Precordial electrode placement in women

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Background. **Precordial ECG electrode positioning was standardised in the early 1940s. However, it has been customary for the V_3 to V_6 electrodes to be placed under the left breast in women rather than in the correct anatomical positions relating to the 4th and 5th interspaces. For this reason, a comparison between the two approaches to chest electrode positioning in women was undertaken.**
Methods. **In total 84 women were recruited and ECGs recorded with electrodes in the correct anatomical position and also in the more commonly used positions under the breast. As a separate study, 299 healthy women were recruited to study normal limits of leads V_3 to V_6 recorded with electrodes in the correct anatomical positions and compare them with published normal limits with electrodes in the more commonly used locations.**
Results. **It was shown that there was less variability with electrodes in the correct anatomical positions and that there were significant differences between the new limits of normality compared with the old established limits.**
Conclusion. **Expansion of the database and further analysis of the data is required to make a definitive recommendation with respect to precordial electrode placement in women. (*Neth Heart J* 2003;11:118-22.)**

Key words: EGG, precordial electrode, women, normal limits, ECG analysis

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The electrocardiogram still remains one of the most commonly used, if not the most commonly used, noninvasive investigative technique in medicine. It is well known that there can be significant day-to-day variation in ECG appearances, which have been quantified,[1] while the effect of using marked positions on the chest to minimise variation has also been assessed.[2] Studies have been undertaken on the effect of electrodes being placed one interspace too high or too low[3] but ultimately, there is no failsafe approach that can guarantee accurate electrode placement given the many variables involved, not the least of which is the training of the medical or technical staff involved in ECG recording. Indeed, medical staff have very little formal training and may often be called upon to record ECGs in the acute situation, out of hours, when no trained technician is available.

On the other hand, little attention seems to have been paid to the effect of electrode placement on ECG interpretation in women. In 1938, a committee of the American Heart Association and cardiologists representing the Cardiac Society of Great Britain and Ireland recommended initially standardising on one chest electrode position.[4] However, it was a subsequent paper published by the American Heart Association[5] which defined the positions now commonly used for recording the precordial leads V_1 to V_6. A supplementary report by this committee was also published in the following year.[6]

As is well known, the reference point for the positioning of precordial leads is the 4th intercostal space. V_1 and V_2 are positioned at this level and V_4 is defined as being placed at the intersection of the 5th intercostal space and the mid-clavicular line. V_3 is placed intermediate to V_2 and V_4 while V_5 and V_6 are positioned at the same level as V_4. The positioning of V_4 according to the above recommendations has proved problematic in women and technicians worldwide have commonly positioned this electrode underneath the left breast in women in the mid-clavicular line rather than strictly at the defined anatomical reference of the fifth intercostal space.

In an earlier publication aimed at technicians in the United Kingdom, it was suggested that precordial

Table 1. Mean R-wave amplitudes (mV) in V3 to V6 according to location.

	Lead			
	V_3	V_4	V_5	V_6
On breast	0.686mV	0.950mV	1.251mV	1.208mV
Below breast	0.720	0.978	1.132	1.074
Mean difference	0.034	0.028	-0.119	-0.134
95% CI (below, on)	0.007, 0.060	-0.009, 0.065	-0.152, -0.087	-0.160, -0.108
P value	0.01	0.14	<0.01	<0.01

CI=confidence interval.

electrodes should be placed underneath the breast.[7] On the other hand, Rautaharju et al.[8] have advocated that electrodes should be placed on top of the breast in keeping with the strict anatomical recommendations.

In addition, one of the authors (PWM) had the subjective impression that poor R-wave progression was more prevalent in females than males, leading to more diagnoses of possible anterior myocardial infarction. One possible reason for this might be the inaccurate positioning of V_3 to V_5 in women.

The question which had to be asked, therefore, was which is the more reliable position for electrode placement, i.e. one that could lead to more consistent and accurate recording? Alternatively, the question might be asked as to whether it really made any difference to ECG measurements if electrodes were placed on, rather than below, the breast.

We set out to examine the problem and consider the implications. This preliminary communication summarises the work so far undertaken.

