ARTICULAR CARTILAGE
(BIOMECHANICS - PHYSIOLOGY - OSTEOARTHRITIS)

An Essay Submitted for the Partial Fulfillment of the Master Degree in Orthopaedics

By

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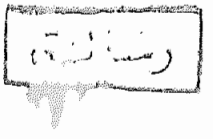
Supervised By



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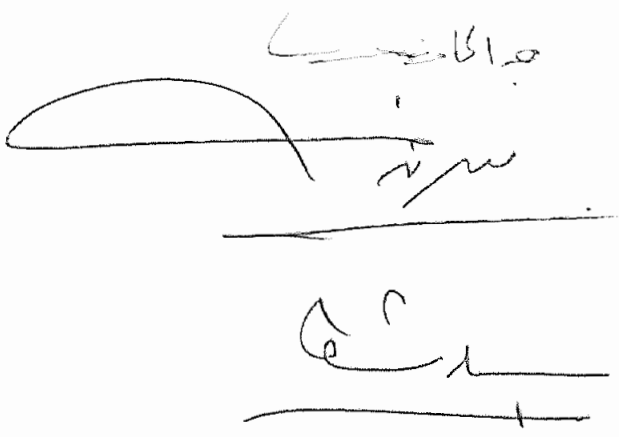
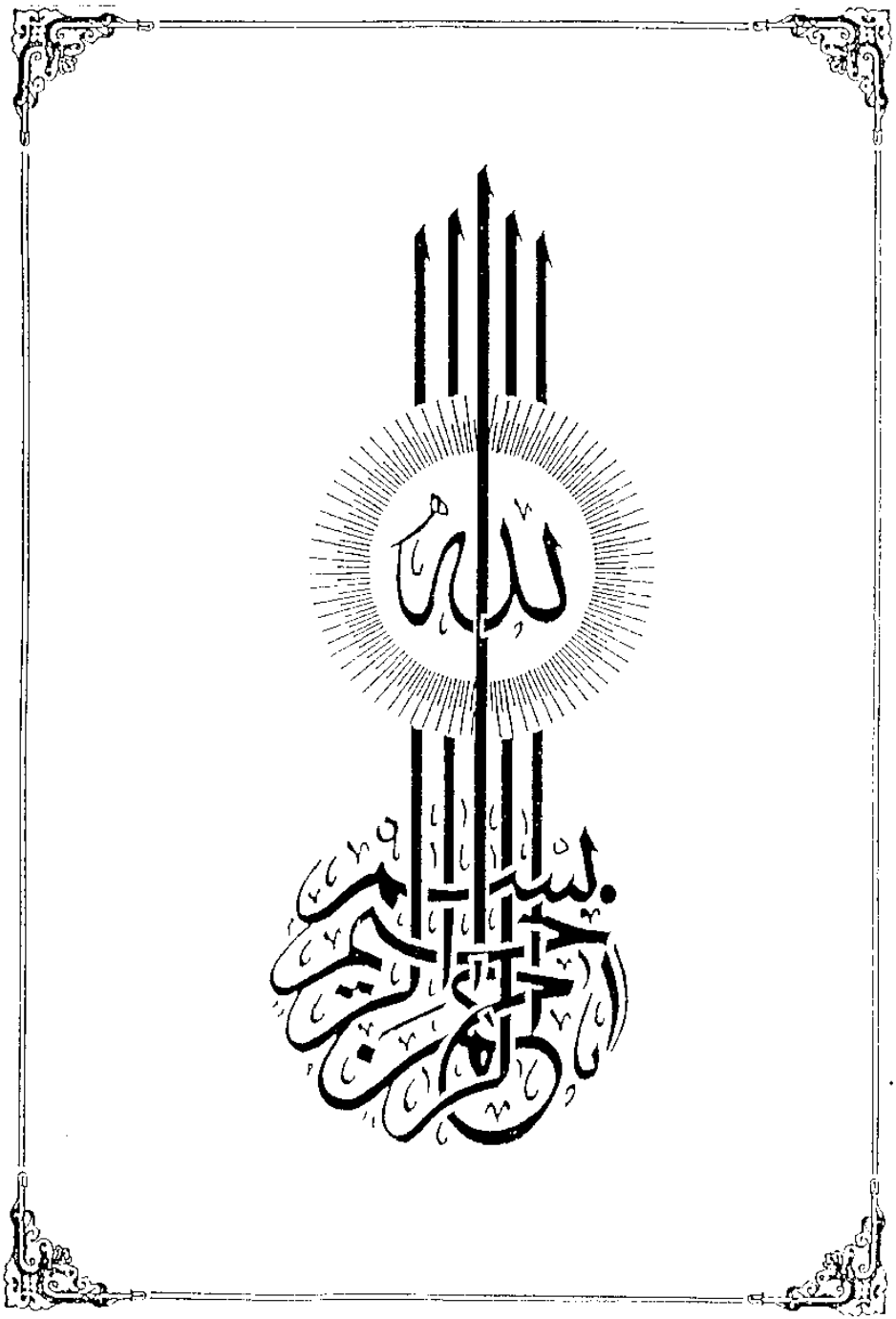


