Statistical Variations of Heart Orientation in Healthy Adults

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Abstract

The orientation of the heart in the chest impacts the shape and amplitude of surface ECG signals. It is also key information in electrocardiographic imaging (ECGI), where a model of the heart and torso is required. In this study we seek to analyze statistical relations between heart orientation and several easily available patient characteristics. Heart orientation data were obtained from an MRI database of 185 healthy adults. Relations with sex, height, weight (collected from case reports forms) and chest circumference (extracted from the images) were analyzed using univariate and multivariate linear regression. Chest circumference was found to be the best single predictor of heart orientation, and simple formulas were determined for its estimation. The proposed heart orientation statistical model might be used for selecting a torso/heart model from an existing database; this approach might allow ECGI techniques to be integrated into an ECG device.

1.   Introduction

In electrocardiographic imaging (ECGI), a model of the heart and torso is required in order to reconstruct cardiac activation and recovery maps from surface ECG measurements [1], [2]. Such models can be obtained from imaging (e.g. MRI or CT); alternatively, when no imaging data from the patient is available, one may use a generic torso model or a model selected from an existing patient database [3]. The latter approach is of particular interest as it would allow ECGI techniques to be integrated into an ECG device. However criteria for selecting a plausible model need to be defined based on easily available patient characteristics. When selecting a torso model for ECGI, the position, size and orientation of the heart in the chest are key information. It has been shown that heart position and orientation can impact both the forward model and the inverse solution [4].

In a recent study [5], the heart size in 622 normal subjects was shown to be correlated with sex, age, height and weight. The authors proposed a multivariate linear model for estimating the heart size from these easily available patient data. Besides the size, the heart orientation remains an important degree of freedom in the torso model.

In this study we investigated the statistical relations between heart orientation and several easily available patient characteristics, including sex, age, weight, height and chest circumference. An MRI database of healthy adults was used for that purpose.

2.   Methods

2.1.   Definition of heart orientation angles

Heart orientation in the chest was described by two axes (see Fig. 1a): (i) the principal axis (or axis 1) was defined to be the longitudinal axis of the left ventricle, pointing towards the apex; (ii) the secondary axis (or axis 2) was defined to be, within a mid-cavity short-axis slice, the axis going from the center of the left ventricular (LV) cavity to the point of the right ventricular (RV) wall with maximal curvature (junction between the RV free wall and RV inferior wall).

The following angles were defined in order to describe the orientation of the two axes of the heart (see Fig 1b), using patient orientation terminology (S=superior, I=inferior, A=anterior, P=posterior, R=right, L=left):
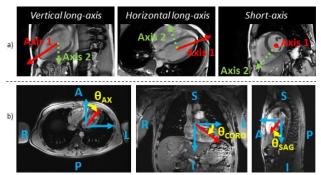

Figure 1 Definition of heart axes (a) and angles (b)

- θ_{AX}^1 (respectively θ_{AX}^2): angle in degrees formed by the principal (respectively secondary) heart axis in the axial plane (0° = P-A direction)
- θ_{SAG}^1 (respectively θ_{SAG}^2): angle in degrees formed by the principal (respectively secondary) heart axis in the sagittal plane (0° = S-I direction)
- θ_{CORO}^1 (respectively θ_{CORO}^2): angle in degrees formed by the principal (respectively secondary) heart axis in the coronal plane (0° = R-L direction)

2.2. Cardiac MRI database

Volunteers underwent an MRI scan on either a 1.5T or a 3T Signa HDxt scanner (General Electric, Milwaukee, USA) at our institution between 2008 and 2016, as part of a general ethics protocol designed to test novel technical developments in MRI. This study was approved by an ethics committee and all subjects gave written informed consent. The volunteers were all adults with no selection criteria other than usual MRI contra-indications. All data were stored in our research database system ArchiMed [6].

Within this database, 185 subjects (122 males) who were imaged with cardiac scans in the 3 main anatomical planes (short axis, horizontal long axis and vertical long axis) were extracted.

The heart orientations were derived from the coordinates of the imaging planes prescribed by the radiographer (short-axis, horizontal and vertical long axes): the principal axis was calculated as the normal to the short-axis planes and the secondary axis was calculated as the intersection of short axis and horizontal long axis planes (see example in Fig. 1). The volunteers' sex, age, weight and height were collected from the case report forms.

2.3. Extraction of chest circumference

Chest circumference was estimated from the acquired images using the low resolution coil calibration scan ("ASSET calibration"). This scan consists of a 2D multi-slice gradient echo sequence with the following typical parameters: field of view = 480 mm, acquisition matrix = 32x32 (reconstructed to 64x64), 30 to 50 contiguous slices covering the whole torso, slice thickness = 10 mm, in-plane resolution = 7.5 mm.

