in cm (atrial areas in cm^2; AV-plane displacement in mm). Confidence intervals were the mean value ±1·97–1·99*SD depending on the number of observations.

Prediction intervals

To calculate individual 2D reference values, multiple linear regression analyses were performed for all cardiac dimensions as outlined above. For four of the dimensions (the left ventricle in the four-chamber view, the right ventricle in both the parasternal and apical views, and also the inferior vena cava in the subcostal view), reasonable equations with $r > 0{\cdot}5$ could not be obtained. The same was true for the for AV-plane displacements of the left and right ventricles. For the remaining eight measured cardiac dimensions, the equations are provided in Table 4. The prediction interval of a regression equation is the calculated individual mean value (from measures of subject characteristics included in that specific equation) ± the respective prediction value. For the Stockholm material, the equations of the atrial areas were also separately calculated [left: = 0·1182*(body mass) + 8·489 ± 4·57 (r = 0,53); right: = −0·0950*(age) + 4·9846*(lnage) − 0·6037*(length in cm) − 0·9414*(body mass) + 88·761*(BSA) + 7·997 ± 4·00 (r = 0.55)].

Discussion

Quantification of cardiac chamber sizes by echocardiography is one of the cornerstones of the diagnostics of cardiac diseases, that is differentiating abnormality from normality in cardiac patients. In spite of this, good 2D reference materials are very scarce, which may cause interpretation problems in the clinical setting.

In the material discussed here, we undertook thorough 2D measurements of healthy subjects with almost even distribution with regard to both sex and age (20–80 years of age). Results are presented as confidence intervals for females and males, respectively. Furthermore, to obtain individualized reference values, we present results from multiple linear regression equations with gender, age and/or different body characteristics as predictors. This was possible in eight of the 12 measurements.

We have principally compared our findings with two existing reference materials: Henry *et al.* (1980; an older M-mode study) and Lang *et al.* (ASE/ESC guidelines; 2006; a study with measurements from 2D images or 2D-targeted M-mode echocardiography). These results are presented in Figs 5–8.

For the *left ventricular diastolic diameter*, it will be seen that our material as a whole shows greater similarity to the older study by Henry *et al.* (1980) than to the more recent study by Lang *et al.* (2006) (Fig. 5). This may be due at least in part to the fact that Henry *et al.* (1980) also used individualized equations to obtain reference values. In Lang *et al.* (2006), the material was mainly categorized according to sex alone. When we expressed our results in the same way (confidence intervals for females and males, Table 3), a greater similarity between our results and that of Lang *et al.* (2006) was found. However, this approach disregards other important characteristics of the investigated subjects.

Table 4 Multiple linear regression equations (regression weight per variable for individually calculated reference values) are depicted for eight variables.

LVd PLAX (2D)	=0·02140*(age) − 0·32057*(age^2/1000) + 5·9505*(BSA$^{1/3}$) − 2·918 ± 0·66
LVs PLAX (2D)	=3·4403*(BSA$^{1/3}$) − 0·11840*(age^2/1000) + 0·0633*(sex, female = 0, male=1) − 0·9064 ± 0·70
Septum PLAX (2D)	=0·06067*(age) − 0·29312*(age^2/1000) − 1·2856*(lnage) − 0·04857*(length in cm) − 0·09525*(BMI) + 8·6124*(BSA$^{1/2}$) + 0·0248*(sex, female = 0, male = 1) + 2·690 ± 0·23
Posterior wall (2D) (i.e. inferior-lateral wall)	=0·00781*(age) − 0·27510*(lnage) − 0·05543*(length in cm) − 0·10612*(BMI) + 9·6819*(BSA$^{1/2}$) + 0·546 ± 0·23
Aortic root PLAX (sinotubular junction, d, 2D)	=0·13954*(age) − 0·78830*(age^2/1000) − 2·5400*(lnage) + 2·0219*(BSA$^{1/3}$) + 0·0776*(sex, female = 0, male = 1) + 5·180 ± 0·59
Left atrium PLAX (s) (2D)	=0·22557*(lnage) + 0·01992*(body mass) + 1·022 ± 0·60
Left atrial area (s) 4CH[a]	=0·0289*(age) + 28·116*(BSA$^{1/3}$) − 20·178 ± 5·80
Right atrial area (s) 4CH[a]	=0·04321*(body mass) + 1·1059*(sex, female = 0, male = 1) + 11·743 ± 5·55

