How bones are formed

Bones are living tissue, and are in a constant state of renewal. They form the basis of the skeleton, and are responsible for locomotion as well as containing bone marrow and vital minerals.

Bones are the rigid body tissues that are the basis of the human skeleton. They are a living tissue, constantly being renewed and shaped by the process of growth and reabsorption.

BONE MATRIX

Bone is composed of a calcified matrix in which bone cells are embedded. The matrix is made up of flexible collagen fibres in which crystals of hydroxyapatite (a calcium salt) are deposited. Three principal bone cell types are found within this matrix:

- Osteoblasts – cells responsible for forming bone
- Osteoclasts – bone-eating cells
- Osteocytes – bone cells that have fully matured.

Bone-forming and bone-eating cells permit the constant turnover of bone matrix that occurs throughout life.

Osteoblasts are bone-forming cells. This micrograph shows osteoblast cells (irregular ovals) surrounded by the bone matrix they have created.

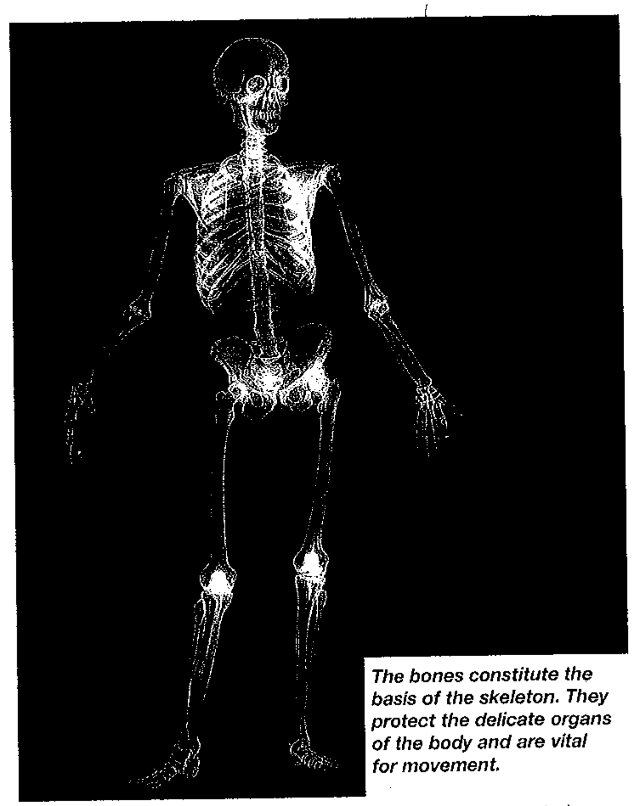
SKELETAL SUPPORT

Linked together at joints by ligaments and moved by attached muscles, bones form levers vital to locomotion.

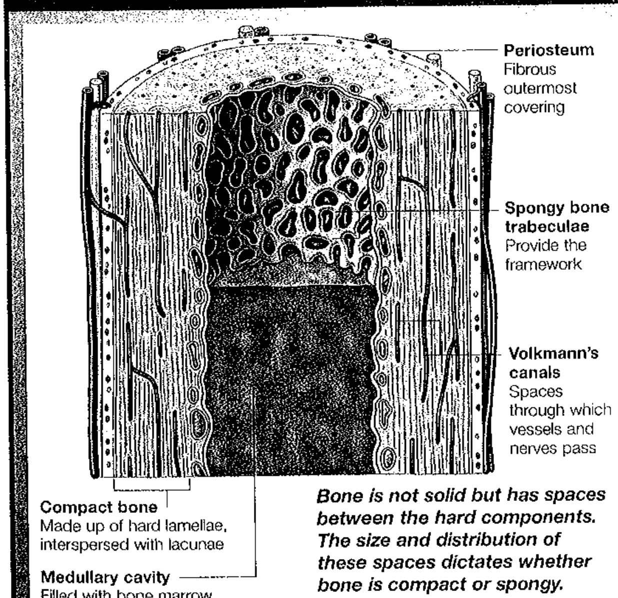
The intricate arrangement of the bones making up the skeleton provides cages which protect the soft, delicate parts of the body, while still allowing for great flexibility and movement.

In addition, bones contain bone marrow, the soft fatty substance that produces most of the body's blood cells.

Bones also act as a reservoir for the minerals calcium and phosphorus, vital to many body processes.



The bones constitute the basis of the skeleton. They protect the delicate organs of the body and are vital for movement.



