Transthoracic Defibrillation: Importance of Avoiding Electrode Placement Directly on the Female Breast

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Objectives. **This study sought to determine the effect on transthoracic impedance of placement of defibrillation electrodes on the female breast versus adjacent to or under the breast.**

Background. **Transthoracic impedance is a major determinant of transthoracic current flow in defibrillation. For a given energy setting, a high transthoracic impedance reduces current flow and may adversely affect the ability of electric shocks to accomplish defibrillation. We hypothesized that the increased interelectrode tissue associated with placement of the apex defibrillation electrode on the female breast would result in increased transthoracic impedance compared with electrode placement lateral to or under the breast.**

Method. **Transthoracic impedance was measured noninvasively by passing a 5-V, 31.25-kHz square wave current through the chest and comparing the low level current flow to known references. We measured transthoracic impedance associated with three different apex defibrillation electrode positions—on the breast, under the breast and lateral to the breast—in 25 women (brassiere size 34A to 46C, 25 to 75 years old, body weight 128 to 328 lb [58 to 148 kg] and 2 men. The measurements were taken with a modified defibrillator that accurately predicts transthoracic impedance without delivering an actual shock. The measurement sequence was random.**

Results. **The average measured transthoracic impedance with placement of the apex defibrillation electrode on the breast was 95 ± 25 ohms (mean ± SD), under the breast 84 ± 17* ohms and lateral to the breast 83 ± 20* ohms (*asterisk* indicates p < 0.01 vs. on the breast by analysis of variance). The study cohort was also classified into two groups: large breasted (brassiere size ≥40) and small breasted (brassiere size ≤39). The measured transthoracic impedances for the large-breasted group were 112 ± 20 ohms for on the breast, 94 ± 13* ohms for under the breast and 98 ± 19* ohms for lateral to the breast. For the small breasted group, the similar transthoracic impedance measurements were 81 ± 21, 77 ± 16 and 71 ± 13* ohms, respectively.**

Conclusions. **In women, placement of the apex defibrillation electrode on the breast results in higher transthoracic impedance, which will reduce current flow. We recommend placing the apex electrode lateral to or underneath the breast.**

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Achieving defibrillation in humans is dependent on supplying enough current to the heart to depolarize myocytes, terminate ventricular fibrillation and allow resumption of a stable electrical rhythm. The flow of current is limited by the transthoracic impedance. Previous investigations have shown that transthoracic impedance is dependent on multiple factors: chest size, energy selected, electrode size, electrode/skin couplants, previous shocks, phase of respiration, electrode–chest contact pressure and previous sternotomy (1–14). Inspiration, small paddles, large interelectrode distance and lack of couplant use all result in increased transthoracic impedance and decreased transchest (and transcardiac) current at any given energy level. This reduces the probability of achieving defibrillation.

The American Heart Association recommends upper right sternum–apex placement of electrodes for defibrillation (15,16). Whether electrode placement on the female breast is to be avoided or not is not specifically stated in the American Heart Association recommendations. In fact, we are unaware of any published data on the effect of electrode placement on the female breast in defibrillation. We hypothesized that impedance to current flow is greater when one electrode is placed on the female breast because of the greater interelectrode distance and the increased tissue between the electrodes. If this is true, the higher impedance would reduce current flow and could impede defibrillation. The present study was undertaken to test this hypothesis.

Methods

Study group. This study was approved by the University of Iowa Human Research Committee; written informed consent was obtained from all patients. Data were collected from 25 women (25 to 75 years old, body weight 128 to 328 lb [58 to

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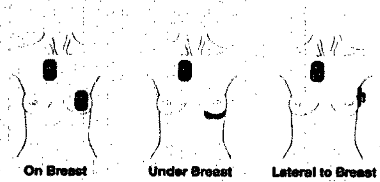

Figure 1. Electrode placement. The "sternum" electrode was placed adjacent to the right upper sternum. The "apex" electrode was placed on the breast, under the breast or lateral to the breast.

148 kg], brassiere size 34A to 48C) and 2 men (25 and 35 years old, body weight 150 and 170 lb [67 to 76 kg]). Twenty-one women were patients seen in the cardiology clinic or inpatient internal medicine wards. Four of the women were medical student volunteers. The two men were physician volunteers. The female subjects reported their brassiere and cup sizes.

