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# Choice of Variables for Predicting the Heart Volume

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## ABSTRACT

**Roentgenological heart volume determinations in the supine posture with calculation according to the formulae of both Jonsell & Kjellberg et al., and measurements of the height, weight, total haemoglobin, blood volume and physical work capacity, were made on 45 men of ages 64–86 years, previously prostatectomized and with no subjective symptoms of cardiopulmonary disease, and on 22 healthy men and 17 healthy women of ages 58–71 years from a health survey. Statistical analysis of these data comprised simple correlation calculations and stepwise regression. The body weight showed, as a rule, a stronger correlation than the body surface area with the heart volume. On testing a combination of variables, measures of body size in combination with blood volume appeared to have a stronger explanatory capacity than other combinations. Measures of physical work capacity seemed to have a weaker predictive capacity in the age groups concerned. All correlations between heart volume and the other variables were weaker in a group with ECG anomalies possibly expressing heart disease than in the groups with a normal ECG.**

## INTRODUCTION

Roentgenological measurement of the heart volume is a very common procedure in clinical practice and is used in the diagnosis of heart diseases, in evaluating the course of a disease and in assessing therapeutic effects. In certain cases, especially for diagnostic purposes, attempts are made to estimate the size of the individual heart chambers, but in general a measurement of the total heart volume is considered adequate. In sports physiology and clinical work physiology heart volume determination is performed with the aim of correlating the size of the heart with the cardiac function. Heart volume determination is also used in health surveys as a screening method for heart disease. With this extensive application of the procedure it is of great importance to have access to a method with good precision and to use uniform and adequate models for prediction of normal values. A recent questionnaire study (3) showed, however, that within Sweden alone several different methods are used, with variations both in the examination technique and in the formula for calculation of the volume. In normal persons the heart volume is related, among other things to body size and circulatory functional capacity. In calculating normal values, therefore, consideration must be taken of one or more such factors.

The methods usually used in Sweden for heart volume determination have been developed by Jonsell (10) and Kjellberg et al. (11, 12, 13). The volume according to the method of Jonsell ($Vol_J$) is calculated from the formula:

$$Vol_J = \frac{\pi}{6} \; a\, b\, c \; \frac{(f-v^{fr})^2\,(f-v^{l})}{f^3}$$

where $a$, $b$ and $c$ are the diameters illustrated in Fig. 1, $f$ is the film–focus distance (=125 cm), $v^{fr}$ is the distance from the centre of the heart to the film in the frontal plane and $v^{l}$ is the corresponding distance to the film in the lateral plane. The formula corrects for degree of magnification.

The volume according to Kjellberg et al. ($Vol_K$) is calculated from the formula:

$$Vol_K = \frac{\pi}{6} \sqrt{1-\frac{c_1^2}{3e_1^2}} \; d\, e\, c \; \frac{(f-v^{fr})^2\,(f-v^{l})}{f^3}$$

where $c_1$ and $e_1$ are $c$ and $e$ reduced for the degree of magnification and $d$, $e$ and $c$ are diameters as illustrated in Fig. 1. The other notation is the same as in the previous formula.

The body position and projection are also of importance. Bergström et al. (1, 2) found that the differences in mean values obtained with the different projections were often considerable and larger in calculation according to Jonsell's formula than

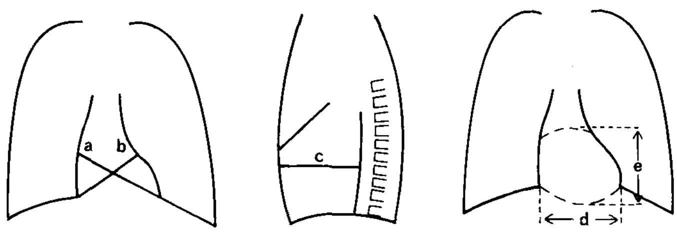


*Fig. 1.* Schematic drawing showing the three diameters according to Jonsell, (*a, b* and *c*) and the three diameters according to Kjellberg et al. (*d, e* and *c*).

in calculation by the formula of Kjellberg. In their material of healthy young men, Kjellberg's formula gave, as a rule, somewhat higher values than Jonsell's formula. The range of variation was smaller with exposure in the recumbent than in the sitting position. Angled projections did not result in smaller ranges of variation than straight projections.

