W. M.

REPORT

of

COMMITTEE ON EXAMINATION

This is to certify that we the undersigned, as a Committee of the Graduate School, have given John Asdal Kittelson final oral examination for the degree of Master of Arts. We recommend that the degree of Master of Arts be conferred upon the candidate.

Minneapolis, Minnesota

May 30 1917

C. M. Jackson
Chairman

E. T. Bell

Thomas G. Lee

REPORT

of

Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by John Asdal Kittelson for the degree of Master of Arts. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts.

C. M. Jackson
Chairman

E. T. Bell.

Thomas G. Lee

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The Postnatal Growth of the Kidney in the Albino Rat.

A Thesis

Submitted to the Faculty

of the

Graduate School

of

The University of Minnesota

by

John A. Kittelson

In partial fulfillment of the requirements for

the degree

of

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The Postnatal Growth of the Kidney of the Albino Rat.

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Minneapolis.

CONTENTS.

I. Introduction.

Many questions concerning the postnatal growth of the kidney are still unsettled. In the rat, the postnatal growth curve of kidney weight in relation to body weight was worked out by Hatai ('13) and Jackson ('13). Waschetko ('14) determined the number of Malpighian corpuscles per cubic millimeter of cortex in the Albino rat at various ages from birth to five weeks. The relative growth of cortex and medulla and the total number of Malpighian corpuscles in the kidney at various ages are the special problems for which data have been collected in the present investigation.

The work was done in the Anatomical Laboratory of the University of Minnesota. The problem was suggested by Prof. C. M. Jackson and carried out under his supervision. I wish to thank Dr. Jackson for his valuable suggestions and criticism. I also wish to thank Dr. E. T. Bell, Department of Pathology, for suggestions and aid in some related work on the human kidney, a few observations on which are incidentally included in the present work.

II. Literature.

Huschke ('28) was apparently the earliest worker to estimate the total number of Malpighian corpuscles in the human kidney. He found the number to be 2,100,000 (according to Schweigger-Seidel).

Schweigger-Seidel ('65) separated the cortex from the medulla in the pig's kidney and obtained the following weights:

Weight of cortex........................102.0 grams.
Weight of medulla...................... 12.5 grams.
Weight of fat and connective tissue in sinus renalli........................ 6.0 grams.

He then took a section of cortex weighing 15.5 centigrams and macerated it with hydrochloric acid. He isolated and counted directly the Malpighian corpuscles, finding 720 in this piece of kidney. From these data he calculated that there would be 46.4 Malpighian corpuscles in one centigram or about 500,000 in the 102.0 grams of cortex. He found the cubical content of the cortex to be 99,000 cubic millimeters, corresponding therefore to somewhat more than five Malpighian corpuscles per cubic millimeter of cortex in the pig. In man he estimated that there would be normally about six Malpighian corpuscles per cubic millimeter of cortex. According to Herring ('00), he divided the growth of the kidney into two periods: embryonal and postembryonal. In the embryonal period, growth takes place by apposition of new elements and by increase in size of material already formed. In the post-embryonal period, the formation of new elements has ceased and growth now takes place by an increase in size only.

Toldt ('74) found that in the human kidney up to eight or ten days after birth, the number of Malpighian corpuscles increases in the whole periphery of the cortex. He gave measurements of the thickness of cortex and medulla, indicating that they are about equal in the two months' embryo. The medulla increases much more rapidly, however, so that at birth the cortex is only 21.5 per cent of the medulla. The postnatal cortex increases regularly, so that at three months it is 27.4 per cent of the medulla; at thirteen months it is 25 per cent; at two years 30 per cent; at seven years 45 per cent; and at 22 years it is 56 per cent of the medulla.

Eckardt ('88) found that the total volume of the human kidney increases from 6.5 cubic centimeters at birth to 120 cubic centimeters in the adult female and 130 cubic centimeters in the adult male. He found no increase in the number of Malpighian corpuscles after the end of the fetal period. Using a microscopic field of constant area, he found the number of Malpighian corpuscles per field decreased from 122.1 in the newborn to 9.35 in the adult female and to 10.36 in the adult male. He noted, however, that the average diameter of the Malpighian corpuscles increases from 84.77 micra in the newborn to 195.80 micra in the adult female and 213.49 micra in the adult male; also that the diameter of the tubuli contorti increased from 37.63 micra at one year to 64.76 micra in the adult female and 54.76 micra in the adult male. He concluded that the tubuli contorti increase both in thickness and length for the first year; while after that period the increase is mostly in length.

Sappey ('89) counted the number of Malpighian corpuscles in cross sections and in longitudinal sections of lobules in the human kidney, and estimated the number of corpuscles in a lobule at about one hundred. He then found that one square centimeter of cortex represents 80 lobules and that one lobe represents seven square centimeters or 560 lobules. Assuming that the entire kidney contains ten lobes, he estimated a total of 560,000 Malpighian corpuscles (or glomeruli) in one kidney.

Miller and Carlton ('95) found the cortex of the kidney in the cat to form 0.700 of a fresh kidney, 0.641 of a kidney hardened in Müllers fluid and 0.633 of a kidney injected with blue gelatin and hardened in alcohol. Cortex and medulla were distinguished by the difference in color and by the position of the arcuate vessels. Small pieces were taken from different regions of the cortex of one kidney and the number of Malpighian corpuscles counted in each piece. These data together with the weight of the pieces used and the weight of the cortex were used in determining the total number of Malpighian corpuscles. This was estimated to be about 16,000 in one adult kidney.

Külz ('99) found that the cortex of the human kidney could be divided into an outer and an inner zone according to the diameter of the Malpighian corpuscles. At birth, he found the average diameter of the Malpighian corpuscles in the outer zone to be 99 micra, and in the inner zone 138 micra. He further found that while the Malpighian corpuscles of the inner zone showed no growth up to 2-1/4 years of age, those of the outer zone showed a rapid increase in diameter, so that at 2-1/4 years of age the average diameter of the Malpighian corpuscles in both zones was equal, being 138 micra.

