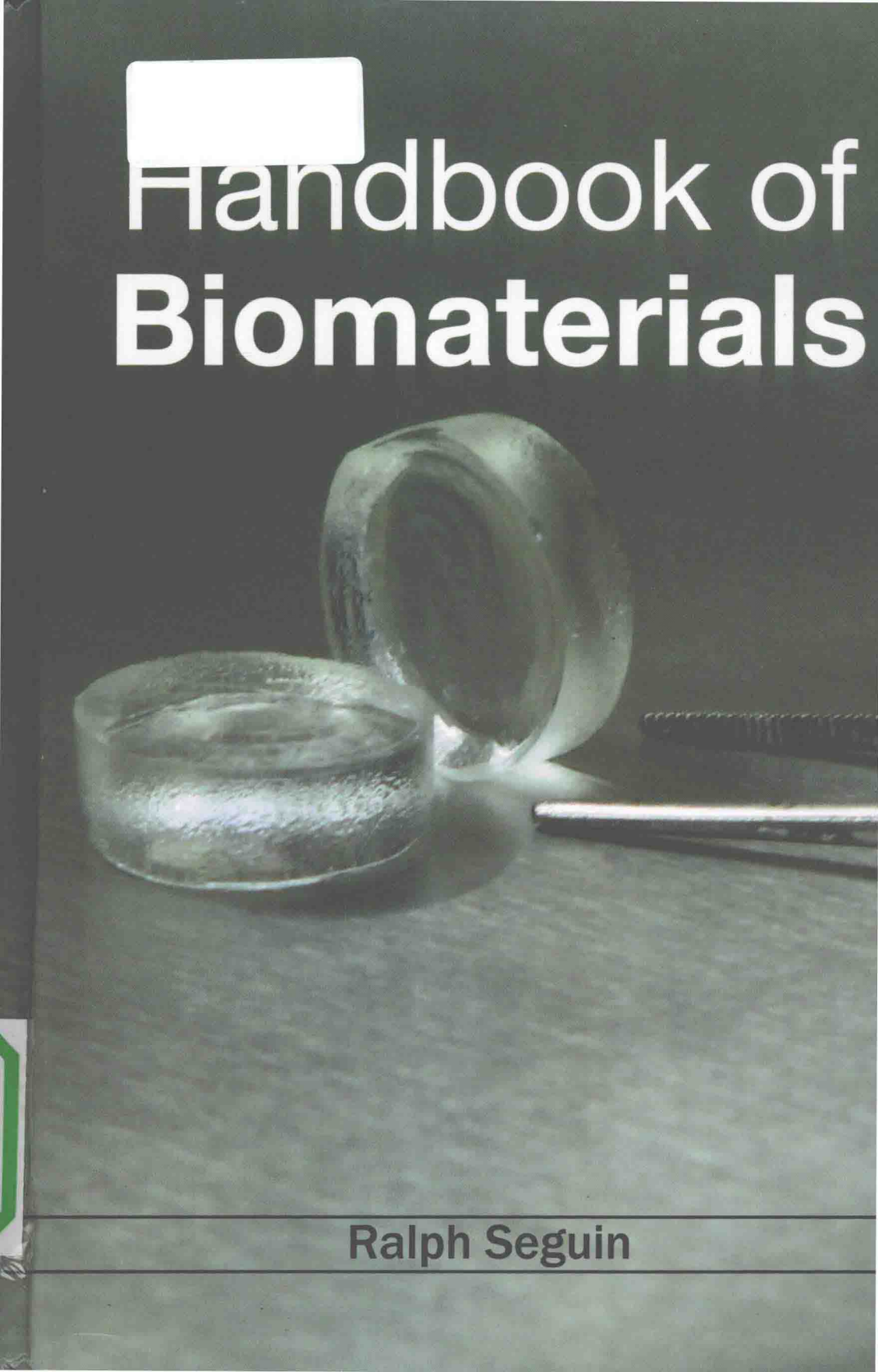
Handbook of Biomaterials



Ralph Seguin

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Edited by **Ralph Seguin**

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Preface

This book has been a concerted effort by a group of academicians, researchers and scientists, who have contributed their research works for the realization of the book. This book has materialized in the wake of emerging advancements and innovations in this field. Therefore, the need of the hour was to compile all the required researches and disseminate the knowledge to a broad spectrum of people comprising of students, researchers and specialists of the field.

