THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by **Oliver Jesse Morehead** 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

J B Mogart

Date Dec. 1, 1922

10-20 5M

THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Examination

This is to certify that we the undersigned, as a committee of the Graduate School, have given Oliver Jesse Morehead final oral examination for the degree of Master of Arts

We recommend that the degree of Master of Arts be conferred upon the candidate.

C. M. Jackson
Chairman

W. H. Scott.

A. T. Rasmussen

J. B. Magath

E. [illegible]

Date Dec. 1, 1922

10-20 SM

THE ANATOMY OF THE SACRO-ILIAC JOINT

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

OF THE

UNIVERSITY OF MINNESOTA

BY

OLIVER JESSE MOREHEAD

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

MASTER OF ARTS

1922

ANATOMY OF THE SACRO-ILIAC JOINT.

Perusal of clinical literature in discussions involving the anatomy of the sacro-iliac joint shows that there is wide disagreement among anatomists regarding that structure, and consequent misconceptions among clinicians. The purpose of the present work is to unify the contributions of previous investigators and to add any new items of interest that may become evident.

Winslow[1], in 1743, described the sacro-iliac joint as connecting the os sacrum with the two coxal bones thru a cartilaginous symphysis. This conception of a firm, cartilaginous union seems to have remained virtually unchallenged until Luschka[2], about the middle of the 19th century, gave a more accurate description, one that has been but little improved since that time. Of special significance is the fact that he concedes the possibility of a limited degree of movement in the joint.

Attention was directed to the obstetrical significance of the joint in a well-written article by Dr. F.J.Snelling[3], in 1870. He makes no claims of originality in this; "As a concomitant of the puerperal state," he says, "it has been maintained by numerous authors from the earliest times, even Hippocrates."

Various investigators have endeavored to demonstrate normal movement at the articulation, due to elasticity or, especially in the female, to relaxation of the ligaments. This latter condition is explained, correctly no doubt, as a normal result of the general congested state of the pelvis at the menstrual period or in the advanced stages of pregnancy. As an example of the methods of research and the results secured, the work of Dr. Gustav Klein[4] might

be cited. Briefly, Klein measured the several pelvic diameters on 47 fresh corpses,(30 female and 17 male), with the lower extremities in four different positions; hyperextension, normal extension, extreme flexion with knees flexed, extreme flexion with legs pressed against the abdomen. His net results are as follows;

Variation in centimeters.

	antero-posterior	diagonal	transverse
male	0.39	0.38	0.05
female	0.58	0.62	0.05

More recently Goldthwaite and Osgood[5] stirred up the discussion anew by an article in the Boston Medical and Surgical Journal. A few quotations may serve to outline the methods and conclusions of these observers. On page 593 we read; "....Many normal subjects have been examined, and much anatomical work performed, and from all these investigations conclusions have been drawn that represent the basis of this paper." On the next page we read; "The large amount of clinical and anatomical study.....during the past two years makes it quite plain that the pelvic articulations..... are true joints, having all the common joint structures. ....Sex is of no importance except that as the female pelvis is less firmly constructed, the mobility is more easily obtained.

"As the cases are studied they at once divide themselves into groups; the first including cases associated with pregnancy,..... the second.....associated with menstruation, and the third, the cases in which the lesion is due to trauma, general weakness or some definitely known pathological process."

A quotation from page 595 throws light upon the anatomical method pursued by these investigators; "In order to still further

study the pelvic articulations, thru the kindness of Prof. Thomas Dwight of the Harvard Medical School and with the assistance of Dr. Elisha Flagg, it has been possible to examine 20 pelves, and in all but one there was clearly demonstrable motion in both sacro-iliac articulations."

On page 596 the explanation continues; "Still further observations were made in connection with autopsies..... In these observations, in both the man and the woman, the motion of the sacro-iliac articulation was distinct.

"The method of examination in the anatomical specimens was as follows: The pelves were dissected, leaving all the ligaments in situ. The sacrum was now sawn thru from the lumbar articulation to the coccyx and the sacro-iliac articulation on both sides studied.

"At the autopsies the mobility was determined by driving nails into the bones. One nail was driven into the ilium near the articulation, the other into the promontory of the sacrum parallel to the first. By raising the leg about 50° with the knee straight the ends of the nails separated, on an average of 3 mm...."

One is impressed by the paucity of material available at autopsy for this study. Further, considering the minute measurements secured (3 mm), it would seem that the method was too crude to produce convincing results.

Still more recently Cyriax[6], an English physician, conducted an interesting series of experiments on the living. He studied movements of the sacro-iliac joints as follows:

1. In normal subjects.
2. During pregnancy.
3. In cases of subluxated ilium.

4. In cases of chronic subluxation of the joints.

5. In cases of compensatory movements of the joints.

The movements were tested as follows;

A. Subject on back, one hand of operator on anterior superior spine, the other below on opposite side. Pressure exerted to test rotatory movement in both joints.

B. Subject on side. Grip same, except that second hand is on tuber ischii. Pressure exerted to test rotatory movement of one ilium.

C. Subject on side. Grip same. Pressure exerted to test for gliding movements.

Results.

1. In normal subjects, slight "give", especially in young females under 30.

2. During pregnancy. More "give", but author states, "I have never seen actual rotary or gliding movements."

3. Subluxated ilium. "Slight displacements of one ilium are common, especially in females. Differences of ½ to 1 inch, or 5° to 20°.

His conclusions are interesting:

A. The sacro-iliac joints under normal conditions permit of no actual rotary or gliding movements.

B. The sacro-iliac joints in early life are not very firmly fixed, and if taken unawares can permit of pathological rotation, and, to a less extent, of pathological gliding movements, resulting in permanent displacements and fixation of the iliac.

C. The presence of actual movements of rotation or gliding at the sacro-iliac joints points to pathological states thereof.

These modern studies, however, along with almost countless others, have been conducted from a clinical, rather than from an anatomical standpoint. Regarding the latter, in 1904 Fick[7] said: "Luschka has found the division of the joint space complete in a 20-week embryo, while Barkow found it still closed in an 8-month fetus, and holds, as a rule, that it is not found in new-borns. The auricular surface of the ilium is not covered with cartilage at this time, but hangs together with the cartilaginous auricular surface of the sacrum thru connective tissue. Also Luschka found the joint surfaces in new-borns often held together thru fibrous cartilage ridges. In the case of a 7 year old girl, on the other hand, Barkow found the space entirely open and believed that from this time on the space was regularly open."

More recently Prentiss[8] has gone over the field. Concerning the earliest condition of the joint he quotes Keibel and Mall[9]: "'(a) The os coxae. -The pelvic scleroblastema of embryos of the stage illustrated in Fig. 275 (11mm.) undergoes a rapid development. Its iliac portion extends in a dorsal direction toward the vertebrae which are to give it support. The costal processes of the latter at the same time become fused into a dense mass of tissue which enters into close association with the iliac blastema (fig. 276), altho for some time separated from this by a narrow band of tissue staining less densely than the blastema.'"

Prentiss states his own conclusions regarding the further development of the joint as follows; "The iliac portion of the limb bud extends backward to the sacral portion of the vertebral column, to which it is joined by a blastemal connection..... A sacro-iliac joint of a child at term..... Here we observe a distinct cavity

lined by a modified fibrocartilage on both opposing surfaces, and not by a hyaline articular cartilage..... In the adult type.... we find a joint cavity lined by a modified fibrocartilage. It is, however, a distinct joint cavity."

The present investigation embraces four stages of life; embryonal, fetal, childhood, and adult. 70 sets of mounted sections of embryos ranging from 2.5 mm CR length to 210 mm CR length have been studied, and photographs made of typical specimens. (See plates XVI - XXVI incl.). These slides are from the University collection in the department of anatomy; many of the smaller ones were supplied by Dr. C.M.Jackson, while the larger ones are from the collection made by Dr. R.E.Scammon and Dr. Fred L. Adair. The embryological work in connection with this study was carried on under the direction of Dr. Scammon, while the work with the adult pelves was directed by Dr. Jackson.

Following is a list of the sections studied, with notations indicating the section in each series which seems to illustrate best the stage of development of the joint in that particular embryo. The last column denoted the crown-rump length of the embryo, the appended letter indicating whether the section was transverse or sagittal. For purposes of ready comparison, where practicable, sections were chosen which also show the coxal joint. Not all were photographed.

series	slide	row	section	crown-rump length in millimeters
H60	29	2	6	11transverse
H68	9	5	11	11t
H14	13	2	1	12t
H386	24	2	8	13t
H374	16	4	1	13t
H97	23	2	3	14t
H1	30	3	5	15t
H23	22	5	10	15t
H18	30	2	4	15.5t
H305	4	4	3	15t
H28	26	3	7	16t
H260	15	6	2	18t

126 to 170, and 170 to 210. But in consideration of the fact that with the exception of a very slight crevice in the joint on one side of section 67, series H35, no evidence of a joint cavity was found in the hundreds of sections examined, it seems safe to assert that there is normally no joint cavity in the sacro-iliac joint in an embryo 210 mm or less in length. The reader is referred to the plates (XVI - XXVI) submitted herewith.

Observation of plates XXI to XXVI inclusive (excepting the sagittal sections and a few others) seems to show that the posterior ligament consists of fibers that run in a general antero-posterior direction, inclining medially, instead of running in all directions as described in most text books. This feature will be mentioned later, in connection with other material studied.

The microscopic work was followed by the dissection and examination of eleven fetal pelves of the following crown-rump lengths;

220 mm	#48 female
260 mm	#704f
250 mm	#19 f
253 mm	#9 f
253 mm	#1813f
260 mm	#1 male
265 mm	#33 m
260 mm	#30 m
280 mm	#32 m
280 mm	#35 m
290 mm	#212m

For purposes of study the pelves were sectioned nearly horizontally at intervals of about 5 mm and the joint was carefully inspected

Seven of these showed a well developed joint with cartilaginous articular surfaces and a definite joint cavity. In most cases the opposed cartilaginous surfaces were weakly united by numerous delicate fasciculi, but these became relatively inconspicuous in the older specimens. In the four smallest of these fetal pelves the joint had not reached full development, tho the constituent parts were clearly discernible. In these instances the opposed surfaces were more intimately adherent thru the medium of the delicate fibers previously mentioned. The direction of the fibers of the posterior ligament was difficult to determine in many of these specimens because of the accummulation of fat. But with certain reservations the assertion may be made that the tendency was antero-posterior, as stated above.

Then the pelves of 17 new-borns were dissected and decalcified by dilute HCl and sectioned as was the fetal material. A few, however, were observed directly by cutting the symphysis pubis and the anterior sacro-iliac ligament then spreading the ilia laterally in a cautious manner. In every case the joint was found well developed and similar in structure to that of the adult. In most of the instances some of the delicate fasciculi were observed passing between the opposed cartilaginous surfaces. But in no instances were these so numerous as in the 260 mm fetus.

As in the case of the fetal dissections, the direction of the fibers of the posterior ligament was concealed by fat and other tissue. Still in many cases there seemed a pronounced antero-posterior tendency.

A very interesting contribution to the series consisted of two post-natal pelves contributed by Dr. Jackson. The one was a male, age 46 days, body length 54 cm., weight 2700 grams; the other a female,

age 6½ months, body length 62 cm., weight 3972 grams. Both were inanition specimens but this fact did not, in my estimation, detract from the value of the observations made. The symphysis was cut, the anterior ligament opened, and the articulation studied. The joint development seemed complete. Intercartilaginous fasciculi were found, but not to an extent that would seem incompatible with a limited degree of motion at the joint.

After cutting the anterior ligament it was found that by the application of some force on the concave surface of the sacrum this bone could be displaced upward a few millimeters, while application of an equal or even a greater force from above produced no appreciable displacement. These observations were construed by the present investigator as tending to confirm in a striking manner the previously implied fact that the fibers of the posterior ligament run in a general antero-posterior direction. Further experimentation and observation is needed on this point. For this purpose fresh adult specimens are desirable, since the formalin hardened bodies offer unnatural resistance.

In the early stages of this work the present investigator dissected a dozen adult pelves, formalin hardened specimens from the dissection rooms of the freshman class, and made certain measurements of the areas involved in the sacro-iliac joint. For this purpose it seemed best to consider both the auricular surface and the area occupied by the interosseous ligament; these were measured separately.

The method followed was to make projections on a glass plate then trace these projections directly upon graph paper ruled to 1/25 square centimeter. Then these small squares were counted.

Owing to the extreme irregularity of the joint surface and the rather crude method of computation, the difficulty of arriving at anything more than a fair approximation of the areas can be appreciated. But the figures are sufficiently reliable to at least give an idea of the average size of the joint surface. Moreover, recently I have measured these surfaces on 24 other adult pelves, following a plan differing in details. This will be elaborated later. Following is a tabulation of the figures obtained in these measurements. The first 11 are those of the pelves measured by the direct count method. Though there were 12 pelves under investigation, measurements were taken on only eleven, the other being ankylosed to such a degree that it was useless for this purpose. Following the figures for the first 11, figures are given for the joints measured recently. The first column denotes, in the case of the early work, an arbitrary number of no particular significance, the specimens not having been preserved. The remaining numbers in the first column indicate identification numbers, the specimens being preserved for reference. In a few cases, however, the identification tag has been lost; These are designated x, xx, etc. The second column gives the total area, including both the auricular surface and the interosseous area, of the right joint. The fourth column carries a similar significance for the left joint. The third column and the fifth are for the auricular surface of the right and left joints respectively, while the third and the sixth are for the interosseous portion of right and left sides. The last figure of each column gives the averages. The figures are single spaced in order that all may be put on one page for purposes of convenience.

MALES

Area in square centimeters. Right				Area in square centimeters Left		
No.	Entire	Auric.	Interos.	Entire	Aurid.	Interos.
1.	34.8	13.8	21.0	31.0	10.8	20.2
2.	41.5	18.0	23.5	33.0	10.5	22.5
3.	35.6	18.1	17.5	43.2	15.0	28.2
4.	38.1	16.3	21.8	42.0	16.5	25.5
5.	32.3	12.8	19.5	30.0	18.5	11.5
6.	39.0	18.5	20.5	37.0	21.5	15.5
7.	34.8	20.3	14.5	41.0	23.8	17.3
8.	23.6	6.8	16.8	24.1	8.6	15.5
9.	30.5	14.5	16.0	35.2	14.6	20.6
10.	32.2	15.0	17.2	36.2	14.4	21.8
11.	28.6	12.2	16.4	23.3	9.8	13.5
20.	28.0	12.5	15.5	30.9	13.1	17.8
22.	26.1	17.0	9.1	31.4	16.6	14.8
23.	32.3	16.6	15.7	32.3	15.6	16.7
24.	30.0	14.1	15.9	32.2	17.5	14.7
25.	30.8	13.7	17.1	27.3	14.6	12.7
26.	34.9	16.5	18.4	30.8	19.5	11.3
26!	37.2	18.2	19.0	35.4	18.8	16.6
27.	38.0	22.4	15.6	35.5	18.3	17.2
29.	29.1	13.6	15.5	(left joint not available)		
30.	26.2	12.7	13.5	29.0	13.1	15.9
32.	27.4	15.8	11.6	24.5	13.9	10.6
32a	31.0	17.6	13.4	(left joint not available)		
32b	27.6	15.5	12.1	27.8	16.5	11.3
33.	28.6	15.8	12.8	32.7	17.9	14.8
34.	29.3	17.5	11.8	32.2	16.6	15.6
37.	37.4	16.6	20.8	31.6	16.1	15.5
39.	36.5	19.7	16.8	37.1	20.7	16.4
40.	35.8	17.9	17.9	33.4	16.2	17.2
42.	36.8	19.2	17.6	33.1	15.7	17.4
X .	32.2	16.0	16.2	24.8	15.7	9.1
O .	40.0	21.2	18.8	38.2	23.4	14.8
Z	32.4	17.4	15.0	30.2	14.8	15.4
			Females.			
19.	36.5	16.8	19.7	33.5	15.4	18.1
31.	32.5	17.0	15.5	32.8	16.5	16.2
38.	31.5	14.9	16.6	28.5	16.0	12.5
41.	26.4	15.2	11.2	31.7	14.5	17.2
Averages for males, first line; averages for females, second line.						
	32.7	16.2	16.5	32.5	16.1	16.4
	31.8	16.0	15.8	31.6	15.6	16.0

All of the specimens from the eleventh were measured by the indirect method. Projections were made and copied as before, but these were carefully cut out and weighed. Then several squares of exactly five centimeters were made and the average weight of these found. By simple proportion the areas of the projections of the

joint surfaces were then calculated.

