Heart Size of Adults in a Natural Population—
Tecumseh, Michigan

Variation by Sex, Age, Height, and Weight

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SUMMARY
Roentgenological determinations of the transverse diameter and cardiothoracic ratio in 3,985 subjects aged 20 years or more, from Tecumseh, Michigan, represent the first report on the measurement of heart size in a total community. The influence of cardiovascular abnormality, height, and weight on heart diameter and cardiothoracic ratio is determined across all age and sex divisions for the entire adult population. A consistent hierarchy of heart diameter, independent of age, height, and weight, has been demonstrated so that the diameter of the hearts of abnormal males > normal males > abnormal females > normal females. Heart diameter, especially in the males, distinguishes the abnormal segment of the population more effectively than the cardiothoracic ratio, but an age and sex-specific cardiothoracic ratio may be the most valuable in the clinical situation. Both measurements relate directly to age, sex, and weight, but the relation to height is dependent on weight. Study of heart size in a general population reveals that measurements as simple as heart diameter and cardiothoracic ratio may be effectively applied to clinical and epidemiological cardiovascular evaluations.

Additional Indexing Words:
Heart size  Transverse heart diameter  Cardiothoracic ratio
Cardiovascular epidemiology  Cardiac enlargement

CARDIAC MENSURATION has afforded an objective means for clinical investigation, serial evaluation, and population studies of cardiac size despite known limitations. Subtle changes in heart contour may be a better index of specific cardiovascular abnormality, but these do not provide a basis for quantitation. Yet, controversy over methodology and the wide range of cardiac size in “normal persons” has discouraged the general use of cardiac measurements.

Investigators have attempted to determine the mean heart size corrected for height and weight in various age groups, either normal or diseased, but seldom for both categories. From these studies of linear diameters of the cardiac silhouette and more complicated volumetric analyses, have evolved a series of standards, tables, formulae, and nomograms. These data, even though from such selected groups as insurance applicants, medical personnel, and patients, have been applied to other groups with some success.

Nevertheless, standards available from such preselected groups are not easily translated to a more heterogeneous population. In order to provide reasonable diagnostic separation...
between diseased and healthy people, normal standards must be drawn from "the distribution of diagnostic items in a healthy population, selected by careful clinical examination from a sample, reasonably representative of the general population." Few, if any, studies of heart size have met these criteria.

An ongoing epidemiological investigation\(^b,10\) of a number of physiological variables in a total community, Tecumseh, Michigan, provides the opportunity to examine heart size and related factors in a "free living" American community. Sufficiently large numbers of subjects are available to permit the reliable assessment of heart size in different segments of this population.

This report describes transverse heart diameter and the cardiothoracic ratio in persons with and without cardiovascular disease as a function of sex, age, height, and weight. From these data an attempt is made to determine a normal range of values and to compare the transverse diameter and cardiothoracic ratio as measures of heart size in the general population.

Methods

The community of Tecumseh, Michigan, contains 8,641 persons from a total population of 9,822 on whom complete medical histories were available and who had undergone, physical examinations and selected laboratory procedures in 1959-1960. Data collected during this evaluation period provide the basis for this initial report on heart size.

Posteroanterior roentgenograms of the chest were taken at a standard distance of 6 feet for all persons aged 20 years or older—2,238 men and 2,449 women. Of this total group 329 were excluded from this study because of insufficient data or technical difficulties; another 373 could not be objectively evaluated because of one or more abnormalities on the chest roentgenogram such as segmental collapse, emphysema, pleural effusion, pericardial disease, unusual mass or infiltrate, or skeletal deformities.

Roentgenological measurements performed on the 3,985 remaining subjects included the transverse diameter of the thorax (TTD) at the level of the dome of the right diaphragm and the transverse diameter of the heart (HD), the sum of the maximum projection to the right and left heart borders from the midline. In addition, the cardiothoracic ratio (CTR) was calculated as CTR = HD/TTD.

Standardized histories were obtained by trained interviewers, and all positive answers were verified by a team of examining physicians. Findings on physical examination were recorded on specially designed forms to enhance objectivity and ensure completeness of reporting. Participants wore a hospital gown without shoes for determinations of weight and height.