Counting the Malpighian corpuscles per field in the two zones, and using a microscopic field of constant area, Külz found five times as many Malpighian corpuscles per field in the outer zone. In the growing kidney he found regions which are more thickly beset with Malpighian corpuscles than others, a condition which disappears in the adult kidney. He claimed that the tubuli contorti double both diameter and length between birth and adult life. He compared the growth of the kidney with the growth of the body and found that for the first 2-1/4 years the kidney grows more slowly than the rest of the body. For the first year, the body increases its weight three times while the kidney increases its weight only twice. In comparing the thickness of cortex and medulla he found the relationship to be 1:5 in the newborn and 1:3 to 1:2 in the adult.

Herring ('00) found that the connective tissue is relatively large in amount in the human early fetal kidney but diminishes to a relatively slight amount at birth. He further found that new Malpighian corpuscles were continually being added up to the end of the eighth or beginning of the ninth fetal month. Thereafter no new corpuscles are formed, although in the newborn some might still be imperfectly formed. He thought that the postnatal growth of the medulla is due to increase in length of the collecting tubules and to the descent of Henle's loops.

Hauch ('03) in newborn and children found the length of the pyramids to be 1/4-1/6 of the length of the kidney, while in adults the length of the pyramid is 1/8-1/12 of the length of the kidney. He observed great increase in cortical mass from birth to seven years. In tables on measurements of cortex and medulla in cross section, he showed great variation in the same individual, using right and left kidneys, and even when measuring different parts of the same kidney.

Stoerk ('04) discussed the general mode of growth in the human fetal kidney, stating that from the eighth month to birth there is no further new formation of Malpighian corpuscles and tubules, the increase being in length and thickness of those already formed.

Peter ('07) studied the kidneys of the rabbit, cat and man, using the isolation method by hydrochloric acid. He estimated the total number of uriniferous tubules to be 250,000 (200,000-300,000) in the cat.

Peter ('09) gave further data on the kidney of the mouse, rabbit, cat, sheep, dog, swine and man. The kidneys were studied both by isolation methods and by sections. No new data on the number of Malpighian corpuscles or volumetric data on cortex and medulla were given.

Policard ('09) summed up the previous data on the number of uriniferous tubules or Malpighian corpuscles in the accompanying table.

Table by Policard ('09)

Espèces	Nombre de tubes urinaire	Auteurs
Homme	2,000,000	Schweigger-Seidel
Homme	560,000	Sappey
Chien	300,000	Peter
Porc	500,000	Huschke
Chat	160,000	Miller et Carlton
Chat	1,024	Peter

Corrected table

Species	Number of tubules	Authors
Man	2,100,000	Huschke
Man	560,000	Sappey
Pig	500,000	Schweigger-Seidel
Cat	200,000-300,000	Peter
Cat	16,000	Miller and Carlton

In this table there is a series of apparent errors, as shown by the accompanying corrected table. The names of Huschke and Schweigger-Seidel are evidently interchanged. Then a zero has been added to the number of Malpighian corpuscles given by Miller and Carlton ('95) changing the number from 16,000 to 160,000. Peter ('09) found the number of uriniferous tubules in the cat to be 200,000-300,000 instead of 1,024, and I cannot find his estimate of 300,000 uriniferous tubules in the dog as quoted by Policard ('09).

Felix ('12) stated that the formation of new collecting tubules ceased at the end of the fifth fetal month. The formation of uriniferous tubules, on the other hand, continues up to the tenth day after birth. The youngest corpuscles lie close beneath the capsule till about the tenth day, when the tubuli contorti of the last generation begin to grow out and form the outermost layer of the cortex - cortex cortices - which contains no Malpighian corpuscles. Concerning the growth of cortex and medulla a series of growth periods may be detected from the fifth fetal month to birth. During fetal development, the medulla grows principally. It enlarges its transverse diameter on the average of 100 per cent and in thickness, at the same time, only 20-25 per cent. According to Felix, there is little or no growth of the medulla from birth to seven years of age, while the cortex shows regular growth. After seven years, they both grow equally and double their diameter by the age of puberty.

Hatai ('13) worked out formulas and curves of postnatal growth in absolute weight for the various organs, including the kidney, of the albino rat.

Jackson ('13) investigated the relationship between kidney weight and total body weight for the normal albino rat of various ages. He also worked out the coefficient of variation in organ weights, including the kidney, and the coefficient of correlation between organ weight and body weight for various ages.

Waschetko ('14) investigated the relative number of Malpighian corpuscles in the kidney of the albino rat at birth, one, two, three, four and five weeks. He used microscopic sections 10 micra thick, with a microscopic field of 0.2209 square millimeter area, corresponding to 0.002209 cubic millimeters. He then determined the average number of Malpighian corpuscles in this field for the various kidneys, and estimated the number of corpuscles per cubic millimeter, finding a decrease from 1125 at birth to 567 at five weeks.

Donaldson ('15) has compiled the previous work done on growth of the albino rat and its various organs, including the weight of the kidney from birth to adult.

III. Material and Methods.

The material used included the kidneys of five albino rats (Mus norvegicus albinus) from the colony in the Anatomical Laboratory. The general data are given in table 2.

The identification numbers of the rats are used as follows. The letter "V" (Vaughn) indicates the series, the number preceding the decimal point is the litter number, while the number following the decimal point designates the individual rat. Possible variations due to sex were included by using three female and two male rats. Their ages were newborn, two, three, seven and twelve weeks.