Figures from the joints of the males are tabulated separately from those of the females. Extended comment is unnecessary. While the number of sacro-iliac joints of females available for observation is far too small to warrant positive conclusions, inspection of the figures indicates results that might reasonably be expected.

Several things are evident. Turning to the averages, there is noted a marked similarity, point for point, of the two sides, in the cases of both males and females. Second, it is interesting to note that the female joint is slightly smaller than that of the male, there being a variation of a few tenths of a square centimeter in each area, right and left. As previously stated, however, it must be borne in mind that the total number of female pelves used in this investigation was so small that caution must be used in drawing conclusions, especially where small figures are involved. Third, the area of the auricular surface is practically the same as that occupied by the interosseous ligament. Fourth, inspection of the columns shows that the median size of the auricular surface of all the right joints is 16.5 square centimeters, while that of all the left joints is 16.2 square centimeters. These figures are interesting in that they eliminate extremes. Moreover, the close correspondence of the median with the averages tends to strengthen the validity of both findings. To sum up, it may be stated with considerable confidence that the area of the auricular surface in the adult, both male and female, is about 16 square centimeters. This is probably of more practical importance than determining the area occupied by the interosseous ligament for this latter determination is necessarily more or less an estimation, for it is not well delineated. Moreover, it is only one of several ligaments that strengthen the sacro-iliac articulation.

As stated above, about two dozen adult pelves have been dissected and observed this year. After the bones were cleaned the anterior and posterior ligaments were cut and the articular surfaces carefully separated. Study of these surfaces indicated that almost without exception calcification had proceeded to a greater or a less degree. (This condition is directly opposite to that encountered in the dozen adult pelves dissected last year. Most of those, according to the records, showed little or no calcification or ossification of the articular cartilages. Unfortunately, however, those specimens were not preserved for comparison.) In two cases a sheet of bone had grown over the superior surface of the joint, uniting the bones so firmly that it was necessary to saw them apart in order to inspect internal conditions. The cavity was found mainly intact, in spite of its obviously nonfunctional nature. In three other pelves the joints seemed completely ankylosed, so that all effort directed toward separating the articular surfaces resulted only in fracturing the bones.

After the remaining pelves were disarticulated several measurements were taken on each sacrum. First, the distance between corresponding points near the external or anterior angles of the auricular surfaces were taken. These figures for each sacrum are found in the first column below. The figures in the next column represent the widest point of the sacrum, usually found about one centimeter posterior to the points first taken. The third column consists of measurements taken by the calipers being placed with their points very near the posterior end of the upper leg of the respective auricular surfaces. The fourth column of figures gives the distance between corresponding points at the lower end of the auricular surfaces. (See plate III).

series	slide	row	section	Cr. length in mm.
H22	36	1	1	19t ransverse
H24	42	3	6	19t
H273	15	4	5	20t
H7	45	3	5	20t
H2	48	2	1	20t
H265	24	6	5	21t
H3	35	1	5	22t
H15	58	3	4	22t
H64	23	1	3	23s
H304	47	3	2	24t
H5	95	3	8	25t
H326	31	3	5	25t
H29	78	2	6	26t
H99	196	1	8	26t
H21	88	2	4	26t
H48	90	4	3	27t
H x	338			27.5t
H10	106	2	6	29t
H375	80	3	6.	29t
H98	144	1	3	30sagittal
H108	6	1	4	30t
H259	67	6	2	30t
H57	244	1	5	31t
H16	145	2	5	33t
H298	97	1	2	35t
H313	86	4	3	35t
H51	30	2		35s
H122	98	4	3	39t
H8	222	1	4	41t
H12	198	2	4	41t
H100	81	1		45s
H124	83	4		46t
H115	83	4		46t
H11	477	1	2	60t
H38				63s
H26	239	2	4	65t
H55	65			65t
H32	100			100t
H33				113t
H49				126t
H35				170t
H36				210t

This list does not include a number of series of embryos under 11mm CR length, which do not show the sacro-iliac joint; nor does it include a few series which were examined but which, for one reason or another, did not seem to contribute to the elucidation of the point in question.

The material seems deficient between the lengths 65 to 100,

Specimen	Age	Sacral width in centimeters (between auricular surfaces)			
males		Anterior	middle	posterior	lower
3257	69	11.5	12.2	12.2	9.7
record lost		11.4	12.5	11.9	10.2
3218	23	11.3	11.3	11.3	8.8
3302	-	10.5	11.4	11.6	8.9
3357	73	11.4	12.0	11.7	9.3
record lost		11.5	12.1	12.3	10.0
3330	56	11.3	12.2	12.7	9.0
3152	38	11.1	11.9	12.0	9.5
3355	35	11.4	12.0	12.3	9.4
3158	57	10.7	11.4	11.7	8.8
3385	35	11.7	11.8	12.2	9.5
3437	-	11.7	13.2	13.2	9.2
record lost	50?	11.2	11.8	11.7	9.4
3204	56	11.7	12.4	11.9	9.5
3286	51	10.2	10.7	10.9	8.4
3274	22	11.3	12.5	12.0	9.1
record lost	50?	10.9	11.7	11.4	9.3
3326	52	11.4	12.2	12.7	9.8
record lost	45-55	11.2	12.0	11.6	9.6
3315	46	11.4	12.7	11.6	9.8
	Averages	11.3	12.0	11.9	9.6
females					
3316	90	11.0	11.9	11.6	9.9
3364	80	11.0	11.3	12.2	9.0
3153	54	11.9	12.2	12.4	9.5
3398	61	11.6	12.2	12.3	9.4
	Averages	11.4	11.9	12.1	9.5

Mathematical accuracy in taking such dimensions is impossible, due to the extreme irregularity of the auricular surfaces. This

point needs not be dilated upon. Suffice it to say that the discovery of a general tendency is all that could be expected. Moreover, unless this general tendency is pronounced it would mean nothing. In order to minimize errors all these measurements were taken twice, at periods more than a month apart. Since both sets of figures indicate the same conclusion by practically the same margin only the last set is submitted herewith.

Inspection of the columns above reveals that in every case but one (#3218 shows the same figures for each of the three upper dimensions) the numbers in both the second and third columns are larger than those of the first. In 50 per cent. of the cases the figure in the third column is larger than that of the second, while in 37½ per cent it is smaller. Averages of the width of the sacrum in front give 11.25 centimeters. The average of each of the other columns is practically 12 centimeters. That is, 23 of the 24 sacra measured were obviously wedge-shaped in the region of the upper limb of the auricular surfaces, averaging 7.5 millimeters narrower at the anterior face than thru the body. Thus the sacrum is the pelvic keystone.

Averaging the same widths of the four sacra of female pelves we find that the figures are 11.4 centimeters, 11.9 centimeters, and 12.1 centimeters. Because of the small number of pelves involved definite conclusions would not be justified. Yet we may note that the sacral dimensions of the female in the region of the auricular surfaces correspond closely, in the four specimens studied, with the same dimensions of the male sacrum.

Nothing has been said regarding the fourth column of figures. An attempt was made to secure two measurements of the sacral width at the extremity of the inferior leg of the auricular surface, one

toward the front and another toward the back. But this portion of the surface is irregular and narrow, and nothing seems to be gained by taking two measurements. In general it may be said that the lower extremities of the auricular surfaces, including an area of four or five square centimeters on each, are roughly parallel to each other and to the midsagittal plane of the body. Averaging the figures of the fourth column above we find that the normal sacrum is about 9.37 centimeters wide over this area, or about 3.4 centimeters narrower than at its broadest portion.

Another method of approaching this phase of the subject is to make vertical projections of the sacrum is such a way as to give ocular proof of the variation in sacral width. The ordinary text-book view of the sacrum presents this structure as viewed by the eye, evidently from the most artistic standpoint. This may be adequate in those cases where the purpose of the artist is to teach identification of the sacrum. But for purposes of teaching its exact form and function the sacrum is better delineated as seen by means of the projectoscope. (See Plates XI and XII and the explanation of these found on pages 24 and 25)

For this purpose three specimens were chosen almost at random; #3302 and #3357 were sacra of males, while #3398 was that of a female. Dr. Scammon's projection apparatus(see reference in last two lines of paragraph above) was used, insuring a degree of accuracy to approximately 1 millimeter. Now since the projectograms of the sacrum submitted herewith (see Plates XIII, XIV, and XV) are designed to show that the sacrum acts as a keystone of the pelvis the sacra were placed in the projectoscope in a position that would give the view of the sacrum by an observer at points in the plane P-P' (Plate XI). ~~To this~~

To this end the sacrum under the glass of the projectoscope was tipped sharply backward by means of a block of wood placed under the caudal end.(See Plate XIV). For the projectograms obtained by this procedure the reader is referred to charts XIII, XIV, and XV. No effort was made in these drawings to depict any feature of the sacrum with accuracy excepting the general outline, especially the auricular surfaces.

These projectograms demonstrate clearly that the sacrum is not only wedge-shape vertically but also antero-posteriorly, being broader behind than in front. All the other adult specimens that were measured in this investigation, 23 in number, with the sole exception of one, #3218, would have demonstrated this same feature. It seems reasonable to suppose that this is the normal condition of both the adult and the immature human sacrum.

While it is not within the scope of this paper to discuss the physiology of the sacro-iliac joint, yet it may not be improper to point out here that the significance of the antero-posterior course of the powerful interosseous ligament can now be appreciated; for upon relaxation of the anterior ligament and the long ligaments below, the sacrum is allowed to slip up and back, thus materially enlarging the antero-posterior diameter of the pelvis, an adjustment that might frequently be very desirable in parturition. This view of the sacral shape and function is in sharp contradiction to the view held by Williams[10] who says, ".....it (the sacrum) represents an inverted keystone, inasmuch as it is wider along its anterior than along its posterior surface, so that it would tend to slip downward and forward into the pelvic cavity under the influence of the body weight were it not held in position by the strong posterior

iliosacral ligaments." Were this true, the movement of the sacrum upward and backward, as described at the beginning of this paragraph, would be hampered by the clamping action of the ilia, necessitating lateral movement of the ilia, thus imposing additional strain upon all the ligaments and limiting the possible movements of the sacrum accordingly.

But instead of being suspended solely by its ligaments between the ilia as stated by Williams (see above) and others, the sacrum, according to the findings of the present investigator, is wedged between the ilia from above and behind. Moreover, the pressure of the femora from the sides and the coherent tendency of the symphysis in front relieve the ligaments of the sacro-iliac joints of much of the responsibility usually assigned to them. Observation of the photographs of cross sections of fetal pelves bear out this assertion. (See Plates XXI - XXVI inclusive). This fact is by no means a recent discovery. Luschka included in his discussion of the human pelvis a diagram which clearly shows the sacrum wedged between the ilia from behind. Fick[7] (p. 289) definitely emphasizes this same condition, while numerous authors have copied Luschka's diagram or originated one similar to it without calling attention to the feature under discussion here.

Summary

1. First traces of the developing sacro-iliac joint are seen in the 11 millimeter embryo.
2. This joint develops slowly and steadily and is practically complete, including a joint cavity, by birth.
3. Due to the greater width between the articulatory surfaces of the sacrum above and behind, the weight of the body is supported to

some extent, at least, by the opposed articulatory surfaces of the ilia, which face upward and backward.

4. The assertion may tentatively be made that the interosseous ligament is truly a suspensory ligament, its fibers passing from front to back, inclined medially and downward.
5. There seems to be no essential difference in any respect between the sacro-iliac joints of males and those of females.
6. The auricular surface occupies an area of approximately 16 square centimeters in both the male and the female, tho it seems probable that this surface in the female is slightly smaller than in the male.
7. An area of about 4 square centimeters at the lower end of the auricular surface of one sacro-iliac joint is roughly parallel to the corresponding area of the opposite joint. Passing upward the auricular surfaces diverge laterally (on the sacrum) and swing forward from behind. (See note at end of page 21).
8. The average sacral width is 7.5 millimeters greater toward the back of the upper part of the auricular surfaces than at the front, and the sacrum averages 3.4 centimeters wider at the upper margin of the auricular surface than at the lower end.

Bibliography.

1. Winslow, J.W. Exposition anatomique de la structure du corps humain. Amsterdam, 1743.
2. Luschka, Herb. von. Die Anatomie des menschlighen Beckens. P.88.
3. Snelling, J.F. Relaxation of the Pelvic Symphyses during Pregnancy and Parturition. American Journal of Obstetrics. Vol. II, No. 4, Feb. 1870.
4. Klein, Gustav. Zur Mechanik des iliosacral Gelenkes. 1892.

5-22-4M

5. Goldthwaite and Osgood. A Consideration of the Pelvic Articulations from the Anatomical, Pathological, and Clinical Standpoint. Boston Medical and Surgical Journal. May 18, 1905.

6. Cyriax, Edgar F. The Movements of the Sacro-iliac Joints; a Clinical Study. Edinburgh Medical Journal. 1917, XIX, 370 - 373.

7. Fick, R. Handbuch der Anatomie und Mechanik der Gelenke. 1904.

8. Prentiss, H.J. Sacroiliac Articulation. Journal Iowa State Medical Society, Des Moines. 1917. VII. 172 - 174.

9. Keibel and Mall. Human Embryology. Volume I, P. 367.

10. Williams, Textbook of Obstetrics. Fourth Edition, 1920. P. 4.

Note.

Since the completion of the above the author has had access to a recent addition to the medical library of the University of Minnesota, a new work on human anatomy, "Anatomie des Menschen. Erster Band, Bewegungsapparat," von Hermann Braus. This book gives a very exhaustive discussion of the sacro-iliac joint. On page 469, under the subtitle "Gelenkflaechen der Articulatio sacroiliaca," is a statement of special interest in the light of the present investigation. "......Die Spalten der rechten and linken Koerperseite konvergieren in doppelter Weise, erstens in der Richtung der Basis des Kreuzbeines zur Spitze und zweitens von dorsal nach ventral in der Richtung der Hauptbelastung durch den Oberkoerper (Abb.236)." The diagram to which reference is made represents the pelvis "Saegeschnitt in der senkrechten Koerperebene," and clearly conveys the idea that the sacrum is the pelvic keystone, supporting "die Last des Oberkoerpers."

5-22-4M

Explanation of Plates.

The technique employed in the first series of investigations of the sacro-iliac joint is explained by plates I - VII inclusive. Plate I, drawing A, represents a typical pelvis such as was used in the first series of eleven specimens. Heavy lines indicate the anterior ligament of the sacro-iliac joint. All the pelves were obtained from specimens dissected by the freshmen medical class, hence the symphysis is sawn out in accordance with instructions which they followed. Drawing B indicates the anterior aspect of the disarticulated sacrum, while drawing C shows the ilial face of the sacro-iliac joint.

Plate II, drawing A, indicates the manner in which four of the eleven pelves, after having been decalcified in 5 per cent. HCl, were sectioned transversely at intervals of about 5 millimeters for the purpose of exposing the joint so that the surfaces might be studies in situ. Drawing B represents the part of the pelvis below line 5 (drawing A), showing the manner in which the joint was exposed for study at the several levels. This method of sectioning displays the joint cavity without disturbing the natural relations of its components at the levels indicated.

After careful observation of the joint as revealed by the successive sectioning, (Plate II), in which the posterior and anterior ligaments were left intact, the joint was disarticulated and the sections of the sacral side and the ilial side were reassembled in order to study the joint surfaces as an entity. Plate III shows this second stage of the study, lines 1 - 9 indicating, as before, the planes of sectioning.

Plate IV is offered to illustrate the method which was followed with pelves 5 - 11 inclusive, there being a slight variation

from the preceding. This variation consisted simply in cutting thru the sacrum lengthwise in a sagittal plane, on each side, just medial to the auricular surface. This was done before the pelvis was sectioned transversely. The only advantage gained was a decrease in bulk which facilitated the work. Drawings AA' show the appearance of the pelvis after being sectioned both sagittally and transversely. Drawings BB' show the same after the sacral portions of the joint were taken away, exposing the cartilaginous surfaces of the joint cavities on both sides.

Plates VII - XII inclusive show vertical projections of the several joint surfaces as indicated in each case. Each projection is intended to show as accurately as possible the actual area of both the auricular surface and the adjacent interosseous surface, the area occupied by the dense interosseous sacro-iliac ligament. Because of the extreme irregularity of these surfaces a vertical projection would, of course, represent the areas as smaller than they are. Therefore some allowance was made, the areas being represented slightly larger than a vertical projection would have shown them. These drawings were first made by placing a glass plate directly over the surface to be represented and parallel to the surface, then tracing the outline in India ink on the glass. These tracings were readily transferred to paper by placing the paper on the glass and turning the whole toward the light, when the dark lines on the glass could readily be seen thru the paper and traced thereon. To ascertain the area graph paper ruled to one-fifth centimeter was used. These small squares were then counted. The margin of error in the estimation of the auricular areas is hard to determine but is doubtless well within five per cent.