This book consists of reviews and original researches conducted by experts and scientists working in the field of biomaterials, its development and applications. It offers readers the potentials of distinct synthetic and engineered biomaterials. This book gives a comprehensive summary of the applications of various biomaterials, along with the techniques required for designing, developing and classifying these biomaterials without any intervention by any industrial source. It also elucidates the various techniques used to produce biomaterials with the required physical and biological features for medical and clinical applications.

At the end of the preface, I would like to thank the authors for their brilliant chapters and the publisher for guiding us all-through the making of the book till its final stage. Also, I would like to thank my family for providing the support and encouragement throughout my academic career and research projects.

Editor

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Part 1

Biomechanical and Physical Studies

1

Biomechanical Properties of Synovial Fluid in/Between Peripheral Zones of Articular Cartilage

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1. Introduction

The properties and behaviour of articular cartilage (**AC**) have been studied from numerous aspects. A number of biomechanical models of the properties and behaviour of AC are available today. The traditional model presents cartilage as homogeneous, isotropic and biphase material (Armstrong et al., 1984). There also exist models of transversally isotropic biphase cartilage material (Cohen et al., 1992; Cohen et al., 1993), non-linear poroelastic cartilage material (Li et al., 1999), models of poroviscoelastic (Wilson et al., 2005) and hyperelastic cartilage material (Garcia & Cortes, 2006), models of triphase cartilage material (Lai et al., 1991; Ateshian et al., 2004), and other models (Wilson et al., 2004; Jurvelin et al., 1990). The published models differ, more or less, by the angle of their authors' view of the properties and behaviour of articular cartilage during its loading.

The authors base their theories on various assumptions concerning the mutual links between the structural components of the cartilage matrix and their interactions on the molecular level.

The system behaviour of AC very depend on nonlinear properties of synovial fluid (**SF**). Certain volumes of SF are moveable components during the mechanical loading in the peripheral zone of AC. Biomechanical properties of peripheral zone of AC are significantly influenced by change of SF viscosity due to mechanical loading.

The hydrodynamic lubrication systems and influences of residual strains on the initial presupplementation of articular plateaus by synovial fluid were not sufficiently analyzed up to now.

Our research has been focused on analyses of residual strains arising in AC at cyclic loading and on the viscous properties of SF. Residual strains in articular cartilage contribute the preaccumulation of articular surfaces by synovial fluid.

SF reacts very sensitively to the magnitude of shear stress and to the velocity of the rotation of the femoral and tibial part of the knee joint round their relative centre of rotation when the limb shifts from flexion to extension and vice versa. Shear stresses decrease aggregations of macromolecules of hyaluronic acid in SF.

Articular cartilage (AC) is a viscohyperelastic composite biomaterial whose biomechanical functions consist

1. in transferring physiological loads into the subchondral bone and further to the spongious bone,
2. in ensuring the lubrication of articular plateaus of joints and
3. in protecting the structural components of cartilage from higher physiological forces.

The macromolecular structure of AC in the peripheral zone (Fig. 1.) has two fundamental biomechanical safety functions, i.e. to regulate the lubrication of articular surfaces and to protect the chondrocytes and extracellular matrix from high loading.

The rheological properties of SF play the key role in the achievement of the optimum hyaluronan concentration.

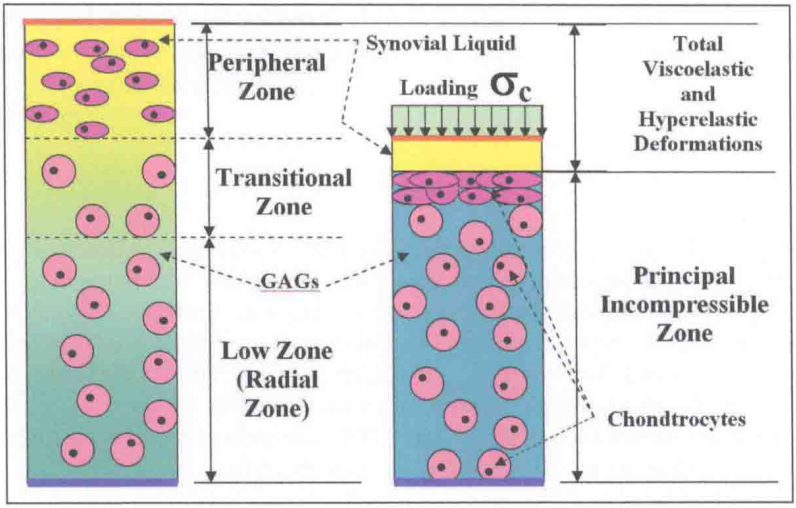

Fig. 1. Complex structural system of articular cartilage (collagen fibres of 2nd type are not drawn)

