4. CONCEPT EVOLUTION

4.1. Pauwel's Theory

With better understanding of statics and the theory of elasticity, and from the results of his own experiments and clinical observations, Pauwel's arrived at the conclusion that the differentiation of connective tissue arises from changes in its shape and in its volume. Stretching of a tissue whether it is due to tension or shear, or even compression, produces fibrous tissue. Hydrostatic pressure generates cartilage. [Figure 4.1] Bone, he concluded, develops from either fibrous tissue or from cartilage in pre-existing stressed scaffolding, under certain conditions of relative immobility. Moreover, bone once formed, reacts to increased Stress, both tensile and compressive, by making more bone and to decreased stress by resorption, both phenomenon being restricted between certain limits. Above the upper limit bone breaks or resorbs [19].

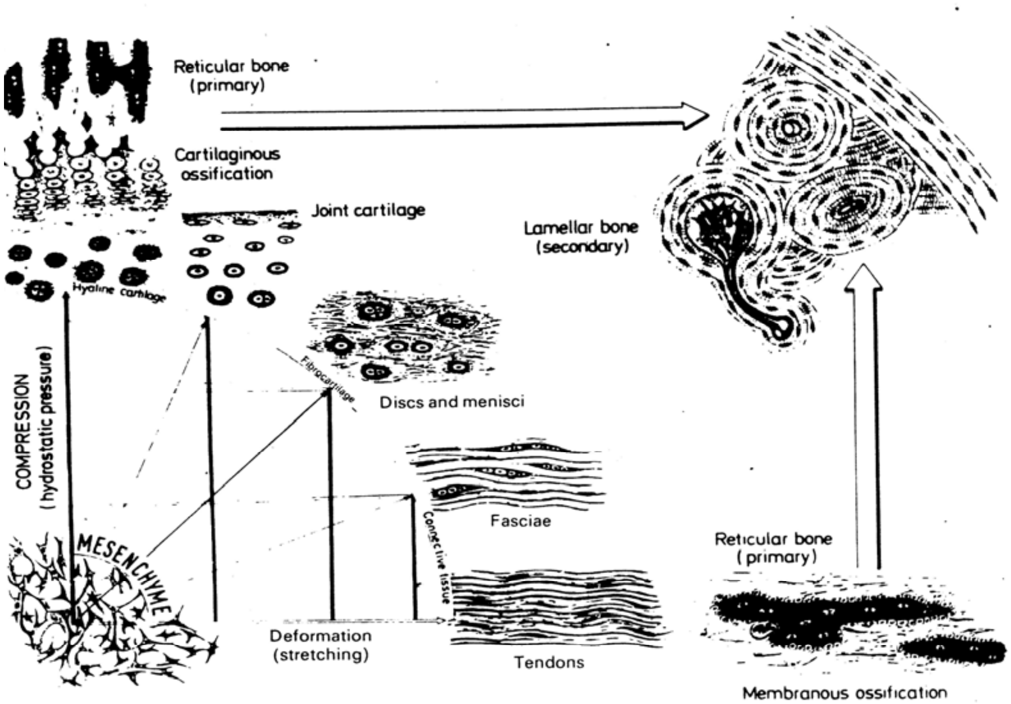


Figure 4.1- From Pauwel's histogenesis in the locomotor apparatus as a result of mechanical stresses. (As illustrated by Kummer in Pauwels)

Locomotor apparatus of man is actually constructed with a minimum of material for the maximum resistance to stress (Pauwels 19 65) [19].

4.2. Ilizarov Tension Stress Theory

Osteosynthesis with Ilizarov ring fixator is achieved by securing the bone fragments to the external fixator with wires. Ilizarov [21] discovered that the limited elasticity type of fixation with the wires had a particular advantage, in that it generated more rapid callus formation and maturation. This led on to two hypothesis of fracture gap motion.

1. Cyclic axial micro motion is beneficial to fracture healing [22].
2. Translational shear at fracture site is deleterious to fracture healing [23].