The determination of the interosseous area involves a difficul-

ty not confronted in the case of the auricular surfaces. In the latter the outlines are very clearly delineated and can, therefore, be traced accurately. But in most cases it is difficult to decide upon the exact limits of the interosseous area except where it borders upon the auricular area. But it is hoped that these measurements will give at least a fair idea of the relative areas.

Plate XI is a sketch of the projectoscope with which drawings XIII - XV inclusive were made. This instrument is simply a box with one side open and the top covered by a glass which is ruled to centimeters both longitudinally and cross-wise, the longitudinal lines being lettered and the cross-wise lines numbered. The object to be measured, O, is placed in the box under the glass. It is illuminated by electric bulbs LL and supported by block B. Desired points on O are located with reference to the rulings on the glass by means of a tubular eye-piece which is equipped with a minute aperture at the proximal end and wires crossed perpendicular to each other in the plane of the glass at the distal end of the tube. A quadrant is cut out of the circular base of the eye-piece and the cut edges are ruled to millimeters. Further details of the use of this instrument will be explained in connection with the following exposition of Plate XI.

The object in question having been placed in the box in the desired position the observer looks thru aperture A of eye-piece I and locates some point P on the object O, centering this point by means of the fine wires at the base of the eye-piece I. (See Plate XI, drawing 2). Then by means of scale S at the base of eye-piece any point P on the object O can be localized with reference to ruled glass G and transferred to graph paper with lines lettered and numbered in a manner corresponding to the letters and numbers of ruled

glass G. By thus locating successive points an outline and any desired details of the object may be obtained. It can readily be appreciated that such a representation would not be the same as a picture or drawing made in the conventional manner from a single "point of vision," but on the contrary there would be as many "points of vision" as there were points of reference as viewed thru the eyepiece. The resulting picture would be a vertical projection. In the case under consideration we get a vertical projection of the sacrum approximately in line with the long axis of the body, and from below. Plate XII is designed to further explain Plates XIII, XIV, and XV. The parallel lines extending down from the brim of the pelvis indicate the same field of view with the sacrum in situ as that depicted in Plates XIII, XIV, and XV with the disarticulated sacrum under the ruled glass of the projectoscope as illustrated in Plate XII. Imagine a plane passed thru the line PP' in Plate XII parallel to a transverse plane of the body. Now points on the sacrum S projected vertically to plane P-P' would give the same representation as that secured by the projectoscope as explained above. Thus, for our purpose in this connection, the sacrum is viewed from such points as it would be seen if projected down to a vertical plane parallel with the long axis of the body and from below.

Reference to the next three plates, XIII - XV inclusive, shows projections of the sacrum secured as stated above. The special feature to be noted is that a very considerable expanse of the auricular surfaces of both sides is visible when thus viewed. This can only mean that the auricular surfaces of the sacrum project laterally and slightly backward from above, making a keystone of the sacrum, which is thus wedged between the ilia.

The remaining plates, XVI - XXVI inclusive, are enlarged photographic reproductions of cross sections thru the sacro-iliac joint of human embryos ranging in size from 11 millimeters to 150 millimeters. These were made with an electric projection apparatus by transmitted light, the enlarged image of the desired portion of the section falling directly upon the sensitized paper lying on the stage below, in a plane perpendicular to the transmitted rays of light. These photographs show the joint at different stages of development in the embryo and the early fetus.

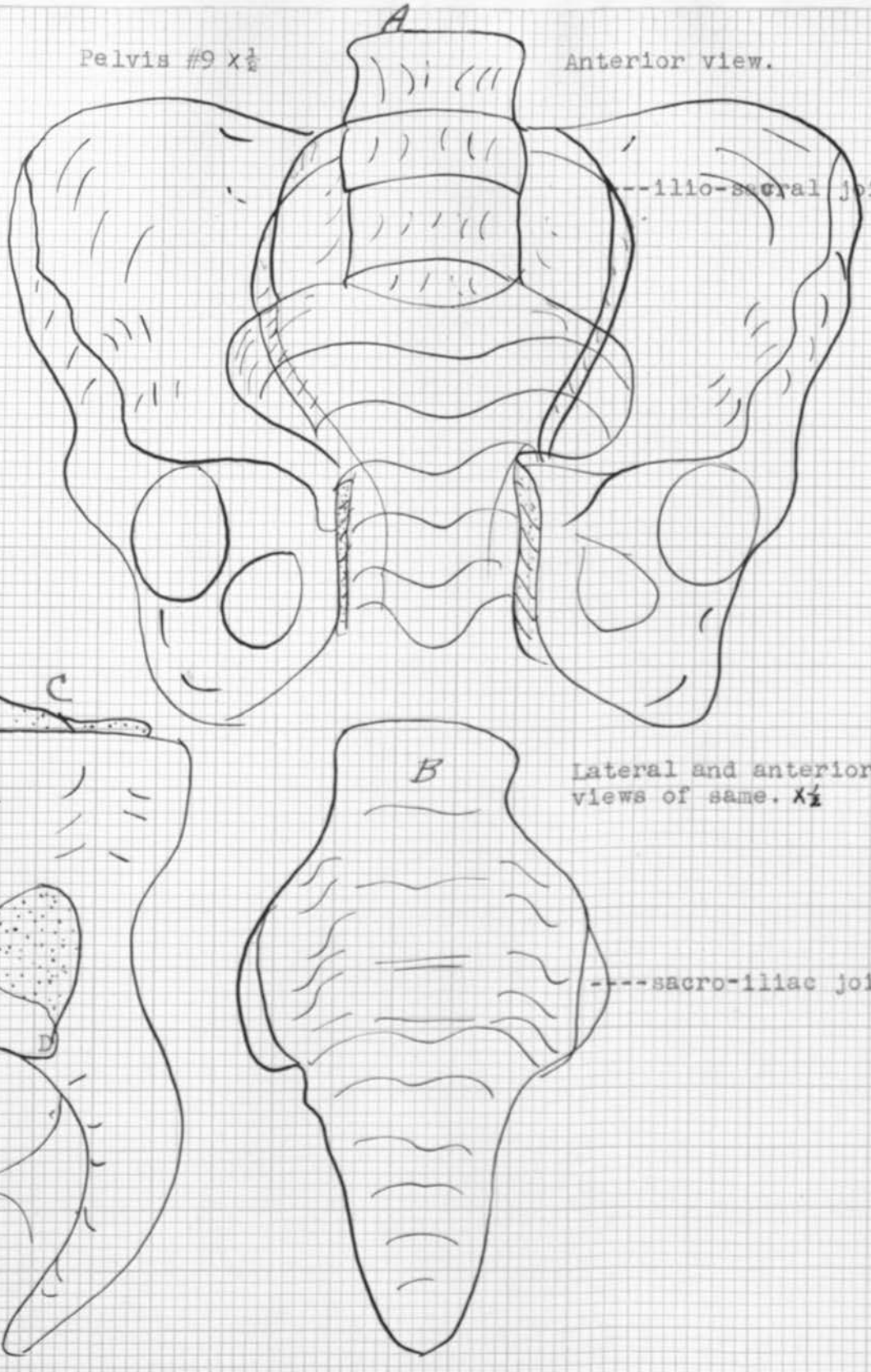
On each photograph are inscriptions for explanation and identification. At the top of the first photograph, for example, (upper left corner of Plate XVI) and below the center of the second (upper right of Plate XVI) are the self-explanatory statements, "Condensation of mesenchyma at site of future sacro-iliac joint indicated by arrow." The annotations at the bottom of these, "H60-29-2-6. 11mm. x 30" and "H 68-9-5-11. 11mm. x 30", need to be elucidated. H means that these are human embryos. The first figure, 60, is the number by which all the slides holding mounted sections of a certain specimen are known. All these slides are marked H60. The next figure, 29, means that this is the 29th slide of series H60. In the case of the larger specimens, as for example the two lower photographs on Plate XXVI, there is only one specimen to the slide and consequently the two figures, H49 - 133 for the photograph to the left, and H54 -690 for the photograph to the right, make complete identification possible. But not so in the case of the photographs of smaller specimens. With these the third figure (returning to consideration of the first photograph on Plate XVI), 2, means that there are several rows of sections mounted on slide 29, and this view is one of the sections in row 2. The fourth figure, 6, tells which one of the sec-

tions in row 2 we have before us. That is, counting from the left, section number 6 has been chosen. So, to find the slide from which any photograph is taken, for example H 326 (lower left corner, Plate XX), find in the collection, series H 326 by means of the index to the sectioned and mounted human embryos. Look thru the several trays containing these sections until slide #31 is found. Going down to the third row on this slide, the fourth section from the left is the section here represented.

Many of the sections are mounted on slides which contain only one row each. In such cases only the first three figures are needed for complete identification. For example, in the upper right hand corner of Plate XX is a photograph of specimen H 64, slide 23, section 3 from the left, there being only one row on this slide.

The significance of the remaining characters on the photographs is fairly obvious. Thus the section indicated immediately above is that of a human embryo of 23 millimeters crown-rump length, magnified 20 times.

PLATE I

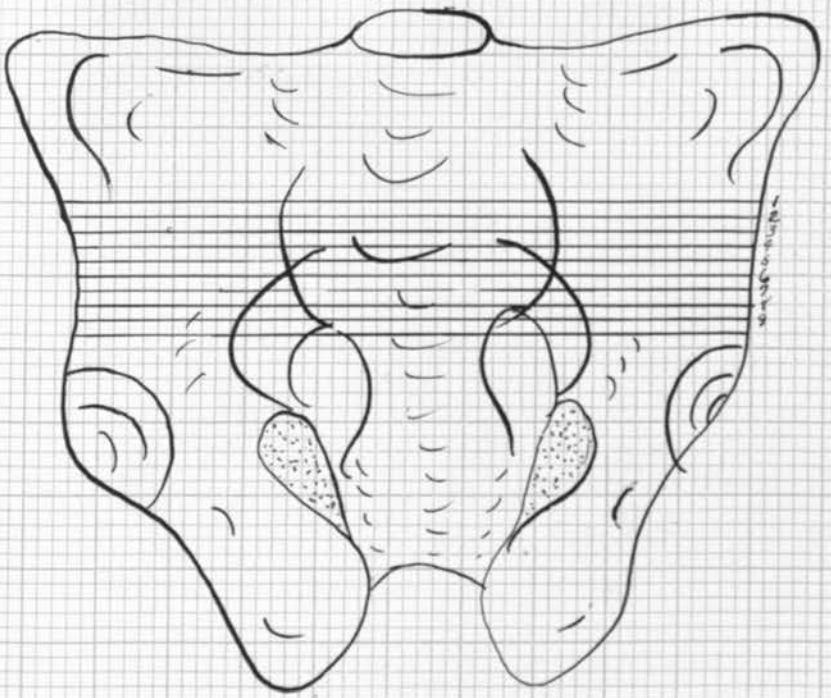


5-22-4M

PLATE II

A

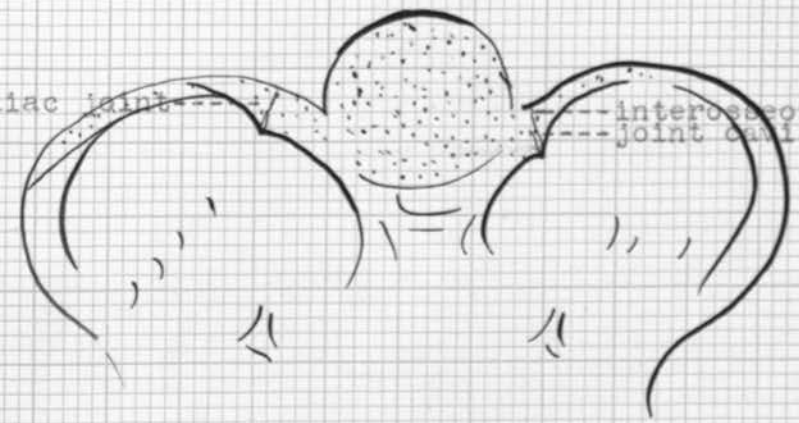
Pelvis # 1, Anterior View. ×½



Lines 1-9 indicate sections sawed thru pelvis transversely, as described in text.

B

Same, from above, thru section 7.

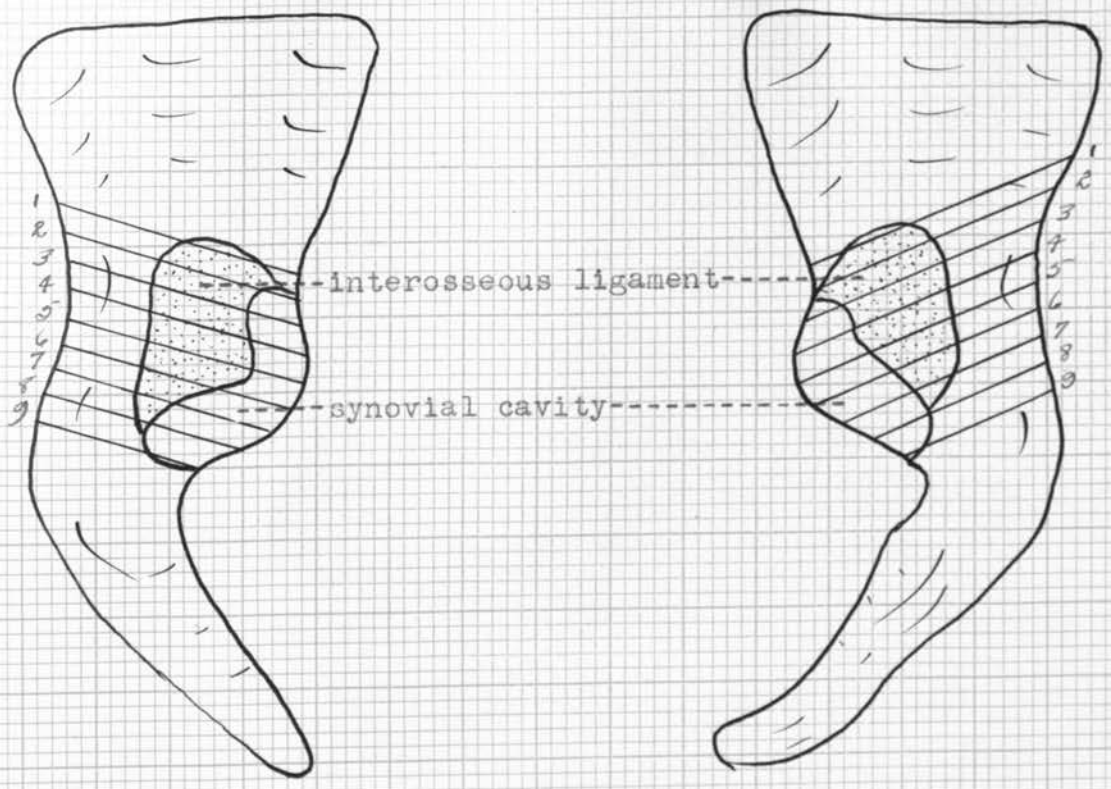


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

5-22-4M

PLATE III

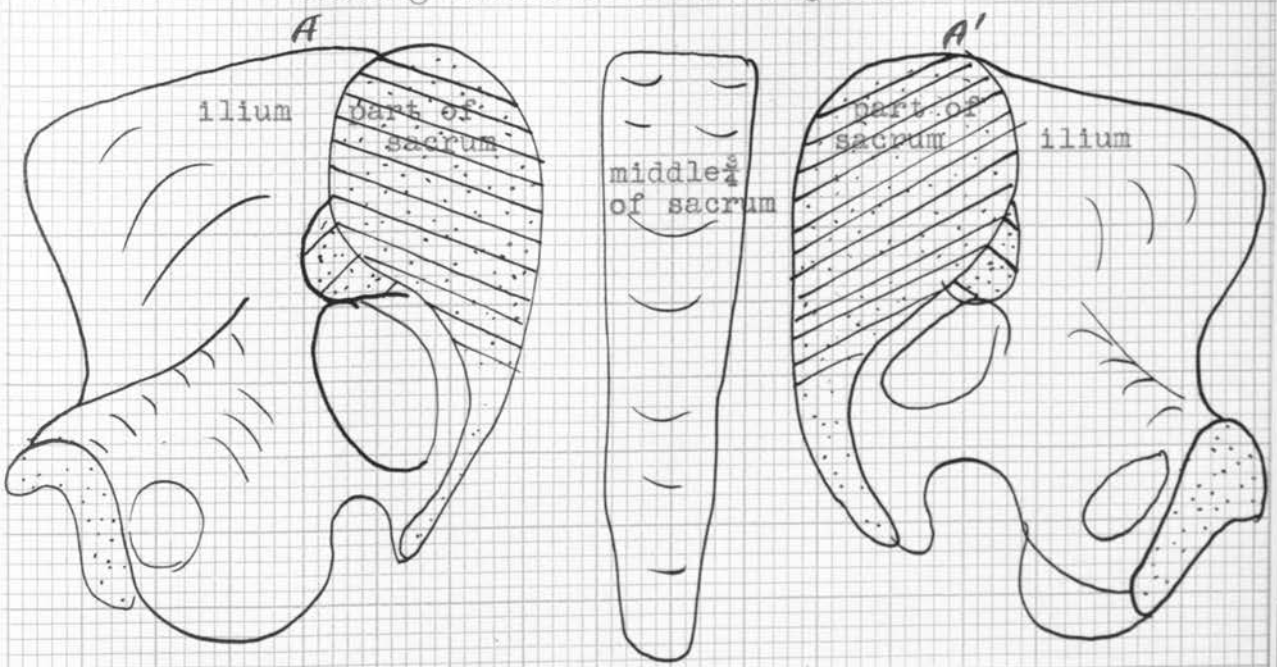
Sacrum of Specimen #1.
Sections reassembled. ×½