The heart volume is usually expressed in relation to calculated body surface area as a measure of body size. Reindell et al. (14) have pointed out, however, that body weight has a stronger and more constant correlation than the calculated body surface area with the heart volume. Other methods of predicting the heart volume are to use measures of the circulatory functional capacity, e.g. physical work capacity, or measures of the volume of the circulatory system, e.g. total haemoglobin or blood volume (6, 7, 14). To increase the possibilities of accurate prediction it is important to ascertain which variables have the strongest correlation with the heart volume, but also to know how these correlations vary with age. Reindell et al. (14) have shown that both age and sex as well as degree of physical fitness influence the correlations between physical work capacity and heart volume. At a given heart volume the oxygen pulse at submaximal work is lower in women than in men and higher in well-trained athletes than in normal men. Further, there is a weaker correlation between oxygen pulse and heart volume in higher than in younger ages.

The aim of the present study was to find out which single variable and which combination of 2, 3 and 4 relevant variables, respectively, have the greatest explanatory value in prediction of the heart volume in elderly persons free from heart disease.

## MATERIAL

The study comprised both a group of men with no subjective symptoms of cardiopulmonary disease, who 5–7 months previously had undergone prostatectomy with no postoperative complications, and a group of men and women from a health survey on a selection from the population of the urban district of Uppsala. This latter group had undergone a comprehensive clinical examination, including static and dynamic spirometry and a submaximal work test, at which they had exhibited no signs indicative of respiratory or circulatory disease or other abnormality. None of them suffered from any disease which could be assumed to be limiting for the physical work capacity or to affect the blood formation. In the group of prostatectomized patients all were *clinically* free of cardiopulmonary disease. This group was divided into two sub-groups, one with a normal ECG both at rest and during exercise and the other with a pathological ECG at rest and/or during exercise. The sub-groups are referred to in the following as ECG-normal and ECG-abnormal. The ECG

Table I. *Anthropometric data for the material*

| Group | *n* | Age, yrs $\bar{X}$ | Age, yrs Range | Height, cm $\bar{X}$ | Height, cm Range | Weight, kg $\bar{X}$ | Weight, kg Range |
|---|---|---|---|---|---|---|---|
| A. Prostatectomized, ECG-normal | 23 | 72.5 | 64–82 | 173.3 | 166–183 | 75.5 | 58–95 |
| B. Prostatectomized, ECG-abnormal | 22 | 73.2 | 61–86 | 172.1 | 165–184 | 76.8 | 53–97 |
| C. Health survey, men | 22 | 64.6 | 59–71 | 176.0 | 164–184 | 75.3 | 59–95 |
| D. Health survey, women | 17 | 63.0 | 59–69 | 162.9 | 150–178 | 63.5 | 47–79 |

Table II. *Mean values, standard deviations and ranges for measures of heart volume, physical work capacity and total haemoglobin*

| Group | Variable | $\bar{X}$ | S.D. | Range | *n* |
|---|---|---|---|---|---|
| A. Prostatectomized, ECG-normal | $Vol_J$ | 985 | 226 | 666–1 377 | 23 |
| | $Vol_K$ | 843 | 206 | 523–1 280 | 23 |
| | $W_{150}$ | 733 | 145 | 498–1 145 | 21 |
| | THb | 695 | 127 | 509–1 140 | 21 |
| B. Prostatectomized, ECG-abnormal | $Vol_J$ | 967 | 219 | 663–1 341 | 22 |
| | $Vol_K$ | 810 | 132 | 623–1 096 | 22 |
| | $W_{150}$ | 713 | 154 | 340–1 000 | 19 |
| | THb | 672 | 142 | 442– 907 | 22 |
| C. Health survey, men | $Vol_J$ | 890 | 177 | 667–1 336 | 22 |
| | $Vol_K$ | 649 | 94 | 487– 827 | 22 |
| | $W_{150}$ | 798 | 170 | 497–1 108 | 20 |
| | THb | 673 | 103 | 525– 998 | 22 |
| D. Health survey, women | $Vol_J$ | 641 | 110 | 426– 904 | 17 |
| | $Vol_K$ | 505 | 90 | 389– 712 | 17 |
| | $W_{150}$ | 484 | 158 | 200– 810 | 16 |
| | THb | 520 | 88 | 395– 734 | 17 |

changes consisted in bundle branch block, low-grade A–V block or unspecific ST–T changes.

Table I gives the age distribution and certain anthropometric data for the different groups.

