RENAL SIZE IN NORMAL CHILDREN

A RADIOGRAPHIC STUDY DURING LIFE

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The clinical value of measuring the size of the two kidneys has now received general acknowledgment. Among other things it has provided a means of studying the natural history of certain renal diseases in a manner not possible before. One of the important results of this study is the realization that a number of renal conditions which first draw attention to themselves in adult life have in fact been present since childhood. Examples are chronic pyelonephritis, certain types of ischaemic kidney, previously obstructed kidneys in which the obstruction has been relieved, and chronic glomerulonephritis. Measurement, of course, also provides a means of demonstrating bilateral enlargement of the kidneys such as occurs in polycystic disease and some of the lipid storage upsets.

When the study is carried into childhood these diseases can be seen to progress from an early stage, and it seems inevitable that prophylactic treatment of these early states will be regarded as the logical approach.

Using the commonest condition, chronic pyelonephritis associated with vesico-ureteric reflux as an example, it has been shown that if the disease is confined to one kidney, and even if this kidney is only slightly affected, it often ceases to grow or further growth is severely curtailed. When both kidneys are affected growth occurs on both sides, often unevenly and below the normal rate. In unilateral cases, therefore, by making use of the size of the affected kidney and the degree of hypertrophy on the sound side, the date of onset of the disease can be estimated in some cases with reasonable accuracy.

The bearing of renal size estimation on prognosis is still largely an unknown factor, but observations in cases of glomerulonephritis, nephrocalcinosis and back-pressure kidneys are already accumulating and may in the future form a logical basis for forecasting.

Simultaneously with the collection and publication (Karn, 1962) of a large series of kidney measure-

ments in normal adults, we have more slowly been accumulating data on normal children. The numbers collected are still not large, but the very gratifying correlations between kidney size, height and age that have emerged lead us to believe that there is sufficient evidence already on which to base an average size estimation, by which the abnormal can be judged.

The Measurements Used

These studies were carried out on the intravenous pyelogram, taken under standard conditions, of patients whose kidneys were regarded clinically and radiologically as normal, and except where specifically stated otherwise, the kidneys were those of children between 0 and 16 years. Where reference is made to 'adults', an age-group of 20-80 years is indicated. The age-group 16-20 years has not been included, as it appears to be a transitional stage for several variables.

The variables used were the patient's age, height and the average length and cross-sectional area of the two kidneys. The age was taken in years and months and the height in inches. The kidney measurements were taken from tracings of the intravenous pyelograms. The 'sectional area', in square centimetres, was the area of longitudinal cross-section in the coronal plane of the body, i.e. the kidney shadow that appears on the radiograph, and was measured by means of the compensation planimeter; the length, in centimetres, was taken as the maximum length of the kidney in the same plane. No attempt was made to calculate the volume of the kidneys, but it may be assumed that the volume is correlated to some extent with the sectional area. It has been shown (Hodson, 1960) that post-mortem kidneys of the same radiographic size and shape may differ in weight by as much as 20%, but it also seems likely that some shrinkage may occur at death, depending on several factors, so that post-mortem measurements cannot be taken

FIG. 1.—Histogram showing the distribution of cases with ages.

as a true representation of the living state (Hodson, 1961).

The series comprises 393 cases. In about 8% the data relating to patient height and weight were missing. No distinction has been drawn between right and left kidneys, the average values of the two being taken. A difference in length up to 5 mm. between the two was not infrequently observed.

Application of Statistics

For any set of figures it is possible to calculate the mean and standard deviations. From these, assuming a Gaussian distribution of the variables used, 68% of the results can be expected to lie within the range of 'mean plus or minus one standard deviation', 96% of the results within 'mean plus or

minus two standard deviations' and 99.4% of the results within 'mean plus or minus two and a half standard deviations'. Only six in a thousand will lie outside the limits of 'mean plus or minus two and a half standard deviations'. The practical application of these principles means that though the majority of the normal results will fall within the range of 'mean plus or minus one standard deviation', some will fall *outside* this range but *within* the range of 'mean plus or minus two and a half standard deviations', and these *cannot* be classed as abnormal on these grounds alone, although the possibility of abnormality will of course be increased. In all of the graphs relating to this series, the vast majority of readings fell within 'mean plus or minus one standard deviation', as

FIG. 2.—Graph of height of child against age.