[a]Stockholm and Umeå material, see above. To be able to calculate individual reference values, multiple linear regression (best subset) was used (see Methods). These equations are shown if r > 0·50 (for atrial area r > 0·40) and if the intercept was 'reasonable'. The 95% prediction intervals for the regression equations are the mean value ± the prediction range of the corresponding equation as seen above.

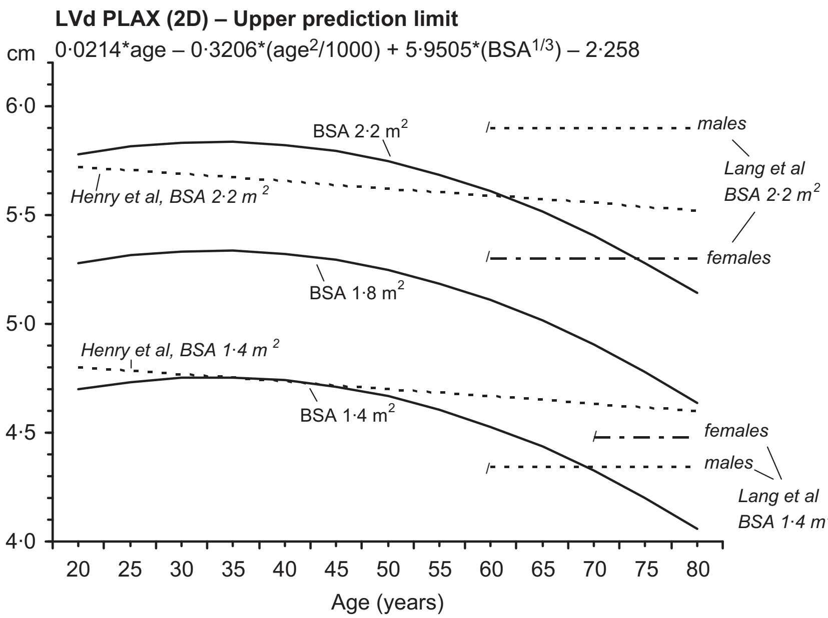

Figure 5 The left ventricular diameter (upper prediction limit) relative to age for specified BSA values of 1·4 and 2·2 m^2. The present reference material is compared with that of Henry *et al.* (1980) and Lang *et al.* (2006).

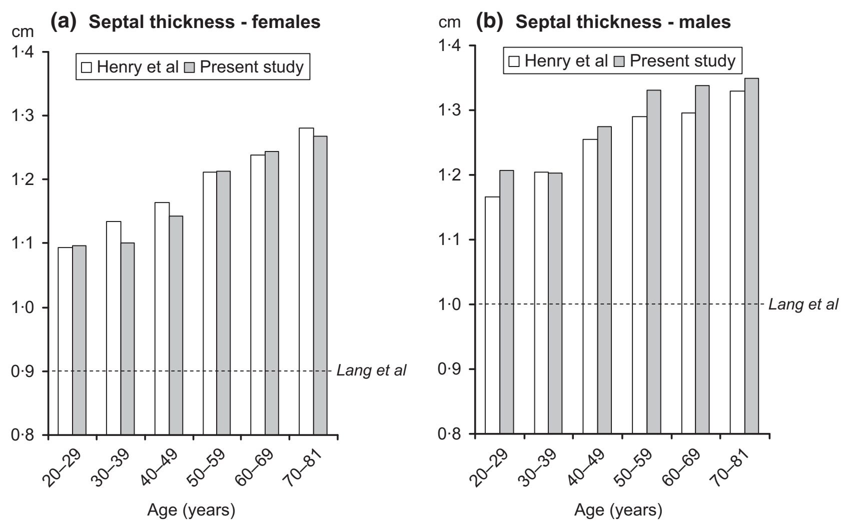

Figure 6 Comparison between upper reference values for septal thickness when a 'mean' patient in each age decade in this study is used as reference. Mean values of age, body mass and length in each decade are entered in the formula derived in the present study (Table 4) and that of Henry *et al.* (1980). Septal thickness in cm for females is shown in (a) and for males in (b). The upper reference limits of Lang *et al.* (2006) are shown.