Bone is not solid but has spaces between the hard components. The size and distribution of these spaces dictates whether bone is compact or spongy.

Bone tissue exists in two forms: compact (or cortical) bone and spongy (or cancellous) bone.

Compact bone

Compact bone makes up the outer covering of all bones and is thickest in the places that receive the greatest stress. It is made up of a series of canals and passageways; these provide a route for the nerves, blood vessels and lymphatic vessels that extend through each bone.

The structural units of compact bones (osteons) are elongated cylinders which lie parallel to the long axis of the bone. Osteons are composed of a group of lamellae (hollow tubes) of bone matrix arranged concentrically.

The lamellae are organized in such a way that the collagen fibres in adjacent lamellae run in opposite directions; this is intended to reinforce the bone against twisting forces. Each osteon is nourished by blood vessels and served by nerve fibres which run throughout its centre, known as the Haversian canal.

The Volkmann's canals connect the blood vessels and nerve supplies of the periosteum (membrane around the bone) to those in the central canals and medullary cavity (which contains bone marrow).

Mature bone cells (osteocytes) are located in the small cavities (lacunae) between each lamella.

Spongy bone

Spongy bone makes up the inner part of most bones and is much lighter and less dense than compact bone. This is due to the fact that it contains a number of cavities which are filled with marrow. Spongy bone is strengthened by a criss-cross network of boney supports, known as trabeculae.

Formation of bone

Bone formation begins in the embryo and continues throughout the first 20 years of life. Development takes place from a number of ossification centres and, once these are fully calcified, no further elongation can occur.

The skeleton is made up of a variety of different bones, ranging from the flat bones found in the skull to the long bones of the limbs. Each bone is designed for a different function.

LONG BONES

The longest bones within the body are those of the upper and lower limbs. Each long bone consists of three main components:

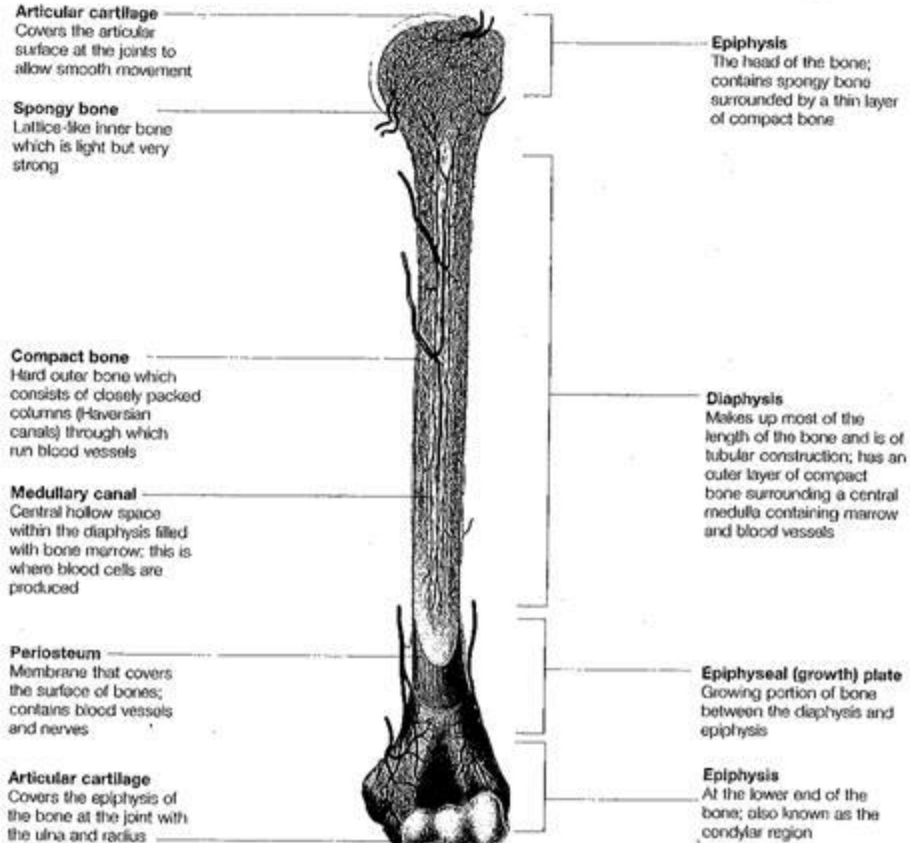
- Diaphysis – a hollow shaft, composed of compact bone
- Epiphysis – at each end of the bone; site of articulation between bones
- Epiphyseal (growth) plate – composed of spongy bone and the site of bone elongation.

