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# Weights of Brain, Heart, Liver, Kidneys, and Spleen in Healthy and Apparently Healthy Adult Danish Subjects

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*ABSTRACT* Based on a forensic material of 1,598 autopsies of Danish adults (1,086 males, 512 females ≥16 years of age), who prior to death were healthy or apparently healthy based on clinical evidence, the weights of brain, heart, liver, kidneys, and spleen were registered. The variability of organ weights was estimated. Relationships between organ weights and body size, and among organ weights were also evaluated. Males had larger organ weights than females. When organ weights were based on the same estimated fat free mass, interesting differences between the sexes were observed: weights of the heart and brain were smaller in females, but weights of the kidney were the same; weights of the liver were consistently larger in females than in males. Useful comparisons of the data with previous studies were impossible because of differences in the criteria of health and of insufficient numbers. 

The desire to establish reference data for weights of organs from normal human subjects develops naturally when dealing with human beings in health and disease. The literature bears evidence of the difficult task of defining a study population which may be considered essentially normal. Boyd (1933) defines a "normal" population as subjects who died of accidents without gross haemorrhage, with illness for less than 24 hr and no evidence of additional disease. These criteria, followed by Wald (1937) and Krumbhaar and Lippincott (1939), have the obvious advantage of using sudden, violent deaths to avoid autopsy material in which organ weights might be influenced by protracted illness and confinement prior to death. Greenwood and Brown (1913) and Smith (1928) and Zeek (1942) defined their study populations by including cases which, based upon the autopsy records, could be considered relatively normal both in clinical and pathoanatomical terms.

Useful estimates of mean values of organ weights, their variability and intercorrelations, and relationships to sex, body weight, and fat-free mass require large samples of both sexes and reasonably well-defined criteria of health. We have found no data in the literature that fulfill both requirements.

The present study was undertaken to (1) register the weights of brain, heart, liver, kidneys, and spleen, (2) estimate the variability of organ weights, (3) estimate the relationship between organ weights and body size, and (4) evaluate correlations among organ weights. In addition, the study attempts to use the results relative to observations on living subjects. The study was based upon 1,598 autopsied cases, who prior to death were healthy or apparently healthy according to clinical criteria.

## MATERIALS AND METHODS

According to Danish law, all cases of unexpected deaths, accidents, homicides, suicides, suspected crimes, and deaths due to occupational diseases are subject to a legal inquest to establish the cause and mode of death. In about one-third of these cases, a medicolegal autopsy is performed.

In the counties of Funen and Southern Jutland (population in 1988: 707,735), all of the medicolegal autopsies are performed at the Department of Forensic Medicine at Odense University. Information on the

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*TABLE 1. Composition of the sample: total number of autopsies of individuals ≥16 years, 1972–1990, 3,137: 2151 males, 986 females*

| Healthy | | Apparently healthy | | Others | |
|---|---|---|---|---|---|
| Males | 630 | Males | 456 | Diseased | 1,217 |
| Females | 334 | Females | 178 | Doubtful | 31 |
| | | | | Decayed | 291 |

health of the decreased is routinely obtained by the police from the general practitioner and relatives of the deceased, and is kept with the autopsy report in the files of the Department. From January 1, 1972 through December 31, 1990, a total of 3,137 autopsies were performed. The autopsy reports, including health information, were examined, and the reports of individuals ≥16 years of age were divided into the categories according to the following criteria (Table 1):

1. *Healthy subjects:* information from the general practitioner, positively stating that the deceased was "not ill."
2. *Apparently healthy subjects:* no statement from the general practitioner; relatives reported that the deceased was "not ill."
3. *Diseased subjects:* information from the general practitioner or relatives, positively reporting illness in the deceased.
4. *Doubtful cases:* lack of information concerning health status.
5. *Decayed cases:* cases unsuitable because of obvious putrefaction; cases in which more than two days had passed from the assumed time of death until the deceased was found.

The autopsies were performed within 2–5 days of death, and in the majority of cases within 2 days. Until the time of the autopsy, the deceased was kept in a morgue at a temperature of 5°C.