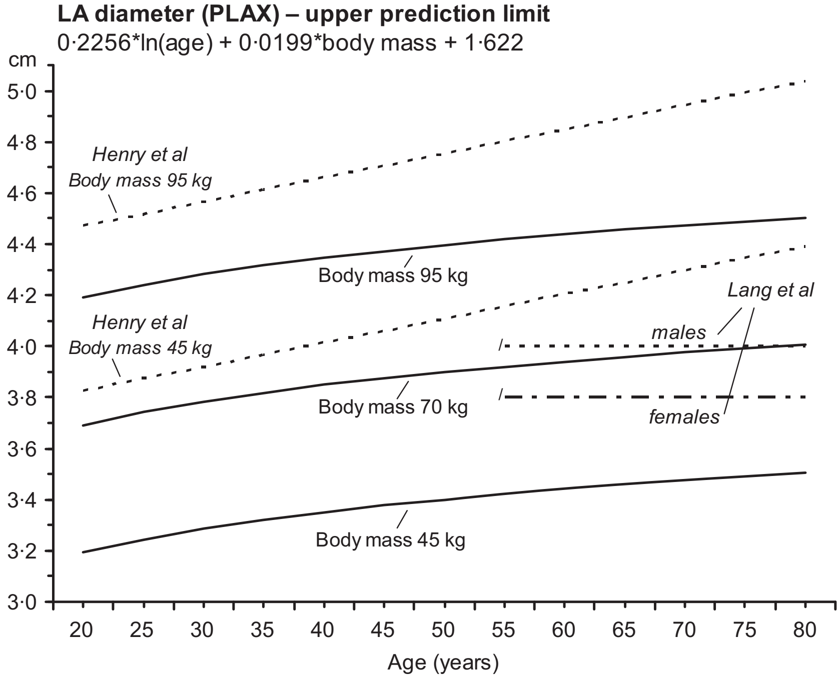

Figure 7 The parasternal left atrial diameter (upper prediction limit) relative to age for specified body mass values of 45 and 95 kg. The present reference material is compared with that of Henry *et al.* (1980). The reference values (females and males) of Lang *et al.* (2006) are also shown.

In addition to absolute figures, the left ventricular diameter of Lang *et al.* (ASE/ESC guidelines; 2006) was also expressed per m^2 body surface area (BSA). However, this expression may have exaggerated the role of BSA. Rather, in the equations of both our study and that of Henry *et al.* (1980), the left ventricular diameter was found to be related to $BSA^{1/3}$, which thus seems to have a much greater predictive value than that of BSA as such.

There remains a divergence between our equation and that of Henry *et al.* (1980) for left ventricular diastolic diameter, but that is more related to how age is factored in. Henry *et al.* (1980) only used age as a linear predictor, while we additionally tested and established a relationship with the square of age. In our results, this takes on a curvilinear appearance with age, and a smaller left ventricular diameter in the oldest subjects.

We also compared our results of *septal thickness* with that of Henry *et al.* (1980) and Lang *et al.* (ASE/ESC guidelines; 2006) (Fig. 6). As a whole, our results once again display a greater resemblance to the old M-mode material from Henry *et al.* (1980) than to the more recent guidelines presented by Lang *et al.* (2006). As mentioned above, this may be partly due to the fact that Henry *et al.* also used individualized equations to obtain their reference values. Even so, the very much smaller septal thickness in the Lang *et al.* study (upper reference limit for females of only 0·9 cm and only 1·0 cm for males) compared to our results and those of Henry *et al.* (Fig. 6) suggests some shortcomings in their septal thickness values. As Lang *et al.* (2006) relied on a combination of several smaller materials, this may have resulted in a lower degree of accuracy in their findings, at least with regard to wall thickness.