The rats were killed by chloroform and weighed, their nose-anus and tail lengths also being measured. Both kidneys were weighed together and the weight of each kidney used assumed to be one-half of the combined kidney weight. Of the five rats used, three were females and two males. Three of the five were from the same litter (V1). The twelve weeks rat was assumed to be adult, so far as the absolute number of Malpighian corpuscles and the adult ratio of medulla to cortex were concerned. It was realized, however, that there would be some increase in the absolute volumes of medulla and cortex, and in the total volume of the Malpighian corpuscles between twelve weeks and the fully adult stage.

One kidney (no record of whether right or left) from each rat was fixed in Zenker's fluid for 18 to 24 hours. They were then embedded in paraffin and cut in serial cross sections at ten micra in thickness. They were then mounted in complete series, and stained with haematoxylin and eosin.

The method used in obtaining the total volume of medulla and cortex was the paper method similar to that used by Hammar ('14) in his volumetric work on the thymus, and by Jackson ('17) in his work on the hypophysis. The sections were enlarged by means of a Leitz-Edinger projection apparatus and the outlines of medulla, cortex and pelvis were drawn on "American Linen Record" paper (sheets 18 x 23 inches, 36 lbs. per ream). The paper outlines of cortex and medulla were then cut out and weighed, the results being shown in table 1.

It was necessary, however, to find the area corresponding to a given weight of the paper. To find this, samples were taken from 100 sheets of the paper. Each sample consisted of four pieces (one from each corner of the sheet), each five centimeters square, amounting to 100 square centimeters. The 100 samples weighed 122.85 grams or one sample (100 square centimeters) weighed 1.2285 grams. From this it is readily seen that one gram of paper corresponds to 81.400 square centimeters of area. The total weight of medulla or cortex in paper is therefore multiplied by 81.4 to obtain the corresponding area. This magnified area in square centimeters was then divided by the square of the magnification to reduce it to actual area. The actual area multiplied by the thickness of the section (or sections, since every other section or every fourth section was used) gives the actual volume of medulla or cortex in each case (tables 1 and 2).

In table 2, the volumes of the kidneys appear much smaller than might be expected from the corresponding weights. This difference is due to three factors: (1) the volume of the capsule and of the renal-sinus (pelvis), both of which were excluded; (2) shrinkage of material in the process of preparation; (3) the specific gravity of the kidney, making the volume (in cc.) less than the corresponding weight (in g.).

In counting the Malpighian corpuscles in mounted sections, a two-fold problem is presented. The corpuscles of varying sizes must all be counted once and none must be counted more than once. In order to count them all at least once, it is only necessary to cut the sections so thin that they are thinner than the diameter of the smallest Malpighian corpuscle. In the newborn rat, the smallest Malpighian corpuscles were found to be about 20 micra in diameter, hence sections cut at 10 micra would be certain to section every Malpighian corpuscle at least once.

In order to be certain that no Malpighian corpuscles were counted more than once, Miller and Carlton ('95) used the following method: The average diameter of the Malpighian corpuscles was determined, and sections of a piece of cortex, cut at about the average diameter obtained. Section 1 was then projected by a camera lucida and the Malpighian corpuscles marked by dots. Section 2 was then drawn upon the drawing of section 1 and the Malpighian corpuscles coinciding in both sections noted and eliminated.

In my work this method was modified as follows. The work was done by the use of a Leitz-Edinger projection apparatus. A projected image of any given section, say section 1, was drawn and the Malpighian corpuscles indicated by circles (black). When the drawing was finished, the next section to be drawn, section 2, was projected on the drawing of section 1. Drawing 1 was then made to fit projection 2 and, this accomplished, drawing 1 was fastened securely. A sheet of carbon copying paper (similar to that used in typewriting) was then placed over drawing 1 and a fresh sheet of drawing paper placed over the carbon paper. Section 2 was then drawn on the fresh sheet of drawing paper, at the same time being automatically transferred to drawing 1 as a carbon copy in different color (blue). Now everything that coincides in the two sections also coincides in the two drawings, and the color of any isolated corpuscle tells to which section it belongs. By using this method the Malpighian corpuscles were seen in the drawings in three ways: (1) as double circles, one circle blue the other circle black; (2) as single blue circles; and (3) as single black circles. All the double circles were drawings of corpuscles which occurred in both sections and were not counted, since they had already been counted once. The single blue circles represented the first section of a corpuscle and a single black circle represented the last section of a corpuscle. Hence, the total number of all the single blue circles in all the drawings would equal the total number of Malpighian corpuscles in the kidney. The total number of all the single black circles in all the drawings would also equal the total number of Malpighian corpuscles in the kidney. The method, therefore, gives a check on itself as well as the total number of Malpighian corpuscles in the kidney.

Imperfect sections were avoided whenever possible. When a wrinkled section had to be used, the resulting displacement of the double drawings was measured and the displacement of the Malpighian corpuscles was checked against the displacement of vessels and section outlines. The result was also checked up under the microscope.

IV. Data and discussion of postnatal growth of the kidney.

1. Growth of kidney as a whole in comparison with body growth.

The gross body weight and the weight of both kidneys of the rats used correspond rather closely to normal rats of the same sex and body length as worked out by Hatai ('13) and Jackson ('13). The differences in weight between both kidneys of the rats used and both kidneys of normal rats of the same sex and body length (as shown by the tables of Donaldson ('15) are as follows. The kidneys of the newborn rat are 0.003 gram above normal weight; those of the two weeks rat 0.001 gram above; those of the three weeks rat 0.036 gram below; those of the seven weeks rat 0.012 gram below; those of the twelve weeks rat 0.082 gram above. These differences are all small. The largest relative difference occurs at three weeks (0.036 gram). However, the coefficient of variation in kidney weight is greatest at three weeks as shown by Jackson ('13). It is evident that the above variations are all well within the limits of normal variation.

