STUDIES ON THE FEMUR

III. THE EFFECTS OF MACERATION AND DRYING IN THE WHITE AND NEGRO

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ONE FIGURE

The present paper may be looked upon as a continuation of our observations upon the femur as given in a recent number of this journal (Ingalls, '26). At that time we were concerned, among other things, with the rôle of the various articular cartilages of the femur in determining or altering certain standard measurements, and all references were to the fresh bone, either before or after the removal of the cartilage. Our purpose at this time is to record the changes which take place in the femur from the time when it still preserves all of its natural characters until it may have found its place in some museum or osteological collection.

The material is identical with that used in the investigation of cartilage of the femur—the same bones, the same measurements, and the same technique. The total of 106 femora is made up as follows: thirty-six pairs from male whites, ten pairs from male colored, and seven pairs from female colored. The point of departure in all cases has been the dimensions of the fresh, cartilage-free bone, still moist and preserving all of its original characters except the cartilage. Some of the material was left in this condition for a considerable length of time, or, in other words, it was allowed to dry or mummify, and during this period any resulting alterations were noted. Eventually all the material was subjected to the usual routine procedure of maceration. At the completion

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of this process, and while still wet, the bones were again measured, and this was repeated at various intervals during the progress of drying and shrinking for a number of months.

While the final dry measurements on the macerated bone include all the dimensions and all of the material given in our previous article, we have confined our attention, during the actual process of drying and shrinkage, to a much smaller number of characters. These are the various lengths of the entire bone and angles of obliquity and of torsion. In other words, the capital and condylar dimensions have been taken only in their initial and final conditions. Indices in all cases are indices of means, and not mean indices. Furthermore, the figures which will be presented regarding the rate and character of the shrinkage process are based largely upon the white material, or rather upon a part of it, since the entire series was not utilized for this purpose.

MUMMIFICATION

The effects upon the oblique length of the femur of that simple and primitive method of preservation, drying, are indicated by the interrupted curve, beginning at *D*, in the accompanying graph. The results shown here were obtained on eleven pairs of femora—twenty-two bones in all. Not only had the cartilage been entirely removed in these cases, but practically all of the periosteum as well, so that there was nothing to prevent thorough and rapid drying by exposure of the bones in the open at ordinary room temperature. Other bones, subjected to the same treatment, but measured at rather less regular intervals, are not represented in the graph.

The curve of mummification begins at *D*, naturally at the same level as *B*, since the latter represents the mean oblique length of the moist, fresh femur after the removal of the cartilage, which condition is the starting-point for the series *D*. The loss in length is most rapid during the first week, after which it gradually becomes less marked, until by the end of four weeks about 80 per cent of the total final shrink-

age has occurred, although nearly half of the final shrinkage takes place during the first two weeks. During the second month the process is much slower and the bones appear to have settled down to a final, definite size, from which they tend to vary slightly, depending upon atmospheric conditions. Individual bones often differ considerably in their behavior during the process of drying. Some have attained