As for the left atrium, we measured the left atrial diameter in the parasternal view and the left atrial area in the apical four-chamber view. Measurements of atrial size are important as it may be a risk marker of both atrial fibrillation and heart failure (Tsang *et al.*, 2001; Ristow *et al.*, 2008).

For the parasternal *left atrial diameter*, the present results show lower values than those of Henry *et al.* (1980) but are more in line with that of Lang *et al.* (2006) (Fig. 7). The older M-mode technique may thus be inferior with regard to measuring the left atrial diameter in parasternal view. This may in part be due to differences in the measuring technique used ('trailing edge to leading edge' as compared to the former 'leading edge to leading edge').

Regarding the *left atrial area* in the apical four-chamber view, it was found to be linearly related to age (see Table 4, Fig. 8a). There has for many years been a discussion in the literature about whether or not left atrial size increases with advancing age in healthy subjects (Wang *et al.*, 1984; Pearlman *et al.*, 1990; Thomas *et al.*, 2002). The linear increase in left atrial area with age of our healthy material is in contrast with the curvilinear decrease in left ventricular diastolic and systolic diameter with age. Speculatively, this could reflect both the ageing process as such and an altered activity level of older but still healthy individuals. As sex was not found to be a predictor either of left ventricular diastolic diameter or in the measurements of left atrium, this ageing effect is similar in both sexes. In addition to age, the left atrial area was also related to $BSA^{1/3}$ (Table 4), showing the same BSA relation as that of the left ventricular diameter.

As far as we are aware, equations for obtaining individual reference values of left atrial area have not been presented before. If we instead compare our confidence intervals of females (9–21 cm^2) and males (10–23 cm^2) to the atrial areas presented by Lang *et al.* (2006) ($\leq$20 cm^2 for both females