As shown in table 2, the kidneys in the present series increase in weight nearly 25 times from birth to twelve weeks, while the gross body weight increases, in the same period, only 23.5 times. In table 6, however, it is seen that the increase in kidney volume is not regular but that it increases an average of 118.5 per cent per week for the first two weeks, then falls gradually to only 18.0 per cent per week (in three to seven week period) and finally is followed by a period of greater activity, 28.6 per cent per week (seven to twelve week period). Table 6 also shows that only for the first two weeks is the per cent of increase of kidney volume above that of gross body weight.

This agrees well with the findings of Hatai ('13) and Jackson ('13) who have shown that the weight of the kidneys of the albino rat increases relatively more rapidly than the gross body weight for the first three weeks of life.

Eckardt ('88) found that the human kidney increased 3.2 times in volume during the first year, thus increasing slightly more than the gross body weight which increases three times in the same period. Külz ('99) found, however, that the human kidney increases its weight only two times in the first year.

Thus, while my observations on this point are too few to have any special significance, the kidneys used are evidently of normal weights, and the relations between kidney weight (and volume) to body weight at the various periods agree fairly with the established norms.

2. Growth of cortex and medulla.

As seen in tables 2 and 6, the cortex increases from 9.9205 to 29.7860 cubic millimeters, or at the rate of 9.93276 cubic millimeters per week from birth to two weeks. This is an increase of about 100 per cent, in comparison with the initial volume of the cortex. For the whole kidney, however, the corresponding increase per week amounts to about 118.5 per cent of the initial volume; so that the cortex, in spite of its rapid growth, falls behind the rate of growth of the whole kidney. The gross body weight, on the other hand, increases at the rate of only 63.5 per cent, so that both kidney and cortex grow faster than the body during this period.

Between the ages of two and three weeks, the cortex shows a total increase of about 50 per cent, showing a considerable decrease in growth rate compared with the preceding period. The whole kidney also shows a decrease in growth rate, falling from 118.5 to 71.0 per cent. The gross body weight, on the other hand, shows a growth rate increasing from 63.5 to 91.0 per cent.

Between three and seven weeks, the cortex shows a total gain of 44.67560 cubic millimeters and an increase per week of about 25 per cent of the initial volume. This is considerably above the rate of increase per week for the whole kidney (18 per cent), but only slightly above the rate of increase per week of gross body weight (24.3 per cent).

In the period between seven and twelve weeks, the cortex gains 128.656 cubic millimeters and its rate of increase per week is 28.6 per cent of the initial volume. This equals the rate of increase per week for the whole kidney. The rate of increase per week of the body weight is, however, 34.8 per cent.

The greatest rate of increase of the cortex, therefore, is during the first two weeks of life in the rat. The activity of growth in the cortex then decreases up to seven weeks after which time it shows a slight increase. Compared with the growth of the whole kidney, the cortex grows more slowly up to three weeks, after which it exceeds (three to seven weeks) then equals (seven to twelve weeks) the average rate of increase for the whole kidney. Compared with the rate of increase in gross body weight, the cortex grows more rapidly for the first two weeks. During the third week the cortex gains at a lower rate than the body; then their rates of growth are about equal (three to seven weeks), and finally the body grows at a more rapid rate than the cortex.

Hauch ('03) observed, in the human kidney, great increase in cortical mass from birth to seven years. Felix ('12) stated that the cortex shows regular growth from birth to seven years and that after seven years cortex and medulla grow equally and double their diameter by puberty.

The medulla of the rat's kidney (tables 2 and 6) from birth to two weeks increases from 3.2504 to 14.7160 cubic millimeters, or at the rate of 5.73271 cubic millimeters per week. This average increase per week is about 176 per cent of the initial volume. During this period, the medulla has a higher average rate of increase than either gross body weight, kidney as a whole or cortex.

Between the ages of two and three weeks, the medulla increases 16.8692 cubic millimeters or 107 per cent. During this week the growth of the medulla is greater than that of the cortex, both relatively and absolutely. Its rate of growth is also higher than that of either the whole kidney or the body.

Between the ages of three and seven weeks, the medulla adds only 2.68170 cubic millimeters and ~~the~~ its average increase per week is lowered to 8.7 per cent of the initial volume. Its average rate of increase for this period is far below that of either body, kidney or cortex.

Between seven and twelve weeks, the medulla increases on the average 13.05152 cubic millimeters in volume per week. Its average weekly increase is now 32.3 per cent, which is higher than that of either cortex or kidney and almost equals the rate of increase in body weight for this period.

The growth of the medulla in the kidney of the albino rat accordingly appears more varied than the growth of the cortex. Its rate of increase per week exceeds that of both cortex and kidney except in the three to seven weeks period. The growth rate of the medulla (weekly increase percentage) decreases between birth and seven weeks from about 176 per cent to 8.7 per cent, increasing to an average of about 32 per cent in the period between seven and twelve weeks.

According to Toldt ('74), the medulla in the human fetus increases much more rapidly than the cortex, so that at birth the diameter of the cortex is only 21.5 per cent of that in the medulla. Postnatally, however, the medulla falls behind, so that at three months the cortex is 27.4 per cent of the medulla, at thirteen months it is 25 per cent, at two years 30 per cent, at seven years 45 per cent and at 22 years it is 56 per cent of the medulla (linear measurements).

According to Felix ('12), there is in the human kidney little or no growth of the medulla from birth to seven years, while thereafter both cortex and medulla grow equally and double their diameter by puberty.

The ratio between the volumes of medulla and cortex (table 2) changes from 1:3.05 at birth to 1:2.00 at twelve weeks. This relative increase on the part of the medulla, however, is rather varied. At two weeks, the ratio has changed to 1:2.02, showing a relatively greater growth in the medulla, which continues for the third week, the ratio then being 1:1.50. At seven weeks, however, a relative increase in cortical growth has restored the ratio of medulla and cortex to 1:2.10, which remains nearly the same (1:2.00) at twelve weeks.