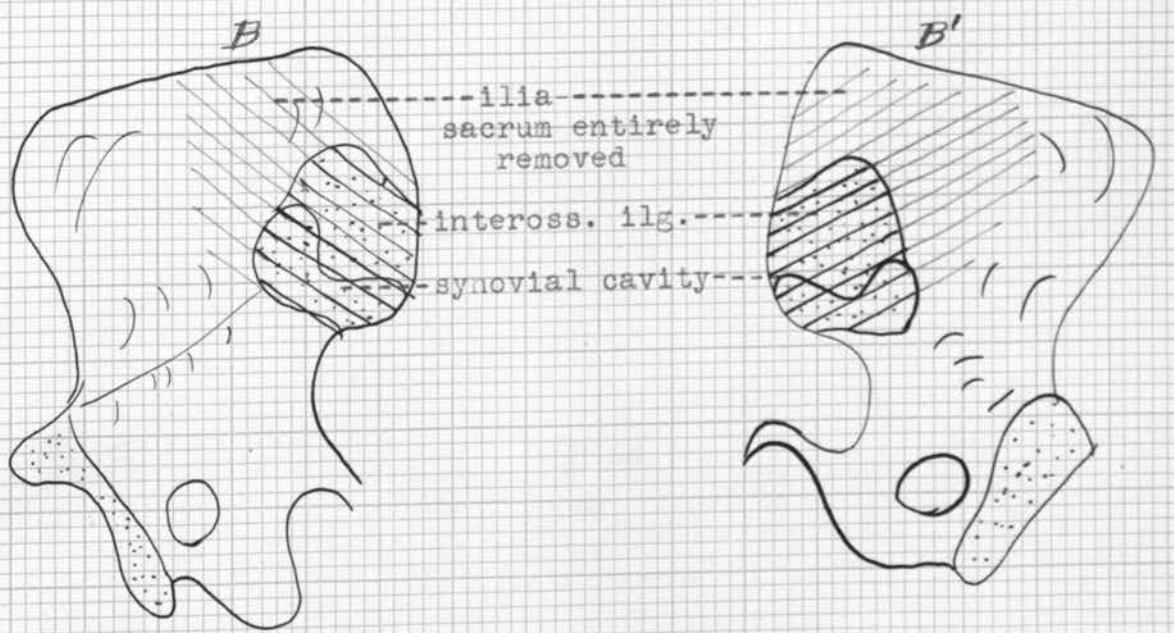


5-22-4M

PLATE IV

Typical Pelvis
Showing method of sectioning used.

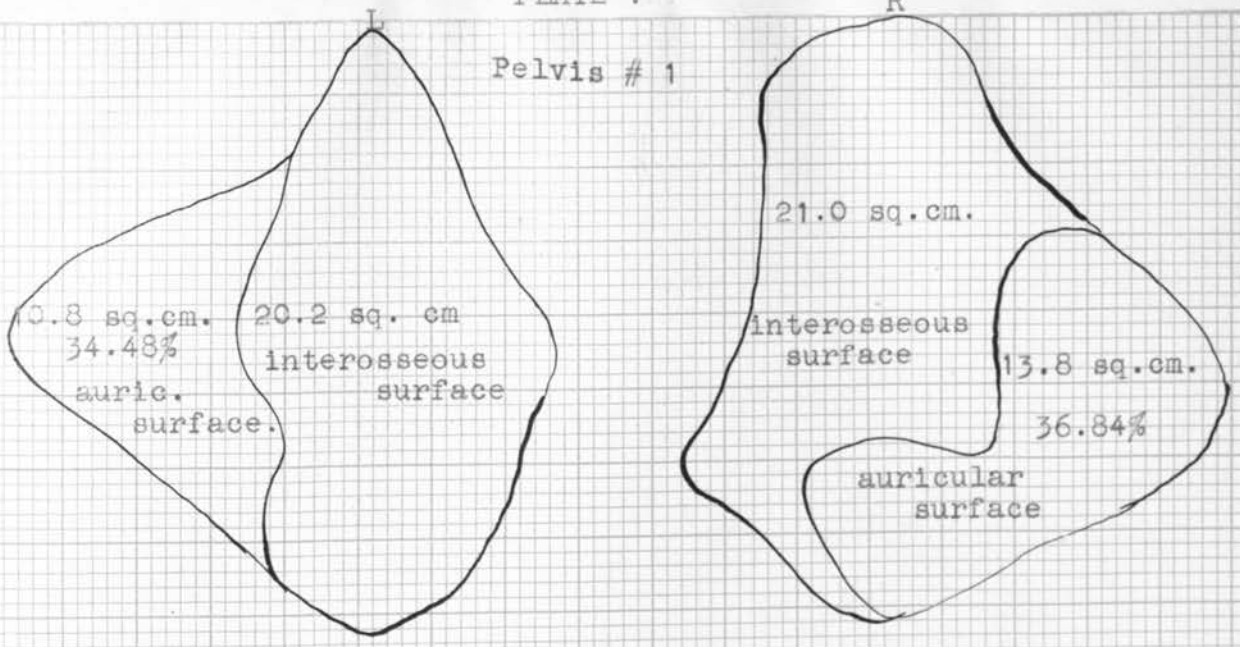




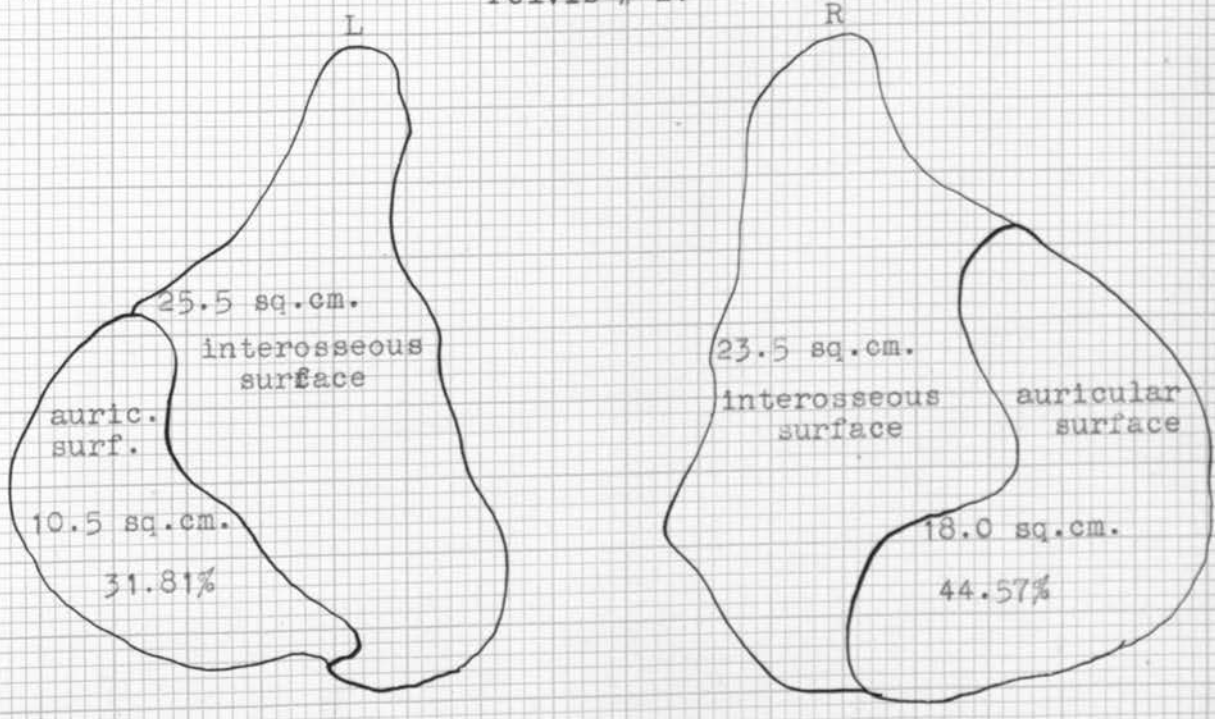
5-22-4M

PLATE V

Pelvis # 1



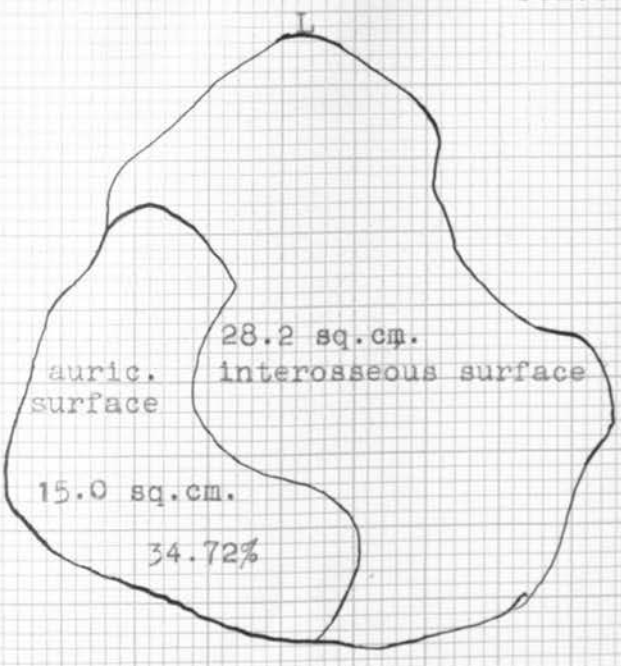
Pelvis # 2.

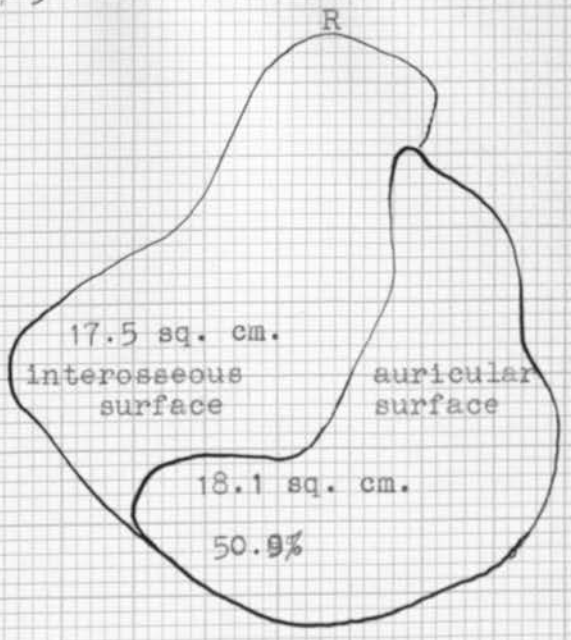


5-22-4M

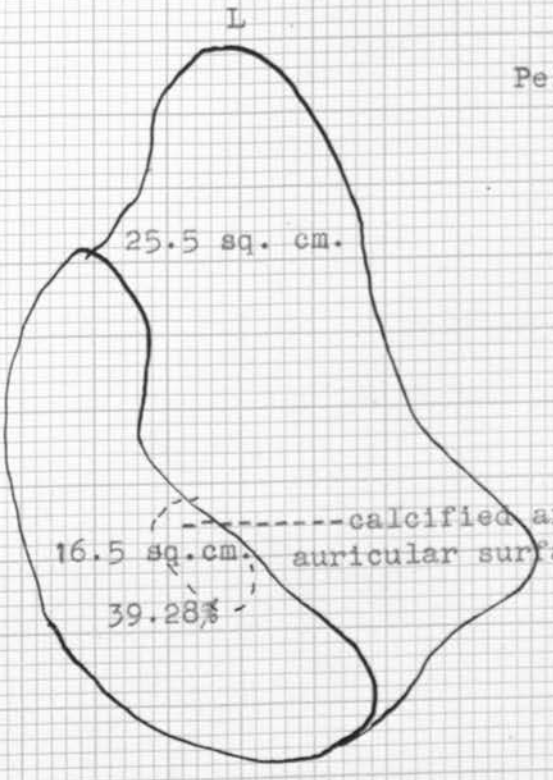
PLATE VI

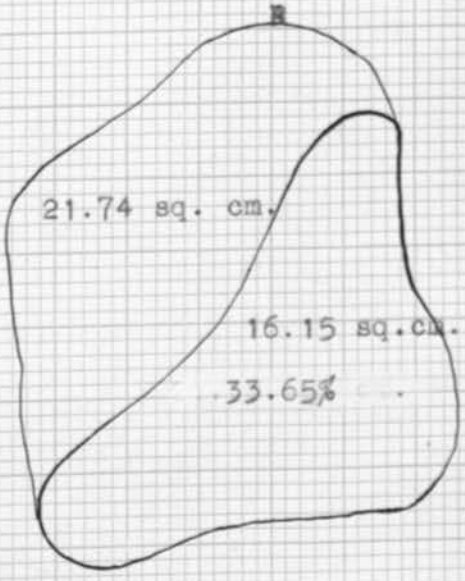
Pelvis # 3





Pelvis # 4



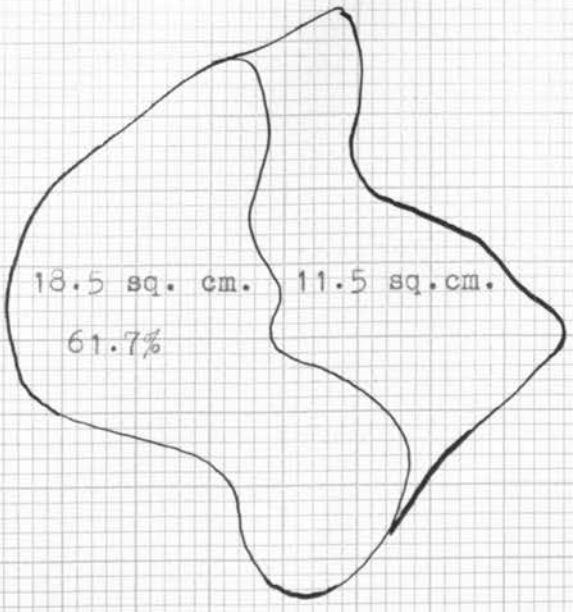


5-22-4M

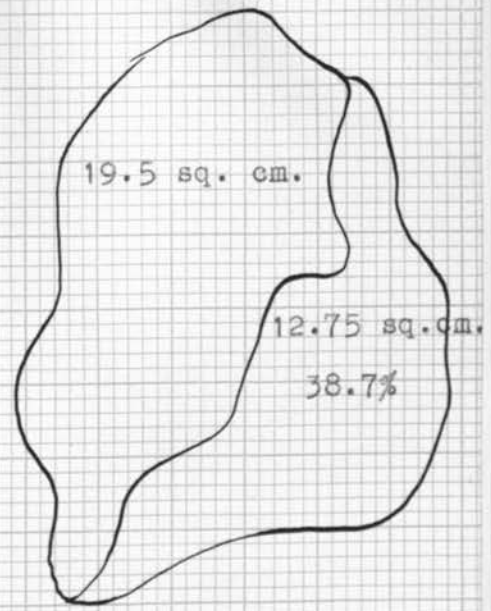
PLATE VII

L

Pelvis # 5

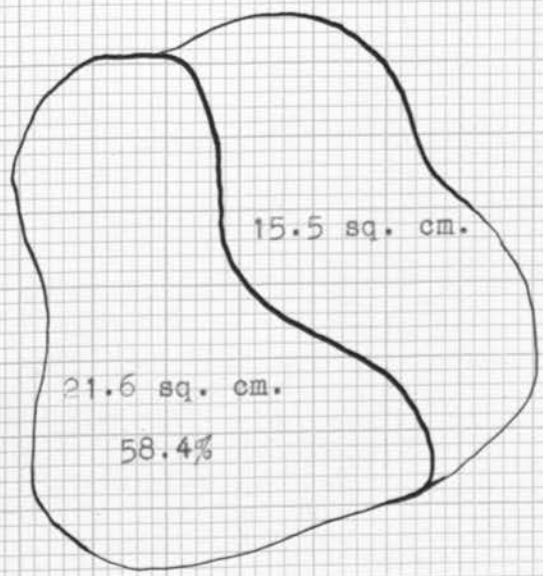


R

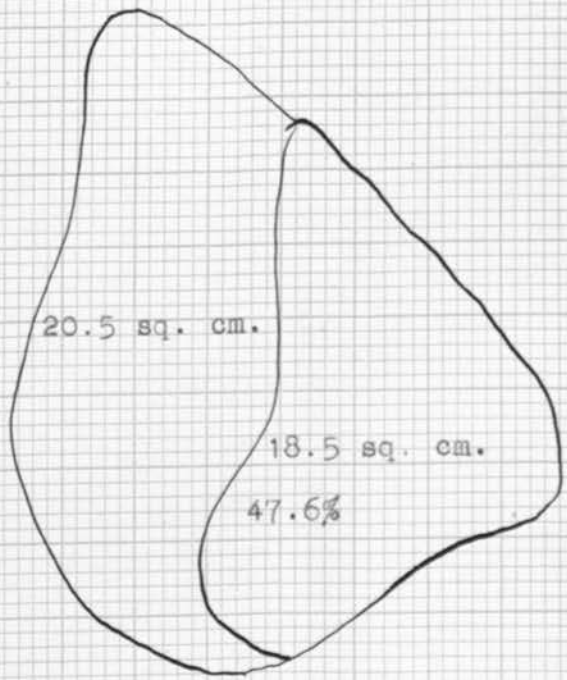


L

Pelvis # 6.