The properties of SF in the gap between the opposite surfaces of articulate cartilage are not homogeneous during loading. The properties of SF change not only during biomechanical loading, but also during each individual's life time. The viscous properties of this fluid undergo changes (in time) due to mechanical loading. As a consequence of its very specific rheological characteristics, SF very efficiently adapts to external biomechanical effects. Exact knowledge of the rheological properties of synovial fluid is a key tool for the preservation and treatment of AC. The significance of the specific role of SF viscosity and viscosity deviations from predetermined physiological values were first pointed out as early as the 1950s to 1990s (Johnson et al., 1955; Bloch et al., 1963; Ferguson et al., 1968; Anadere et al., 1979; Schurz & Ribitsch, 1987; Safari et al., 1990 etc.). The defects of concentrations of the dispersion rate components were noticed by Mori (Mori et al., 2002). In this respect, it cannot be overlooked that mechanical properties of SF very strongly depend on the molecular weight of the dispersion rate (Sundblad et al., 1953; Scott & Heatley, 1999; Yanaki et al., 1990; Lapcik et al., 1998) and also on changes in the aggregations of macromolecular complexes in SF during mechanical effects (Myers et al., 1966; Ferguson et al., 1968; Nuki & Ferguson, 1971; Anadere et al., 1979 and Schurz & Ribitsch, 1987).

Synovial fluid is a viscous liquid characterized by the apparent viscosity η. This viscosity depends on stress and the time during which the stress acts. SF is found in the pores of the

peripheral zone of AC and on its surface (in the gap between the opposite AC surfaces). The viscosity of synovial fluid is caused by the forces of attraction among its molecules being fully manifested during its flow. In other words, viscosity is a measure of its internal resistance during the SF flow. In the space between the opposite AC surfaces, its flow behaves like a non-Newtonian fluid.

As was pointed out above, biomechanical effects play a non-negligible and frequently a primary role in regulating rheological properties.

The principal components of synovial fluid are water, hyaluronic acid **HA**, roughly 3-4 mg/ml, D-glucuronic acid and D-N-acetylglucosamine (Saari et al., 1993 and others). By its structure, hyaluronic acid is a long polymer, which very substantially predetermines the viscous properties of synovial fluid. Its molecular structure is evident from Fig. 2. ***Synovial fluid*** also contains an essential growth hormone *prolactin* (PRL) and *glycoprotein lubricin*.

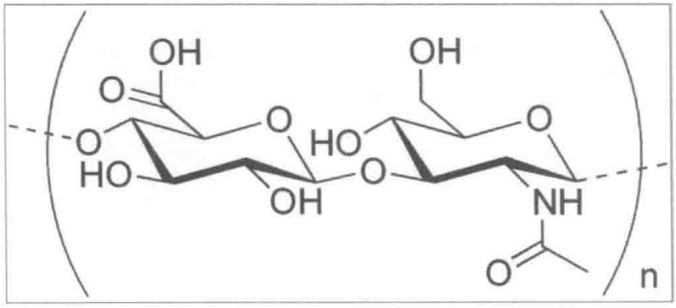

Fig. 2. Molecular complex of hyaluronic acid (HA)