## PHYSIOLOGICAL METHODS

The physical work capacity was determined by bicycle ergometry (graded loads of 6 min duration). $W_{130}$ and $W_{150}$, defined as the work intensity at heart rates of 130 and 150 beats/min, respectively, were calculated by inter- or extrapolation (7). At the end of the work test capillary blood was taken for lactate determination, whereafter the variable $W_{lact}$, defined as the work load in kpm/min performed at a lactate concentration of 5 mEq/l, was calculated for the group of prostatectomized patients (15). Total haemoglobin (THb) was determined by the alveolar CO method, wherewith duplicate determinations were performed on the "health survey" group (5) and single determinations on the group of prostatectomized patients (15). Determinations of the haemoglobin concentration (Hb) was performed on capillary blood and from the value of THb and Hb the total blood volume (TBV) was calculated.

## ROENTGENOLOGICAL METHODS

All patients were examined in the supine posture with antero-posterior and lateral projections and with the central beam directed at right angles to the frontal plane and lateral plane. The film-focus distance was 125 cm and frontal and lateral films were exposed simultaneously without ECG triggering. The subject breathed calmly and shallowly during the exposure. Measurement on the films was performed by two of the authors in collaboration (K. B. and U. E.) and in all cases the volume was calculated according to the formula of both Jonsell ($Vol_J$) and Kjellberg ($Vol_K$). In the calculations correction was made for the fact that the formula of Kjellberg et al. is intended for 30° angulation in the frontal projection, while in the present study the central beam was directed perpendicularly to the frontal plane (1, 2).

## COMPUTER ANALYSIS AND STATISTICAL METHODS

The body surface area (BSA), THb, TBV and heart volume were calculated from measured primary data by

Table III. *Certain regression equations, giving residual variances and correlation coefficients (r)*

| | Regr. coeff. | Const. | Residual variance | *r* | *n* |
|---|---|---|---|---|---|
| A. *Prostatectomized, ECG-normal* | | | | | |
| $Vol_J$= | 13.5 BW − | 36.7 | 171 | 0.69 | 23 |
| $Vol_K$= | 9.5 BW + | 128.0 | 183 | 0.53 | 23 |
| $Vol_J$= | 1 068.2 BSA − | 1 033.8 | 176 | 0.67 | 23 |
| $Vol_K$= | 748.9 BSA − | 572.6 | 185 | 0.51 | 23 |
| $Vol_J$= | 0.6 $W_{150}$ − | 585.1 | 233 | 0.29 | 20 |
| $Vol_K$= | 0.2 $W_{150}$ + | 742.4 | 219 | 0.10 | 20 |
| $Vol_J$= | 54.7 TBV + | 627.4 | 201 | 0.29 | 20 |
| $Vol_K$= | 80.9 TBV + | 351.1 | 186 | 0.44 | 20 |
| B. *Prostatectomized, ECG-abnormal* | | | | | |
| $Vol_J$= | 8.7 BW + | 301.7 | 208 | 0.43 | 22 |
| $Vol_K$= | 4.4 BW + | 472.1 | 129 | 0.36 | 22 |
| $Vol_J$= | 563.3 BSA − | 101.1 | 215 | 0.36 | 22 |
| $Vol_K$= | 313.3 BSA + | 215.5 | 131 | 0.33 | 22 |
| $Vol_J$= | 0.7 $W_{150}$ + | 434.2 | 207 | 0.41 | 17 |
| $Vol_K$= | 0.2 $W_{150}$ + | 632.2 | 115 | 0.23 | 17 |
| $Vol_J$= | −16.7 TBV + | 1 055.5 | 229 | −0.08 | 22 |
| $Vol_K$= | 7.0 TBV + | 772.3 | 138 | 0.06 | 22 |
| C. *Health survey, men* | | | | | |
| $Vol_J$= | 13.5 BW − | 129.8 | 138 | 0.67 | 22 |
| $Vol_K$= | 1.5 BW + | 537.1 | 98 | 0.14 | 22 |
| $Vol_J$= | 907.7 BSA − | 845.4 | 137 | 0.68 | 22 |
| $Vol_K$= | 139.2 BSA + | 382.5 | 97 | 0.20 | 22 |
| $Vol_J$= | 0.5 $W_{150}$ + | 490.2 | 170 | 0.48 | 20 |
| $Vol_K$= | 0.1 $W_{150}$ + | 550.0 | 101 | 0.21 | 20 |
| $Vol_J$= | 115.4 TBV + | 249.8 | 155 | 0.56 | 22 |
| $Vol_K$= | 66.9 TBV + | 277.6 | 79 | 0.61 | 22 |
| D. *Health survey, women* | | | | | |
| $Vol_J$= | 8.9 BW + | 83.2 | 77 | 0.76 | 17 |
| $Vol_K$= | 6.9 BW + | 69.0 | 66 | 0.73 | 17 |
| $Vol_J$= | 564.4 BSA − | 307.2 | 81 | 0.72 | 17 |
| $Vol_K$= | 471.9 BSA − | 287.5 | 65 | 0.74 | 17 |
| $Vol_J$= | 0.4 $W_{150}$ + | 453.8 | 102 | 0.53 | 16 |
| $Vol_K$= | 0.3 $W_{150}$ + | 344.8 | 80 | 0.56 | 16 |
| $Vol_J$= | 44.5 TBV + | 438.9 | 111 | 0.31 | 17 |
| $Vol_K$= | 34.6 TBV + | 347.9 | 92 | 0.29 | 17 |

