Improved Estimation of Left Ventricular Hypertrophy

Models Based on Data from ABPM-24h and on Arterial Compliance as Alternatives to Using Echocardiograms

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When considering the possibility of requiring a patient to take an additional exam, the doctor decides based on the amount of information that this exam will give to him or her about the patient's health and on the costs involved with this procedure. For that reason, it was decided to study the data obtained from a 24-hour ambulatory blood-pressure monitoring (ABPM-24h) in order to extract more information from it than is usually done.

An important variable that indicates a well-functioning heart is the left ventricular mass index (LVMI). The test that measures this variable is the echocardiogram, which is considered as the "gold standard" exam. But the costs involved with this exam are high when compared to the costs of performing an ABPM-24h. In his doctoral thesis [2], Chaves proposed two statistical models to approach the problem: a multiple regression model [3] to quantify the LVMI and a logistic regression model [3] to estimate the probability of a person having left ventricular hypertrophy (LVH). In his work, Chaves said that if other variables, especially the pulse wave velocity (PWV), were included in his models, their predictive power could be improved.

This article presents the two models for estimating the left ventricular hypertrophy. An estimation of the arterial compliance based on a first-order approximation of the pulse cycle and on the systolic stroke volume is proposed. By including this variable in the models elaborated by Chaves, a substantial improvement in their power is obtained.

Methodology

A statistical analysis of the same data collected and used by Chaves was done. The 101 individuals in the sample were living in the metropolitan area of Recife, Brazil.

The sample was designed so that it encompassed the largest number of possible individuals' profiles. The sample was subdivided in terms of gender, age, hyper-

Table 1. Descriptive Statistics of the Main Variables of the Sample.

	Average	Median	Min	Max	STDS
Gender	0,475248	0	0	1	0,501878
Age	53,17822	53	21	81	15,09596
Weight	73,24257	73	48	115	14,79026
Height	1,635644	1,64	1,4	1,85	0,097646
Waist	93,11881	93	70	121	11,81972
hip	101,0099	99	84	149	10,87336
hypertensive	0,73	1	0	1	0,4448
CORNELL	0,19	0	0	1	0,394277
CORNELLC	19,245	18,5	4	53	8,23901
MAPSAVG01	0,5050	1	0	1	0,50247
PSSAVG	126,7054	124,5151	95,71272	177,4863	15,75875
C_{DAY}	1.686315	1.709280	0.801784	2.998160	0.483540

tension type, and the presence or not of LVH to the echocardiogram (see Table 1).

The following variables were collected for each individual:

1) **Anthropometric.** Gender, age (years), weight (kg), height (m), waist (cm), hip (cm).

2) **Biochemical series.** Fast glucose, postprandial glucose, creatinine, potassium, sodium, total cholesterol, HDL cholesterol, LDL cholesterol, VLDL cholesterol, triglycerides, uric acid.

3) **Hormones and enzymes.** Angiotensin Converting Enzyme, renin, adrenaline, noradrenaline, and dopamine.

4) **Electrocardiogram.** Cornell Index and Continuous Cornell Index (mV).

5) **Echocardiogram.** Transverse axis, cardiac sept, wall of the left ventricle, mass of the left ventricle, mass index (LVMI), mass volume, dimension of the left atrium, diameter of the aorta, final diastolic volume, final systolic volume, ejection volume, ejection fraction, E-wave, A-wave, duration of the diastole, and duration of the isovolumetric recovery.

6) **Ambulatory blood pressure monitoring (ABPM-24h).** Three ABPM-24h exams were taken within intervals from 8 to 15 days among them. From these data the hourly average values of the following variables were estimated: mean arterial blood pressure (MAP), the systolic pressure (P_S), the diastolic pressure (P_D), and the cardiac frequency(F_C).

The Calculation of the Arterial Compliance

The arterial pulse cycle is the value of the aortic arterial pressure along the systole and diastole. On average, for large world samples, the maximum value of the pressure, denominated systolic pressure, is 120 mm Hg and the minimum value, diastolic pressure, is 80 mm Hg, and the duration of the pulse is 1/80 min. Figure 1 shows the dynamics of the arterial pressure.

