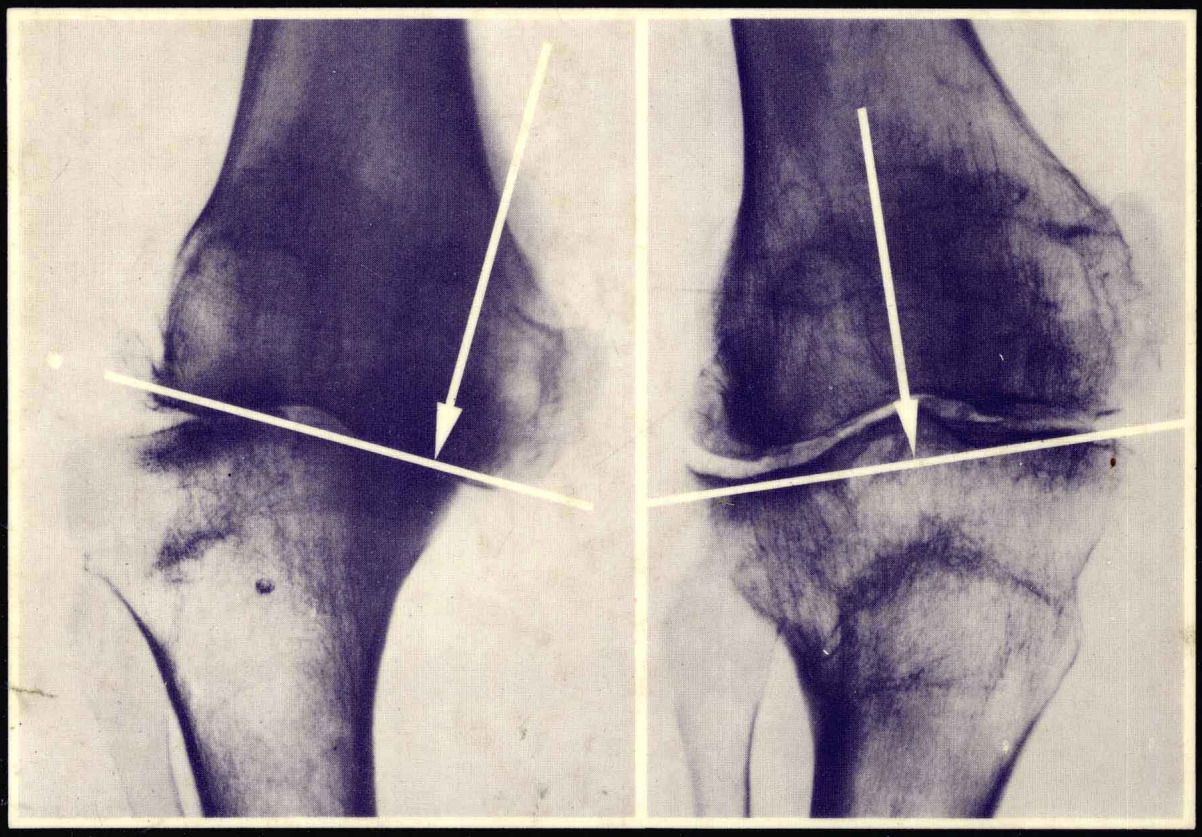
Paul G. J. Maquet

Biomechanics of the Knee

With Application to the Pathogenesis and the Surgical Treatment of Osteoarthritis

Second Edition, Revised and Expanded



Springer-Verlag Berlin Heidelberg New York Tokyo

Paul G. J. Maquet

Biomechanics of the Knee

With Application to the Pathogenesis and the Surgical Treatment of Osteoarthritis

2nd Edition, Expanded and Revised

With 243 Figures

Springer-Verlag
Berlin Heidelberg NewYork Tokyo 1984

Docteur PAUL G.J. MAQUET
25, Thier Bosset, B-4070 Aywaille

ISBN 3-540-12489-6 Springer-Verlag Berlin Heidelberg New York Tokyo
ISBN 0-387-12489-6 Springer-Verlag New York Heidelberg Berlin Tokyo

ISBN 3-540-07882-7 1st edition Springer-Verlag Berlin Heidelberg New York
ISBN 0-387-07882-7 1st edition Springer-Verlag New York Heidelberg Berlin

Library of Congress Cataloging in Publication Data

Maquet, Paul G.J., 1928 –
Biomechanics of the knee.

Translation of: Biomécanique du genou.
Bibliography: p.
Includes index.
1. Knee. 2. Knee-Surgery. 3. Osteoarthritis-Surgery. 4. Human mechanics. I. Title.
RD561.M3613 1983 617'.582 83-14833

Typesetting, printing, and bookbinding: Universitätsdruckerei H. Stürtz AG, Würzburg.
2124/3130-543210

Ce n'eſt autre choſe practique
Sinon l'effect de Theorique.

