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The architecture of cancellous bone

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INTRODUCTION

The structure of bone has been the subject of considerable investigation. However, interest has been confined, almost exclusively, to compact bone. The orientation of the bony elements constituting cancellous bone in relation to direction of stress has excited interest; nevertheless the basic architecture of cancellous bone remains inadequately described. This is obvious from the sketchy, and often contradictory, descriptions to be found in various texts of anatomy and histology.

Cancellous bone is most often described as a meshwork or spongework of bony spicules or trabeculae (Warwick & Williams, 1973; Clark, 1965; Ham, 1969; Bradbury, 1973; Moss, 1966; Bloom & Fawcett, 1968; Copenhaver, 1964). Other authorities describe it as being made up of thin plates or lamellae (Hamilton & Appleton, 1958; Amstutz & Sissons, 1969). Yet others describe cancellous bone as being made up of a combination of both trabeculae and lamellae (Bloom & Fawcett, 1962; Leeson & Leeson, 1966; Goss, 1973). The word 'trabecula' is used rather loosely, sometimes including all elements of cancellous bone (Clark, 1965; Moss, 1966) sometimes only the lamellar elements (Hamilton & Appleton, 1958). Confusion is also created by the fact that the word 'lamella' is also used in a histological sense when referring to the units of bone structure that make up both compact and spongy bone.

Examination of cancellous bone from various parts of the human skeleton revealed an unsuspected wealth of architectural variety.

MATERIAL AND METHODS

The observations reported in this paper are based on a study of a large number of macerated adult human bones from the undergraduate teaching collection of the College in Northwest India. They were cut in various planes using either a band- or a hand-saw. When necessary the cut surface was ground on a carborundum stone to remove loose tags, any bone dust produced being removed with a blast of air from a pressure pump. Other extraneous matter was removed by washing in warm water, followed by gentle brushing of the cut surface.

The specimens were examined with a binocular loupe and also with a stereoscopic microscope at a magnification of × 20. In some cases stereo-macrophotographs were prepared using a simple twin-lens reflex camera with close-up attachments. These photographs permitted three-dimensional viewing in much greater depth than was possible under the stereoscopic microscope. Measurements were made with an ordinary microscope and an eyepiece micrometer.

OBSERVATIONS

It was concluded from the observations that human cancellous bone may be classified into Types I, IIa, IIb, IIc, IIIa, IIIb and IIIc.

Type I

This is the most delicate type of cancellous bone encountered. It is made up exclusively of fine straight or curved rods 0·08–0·14 mm in diameter and about 1 mm in length. The rods anastomose with each other to form a three-dimensional meshwork (Fig. 1). The rods do not appear to have any preferential orientation.

This variety of cancellous bone is widely distributed, and is to be seen typically in the deeper parts of the ends of long bones; in some bones (e.g. the tibia) it may extend for a considerable distance into the shaft. Isolated patches of a similar meshwork of delicate rods are also frequently seen in relation to the wall of the marrow cavity of long bones (see below).

Type II

This variety of cancellous bone is made up of both rods and plates.

Sub-type IIa. In several situations at the ends of long bones some of the rods of the meshwork described in Type I are replaced by small delicate plates of bone. These plates are 0·1–0·2 mm thick and about 1 mm in their long dimension; they are of extremely variable form. We have here a meshwork similar to Type I, but with the difference that it is made up of both rods and plates. All gradations can be seen between a meshwork with only an occasional plate and one that is made almost entirely of plates with only an occasional rod. The larger plates show numerous fenestrations.

The density of the meshwork is variable. An extremely open structure is encountered in some situations, e.g. in the body of the pubis and in the scapula near the glenoid cavity.

Sub-type IIb. This differs from IIa in that some of the plates are much more extensive, being up to several millimetres long, and often showing a well marked orientation in preferred planes. The plates are of irregular shape and show numerous fenestrations. They are interconnected by smaller plates and by rods.

In some situations the rod-shaped elements are also much thicker and longer than those in Type IIa, being up to 0·5 mm thick and several millimetres in length. These rods may be connected to one another by thinner elements running at right angles to them, thus producing appearances suggestive of ladders or scaffolding. When present, such rods replace plates as the major elements placed along the lines of stress.

Cancellous bone of Type IIb is encountered most typically in the calcaneum.

Sub-type IIc. This type is to be seen in close relationship to some articular surfaces. It is encountered most typically at the lower end of the femur. It consists mainly of plates arranged parallel to each other. The plates are 0·16–0·3 mm thick. The parallel orientation of the plates is striking when they are viewed in a section at right angles to the articular surface (coronal plane in the femoral condyles; Fig. 2, left) and also in a plane parallel to the surface (transverse plane in femoral condyles; Fig. 2, top). The plates may retain their parallel formation for distances up to a centimetre or more before anastomosing with adjacent plates. The plates are separated from each other by an interval of 0·4–0·8 mm, which is traversed by numerous rods of the kind seen in Type I. The rods appear to be holding the plates apart.