Transthoracic impedance. Transthoracic impedance measurements were obtained using a previously described and validated test pulse method (4,9). Briefly, the method predicts transthoracic impedance by applying a 5-V, 31.25–kHz square wave through the chest. The low level current flows between two hand-held electrode paddles that are pressed firmly against the skin. Transthoracic impedance is predicted by comparison to known references and annotated every 10 s. No shocks are delivered, and the patient feels no discomfort.

Skin and electrode paddles were coupled by coating the electrode paddles with a commonly available conductive paste (Hewlett-Packard Redux paste). All measurements were made at end-exhalation while the patients were holding their breath. Three paddle placement configurations were investigated in random order. In all configurations, the "sternum" (right) paddle electrode was placed adjacent to the right upper sternum below the clavicle. The "apex" (left) paddle electrode was placed in one of three locations: directly on the breast (over the nipple), under the breast (the breast was lifted and the electrode placed underneath) or on the midaxillary line lateral and adjacent to the breast (Fig. 1). Three measurements of impedance were recorded at each location and averaged to yield the transthoracic impedance data point for each location in each patient.

This procedure was followed in 23 women and the 2 men. Two additional women who had previously undergone left mastectomies were also studied. The same protocol was used with a small variation: 1) The right electrode was placed on the right upper sternum below the clavicle, and 2) the apex electrode was placed on the site where the nipple would have been (as best as could be approximated visually). The apex electrode was also placed below this site and lateral to it, as previously described. Measurements of impedance were obtained as before. This process was then repeated with the electrodes placed contralaterally: one electrode at the left upper parasternal area below the clavicle and the other on the right breast (nonmastectomy side), under the breast and lateral to the breast.

Statistical analysis. Transthoracic impedance values associated with each paddle configuration for the 23 women without mastectomy were compared with a two-factor repeated-measures analysis of variance. Post hoc pairwise comparisons were tested using the Bonferroni method (17). Data are expressed as mean value ± SD in the text and mean value ± SE in the table and graph. A p value <0.01 was considered significant. For the two women with a mastectomy and the two men, mean transthoracic impedance measured at each location is presented.

Results

Table 1 shows the results. Mean transthoracic impedances measured on breast, under and lateral to the breast were 95 ± 25, 84 ± 17 and 83 ± 20 ohms, respectively ($p < 0.01$, under and lateral to the breast vs. on the breast). We also classified the patients into two arbitrary groups as large breasted (n = 10) and small breasted (n = 13), on the basis of brassiere size ≥40 and ≤39, respectively. In the large-breasted group, transthoracic impedance measured with the apex electrode on the breast was significantly higher than that measured lateral to

Table 1. Body Weight, Brassiere Size and Transthoracic Impedance for All Electrode Locations

Electrode Location	Transthoracic Impedance (ohms) (mean ± SD)	Body Weight (lb) (mean ± SD)	Brassiere Size (mean)
All women (n = 23)		187 ± 48	39
On breast	95 ± 25		
Under breast	84 ± 17*		
Lateral to breast	83 ± 20*		
Large-breasted women (n = 10)		225 ± 47	43
On breast	112 ± 20		
Under breast	94 ± 13*		
Lateral to breast	98 ± 19*		
Small-breasted women (n = 13)		157 ± 21	37
On breast	81 ± 21		
Under breast	77 ± 16		
Lateral to breast	71 ± 13*		

*$p < 0.01$ versus on-breast location.

and under the breast. In the small breasted group, transthoracic impedance measured with the apex electrode on the breast was significantly higher than the lateral to breast position only. In both groups there was no significant difference in the measured transthoracic impedance when the apex electrode was placed under the breast versus lateral to the breast.

An overall analysis of transthoracic impedance measured by brassiere cup size (A, B or C) in all the configurations mentioned above demonstrated no significant differences.