Further research showed that the restricted elasticity of the wires tensioned activated the piezoelectric phenomenon in the cells of the marrow, in compact bone, and in the newly formed regenerated bone. Membrane potential differs in the electrical changes within and outside a cell. It has been demonstrated that electrical current in the cell can stimulate ion channels selectively. If the elastic micro motion stimulates the tissues the nerve impulses are activated. The nerve impulse helps to control the passage of electrically charged ions through the cells activating these ion channels. [Figure 4.2] The exact mechanism of the elastic micro motion and cellular development interaction is not clear; however Ilizarov considers it an analog to the mechanism of fetal growth plate. He coined the term “TENSION-STRESS” for this mechanism. Elastic micro motion has stimulating effect of the wires on the ion channels of the bone cells and result in rapid cellular mitosis during bone distraction. There is selective stimulation of microtubules and nucleolus. The microtubules are the ion channels in a state activation [24]. This later led to the discovery of a general biologic principle that governs the simulation of tissue growth and regeneration during distraction [25]. Gradual traction on living tissues creates stresses that can stimulate and maintain the regeneration and active growth of certain tissue structures [26]. This principle is called law of “Tension – Stress”. Tissues subjected to slow, steady traction become metabolically activated, a phenomenon characterized by the stimulation of both proliferative and biosynthetic cellular function. These regenerative processes depend upon adequacy of blood supply and stimulating effect of weight bearing [25, 26, and 27].

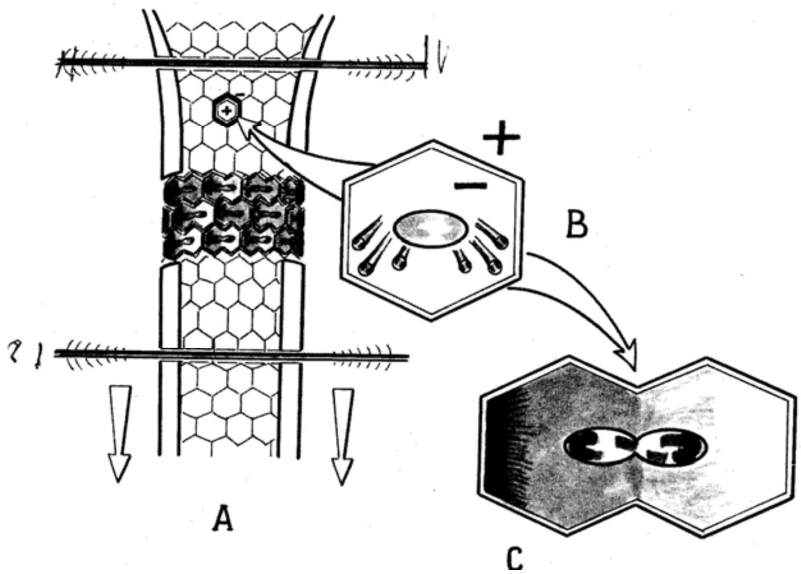


Figure 4.2 -Elastic micro motion

Schematic of the elastic micro motion stimulating effect of the wires on the ion channels of the bone cells and the resulting rapid cellular mitosis during bone distraction.

A. Bone segment with two transfixing wires in a state of vibration. The marrow cells are shown as hexagons. Interruption of the cortex showing the osteotomy; arrows show the direction of distraction. Shaded figures represent doubled cells in the telophase stage of mitosis. A cell is shown in a polarized state.

B. Magnified representation of a bone marrow depolarized cell with the selectivity stimulated micro tubes and nucleolus. The micro tubes are the ion channels in a state of activation.

C. Same cell as in B, shown in telophase of mitosis with doubled nucleolus and cytoplasm.

By Pauwel's theory we understand many of the orthopaedic conditions could be treated if basic biomechanics of the locomotor system and tissue healing is understood. By using Ilizarov ring fixator system it is now proved the tissues can be regenerated by distraction osteogenesis in any direction, the fractures can heal early when properly stabilized, compression and distraction can be given, deformities can be corrected and the frame can be kept till the end of the procedure. When our body tissue is manipulated to regenerate its own many orthopaedic conditions can be treated in an environmental friendly way, maintaining the milieu interior in a cost effective way.

4.3. Biomechanics

Biomechanics encompasses the study of the (1) mechanical stresses to which living tissues are subjected under physiological and pathological condition (2) the biological response of the tissues to these mechanical stresses and their modification, and (3) the alteration of the stresses in the living body to achieve a therapeutic effect [20].

