SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 61, NUMBER 8

THE COMPARATIVE HISTOLOGY OF THE FEMUR

(WITH THREE PLATES)

BY

DR. J. S. FOOTE
Professor of Histology and Pathology, Creighton Medical College,
Omaha, Nebraska

(PUBLICATION 2232)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
AUGUST 22, 1913

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

THE COMPARATIVE HISTOLOGY OF THE FEMUR

By DR. J. S. FOOTE

PROFESSOR OF HISTOLOGY AND PATHOLOGY, CREIGHTON MEDICAL COLLEGE, OMAHA, NEBRASKA

(With Three Plates)

The comparative study of the minute structure of the femur was begun by the present writer in 1909. The first report described 46 microsections of the femora of as many different animals and was published in the Transactions of the American Microscopical Society of April, 1911. Following the first report and largely upon the suggestion of Dr. Aleš Hrdlička, Curator of the Division of Physical Anthropology in the United States National Museum, the writer has extended his investigations to man of different ages and races, as well as to many additional genera and species of animals; and an abstract of these further studies which revealed many important and new points, is here presented.

For the valuable material, facilities for study, and courtesies extended, the writer is especially indebted to the Division of Physical Anthropology of the United States National Museum; and to the Division of Mammals and Reptiles of the same institution; the Departments of Reptiles, Birds, and Mammals of the American Museum of Natural History, and the Departments of Anatomy and Medicine of the Northwestern, the Tulane, and the Creighton Universities.

The total number of genera and species whose femora have up to this date been examined amounts to 400, including amphibians, reptiles, birds, mammals, and man. The observations have been made on complete cross-sections of the femur at the middle of the shaft. Embryological, adolescent, adult, and senile bones of the same species were examined whenever it was possible, and controlling studies were also made on other bones of the body. The drawings have been made for the most part with the aid of the Edinger apparatus.

The investigations, which are of pioneer nature, have brought out many facts that are new to science. The existence of three types of bone, together with a number of combinations of these types, is established. They might be called the early, intermediate, and advanced, or, more definitely, the undifferentiated, laminar, and Haversian-system types. As a matter of convenience they will be referred to as the first, the second, and the third types, respectively. They are illustrated in plate 1. They are doubtless connected intimately with vascular development, and may be defined as follows:

The *first type* (pl. 1, fig. 1) is composed of homogeneous bone substance enclosing more or less numerous lacunæ, from which radiate their minute canaliculi. It is very poor in vascular canals. The lacunæ present a simple concentric arrangement; they may be comparatively few or many in number; they may be round or oval in shape, with few or again many canaliculi; and the bone may show an approach to the simplest form of lamination.[1]

The *second type* (pl. 1, fig. 2) is composed of groups of concentric laminæ which show vascular canals running parallel to the axis of the bone, as well as about the laminæ, and are frequently crossed by smaller canals running in various directions. The lacunæ are considerable in number, and may be oval, or long and narrow, according to the species.

The *third type* (pl. 1, fig. 3) is composed of Haversian systems, such a system is defined by Cunningham as follows: "The Haversian system consists of a central or Haversian canal which contains a vessel of the bone. Around this osseous lamellæ are arranged concentrically, separated here and there by interspaces called lacunæ, in which the bone corpuscles are lodged. Passing from these lacunæ are many fine channels called canaliculi. These are disposed radially to the Haversian canal and pass through the osseous lamellæ. They are occupied by the slender processes of the bone corpuscles."

These three types, either singly or in combination, enter into the formation of the femora of all animals; and there is no suggestion of any additional form of bone structure. Taken as a whole, combinations of types are more common in the structure of bone than single types, and are more frequent in the mammals than in the classes below them.

[1] The term *lamellæ* is restricted in this paper to the small concentric layers of bone surrounding the Haversian canal, while that of *laminæ* is applied to the larger more or less irregular rings of bone that run concentrically in relation to the medullary canal.

As to the significations of these types, the subject has been studied from the following standpoints:

(1) The grade of the animal in biological classification.
(2) Geographical location.
(3) Sex.
(4) Age.
(5) Function.
(6) Individuality.
(7) Health; and
(8) Heredity.