PROTECTIVE MEMBRANE

The entire bone is covered by the two-layered periosteum.

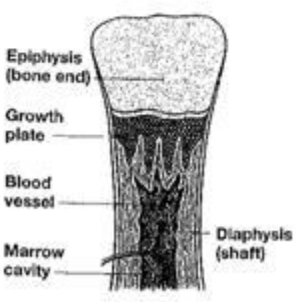
The outer layer of this membrane consists of fibrous connective tissue. The inner layer of the periosteum contains osteoblasts and osteoclasts, the cells that are responsible for the constant replenishment of the bone.

The humerus, a typical 'long bone', is found in the upper arm. The bone is divided into a diaphysis (shaft), with epiphyses (heads) at either end.

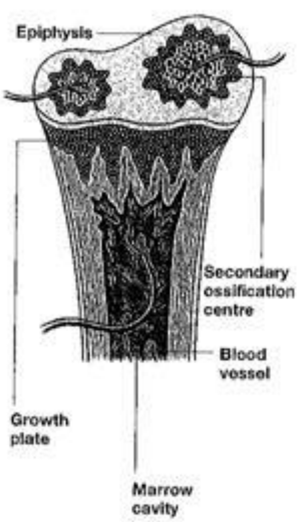


Bone development

Long bone of a newborn



Long bone of a child



In a newborn baby, the shaft is mostly bone, while the bone ends consist of cartilage. In a child, new bone forms from secondary ossification centres in the bone ends.

Skeletal development begins in the embryo and continues for around two decades. It is a complex process under genetic control, and is modulated by endocrine, physical and biological processes.

A template of the skeleton forms in the embryo from the primitive embryonic tissue. As the embryo develops, this tissue becomes recognisable as cartilage (soft, elastic connective tissue) and individual 'bones' begin to be seen.

OSSIFICATION

Normal bone then forms within these templates by a process known as ossification. This takes place either directly around the early bone-forming cells of the fetus (intramembranous ossification) or by replacing a cartilage model with bone (endochondral ossification).

The formation of compact bone commences at sites in the bone shafts known as primary ossification centres. Osteoblasts within the cartilage secrete a gelatinous substance called osteoid, which is hardened by mineral salts to form bone. The cartilage cells die and are replaced by further osteoblasts.

Ossification of long bones continues until only a thin strip of cartilage remains at either end. This cartilage (the epiphyseal plate) is the site of secondary bone growth up to late adolescence.

The sequence of formation of ossification centres follows a prescribed pattern, allowing experts to age skeletons by the extent of ossification.

MATURE BONE

Once the bone has reached full length, the shaft, growth plate and epiphyses are all ossified and fuse to form continuous bone. No further elongation can take place after this time.

How bone repairs itself

Although bones cease to grow after late adolescence, bone is a very dynamic tissue. Bone is continually being reabsorbed and regenerated as its structure is constantly changing.

One of the most amazing features of bone is its ability to reshape itself. This process, known as remodelling, occurs during growth and continues throughout life.

BONE REMODELLING

During bone formation, bone is deposited in a random pattern by a process known as ossification. Remodelling continually occurs, organizing the bone into orderly units that enable the bone mass to best withstand mechanical forces. Old bone is removed by osteoclasts (bone-eating cells), and osteoblasts (bone-forming cells) deposit new bone.

BONE REABSORPTION

Osteoclasts secrete enzymes that break down the bone matrix, as well as acids which convert the resulting calcium salts into a soluble form (which can enter the bloodstream).

Osteoclast activity takes place behind the epiphyseal growth zone to reduce expanded ends to the width of the lengthening shaft. Osteoclasts also act within the bone in order to clear the long tubular spaces that will accommodate bone marrow.

HORMONAL REGULATION

While the osteoclasts reabsorb bone, osteoblasts make new bone to maintain the skeletal structure. This process is regulated by hormones, growth factors and vitamin D.

During childhood, bone formation outweighs bone destruction, resulting in gradual growth. After skeletal maturity has been reached, however, the two processes occur in equilibrium so that growth proceeds more gradually.

LONG BONES

The process of remodelling is especially important for the long bones which support the limbs. These are wider at each end than in the middle, providing extra strength at the joint.