بسم الله الرحمن الرحيم

قالوا **سبحانك** لا علم لنا إلا ما علمتنا

إنك أنت **العليم الحكيم**

صدق الله العظيم



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List of contents

INTRODUCTION

Introduction

Hyaline articular cartilage which covers articulatory bone ends inside the diarthordial joint is a peculiar tissue inside the human body, this tissue owing to its histological structure performs two functions which are the basic events needed for the normal biomechanics of human body, these two functions are:

A) Increase the area of load distribution so as to reduce the static and dynamic loads imposed on bone ends.

B) Allowing relative movement of the opposing joint surfaces with minimal friction and wear (1).

The biomechanical functions of articular cartilage fail when the cartilage is affected by chronic joint disorder called osteoarthritis in which there is progressive softening and disintegration of articular cartilage accompanied by new growth of cartilage and bone at the joint margins (osteophytes) and capsular fibrosis. Osteoarthritis is designated primary when no cause is obvious and secondary when it follows a demonstratable abnormality, in general it is a disease of advancing years but young people can develop OA if articular cartilage is damaged or subjected to abnormal stress from an early age.

Osteoarthritis (OA) is more common in some joints (hip, knee, spine) than in others (elbow, ankle). Moreover,

individual joints are affected with different frequency in men and women (Terminal I-P in postmenopausal women) and indifferent ethric groups (OA of hip is rare in Africans but common in Souther Europeans). Osteoarthritis is a universal disorder, every one will get it somewhere if he lives long enough (2).

ATRICULAR CARTILAGE HISTOLOGY AND BIOMECHANICS

Articular cartilage

Histology:

The human body has three types of joints; fibrous, cartilagineous and synovial. Only one, the synovial or diarthorial joint allows a wide range of motion.

The articulatory bone ends of diarthrodial joints are covered by a thin (1-5 mm) dense white connective tissue called hyaline articular cartilage.

Articular cartilage is a highly specialized tissue precisely suited to withstand the vigorous joint environment without failing during an average person's life time.

Physiologically, it is virtually an isolated tissue devoid of blood vessels, lymph channels and nerves.

The articular cartilage is formed of cartilage specific cells, chondrocytes (2-10% of tissue volume) and extracellular matrix which can be viewed as a fiber reinforced composite material, the matrix is formed of water (65-80%) of tissue net weight) and collagens (10-30% of wet weight) and proteoglycans (PG) which present 5-10% of wet weight.

About 90% of the cartilage collagen is type II forming a 3-dimensional fibrillar network of rope-like molecular aggregates (3). This fibrillar network is essential for maintaing the tissue's volume and shape and it gives articular cartilage its tensile strength, a property that is enhanced by the presence of crosslink between the collagen molecules, the basic biologic unit of collagen is tropocollagen, a structure composed of three procollagen polypeptides chains (α-chains) coiled into left handed helices which are further coiled about each other into a right handed triple helix. These rod-like tropocollagen molecules polymerize into large collagen fibrils (Fig. 1).

Covalent cross-links from between these tropocollagen molecules, adding to the fibrils high tensile strength.

The collagen in articular cartilage is arranged in zonal pattern as follows: (Fig. 2)

[A] The superficial tangential zone:

Which represents 10 to 20% of the total thickness, here, the collagen fibres are sheets of fine, densely packed fibres randomly woven in planes parallel to articular surface.

