Liquid Crystals in Biotribology

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Synovial Joint Treatment

Springer

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Preface

The book is given over to study of nature of abnormally low friction and wear of human and animal joints. Trends in joint function and lubrication, possibilities of rheological correction and cartilage mechanodestruction prophylaxis during arthropathies are generalized.

The complex researches of cartilage friction process in natural and artificial lubricants that lead to breakthrough understanding of joint boundary lubrication nature take a large part of the book. It has been proved that liquid-crystal state of synovial fluid, such as cholesteric-nematic crystals, plays an essential role in intra-articular friction decrease. The results of this discovery have fundamental and applied meaning. They greatly expand up-to-date understanding of the role of liquid crystal in biological tribosystem function and expose a completely new trend of joint lubrication properties research.

Creation of novel pharmaceuticals—artificial synovial fluid reproducing lubrication mechanism inherent to natural synovia—a new and important balance of the work.

Experimental and clinical data on chondroprotective efficiency of preparation are of practical interest for further research in the field. It should be noted that only a combination of biological, technical, physical, chemical and medical knowledge makes it possible to investigate the lubrication mechanism of joint cartilage and the prophylaxis methods of premature wear.

The book should be of interest to communities of scientific workers, practicians and students of medicobiological and technical specialties. It will draw the attention of researches to problems of biotribology, chondroprotection, liquid-crystal biological environment function and creation high-performance materials for endoprosthetics.

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Contents

Acronyms and Nomenclature

ANS	8-aniline-1-naphthylsulphonate (fluorescent probe)
BS	Blood serum
C	Cholesterol
CE	Cholesterol ester
CL	Common lipids
DMSO	Dimethylsulfoxide
HUA	Hyaluronic acid
LC	Liquid crystal
LCCC	Liquid-crystal cholesterol compound
MP	Medicinal preparations
Na-CMC	Sodium carboxymethyl cellulose
NCID	Non-steroid counter inflammatory drugs
NSA	Non-steroidal anti-inflammatory drugs
PVP	Polyvinyl pyrrolidone
RF	Rheumatoid factor
RSR	Relative specific radioactivity
SAA	Surface active agent
SCMC	Sodium carboxymethyl cellulose modulus of tension
SF	Synovial fluid
SR	Specific radioactivity
TG	Triglycerides
E	Modulus of tension
F_a	Adhesion component of friction
F_c	Cohesion component of friction ия
F_f	Friction force
G	Coefficient of rigidity
I_{fl}	Fluorescence strength
K	Forces of action of body weight part

K_{22}	Elastic constant
M	Forces of action of lateral abductor muscles
P	Reliability
Q	Liquid volume flow
R	Resulting compressive forces
S	Liquid crystal order parameter
S_5	Body center of gravity
T	Temperature
W	Free energy of liquid crystal
W_s	Surface energy of liquid crystal
W_e	Elastic energy liquid crystal
a	Cholesterics molecular layer thickness
b	Extrapolative path
d	Thickness of liquid crystal
h	Thickness of lubricant layer
h_i	Range of sinusoidal relief
h_l	Thickness ratio of lubricant layer
Δh	The thickness of the specimen
k	The coefficient of permeability
Δl	Deformation
$\overrightarrow{n}$	Unit vector (director)
p	Pressure
$\tilde{p}$	Dimensionless pressure
Δp	Differential pressure
S	Pitch of the helically-coiled cholesteric
t	Time
v	Speed
Φ	Pressure in the fluid
Θ	Calorific endothermal effect
Ψ	Pressure in the articular cartilage
α	Angle
η	Viscosity
φ	The angle of molecular orientation in cholesteric
λ	Wave-length of sinusoidal relief
θ	The angle of director orientation $\vec{n}$ relatively to the instantaneous direction of the cholesteric major molecule axis
ρ	The radial measure in the cartilage
τ	Dimensionless time parameter

Introduction

Synovial joints is a unique biological body of movement (motion). They can function under significant live loads, at high and low speeds for a long time and not wear for lifelong. A study that deals with the design, friction, wear and lubrication of interacting surfaces in relative motion is called tribology. In spite of considerable progress in tribology in recent years, neither technical unit exhibits the same friction characteristics as natural joints do. Therefore, synovial joints are of great interest to present and future tribology. Investigation of such complicated processes can be made at the intersection of disciplines about the physical and chemical properties of rub surfaces, the interaction of a solid phase and its field with atoms and molecules of various substances, mechanics of solids and liquids and others. Thus, tribology is an up-to-date cross-disciplinary science that encompasses various aspects of the world.

Biotribology is a medical-biological branch of tribology. It studies friction interaction of biopolymer composites having unique structure—cartilages in the synovial joint of humans and animals. Comprehension of joint tribology opens up great perspectives in the destruction pathogenesis during trauma and arthropathies. Thus, one can also speak of development of new methods for effective cartilage protection against premature destruction and wear.

Biotribology arose with swift advance in the past five decades. A significant amount of information about friction and wear features of joint cartilage in health and disease, importance of joint structure specificity, joint surface macro- and microgeometry, biochemical composition and rheology of synovial fluid for load transfer and decrease, joint kinematics and lubrication has been collected.

It is doubtless that the biotribology developmental pathway is closely associated with researches in frictional interaction of various materials and units in engineering. Simultaneously, researches in engineering cannot be automatically used in tribology of synovial joints. It is impossible to describe their abnormally low friction and wear nowadays.

Meantime, the authors think that abnormally low friction of joints is conditional upon synovial fluid lubricity. The last achievements in physics of liquid crystals and

the obtained data on their unique lubricant properties are very promising and encouraging.

It has been found that liquid-crystal state is inherent to a number of biological tissues and matrixes, but there were no similar evidence for synovial fluid. Therefore, research of cholesteric liquid crystals and definition of their role in natural lubrication is considered to be a brand new scientific approach to further knowledge of the nature of articulate cartilages abnormally low friction, and also to development of new arthropathy treatment mode.

Intensive biotribological researches are carried out mainly in England, the USA, Germany and some other countries in recent years. Similar works are also conducted at research institutes and laboratories in Gomel, Minsk, Moscow, Vilnius, Kiev and Ivanovo. The primary goal of this study is to create artificial synovial fluid for destruction prophylaxis and new effective biopolymer self-lubricating materials for joints endoprosthetics. However, the available scientific works and publications on biomechanics and tribology of the joint synovial have incidental character, and are insufficiently generalized.

In the work the authors made an attempt to analyze the available literature data on structure and function features of synovial joints, lubrication mechanisms, pathogenesis of cartilage mechanodestruction and opportunities of its prevention with known pharmaceuticals and physical factors.

Our own study of cartilage friction and wear, experimental and theoretical proofs of interfacial liquid-crystal state of synovial fluid, justification for new intraarticular friction decrease concept and a new scientific field for creation of artificial synovial fluid and new arthropathy treatment mode take up a large part of the book.

The authors hope that this study will be of interest and use for not only arthrology, biomechanical and tribology experts, but also the engineering, medical and biological communities.