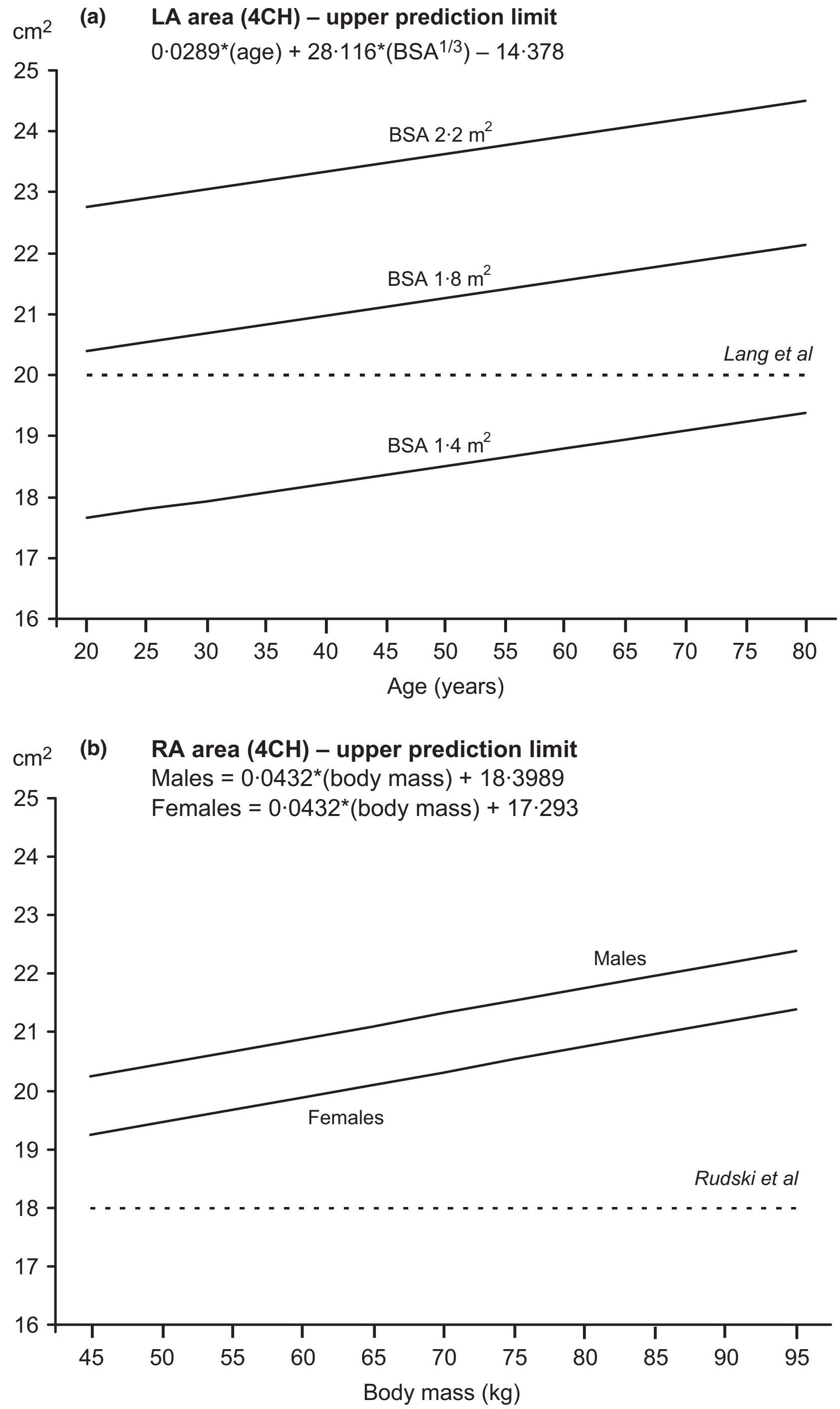

Figure 8 (a) The left atrial area (upper prediction limit) relative to age for specified values of BSA. The present reference material is compared with the general reference limit of Lang *et al.* (2006). (b) The right atrial area (upper prediction limit) relative to body mass for females and males. The present reference material is compared with the general reference limit of Rudski *et al.* (2010).

and males), the results are rather similar. Furthermore, Fig. 8a shows that this study and that of Lang *et al.* (2006) show the greatest similarity in lower age classes, while we report higher values for the older subjects.

We have not presented reference values for left atrial volume in this paper. This is because we did not perform measurements of the left atrium in the apical two-chamber view (nor can this be calculated afterwards from the stored images). There may also be situations in which proper measurements of atrial size in the apical two-chamber view are difficult to obtain. To perform left atrial volume determinations from a single-plane measurement (i.e. in this case, the four-chamber view) seems inappropriate, as the result would be far too uncertain. Furthermore, it is known that the approach of calculating volume from 2D measurements may influence the results obtained (the area–length method yielding greater values than the Simpson method, Jiamsripong *et al.*, 2008). If, for comparison, we were still to calculate the *mean* left atrial area and single-plane atrial volume (area–length method) in the Stockholm study, the values would be 16·8 cm^2 and 50·5 ml (27·6 ml m^{-2}), i.e. higher than those in several existing studies/guidelines (Wang *et al.*, 1984; Lang *et al.*, 2006). We feel that calculating atrial volumes in this way also leads to an unacceptably large interindividual volume variation among the healthy subjects in our sample, even when attempting to relate the volume to BSA.

Finally, the *right atrial area* was found to have other predictors than that of the left atrial area. In this case, there was no relation to age or $BSA^{1/3}$, but instead to sex and body mass. Our values are also slightly higher than those presented earlier by Rudski *et al.* (2010) (Fig. 8b).

Limitations

Our study material consisted of locally recruited individuals in Stockholm, and the majority of the population studied was Caucasian. This may limit the use of our results in non-caucasian populations. Secondly, the inclusion of individuals was not random, which may have resulted in a slightly different study population than a completely random inclusion. Thirdly, the study presents echocardiographic *reference limits* for cardiac dimensions in a fairly large group of apparently healthy individuals, with strict inclusion criteria excluding present cardiovascular disease. We are aware that our study is not prospective, taking future incidence of disease in account. Nonetheless, we believe that our reference values will be very useful in daily clinical routines.

In conclusion, we have presented a new reference material for 2D echocardiography dimensions. These cardiac dimensions appear to be dependent on several factors including the sex, age and body characteristics of the subjects. Using our equations of these cardiac dimensions, more individualized reference values may be obtained, which clinically may be a better way of distinguishing pathological states from normality.