Note that in clinical practice, generally, one has access only to the values of the systolic pressure, diastolic pressure, and cardiac frequency, and not to the shape of the cardiac pulse waveform. A first-order approximation is used here, following [4], as shown in Fig. 2.

This model can be described as a first-order differential equation:

$$\frac{dP}{dt}+\frac{1}{RC}P=\sum_{i}\delta(t-iT) \qquad (1)$$

where R is the average arterial vascular resistance of the system and C is the average arterial vascular compliance of the system. The solution of the homogeneous equation (zero input) is:

$$P(t)=P(0)\exp\left(\frac{-t}{RC}\right). \qquad (2)$$

Considering that the systole begins at $t=0$, $P(0)$ is the systolic arterial pressure, and therefore for $t=T=1/F_C$, $P(T)$ is equal to the diastolic arterial pressure. So, Eq. (2) can be written as:

$$RC=\frac{1}{F_C\cdot\ln\left(\frac{P_S}{P_D}\right)}. \qquad (3)$$

An estimate for the parameter RC can be obtained from Eq. (3), using the ABPM-24h data. Now remains the task of isolating the compliance (C). In order to do this, the approach was to estimate the arterial resistance first, using the available data. Multiplying the systolic stroke volume (obtained in the echocardiogram) by the individual's average heart rate during the day (average between 07:00 hours and 19:00 hours, which is the period when the echocardiogram was taken) estimated from the ABPM-24h data, an estimate was obtained for the blood flow:

$$Q_{\text{DAY}}=V_S\cdot F_{C_{\text{DAY}}}. \qquad (4)$$

But it is also known that:

$$MAP_{\text{DAY}}=Q_{\text{DAY}}\cdot R_{\text{DAY}}. \qquad (5)$$

An estimate for the arterial vascular resistance will be given then by:

$$R_{\text{DAY}}=\frac{MAP_{\text{DAY}}}{V_S\cdot F_{C_{\text{DAY}}}}. \qquad (6)$$

Finally, the arterial vascular compliance will be given by separating it from the parameter RC:

$$C_{\text{DAY}}=\frac{RC_{\text{DAY}}}{R_{\text{DAY}}}. \qquad (7)$$

Note that all estimates are made for an average of the variables during the period of the day when the echocardiogram was taken.

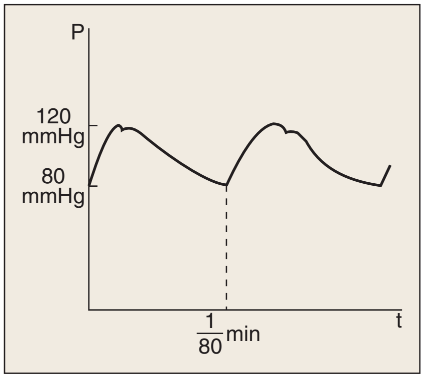
The inclusion of the arterial compliance in the predictive models increases the performance of these models in predicting the LVH.

Diagnostic Models Obtained Without the Arterial Compliance

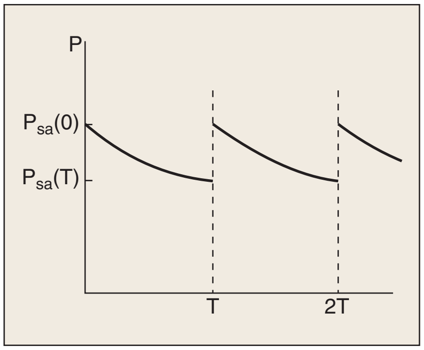
In this section we will describe the models obtained by Chaves [2] for evaluation of the LVH.

Logistic Regression

This model predicts the individual's probability of having hypertrophy of the left ventricle based on the results of the ABPM-24h, on some anthropometric variables, and on the electrocardiogram.



1. Aortic arterial pressure during the systole and diastole.



2. First-order approximation for the aortic arterial pressure during the systole and the diastole.

Table 2. Classification of Cases (2×2 table).

Observed	Predicted 0	Predicted 1	% Correct	
0	45	7	86,53846	Specificity
1	8	40	83,333340	Sensibility

Table 3. The ANOVA Table.

