ORIGINAL ARTICLES

Signal-Averaged P Wave Duration and the Dimensions of the Atria

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Background: Delay of atrial electrical conduction measured as prolonged signal-averaged P wave duration (SAPWD) could be due to atrial enlargement. Here, we aimed to compare different atrial size parameters obtained from echocardiography with the SAPWD measured with a signal-averaged electrocardiogram (SAECG).

Methods: In 74 patients scheduled for elective echocardiography, an SAECG was recorded directly after the echocardiogram. We measured the SAPWD and registered clinical characteristics. The correlation between the SAPWD and the left atrial diameter (LAD), left atrial volume (LAV), right atrial volume (RAV), and total atrial volume (TAV) was analyzed by linear regression analyses. The effect of concomitant risk factors on TAV and the SAPWD was examined.

Results: Linear regression analysis showed that the correlation between the SAPWD and the LAD was significant ($R^2 = 0.11$, $P = 0.03$). However, LAV ($R^2 = 0.15$, $P = 0.009$), RAV ($R^2 = 0.27$, $P = 0.0003$), and TAV ($R^2 = 0.37$, $P < 0.0001$) were more strongly correlated to the SAPWD. The TAV and the SAPWD were not significantly associated with coexisting risk factors.

Conclusions: The SAPWD is significantly correlated to the atrial size; most strongly to the TAV. The size of the right atrium, with the sinus node area, appears to affect the SAPWD.

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Prolonged signal-averaged P wave duration (SAPWD) has been shown to mark atrial fibrillation (AF) and in some clinical settings influence the prognosis of the arrhythmia.^{1–4} Atrial enlargement has also been linked to AF and the risk of complications.^{5–7} In clinical routine, the size of the atria is often estimated from an echocardiographic assessment of the left atrial diameter (LAD). The degree to which the interatrial conduction time is determined by the size of the atria is unclear; moreover, concomitant diseases could influence the atrial electrophysiology and the dimensions of the atria.^{8,9} Lastly, more precise estimates of the atrial size, such as volume parameters including the right atrial volume (RAV), may be closer

correlated to the SAPWD because of the location of the sinus node.

Therefore, we compared the different atrial size parameters, obtained from an echocardiography, with the SAPWD measured with a signal-averaged electrocardiogram (SAECG), and studied the correlation between prolonged SAPWD, the atrial size, and the clinical characteristics.

METHODS

Patient Population and Design

Between May 7 and July 6, 2001, all patients scheduled for elective echocardiography at the Department of Cardiology, the University

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Hospital of Hvidovre, Copenhagen, were consecutively screened for participation in the study. Exclusion criteria were presence of supraventricular arrhythmia, pacemaker, Parkinson's disease or other neuromuscular disease with tremor causing a high noise level above $1.0 \mu\text{V}$ on the SAECG recording, a high noise level on the SAECG for other reasons, psychiatric disease, inability to communicate in Danish or in English, and lack of informed consent. All patients had stable sinus rhythm at the time of the SAECG recording. The project was approved by the local Ethics Committee.

Clinical characteristics and concomitant diseases were ascertained from a thorough interview of the patient and data from the patient's file. On inclusion, an echocardiogram was obtained, and immediately after the echocardiography an SAECG was recorded.

SAECG Recordings

The SAECG data were recorded with a MAC VU Resting ECG Analysis System with Late Potential Analysis Option, P Wave HI-RES from Marquette Electronics, Inc., Milwaukee, WI, using Ag/AgCl electrodes. Modified orthogonal leads X, Y, and Z (Frank leads) were recorded. The noise level was reduced by placing the patient in a relaxed position, skin preparation was done carefully, and electrical equipment in the proximity of the recording site was switched off whenever possible.