[B] The middle zone:

Which represents 40 to 60% of the total thickness, here, the fibres are randomly oriented and homogeneously dispersed fibres.

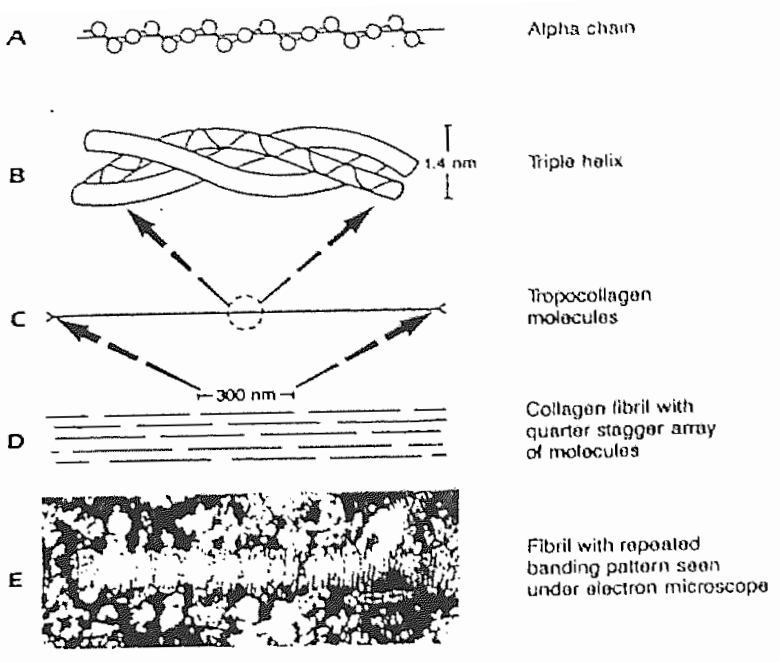
[C] The deep zone:

It is about 30% of the total thickness, here, the fibres come together, forming larger, radially oriented fibre bundles, these bundles then cross the tide mark, the interface between articular cartilage and the calcified cartilage beneath it, to enter the calcified cartilage forming an interlocking (root) system that anchors the cartilage to the underlying bone (4).

Proteoglycans are embedded within the fibrillar network and give articular cartilage its ability to undergo reversible deformation (3).

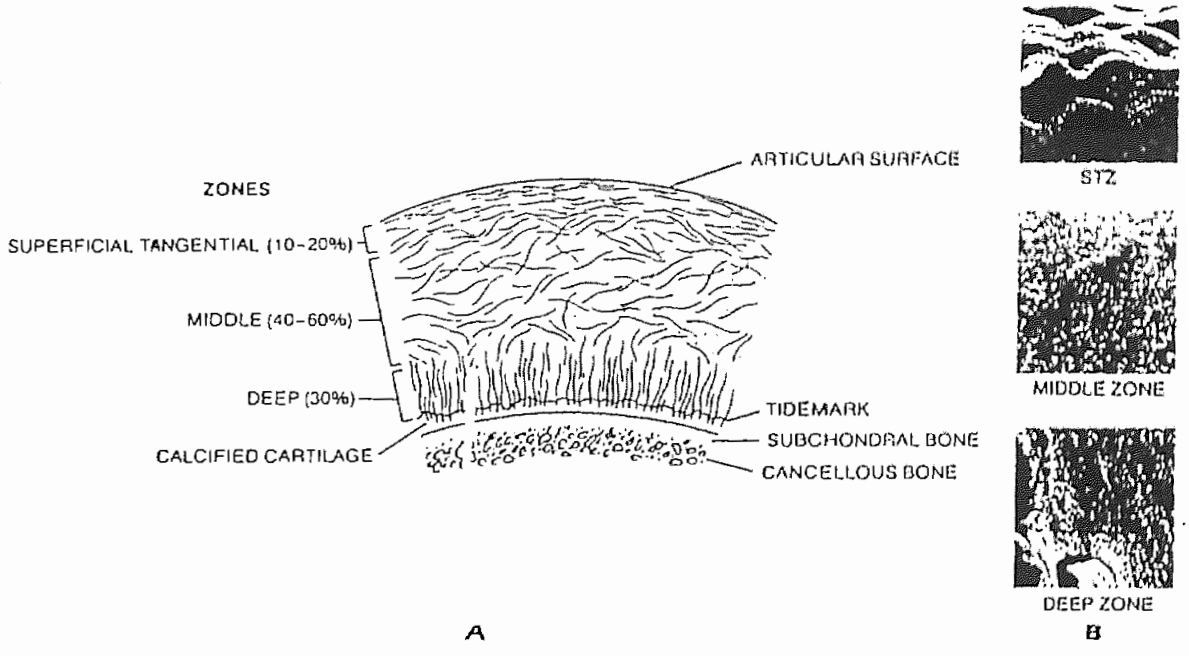
These proteoglycans are large protein polysaccharide molecules that exist either as monomers or as aggregate.