The relative growth of cortex and medulla may also be seen by comparing the volume of each with the corresponding total body weight. An arbitrary index is thus obtained, as shown in the last two columns of table 2. The growth of the cortex thus appears to conform in general to that of the whole body, although there is a moderate increase between birth and two weeks, followed by a slight decrease thereafter. The medulla, however, shows a more varied growth rate. It doubles its growth index (compared with the entire body weight) between birth and two weeks, continuing its relative increase to a maximum at three weeks. Thereafter it shows continuous and rather marked decrease, indicating that its growth lags behind in comparison with that of the whole body.

Jackson ('13) has shown that kidneys of the albino rat (postnatal) at first increase in weight more rapidly than the body, increasing from 0.96 per cent of the body at birth to a maximum of 1.44 per cent at twenty days, decreasing thereafter to 1.03 per cent at ten weeks. The data from the present investigation indicate that this early rapid increase in weight (up to three weeks) is due chiefly to growth of the medulla, the relative increase of cortex being less marked during the corresponding period. The later decrease in the relative weight of the kidney likewise appears to be due chiefly to decrease in the growth rate of the medulla, since the growth rate in the cortex is more uniform.

Miller and Carlton ('95) found the total cortical volume in the fresh kidney of the adult cat to be 12.5 cubic centimeters and the volumetric ratio between medulla and cortex to be 3:7 (or 1:2.33). In hardened kidneys the ratio was more nearly 1:2.

Schweigger-Seidel ('65) gave the weight of the cortex, in an adult pig's kidney, as being 102.0 grams (volume of 99,000 cu.mm.) and the weight of the medulla 12.5 grams. This gives a ratio of medulla to cortex in the adult pig of about 1:8 by weight. The pig, however, has been characterized by Peter ('09) as having relatively an extremely large cortex.

Toldt ('74), Külz ('99) and Hauch ('03) have studied the relationship of medulla and cortex in human material of various ages, making linear measurement of medulla and cortex from cross and longitudinal sections of the kidney, as shown in table 3. The ratio of medulla to cortex is four or five to one at birth and about two to one from the age of twelve years on. That is, the cortex appears to increase much more than the medulla. Such linear measurements, however, are not conclusive in showing the actual ratio between medulla and cortex, and are apt to be misleading as an index to total volumetric or weight relations.

As a matter of fact, in work now in progress in an adult human kidney, I find the ratio between medulla and cortex to be about 1:2 (by volume).

In general, therefore, it appears that in the kidney of the rat the volumetric ratio between medulla and cortex changes from about 1:3 in the newborn to 1:2 in the twelve weeks rat. This is about equal to the ratio in the human adult kidney, the earlier relations being uncertain. In the adult cat the volumetric ratio of medulla to cortex is similar (Miller and Carleton). In the pig the cortex appears relatively enormous, the ratio of medulla to cortex being about 1:8 (by weight).

3. Growth of the Malpighian corpuscles.

a. Total number of corpuscles at various ages.

As shown in table 2, the total number of (fully developed) Malpighian corpuscles apparently increases from 10465 in the newborn to 28863 at twelve weeks. In addition to these, however, 5068 developing Malpighian corpuscles were observed in the newborn kidney and about thirty in the two weeks kidney, but none in the three older kidneys. This seems to show that although the process of new formation had not yet entirely ceased at two weeks, it had become very slow. Since a developing Malpighian corpuscle is usually so large and distinct that it can hardly be overlooked when searched for, I am forced to conclude that the relatively small apparent increase in the number seen after the third week is probably due to individual variation. If this be true, the permanent number of Malpighian corpuscles in the albino rat might be placed at about 27800, which is the average of the numbers given in table 2 for the rats at three, seven and twelve weeks. In round numbers, this would be about 28,000.

Miller and Carlton ('95) estimated the number of Malpighian corpuscles in the cat's kidney to be 16,000 which appeared too low.

Peter ('09) estimated for the cat the number of tubules to be 250,000 in one kidney. Schweigger-Seidel ('65) estimated the total number of Malpighian corpuscles in the pig to be 500,000. Huschke ('28) calculated the total number of Malpighian corpuscles in the human kidney to be 2,100,000. Schweigger-Seidel ('65) considered this estimate impossible, since the cubical content of 2,000,000 corpuscles, at an average diameter of 0.200 millimeter would equal one-eighth the total kidney volume. Sappey ('89) estimated the total number of corpuscles in one human kidney at 560,000.

In some work on an adult human kidney (still in progress), I have measured the volume of the entire cortex and have counted the Malpighian corpuscles in serial sections of several measured pieces taken from different parts of the cortex. From the data thus obtained I estimate that the number of corpuscles in the entire cortex of one kidney is about 1,040,000, or, in round numbers, one million. This number is intermediate between the estimates of Huschke and Sappey.

The time when the Malpighian corpuscles cease to appear in the kidney of the rat, according to the data above mentioned, must be some time during the third week after birth. A few newly-developing corpuscles appeared at two weeks, but none at three weeks of age. This would place the date of cessation in the new formation of renal corpuscles slightly later than that given by Riedel ('74), who stated that in the mouse and other animals born blind the new formation of corpuscles continues during the first two weeks of postnatal life. As to the human kidney, opinions may be divided into two groups. According to Toldt ('74) and Felix ('12), the new formation continues during the first week or ten days after birth.

According to Herring ('00) and Stoerk ('04), on the other hand, the new formation ceases during the late fetal period, about the eighth or ninth month.

b. Number of corpuscles per cubic millimeter.