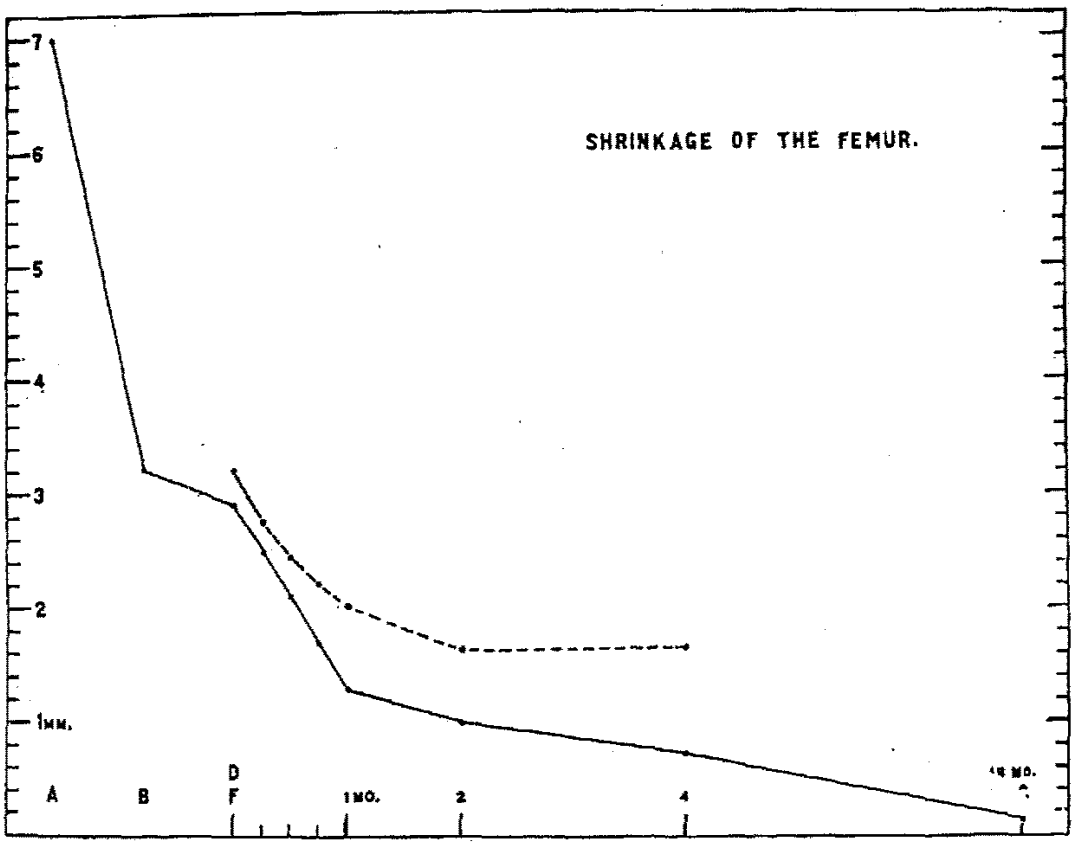

Fig. 1 The continuous line, beginning at *A* on the left and terminated at *C* on the right, represents the gradual reduction in the mean oblique length of twenty-five pairs of male white femora—fifty bones in all. The graduations represent 0.2 mm.

A is the oblique length with all cartilage in place, the mean for this series being 461.68 mm. The removal of all cartilage reduces the length by 3.78 mm. to 457.90 mm. the length of the moist cartilage-free bone at *B*. Maceration occurred between *B* and *F*, reducing the length by 0.31 mm. At *F* the wet, macerated bones begin to dry, and at *C*, eighteen months later, they are 2.78 mm. shorter than at *F*.

The interrupted line, beginning at *D* on the left, represents the shrinkage of twenty-two bones due to mummification, i.e., drying of the green, cartilage-free bone before maceration. At the end of two months, these bones showed a mean loss of 1.55 mm. on an initial length of 467.18 mm.

their final condition by the end of the first month, occasionally this is delayed until after the end of the second month or, rarely, it may be found by the end of the third week. Comparing right and left bones it may be noted that there may be considerable differences in shrinkage which disappear later, or, on the other hand, the difference may not appear until later in the experiment. Individual bones vary in the amount of shrinkage which occurs, the range being from 1 to 2 mm., but there is a tendency for the right and left bones of a pair to keep rather close together. The initial condition of the bones seem to have little if any effect upon the subsequent shrinking, very greasy bones behaving in all respects like those which were clean and dry. In two right bones longitudinal cracks appeared in the shaft during the first week, quite unassociated with any alteration in form.

After the second month, the mean length varies slightly, due to atmospheric conditions, but the shrinkage appears to have ceased. In the present series the mean length was 0.02 mm. greater at the end of the fourth month than at the end of the second.

In actual figures, four months' drying has brought about a mean reduction of 1.55 mm. on a mean original oblique length of 467.18 mm.; for the fresh bone devoid of cartilage, a loss of 0.33 per cent of the original length. The oblique trochanteric and maximum trochanteric lengths have been reduced by 1.43 and 1.66 mm., respectively. The angle of obliquity and the angle of torsion, determined in the manner given in our previous article, but not measured directly in angular values, suffer no material alteration during drying, beyond a slight tendency of the former to decrease. There is, therefore, only a very slight tendency of the bone to warp, even in those cases where cracks appear in the shaft—a tendency so slight that it is safely negligible.

The shrinkage due to simple drying is completed in about eight weeks, and the same was found to hold for the male white cranium (Todd, '25). In this cranial series, however, there was a shrinkage of from 0.6 to 0.8 per cent, while for

femoral lengths the reduction in length is only about half this amount. From evidence which will appear later, it is apparent that the differences in behavior are due to difference in bony structure, essentially the difference between compact and cancellous bone. The lengths of the femur are throughout most of their extent dense compact bone, with more or less cancellous bone covered by a thin compact layer at the ends. While the structure of the bones making up the cranial vault may quite easily vary more widely than the structure of the femur, as a rule their condition is certainly more like the articular ends of the bone than like the shaft. We have no data regarding either longitudinal or transverse shrinkage of the shaft of the femur alone, neither are there data on the effects of mummification upon the epiphyseal ends as such. If, however, we suppose that the ends of the bone preserve the same relation to the entire bone during mummification, as they do during maceration and subsequent drying, then the shrinkage in mummification of the cancellous ends of the bone would be, in percentage values, about double that of the entire bone. In this case the results would be in harmony with Doctor Todd's values for mummification of the cranium in male whites.

Four pairs of unmacerated bones which had been dried for four months were later subjected to soaking in water for seventy-two hours. Of these bones, four were male white, two male colored, and two female colored. Only three times in twenty-four length measurements, three on each bone, did three days' immersion in water restore the initial dimension, and these three cases are made up of the three different lengths, and each on a different bone. The eight bones just referred to lost 1.41 mm. from their mean oblique length and gained, by soaking, 0.94 mm., leaving a net loss of 0.47 mm., which is a trifle more than 0.1 per cent of the length of the dry but unmacerated bone. For the oblique trochanteric length the loss from drying was 1.37 mm., of which 1.09 mm. was regained on immersion in water. The corresponding figures for the maximum trochanteric length are 1.37 and

0.97 mm. The angles of obliquity show slight fluctuations, but they are much too small to be of any consequence, they simply indicate that the shrinkage or swelling of the bone is not absolutely uniform, but subject to local or temporal irregularities. The torsion angle is even more stable, doubtless on account of the much shorter mass of bone involved.