Table IV. *Some results from stepwise regression, giving the multiple correlation coefficient (R) as an index of the explanatory value of the regression*

| Dependent variable | Regression coefficients | | | | | | |
|---|---|---|---|---|---|---|---|
| | Const. | BW | TBV | $W_{130}$ | $W_{lact}$ | BSA | *R* |
| A. *Prostatectomized, ECG-normal, n=20* | | | | | | | |
| $Vol_J$ | 127.3 | 11.0 | | | | | 0.63 |
| $Vol_J$ | −263.0 | 11.4 | 62.8 | | | | 0.71 |
| $Vol_J$ | 133.5 | 11.0 | | −0.01 | | | 0.63 |
| $Vol_J$ | −413.9 | 11.4 | 69.3 | 0.2 | | | 0.72 |
| $Vol_J$ | −322.6 | 12.3 | 62.3 | 0.4 | −0.5 | | 0.76 |
| $Vol_J$ | −958.6 | | 44.5 | | −0.5 | 1 003.7 | 0.73 |
| B. *Prostatectomized, ECG-abnormal, n=22* | | | | | | | |
| $Vol_J$ | 301.7 | 8.7 | | | | | 0.43 |
| $Vol_J$ | 448.7 | 9.8 | −43.9 | | | | 0.47 |
| $Vol_J$ | 1.9 | 7.7 | | 0.7 | | | 0.51 |
| $Vol_J$ | 147.0 | 8.9 | −52.1 | 0.7 | | | 0.56 |
| $Vol_J$ | 899.7 | 10.4 | −134.9 | 1.1 | −1.2 | | 0.67 |
| $Vol_J$ | 412.4 | | −88.0 | | −0.8 | 737.0 | 0.46 |
| C. *Health survey, men, n=22* | | | | | | | |
| $Vol_J$ | −129.8 | 13.5 | | | | | 0.67 |
| $Vol_J$ | −389.9 | 11.1 | 80.0 | | | | 0.77 |
| $Vol_J$ | −148.4 | 12.8 | | 0.1 | | | 0.68 |
| $Vol_J$ | −399.1 | 11.5 | 87.6 | −0.1 | | | 0.77 |
| $Vol_J$ | −816.9 | | 60.8 | | | 716.3 | 0.73 |
| $Vol_J$ | −827.9 | | | 0.1 | | 866.9 | 0.69 |
| D. *Health survey, women, n=16* | | | | | | | |
| $Vol_J$ | 52.5 | 9.4 | | | | | 0.78 |
| $Vol_J$ | −76.0 | 9.0 | 34.7 | | | | 0.81 |
| $Vol_J$ | 60.2 | 8.8 | | 0.1 | | | 0.79 |
| $Vol_J$ | 82.5 | 9.1 | 36.0 | −0.02 | | | 0.81 |
| $Vol_J$ | −420.7 | | 25.4 | | | 566.8 | 0.76 |
| $Vol_J$ | −313.1 | | | 0.1 | | 546.9 | 0.75 |

means of a computer. The statistical analysis was also performed by a computer; in this analysis the regression line, residual variance and coefficient of correlation were calculated for each individual variable against each of the other variables. Stepwise linear regression analysis (4) was performed in order to determine which variable and which combination of variables had the greatest value for predicting the heart volume. Only persons for whom complete data had been obtained were included in these analyses.