Methods

ECGs were recorded in a group of female volunteers recruited from the cardiorespiratory, medical and surgical units at Glasgow Royal Infirmary with the chest electrodes V_1 to V_6 placed strictly in accordance with the recommendations described above (approach 1) and in addition, with the V_4 electrode placed at the highest point below the breast in the appropriate longitudinal reference line. In this case, V_3 to V_6 were then placed according to the standard definitions, i.e. V_3 was midway between V_2 and V_4 while V_5 and V_6 were at the same horizontal level as V_4, whatever level that might be (approach 2). Two consecutive recordings were made with approach 1 and a further two consecutive recordings were made with approach 2 to assess repeatability of each approach. Electrodes were removed and the whole process was repeated 30 minutes later so that a total of eight recordings were made on each female volunteer.

To obtain an estimate of breast volume, bra cup size (A to E) was also noted.

As a separate component to the project, 12-lead ECGs were also recorded in a group of healthy female volunteers in whom the precordial electrodes were placed strictly according to the anatomical reference points (approach 1). This study was aimed at comparing measurements with normal limits determined several years ago using electrodes placed under the breast in women.[7]

As part of the study, electrocardiograms from all male and female patients in Glasgow Royal Infirmary were reviewed over a period of two weeks to identify the incidence of reports of poor R-wave progression, reversed R-wave progression and low R waves.

Statistical methods

The comparison between normal ranges using anatomical reference marks and previously published normal ranges was made on a simple basis of comparing differences between means.

On the other hand, a more complex model was used for determining whether there was any difference in ECG wave amplitudes because of the variation in electrode positioning on or below the breast in females. This model included checks for between-female patient variability, within-patient long-term variability, i.e. over 30 minutes and within-patient short-term variability, i.e. over one minute.

Results

Variation in precordial electrode placement

Altogether, 84 women (mean age 60±10 years) were recruited into the repeated measurements study for which ethical permission had previously been obtained. There was no consistent trend found in R-wave measurements with electrodes placed on or below the breast as shown in table 1. Measurements in V_5 and V_6 with electrodes on the breast were significantly higher than below. On the other hand, the reverse was true for V_3 while for V_4 there was no significant difference between the two positions.[8]

Repeatability

The eight recordings from each of the 84 females were studied to answer the question on stability of electrode placement and hence measurement. Table 2 shows the total variance between replicates, i.e. measures repeated one minute and 30 minutes apart, from which it can

Table 2. Variance (μV^2) between replicates.

Lead	On breast	Below breast	Ratio On/Below	P value	Approx 95% CI
V_3	26111(μV^2)	30551	0.85	0.3	(0.45, 1.59)
V_4	52298	61106	0.86	0.3	(0.46, 1.61)
V_5	11237	29972	0.37	0.001	(0.20, 0.69)
V_6	17447	19456	0.90	0.4	(0.48, 1.69)

CI=confidence interval.

be seen that there is less variability of measurements from electrodes on the breast, essentially for all leads but significantly so only for V_5.

There were 41 women with bra cup size A or B, 28 with size C and 15 with D or E. It was found by comparing these three groups that as breast (cup) size increased, the repeatability of measurements within each volunteer decreased for V_3 and V_4. The finding of reduced variability of R-wave measurements on as compared with under the breast was replicated across all breast sizes.

Normal limits

A total of 299 women were recruited to the study on normal limits. Their age distribution is shown in table 3 from where it can be seen that it was easier to recruit younger females to the study. Figure 1 shows the difference between the existing and revised upper and lower limits of normal R waves for leads V_3 to V_6 recorded from females aged 30 to 39 years. Table 4 shows differences in mean R, S and T+ values using the two approaches to electrode positioning in 18- to 29-year-old females.

Poor R-wave progression

Altogether, 1315 patients (755 men and 560 women) effectively were recruited for this part of the study. The prevalence of all forms of poor R-wave progression, including reversed R-wave progression and low R waves in V_2 to V_4, was 19% in women and 11% in men. In the group of 84 women, the incidence of poor R-wave progression was not high enough to determine whether this ECG finding could be related to breast size.

Table 3. Study population subgroups according to age (years). Mean±SD age values (years) for each age range are also shown.