The number of Malpighian corpuscles per cubic millimeter of cortex in the rat at the various ages is shown in table 2. There is a steady reduction in the number per cubic millimeter from 1057 at birth to 131 at twelve weeks, considering only fully formed Malpighian corpuscles. If the developing Malpighian corpuscles are counted with those fully formed, the number per cubic millimeter at birth is 1586. This is in general agreement with the results of Waschetko ('14) who found in the albino rat kidney a decrease of Malpighian corpuscles per cubic millimeter from 1125 at birth to 567 at five weeks. Eckardt ('88) first noticed this reduction in the human kidney, where he found, in the same microscopic field area, an average of 122.1 Malpighian corpuscles in the newborn and only 9.35 in the adult.

The number of Malpighian corpuscles per cubic millimeter of cortex therefore steadily decreases from birth to adult life. This seems to be true both in the rat and the human. This is due partly to the growth of the corpuscles themselves, but chiefly to expansion of the convoluted tubules.

c. Diameter and volume of the Malpighian corpuscles.

Table 4 shows the average diameter of the Malpighian corpuscles in the twelve weeks rat to be 0.075 millimeter (average of thirty measurements). Calculating the volume of one Malpighian corpuscle, using the formula $\frac{4}{3}\pi r^3$, and multiplying the result by the total number of Malpighian corpuscles in the kidney, I find the total volume of the corpuscles in the twelve weeks rat to be 6.63 cubic millimeters.

Miller and Carlton ('95) found the average diameter of the Malpighian corpuscles in an adult cat to be 0.1027 millimeter, or about 13.6 times that of the rat, but owing to their extremely low estimated number of Malpighian corpuscles, the resulting total volume of the corpuscles is only 9.04 cubic millimeters. Peter ('07) found a slightly larger average diameter (0.124 mm.) of the Malpighian corpuscles in the cat's kidney, but he estimated the number of corpuscles at 250,000. He consequently obtained a much greater total volume of the corpuscles, amounting to 141.37 cubic millimeters.

Schweigger-Seidel ('65) estimated average diameter of the Malpighian corpuscles in the human adult kidney at 0.200 millimeter. Using the two estimates of the total number of Malpighian corpuscles in the human kidney, Huschke's ('28) of 2,100,000 and Sappey's ('89) of 560,000, we obtain total volumes respectively of 8796.48 cubic millimeters and 2345.72 cubic millimeters. If the number of Malpighian corpuscles as estimated by me (1,040,000) is used, a total volume of 4356.35 cubic millimeters for the corpuscles is obtained.

Ratio of the total volume of the corpuscles to that of the renal cortex.

For the twelve weeks rat, as seen in table 4, the ratio between the total volume of Malpighian corpuscles and the total cortical volume is 1:33, while the ratio to the total kidney volume is 1:49.

In an adult cat, Miller and Carlton ('95) found the ratio between total volume of Malpighian corpuscles and the total cortical volume to be 1:996 and the ratio between total volume of Malpighian corpuscles and total kidney volume to be 1:1427. These extremely small ratios are due to their low estimate of the number of corpuscles. Peter ('07), however, as before mentioned, calculated the total volume of Malpighian corpuscles to be 141.37 cubic millimeters. If we use the total cortical volume and total kidney volume as given by Miller and Carlton ('95), we find the ratio between total volume of Malpighian corpuscles and total cortical volume to be 1:64, while the ratio between total volume of Malpighian corpuscles and total kidney volume becomes 1:91. These ratios are more nearly comparable to the corresponding ratios for the rat.

In order to carry out the same calculation for the human kidney, it is necessary to have data for the total cortical volume and total kidney volume in the normal adult kidney. According to my observations, the human renal cortex measures 93,000 cubic millimeters, the total volume of the corresponding kidney being 186,000 cubic millimeters. Taking Schweigger-Seidel's estimate of 0.200 mm. for the average diameter of the Malpighian corpuscle, the ratios between total volume of Malpighian corpuscles and total cortical volume will vary according to the estimated total number of corpuscles. The ratios accordingly are 1:10 for Huschke's ('28) estimate; 1:39 for Sappey's ('89) and 1:21 for my own estimate. The corresponding ratios between total volume of Malpighian corpuscles and total kidney volume become 1:16 (Huschke); 1:61 (Sappey) and 1:32 (Kittelson). It may be further noted that Huschke's ('28) data give a ratio of 1:16 between total volume of Malpighian corpuscles and total kidney volume instead of 1:8 as stated by Schweigger-Seidel ('65).

Even excluding the aberrant data of Miller and Carlton, it would appear that the relative total volume of the Malpighian corpuscles, as compared with total cortical or kidney volume, is in the rat much nearer to the human than it is in the cat.

A careful volumetric study of the cortex and medulla, together with complete numerical counting of the Malpighian corpuscles, was made upon serial sections of the kidney of the albino rat at birth, two, three, seven and twelve weeks of age. The volumes of cortex and medulla were also measured, and the number of corpuscles estimated, in an adult human kidney. The principal results may be summarized briefly as follows.

V. Summary of Conclusions.

1. The postnatal growth of the cortex in the rat's kidney is fairly uniform, showing in comparison with the entire body a relative increase between birth and two weeks of age, decreasing slightly thereafter.

2. The growth of the medulla in the rat's kidney is more varied. Its rate of growth between birth and three weeks of age increases much more rapidly than that of the cortex or of the entire body, and also decreases more rapidly thereafter. The characteristic curve of relative growth for the entire kidney, increasing to a maximum at three weeks and decreasing thereafter is therefore apparently due chiefly to the varying rate of growth in the medulla.

3. The volumetric ratio of medulla to cortex in the rat's kidney changes from 1:3.05 at birth to 1:2.02 at the age of two weeks, 1:1.50 at three weeks, 1:2.10 at seven weeks and 1:2.00 at

twelve weeks. Linear measurements are inadequate to indicate volumetric relations.