For analysis, the population was divided into normals, those persons without manifest cardiovascular disorders, and abnormals, those with one or more of the following cardiovascular disorders which may be characterized by heart enlargement;\(^2,11\) (1) coronary heart disease; (2) rheumatic heart disease; (3) congenital heart disease; (4) hypertension—upper twentieth percentile of Tecumseh population or greater than 160/90 mm Hg; (5) hypertensive heart disease; and (6) congestive heart failure.

All cardiovascular diagnostic categories in the Tecumseh study fulfilled rigid criteria as described by Epstein and co-workers.\(^a\)

Results

Normal Versus Abnormal

Sex-specific mean HD for the abnormal segment of the population ranks consistently (\(P \leq 0.05\)) above the values of the normal group for all ages, women more so than men (tables 1 and 2). For both sexes, the range of the normal group is more restricted than that of the abnormal segment, but still overlaps the lower portion of the abnormal range. Of the four sex-clinical status groups, the normal women have the least variance in HD, though the difference is small from group to group.

The CTR is also greater for each abnormal age-sex group. Differences in CTR are significant in all female age groups except those 70 years or older; however, significant differences are evident only in three of the male age groups: 30 to 39, 60 to 69, and 70 or more years. As with HD, the variance of TTD is relatively constant for the entire population, though larger for the women.

Age

For every age group, normal men have a larger HD than women, as might be expected from the influence of physical activities and body size.\(^13\) The increased HD in abnormal
women only partially encroaches on this sex disparity as the normal men maintain higher HD values than the abnormal women at all ages (fig. 1); the abnormal men are, of course, at the upper end of the distribution of HD and normal women at the lower end of the distribution for each age group. The trend of HD with age for normal women parallels the trend for normal men to age 70 or more, at which point there is a further increment for women, but not for men. The curves of HD with age for the abnormal subjects are of similar configuration for both sexes.

Using the CTR as an index of heart size, the women, both normal and abnormal, have higher mean values than the men. Since male heart diameters were larger, the reversal can be attributed to the smaller denominator, TTD, in the women. There is some overlap between normal women and abnormal men

**Table 1**

*Heart Size in Normal and Abnormal Males by Age*

<table>
<thead>
<tr>
<th>Age group (yr)</th>
<th>No.</th>
<th>Min-Max</th>
<th>Mean</th>
<th>SD</th>
<th>No.</th>
<th>Min-Max</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
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<td></td>
<td></td>
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<tr>
<td>20-29</td>
<td>263</td>
<td>10-17</td>
<td>12.8</td>
<td>1.4</td>
<td>154</td>
<td>9-18</td>
<td>13.2</td>
<td>1.4</td>
</tr>
<tr>
<td>30-39</td>
<td>378</td>
<td>9-18</td>
<td>13.1</td>
<td>1.4</td>
<td>211</td>
<td>11-21</td>
<td>14.0</td>
<td>1.6</td>
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<tr>
<td>40-49</td>
<td>251</td>
<td>9-18</td>
<td>13.6</td>
<td>1.5</td>
<td>150</td>
<td>11-20</td>
<td>14.3</td>
<td>1.7</td>
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<tr>
<td>50-59</td>
<td>136</td>
<td>9-18</td>
<td>13.9</td>
<td>1.6</td>
<td>138</td>
<td>11-19</td>
<td>14.3</td>
<td>1.4</td>
</tr>
<tr>
<td>60-69</td>
<td>58</td>
<td>11-17</td>
<td>13.9</td>
<td>1.4</td>
<td>63</td>
<td>12-18</td>
<td>14.6</td>
<td>1.5</td>
</tr>
<tr>
<td>70+</td>
<td>31</td>
<td>11-16</td>
<td>13.9</td>
<td>1.3</td>
<td>50</td>
<td>12-20</td>
<td>14.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Total</td>
<td>1117</td>
<td>9-18</td>
<td>13.5</td>
<td>1.5</td>
<td>766</td>
<td>9-21</td>
<td>14.0</td>
<td>1.6</td>
</tr>
</tbody>
</table>