Category	Age range (years)	Number of volunteers	Mean age ± SD (years)
1	18-29	121	22.2±3.0
2	30-39	49	34.5±5.9
3	40-49	69	44.9±2.7
4	≥50	60	56.1±6.5

Discussion

This ongoing study has drawn together various threads of a project designed to determine whether precordial electrodes in women should be placed on or beneath the breast. Several points can be made from a philosophical point of view. It has long been the practice in women for electrodes to be placed below the recommended positions perhaps as much for convenience and cosmetic reasons as anything else. The suction electrodes which were commonly used throughout the period from around 1930 to 1990 tended to leave weals on the skin, particularly if left in place for too long. Furthermore, personal communication with Proudfit,[9] who worked in the laboratory of Wilson and his colleagues who developed the precordial lead recording system,[10] indicated that chest electrodes were indeed placed underneath the breast, sometimes supported by towelling if necessary.

Personal observation and communication suggest that normal limits of precordial leads, certainly as developed in this laboratory,[11] were derived from electrodes placed underneath the breast. However, modern technology based on adhesive electrodes makes it much more acceptable and straightforward to place electrodes on top of the breast. As indicated in this study, this results in a slightly more reproducible recording than would be the case with the alternative positioning.

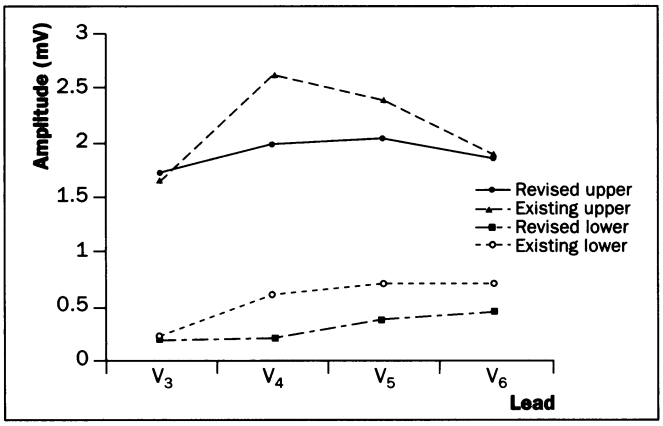

Figure 1. Upper and lower 96% limits of normal ranges (V_3 to V_6) of R-wave amplitude in females aged 30 to 39 years. Existing[11] and revised limits are shown. See text for further details.

Table 4. Mean amplitudes (mV) of R, S and T+ waves in leads V_3 to V_6 in 18- to 29-year-old females from the existing normal values (EXS) and the newly revised data (REV). P values (two-sample t test) for the differences are also shown. Note that, by convention, S waves have a negative value. Measurements were available from up to 318 females to derive the existing normal values. Not every individual had an R and S wave in every lead.

	Lead			
	V_3	V_4	V_5	V_6
R amp (REV)	0.752	1.0489	1.17	1.092
R amp (EXS)	0.81	1.302	1.342	1.219
P value	<0.1	<0.0005	<0.0005	<0.0025
S amp (REV)	-0.731	-0.532	-0.281	-0.164
S amp (EXS)	-0.794	-0.382	-0.244	-0.15
P value	<0.05	<0.0005	<0.1	>0.2
T+ amp (REV)	0.555	0.561	0.472	0.373
T+ amp (EXS)	0.533	0.426	0.399	0.337
P value	<0.4	<0.0005	<0.0005	<0.01

The effect of age and gender on ECG amplitude has been well documented.[11,12] ECG criteria for diagnosing left ventricular hypertrophy (LVH), for example, must be age and gender based but rarely are, with some exceptions, e.g. as built into the Glasgow Programme.[13] Such criteria differences may well be a function of body mass index but the differences between male and female ECG voltages tend to narrow with increasing age. Electrode positioning in women is not likely to have a significant influence on this particular diagnosis and the lack of sensitivity of ECG criteria is simply a reflection of the inadequacy of the ECG in diagnosing LVH with high sensitivity and specificity.

Some authors advocate the use of body surface mapping with multiple chest electrodes, e.g. 64, which minimises the effect of misplacement of one electrode. The gain in sensitivity, however, is marginal which can be explained in some cases by concentric LVH leading to a cancellation effect among electrical forces and hence a normal voltage, so that no matter how many electrodes are used, the ECG will not detect LVH.