As osteoclasts destroy the old epiphyseal swellings of the bone, osteoblasts within the growth zone create a new epiphysis.

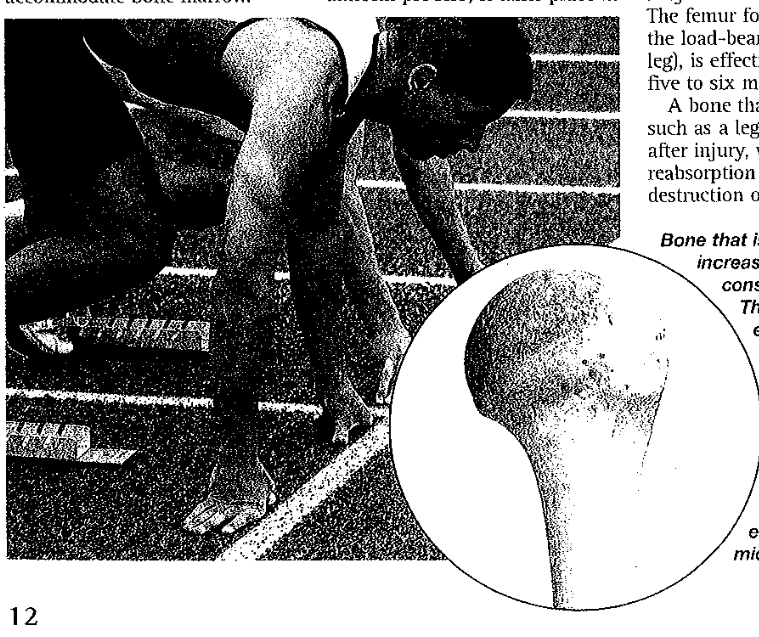
Within each of the tubular spaces cleared by osteoclasts inside the bone, the osteoblasts follow along, laying down a layer of new bone.

RATES OF REMODELLING

Bone remodelling is not a uniform process; it takes place at different rates throughout the skeleton. Bone formation tends to take place in areas where the bone undergoes the greatest stress. This means that bones which receive the most stress are subject to much remodelling. The femur for example (one of the load-bearing bones of the leg), is effectively replaced every five to six months.

A bone that is under-used, such as a leg that is immobilized after injury, will be prone to reabsorption however, as bone destruction outweighs formation.

Osteoblasts (the orange cell pictured) secrete a substance called osteoid which hardens to become bone. This bone may be reabsorbed by osteoclasts as remodelling occurs.



Bone that is subject to increased stress is constantly remodelled. The femur, for example, is effectively replaced every six months.

Remodelling gives rise to the distinctive shape of the long bones. These are wider at each end than in the middle.

Bone remodelling not only alters the structure of the bone, but also helps to regulate the levels of calcium ions in the blood. Calcium is necessary for healthy nerve transmission, the formation of cellular membranes and the ability of the blood to clot.

Bone contains about 99 per cent of the body's calcium. When body fluid calcium levels fall too low, parathyroid hormone stimulates osteoclast activity and calcium is released into the bloodstream. When body fluid calcium levels become too high, calcitonin hormone inhibits reabsorption, restricting the release of calcium from the bones.

Bone repair

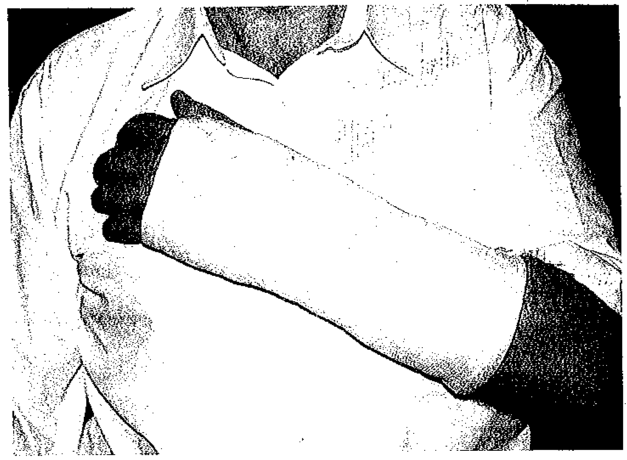
If bone is subjected to a force beyond its strength it will fracture. New bone must be formed and remodelled for the fracture to heal.

One of the processes which is dependent on the remodelling of bone is the repair mechanism that takes place after a fracture.