## RESULTS

The mean values and ranges for heart volume, $W_{150}$ and THb in the different groups are presented in Table II. It can be seen in the table that $Vol_J$ was higher than $Vol_K$ in all groups ($P_A<0.05$, $P_B<0.01$, $P_C<0.001$, $P_D<0.001$). It is also evident from the table that the heart volume was somewhat higher in the two groups of prostatectomized patients than in the healthy men from the health survey. This difference was statistically significant for $Vol_K (p<0.001)$. There was no significant differences in heart volume, however, between ECG-normal and ECG-abnormal prostatectomized patients.

Table III A–D presents certain regression equations, giving residual variance and coefficient of correlation as measures of the predictive value of the regression. It is evident from the table that the residual variance was generally somewhat lower and the coefficient of correlation somewhat higher when body weight (BW) was the independent variable than when this variable was body surface area (BSA). The explanatory value for BW and BSA was, in general, higher than for $W_{150}$ and TBV. The coefficient of correlation was usually higher in regressions with $Vol_J$ than with $Vol_K$ as the dependent variable.

Table IV A–D gives certain results from the stepwise regression analysis with the multiple correlation coefficient (*R*) as a measure of the prediction value of the regression. The starting point of the calculations was the finding that in the simple regression analysis $Vol_J$ and BW had shown a higher degree of correlation to different variables than $Vol_J$ and BSA, respectively. The table shows that all regressions had a considerably lower prediction value in the ECG-abnormal group of prostatectomized patients than in the other groups. It can also be seen in the table that BW alone has a relatively high explanatory value and that BW in combination with blood volume seems to have a higher explanatory value than BSA in combination with blood volume. $W_{130}$ as a further variable did not increase the predictive value of the regression noteworthily except in the group of ECG-abnormal prostatectomized patients.

## DISCUSSION

Groups C and D were taken from a statistically selected sample of the population in the age section concerned. The persons included comprise a relatively stringently selected group among those who fulfilled the criterion of having no manifest disease of importance for the ventilatory capacity, central circulatory capacity or blood formation. These groups (C and D) can thus be said to represent healthy people in this age section. Group A (prostatectomized patients with no manifest cardiopulmonary disease) reasonably can be considered to be representative of healthy men of the age range in question. Groups A, C and D exhibited essentially the same pattern as regards the correlation between heart volume and body dimensions and between circulatory functional capacity and blood volume. In group B (ECG-abnormal prostatectomized patients) these correlations were weaker despite the absence of a history of or other *clinical* signs of heart disease. The importance of ECG changes for correlations with the heart volume has been demonstrated previously by Strandell (16).

Reindell et al. (14), among others, have found the heart volume to be more strongly correlated to body weight than to body surface area. This observation is also corroborated by the present investigation. Thus there appear to be convincing arguments favouring the view that the total heart volume shall be related to body weight rather than to body surface area. Situations with rapid changes in weight or other abnormal weight conditions should probably comprise exceptions. In these extreme cases, however, it is doubtful whether any measure of body size at all can be of value for predicting the heart volume.

A further improvement in prediction of the heart volume and establishment of normal values is obtained if the blood volume is added to the body weight. This is in agreement with previous results (16). The findings in the present study indicate, on the other hand, that the predictive value of physical work capacity is considerably smaller than has been reported earlier for younger age groups (8, 9, 16). In our material the correlation between physical work capacity, as a measure of the central circulatory capacity, and the heart volume, as an expression of the volume of the circulatory system, was relatively weak. THb and TBV can also be said to be measures of the volume of the circulatory system. In a larger sample of men and women of corresponding ages from the same health survey material, the correlations between physical work capacity and THb and TBV, respectively, were studied and found to be weaker than those reported earlier for younger persons (5). Both of these observations may indicate that in a population such as this the physical work capacity is limited by other factors than the volume of the circulatory system and the oxygen transport capacity.

In a comparison between the calculation procedures of Jonsell and Kjellberg et al., the correlations between heart volume and other variables were found to be stronger throughout with the Jonsell formula despite the fact that the variance was, as a rule, lower in calculations according to Kjellberg et al. The implication of this observations cannot be stated with certainty, and further analysis would seem to be motivated. A possible explanation can be that determinations according to Kjellberg for special body types and/or in the case of obesity have a poorer volume discriminatory capacity than Jonsell's method. This might possibly explain the observation that the residual variances are lower for Kjellberg's method while the correlation coefficients are higher for measurements according to Jonsell.

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