R

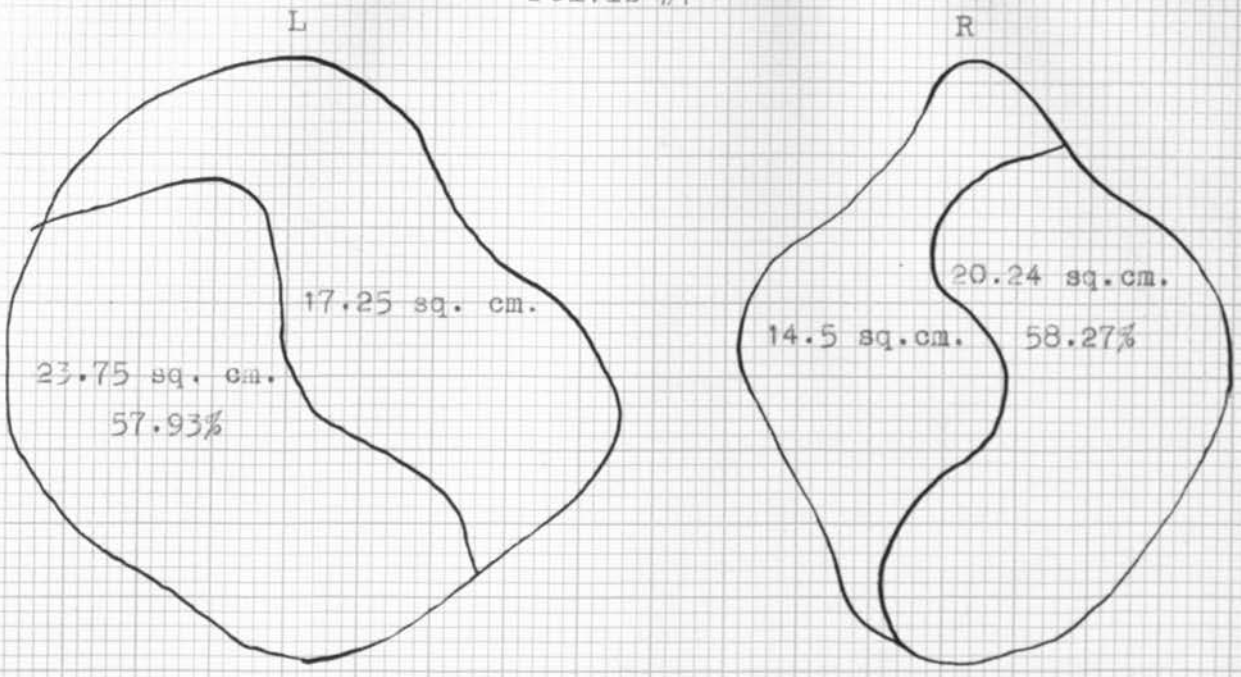


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

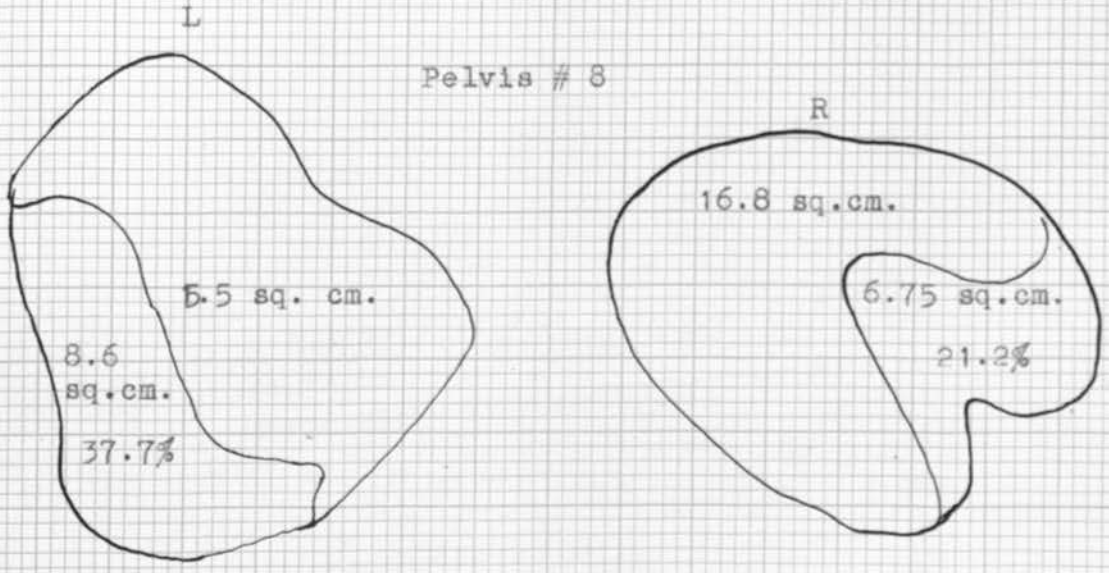
5-22-4M

PLATE VIII

Pelvis #7



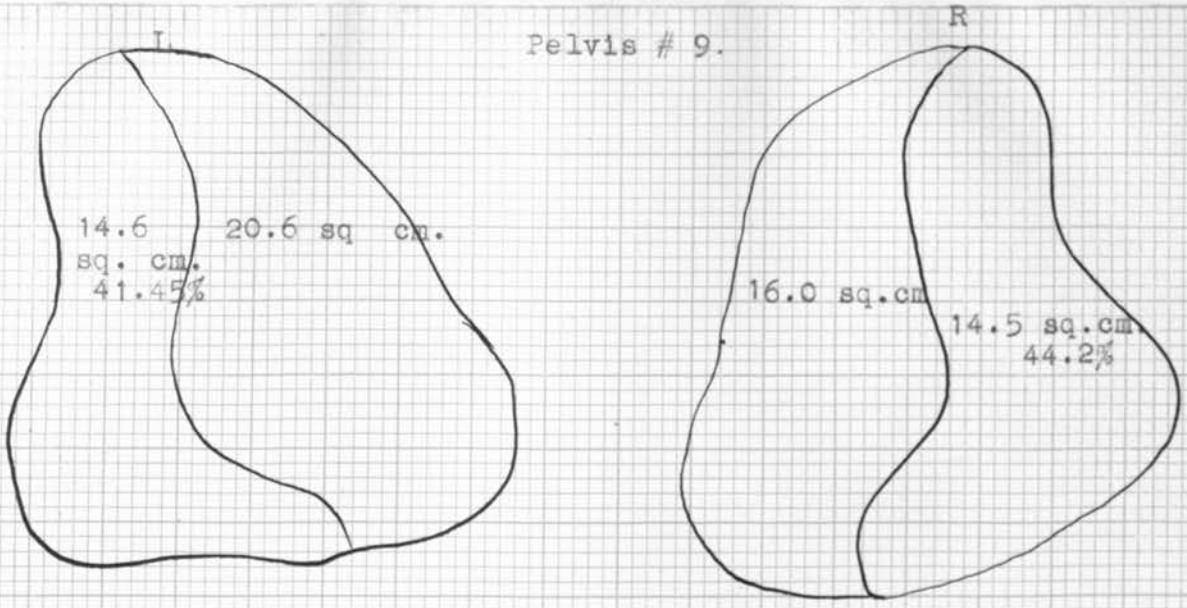
Pelvis # 8



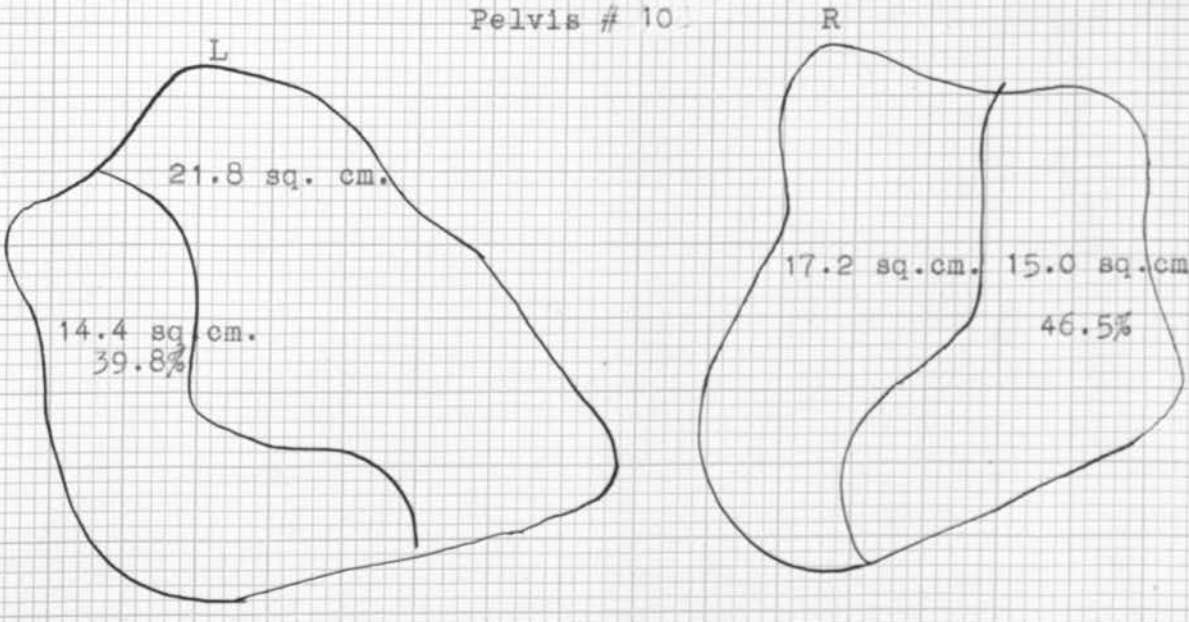
5-22-4M

PLATE IX

Pelvis # 9.

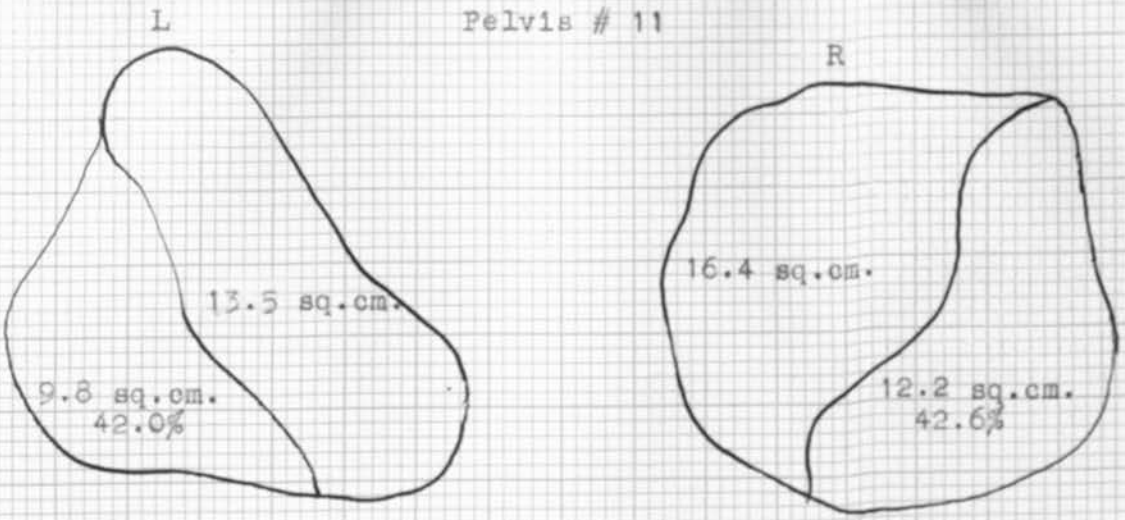


Pelvis # 10



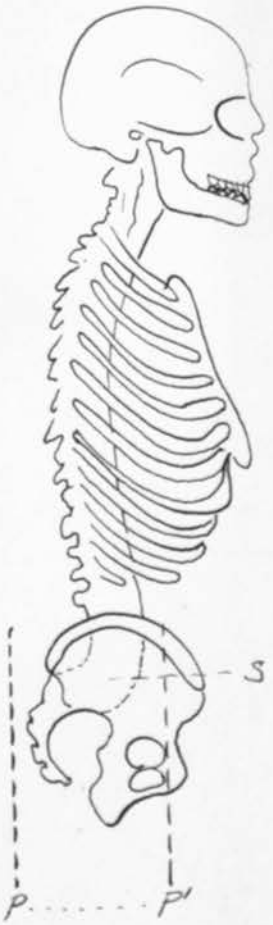
5-22-4M

PLATE X



Pelvis # 12, being completely calcified in the sacro-iliac joint, was not charted.

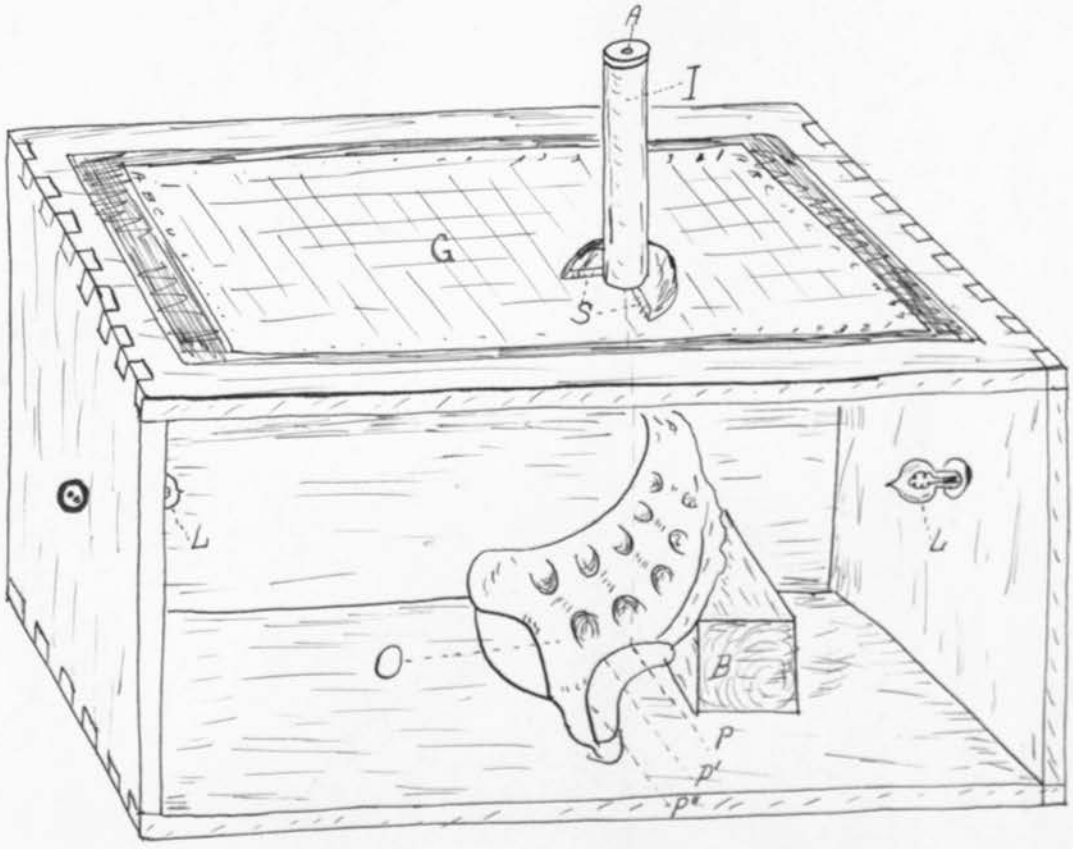
PLATE XI

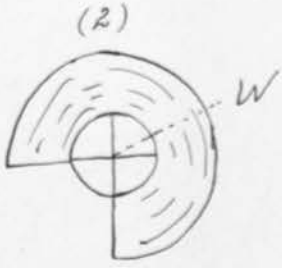


P-P' indicates plane parallel to transverse section of body, from which drawings XIII-XV inclusive may be considered to have been made.