4. The total number of fully formed Malpighian corpuscles found in the kidney of the newborn rat is 10465, or 15533 including those incompletely formed. The number increases to 24061 at two weeks (plus about 30 incompletely formed) and to 2~~1~~5930 at three weeks; 28583 were counted at seven weeks and 28863 at twelve weeks.

5. The total number of Malpighian corpuscles in the rat's kidney is apparently reached during the third postnatal week, as but few could be found in process of formation at the age of two weeks and none at three weeks or thereafter. The apparent slight increase in the total number of corpuscles at seven and twelve weeks is therefore probably due to individual variation.

6. The number of fully formed Malpighian corpuscles per cubic millimeter of cortex in the kidney of the rat decreases from 1057 (or 1586, including the ~~x~~ incomplete) at birth to 131 at twelve weeks.

7. The average diameter of the Malpighian corpuscles in the twelve weeks' rat is about 0.075 millimeter.

8. The total volume of the Malpighian corpuscles in the twelve weeks' rat is 6.63 cubic millimeters, forming 1/33 of the total cortical volume, or 1/49 of the total ~~kidney~~ volume (both cortex and medulla) of the kidney.

9. In an adult human kidney, the cortex formed about 93,000 cubic millimeters and the medulla ~~139,500~~ 46500 cubic millimeters. The number of corpuscles is estimated at 1,040,000, with a total volume of 4356.35 cubic millimeters, forming 1/21 of the total cortical volume or 1/32 of the total kidney volume (both cortex and medulla).

VI. Literature Cited.

Donaldson, Henry H. 1915 The Rat. Memoirs of the Wistar Institute of Anatomy, No.6, Philadelphia.

Eckardt, C.T. 1888 Ueber die compensatorische Hypertrophie und das physiologische Wachstum der Niere. Arch. f. path. Anat.,CVIV, S.217-245.

Felix, W. 1912 The development of the urogenital organs. Keibel and Mall's Human Embryology, Vol.II.

Hammar, I.A. 1914 Methode, die Menge der Rinde und des Macks der Thymus, sowie die Anzahl und die Grösse der Hassal'schen Körper zohlenmässig festzustellen. Zeitschr. f. angew. Anat. u. Konst., Bd.1, H.4-5, Berlin.

Hatai, S. 1913 On the weight of the abdominal and thoracic viscera, the sex glands, ductless glands and the eyeballs of the albino rat (Mus norvegicus albinus) according to body weight. Am. Jour. Anat., vol.15, No.1.

Hauch, E. 1903 Ueber die Anatomie und Entwickelung der Niere. Anat. Hefte.

Herring, P.J. 1900 Development of the kidney and its relation to pathological changes which occur in them. Jour. of Path. and Bact., vol.6, p.459.

Huschke, 1828 Ueber die Textur der Nieren. Isis, vol.XXI, S.550-599. (Cited by Schweigger-Seidel.)

Jackson, C.M. 1913 Postnatal growth and variability of the body and of the various organs in the albino rat. Am. Jour. Anat., vol.15, No.1.

1917 Effects of inanition and refeeding upon the growth and structure of the hypophysis in the albino rat. Am. Jour. Anat., vol.21, No.2.

Külz, Ludwig, 1899 Untersuchungen über das postfötale Wachstum der menschlichen Niere. Inaug.-Diss. Kiel.

Miller, W.S. and Carlton, E.P. 1895 The relation of the cortex of the cat's kidney to the volume of the kidney and an estimation of the number of glomeruli. Transactions of the Wisconsin Academy of Science, X, pp.525-533.

Peter, Karl 1907 Ueber die Nierenkanälchen des Menschen und einiger Säugetiere. Verhandl. d. anat. Ges., 21te Vers. Würzburg, pp.114-124.

1909 Untersuchungen über Bau und Entwickelung der Niere.

Policard, J. 1908 Le tube urinaire des mammiféres.

Riedel, 1874 Entwickelung der Saugethierniere. **Rostock.** (Cited by Miller and Carlton).

Sappey, C. 1889 Traité d'anatomie descriptive, T.IV, p.499.

Schweigger-Seidel, F. 1865 Die Nieren des Menschen und der Saugetiere im ihrem feinerem Bau. Halle.

Stoerk, O. 1904 Beitrag zur Kenntnis des Aufbaus der menschlichen Niere. Anat. Hefte, No.72.

Toldt, C. 1874 Untersuchungen über das Wachstum der Nieren des Menschen und der Saugetiere. Sitz. Ber. d. k. Akad. d. Wiss. Wien. 69 Bd., 3 Abt. Aprilheft.

Waschetko, N.P. 1914 Zur Frage von dem physiologischen Wachstum der Niere. Centralblatt allg. Pathol., Bd.25, No.14.

Table 1.

Data to illustrate the method used in finding volume of cortex and medulla in the kidneys of the albino rat at various ages (see table 2).

Rat No.	Paper weight of Cortex	Paper weight of Medulla	Paper weight in terms of area Cortex	Paper weight in terms of area Medulla	Magnification (diameters)	Area divided by square of magnification Cortex	Area divided by square of magnification Medulla	Number of sections used	Volume obtained from reduced area multiplied by thickness of sections Cortex	Volume obtained from reduced area multiplied by thickness of sections Medulla
	grams	grams	sq.cm.	sq.cm.		sq.cm.	sq.cm.		cc.	cc.
V2.1	750.8	246.0	61115.12	20024.40	111	4.9602	1.6252	Every other section	0.0099205	0.0032504
V1.3	1113.2	550.0	90614.48	44770.00	78	14.8930	7.3580	"	0.0297860	0.0147160
V13.1	760.0	508.0	61864.00	41351.20	52	22.8786	15.2926	"	0.0457572	0.0305852
V1.7	550.0	251.5	44770.00	20472.00	44.5	22.6082	10.3381	every fourth section	0.0904328	0.0413524
V1.8	687.8	323.0	56086.92	26292.00	32	54.7722	26.6525	"	0.2190888	0.1066100

Table 2.