BONE FRACTURES

Fractures occur when a bone experiences a force greater than its resistance or strength.

These can occur as the result of a spontaneous force, or after years of continued stress upon a bone. Bones are particularly susceptible to fractures later in life when they are less elastic and bone mineral density declines. Bone repair takes place in four main stages.

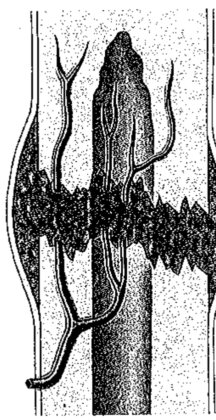


A plaster cast aids the healing of fractured bone by immobilizing the limb. This is important to ensure that the ends of the broken bone realign correctly.

Blood clot formation

1 A fracture of the bone causes the blood vessels in the area (mainly those of the periosteum, the protective covering of the bone) to rupture.

As these vessels bleed, a clot is formed at the site of the fracture giving rise to the characteristic swelling that often accompanies a broken bone. Very soon, bone cells deprived of nutrition begin to die and the site becomes extremely painful.

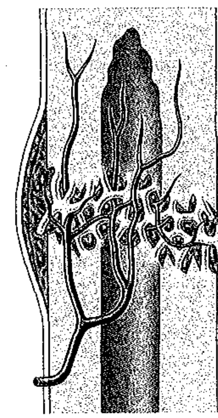


Blood vessels at the site of the fracture rupture, causing a blood clot to form. The nerves lining the periosteum are also severed, causing much pain.

Fibrocartilage callus formation

2 Several days after the injury, blood vessels and undifferentiated cells from surrounding tissues invade the area. Some of these cells develop into fibroblasts, which produce a network of collagen fibres between the bone fragments. Other cells form chondroblasts, which secrete cartilage matrix.

This zone of tissue repair between the two ends is known as a fibrocartilage callus.



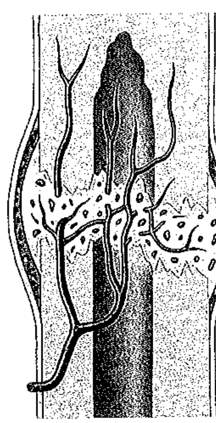
Blood vessels and cells invade the site of the fracture. The cells produce a matrix of collagen fibres and cartilage, forming a fibrocartilage callus.

Bony callus formation

3 Osteoblasts and osteoclasts migrate towards the affected area multiplying rapidly within the fibrocartilage callus.

Osteoblasts within the callus secrete osteoid, converting it into a bony callus.

This bony callus is composed of two portions: an external callus located around the outside of the fracture and an internal callus located between the broken bone fragments.



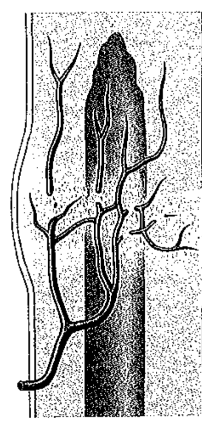
Osteoblasts and osteoclasts multiply within the fibrous callus. Osteoblasts secrete a substance known as osteoid, which hardens, forming a bony callus.

Bone remodelling

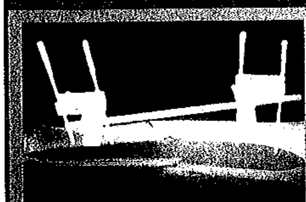
4 Bone formation is usually complete within four to six weeks of injury.

Once the new bone has been formed it will slowly be remodelled to form compact and spongy bone.

Total healing may require up to several months depending on the nature of the fracture and the specific function of the limb – weight-bearing limbs take longer to repair.



As the new bone is formed it is remodelled by osteoclasts. In this way the bony callus is smoothed out, and the bone regains its original structure.



In some cases the extent of a fracture can be so severe that the normal process by which the bone repairs itself cannot occur.

Examples include shattered bones, or fractures in which fragments of bone are lost, so that the gap between severed ends is too great to heal.

The bones may need to be fixed in place with the use of orthopaedic screws, pins, plates or wires, in order to encourage the bone's repair mechanism to take place.

Bone chips can be transplanted from other parts of the patient's skeleton in order to aid bone formation. In cases where there is massive injury, amputation may be necessary.

In cases where damage to the bone is very severe it may fail to heal. The use of orthopaedic pins to hold the bone in place may therefore be necessary.