**Table 2**

*Heart Size in Normal and Abnormal Females by Age*

<table>
<thead>
<tr>
<th>Age group (yr)</th>
<th>No.</th>
<th>Min-Max</th>
<th>Mean</th>
<th>SD</th>
<th>No.</th>
<th>Min-Max</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-29</td>
<td>326</td>
<td>8-15</td>
<td>11.3</td>
<td>1.1</td>
<td>161</td>
<td>8-16</td>
<td>11.8</td>
<td>1.4</td>
</tr>
<tr>
<td>30-39</td>
<td>445</td>
<td>7-16</td>
<td>11.5</td>
<td>1.2</td>
<td>184</td>
<td>9-18</td>
<td>12.3</td>
<td>1.4</td>
</tr>
<tr>
<td>40-49</td>
<td>293</td>
<td>9-16</td>
<td>12.1</td>
<td>1.3</td>
<td>135</td>
<td>9-18</td>
<td>12.8</td>
<td>1.4</td>
</tr>
<tr>
<td>50-59</td>
<td>135</td>
<td>10-16</td>
<td>12.4</td>
<td>1.3</td>
<td>156</td>
<td>10-17</td>
<td>13.1</td>
<td>1.3</td>
</tr>
<tr>
<td>60-69</td>
<td>53</td>
<td>10-15</td>
<td>12.3</td>
<td>1.0</td>
<td>108</td>
<td>11-18</td>
<td>13.6</td>
<td>1.4</td>
</tr>
<tr>
<td>70+</td>
<td>29</td>
<td>10-15</td>
<td>12.7</td>
<td>1.2</td>
<td>77</td>
<td>11-24</td>
<td>13.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Total</td>
<td>1281</td>
<td>7-16</td>
<td>11.8</td>
<td>1.3</td>
<td>821</td>
<td>8-24</td>
<td>12.7</td>
<td>1.5</td>
</tr>
</tbody>
</table>

|               |     |         |      |    | Abnormal |         |      |    |
|               |     |         |      |    |          |         |      |    |
| 20-29         | 326 | 0.32-0.53 | 0.42 | 0.03| 161  | 0.23-0.56 | 0.43 | 0.04|
| 30-39         | 445 | 0.33-0.58 | 0.43 | 0.04| 184  | 0.34-0.66 | 0.45 | 0.05|
| 40-49         | 293 | 0.33-0.60 | 0.44 | 0.04| 135  | 0.37-0.71 | 0.46 | 0.05|
| 50-59         | 135 | 0.27-0.65 | 0.47 | 0.05| 156  | 0.36-0.64 | 0.48 | 0.04|
| 60-69         | 53  | 0.33-0.58 | 0.48 | 0.05| 108  | 0.41-0.64 | 0.51 | 0.05|
| 70+           | 29  | 0.40-0.64 | 0.51 | 0.05| 77   | 0.42-0.67 | 0.53 | 0.05|
| Total         | 1281 | 0.27-0.65 | 0.44 | 0.05| 821  | 0.23-0.71 | 0.47 | 0.06|

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Heart size varies directly with weight for all groups; the relationship is almost perfectly linear. As weight increases, the normal and abnormal HD curves, for each sex, tend to converge.

For subjects other than those at the extremes of height, the CTR decreases as height increases and is positively associated with weight except for women at the highest weights, and both sexes in the lowest weight group.

A better understanding of the contributions of height and weight to heart size may be obtained by examining the interrelationships of these variables.

**Age, Height, and Weight Specific Groups**

Heart diameter against either age, height, or weight, specified for the other two variables, is plotted in figure 2.
Heart diameter increases with age independent of height and weight; the single divergent point for men aged 50 to 59 years and 185 to 189 cm tall represents only two subjects. In any given age group there is minimal spread of HD with height; however, there is a definite distribution of HD values according to weight specific groups at any age. The curve for the heaviest women coincides with the curve for the lightest men.

The most marked association is HD with weight specified for age and height; the results are similar for both specified variables: (1) curves for men and women are parallel, of relatively constant slope, and tend to converge for each sex at the heavier weights; and (2) the spread of the distribution of HD values at most weights is greater for the males.

Relationships of the CTR to age, height, and weight were similar to those of the HD with the same variables, but the highest CTR


values for any of the three variables are found in the women and the lowest values in the men.