General and volumetric data on the kidney of the albino rat at various ages.

Rat numbers	Sex	Age	Nose-anus length mm.	Gross body weight grams	Weight of 2 kidneys grams	Total volume of 1 kidney, cortex and medulla cu. mm.	Volume of medulla in one kidney cu. mm.	Volume of cortex in one kidney cu. mm.	Ratio of medulla to cortex	Total number of Malpighian corpuscles in 1 kidney	Number of Malpighian corpuscles per cu. mm. of cortex	Index of gross body weight (g.) divided into volume (cu. mm.) of Cortex	Index of gross body weight (g.) divided into volume (cu. mm.) of Medulla
V2.1	F	Newborn	51	5.2	0.055	13.1709	3.2504	9.9205	1:3.05	15533[1] 10465	1586[1] 1057	1.908	0.625
V1.3	M	2 weeks	69	11.8	0.169	44.5020	14.7160	29.7860	1:2.02	24061	802	2.52	1.25
V13.1	F	3 weeks	94	22.6	0.290	76.3424	30.5852	45.7572	1:1.50	25930	566	2.01	1.35
V1.7	M	7 weeks	122	44.6	0.498	131.7852	41.3524	90.4328	1:2.10	28583	316	2:03	0.93
V1.8	F	12 weeks	166	122.2	1.207	325.6988	106.6100	219.0888	1:2.00	28863	131	1.79	0.83

[1] Including Malpighian corpuscles still in stages of formation.

Table 3.

Linear measurements of cortex and medulla upon cross sections of the human kidney at various ages. Compiled from various authors.

Age	Author	Width of medulla	Width of cortex	Ratio of medulla to cortex
Newborn	Toldt	8.31	1.80	100:21.5
"	Hauch	----	----	100:24.9
"	Külz	8.5	1.80	100:21.1
3 months	Toldt	10.20	2.80	100:27.4
3 "	Külz	9.0	2.4	100:26.6
13 "	Toldt	12.0	3.0	100:25.0
13 "	Hauch	----	----	100:40.9
2 years	Toldt	13.20	4.0	100:30.0
2-1/4 "	Külz	11-12	4.2	100:35.0
12 "	"	14-16	7-8	100:50.0
22 "	Toldt	16.00	9.00	100:56.0
38 "	Külz	18-20	6-7	100:35.0
51 "	"	18-20	7-8	100:40.0
58 "	"	15-17	6-8	100:47.0

Table 4.

Data on number and diameter of Malpighian corpuscles and their volumetric ratio to the kidney and to the cortex in the rat, cat and man.

Species	Author	Number of corpuscles in one kidney	Diameter of Malpighian Corpuscles mm.	Total volume of Kidney cu.mm.	Total volume of Cortex cu.mm.	Total volume of Malpighian Corpuscles cu.mm.	Ratio of total volume of Malpighian corpuscles to total: Volume of Kidney	Ratio of total volume of Malpighian corpuscles to total: Volume of Cortex
Rat (12 wks)	Kittelson	28863	0.075	325.7	219.1	6.63	1:49	1:33
Cat	Miller and Carlton	16000	0.1027	12900	9030	9.04	1:1427	1:996
Cat	Peter	250000	0.124	12900[2]	9030[4]	141.37	1:91	1:.64
Man	Huschke	2100000	0.200[1]	139500[3]	93000[5]	8796.48	1:16	1:10
Man	Sappey	560000	0.200[1]	139500[3]	93000[5]	2345.72	1:61	1:39
Man	Kittelson	1040000	0.200[1]	139500	93000	4356.35	1:32	1:21

[1]From Schweigger-Seidel ('65)

[2]From Miller and Carlton ('95)

[3]From original observation by Kittelson

[4]From Miller and Carlton ('95)

[5]From original observation by Kittelson

Table 5.

Average diameters and volume of Malpighian corpuscles in the kidneys of the human newborn and adult.

	Average diameter of Malpighian Corpuscles			Corresponding volume of Malpighian corpuscles		
Author	Newborn micra	Adult micra	Ratio	Newborn cu.mm.	Adult	Ratio
Eckardt	84.77	200.0	1:2.3	0.000319	0.004189	1:13
Külz	99.0[1]	238.0	1:2.4	0.000508[1]	0.006538	1:12.8[1]
Külz	138.0[2]	238.0	1:1.7	0.0001376[2]	0.006538	1:5[2]

[1]For outer zone

[2]For inner zone

Table 6

Data showing absolute and relative growth of kidney, medulla and cortex per week in the albino rat. Derived from data in table 2.

	Length of period	Total volumetric increase during the period in			Volumetric increase per week in			Percentage increase per week in the			
		Kidney cu.mm.	Medulla cu.mm.	Cortex cu.mm.	Kidney cu.mm.	Medulla cu.mm.	Cortex cu.mm.	Gross body weight %	Kidney volume %	Volume of Medulla %	Volume of cortex %
Birth to 2 wks.	2 wks.	31.33108	11.46556	19.86552	15.66554	5.73276	9.93276	63.5	118.5	176.1	100
2 wks. to 3 wks.	1 wk.	31.84040	16.86920	15.97120	31.84040	16.86920	15.97120	91.0	71.0	107.1	50
3 wks. to 7 wks.	4 wks.	55.44280	10.76720	44.67560	13.86070	2.68170	11.16890	24.3	18.0	8.7	25
7 wks. to 12 wks.	5 wks.	193.91360	65.25760	128.65600	38.78272	13.05152	25.93120	34.8	28.6	32.3	28.6