workload up to the exhaustion. Results (*CO* and *SV* in relation to VO_2 [l/min]) are presented in Fig. 3 for men and in Fig. 4 for women. Higher cardiac output as a function of higher stroke volume plays important role in increased transporting capacity of blood for oxygen and enables well trained subject to achieve significantly higher physical performance.

4. Discission

A totally noninvasive determination of *CO* and *SV* during exercise would be very useful in healthy subjects as well as in patients with various degrees of cardiac insufficiency. This can provide a simple and low-cost assessment of cardiac function in response to exercise. Although it is generally assumed that *CO* increases linearly with VO_2, the pattern of variation in VO_2 and *CO* as maximal O_2 consumption is approached has not been extensively investigated and may vary among individuals. According to Frank-Starling mechanism the amount of blood that the heart pumps works up to a limit of 3 times the normal cardiac output. When the peripheral tissues demand excessive amounts of blood flow, the nervous signals increase cardiac output [2, 3, 4]. Our examples document that the time course of these changes is very similar in the subjects of very different cardio-respiratory fitness level. However, these findings still need to be proved in the groups of subjects of different lifestyle, different athletic background, men and women, and even patients. Our pilot study indicates that top level endurance athletes can reach outstanding values of *CO* and *SV* at about 40 l/min and 200 ml/beat respectively. Hence, this method seems to offer another useful data to evaluate cardio-respiratory capacity and adaptation to physical activity and/or inactivity.

5. Conclusions

A variety of cardiac output estimators have been developed over the past hundred years. Stringer et. al. [3] proved that the data of oxygen uptake during exercise can be used to estimate noninvasively cardiac output. They used Fick´s principle for *CO* estimation during exercise, and these results correlated with direct VO_2 measurements. Using their results we calculated *CO* in our subjects [4]. Estimation is noninvasive and can be used during the stress test.

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Body Surface Potential Mapping Data Conversion Method

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Abstract. *In body surface potential mapping, data conversion can be required whenever merging data sets taken by slightly different data acquisition systems. In this case, we face with a kind of conversion problem. This paper describes a method for solving the problem according to the least-square principle, so the datasets of physically different body surface potential mapping systems become compatible, thus their records can be handled the same way.*

Keywords: ECG, Body surface potential mapping systems, different electrode distribution, Data conversion

1. Introduction

High spatial and temporal resolution body surface potential mapping play an important role in sudden cardiac death risk assessment. These elaboration of decision rules require a high number of validated measurements. To achieve the statistically significant number of records, pooling of data bases recorded in different groups is a realistic approach. However, if the electrode layouts are not strictly identical in the cooperating groups, a measurement data conversion is needed for making the two systems compatible. In the following section, a method will be described for solving this problem with the help of our example, done at the Department of Electrical Engineering and Information Systems, University of Pannonia.

2. Subject and Methods

In the framework of our scientific cooperation with the Polish research group led by Professor Roman Maniewski we had to make compatible the records taken in Hungary and Poland. Since the Polish research group uses a slightly different lead arrangement, we had to elaborate the conversion method.

The two lead arrangements

The lead arrangements of our and the Polish body surface potential acquisition system is shown in Fig. 1 and Fig. 2.

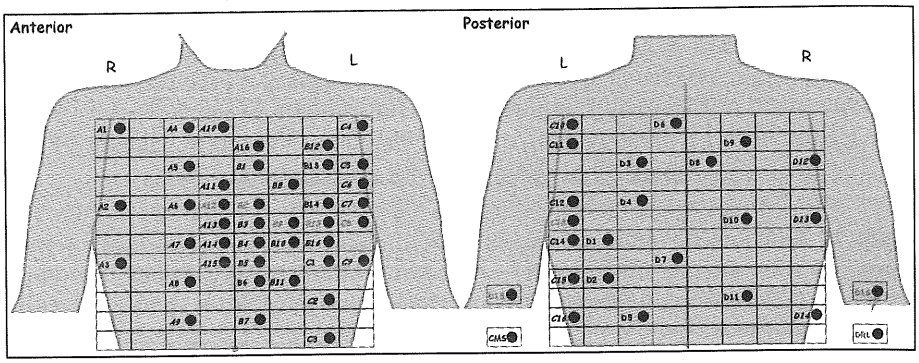


Fig. 1. Electrode positions of our Biosemi Mark-8 body surface potential mapper. Electrodes A1-D14 are on the torso, D15 is on the left arm and D16 is on the right arm. The leads are unipolar (reference is the WCT) [1].