FIG. 3a.—Graph of kidney length against age: 0-16 years, male and female together.

evidenced by Fig. 2 in which the actual readings obtained have been inserted. Almost identical distributions were obtained with all the other graphs. The lines to include both 'mean plus or minus one standard deviation' and 'mean plus or minus two and a half standard deviations' have been included on the graphs.

Another calculation that has been employed in these studies is the 'product moment' method of correlation which gives a measure of the numerical relation between two variables, lying between 0 for no relation, and 1 for perfect correspondence. The correlations obtained in these studies were high, mostly in the region of 0.8-0.9 for the children.

For a good statistical calculation it is important to have a large number of readings; in this set of data, although we have nearly 400 cases, there are comparatively few below 5 years or over 13 years of age, so that the mean values at these ages may be less truly representative (see Fig. 1).

Variation of Body Height and Kidney Size with Age

The data indicate a very close connexion between age and height, and age and kidney size. Between 4 and 15 years there is a steady mean increase of 0.35 cm. kidney length, and 2.0 in. (5 cm.) height per year, which declines between 16 and 20 years. This increase is after the manner of 'simple' rather than 'compound' interest; in fact, 'increase per unit per year', which is the rate of growth, will decline with increasing age from the earliest months. There was no statistically significant difference in height or kidney size between boys and girls between the ages of 0 and 14 years, although the girls had the wider range of variation. A similar result has been found by Stuart and Meredith (1946) for a number of body measurements.

Age/Body Height (Fig. 2). For the range 5 to 13 years, the slope of the graph of age against height may be found from the equation

$$y = 2.0x + 33.6,$$

where y is the body height in inches, and x the age in years. The standard deviation of height is 8.06 in. (20.3 cm.) and the correlation is 0.876. The total number of cases examined was 362. It should be noted that in the first three years of life, variability was very low and gradually increased to a maximum at about 15 years of age. On these readings the growth curves published by Stuart and Meredith working on American children give mean values of height up to 2 in. (5 cm.) greater in the first three years of life (Stuart and Meredith, 1946).

Age/Kidney Length (Fig. 3a and b). For the same range, 5 to 13 years, the slope of the graph of age against kidney length may be calculated from the equation

$$y = 0.379x + 6.65,$$

where y is the length of the kidney in centimetres and x the age in years. The standard deviation of length is 1.45 cm., and the correlation is 0.857. The total number of cases was 393.

Age/Kidney Sectional Area (Fig. 4). The kidney sectional area is less closely correlated with age than are height and kidney length, the correlation being 0.842; the standard deviation of sectional area is 10.5 cm., and the total number of cases was 393.

It may be noted from these three graphs that very rapid growth of both skeleton and kidney takes place in the first few years of life, and at the same time individual variability is greatly reduced. (There are, of course, fewer cases in these age-groups, so that the statistical means plotted in this

FIG. 3b.—Graph of kidney length against age: 0-16 years, male and female together; 16-80 years, male and female separately.

part of the graph may need to be modified slightly when further data are available; the readings already obtained were, however, very closely clustered and a reasonable degree of accuracy is thus to be expected.)

It is of interest that the readings for each age-group were most closely clustered for age/height, only 13 cases lying outside the range of 'mean plus or minus one standard deviation'. For age/

length, they were more evenly distributed throughout the range 'mean plus or minus one standard deviation', 17 cases lying outside; while for age/sectional area 28 cases lie outside this range.

Kidney Sectional Area/Body Height

It has been shown (Karn, 1962) that in adults there is a 1 : 1 regression of kidney sectional area in cm^2 against body height in inches. This cor-

FIG. 4.—Graph of kidney sectional area against age: 0-16 years, male and female together; 16-80 years, male and female separately.

FIG. 5.—Graph of kidney sectional area against body height, for men, women and children.

relation is also found in children, with the difference that in the latter the kidney sectional area is smaller by a constant area of about 10 cm.² for any given height than it would be for an adult of the same height. This does not indicate that the *volume* of the kidney will be smaller by a fixed amount since the thickness of the kidney will also vary with the length and sectional area, but we would expect the volume to be decreased by a constant *proportion*. For children the correlation is 0.847 and the standard deviation is 10.24 cm.² The slope of the graphs of height/sectional area may be found from the equations

$$y = 1.015x + 0.3 \text{ for men}$$

$$y = 0.900x + 4.55 \text{ for women}$$

$$y = 1.0126x - 9.272 \text{ for children,}$$

where y is the kidney sectional area in cm.² and x the body height in inches (Fig. 5).