Two additional patients had undergone left mastectomies. On the remaining (right) breast side, the average transthoracic impedance measured with the apex electrode on, under and lateral to the breast was 76, 61 and 59 ohms, respectively. These are consonant with the data for the main group of 23 patients, where the highest transthoracic impedance was encountered when one electrode was placed on the breast. In contrast, on the mastectomy side (left), the measured transthoracic impedances for positions equivalent to on, under and lateral to the breast were 58, 53 and 57 ohms, respectively. Thus, mastectomy was associated with reduction of transthoracic impedance when the apex electrode was placed where the breast had been. For the two men, the average measured transthoracic impedances on, under and lateral to the breast were 70, 67 and 67 ohms, respectively. Thus, in men, defibrillation electrode placement on the breast made little difference in transthoracic impedance.

Discussion

The major finding of this study is that when the apex defibrillation electrode is placed directly on the female breast, transthoracic impedance is significantly higher than when the apex electrode is placed under or lateral to the breast. This is especially true in large-breasted women. Higher transthoracic impedance results in less transchest current flow for any given energy. The increase in transthoracic impedance for the entire group, comparing placement on the breast to placement lateral to the breast, was 14%; for the large-breasted patients, comparing on-breast with under-breast placements, the increase in impedance was 16%. Assuming constant delivered energy, the corresponding reduction in transchest peak current would be 12% and 14%, respectively. Because achieving defibrillation is primarily dependent on generating an adequate current, shocks may be less likely to achieve defibrillation if the apex electrode is placed on the breast.

Factors determining impedance. The women reported their brassiere and cup sizes. We had expected that the cup size, which intuitively would seem to be the best indicator of breast volume and mass, would be a significant determinant of transthoracic impedance. However, we could not correlate cup sizes with transthoracic impedance by electrode location. Some of the women did not actually know their cup sizes, and others reported that cup size varied greatly by brassiere brand or model, or both. Thus, cup size seemed more variable than brassiere size, and therefore we used brassiere size to subdivide the patients in this study.

In two women with a mastectomy, apex electrode placement in the area of the removed breast was not associated with a substantially higher transthoracic impedance. In the two men studied, breast placement was also not associated with a substantially higher transthoracic impedance. These observations support our hypothesis that the higher transthoracic impedance associated with breast placement results from greater interelectrode distance and more tissue mass between the electrodes. If there is little or no increased tissue associated with breast placement (i.e., in men and in women with a mastectomy), transthoracic impedance is unaffected.

Paddle electrode–chest wall contact pressure is an important determinant of transthoracic impedance (8,11). We attempted to control for this variable by having only one investigator hold the paddle electrodes for all measurements, using as firm pressure as possible. No patient complained of pain or discomfort during the measurements, so we believe that electrode pressure on the breast was similar to the electrode pressure applied to the two chest locations and that the higher transthoracic impedance we found with paddle electrode placement on the breast cannot be explained by lower electrode–breast contact pressure.

Transcardiac versus transchest current. Defibrillation is accomplished by current flowing through the heart. The transcardiac current flow is determined by both transthoracic impedance (which determines net transchest current flow) and by the electrode location on the chest wall. The percentage of transchest current that actually traverses the heart has been measured at 4% (18); estimates from Geddes et al. (19,20) comparing epicardial to transthoracic current requirements suggest that the fraction traversing the heart is higher, 17%. Three-dimensional finite element models yield an estimate as high as 34% (21,22). Prediction of transcardiac current flow is thus complex, and the chest electrode location that maximizes transcardiac current was not determined by our study; we can derive information only about net transchest current.

It is important to emphasize that current flow through the heart is responsible for achieving defibrillation. In this study, transthoracic impedance, not actual transcardiac current flow, has been used as a surrogate for achieving defibrillation. Because no actual shocks were given, we have not demonstrated that avoiding electrode placement on the breast will actually facilitate defibrillation. Nevertheless, previous studies have shown that shock success is lower when transthoracic impedance is high (9). It therefore seems reasonable to assume that avoiding placement of the apex electrode on the breast will improve the likelihood of any shock achieving defibrillation.

Conclusions. We recommend that in defibrillation, placement of the apex electrode directly on the female breast should be avoided. This recommendation is based only on transthoracic impedance; clinical defibrillation trials are needed to further validate the recommendation. Pending such trials, the American Heart Association recommendations for electrode placement should be understood in women as a recommendation to place the "apex" electrode lateral (adjacent) to or underneath the breast.

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