The processing steps included (see Fig. 2): (i) thresholding to create a body mask and a background/air mask; (ii) morphological operations to create a lung mask (identified as large air regions inside the body mask); (iii) selection of the lowest slice contained in the lung mask; (iv) extrapolation of the body mask contour in the arm regions (on right and left edges) with a spline curve to calculate the chest circumference in cm.

2.4. Statistical model

Firstly, univariate linear regression analysis was performed. Each heart orientation angle was subjected to a robust linear fit (statistics toolbox of Matlab) with respect to each parameter of the patient metadata (age, weight, height, chest circumference), for males and females separately. Then a multivariate linear regression was performed with all the metadata used as variables for predicting each angle.
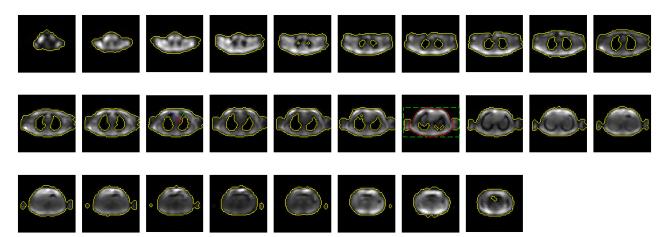

Figure 2 Exemplary low resolution images used for extracting chest circumference: body/lung masks were obtained by thresholding (yellow contours); then the lowest slice containing lung was selected (green rectangle); finally chest circumference was estimated from the body contour after a spline extrapolation in the arm regions (red contour).

3. Results

3.1. Heart orientation statistics

Statistics of the population are summarized in Table 1. Standard deviations of the heart orientation angles, over the population, ranged between 9 and 32 degrees.

Table 1 Statistics of heart orientation in our volunteer database

	Males	Females
Number	122	63
Age (years)	32.6 (±11.5)	29.6 (±10.8)
Height (cm)	179.0 (±6.8)	165.7 (±7.7)
Weight (kg)	74.2 (± 9.1)	61.2 (±11.5)
Chest circumference (cm)	107.7 (± 6.7)	103.4 (±9.3)
θ^1_{AX} (degrees)	49.6 (±8.8)	49.5 (±9.0)
θ^1_{CORO} (degrees)	35.7 (±10.3)	36.9 (±10.1)
θ^1_{SAG} (degrees)	49.7 (±12.2)	48.8 (±10.6)
θ^2_{AX} (degrees)	51.6 (±22.0)	49.6 (±17.2)
θ^2_{CORO} (degrees)	149.6 (±32.2)	151.6 (±27.2)
θ^2_{SAG} (degrees)	79.4 (±30.1)	77.0 (±29.9)

3.2. Univariate linear regression

Example linear fits obtained for the regression of the principal heart orientation axis in the coronal plane (θ^1_{CORO}) are shown in Fig. 3.

Detailed results for all angles are gathered in Table 2. The univariate analysis showed that the best single predictor of heart longitudinal axis is chest circumference, both for males and females. The most significant correlations were found for θ^1_{SAG} and θ^1_{CORO} angles (p<0.003), with goodness-of-fit R^2 = 0.14 to 0.44.
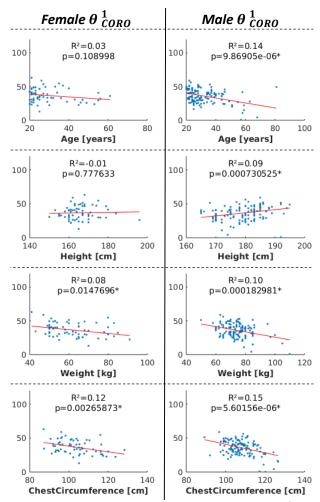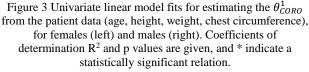
3.3. Multivariate linear regression

In the multivariate analysis of the form $\theta^{1/2}_{AX/SAG/CORO} = a0 + a1.Age + a2.Height + a3.Weight + a4.ChestCircumference$, the best fit of the data was found for θ^1_{SAG}, with R²=0.43 in males and R²=0.21 in females. However chest circumference was not found to be an independent predictor (p>0.1 in all cases).