Initially, a P wave template was formed using the first recorded 8 seconds. During the procedure, each new P wave was matched to the template and included in the calculation of P wave parameters only when a cross-correlation coefficient of >0.97 was achieved. The recording was completed when 250 P waves had been averaged. The result was accepted only if a noise level below $1.0 \mu\text{V}$ was obtained during the averaging process. A spectral filter of 40 to 250 Hz was used. If the patient was unable to lie down without moving until the 250 P waves had been accepted for signal-averaging analysis, the recording was stopped when the noise level had reached a stable level below $1.0 \mu\text{V}$.

The primary parameter was the total filtered P wave duration estimated from a visually based measurement of the P wave; thus, one investigator (CJ) manually set the marks for the onset and the cut-off point of the P wave before the analysis of the echocardiogram, which was digitally stored

Figure 1. A signal-averaged ECG showing a normal intratrial conduction time, SAPWD, of 119 ms.

for later analysis. Figure 1 shows an example of a recording of the SAPWD.

The other electrophysiological parameters obtained from the SAECG were not used in this analysis. In all the patients, the SAECG was recorded on inclusion; each patient had two recordings performed with the same electrodes, and the mean value of the two P wave durations was used for further analysis.

Echocardiogram

The echocardiograms were recorded using a Vingmed GE Echopac System V, 1999, Norway with a 3.5-MHz probe during continuous ECG monitoring. All patients had a parasternal M-mode picture recorded, and most also had an apical four-chamber picture with a loop recorded. All

Table 1. Echocardiographic Parameters

LAD	Parasternal M-Mode
LSI	Four-chamber apical recording
LML	
RSI	
RML	
LAV	$\frac{4}{3} \times \pi \times \frac{\text{LAD} \times \text{LSI} \times \text{LML}}{8}$
RAV	$\frac{4}{3} \times \pi \times \frac{\text{RSI} \times \text{RML}}{8}$
TAV	RAV + LAV

This table demonstrates the echocardiographic parameters used in the study, the recordings from where they have been measured, and the formulas used to estimate the atrial volumes.

LAD = left atrial diameter; LSI = left superoinferior; LML = left mediolateral; RSI = right superoinferior; RML = right mediolateral; LAV = left atrial volume; RAV = right atrial volume; TAV = total atrial volume.

recordings were performed by trained doctors at the Department of Cardiology and were digitally stored on an optical disc for later analysis.

The size of the atria was estimated with different parameters: the left atrial anteroposterior diameter (LAD) was measured from the M-mode picture at the end of the T wave corresponding to the end of the atrial diastole, and from the apical four-chamber view the left superoinferior and

mediolateral diameters of both atria were estimated (Table 1 and Fig. 2). From the formula of the volume of an ellipse, the volumes of left atrial volume (LAV) and RAV were calculated, and the total atrial volume (TAV) was estimated from the sum of the two atrial volumes. Note that the superoinferior diameter was used twice in the formula for the RAV due to the lacking anteroposterior diameter of the right atrium. The analysis of the echocardiograms was performed by the same investigator (CJ) on a Power MAC computer linked to the Echopac System. This analysis was done blinded in relation to the SAECG analyses.

Statistical Analyses

Clinical and study characteristics were expressed as mean and standard deviation if normally distributed, and as median and range in the case of skewed data. First, we explored the correlation between the SAPWD and the different parameters for the atrial size. There was a linear relationship, and simple linear regression analyses were then performed with the SAPWD as the dependent variable and LAD, LAV, RAV, and TAV as explanatory variables. In each analysis, the measure of correlation

Figure 2. An echocardiographic four-chamber view demonstrating the parameters used for the estimation of the atrial volume. LAD = left atrial diameter; LSI = left superoinferior; LML = left mediolateral; RSI = right superoinferior; RML = right mediolateral; LAV = left atrial volume; RAV = right atrial volume; TAV = total atrial volume.

R^2 was estimated and the P value of no correlation was assessed.

The effect of one or more coexisting risk factors defined as age above 75 years, hypertension or congestive heart failure, and the most frequent medication on the TAV and the SAPWD was examined. In these analyses, only data from the patients with all echocardiography parameters available were used. Finally, the effect of medication on the SAPWD was examined.