PLATE XII

Vertical projection apparatus





Base of eye-piece, as seen from below.

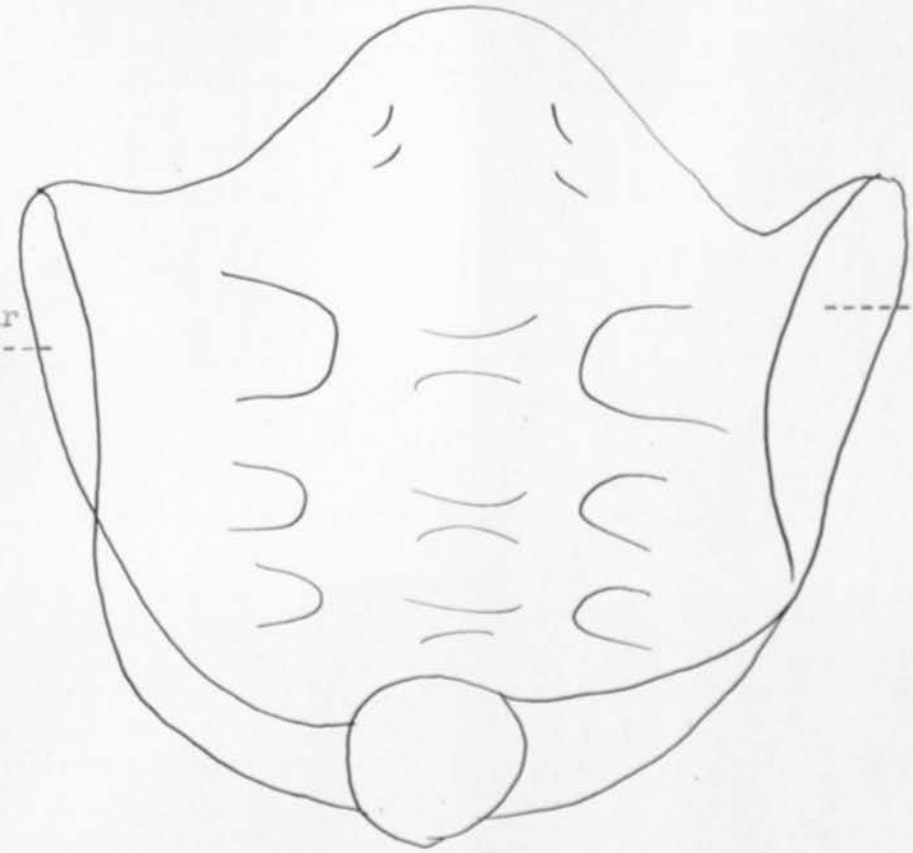
5-22-4M

PLATE XIII

Sacrum

Inferior aspect.

Vertical projection.



From specimen 3357 (male)

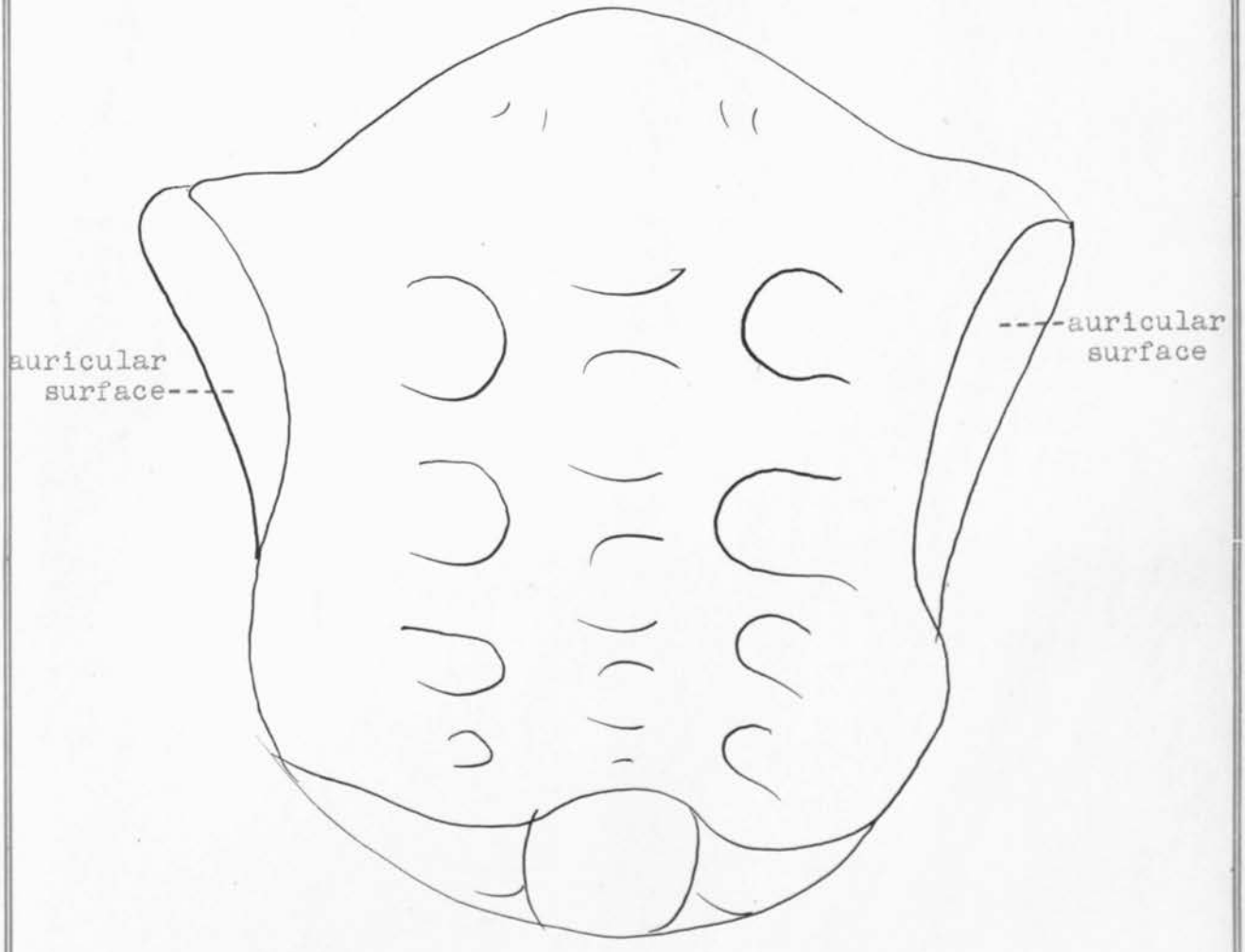
5-22-4M

PLATE XIV

Sacrum

Inferior aspect

Vertical projection



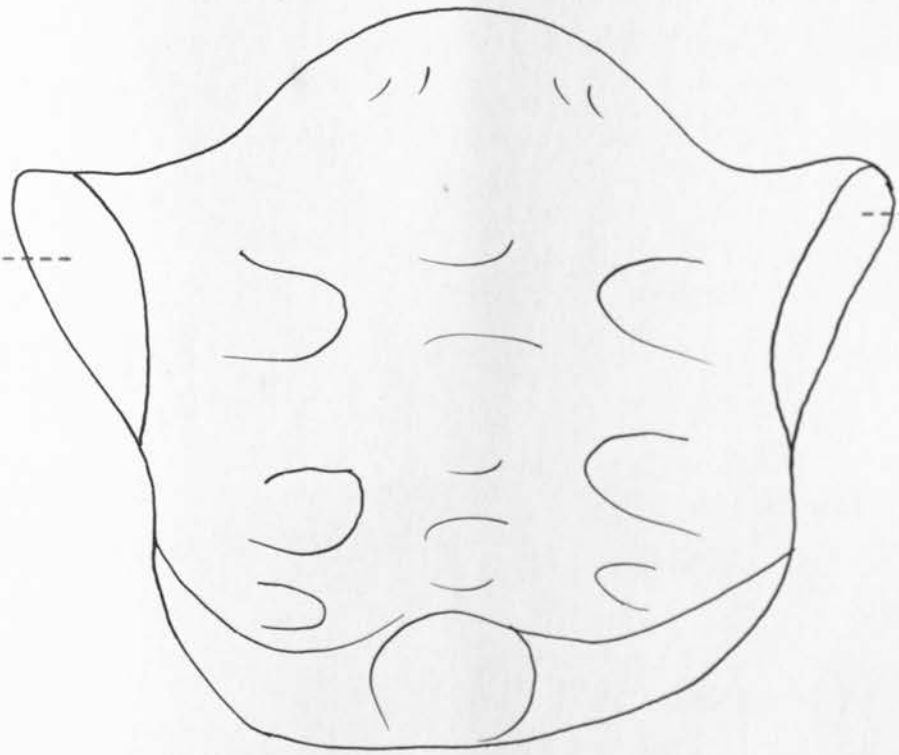
From specimen 3398 (female)

PLATE XV

Sacrum

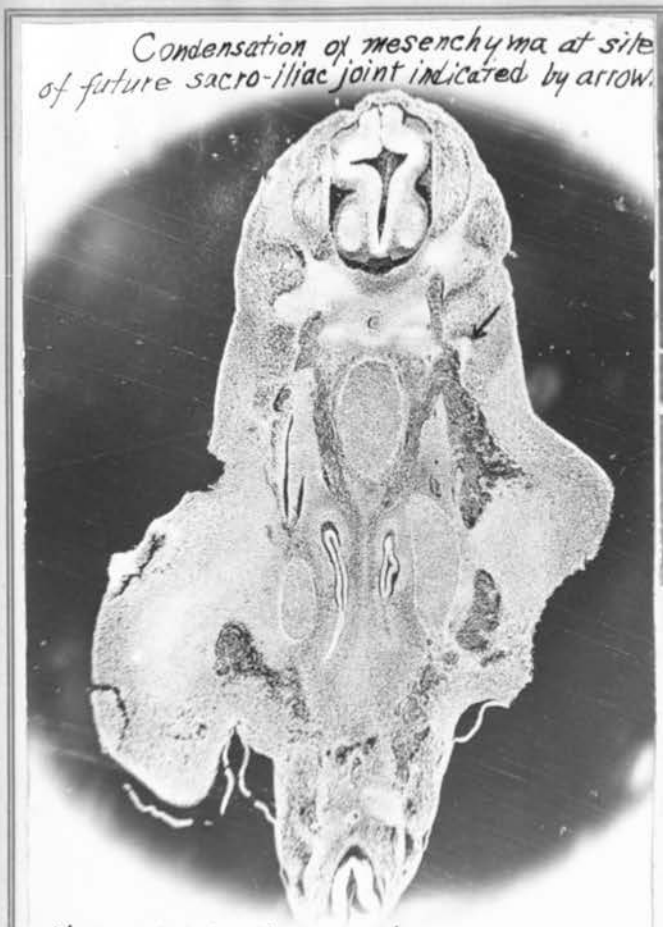
Inferior aspect

Vertical projection.



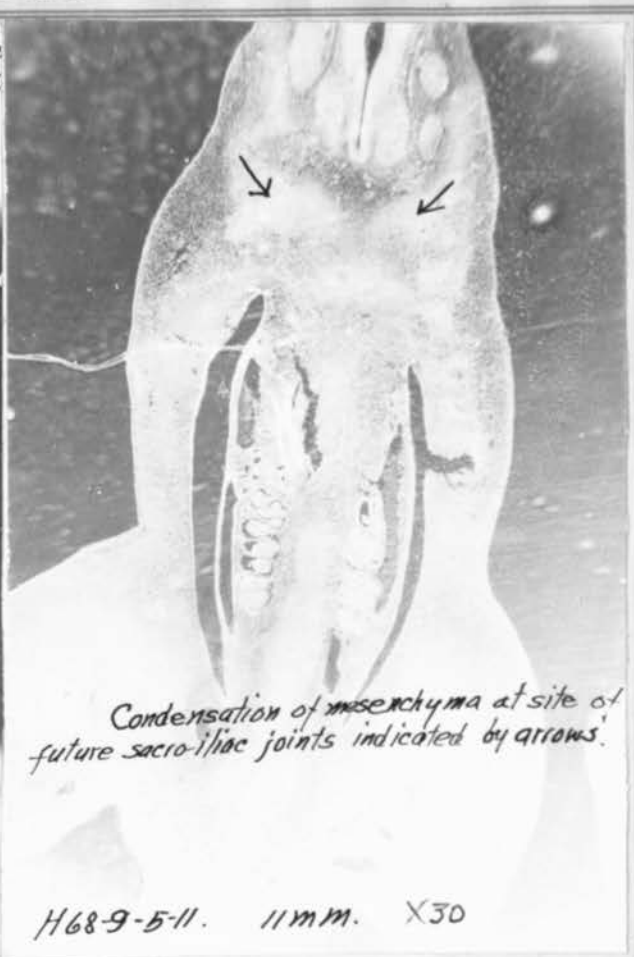
From specimen # 3302(male)

PLATE XVI



Condensation of mesenchyma at site of future sacro-iliac joint indicated by arrow.

H60-29-2-6. 11mm. X30



Condensation of mesenchyma at site of future sacro-iliac joints indicated by arrows.

H68-9-5-11. 11mm. X30

Sacro-iliac joints indicated by arrows.