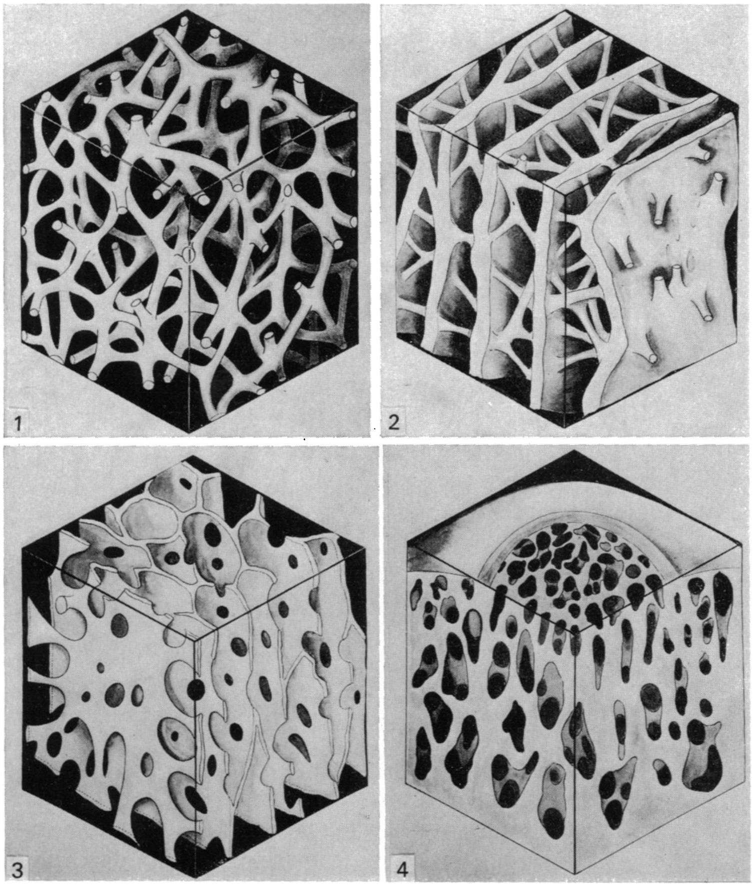

Fig. 1. Diagram showing cancellous bone of Type I, made up entirely of fine rods anastomosing to form a meshwork.

Fig. 2. Diagram showing cancellous bone of Type IIc, consisting of plates arranged parallel to each other. The plates are separated by spaces traversed by rods that appear to hold the plates apart.

Fig. 3. Diagram showing cancellous bone of Type IIIb. This is made up entirely of plates. The left face of the 'cube' shows that individual plates are irregular in outline with numerous fenestrations. The right face gives the impression of the plates being arranged parallel to each other and bounding longitudinal spaces. The top face, however, reveals that the plates really form a meshwork and enclose tubular spaces orientated parallel to each other.

Fig. 4. Diagram showing cancellous bone of Type IIIc. The right and left faces of the 'cube' give the impression of a solid mass of bone fenestrated by irregular spaces. The top face shows part of an articular surface, a small area of which has been ground away to expose the underlying cancellous bone, revealing that the architecture resembles that of a honeycomb with small spaces bounded by relatively thick plates. The spaces become larger in proceeding away from the articular surface.

Similar arrangements are to be encountered in many situations where the lines of transmission of force are clearly defined, but the parallel plate arrangement is generally obscured by frequent lateral anastomoses between the plates.

Type III

This variety of cancellous bone is made up entirely of plates of varying size and shape that anastomose to form a meshwork. The spaces of the mesh communicate with each other through fenestrations in the plates. The appearances vary considerably depending on the density and orientation of the plates, as described below:

Sub-type IIIa. This is similar to Sub-type IIa with the difference that the meshwork is made up entirely of plates 0·1–0·2 mm thick and about 1 mm in their long dimension. The spaces of the mesh communicate freely by means of numerous fenestrations in the plates. A slight tendency to preferential orientation of plates in particular planes is often discernible.

Sub-type IIIb. This has a superficial resemblance to IIc in that it appears to be composed of plates in parallel formation. However, no rods are present, the entire meshwork being made up by the plates themselves. The appearances presented by this variety of cancellous bone when sectioned in three planes at right angles to each other are illustrated in Figure 3. The right face of this figure shows that the plates run more or less parallel to each other with large longitudinally orientated spaces between them. The left face of the figure shows that the individual plates are irregular in outline, with numerous fenestrations, and are of a much more delicate construction than those of Sub-type IIc; the plates are only 0·12–0·24 mm thick. The top face of the figure shows that the plates are strictly not in parallel formation at all; they anastomose to enclose a series of more or less tubular spaces having a diameter of 0·7–2·00 mm. These tubes have a distinct orientation along the direction of stress. This arrangement is seen typically at the ends of the tibia adjacent to the articular surfaces, where the tubes are vertically orientated. This type of cancellous bone is widely distributed in the skeleton. The architecture of the cancellous bone in the bodies of the lower vertebrae is basically of this type.