1. The first type of bone appears as the basic structure in the amphibians, reptiles, birds, and mammals. It exists, in a pure or but little complicated form, throughout life, in the amphibians, in the lizards, in some of the birds, and in the bats, excepting the Pteropus. It exists or predominates in the fetal life of higher animals, including man. It may well be regarded as the simplest and oldest or fundamental form of bone structure. Its first variation is shown by a change of the round or oval to long and narrow lacunæ, by a more concentric arrangement of the lacunæ, and by increase in vascularity, which is accompanied by a change from the first to the second or third type of bone structure.

The second or intermediary type of bone structure develops as a rule from the first type and represents often, though not invariably, a stage in the differentiation of the bone from the first to the third type. Traces of it are seen first in the amphibians and reptiles, while more pronounced instances of it occur in a few birds, some of the mammals, and at some stages of development, especially in some races, in man. It is best represented in certain mammals, such as the various deer.

The third type, foreshadowed in a few amphibians, appears in part in some of the reptiles and a few birds; it is more strongly represented in certain mammals, and is characteristic of man.

2. The effect of *geographical position* upon bone variation is not yet reducible to exact deductions. However, it is a fact that the femora of the African and Asiatic elephants differ from each other very materially.

3. As to *sex,* the femora examined showed no evidence that this is an important factor in the minute structural variation of the bone.

4. *Age* influences the type of the bone very greatly; at least so in the higher mammals and particularly in man. All femora of higher mammals, and especially man, change in structure with advancing

development of the subject. Some femora, however, arrive at a completion, or rather at a cessation of the changes, regardless of the stage reached, earlier than others. The only future change in such bones is senility. The progress, however irregular or incomplete it may be, is always from the first towards the second or the third type, never the reverse.

5. The effect of *function* upon variation in bone structure can scarcely be doubted, but the exact causes and effects are as yet difficult to determine. In the study of 50 genera of bats, the small Pteropus presents still, like the rest of the bats, the first type of bone structure, while the large Pteropus shows already an early and crude third type in process of formation. In a turkey of 16 pounds weight only the second type appeared, while in a turkey of 32 pounds weight there was noticeable a number of Haversian systems. In many femora of all classes the linea aspera, the most "functional" part of the bone, is composed chiefly of third type units regardless of the type of the rest of the bone. Finally, a lack of function in an adult bone doubtless favors an earlier setting in of senile changes.

6. *Individual* variations are rare in the lower vertebrates and increase in frequency in the higher forms. But they are mostly of secondary importance, the characteristic structure in species remaining pretty true. The slight variations present are probably partly accidental, partly hereditary and partly functional.

7. Variations due to *health and disease* remain very largely for studies in the future. They will be almost wholly restricted to man.

8. *Hereditary influence* finally, is clearly demonstrated by the predominance of a certain form of structure in every given species. In families the subject needs much further attention.

DETAILS CONCERNING GENERA

AMPHIBIANS

The amphibians present the following conditions:

1. Simple first type bone with round and oval lacunæ and few canaliculi. In some forms cancellous bone occupies the medullary canal; this is seen, for instance, in the *Amblystoma tigrinum,* one of the most primitive amphibians.

2. A division of the simple bone into two concentric laminæ, external and internal.

3. A differentiation into external, central and internal laminæ; and

4. In a few amphibians, as in the Toad group, very crude Haversian systems become outlined in the central lamina. These primitive

systems are composed of Haversian canals communicating with adjacent lacunæ by a few canaliculi. No concentric arrangement of the lacunæ and no Haversian system lamellæ are in evidence.

REPTILIANS

The reptilian femora show much the same conditions as those of the amphibians, but the differentiation of bone structure has in some forms advanced to a greater extent. Some species present the simple first type of bone. This is especially the case in the lizards. But in the turtles, curiously, a fairly well developed third type of bone structure has made its appearance. Again cancellous bone, which is not a structural feature of the lizards, is generally present in the turtles. These are remarkable differences and separate widely the two genera.