Naturally, the bones take up water with far greater rapidity than they lose it. At the end of three hours, practically all of the specimens had increased appreciably in length, often to the extent of half a millimeter, and, at the end of twenty hours, four of the eight bones were as long as at the end of seventy-two hours. One femur, right colored, showed the same length at six hours as at seventy-two, although at forty-eight hours it seemed a trifle longer than at 72. In only three cases was attainment of the maximum size delayed beyond forty-eight hours, and these were all white material. As far as these eight bones are concerned, the colored material increased in size more rapidly than the white, but the small number of specimens makes one hesitate in taking the results very seriously.

In order to have some additional evidence on the effects of drying unmacerated bones, particularly as to the practical absence of warping, a number of bones, quite different from the femur in shape and structure, were subjected to the same drying process. The bones used, all from the same body, male colored, no. 1062, comprised both scapulae and all of the ribs—a total of twenty-six bones.

Both scapulae showed the same reduction in length—0.5 mm., or 0.27 per cent of the original length while fresh. The loss in width, measured from the prominent lower margin of the glenoid cavity to the summit of the vertebral convexity near the base of the spine, was rather greater—a mean of 1.12 mm. for the two bones, or 0.92 per cent. For the third dimension on the scapulae, the elevation of the highest point on the spine above the plan upon which the ventral surface of the bone was resting was taken. Here again the losses on the two sides are equal—0.5 mm., or 0.6 per cent. The results on

these two bones are given for what they may be worth; as far as they go, they point to a differential shrinkage rather than to any real warping.

Two measurements were made in the case of the ribs. Their length was taken with slide calipers, as the chord between the extreme dorsal and ventral points. For the curvature, the bones were placed on the osteometric board with the lower border below and the two ends in contrast with the vertical, the distance between the vertical and the summit of the convexity of the rib was then determined. Measured in this manner, the mean length of all the ribs, both right and left, was 185.11 mm. in the fresh, unmacerated state. Two months' drying brought about a mean reduction of 1.08 mm., or 0.58 per cent. While the ribs on each side show practically the same mean length, the shrinkage was rather greater on the right, being 1.27 mm., or .69 per cent, as compared with 0.896 mm., or .49 per cent, on the left. The mean curvature for all ribs was 78.32 mm. when fresh; drying reduced this dimension by 0.19 mm., or 0.24 per cent. For the right and left sides the actual figures are as follows: right, curvature 79.19 mm., reduction 0.25 mm., or 0.32 per cent; left, curvature 77.46 mm., reduction 0.12 mm., or 0.16 per cent. Of all the bones of the body, one might have expected the ribs to show the greater disposition to warp, but even here the effects of drying are entirely negligible.

MACERATION AND SUBSEQUENT DRYING

The effect of live-steam maceration upon the green bone is to bring about a very small amount of shrinkage. Fifty femora showed a mean loss on the oblique length of 0.31 mm., or 0.07 per cent. Maceration of twenty-two bones which had been mummified for four months resulted in a mean loss of 0.40 mm., or 0.09 per cent. From this it would appear that the effects of mummification are not entirely removed by maceration. During the former process the bones lost 0.33 per cent of the oblique length, but gained during maceration only 0.25 per cent of the same, regaining, therefore, 75 per

cent of what was lost, the soaking of mummified bones restores 67 per cent of what was lost. In all of these cases the measurements refer to the macerated bones, while still wet; subsequent drying naturally reduces the dimensions very materially.

The entire history of the oblique length of fifty male white femora, twenty-five pairs, from the cadaver to the catacombs (to the bone boxes), is shown in the graph, the continuous line beginning with *A* on the left and terminating at *C* on the right. *A* represents the oblique length of the fresh, moist bones with all cartilage intact, the mean for this series being 461.68 mm. *B* represents the same dimension after the removal of the cartilage, the bones being still moist and otherwise unchanged. As noted previously, it is at this level, at *D*, that mummification begins. In this series the removal of all cartilage brought about a reduction in the oblique length of 3.78 mm., or 0.82 per cent of the original length. Between *B* and *F* occurs the slight drop already referred to, due to maceration and amounting to 0.31 mm., or 0.07 per cent of length at *B*. In all of these cases, *A*, *B*, (*D*), and *F*, the bones are wet; at *D* the unmacerated bones begin to mummify; at *F* the macerated bones begin their final drying.

During the first week of drying there is little difference between the unmacerated and macerated bones, as far as shrinkage is concerned. For the remaining weeks of the first month there is a gradual slowing down in the case of the unmacerated bones, while the macerated ones continue at the same rate to the end of this time. During the second month both series run nearly parallel, but while the unmacerated material has completed its shrinkage by this time, the macerated bones continue to shrink even after four months' drying, although about half the final reduction in length has occurred by the end of the third week. We cannot be sure of the length of time required to reduce the macerated material to its final dimensions, but, judging from the graph, it may very well be six or eight months, if not even longer. The final figures show that drying has reduced the mean

length of the wet macerated femur 2.78 mm., which is 0.61 per cent of the final dry measurement. As compared with the fresh, unmacerated bone, devoid of cartilage, maceration and prolonged drying result in a mean loss of 3.09 mm. on the oblique length, which is 0.67 per cent of the initial dimension, or 0.68 per cent of the final dimension. In terms of the fresh bone, with all cartilage intact, i.e., in its natural condition, the results of the removal of the cartilage of maceration and drying are a mean loss of 6.87 mm., or 1.49 per cent of the length in the recent state, or, on the other hand, 1.51 per cent of the final dry length.