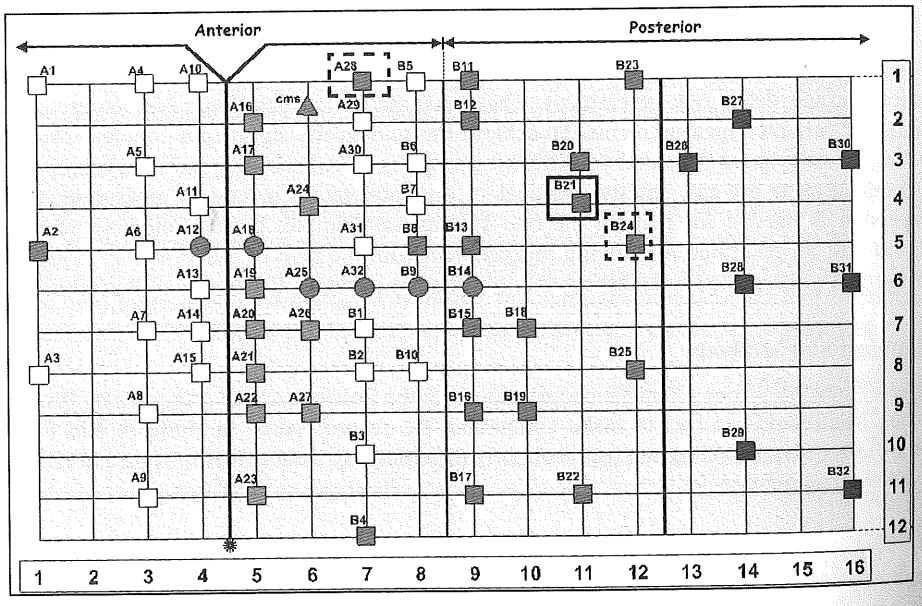


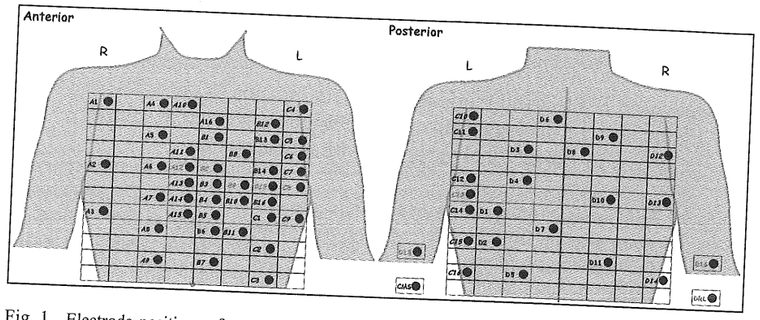
Fig. 2. Electrode positions of the Polish body surface potential mapper and the difference between the electrode locations of the two systems. Dashed frames mark the two leads missing from our system and solid frame signs the channel which is one unit higher than the corresponding D4 channel in our system. The other 61 leads are in the same positions regarding the two systems [2].

Principle of the method

There is a method based on least squares for estimating unknown lead data from known ones. The method was published by Robert L. Lux, et al. [3]. Its principle is as follows:

$$\phi_{est} = T \cdot \phi_m \tag{1}$$

where



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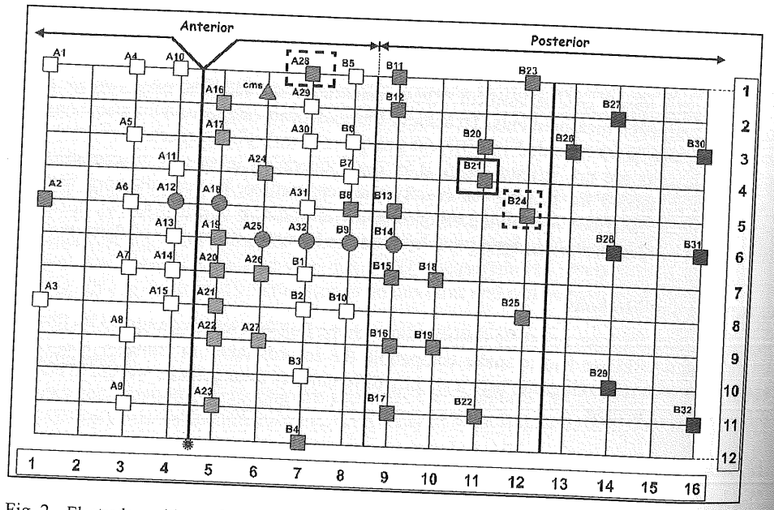