BIRDS

Birds present in general the appearance of an incompleted development of the structural state. The first, second, as well as the third type of bone structure are found, and also various combinations, but all give the impression of incompleteness. The bone units are rather dim and unsatisfactory. The first type is present in some birds and is generally of a very simple form. The second type appears in a larger number of species and is, perhaps, the most representative type in birds. In some of these femora a few Haversian systems appear, especially in the posterior ridge, and in some birds of large size the second type structure is reinforced by some Haversian systems in the anterior wall. Finally, in a few species the central ring of lamellæ has become displaced by Haversian systems and the bone must be classified as that of the third type. As a rule the systems are rather dim and do not stand out clear cut. Their lacunæ are oval and their canaliculi bushy. In a few birds the medullary canal is occupied by cancellous bone. In about half the bird femora the medullary canals are full of marrow, while in the remainder they are empty. Comparing the birds with the reptiles, there is a distinct increase in the proportion of differentiation, although this has not reached full development.

MAMMALS

In these animals the bone structure is in general much more differentiated than in birds. As a rule the types and their combinations have lost the illy defined characters so frequently present in the foregoing classes. Furthermore, type combinations are more common.

The first type is present in certain genera. It was found in 50 different genera of bats and a number of genera of shrews. In a few of these forms the division of the bone substance into three concentric rings has occurred. In one genus, the Pteropus, this modification is well marked, and beyond that, rather crude Haversian systems are found in the central ring, the bone showing thus an advance toward the third type.

Quite a large number of mammalian femora present a well marked second type structure. The laminæ are well developed, and enclose long, narrow lacunæ, with straight canaliculi. In all these bones Haversian systems are found in the posterior ridge corresponding to the linea aspera. A few mammals show a pure third type of bone structure. In such animals the first and second types are eliminated and fully developed Haversian systems have taken their places. But only three or four of the 178 mammalian femora (other than bats and shrews) examined were composed of this type.

By far the greatest number of mammalian femora shows combinations of the first and third type. In these bones the structural units are well developed, but vary much in proportions. But they frequently occupy the same relative positions. The laminæ, with bone structure of the first type, are external and internal, while the Haversian systems occupy the central ring. The second and third types form the structure of also a large number of mammals. In this combination the units are well developed and about equally important. Finally, in still another large group of mammals, the femora show all the first, second and third types of bone structure, in varying proportions.

Looking over the mammals as a whole, it is noticed that their femora exhibit structural differentiation much more advanced and definite than that observed in the femora of other animals. From species to species there are many variations.

It is a peculiar fact that amphibians, reptiles, birds, and mammals all present, though in a widely varying proportion, the first type as well as some form of advanced type of bone structure. The advanced type is the variable factor and occurs in the greatest variety of forms and combinations. The early or first type differs merely in simplicity. It is more simple in the amphibians than in the mammals. The third type, on the other hand, in amphibians, merely a suggestion, is better developed in reptiles, still better in birds and in mammals reaches its highest state of advancement. Clean cut, well developed third type units are not at all common below mammals, but are the important structures of mammals and especially man.

MAN

The human fetus presents in varying combination the first and second type of structure with wide canals and incompletely formed lacunæ. As development progresses, the first and second type bone is gradually displaced by the Haversian system structure.

More in detail, in the very young human fetus of two to three months, the first type of bone structure is present in an incomplete form and is marked off into irregular areas by crude, branching canals. As fetal life advances the canals become less branching and more concentric. Gradually the first becomes the second type of bone and remains so until about one year after birth, when sufficient differentiation has occurred by the formations of Haversian systems to make it second and third type, or first, second and third type combination. Throughout childhood and youth, the laminæ tend to disappear and to be replaced by Haversian systems, until the bone development is completed. In the early period, a horseshoe-shaped band of laminæ is often observed forming the anterior and lateral walls of the bone. A remnant of this horseshoe may remain throughout life in those femora which do not complete the third type differentiation. The proportion of this remnant to the other bone units in the adult bone varies greatly and the result is that adult femora present many secondary variations.

A white child, a Pueblo Indian, and a Peruvian Indian child, each about one year of age, exhibited already a combination of the second and third types of bone structure. A femur of an Egyptian child of the XIIth Dynasty showed the development of the Haversian system directly from the circulation, which is an evidence of the causal association of bone structure with the development of the vascular system of the bone.