The oblique trochanteric and maximum trochanteric lengths lose 3.11 and 3.36 mm., respectively, due to maceration and drying, as compared with 3.09 for the oblique length. The angle of obliquity is reduced very slightly, probably not over 0.5°, while the torsion angle undergoes no appreciable alteration.

There are certain minor differences in the behavior of the femur after maceration and drying as compared with the skulls studied by Dr. Todd ('23, '25, '26). The initial shrinkage of the femur is distinctly slower than that of the skull, and completion of the process demands a much greater length of time. Skulls attain the final dry dimensions in one month, while femora require several months. Two factors are apparently at work here—the greater amount of dense bone in the femur and its relatively smaller surface. These distinguishing characters may also account for the fact that the skull shrinks rather more after maceration than the femur, the male white skull losing on the average 0.71 per cent, excluding the auricular height, while the femur loses 0.61 per cent of its final dimension. Furthermore, the macerated and dried skull has lost an average of 0.84 per cent as compared with the green state, but the femur has lost only 0.68 per cent. To some extent this somewhat lower value for the shrinkage in the oblique length of the femur may be due to a slight warping of the bone, possibly changes in the collar angle, since, as may be seen in table 1, the percentage

loss on the trochanteric lengths is slightly higher—0.73 and 0.76 per cent; but these results are based upon seventy-two bones instead of upon fifty.

Four pairs of macerated femora, two white and two colored, which had been drying for five months, were immersed in water for three days in order to compare their behavior with that of unmacerated bones. It should be noted, however, that, although these bones had been drying for five months, they had not yet shrunk to the final dimensions. The mean increase in length following a sojourn of seventy-two hours in water was 1.97 mm. Even with this increase in length they were still 0.34 mm. shorter than immediately after maceration and before drying, and 0.59 mm. shorter than in the green unmacerated state. The 0.59 mm. not regained by soaking represents a percentage value of 0.14. The oblique trochanteric length regains 1.66 mm. on soaking, but is still 1.03 mm. below the initial green length; for the maximum trochanteric length the corresponding figures are 1.84 and 0.75 mm. There is a slight increase in the angle of obliquity, which brings it back practically to its value in the cartilage-free, unmacerated bone. The increase in the torsion angle is too small to be of any importance.

It may be noted in passing that, on immersion after maceration, the colored bones seem to take up water and increase in length rather more rapidly than the white material. This was noted above, but on a different set of bones, for the soaking of dried but unmacerated bones.

The scapulae and ribs, referred to above, were macerated and dried with the following results. Measured wet, after maceration, the length has been reduced on both sides 1.75 mm., or 0.94 per cent of the fresh length; the width has remained unchanged, while the elevation of the spine has increased 0.25 mm., or 0.30 per cent. After eighteen months' drying, the length is the same as after maceration, but still wet; indeed, the left bone appears a trifle longer, the mean reduction in length from the recent state being 1.62 mm., or 0.87 per cent. The width, however, which showed no change

during maceration, loses a mean of 2.62 mm. on drying, which is 2.17 per cent of its green length. The elevation of the spine, which increased as the result of maceration, decreases again during the subsequent drying, so that its final position is 1.25 mm. lower than in the fresh bone—a decrease of 1.50 per cent.

It would appear that the spine of the scapulae is largely responsible for the peculiar behavior of this bone. This would explain the much greater decrease in width than in length, both as the result of mummification and of drying. The apparent failure of the width to decrease drying maceration is offset to some extent by the increase transverse curvature. This irregular shrinkage gives other evidence of its presence in the checking and buckling which frequently occur in the thin bone of the infraspinous fossa. During maceration of the mummified bones, the length decreases, while both the width and curvature increase; during subsequent drying the length remains stationary, while the width and curvature decrease. The mean scapular index for the two bones concerned was 64.91 in the recent state and 63.91 after maceration and final drying.

The mean fresh length of all the ribs is reduced 1.98 mm. by maceration and drying—a percentage loss of 1.07; the curvature is reduced 0.67 mm., or 0.86 per cent. The mean result is, therefore, that the form of the rib remains practically constant and unchanged, although individual bones may vary considerably in their reactions to maceration and drying.

The effects of maceration and drying upon the head and condylar regions of the femur are known only from a comparison of the initial and final conditions, no measurements having been taken in the interval. The results on these portions of the bone have been brought together in table 1. There also appear here similar data on the lengths of the entire bone, both white and colored, which data differ slightly from that already discussed, since they are based upon a somewhat more extensive material. It may be noted that both the mean and percentage losses for the three lengths of

the femur are, with one exception, higher in the colored than in the white.