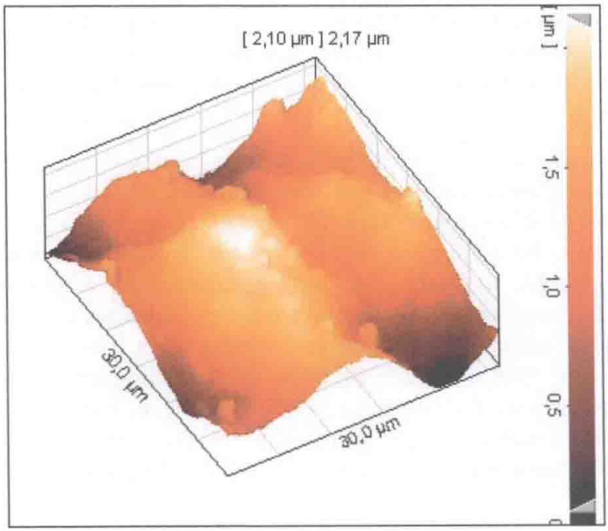

Fig. 3. Topography of the surface of articular cartilage verified by means of FAM (Force Atomic Microscope). The height differences of surface points range up to ca 200 nm - 2,4 µm. In unloaded condition, they are flooded by synovial fluid

Prolactin induces the synthesis of proteoglycans and, in combination with glucocorticoids, it contributes to the configuration of chondrocytes inside AC and to the syntheses of type II collagen. The average molecular weight of human SF is 3 - 4 MDa.

Important components of SF are lubricin and some proteins from blood plasma (γ-globulin and albumin), which enhance the lubricating properties of SF (Oates, 2006). The importance of HA and proteins for the lubricating properties of SF was also described (Swann et al., 1985; Rinaudo et al., 2009).

In the gap between AC surfaces, synovial fluid forms a micro-layer with a thickness of ca 50 μm. It fills up all surface micro-depressions (Fig. 3. and 4., Petrtýl et al., 2010) and in accessible places its molecules are in contact with the macromolecules of residual SF localized in the pores of the femoral and tibial peripheral zone of AC.

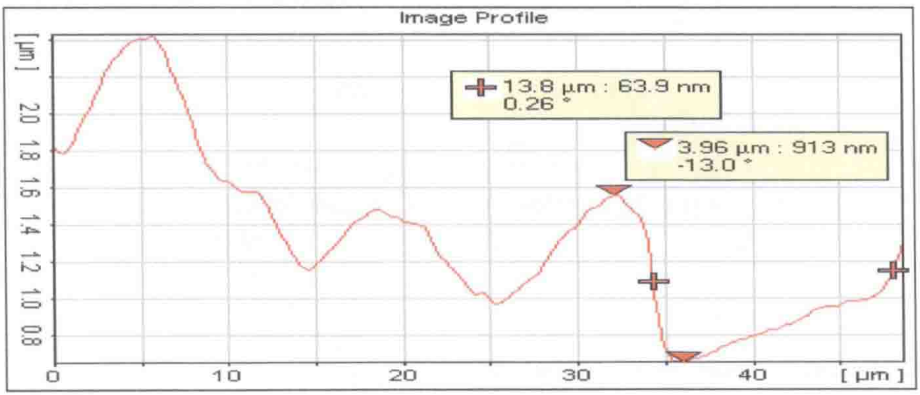

Fig. 4. Topography of the articular cartilage surface of a man (58 years of age). The AC surface oscillates to relative heights of 2.5 μm. During fast shifts of the AC surface (due to the effect of dynamic shifting forces/dynamic bending moments or shear stresses), the AC surface is filled up with generated synovial gel (with less associated NaHA macromolecules) with ***low viscosity***

SF is a rheological material whose properties change in time (Scott, 1999 and others). As a consequence of loading, associations of polymer chains of HA (and some proteins) arise and rheopexic properties of SF are manifested (Oates et al., 2006). Due to its specific rheological properties, SF ensures the lubrication of AC surfaces. The key component contributing to lubrication is HA/NaHA. In healthy young individuals, the endogenous production of hyaluronic acid (HA) reaches the peak values during adolescence. It declines with age. It also decreases during arthritis and rheumatic arthritis (Bloch et al., 1963; Anadere et al., 1979; Davies & Palfrey, 1968; Schurz & Ribitsch, 1987 and numerous other authors). Some AC diseases originate from the disturbance of SF lubrication mechanisms and from the defects of genetically predetermined SF properties. Therefore, the lubrication mechanisms of AC surfaces must be characterized with respect to the rheological properties of SF.

2. Contents

The objectives of our research has been aimed on the definition of the biomechanical properties of SF which contribute to the lubrication of the opposite surfaces of articular