A level of 0.05 was used for significance. All analyses were performed with SAS 8.2 statistical package programs (SAS Institute, Cary, NC).

RESULTS

During the inclusion period, 168 patients scheduled for elective echocardiography were screened. Of these, 47 were excluded due to other examinations scheduled directly after the echocardiography or lack of informed consent, 26 due to present supraventricular arrhythmia, 8 due to a high noise level on the SAECG, 6 due to serious concomitant diseases such as cancer and disabling stroke, 5 had a technically insufficient echocardiogram, 1 had a pacemaker, and 1 had Parkinson's disease. Thus, 74 patients were primarily included in the study.

However, only 48 patients (65%) had all four echocardiographic parameters of the atrial size measured in the echocardiogram; from 68 patients (92%) the LAD was obtained, and in 57 patients (77%) the RAV could be estimated. In the 48 patients (65%) with measurements of the LAV, all parameters were provided. All 74 patients had an SAECG, but patients without at least one echocardiography-derived parameter were excluded from the analysis. The clinical characteristics, the electrophysiological data, and the echocardiographic data appear in Table 2.

The plots of the correlation between the SAPWD and the different estimates of the atrial size are demonstrated in Figure 3A–D. Linear regression analysis showed that the correlation between the SAPWD and the LAD obtained from the M-mode recording was $R^2 = 0.11$, $P = 0.03$. However, when the LAV was estimated from the volume measurements in the four-chamber recording, the correlation was increased to $R^2 = 0.15$, $P = 0.009$. The correlation between the SAPWD and the RAV was $R^2 = 0.27$, $P = 0.0003$. The correlation between the SAPWD and the TAV derived from the sum of the estimated LAV and RAV showed a correlation

Table 2. Clinical and Demographic Characteristics in Study Patients

Number of patients (n)	74
Age (years) median (range)	63 (19–86)
Sex M/F (n)	41/33
Concomitant diseases (n)	
Ischemic heart disease	24
Hypertension	23
Congestive heart failure	9
Diabetes mellitus	11
Previous atrial fibrillation	3
Mitral valve regurgitation	4
Previous stroke	2
Medication at inclusion (n)	
ACE-I	20
Beta blocker	15
Calcium antagonist	16
ASA	32
Warfarin	14
Digoxin	4
Diuretics	33
Statin	12
Echocardiographic and signal-averaged electrocardiographic data	
Median (range)	
Left atrial diameter (mm); n = 68	40.3 (27.0–53.2)
Left atrial volume (cm ³); n = 48	38.7 (11.0–66.7)
Right atrial volume (cm ³); n = 57	39.5 (13.4–105.6)
Total atrial volume (cm ³); n = 48	76.1 (24.4–122.9)
SAPWD (ms); n = 68	138.0 (101.0–210.0)

ACE-I = angiotensin-converting enzyme inhibitors; ASA = acetylsalicylic acid; SAPWD = signal-averaged P wave duration; ms = milliseconds.

coefficient $R^2 = 0.37$, $P < 0.0001$. Thus, the TAV had the highest correlation with the SAPWD.

Then, the effect of a coexisting risk factor defined as high age, concomitant hypertension, or congestive heart failure on the SAPWD and TAV was examined. In this study population, these risk factors did not affect the TAV or the SAPWD. Likewise, no significant effect of medication (angiotensin-converting enzyme inhibitors, beta blockers, or calcium antagonists) was found.