The most striking feature about the head is the fact that the vertical diameter shrinks less than the horizontal. This applies to both mean and percentage losses and to both white and colored material. The great difference in the behavior of the two diameters of the head in the female colored—a difference of 0.44 per cent—may naturally be due to a greater or less extent to the relatively small number of bones, 14 as compared with 20 for the male colored and 72 for the male

TABLE 1

The effect of maceration and drying. A comparison of the moist, cartilage-free, but unmacerated bone with the macerated and dried bone; series B–series C. Right and left combined; means in mm.; Percentages in terms of B

DIMENSION	MALE, WHITE. 72		MALE, COLORED, 20		FEMALE, COLORED, 14	
	Loss		Loss		Loss	
	Mean	Per cent	Mean	Per cent	Mean	Per cent
Oblique length	3.17	.69	3.5	.75	3.34	.76
Oblique trochanteric length	3.19	.73	3.5	.79	3.31	.79
Maximum trochanteric length	3.40	.76	3.80	.83	3.23	.75
Head, vertical	.64	1.29	.72	1.49	.52	1.25
Head, horizontal	.72	1.47	.81	1.69	.7	1.69
Lateral, condyle, projected	.78	1.17	.86	1.26	.7	1.14
Median, condyle, projected	.84	1.33	.77	1.19	.85	1.44
Epicondylar breadth	1.25	1.48	1.42	1.66	1.32	1.81

white. Since compact bone shows less alteration on drying than cancellous bone, one is drawn to the conclusion that there is a slight difference in structure, or density, between the vertical and horizontal trabeculae of the femoral heads. The former appear rather more resistant and less changeable, these properties being correlated with their weight-bearing function as is also the greater vertical diameter of the head as compared with the horizontal.

The inevitable result of the greater shrinkage in the smaller diameter of the head is an increase in its ellipticity or a lowering of the primary capital index. The effect of macera-

tion and drying upon the fresh femoral head devoid of cartilage is a reduction of the mean index for both sides from 98.57 to 98.49 in male whites, from 99.48 to 99.40 in male colored, and from 99.47 to 98.92 in the female colored.

The effects of maceration and drying upon the condylar lengths are less consistent than in the case of the head. They differ from the head also in the fact that the percentage shrinkage is somewhat less, and, moreover, the difference between the white and colored material is much less conspicuous. In fact, as regards percentage loss, the male colored occupies an intermediate position between the male white and the female colored. The difference in shrinkage between the two condyles is greatest in the female colored, which behaves like the male white in showing a higher value for the median condyle. The opposite is the case in the male colored, but the difference is considerably less.

Like the head, the epicondylar breadth loses more in the colored material than in the white, but the greatest loss is in the female, whereas in the head it is in the male. Not only is the shrinkage of the lower end of the femur greater in the transverse direction—the epicondylar breadth—than it is in the anteroposterior direction—the projected lengths of the condyles—but the excess in the shrinkage of the former increases steadily from the male white, through the male colored, to the female colored. We have no means of determining the shrinkage of this region in the third direction, in the axis of the shaft, but it is to be expected that it would be less than in the transverse direction if not also less than in the anteroposterior.

The average of the absolute and percentage losses for the eight measurements given in table 1 are as follows: male white, 1.75 mm., or 1.11 per cent; male colored, 1.92 mm., or 1.21 per cent, and female colored 1.75 mm., or 1.20 per cent.

THE FEMUR LIVING AND DEAD

There remains for consideration a comparison of the femur in the recent state, fresh and with all cartilage intact, with

its condition after removal of the cartilage and after maceration and final drying. In other words, a comparison of the characters of the bone as they exist during life, with the same characters of the bone in the condition in which it ordinarily presents itself for examination. Since the essential points are contained in tables 2 to 5, the following discussion will be rather brief.

TABLES 2 TO 5

Comparisons of the femur in the recent state, fresh and with all cartilage intact, with the macerated and dried bone; series *A*—series *C*. Means and range of loss in millimeters; percentages in terms of *A*, i.e., the condition in the recent state.

TABLE 2

Oblique length

		MEAN	MEAN LOSS	PERCENTAGE LOSS	RANGE OF LOSS	
					Minimum	Maximum
Male, white, 36 cases	Right	457.67	6.89	1.50	4.25	8.75
	Left	458.03	6.79	1.48	4.75	8.50
Male, colored, 10 cases	Right	468.8	7.25	1.55	6.	9.25
	Left	472.8	6.87	1.45	5.75	8.25
Female, colored, 7 cases	Right	440.71	6.61	1.50	5.5	8.
	Left	441.57	6.75	1.53	6.	7.75

Oblique length (table 2)

Mention has already been made of this dimension, and its gradual shrinkage for twenty-five pairs of male white femora is shown in the graph. As noted previously, the mean length of these fifty bones in the recent state, at *A*, 461.68 mm. is reduced by 3.78 mm. to *B*, due to the removal of cartilage—a loss of 0.82 per cent of the original length. There is a second loss of 0.31 mm., due to maceration, at *F*, and a final additional loss of 2.78 mm., due to drying, at *C*. The total loss, therefore, for the fifty bones concerned is 6.87 mm., which is 1.49 per cent of their original live length. On the basis of their final dry length, these bones have suffered a reduction in length of 1.51 per cent. As regards the white

and colored material, the data contained in the table are in accord with our previous finding, that the cartilage is somewhat thicker in the colored and also that the colored material suffers slightly greater shrinkage.

It should be noted in passing that slight irregularities in the lengths of the right and left bones, as measured after maceration and drying, might be canceled or even reversed if it were possible to restore the original dimensions of the bone, including the cartilage. In the present series of thirty-six pairs of male white femora, the mean oblique lengths of the left bones exceeded that of the right by 0.36 mm. in the recent state. This difference in favor of the left was increased to 0.48 mm. by maceration and drying. Not only did the shorter side lose more on the removal of cartilage, but it also suffered more in the later shrinking process. Although the rôle of articular cartilage can hardly be extended to include altering the length of the long bones or compensating for their inequality, it may, in many cases, have this effect, due to variations in thickness on the two sides.