The composition and structure of articular cartilage allow for optimal performance of its functions.



Molecular features of collagen structure from the α chain to the fibril. The flexible amino acid sequence in the α chain **(A)** allows these chains to wind tightly into a right-handed triple helix configuration **(B)**, thus forming the tropocollagen molecule **(C)**. This tight triple helical arrangement of the chains contributes to the high tensile strength of the collagen fibril. The parallel alignment of the individual tropocollagen molecules, in which each molecule overlaps the other by about one quarter of its length **(D)**, results in a repeating banded pattern of the collagen fibril seen by electron microscopy (20,000×) **(E)** (reprinted with permission from Donohue et al., 1983). (Adapted from Eyre, 1980.)

Fig. 1



Schematic representation **(A)** (adapted from Mow et al., 1974) and photomicrographs (3000×) **(B)** (courtesy of Dr. T. Takei, Nagano, Japan) of the ultrastructural arrangement of the collagen network throughout the depth of articular cartilage. In the superficial tangential zone (STZ), collagen fibrils are tightly woven into sheets arranged parallel to the articular surface. In the middle zone, randomly arrayed fibrils are less densely packed to accommodate the high concentration of PGs and water. The collagen fibrils of the deep zone form larger, radially oriented fiber bundles that cross the tidemark, enter the calcified zone, and anchor the tissue to the underlying bone. Note the correspondence between this collagen fiber architecture and the spatial arrangement of the chondrocytes shown in Figure 2–1. In the photomicrographs **(B)**, the STZ is shown under compressive loading, while the middle and deep zones are unloaded.

Fig. 2

Biomechanics of articular cartilage:

The biomechanical properties of articular cartilage depend on properties of the intrinsic materials of the articular cartilage's solid matrix and the frictional resistance to the flow of interstitial fluid through the permeable solid matrix. So biomechanically the articular cartilage can be viewed as a biphasic material (solid-fluid): the collagen-PG solid matrix (approximately 25% of wet weight) surrounded by the free movable interstitial fluid (approximately 75% of wet weight). This is proved by the fact that if a material is subjected to the action of a constant (time-independent) load or a constant deformation and its response varies (is time dependent), then the behaviour of the material medically is said to be viscoelastic (4).

The fundamental responses of a visco-elastic material (e.g. articular cartilage):

(I) Creep response (II) Stress relaxation

(I) Creep response:

It occurs when a viscoelastic material is subjected to the action of a constant load typically, a viscoelastic material responds with rapid initial deformation followed by a slow (time-dependent), progressively increasing deformation known as creep, until an equilibrium is reached, in articular cartilage creep is caused by exudation of the interstitial fluid.

Exudation is most rapid initially, as evidenced by the early rapid rate of increased deformation and it diminishes gradually until flow ceases.

During creep, the load applied at the surface is balanced by the compressive stress developed within the collagen-PG solid matrix.

Creep ceases when the compression stress developed within the solid matrix is sufficient to balance the applied stress alone, at this point no fluid flows and the deformation equilibrium is reached (1).

(II) Stress relaxation:

It occurs when a viscoelastic material is subjected to the action of a constant deformation, typically there is a high initial stress followed by a slow (time-dependent) progressively decreasing stress required to maintain the deformation, this phenomenon is known as stress relaxation.

During compression, the high stress is generated by forced exudation of the interstitial fluid and the compaction of the solid matrix near the surface. While stress decreases later because of redistribution of fluid within the matrix (5). (Fig. 4)