The application of a large number of electrodes permits the use of so-called inverse models to calculate the electrical activity on the epicardial surface[14] but there has, as yet, been no major study showing improved diagnosis of a variety of cardiac abnormalities with this approach.

It was interesting to find that poor R-wave progression in chest leads was more prevalent in females than in males but, paradoxically, the average R-wave amplitude in V_4 with electrodes placed on the breast was lower than that with electrodes placed beneath the breast. This could be due to attenuation of voltages due to breast tissue. This simply indicates that criteria for poor R-wave progression have to be carefully developed particularly in women in whom false positive reports of anterior myocardial infarction are not uncommon.[15]

The female volunteers in the study had a variety of cardiac and respiratory problems. A wide spectrum of pathology was therefore embraced, but as each individual acted as her own control, the inhomogeneity of the population studied was immaterial in terms of repeatability of measurements and effect of electrode placement variation.

The other component of the study clearly indicates that revised normal limits of the ECG in females would have to be used if chest leads were placed at the correct anatomical level. However, a larger number of volunteers would be required to give added strength to this conclusion.

Conclusion

Expansion of the database and further analysis of the data is required in order to make a definitive recommendation with respect to precordial electrode placement in women. Such a recommendation would be based not only on objective experimental data but also on more subjective considerations involving ease of electrode placement. ■

References

1 Cawood HT, Macfarlane PW, Hillis S, Lawrie TDV. Day to day and beat to beat variation in normal 3 orthogonal lead electrocardiograms. *Br Heart J.* 1974;**36**:1225-30.

2 Willems JL, Poblete PF, Pipberger HV. Day-to-day variation of the normal orthogonal electrocardiogram and vectorcardiogram. *Circulation* 1972;**45**:1057-64.

3 Schijvenaars RJA, Kors JA, Herpen G van, Bemmel JH van. Use of the Standard 12-lead ECG to simulate electrode placements. *J Electrocardiology* 1996;**29(Suppl)**:5-9.

4 Joint Recommendations of the American Heart Association and the Cardiac Society of Great Britain and Ireland. Standarization of precordial leads. *Am Heart J* 1938;**15**:107-8.

5 Committee of the American Heart Association for the Standardization of Precordial Leads. Standarization of precordial leads. Supplementary report. *Am Heart J* 1938;**15**:235-9.
6 Committee on Precordial Leads of the American Heart Association for the Standarization of Precordial Leads. Standardization of Precordial Leads. Second Supplementary report. *J Am Med Assoc* 1943;**121**:1349-51.
7 Macfarlane PW, Coleman EN. Resting 12 lead ECG electrode placements and associated problems. *Soc Cardiological Technicians Update* 1995;**2**:10 and 1995;**2**:6.
8 Rautaharju PM, Park L, Rautaharju FS, Crow R. A standardized procedure for locating and documenting ECG chest electrode positions. *J Electrocardiology* 1998;**31**:17-29.
9 Proudfit W. Cleveland Clinic. Personal Communication. (1996).
10 Wilson FN, Johnston FD, Macleod AG, Barker PS. Electrocardiograms that represent the potential variations of a single electrode. *Am Heart J* 1934;9:447-71.
11 Macfarlane PW, Lawrie TDV. Comprehensive Electrocardiology Oxford; Pergamon Press. Vol 3, 1988.
12 Simonson E. Differentiation between normal and abnormal in electrocardiography. St. Louis, CV Mosby. 1961.
13 Macfarlane PW, Devine B, Latif S, McLaughlin S, Shoat DB, Watts MP. Methodology of ECG Interpretation in the Glasgow Program. *Meth Inform Med* 1990;**29**:354-61.
14 Ramanathan C, Rudy Y. Electrocardiographic imaging II. Effect of torso inhomogeneities on noninvasive reconstruction of epicardial potentials, electrograms and isochrones. *J Cardiovasc Electrophysiol* 2001;**12**:241-52.
15 Colaco R, Reay P, Beckett C, Aitchison TC, Macfarlane PW. False Positive ECG Reports of Anterior Myocardial Infarction in Women. *J Electrocardiology* 2000;**33(Suppl)**:239-44.

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