4.4. Mechanical Factors

4.4.1. Basic Load

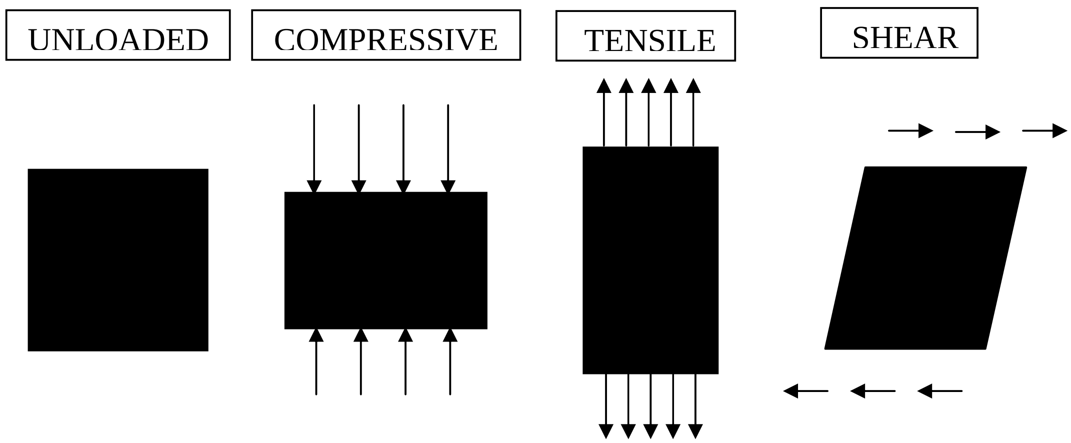


Figure 4.3- Basic load

Three fundamental force components acting on a material and the resulting deformation of the material unloaded, compressive, tensile and shear.

Force acting on a material can be broken into three fundamental components - Compressive acting inwards relative to the object and perpendicular to the surface of the material, tensile, acting outward, and shear, which acts parallel to the surface of the material and tend to distort it from a rectangular to parallelogram shape. Internal shearing also results from the application of other types of loads such as bending in a beam or twisting of a bar.

4.4.2. Stress And Strain

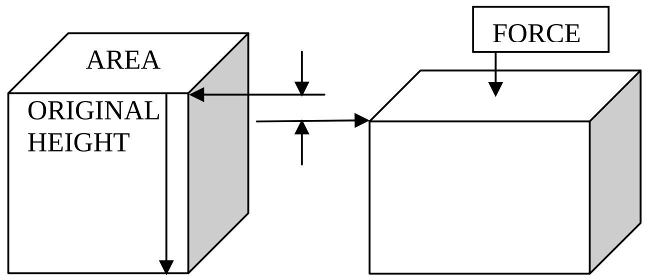


Figure 4.4 - Stress and strain.

$$\text{STRESS} = \frac{\text{Force}}{\text{Area}}$$

$$\text{STRAIN} = \frac{\text{Change in Height}}{\text{Original Height}}$$

The Stress is defined as the force applied to a cross section of a material, divided by the area of that cross section.

The Strain is the resulting change in height of an object divided by its original height.

Elastic modulus is the ratio of stress to strain.

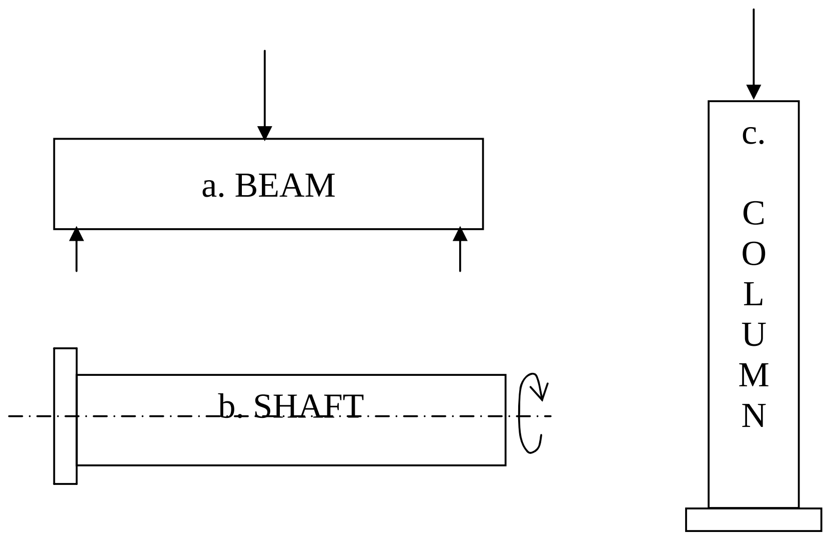
$$E = \frac{\text{Stress}}{\text{Strain}}$$

$$E = \frac{\text{Force/Area}}{\text{Elongation/Length}}$$

4.4.3. Column and Shaft

A long bone can act as a column, supporting compressive load acting along its long axis, or as a shaft resisting rotation. The tibia and femur act as columns supporting the compressive load of the torso. The tensioned wires act as stressed beam.

Three types of load bearing structures:



a. A beam supports loads between two supports;
b. A shaft resists torsion;
c. A column supports compressive loads [28].

Figure 4.5 - Three types of load bearing structures.