Acknowledgments

Our grateful thanks go to the following people for their significant contributions in the collection of the Stockholm material: physicians Ernst Zuber and Reidar Winter; and sonographers Margareta Kindahl, Maria Westerlind, Helena Flodén, Nahid Abedin, Isabella Norgren and Gazize Yasini. For statistical assistance, we thank Jonas Selling, StatSoft Scandinavia AB. For language guidance and general wise counsel, we thank Prof. Torbjörn åkerstedt, Karolinska Institute. For language revision, we also thank Trevor Datson. This study was partly supported by Siemens and GE, by local research fund FoUU at Danderyds Hospital, and by Capio S:t Görans Hospital.

Conflict of interest

The authors have no conflict of interests.

References

Edler I, Hertz CH. The use of ultrasonic reflectoscope for continous recording of the movements of the heart walls. *Kungl Fysiogr Sållsk i Lund Förhandl* (1954); **24**: 40–58.

Henry WH, Gardin JM, Ware JH. Echocardiographic measurements in normal subjects from infancy to old age. *Circulation* (1980); **62**: 1054–1061.

Jiamsripong P, Honda T, Reuss CS, Hurst RT, Chaliki HP, Grill DE, Schneck SL, Tyler R, Khandheria BK, Lester SJ. Three methods for evaluation of left atrial volume. *Eur J Echocardiogr* (2008); **9**: 351–355.

Knutsen KM, Stugaard M, Michelsen M, Otterstad JE. M-mode echocardiographic findings in apparently healthy, non-athletic Norwegians aged 20–70 years. Influence of age, sex and body surface. *J Intern Med* (1989); **225**: 111–115.

Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellika PA, Picard MH, Roman MJ, Seward J, Shanewise JS, Solomon SD, Spencer KT, Sutton MJ, Stewart WJ. Recommendations for chamber quantification: a report from the American Society of Echocardiography's guidelines and standards committee and the chamber quantification writing group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. *J Am Soc Echocardiogr* (2005); **17**: 1440–1463.

Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellika PA, Picard MH, Roman MJ, Seward J, Shanewise J, Solomon S, Spencer KT, Sutton MJ, Stewart W. Recommendations for chamber quantification. *Eur J Echocardiogr* (2006); **7**: 79–108.

Pearlman JD, Triulzi MO, King ME, Abascal VM, Newell J, Weyman AE. Left atrial dimensions in growth and development: normal limits for two-dimensional echocardiography. *J Am Coll Cardiol* (1990); **16**: 1168–1174.

Ristow B, Ali S, Whooley MA, Schiller NB. Usefulness of left atrial volume index to predict heart failure hospitalization and mortality in ambulatory patients with coronary heart disease and comparison to left ventricular ejection fraction (from Heart and Soul Study). *Am J Cardiol* (2008); **102**: 70–76.

Rudski LG, Lai WW, Afilalo J, Hua L, Handschumacher MD, Chandrasekaran K, Solomon SD, Louie EK, Schiller NB. Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography. *J Am Soc Echocardiogr* (2010); **23**: 685–713.

Schnittger I, Gordon EP, Fitzgerald PJ, Popp RL. Standardized intracardiac measurents of two-dimensional echocardiography. *J Am Coll Cardiol* (1983); **2**: 934–938.

Thomas L, Levett K, Boyd A, Leung DYC, Schiller NB, Ross DL. Compensatory changes in atrial volumes with normal aging: is atrial enlargement inevitable? *J Am Coll Cardiol* (2002); **40**: 1630–1635.

Tsang TSM, Barnes ME, Bailey KR, Leibson CL, Montgomery SC, Takemoto Y, Diamond PM, Marra MA, Gersh BJ, Wiebers DO, Petty GW, Seward JB. Left atrial volume: important risk marker of incident atrial fibrillation in 1655 older men and women. *Mayo Clin Proc* (2001); **76**: 467–475.

Wang Y, Gutman JM, Helibron D, Wahr D, Schiller NB. Atrial volume in a normal adult population by two-dimensional echocardiography. *Chest* (1984); **86**: 595–601.