Special interest attaches to the oblique length of the femur, since it has so often formed the starting-point in attempts to reconstruct the stature. Although it is in this natural, or so-called oblique, position of the femur that it forms one of the important factors in determining stature, it is the maximum length of the bone rather than the oblique length, according to Pearson, which shows the greater correlation with stature.

In view of the obvious fact that the dry bone, as commonly measured, is somewhat shorter than during life, a few isolated attempts have been made to approximate the original dimensions. In other words, the intention has been to restore what has been lost in the removal of cartilage and in the loss of water and organic material. Manouvrier ('92), on the basis of Rollet's findings, added 2 mm. to the oblique length in the computation of stature. The figures of Rollet, however, are apparently based on mummified material with the articular cartilages still in place. He noted an average

diminution in length of 2 mm. after some months of drying. We have no data on the effects of drying upon cartilage, but certainly 2 mm. would not restore the original length, including the cartilage. Mummification of the bone, without cartilage, would reduce its mean length at least 1.5 mm., while the 3.5 mm. or more of cartilage would doubtless shrink more than enough to make up the remaining 0.5 mm.

Pearson ('99) was, quite naturally, dissatisfied with Rollet's results, since they did not take into account both the articular cartilage and the organic material in the bones. For the cartilage he uses Werner's measurements, and allows 2 mm. for the cartilage on the head and 2.5 mm. for that over the condyles. The total amount of 4.5 mm. he would add to both the oblique and the maximum lengths. This allowance, however, is too great by nearly 1 mm. The 2 mm. on the head is only slightly less than the thickness of two layers of cartilage, but only one is concerned in any femoral length. Our own results show that the mean loss on the oblique length due to the removal of all cartilage is 3.67 mm. for seventy-two white femora.

In his estimation of the amount of shortening due to the disappearance of organic material and water, Pearson was rather more fortunate. Long before this time, Welker had soaked one male femur for three days and found an increase in length of 1.2 mm. Later, Broca carried out a similar experiment, using three femora; one had been macerated the same year, another was of the fifteenth century, while the third was of the polished stone age. Seven days' soaking increased the length of the first two by 1.5 mm., of the last, however, by only 1 mm. Pearson's own data on the femur are the results of immersing one bone in water for five days. The femur used was between two and three hundred years old, and the increase in length after soaking was 2.6 mm., or 0.61 per cent of the initial length. This increase in length is notably greater than the 1.97 mm., or 0.46 per cent, which we have obtained after three days' soaking. The difference may be accounted for possibly by the greater length of time

during which Pearson's material was soaked in water, or, in addition, by the bone's being more completely shrunken, in view of its much greater age, and therefore relatively shorter at the beginning of the experiment. However, after seventy-two hours' drying following the soaking, completed by "six hours in the neighborhood of a stove," the femur in question was 0.8 mm. shorter than when 'dry as received.' Warren's experiments on his ancient Naqada material, as cited by Pearson, gave increases on two femora of 2.4 and 2.2 mm., or 0.59 and 0.50 per cent. Here, again, the prolonged immersion five and six days, with the great water-logging of the bones, may explain the considerable increase in length.

The conclusion of Pearson is that it would be necessary to allow 7.1 mm., 4.5 for cartilage and 2.6 for organic material and water, as the difference between the bone during life and when dry and entirely free from animal matter. This is in substantial accord with our own results which indicate a loss of 6.8 mm., between the recent state and the dry, macerated bone, but we do not think that it could be applied in all cases, and, moreover, it is an allowance on bones which are definitely shorter than those which compose our series.

It is evident that the water and organic content of bone introduce some rather disturbing factors in the determination of any given dimension. Pearson is certainly right in thinking that the low increases obtained by Broca were due to the fact that he allowed the bones to dry for twenty-four hours before measuring them. On the other hand, Pearson's own figures show that the bones at the beginning of his soaking experiment were definitely longer than after they had been subjected to artificial drying, 'in the neighborhood of a stove.' He quite properly employs the first length, since it represents the length of the bone under the ordinary conditions of preservation and measurement. Although the length of the femur varies with the amount of water it contains, it probably never, whether macerated or only mummified, regains its original green dimensions by simple immersion in water. There is something lost by the withdrawal

of water which is not regained when water is again present; the drying process is, to some extent irreversible, and the more trustworthy results should be obtained by following the drying to its completion rather than by attempting to reverse procedure.

As regards the rôle of the organic material in either the shrinking or swelling of bone, we have no very definite quantitative data. Nevertheless, there are certain definite findings which can be explained only on the basis of the organic matter in the bone. It has been noted already that the wet, macerated femur was 0.31 mm. shorter than the green, unmacerated bone—a loss of 0.07 per cent on its oblique length in the green condition. This loss can only be explained in terms of loss or alteration in the organic content of the bone. It will also be remembered that the mummified bones did not increase in length to the same extent as the result of soaking, as was observed in the macerated bones when subjected to the same treatment. The organic matter in the mummified bones has been so affected by drying that not only does the presence of water fail to restore it, but it also tends to tie down the remaining osseous material and so prevent the swelling which would otherwise occur.