On the whole, the study of human femora from fetal life and childhood shows various transitional stages from the first and second to the third type of bone.

ADULT HUMAN FEMORA

The adult human femora are, in general, characterized by the predominance of a well differentiated third type of structure. An exclusive presence of the first type of structure has never been found in the adult human femur. The most primitive form is a combination of the first and third types. The proportions of the structural units varies greatly. In some femora, the first type was found to amount to more than half of the section, while in others it is reduced to a small fraction. In other human femora there will be a second and third, instead of first and third type combination; and still others, the bone shows all the three types. When the first type is present, it is generally found in the form of a horseshoe band extending under the external surface of the bone—the heel of the shoe embracing the posterior ridge. Segments of laminæ with a first type of bone, frequently found in bone sections, are the remains of a disappearing horseshoe band of first type units. In a complete third type bone, the first and second type units have been entirely displaced by well developed Haversian systems. There may be cancellous bone around the medullary canal.

Three human races have been examined, namely, the black, the white (including the ancient Egyptian), and the yellow-brown. An early and late differentiation has been found in each. The negro, modern white, Egyptian of the XIIth Dynasty, the Pueblo and Peruvian Indians all show these variations. The variations are the same in kind, but somewhat different in degree. The negro bone, barring individual exceptions, does not perhaps equal that of the other races in the degree of the differentiation.

The posterior ridge is generally composed of Haversian systems. This occurs in each race.

Senile changes, absent or very rare in animals, are unexpectedly frequent in human femora, particularly those of civilized races.

SENILE CHANGES

After a human bone has reached its developmental limitation and perhaps the climax of its function, it soon begins to undergo certain changes which are properly those of degeneration of senility. Such changes are evidently far more common than is supposed. Age in years is not to be the determining factor. A femur may be more or less senile at 30 or 40 years of age. There is no structural differentiation beyond the Haversian system type; when that has been completed it may remain as such for years, but sooner or later a process of aging sets in. The senile changes begin around the canals of the Haversian systems. They involve first the systems around the medullary canal. As the changes extend the bone becomes lighter in weight and its walls become thinner (pl. 3, figs. 1, 2, 3, 4, 5). It is a slow destruction.

TABLE OF TYPE PERCENTAGES

	Amphibians	Reptiles	Birds	Mammals	Man—Adult	Man—Fetus Child, Youth
Number	34	35	39	178	105	13
First type	97%	77%	30%	23%	0%	0%
Second type	0	0	23%	13%	0	54.8%
Third type	0	0	10%	2.5%	37%	0
First and second type	0.3%	0	2.5%	0	0	7.8%
Second and third type	0	0	13%	11%	13%	14.3%
First and third type	0	0	11%	27.5%	33%	77%
First, second and third type	0	0	5%	11%	15%	15.4%
Undeveloped third type	3%	23%	5.5%	7%	0	0
Medullary canal, full	100%	100%	54%	100%	100%	100
Medullary canal, empty	0	2%	46%	0	0	0
Senile	0	0	0	0.1%	56%	0

Fig. 1

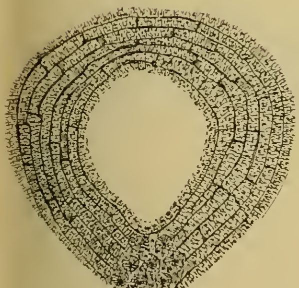

Fig. 2

Fig. 3

THE THREE TYPES OF BONE STRUCTURE

Fig. 1.—First type as seen in the amphibian, Nyctalus aviator.
Fig. 2.—Second type as seen in the turkey.
Fig. 3.—Third type as seen in man.