Correlations Between Selected Variables

Because HD and CTR are influenced by age and sex, correlation coefficients are calculated separately by 10-year age groups for each sex and are further subdivided into normal and abnormal. Correlations different from zero at the 0.05 significance level are found for most of the interrelationships of HD with height, weight, TTD, and CTR. For both sexes the relationship of HD to CTR is highly significant, accounting for 45 to 69% of the variance in CTR for persons less than 60 years old. An interesting trend is apparent for women: the relationship of HD to CTR decreases with age, presumably because TTD becomes more independent with age in women.

Weight almost consistently accounts for 25% or more of the variance in HD in all subjects except those 70 years of age or more. The association of TTD with HD no doubt is due in part to its correlation with height and weight. Few correlations of height with HD are significant at the 0.05 level; furthermore, the significant associations are of low magnitude. The HD of normal women, but not normal men, shows a significant positive association with height in most age groups. Conversely, the HD of abnormal men relate better to height than does the HD of abnormal women.

Intercorrelations for CTR with height and weight are smaller than those of the same variables with HD. A positive association of CTR with weight for both sexes at all ages is the only consistent relationship.

Discussion

Admittedly, roentgenological measures other than the HD may relate better to actual heart size, but the advantages of a simple, reliable, quantitative measure of heart size, agreeing in principle with that determined by physical examination, far outweighs this limitation. Moreover, serial evaluations of HD preclude many of the inherent limitations. Subjective interpretation of cardiac enlarge-

ment by radiologists in population studies is fraught with problems, even when an attempt is made to standardize the readings. Unidimensional measurements of heart size, especially HD, remain the favored technique as attested to by its widespread endorsement and common usage in clinical evaluations and investigations as well as population studies.

It is generally agreed that sex, age, and body size influence the HD to varying degrees; available data from selected groups of subjects do not permit the accurate assessment of these factors. The ABCC-NIH adult health study on heart size norms in Hiroshima provides comprehensive information on the influence of these variables in a general Japanese population. Height-weight specific values for the HD of the Japanese population exceed those of comparable American subjects, but the trends of HD with age, sex, height, and weight correspond amazingly well for two such diverse groups.

Sex, a determinant of HD, may account for as much as a 20% difference in heart size. Zdansky attributes this sex difference to the fact that "males work harder physically and their skeletal muscles are more developed than those of women." Bainton in an orthodiagraphic study of transverse diameter reduced the HD of men by 0.8 cm to obtain the standard for women. The findings of this study reveal a consistent sex differential in HD of 0.5 to 1.0 cm between normal men and women for all age groups of comparable weights and heights. In fact, there is a definite hierarchy of HD values throughout this study with regard to all independent variables—those of abnormal males are greater than those of normal males; those of normal males are greater than those of abnormal females; those of abnormal females are greater than those of normal females. Neither body size nor clinical status can fully compensate for the discrepancies in heart size between sexes.

Age has a recognizable influence on the HD, principally thought to be at the younger and older ages. Results in this study and the Hiroshima report21 demonstrate a distinct rise
of HD with age to about 50 years after which HD is stable. At this period of life, occult cardiovascular disease, in addition to myocardial and vascular changes as a result of age, interact with the persistent cohort phenomenon to confound the change of HD with age. It is impossible to delineate these factors from age in the present report.

Height has always been used as an independent variable in standard tables of HD, often to the neglect of sex and age. Although the direct correlation of height with HD is insignificant, men show a decrease in HD with increasing heights at specified weights. Height has less influence on HD than any of the other variables studied; this finding again is corroborated in the Hiroshima investigation.

Weight correlates highly with HD; the relationship is even more striking for age and height-specific groups. There is no question about this association. How much weight contributes to the transverse diameter by virtue of an increase in the pericardial fat pad is unknown. In very obese subjects, Alexander postulates that cardiac hypertrophy is due to an increase in the work load of the heart.

The standard reference tables for heart size compiled by Ungerleider have been a valuable source of information for evaluation of heart size. Yet, standards based on male, life insurance applicants of middle or higher income, further qualified by a systolic blood pressure of at least 110 mm Hg are not really applicable to a general population. Moreover, derivation of a prediction table requires certain approximations introducing bias to any standard. For example, the relationship of height and weight to HD is not truly linear throughout the range of these variables.