DISCUSSION

Major Findings

We found that the SAPWD was significantly correlated to the size of the atria. Furthermore, this

Figure 3. (A) Regression plot of the SAPWD versus LAD, $R^2 = 0.11$, $P = 0.03$. (B) Regression plot of the SAPWD versus LAV, $R^2 = 0.15$, $P = 0.009$. (C) Regression plot of the SAPWD versus RAV, $R^2 = 0.27$, $P = 0.0003$. (D) Regression plot of the SAPWD versus TAV, $R^2 = 0.37$, $P < 0.0001$. When the volumes of the atria are estimated, the correlation between intra-atrial conduction time and atrial size increases. SAPWD = signal-averaged P wave duration; LAD = left atrial diameter; LAV = left atrial volume; RAV = right atrial volume; TAV = total atrial volume.

correlation was stronger when estimates of the atrial volume were applied with the closest relation between the TAV and the SAPWD. The presence of a risk factor defined as high age, concomitant hypertension, or congestive heart failure was not associated with prolonged SAPWD or enlargement of the atria.

The demonstrated significant correlation between the atrial size and the interatrial conduction time is partly in accordance with the results reported by Ishimoto and coworkers.¹⁰ They found that in healthy control persons, the filtered P wave duration measured with SAECG was significantly correlated with the LAV

and TAV, but not with the RAV, when atrial size was calculated by cine magnetic resonance imaging.

Our finding of a closer relation between the SAPWD and the volume parameters of the atrial size favors the hypothesis of a true association between size and conduction time, and indicates that the endocardial area of the atria is important. De Ponti et al. have demonstrated that in the human atria the propagation of the sinus impulse is reproducible, that it follows a typical pattern, and that the time of the impulse propagation through the atria equals the duration of the conduction from the sinus node area to an area near the coronary

sinus.¹¹ Accordingly, we find it important that inclusion of the RAV appears to strengthen the correlation analyses.

Until now, only little attention has been given to the right atrium, and often, only the LAD is available in clinical routine. Ehrlich et al. studied the relationship between clinical and echocardiography-derived parameters and atrial activation; they found significant correlation between left atrial size and the SAPWD, but in multivariate analysis age was the only independent factor affecting the SAPWD.¹² Our finding of stronger correlation between size and electrophysiological parameters might be due to the inclusion of the right atrial size.

Pressure or strain changes may be even closer and dynamically related to electrophysiological changes than size estimates. In a study of patients with obstructive pulmonary disease, Asad, Johnson, and Spodick reported that using magnifying technique in the measurement of the P wave amplitude from a standard ECG, the P wave amplitude decreased once the acute exacerbation of bronchitis subsided; thus, the results indicated a relation between the P wave parameters and the right atrial strain.¹³ Moreover, Vainer et al. have demonstrated in a small study of eight healthy men that subtle changes in the P wave morphology could be detected by SAECG after volume changes obtained through infusion of plasma expander and later sublingual administration of nitroglycerin.¹⁴

The neutral effect from coexisting risk factors in our study, including high age, on the SAPWD and the TAV could be due to the mixed and relatively small study group; moreover, the study was not designed to show such effects. Conversely, Madu et al. have reported that patients with hypertension, especially blacks, have prolonged atrial conduction time using the SAECG technique.⁸ Regarding high age, two studies by Babaev et al. and Ehrlich et al. have demonstrated significant correlation between age and the SAPWD.^{12,15}

Study Limitations

The neutral effect of concomitant diseases, high age, and medication on atrial size and electrophysiological parameters may be due to the low number of patients with all echocardiography parameters available for analysis. Nevertheless, regarding

simple correlation analyses, a sample size of 48 or higher is acceptable.

The echocardiograms were recorded by different observers; however, all of them were competent and carefully instructed to follow the protocol. All recordings were analyzed by the investigator CJ.

Many patients were excluded due to the need for an SAECG directly after the echocardiogram in our protocol. This reduced the number of included patients; conversely, time-dependent variance and variation due to hemodynamic changes were minimized.

In conclusion, the intra-atrial conduction time was significantly correlated to atrial size parameters; most closely when the TAV was used. Thus, it appears that prolonged SAPWD is partly caused by a longer pathway for the electrical impulse, and that the size of the right atrium is important for the global atrial conduction time.

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