At autopsy, body height, measured as the length of the body, and body weight of the deceased were recorded. The weights of the brain, heart, kidneys, liver, and spleen were also measured. Weights were recorded to the nearest gram. Brain weight included the cerebrum, cerebellum, pons, and oblongate medulla, and included the intracerebral fluid. The heart was freed of the pericardial sac, emptied of blood including clots of blood adherent to the walls; the aorta and pulmonary trunk were cut close to the heart before weighing. The kidneys were freed of their capsules, and the ureters were cut close to the pelves before weighing. The liver was freed of the diaphragm and duodenum before weighing, and the weight included the gall bladder and biliary ducts. The portal and inferior caval veins were opened, emptied of blood, and cut as close to the liver as possible before weighing. The organs were

*TABLE 2. Age, body weight, height, and the body mass index % in the sample*[1]

| | Healthy | | | | Apparently healthy | | | |
|---|---|---|---|---|---|---|---|---|
| | Males | | Females | | Males | | Females | |
| | M | SD | M | SD | M | SD | M | SD |
| Age, years | 45 | 17 | 48 | 16 | 41 | 18 | 44 | 18 |
| Body weight, kg | 76 | 13 | 61 | 12 | 75 | 12 | 60 | 11 |
| Height, cm | 177 | 7 | 164 | 7 | 177 | 7 | 165 | 7 |
| Body mass index, kg/m$^2$ | 24.0 | 4 | 22.3 | 4 | 24.1 | 3 | 22.0 | 4 |

[1]The number of subjects in each group is shown in Table 1.

*TABLE 3. Brain weight (grams): difference between healthy and apparently healthy, % (P value)*

| | Males | | | Females | | |
|---|---|---|---|---|---|---|
| | *N* | M | SD | *N* | M | SD |
| Healthy | 600 | 1498 | 128 | 318 | 1332 | 112 |
| Apparently healthy | 401 | 1501 | 133 | 170 | 1301 | 111 |
| Difference, % (*P* value) | 0.2 | (>0.5) | | 2.4 | (<0.005) | |
| Healthy + apparently healthy | 1001 | 1499 | 130 | 488 | 1321 | 112 |

*TABLE 4. Heart weight (grams)* [1]

| | Males | | | Females | | |
|---|---|---|---|---|---|---|
| | *N* | M | SD | *N* | M | SD |
| Healthy | 626 | 423 | 87 | 334 | 320 | 67 |
| Apparently healthy | 454 | 398 | 76 | 176 | 301 | 65 |
| Difference, % (*P* value) | 6.2 | (<0.001) | | 6.1 | (<0.05) | |
| Healthy + apparently healthy | 1080 | 412 | 86 | 510 | 313 | 67 |

[1]Notation as in Table 3.

*TABLE 5. Spleen weight (grams): values in parentheses are the lowest weights in the groups in the upper 70, 80, and 90% of the samples*

| | Males | | Females | |
|---|---|---|---|---|
| | *N* | Median | *N* | Median |
| Healthy | 615 | 170 (220,245,305) | 318 | 120 (150,170,210) |
| Apparently healthy | 433 | 160 (190,220,270) | 172 | 110 (135,160,195) |
| Difference, % | | 5.9 | | 8.3 |
| Healthy + apparently healthy | 1048 | 167 (205,235,297) | 490 | 117 (142,167,205) |

*TABLE 6. Liver weight (grams)* [1]

| | Males | | | Females | | |
|---|---|---|---|---|---|---|
| | *N* | M | SD | *N* | M | SD |
| Healthy | 594 | 1851 | 442 | 310 | 1591 | 436 |
| Apparently healthy | 399 | 1742 | 381 | 152 | 1443 | 326 |
| Difference, % (*P* value) | 6.0 | (<0.001) | | 9.6 | (<0.001) | |
| Healthy + apparently healthy | 993 | 1807 | 422 | 462 | 1542 | 409 |

[1]Notation as in Table 3.

usually weighed as soon as they were freed of surrounding tissue, i.e., within 5 min. Fat-free mass and fat mass were estimated from body weight, height, age, and sex using the algorithms of Heitmann (1991).

## RESULTS

Based on the review of 3,137 subjects (Table 1), 1,598 adults (≥16 years of age) were considered "healthy" or "apparently healthy" prior to death and included in the study. In some of the autopsied cases, one or more of the organs were excluded because of laceration and loss of substance (traffic accidents, shootings) or because the organs were removed for organ donation. This accounts for the fact that the number of observations in Tables 3 through 7 is not the same.

The anthropometric characteristics of the 1,598 autopsied subjects are shown in Table 2. Means and standard deviations of organ weights are shown in Tables 3 through 7. Table 5, concerning the spleen weights, includes medians instead of means; the values were positively skewed to the right. Intercorrelations between organ weights are shown in Table 8. All correlations, except those between heart and brain, are significant ($P < 0.05$, most at $P < 0.01$).

Regressions of organ weights on body weight (BW), body height (BH), and age are shown in Table 9 with the corresponding root mean square residuals (RMS). Prediction of organ weights using BW, BH, and age does not materially diminish the standard deviations. Regressions of organ weights on estimated fat-free mass (FFM) are shown in Table 10 with corresponding root mean square residuals. As with BW, BH, and age, correction for FFM does not materially change the variation.