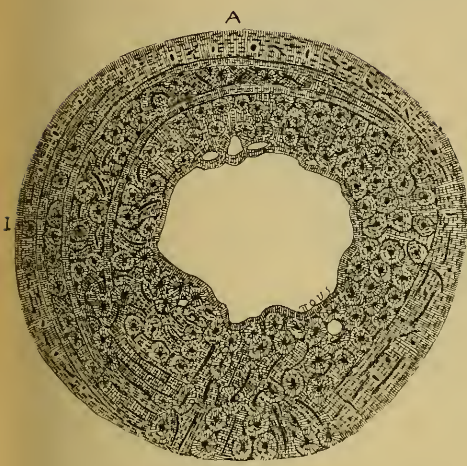

Fig. 1

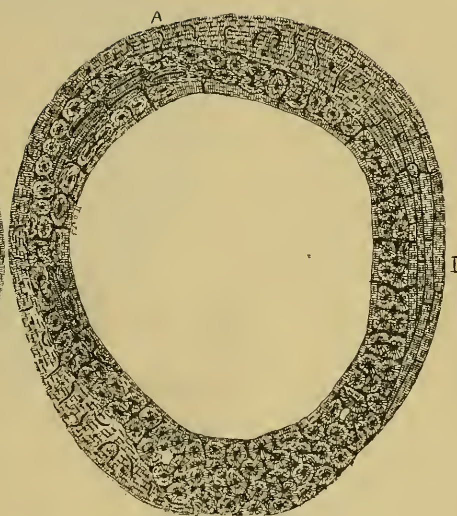

Fig. 2

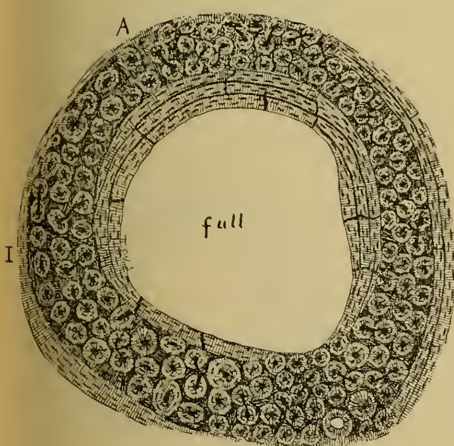

Fig. 3

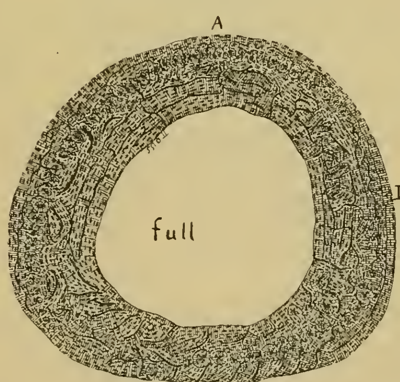

Fig. 4

SECTIONS OF FEMORA, SHOWING VARIOUS COMBINATIONS OF TYPES.

FIG. 1.—Right femur of a sloth bear, Melursus labiatus. No. 2272, A. M. N. H.
FIG. 2.—Left femur of a jackal, canis. No. 7172, U. S. N. M.
FIG. 3.—Right femur of a coyote, canis latrans.
FIG. 4.—Left femur of a badger, taxidea Americana.

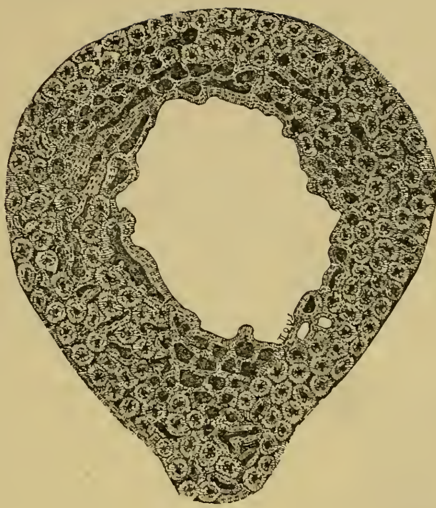

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

SENILE CHANGES IN THE HUMAN FEMUR

Fig. 1.—Left femur of a colored man. Large black spaces represent senile absorption of bone.
Fig. 2.—A single Haversian system, much enlarged, without definite signs of senility.
Fig. 3.—A single Haversian system, much enlarged, showing early signs of senility.
Fig. 4.—A single Haversian system, much enlarged, showing a later stage of senility.
Fig. 5.—A single Haversian system, much enlarged, showing the latest stage of senility.