Comparison of predicted HD from the nomogram prepared by Ungerleider with the values obtained from normal men and women of Tecumseh, separately and combined, reveals that: (1) When both sexes are
HEART SIZE

combined, the women predominate at the shorter heights for all weight groups resulting in a divergence of HD from the predicted value of Ungerleider; as height increases the men predominate, and HD does not deviate excessively from the predicted values. (2) When compared separately the HD of women at all heights and weights is consistently below the predicted value, but the HD of men, as for the combined sexes, approximates the predicted value. In figure 3 it is apparent that the difference between abnormal and normal women is less at all heights and weights than the difference between the higher predicted value of Ungerleider and that of the normal women. By use of standards based on a selected group of males, the extent of cardiac enlargement in a predominantly female hypertensive population may be grossly underestimated. Cognizance must be taken of sex in addition to age, height, and weight for prediction of heart size.

The value of the CTR as an index of heart size has been disputed ever since its introduction in 1919. Evans considers the CTR the simplest and most useful measurement of heart size, while others flatly reject it.

As expected from the high correlation between CTR and HD the influence of age, height, and weight on the CTR in this study parallels that described previously for the HD. The notable exception already mentioned is that the CTR for women exceeds that of the men. Although there is less separation by sex for different age, height, and weight groupings with the CTR than with the HD, simplification of heart size into terms presumably less dependent on body size could have merit, especially for the clinical situation.

Normals and abnormals of all ages were arbitrarily separated with a CTR of 0.5 (fig. 4) to determine the feasibility of this constant in screening a general population, assuming that our categorization of disease is correct. Differentiation of abnormal from normal with this constant is obviously better for the women, although more "false" positives are also present in females. An arbitrary dichotomy of normal and abnormal with a CTR of 0.5 for both sexes of all ages cannot be readily

Figure 4

Distribution of the cardiothoracic ratio for normal and abnormal males and females.
achieved. More discriminating sex and age-specific values must be calculated for required sensitivities and specificities by fitting appropriate adjusted regression lines.

When the sensitivity, specificity, and prevalence of a disorder in the population are known, the predictive value of a diagnostic test may be estimated as follows: 27

$$\text{Predictive value of positive (negative) test} = \frac{\text{Number of diseased (nondiseased) persons with positive (negative) test}}{\text{Total number of persons with positive (negative) test}} \times 100.$$ 

Results of the application of this test to a CTR exceeding 0.5, by age and sex, is shown in table 3. If 100 males 70 years of age or older in a population exceeded the CTR of 0.5, we would expect 75% (75 men) to be truly diseased; conversely, only 41 of 100 males with a CTR of 0.5 or less would really be negative, while 59 would be “false” negatives. The predictive value of a positive test is best for both men and women 60 years of age or older, whereas the negative test is most satisfactory for those less than 50 years of age. Positive and negative predictive values are better in the women. As previously mentioned, the utility of the CTR could be further improved by altering the constant of 0.5 for specified age and sex groupings.

Quantitative expressions for heart size constitute a worthwhile addition to any cardiovascular evaluation. Because complex procedures limit widespread usage, measurements or indices of heart size must remain simple to be useful. Overlap of normal and abnormal values does not preclude the desirability of cardiac mensuration any more than it does the measurement of vital capacity in pulmonary disorders, sedimentation rate in acute illness, or the electrocardiograms in people with heart disease. Optimal separation of normal and diseased populations cannot be achieved without considering the concomitant variables, and the underlying sample from which the standards are derived. Most studies have established abnormality merely as two standard deviations above the mean of the normals, few investigations have compared normals with abnormalities simultaneously, and fewer still have been mindful of extraneous variation from age, sex, height, and weight, or representativeness of the sample. It is remarkable that estimates of heart diameter from various studies agree at all.

Rarely, if ever, can a description of a normal range of a measurement in a group define normality for the individual. A specified CTR or HD from a general population cannot resolve the problems of “false” positives and “false” negatives but can provide a useful standard of comparison for diagnostic separation of individuals and populations with cardiac enlargement.

Documentation Note

Age and sex-specific mean heart diameters and cardiothoracic ratios for various height and weight groupings may be obtained from the Tecumseh Community Health Study, School of Public Health, University of Michigan, Ann Arbor, Michigan 48104.

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