The reactions of a bone, either on the withdrawal or on the addition of water, are determined to a considerable degree by the amount and condition of the organic material already present. To what extent the organic matter has been removed from the femora considered in this series we cannot say. It is quite possible that there might be some individual fluctuations, explaining, in part at least, the varying behavior of different bones. It is further altogether probable that our macerated and dried bones contain more organic matter than Pearson's material from century-old burials, and we are quite prepared to believe that the further abstraction or destruction of the animal matter would again result in some slight diminution in size. We do not, however, believe that there would be any material alterations in the dimensions of the femur or that any serious risk would be incurred in applying our results to dry bones of any age.

In our first article on the femur it was noted that in twelve cases of male whites the mean stature was 1708 mm.; the mean oblique length of the right bones in these cases was 450 mm., or 26.3 per cent of the stature as measured. In the present series the mean stature of the thirty-six cases was 1705 mm., the mean oblique length of the right bones, after maceration and drying, was 450.85 mm., or 26.4 per cent of the stature. In their natural condition the same femora made up 26.8 per cent of the stature, while the removal of all cartilage reduced this to 26.6 per cent.

TABLE 3

Oblique trochanteric length

		MEAN	MEAN LOSS	PERCENTAGE LOSS	RANGE OF LOSS	
					Minimum	Maximum
Male, white, 36 cases	Right	436.58	4.69	1.07	2.75	7.5
	Left	437.25	4.51	1.03	2.5	6.5
Male, colored, 10 cases	Right	443.6	5.45	1.23	4.5	7.
	Left	447.7	5.05	1.13	4.5	6.
Female, colored, 7 cases	Right	420.	4.91	1.17	2.75	6.
	Left	422.14	5.11	1.21	4.25	7.

Oblique trochanteric length (table 3)

Both the mean and percentage losses are less for this dimension, since only one layer of cartilage is concerned, while two layers have been lost from the oblique length. The difference between the white and colored material is, on the other hand, much more pronounced than for the oblique length, being due largely to the thicker cartilage and to the greater obliquity of the bones; in part, perhaps, to the greater shrinkage.

The mean losses of the maximum trochanteric length, including both sides, are as follows: male white, 4.89 mm.; male colored, 5.28, and female colored, 4.54.

As regards the angle of obliquity, it is evident that the removal of the infracondylar cartilage is of greater moment in altering the angle than the subsequent maceration and drying. The behavior of the dry macerated femur in this respect is, consequently, much like that of the fresh bone after the cartilage has been removed, showing the same sort of fluctuations and the same uncertainty as to its original condition as has been pointed out elsewhere. Since it does not appear possible to determine the original angle, it is sufficient to know that the mean angle in the dry, macerated bone is slightly smaller than it was during life, the angle being reduced about 1°, or even less. The torsion angle shows no demonstrable alterations, indicating that the shortening of the bone is not accompanied by any tendency to roll or twist.

The femoral head (table 4)

Considering the small size of the head of the femur, it is not surprising that it should show the high percentage losses noted in the table. The shorter anteroposterior diameter of the head loses both absolutely and relatively more than the longer vertical diameter. In all cases the percentage loss is least in the male white and greatest in the female colored, the extremes being 4.93 per cent for the vertical diameter on the right in the male white and 6.97 per cent for the horizontal diameter on the right in the female colored. Naturally, the removal of the articular cartilage is largely responsible for the high percentage losses, but that shrinkage also plays a considerable part is evident from the data in table 1. As regards the cartilage alone, it has been shown previously that the cartilaginous covering is thicker for the anteroposterior diameter than for the vertical diameter.

The mean effect of these various factors is that the femoral head is most nearly spherical during life and most elliptical after maceration and drying, the thicker cartilage over the shorter diameter being the chief element in compensating for, or relieving, the natural ellipticity of the bare bone. The mean primary capital index for both right and left sides, in

the male white, during life, is 98.94, as the result of maceration and drying this index is reduced to 98.49, which represents a loss of 0.45 per cent of the original value. In the male colored there is a reduction of the index from 99.85 to 99.40, again a loss of 0.45 per cent. For the female colored the corresponding figures are 99.73 and 98.92, but the loss here is much higher—0.81 per cent.

TABLE 4

Head, vertical and horizontal diameters

		MEAN	MEAN LOSS	PERCENTAGE LOSS	RANGE OF LOSS	
					Minimum	Maximum
Vertical diameter						
Male, white, 36 cases	Right	51.87	2.56	4.93	1.75	3.75
	Left	51.67	2.68	5.19	1.75	3.5
Male, colored, 10 cases	Right	50.32	2.9	5.76	2.25	3.5
	Left	50.15	2.72	5.42	2.25	3.25
Female, colored, 7 cases	Right	43.71	2.54	5.81	1.5	3.25
	Left	43.89	2.79	6.35	2.25	3.
Horizontal diameter						
Male, white	Right	51.42	3.04	5.91	2.25	4.25
	Left	51.09	2.84	5.56	2.	4.5
Male, colored	Right	50.17	3.12	6.22	2.75	4.
	Left	50.1	3.	5.99	2.5	3.75
Female, colored	Right	43.64	3.04	6.97	2.5	3.5
	Left	43.72	2.93	6.70	2.5	3.25

Computed on the basis of the macerated and dried bones, and combining the right and left sides, the mean vertical diameter of the femoral head in male whites would have to be increased 5.35 per cent, the horizontal diameter 6.10 per cent, in order to restore the original dimensions as they obtained during life. In the male colored the necessary increases would be 5.93 per cent and 6.49 per cent, in the female colored, 6.48 per cent and 7.33 per cent.