Differences in organ weights between males and females at given combinations of BW, BH, and age were calculated from the regressions shown in Table 9; results are shown in Table 11. In the three cases illus-

*TABLE 7. Weight of the kidneys (grams)* [1]

| | Males | | | Females | | |
|---|---|---|---|---|---|---|
| | *N* | M | SD | *N* | M | SD |
| Healthy | 581 | 326 | 67 | 297 | 260 | 55 |
| Apparently healthy | 392 | 309 | 60 | 158 | 246 | 51 |
| Difference, % (*P* value) | 5.3 | (<0.001) | | 5.5 | (<0.01) | |
| Healthy + apparently healthy | 973 | 319 | 65 | 455 | 255 | 54 |

[1]Notation as in Table 3.

*TABLE 8. Correlations among organ weights in healthy and apparently healthy males (M) and females (F)*

| | M | F | | M | F |
|---|---|---|---|---|---|
| Heart vs brain | 0.09 | 0.10 | Brain vs kidneys | 0.25 | 0.25 |
| Heart vs liver | 0.45 | 0.38 | Brain vs liver | 0.21 | 0.16 |
| Heart vs spleen | 0.29 | 0.30 | Brain vs spleen | 0.17 | 0.19 |
| Heart vs kidneys | 0.49 | 0.38 | Liver vs kidneys | 0.57 | 0.58 |
| Liver vs spleen | 0.39 | 0.36 | Spleen vs kidneys | 0.35 | 0.36 |

*TABLE 9. Regressions of organ weights (grams) on body weight (BW) (kg), height (BH) (cm), and age (yr)*

| Organ | Sex | Equation | RMS residual | $R^2$ |
|---|---|---|---|---|
| Brain | M | 867 + 0.68 BW + 3.70 BH − 1.66 age | 121 | 0.132 |
| | F | 778 + 0.64 BW + 3.42 BH − 1.24 age | 105 | 0.123 |
| Heart | M | −88 + 3.21 BW + 1.08 BH + 1.60 age | 66 | 0.414 |
| | F | −37 + 2.43 BW + 0.81 BH + 1.51 age | 45 | 0.335 |
| Liver | M | 449 + 16.7 BW + 1.72 BH − 4.36 age | 357 | 0.534 |
| | F | −293 + 13.5 BW + 6.7 BH − 1.9 age | 365 | 0.202 |
| Kidneys | M | −62 + 1.39 BW + 1.35 BH − 0.44 age | 57 | 0.225 |
| | F | 35 + 1.19 BW + 1.06 BH − 0.57 age | 50 | 0.150 |

*TABLE 10. Regressions of organ weights (grams) on estimated fat free mass (FFM) (kg)*

| Organ | Sex | Equation | RMS residual | $R^2$ |
|---|---|---|---|---|
| Brain | M | 1253 + 4.18 FFM | 126 | 0.055 |
| | F | 1009 + 7.20 FFM | 106 | 0.110 |
| Heart | M | 142 + 4.58 FFM | 78 | 0.169 |
| | F | 169 + 3.35 FFM | 65 | 0.065 |
| Liver | M | 117 + 28.78 FFM | 365 | 0.249 |
| | F | 190 + 31.6 FFM | 375 | 0.159 |
| Kidneys | M | 94 + 3.82 FFM | 58 | 0.191 |
| | F | 86 + 3.95 FFM | 50 | 0.135 |

trated, organ weights are higher in males than in females. Sex differences of organ weights for given values of estimated FFM were calculated from the regressions of Table 10; results are shown in Table 12. The sex difference of organ weights at given values of FFM shows higher weights in males than in females except for the liver. The weights of the kidneys are practically identical. The sums of organ weights are larger in the females. Standard errors of predictions of organ weights from estimated FFM are shown in Table 13.

## DISCUSSION

In order to use the organ weights of the 1,598 autopsied cases as Danish reference material, the cases should be representative of the whole population. Even if the population in the counties of Funen and Southern Jutland were representative of the Danish population, forensic autopsies would still, however, be subject to selective procedures by the different police constituencies due to a different policy concerning selection of autopsies. The majority of autopsied cases was Caucasian, and only a maximum of 3% was of other races. Means and standard deviations of body weight, height, and the body mass index of both men and women in the present sample were almost identical with corresponding values in a study of 2,987 Danish men and women who were nearly

*TABLE 11. Sex differences (M = males, F = females) in subjects grouped by weight (BW), height (BH), and age*[1]

| | Weight, height, and age group | | | | | |
|---|---|---|---|---|---|---|
| | I | | II | | III | |
| | M | F | M | F | M | F |
| Heart | 293 | 263 | 341 | 299 | 387 | 334 |
| Brain | 1375 | 1260 | 1433 | 1314 | 1488 | 1365 |
| Liver | 1363 | 1286 | 1555 | 1515 | 1744 | 1737 |
| Kidneys | 229 | 227 | 268 | 254 | 304 | 280 |

[1]I: BW = 50 kg, BH = 146 cm, and age = 40; II: BW = 60 kg, BH = 160 cm, and age = 40; III: BW = 70 kg, BH = 173 cm, and age = 40.