4. Discussion

For males, the univariate analysis shows that the best single predictor of heart principal axis orientation is the chest circumference. Correlations were significant for axial, coronal and sagittal angles. The best predictions are found for the sagittal and coronal angles, while the axial angles seem less predictable. For the secondary axis, correlations were not statistically significant. The circumference was not found to be an independent predictor in the multivariate analysis, meaning that chest circumference shares some information for predicting

Figure 3 Univariate linear model fits for estimating the θ^1_{CORO} from the patient data (age, height, weight, chest circumference), for females (left) and males (right). Coefficients of determination R^2 and p values are given, and * indicate a statistically significant relation.

orientation with age, height and weight.

For females, chest circumference is also the best single predictor, but it was significant for both principal and secondary axes of the heart. Correlations were significant for angles in coronal and sagittal planes only. Again, in the multivariate analysis, it was not found to be an independent predictor.

This study has limitations that should be mentioned. Our volunteer population contained more males than females, and the subjects were relatively young, with a high proportion of university students. We did not check that these subjects actually had no cardiopathy, but we assumed the majority of them was healthy.

The accuracy of the heart orientation angles was limited by the reproducibility of the manual placement of the imaging planes by the radiographers. While the longitudinal axis is fairly easy to define on the anatomy, the secondary axis is not always placed in the same way by different radiographers although they are instructed to

Table 2 Univariate regression models for heart orientation estimation: $Y = a0 + a1.X$

Y	X	Males			Females		
		a0	a1	p value	a0	a1	p value
θ^1_{AX} [degrees]	Age[years]	53.926	-0.134	0.064	44.901	0.162	0.15
	Height[cm]	61.209	-0.065	0.60	80.814	-0.188	0.23
	Weight[kg]	61.302	-0.159	0.083	60.982	-0.187	0.069
	ChestCircumference[cm]	78.827	-0.272	0.027*	60.016	-0.101	0.44
θ^1_{CORO} [degrees]	Age[years]	47.635	-0.367	9.9E-06*	42.501	-0.197	0.11
	Height[cm]	-45.347	0.456	0.00073*	28.413	0.050	0.78
	Weight[kg]	64.861	-0.390	0.00018*	53.847	-0.282	0.015*
	ChestCircumference[cm]	103.675	-0.628	5.6E-06*	79.903	-0.418	0.0027*
θ^1_{SAG} [degrees]	Age[years]	36.111	0.420	6.9E-06*	45.311	0.117	0.37
	Height[cm]	114.337	-0.364	0.016*	20.907	0.168	0.36
	Weight[kg]	8.940	0.550	2.2E-06*	19.022	0.482	2.7E-05*
	ChestCircumference[cm]	-49.987	0.925	1.0E-09*	-6.163	0.529	0.00025*
θ^2_{AX} [degrees]	Age[years]	44.822	0.124	0.059	56.637	-0.232	0.15
	Height[cm]	23.424	0.143	0.048	26.727	0.139	0.54
	Weight[kg]	42.235	0.090	0.047	54.158	-0.073	0.63
	ChestCircumference[cm]	36.901	0.111	0.047	68.884	-0.184	0.32
θ^2_{CORO} [degrees]	Age[years]	163.063	-0.082	0.45	161.785	-0.090	0.59
	Height[cm]	110.604	0.278	0.45	112.882	0.279	0.25
	Weight[kg]	156.982	0.045	0.44	140.718	0.305	0.051
	ChestCircumference[cm]	178.338	-0.167	0.45	115.561	0.420	0.034*
θ^2_{SAG} [degrees]	Age[years]	80.313	-0.276	0.15	72.520	-0.091	0.75
	Height[cm]	23.259	0.264	0.17	50.370	0.113	0.77
	Weight[kg]	80.787	-0.137	0.15	37.068	0.529	0.034*
	ChestCircumference[cm]	106.669	-0.330	0.14	0.822	0.658	0.029*

* indicate statistically significant linear relation

follow the same guidelines in our institution. This may explain the larger variability of the secondary axis orientation angles and the less significant results compared to the principal axis. Respiratory motion is another source of variability for all these angles and was not taken into account here.

One possible use of the results presented in this study would be to create a model database for ECGI containing a reduced number of elements, yet covering the same range of angles as in the present population. Then for a given new subject/patient, one may use one of the proposed statistical models in Table 2 (our results suggest using chest circumference) to predict the heart orientation angles, and select the closest model from the database. If this model does not fit the data, then one may chose the second closest model, and so on.

5.   Conclusion

Chest circumference is the best predictor of heart orientation. It is an easy-to-use index which embodies information from height and weight. It might be used to select a heart/torso model from a database for ECGI.

Acknowledgements

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