The condyles (table 5)

Like the head, the condyles lose two layers of cartilage, and therefore the mean and percentage losses are correspondingly high. Like the head, also, the greater part of the loss is referable to the cartilage alone, the remainder being due to shrinkage. The median condyle, however, suffers less than the lateral, and this is especially true for the colored material.

The various condylar indices show little alteration as compared with the fresh bone after the removal of the cartilage. The condylar index in male whites, for combined right and left sides, was 78.71 before maceration and 78.80 after maceration and drying. In the male colored the index remained unchanged, 79.89, while in the female colored it was increased from 84.13 to 84.87. The corresponding changes in the condylar length index were, in male whites, 105.58 to 105.66; in the male colored, 105.49 to 105.19; in the female colored, 104.06 to 104.56.

In terms of the macerated and dried bones, and taking the right and left sides together, it would be necessary to increase the mean projected length of the lateral condyle by 5.82 per cent in male whites, and the same length of the median condyle by 5.76 per cent, in order to restore the dimensions of the recent state, with the cartilage in place. In the male colored the necessary increases would be 6.77 per cent and 6.01 per cent; in the female colored, 6.93 per cent and 5.89 per cent.

In concluding we would take occasion to revert for a moment to certain findings which have already been touched upon briefly. These are the apparent differences in the behavior of the male white and the colored material. In our last article we called attention to the differences in the cartilage of the femur exhibited by the white and colored. These differences were entirely unexpected—in fact, never thought of—and so also were the results in regard to maceration and drying. We would repeat again, also, that, to some extent, the peculiar results may be due to the paucity of colored

material, there being but thirty-four colored femora as contrasted with seventy-two from male whites.

The mean shrinkage during mummification on the oblique length of twenty-two male white femora, was 1.55 mm., or 0.33 per cent; on eight male colored the shrinkage was 1.50 mm., or 0.32 per cent; on four female colored there was 1.25 mm., or 0.29 per cent. Subsequently, eight of these bones,

TABLE 5

Lateral and median condyle, projected length

		MEAN	MEAN LOSS	PERCENTAGE LOSS	RANGE OF LOSS	
					Minimum	Maximum
Lateral condyle						
Male, white, 36 cases	Right	69.61	3.91	5.62	3.	5.5
	Left	69.64	3.74	5.37	2.75	5.25
Male, colored, 10 cases	Right	72.2	4.82	6.68	4.	6.
	Left	71.7	4.3	6.00	3.	6.
Female, colored, 7 cases	Right	65.43	4.36	6.66	3.5	5.75
	Left	64.86	4.07	6.27	2.25	5.
Median condyle						
Male, white	Right	65.86	3.64	5.53	2.25	5.25
	Left	65.69	3.52	5.36	2.75	5.50
Male, colored	Right	67.9	3.9	5.74	3.	5.5
	Left	67.8	3.8	5.60	3.	5.25
Female, colored	Right	61.86	3.39	5.48	2.25	4.5
	Left	61.57	3.46	5.62	3.	4.

four white and four colored, were immersed in water for seventy-two hours with the result that the colored bones increased in size more rapidly and came nearer to the original green length than did the white bones.

The mean percentage losses for the eight dimensions given in table 1 are as follows: male white, 1.11 per cent; male colored, 1.21 per cent, and female colored, 1.20 per cent. These values refer to the effects of maceration and drying,

and have nothing to do with the thicker cartilage of the colored; they are based on seventy-two male white femora, twenty male colored, and fourteen female colored. As noted previously, eight macerated and dried bones were soaked in water for seventy-two hours, of these four were white and four were colored. The results duplicate exactly what was found for soaking after mummification: the colored bones increase in size more rapidly and approximately more closely to the original size.

As regards the skull, Doctor Todd's findings are very similar, both as regards the smaller amount of shrinkage during mummification and the greater amount after maceration and drying. The mean percentage shrinkage for four cranial dimensions, during mummification, were 0.71 in the male white, 0.68 and 0.69 in the colored, male and female. The corresponding figures after maceration and drying were 0.87 in the male white and 1.29 and 1.14 in the colored. However, it should be noted that white female skulls showed a greater shrinkage in both conditions of the bone: 0.79 for the first and 1.44 for the latter.

Although Doctor Todd is inclined to explain these cranial discrepancies on the basis of the small number of colored (and female white) specimens and also upon possible variations of conditions during drying, we believe, in view of the findings upon both skull and femur, that the question as to the possibility of there being some difference in the behavior of white and colored material is not yet definitely settled.

SUMMARY

The present article is a continuation of the study of femoral cartilage which appeared in vol. 9, no. 3 of this Journal. The material is identical, consisting of thirty-six pairs of male white femora, ten pairs of male colored, and seven pairs of female colored. The effects of maceration and drying upon the principal femoral measurements, and also the differences between the bone in the recent state and the same bone after maceration and drying, are tabulated both for absolute and percentage alterations.

For a part of the material there are data available on the effects of mummification, i.e., drying before maceration, and also in regard to the results of soaking of previously mummified as well as macerated and dried bones. The shrinkage on mummification is complete in two months, but after maceration the shrinkage continues for a much longer time. The two important factors in determining the rate and amount of shrinkage are the water and organic content of the bones.

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