H97-23-2-3.
14 mm.
X30

H97

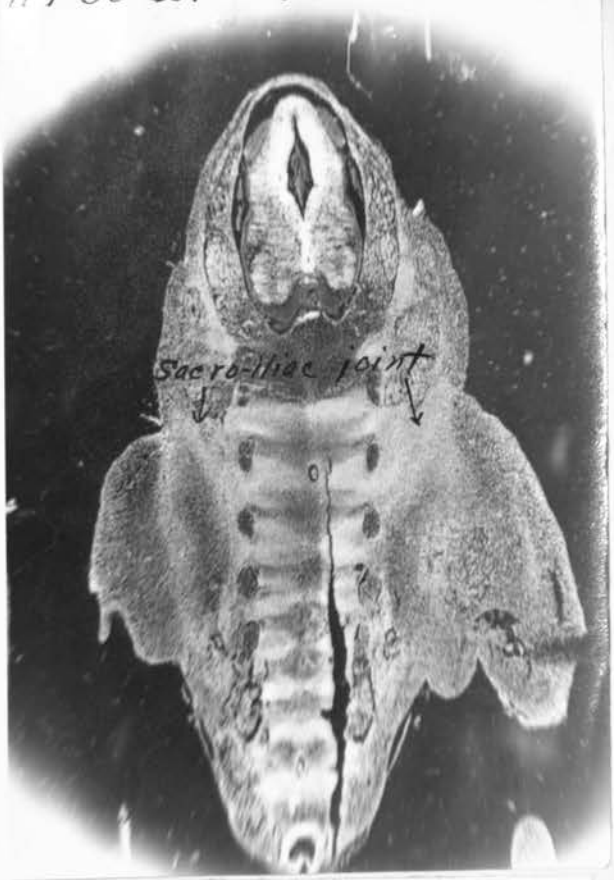
H386-24-2-8. 13 mm. X28

Sacro-iliac joint

Hip joint

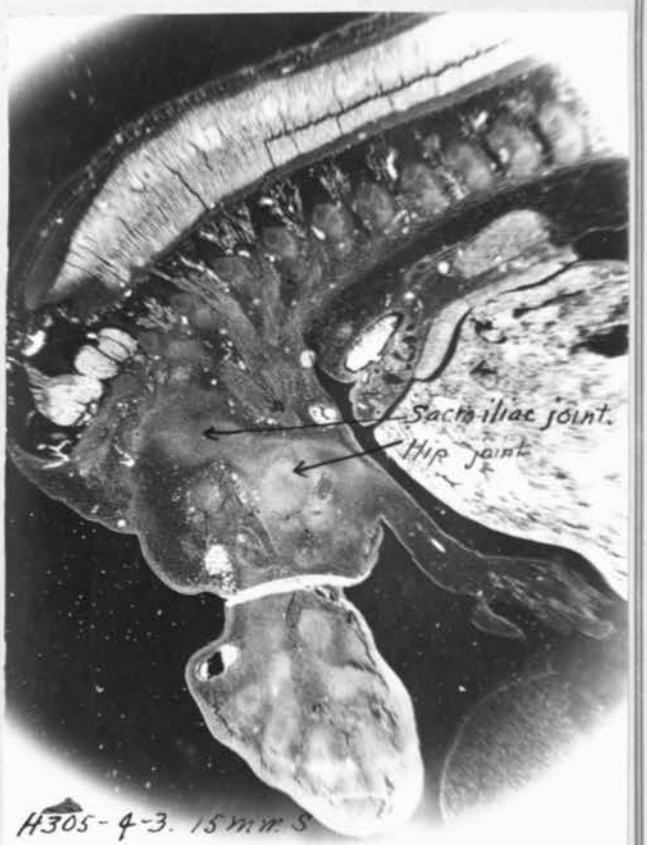
5-22-4M

H 1-30-35. 15 mm. X30



H23-22-5-10. 15 mm. x 27.5

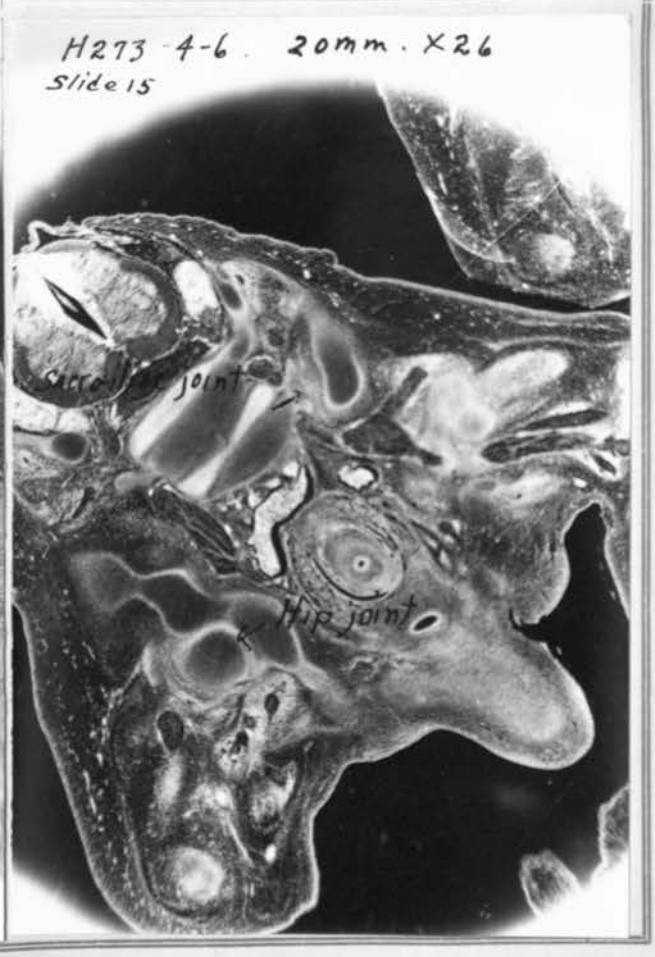
H18-30-2-4. 15.5 mm. X30



H305-4-3. 15 mm. S
Slide 4 X25

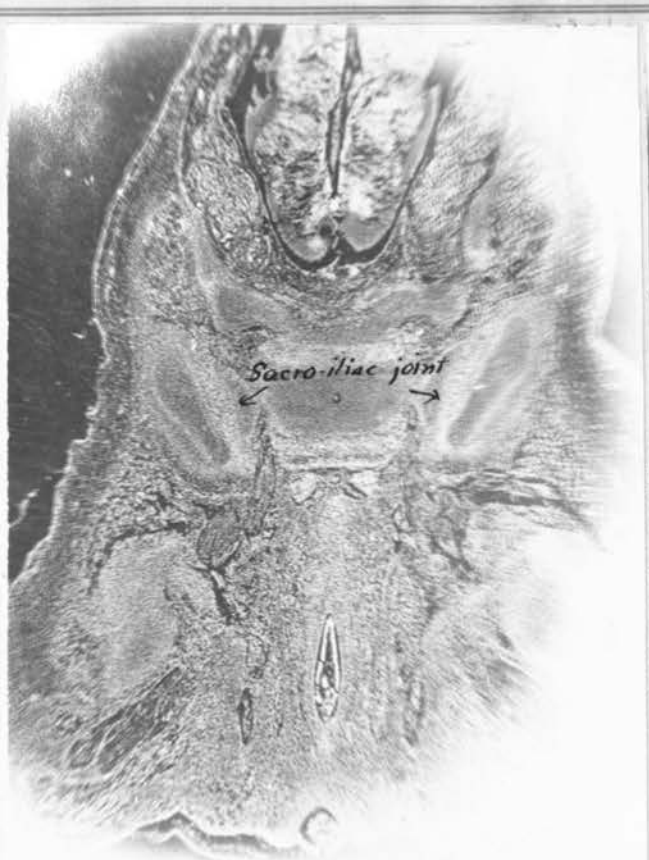
5-22-4M

PLATE XVIII



5-22-4M

PLATE XIX



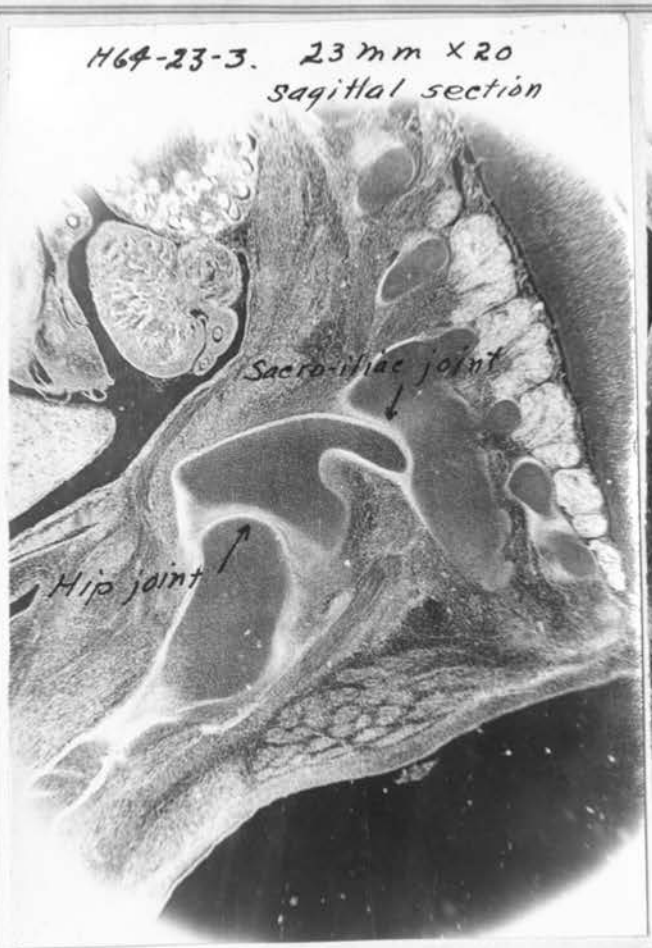
H2-2-2. 20 mm × 26
Slide 48

H265-24-5-6. 21mm. X26

H15-58-3-4. 22 mm. X30

5-22-4M

PLATE XX



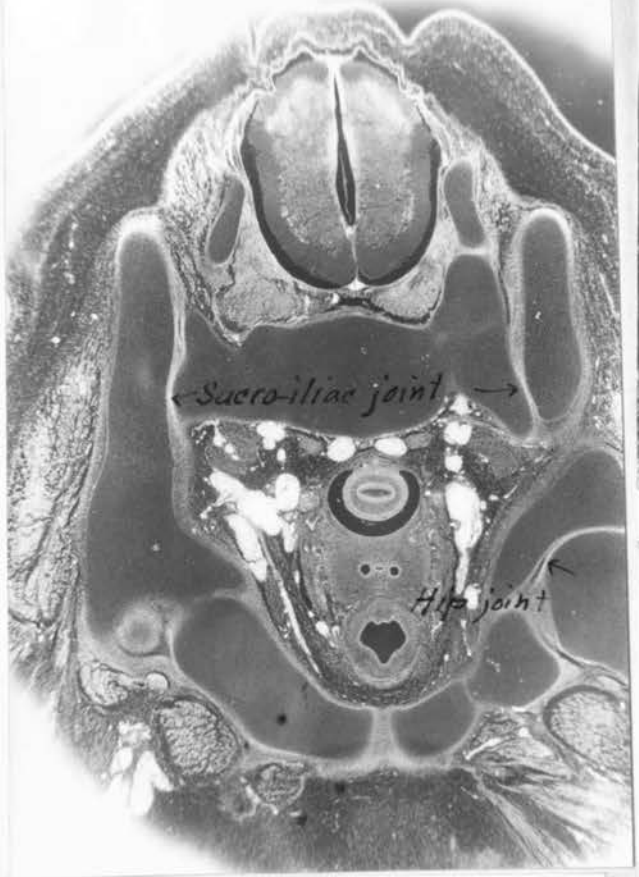
H304-47-3-4. 24mm. x 26

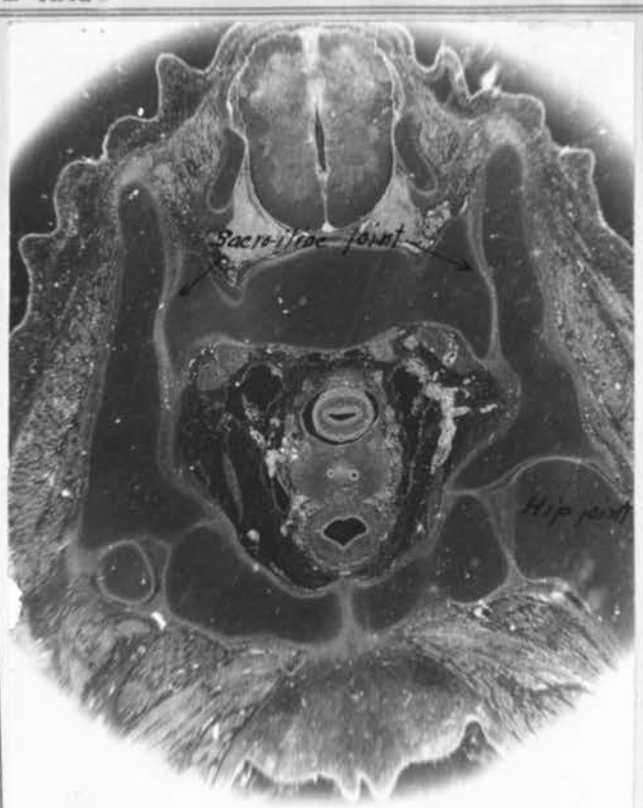
H 5-95-3-8. 25 mm. x26

5-22-4M

PLATE XXI

H21-88-4-4. 26mm. X22

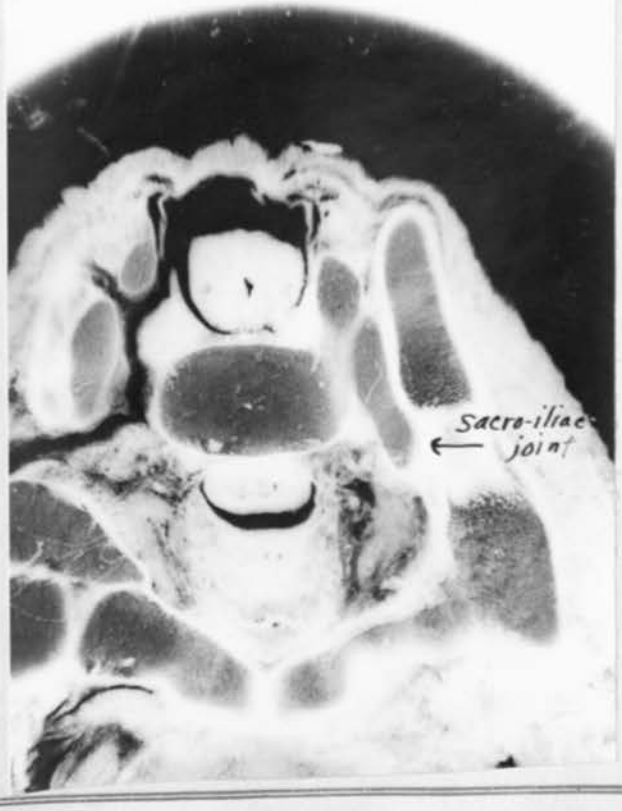




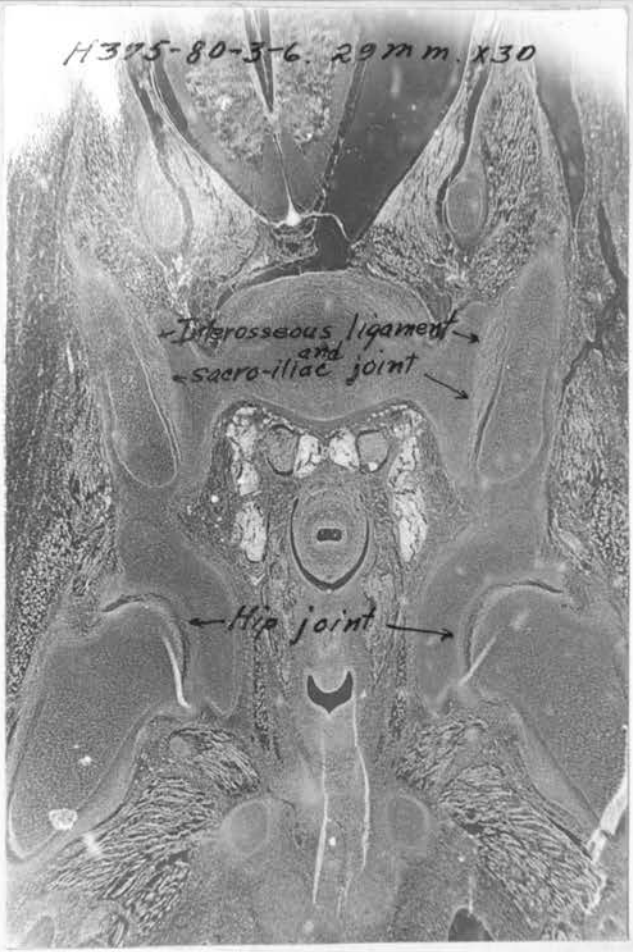
H29-78-2-6 26 mm. X 23

H48-90-4-3. 27mm. X20

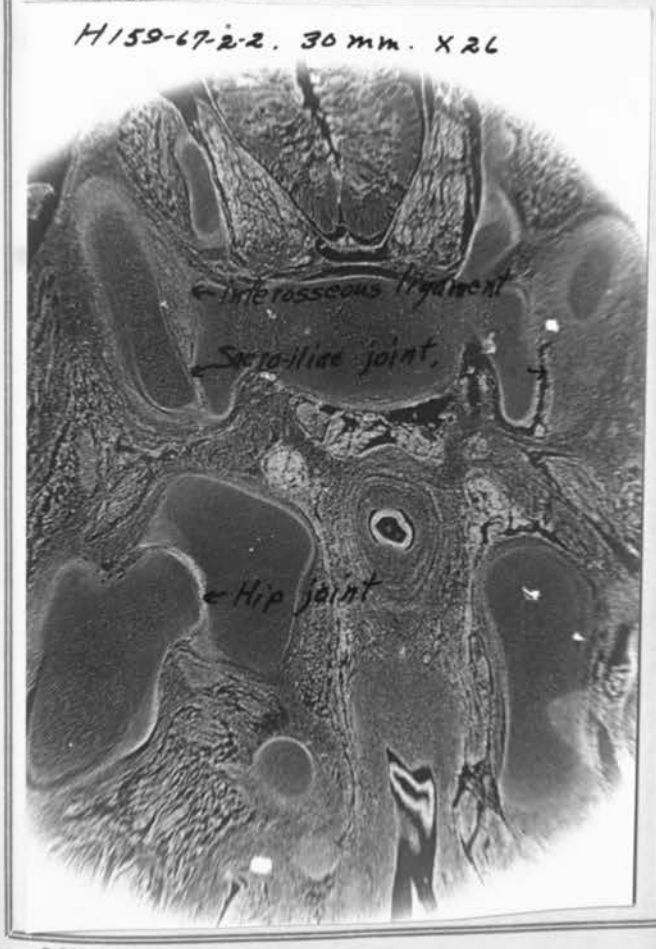
HX-338. 27.5 mm. X20