Body Height/Kidney Length

Although some degree of correlation for these variables may be observed in adults, a much greater correlation is found in children (Fig. 6). Some factors accounting for this may be (a) the wider ranges of values involved, (b) that both body height and kidney length are closely connected with age in children, (c) that considerable changes may occur, and to a varying extent, in the 'build' of the body during adolescence after the main increase in height has ceased.

The slope of the graph of height/length may be found from the equation

$$y = 0.145x + 2.646 \text{ for children}$$

$$y = 0.1118x + 5.5194 \text{ for men}$$

$$y = 0.1888x + 0.628 \text{ for women.}$$

FIG. 6.—Graph of kidney length against body weight for children.

The correlation is 0.874 for children, 0.3097 for men and 0.5006 for women, and the standard deviation is 1.5 cm. for children and 1.0 for adults.

Kidney Length/Kidney Sectional Area

We have found that if the regression lines for kidney length/kidney sectional area of adults are extended in both directions they include not only the readings for children, but also over 90% of those hypertrophied kidneys which are otherwise morphologically normal. The conclusion is that the length of a kidney is a fair indication of its total size in the absence of any morphological abnormality. The regression lines from the children's data alone have a slightly different slope, probably because of the more rapid growth in early childhood, and it is probably more accurate to take the adults' slope as a representation of the whole picture (Fig. 7). This slope may be found from the equation

$$y = 7.23x - 29.37,$$

where y is the sectional area in cm.² and x the kidney length in centimetres. The correlation is 0.751 and the standard deviation is 9.83 cm.²

Body Surface Area/Kidney Sectional Area

It was found that these variables were very closely correlated, the correlation for children being 0.9027. In adults the correlation was also good, though less marked, being 0.4129 in men and 0.291 in women. The regression lines for men and children were almost parallel, being obtained from the equations

$$y = 28.47x + 12.0 \text{ in children}$$

$$y = 29.0047x + 16.62 \text{ in men}$$

$$y = 20.68x + 28.526 \text{ in women,}$$

FIG. 7.—Graph of kidney sectional area against kidney length in adults.

where y is the kidney sectional area, and x the body surface area. The standard deviations were 9.94 cm.² for children, 11.21 cm.² for men and 9.58 cm.² for women.

It may be noted that the graph (Fig. 8) gives a constantly smaller sectional area for any given body surface area on the line for children when compared with that for men, and this may be compared with the graph for sectional area against height. The height is, of course, one of the factors used in estimating the body surface area by the method of Du Bois and Du Bois (1916), the other factor being the body weight.

Conclusions

We may conclude from these studies that in

children there are close correlations between age, body height and kidney length and sectional area, for each pair of variables. These are not all direct functional correlations, but in most cases depend basically on the total growth rate of the child. In many statistical measurements in man, such as those connected with human genetics, one does not expect a correlation greater than 0.5-0.6, whereas in these studies we have obtained correlations of the order of 0.8-0.9. This argues strongly the presence of functional connexions. It has been shown that in the normal kidney length is a good guide to kidney size, and this is particularly useful since it can be measured directly from the x-ray film. The size of the kidney depends largely on the size of the child, and for this body height is probably

FIG. 8.—Graph of kidney sectional area against body surface area, for men, women and children.

the most reliable guide since it is less liable to rapid fluctuations than is body weight.

It is interesting to note that the slope of the graphs of body height against kidney length and sectional area is the same for both adults and children. The constantly smaller kidney size in children may be due to the 'filling out' of the body which develops in late adolescence after increase in height has almost ceased. Further evidence for this theory is given by the observations of Stuart and Stevenson (1954), who found that during adolescence gain in weight was relatively greater than gain in height, and also that the continuing gain in weight persisted for a longer time than gain in height. They noted a wide variability in the timing of the period of maximum growth during adolescence (Stuart, 1946).

Summary

The normal pyelogram films of nearly 400 children between the ages of 0 and 16 years have been

analysed. Close correlations were found between age, body height, and length and cross-sectional area of the kidneys.

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