Sub-type IIIc. This variety is seen in situations where dense cancellous bone underlies articular surfaces, e.g. in the head of the femur. When seen in sections cut at right angles to the articular surface (Fig. 4, right and left) the impression is that of a solid mass of bone fenestrated by numerous intercommunicating spaces. However, when viewed in a section cut tangential to the articular surface (Fig. 4, top) it is seen that the structure is basically similar to Sub-type IIIb in that the bone here is made up of plates anastomosing to enclose spaces. However, the plates are relatively thick (0·2–0·4 mm), and the spaces relatively small (0·4–0·6 mm across). Just below the articular surface the spaces are about as long as they are broad, the total picture being that of a honeycomb. This appearance is, however, seen only for a few millimetres below the articular surface. Deeper in the bone the spaces become much larger and gradually tend to become elongated in a direction at right angles to the articular surface, the pattern changing imperceptibly to that of Sub-type IIc. This type of bone is also encountered in the bodies of the upper cervical vertebrae and in the patella. The structure of the diploe is similar to that seen just below the articular surface of the femur.

The wall of the marrow cavity

(A) *Plates.* The wall of the marrow cavity is seldom a smooth surface. It is usually characterized by the presence of extensive plates of bone 0·24–0·4 mm thick which may be arranged in one of the following ways:

(*a*) Most frequently these plates are placed with their long axis parallel to the shaft. They anastomose with each other to enclose long irregular intercommunicating channels. The channels may sometimes be oblique to the long axis of the shaft. They are most prominent where two surfaces of the shaft of a long bone meet at an acute angle (e.g. along the anterior border of the tibia).

(*b*) Occasionally the plates merely project into the marrow cavity and do not enclose any spaces.

(*c*) A rare but interesting arrangement encountered is that of a plate of bone forming a false wall for part of the marrow cavity; in such cases the space between the plate and the true wall of the cavity is traversed by delicate rods or plates of bone.

(B) *Rod-shaped elements.* Rod-shaped elements of varying length, thickness and orientation are frequently encountered in relation to the wall of the marrow cavity as described below:

(*a*) Isolated patches of a meshwork of delicate rods (identical to that described under Type I) are often seen attached to the wall of the marrow cavity or to the plates described above.

(*b*) In several situations thicker rods are seen traversing the marrow cavity, either at right angles to the long axis of the shaft or with varying degrees of obliquity. These rods are usually 0·5–0·75 mm in thickness and up to 10 mm in length. They are frequently interconnected by finer rods running at right angles to the thicker elements so that ladders are formed (compare with Sub-type IIb). The thickest rods (2·0–2·4 mm thick) have been encountered in the humerus just above the olecranon fossa; they are seen to pass obliquely from the ventral to the dorsal surface of the shaft and are about 10 mm in length. These elements give the impression of acting as struts for resisting compressive forces acting along their long axis.

The epiphyseal scar

The presence of a dense line at the junction of the diaphysis and epiphysis of long bones is a well recognized radiological feature. A study of this region in macerated bones shows that this appearance is produced by a distinctive configuration of the bony tissue in this region; the arrangement is most apparent where the cancellous bone on either side of the epiphyseo-diaphyseal junction is of a loose texture. In such situations (notably in the upper end of the humerus) the epiphyseal and diaphyseal cancellous bone is seen to be separated by a continuous thin sheet of bone with minute fenestrations. This plate is about 0·2 mm thick. The elements of cancellous bone on its epiphyseal and diaphyseal aspects join the corresponding surface of the plate. This plate of bone cannot be isolated in regions where the epiphyseal and diaphyseal bone adjoining it is dense, but even in these situations its presence can be distinctly demonstrated in sections. In some bones this region is not represented by a continuous sheet of bone, but by smaller plates orientated in this plane.

A marrow cavity in the clavicle

Contrary to usual statements, a narrow, but distinct marrow cavity was observed in six out of seven clavicles examined.

SUMMARY

The architecture of cancellous bone has been studied in macerated human bones. A number of distinct types of architecture can be recognized as follows:

Type I consists of a very delicate meshwork of fine rods. Type II is made up of both rods and plates. Sub-type IIa is a meshwork similar to Type I, but a varying proportion of rods are replaced by delicate plates. Sub-type IIb shows the presence of thin but large fenestrated plates with a well marked orientation in preferred planes; these are interconnected by smaller plates and rods. Sub-type IIc is made up of

relatively thick and extensive plates arranged for the most part parallel to one another, the plates being connected to each other by fine rods. Type III is made up entirely of plates. Delicate plates may form a meshwork in which a directional orientation may or may not be apparent (Sub-type III a). Elsewhere better defined, larger plates may enclose tubular spaces (Sub-type III b). In some areas (where cancellous bone is very dense) small relatively thick plates enclose irregular spaces; the appearance may closely resemble that of a honeycomb when the spaces are small, but elsewhere the spaces may show a definite directional orientation.

The wall of the marrow cavity of long bones is seldom smooth. It is characterized by the presence of plates and rods in various configurations. A distinct marrow cavity is seen in the majority of clavicles examined.

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