Sience ſans experience
N'apporte pas grande aſſeurance.

AMBROISE PARE', DE LA VAL CONSEILLER ET PREMIER CHIRVRGIEN du Roy.

CANONS ET REIGLES Chirurgiques de l'Autheur.

"Les Oeuvres d'Ambroise Paré, conseiller, et premier chirurgien du Roy, corrigées et augmentées par lui-même, peu avant son décès. A Paris, chez Barthelemy Macé, au mont St-Hilaire, à l'Ecu de Bretagne. 1607".

Foreword

Pathological conditions affecting the hip and knee joints occupy a particular place amongst the important orthopaedic entities affecting the extremities. On the one hand they are relatively frequent and on the other they mean for the patient limitation of his ability to walk, because of their considerable detrimental effects.

A purposeful basic treatment of these joint diseases (and here osteoarthritis takes pride of place) is only possible if it stems from a reliable biomechanical analysis of the normal and pathological stressing of the joint in question. Whilst the situation in the hip can be considered to be fundamentally clarified, a comprehensive representation of the knee is still lacking, particularly when taking into account the latest knowledge of biomechanics. Recently our concepts of the kinematics of the knee have been completely changed, but the clinically important question of articular stressing remains unanswered.

Dr. Maquet has carried out pioneer work in this field for some years in adapting, by analogy, to the knee joint principles already accepted for the hip joint. Since the knee is not a ball and socket joint, a complicated problem arises for which new thoughts are necessary. The results of the numerous operations carried out by Dr. Maquet according to the biomechanical considerations demonstrate that his thinking is fundamentally correct. Above all, it is here again proven (as earlier in the case of the hip) that healing of osteoarthritis depends decisively on reducing and evenly distributing joint pressure.

In the present book Dr. Maquet proceeds from the earlier static analyses for his evaluation of the kinetic stressing, by taking advantage mainly of the very accurate research of O. Fischer about human gait. The result is a survey of the stressing of the knee joint and until now nothing comparable has existed. Moreover, it is shown in an impressive way how judicious surgical procedures based on biomechanics can cause healing even in severe osteoarthritis of the knee. This happens, above all, without implanting endoprostheses which are certainly still more questionable for the knee than they already are for the hip.

May this book be widely disseminated and may much further discussion of this burning problem be stimulated!

Aachen, Summer 1976

F. PAUWELS

Preface to the First Edition

Pauwels in 1950, relying on an experience of over 15 years, showed that the clinical and radiological signs of osteoarthritis of the hip could be made to disappear by a proper surgical approach which permitted astonishing regeneration of the diseased joint. His interventions were based on a profound knowledge of hip mechanics and biomechanics in general. The aim of these procedures was to diminish as much as possible the articular pressure to render this pressure supportable by the diseased tissues. These procedures decreased the pressure by reducing the load supported by the hip and increasing the weight-bearing surface of the joint.

The laws of biomechanics enunciated by Pauwels (1950, 1951, 1958, 1959, 1960, 1964, 1965a, b, 1968, 1973a, b) and applied by him to the hip, elbow, and shoulder have general application. It seemed logical, therefore, in osteoarthritis of the knee to apply these rules which had permitted Pauwels to obtain spectacular results in patients suffering from osteoarthritis of the hip. This required a knowledge of the mechanics of the normal knee and of the arthritic knee which we have not been able to find in the literature. Certain movements of the knee have already been studied. However, the influence of the mechanical factors on osteoarthritis of the knee has never been clearly explained. Orthopaedic surgeons have empirically corrected varus deformities of the knee by a valgus osteotomy and valgus ones by a varus osteotomy in either the lower part of the femur or upper part of the tibia. They have obtained inconsistent results. From their experience they have concluded that one has to achieve overcorrection of the femoro-tibial angle in the coronal plane in varus deformities and reasonably precise correction for valgus deformities. These recommendations, deduced from empirical experience, are barely sufficient for one who wishes to base treatment on a sound theoretical foundation and obtain consistently good results. The essential aim of our labours is to furnish this theoretical foundation, rationally justifying the choice of one form of intervention over another, thereby improving the treatment of osteoarthritis of the knee.