5-22-4M


H375-80-3-6. 29mm. X30
Interosseous ligament and sacro-iliac joint
Hip joint


Sacro-iliac joint
H108-6-1-7. 30mm. X 28

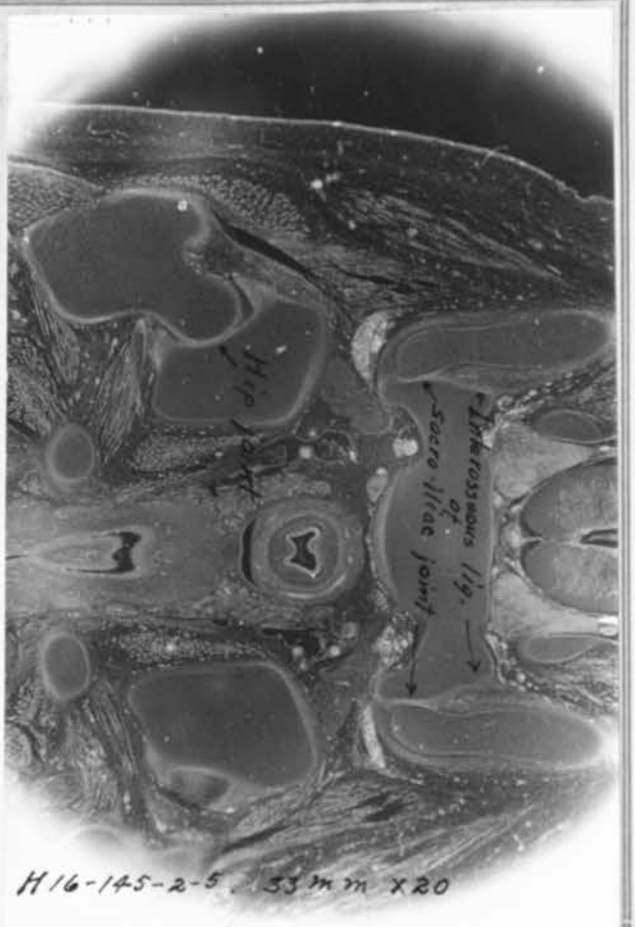

H159-67-2-2. 30 mm. X 26
Interosseous ligament
Sacro-iliac joint
Hip joint


Sacro-iliac joint
H98-144-2. 30 mm. S. X 22

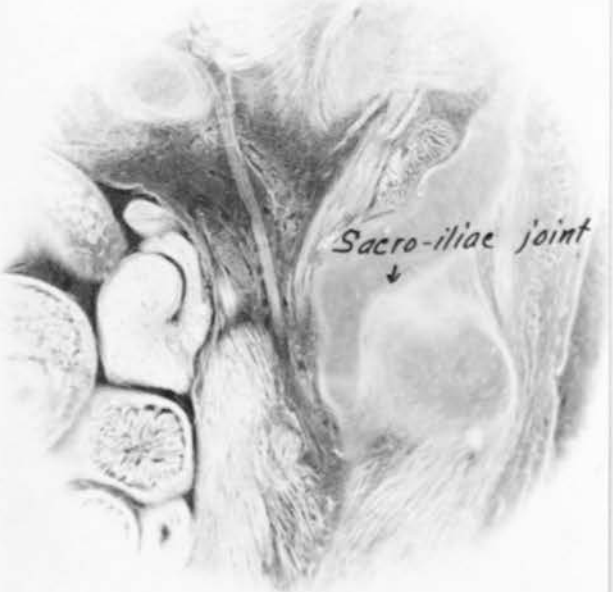
5-22-4M

PLATE XXIII

H298-97-1-2. 35mm, X 20



H16-145-2-5. 33mm X20

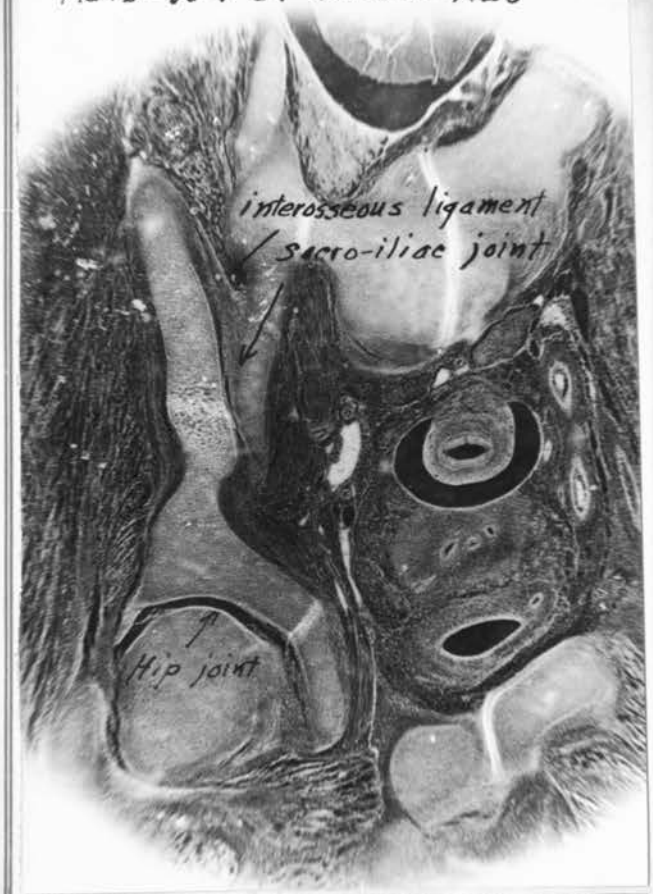


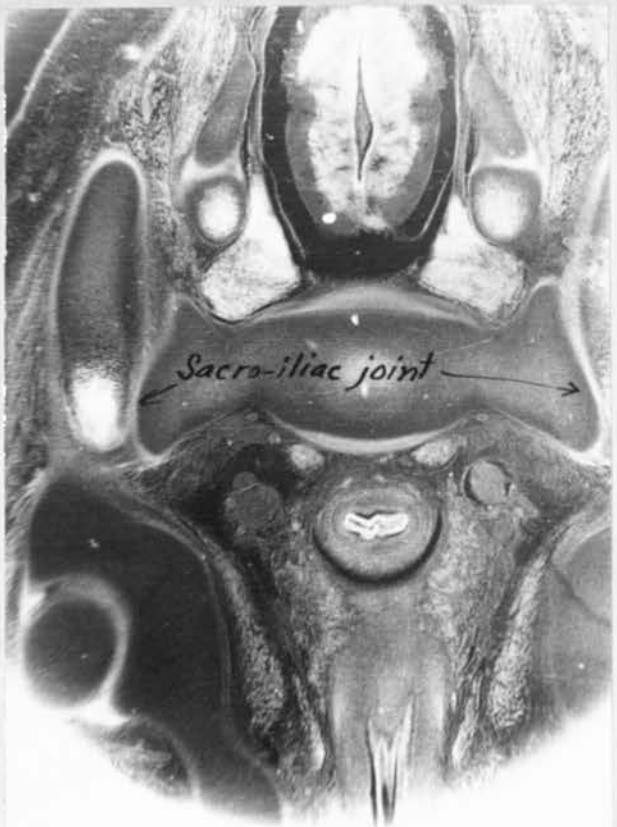
H51-30-2. 35mm. X20

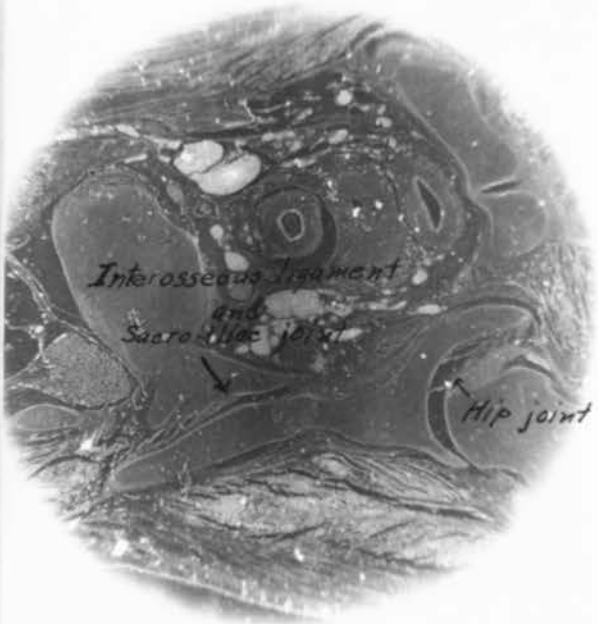
H57-244-1-5. 31mm. X26

5-22-4M

PLATE XXIV



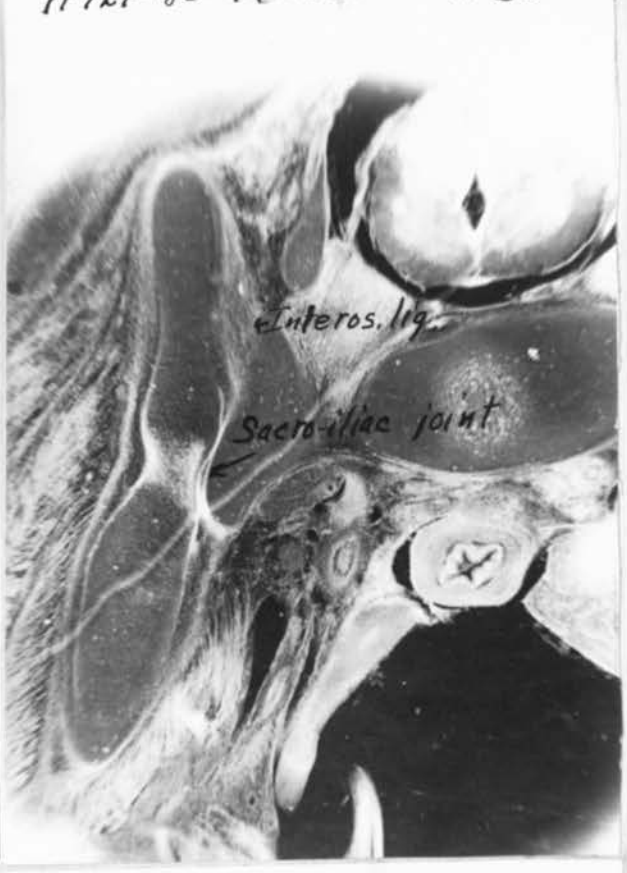




5-22-4M

H100-81-1. 43mm. S. X20

H121-83-4. 46 mm. X 20



H26-239-2-4. 65 mm. X8

H11-477-1-2. 60 mm. X20

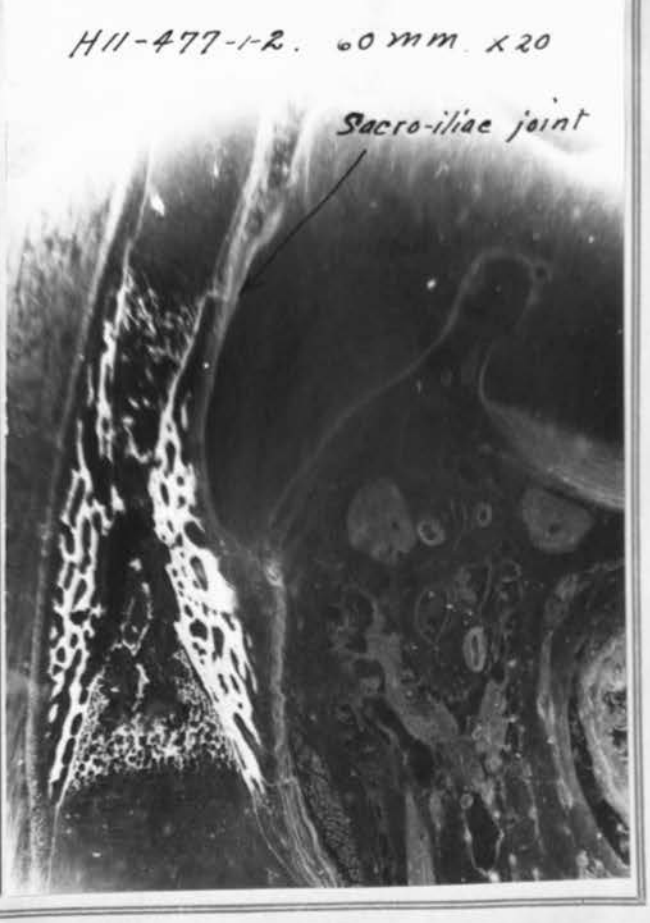
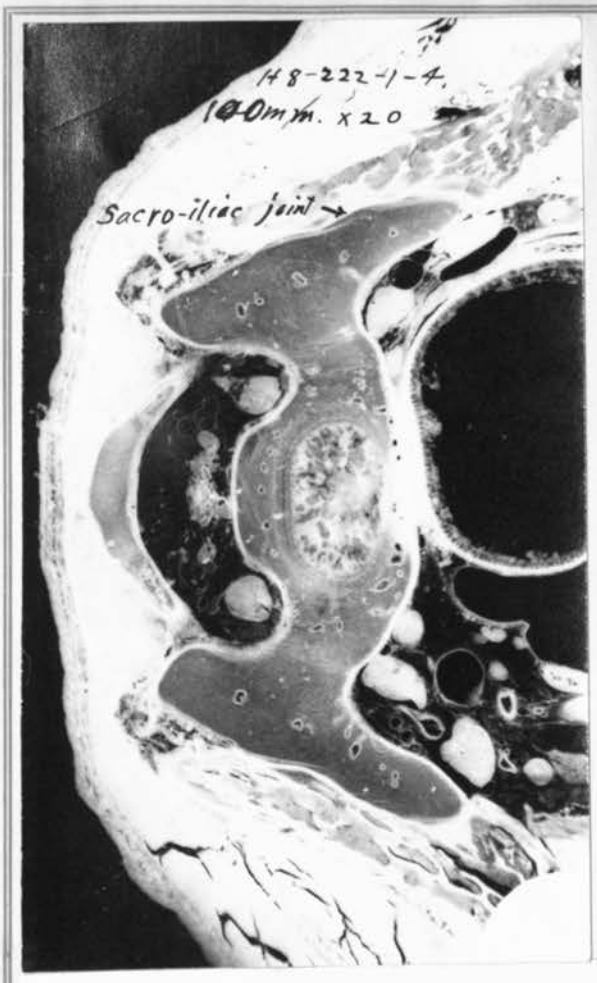
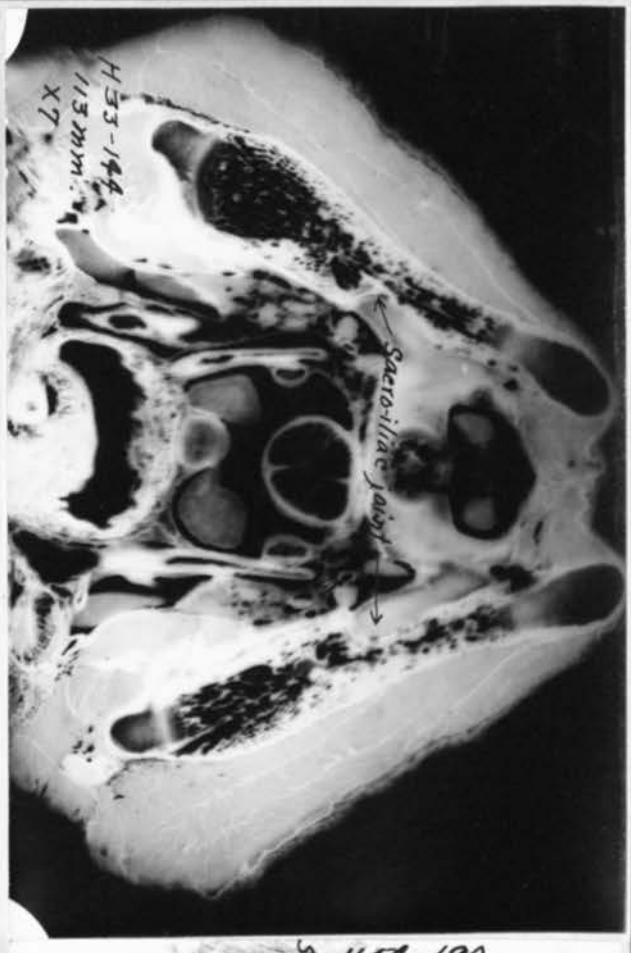


PLATE XXVI





H49-133. 126 mm. X15