*TABLE 12. Sex differences (M = males, F = females) in subjects with estimated fat-free masses (FFM) of 50, 55, and 60 kg*

| | Estimated fat-free mass group (kg) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | FFM = 45 | | FFM = 50 | | FFM = 55 | | FFM = 60 | |
| | M | F | M | F | M | F | M | F |
| Heart | 348 | 320 | 366 | 336 | 384 | 352 | 402 | 368 |
| Liver | 1412 | 1612 | 1556 | 1768 | 1700 | 1924 | 1844 | 2080 |
| Brain | 1441 | 1333 | 1462 | 1369 | 1483 | 1405 | 1504 | 1441 |
| Kidneys | 266 | 264 | 285 | 284 | 304 | 304 | 323 | 324 |
| Sum of organ weights | 3467 | 3529 | 3669 | 3757 | 3871 | 3985 | 4073 | 4213 |

*TABLE 13. Standard errors of prediction of organ weights (grams) from estimated FFM (kg)*

| | | FFM (kg) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Organ | Sex | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| Liver | M | | 356 | 354 | 353 | 354 | 356 | 360 |
| | F | 371 | 365 | 366 | 373 | | | |
| Heart | M | | 83 | 82 | 82 | 82 | 83 | 84 |
| | F | 63 | 62 | 62 | 62 | | | |
| Brain | M | | 127 | 126 | 126 | 126 | 127 | 128 |
| | F | 107 | 105 | 106 | 108 | | | |
| Kidneys | M | | 56 | 56 | 55 | 56 | 56 | 56 |
| | F | 54 | 54 | 53 | 55 | | | |

representative of the Danish population (Heitmann, 1991).

Criteria of health. The criteria for inclusion of subjects into categories "healthy" and "apparently healthy" are, of necessity, somewhat arbitrary. They are, however, similar to those applied in the classical study by Boyd (1933), and more or less followed by Wald (1937).

The criteria for inclusion of subjects in the two categories of healthy and apparently healthy have not been used previously, since these criteria are based on clinical evidence only. Means and standard deviations for body weight, height, and the body mass index were practically identical in the two groups. Mean age was 4 years older ($P < 0.01$) in the healthy than in the apparently healthy groups (Table 2). Except for the brain, organ masses were generally larger, by 5–10%, in the healthy subjects than in the apparently healthy subjects. This was observed for both sexes, and we can offer no explanation for this difference.

Methods. The organs were usually weighed as soon as they were freed of the surrounding tissues. In order to estimate the loss of blood/evaporation from the organs on the dissection table, the organs from 20 autopsies were weighed immediately after removing the surrounding tissues, and the weights were compared to those obtained 15, 30, 45, and 60 min after removal. This showed a maximal loss of weight of 5% in the liver, and less in the other organs. The loss of weight was most pronounced during the first 15 min.

Regressions. The simple and multiple regressions should be interpreted with caution since not all of the variables can be expected

to be strictly randomly distributed. This is particularly true for spleen weights and, in this case, no regressions were calculated. Inclusion of BW, BH, and age as well as estimated FFM decreased the standard deviations in all cases, and this fact is useful for prediction. However, the effect was generally rather small. Since the independent variables, BW, BH, and age, are intercorrelated, the regressions cannot be used for interpretation of causes and effects.

Correlations. Correlations among organ weights were generally positive, relatively high, and significant. This is presumably related to the fact that organ masses are positively correlated to body mass and body height. The correlations among organ weights in subjects within a smaller body weight range were much lower.

Sex differences. The study confirms the well known fact that organ weights in males are larger than those in females. This fact should be interpreted in term of the generally larger body weight and height in males. An interesting observation is the differences between sexes when they are calculated for the same estimated FFM. In this case, the weights of the heart and the brain were smaller in females than in males, but weight of the kidney was the same, while weight of the liver was consistently larger in females than in males. The latter finding may be interpreted in terms of a metabolic cause and effect on liver weight of a larger fat mass, about 10–15 kg, in females with the same FFM. This interpretation is supported by the fact that the weight of the kidneys was the same.

Comparison with previous studies. In the present study, the concept of normality is based upon clinical evidence only, whereas previous studies of "normal" organ weights use criteria including both clinical observations and observations made in connection with the autopsy. Most of the studies referred to in this article date from the first half of this century. An evaluation of the decennial trend of body weight, height, and organ weights would be interesting, based on comparison of the present study with the previous studies on the subject. Comparisons, however, are impossible because of insufficient numbers in the samples and differences in defining health.

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