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where

φ_{est} : $k \times n$ matrix of estimated leads
φ_m : $m \times n$ matrix of measured leads
T : $k \times m$ estimating matrix
k : number of estimated leads
m : number of measured leads
n : number of sampling points

To determine T we need a covariance matrix K, regarding all channels (both measured and estimated). T is defined as follows:

$$T = K'_{est} \cdot K_m^{-1} \tag{2}$$

where

K_{est} : $m \times k$ segment of K regarding estimated leads

K_m : $m \times m$ segment of K regarding measured leads

We searched for a method for estimating our D4 lead from the 61 common leads (see Fig. 2), so we would be able to get the same 62 leads from the Polish records that we have. The steps of finding this method can be seen below in detail.

Determinating K

The more measurements we use, the more accurate our estimate will be, so we concatenated 52 records of our measurements considering leads A1-D14. This way we got a 62 × 10982400 matrix. Then we interpolated this data to 192 lead, so the matrix became 192 × 10982400. After that we calculated the covariance matrix K (192 × 192):

$$K = \begin{bmatrix} \begin{bmatrix} k_{1,1} & k_{1,2} & \cdots & k_{1,62} \\ k_{2,1} & k_{2,2} & \cdots & k_{2,62} \\ \vdots & \vdots & \ddots & \vdots \\ k_{62,1} & k_{62,2} & \cdots & k_{62,62} \end{bmatrix} & \begin{bmatrix} k_{1,63} & k_{1,64} & \cdots & k_{1,192} \\ k_{2,63} & k_{2,64} & \cdots & k_{2,192} \\ \vdots & \vdots & \ddots & \vdots \\ k_{62,63} & k_{62,64} & \cdots & k_{62,192} \end{bmatrix} \\ \begin{bmatrix} k_{63,1} & k_{63,2} & \cdots & k_{63,62} \\ k_{64,1} & k_{64,2} & \cdots & k_{64,62} \\ \vdots & \vdots & \ddots & \vdots \\ k_{192,1} & k_{192,2} & \cdots & k_{192,62} \end{bmatrix} & \begin{bmatrix} k_{63,63} & k_{63,64} & \cdots & k_{63,192} \\ k_{64,63} & k_{64,64} & \cdots & k_{64,192} \\ \vdots & \vdots & \ddots & \vdots \\ k_{192,63} & k_{192,64} & \cdots & k_{192,192} \end{bmatrix} \end{bmatrix} = \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix} \tag{3}$$

The data is sorted like leads 1-62 are the leads before interpolation and leads 63-192 are the additional ones. Considering Fig. 1 it means, that lead 1 is A1, lead 2 is A2, ... and lead 62 is D14. And for the additional ones: lead 63 is the empty cell just below A1, lead 64 is two cells below A1, ... and finally lead 192 is just below D14.

Note that interpolation was unnecessary for this progress (only K_{11} will be used below), but we did it for further applicability.

Determinating K_m and K_{est}

K_m is quadratic and it represents the measured data, so we have to choose it so that it shall contain the covariances of the leads that will be measured (known) in the future. In this case

the measured leads will be the 61 common leads, thus K_m will be 61 × 61. Considering Fig. 2 and Eq. 3 it can be seen that the matrix we are looking for is almost the same as K_{11} (62 × 62). The only difference is, that K_{11} contains the data of D4 too. It poses a problem, because that is the lead we would like to estimate. Since the covariances of D4 are in the 52th row and column, we can simply remove them, and the result will be K_m.

As written above, K_{est} is an $m \times k$ matrix containing the covariances regarding estimated leads, where m is the number of measured leads and k is the number of estimated leads. Because we would like to estimate one lead, K_{est} will be 61 × 1. Due to the estimated lead will be D4, we can simply determine this matrix at the previously written K_m calculation: we have to remove the 52nd row from K_{11} first, then save the 52nd column as K_{est}, and remove the 52nd column from K_{11} after that.

Finally, substituting K_{est} and K_m to Eq. 2, T can be calculated.

3. Results

The covariance matrix was calculated from 52 measurements which means a relatively high population, therefore the estimation with the T matrix is accurate enough. Namely, the correlation between the estimated and measured data is 0.98.

4. Discussion

Whenever conversion has to be made between our and another "foreign" body surface potential mapping systems, a T matrix should be calculated as described above. During the calculation of the matrix, the "measured" data should represent the common channels of the two systems, while the "estimated" data mean the ones that exist in our system, but do not exist in the Polish one. The ones that appear only in the Polish system, can be simply neglected. After determination, the same T matrix can be used for any measurement of that particular device.

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