	Sums of Squares	df	Mean Squares	F	p-level
Regression	6.27854	4	1.569634	34.89737	0.000000
Residual	4.27296	95	0.044979		
Total	10.55150				

If an estimate for either the arterial resistance or the arterial compliance were available, a good evaluation of the LVH could be made with a less expensive apparatus than the echocardiogram.

This model included the age of the patient, the Cornell index (CORNELL), and the average of the mean arterial pressure during the sleeping time dichotomized about its median value (MAPSAVG01) (0 for those below the median and 1 for those above or equal to the median). It has an odds ratio of 21:1, a sensibility of 81%, and a specificity of 83% when compared with the considered gold standard (the echocardiogram).

Multiple Linear Regression

The degree of LVH, as measured by the LVMI, can be evaluated by the multiple linear regression model presented in [2]. This model included the age of the patient, his/her waist/hip relation, the continuous electrocardiographic Cornell index (CORNELLC), and the average of the systolic blood pressure during the sleeping time (PSSAVG).

This model explained 47% of the variability of the neperian logarithm of the LVMI data.

It can be noted that, in these two models, the variables of the ABPM-24h that represent the sleeping time are more significant for the evaluation of the LVH. It can be inferred then that, during that period, the individual's pressure levels are less altered by external stimulus than during the day. Then, those nocturne values are more representative of the dynamics of the arterial system. Knowing that, wouldn't it be worth trying to increase the number of measures taken during the night, despite the increase in the disturbance caused to the patient's rest?

In his thesis, Chaves points out that if new variables were included in his models, one could increase the odds ratio of the logistic regression and the explanatory power of the multiple linear regression. He suggested that the PWV could be a good variable to be included in the models. As the PWV has a close association with the arterial compliance [1], it will be seen that an increase in the odds ratio of the logistic regression and of the explanatory power of the multiple linear regression can be obtained when this new variable is included in the model.

Results

The Characterization of the Sample

Using the variables involved in the construction of the models, the descriptive statistics shown in Table 1 characterizes the sample.

Starting from the results found in [2], either for the logistic or for the multiple linear regression model for LVH, an attempt was made to include more explanatory variables in those models. The PWV was not available in the database, and so, the arterial compliance, a strongly related variable, was used instead.

Predictive Models Including the Arterial Compliance

By adding the compliance as an explanatory variable in the models presented in [2], a substantial improvement in the odds ratio of the logistic regression model and in the determination coefficient of the multiple regression model was obtained.

Logistics Regression

An odds ratio of 32:1, with a sensibility of 83% and a specificity of 87%, was achieved with the inclusion in the model of the arterial compliance during the day as an additional explanatory variable. The model is then:

$$P(HVE) = \frac{exp(-11{,}952 + A + B)}{1 + exp(-11{,}952 + A + B)} \qquad (8)$$

where $A = 0{,}134 AGE + 1{,}974 CORNELL$ and $B = 2{,}623 MAPSAVG01 + 1{,}689 C_{DAY}$.

Multiple Linear Regression

With the inclusion of the arterial compliance during the day in the model, the variable waist/hip relation was excluded from the model because it turned out to be not statistically significant. Then, the new explanatory power of the new model obtained with the arterial compliance and without the waist/hip relation becomes equal to 60%. The model obtained is:

$$\begin{aligned} IMVE = \exp(&2{,}148 + 0{,}010 AGE \\ &+ 0{,}009 CORNELLC \\ &+ 0{,}011 PSSAVG + 0{,}322 C_{DAY}). \end{aligned} \qquad (9)$$

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Conclusions

- The inclusion of the arterial compliance in the predictive models increases the performance of these models in predicting the LVH.
- This result also contributes to strengthening the first-order approximation of aortic arterial pressure pulse.
- The value of the arterial compliance was obtained with the aid of the result from the echocardiogram, but if an estimate for either the arterial resistance or the arterial compliance were available, a good evaluation of the LVH could be made with a less expensive apparatus. Devices for measuring the PWV, a variable correlated with arterial compliance, are already available. On the other hand, arterial resistance could be measured by estimating the oxygen concentration in the venous blood, as suggested by Hoppensteadt [4].

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