Aywaille, Summer 1976 PAUL G.J. MAQUET

Preface to the Second Edition

Since publication of the first edition further research has improved our knowledge of the mechanics of the knee, helping us especially to define more precisely the appropriate approaches to the different types of osteoarthritis. In this edition more emphasis has been put on surgical treatment. Tibial osteotomy remains the method of choice for treating medial osteoarthritis with a varus knee, whereas femoral osteotomy appears the best way of dealing with lateral osteoarthritis with a valgus deformity. Planning and surgical procedures are described more completely. The postoperative results are not only illustrated, but also more thoroughly analysed. These results support our views on biomechanics and osteoarthritis of the knee.

Aywaille, Summer 1983 — Paul G.J. Maquet

Acknowledgments

Professor F. Pauwels taught me the basic principles of biomechanics and spent innumerable hours discussing my clinical cases and shaping my way of thinking in orthopaedics. I am also deeply indebted to the many other individuals who made this work possible and first of all to my wife, Josette, for her patient understanding and for her many hours of work in preparing this manuscript.

My good friend, Dr. P. de Marchin, initially germinated the idea of this research. I would never have carried it out without the constant advice and encouragement of Professor J. Lecomte. Professor B. Kummer was most helpful in freely discussing and constructively criticizing the work.

Professor A. Pirard and his assistants, Mrs. G. Pelzer and Mr. F. de Lamotte, not only provided a solution to the difficult mathematical problems but also allowed me to use their laboratory with the help of their technician, Mr. C. Nihard, for the photoelastic studies. Professor E. Betz has kindly furnished me most of the anatomical specimens I needed. Mr. J. Simonet built the apparatus to measure the loads exerted on the specimens. Dr. A. Van de Berg X-rayed them in his private office. Dr. M. Vercauteren supplied the gait movie. After Dr. N. Matsumoto and Dr. T. Yamaguchi had each spent more than a year with me, they carried out arthroscopies of the knee before and after surgery, with Y. Fujisawa, K. Masuhara, N. Mii, H. Fuyihara and S. Shomi. They kindly granted me permission to reproduce some of their pictures in this book. Dr. F. Burny and Mrs. M. Donkerwolcke, using the computer terminal of the Hôpital Erasme at the Université Libre de Bruxelles and their knowledge of statistical analysis, enabled me to write the chapter dealing with the results. Associate Professor E.L. Radin helped me edit the first edition. Mr. R. Furlong F.R.C.S. offered his time, his patience and his accurate knowledge of the English language to prepare the final version of the text for both first and second editions.

Permission to reproduce

Figures 13, 14, 18, 20, 21, 22, 23, 24, 26, 67, 75, 76, 81, 106, 139 (Maquet, Simonet, and de Marchin, 1967) has been granted by courtesy of the *Revue de Chirurgie Orthopédique et réparatrice de l'Appareil Moteur;*

Figures 11, 15, 65, 74, 82, 107, 109, 116, 236, 242 (Maquet, 1969) by the *Société Internationale de chirurgie Orthopédique et Traumatologique;*

Figures 16, 17, 29, 30, 143, 152, 183a and 184b (Maquet, 1972) and 51, 66, 113, 114, 117 (Maquet, Pelzer, and de Lamotte, 1975) by the *Acta Orthopaedica Belgica;*

Figures 59, 62, 63 (Maquet, Van de Berg, and Simonet, 1975) by the *Journal of Bone and Joint Surgery;*

Figure 54 (Maquet, 1976) by the *Clinical Orthopaedics and Related Research;*

Figures 245, 246 by Fujisawa et al. and by *Igaku Shoin Ltd;*

Figures 155, 156 by Shiomi et al. and by the *Japanese Arthroscopy Association.*

Arthritis of the Knee

Clinical Features and Surgical Management
Editor: **M. A. R. Freeman**
With contributions by numerous experts
1980. 206 figures, 50 tables. XIII, 282 pages. ISBN 3-540-09699-X

M. K. Dalinka

Arthrography

1980. 324 figures, 4 tables. XIV, 209 pages
(Comprehensive Manuals in Radiology). ISBN 3-540-90466-2

H. R. Henche

Arthroscopy of the Knee Joint

With a Foreword by E. Morscher.
Translated from the German by P. A. Casey.
1980. 163 figures, most in colour, diagrams by F. Freuler, 1 table.
XII, 85 pages. ISBN 3-540-09314-1

Late Reconstructions of Injured Ligaments of the Knee

Editors: **K.-P. Schulitz, H. Krahl, W. H. Stein**
With contributions by M. E. Blazina, D. H. Donoghue, S. L. James, J. C. Kennedy, A. Trillat
1978. 42 figures, 21 tables. V, 120 pages. ISBN 3-540-08720-6

W. Müller

The Knee

Form, Function, and Ligament Reconstruction
Translated from the German by T. C. Telger
Preface by J. C. Hughston. Illustrations by R. Muspach
1983. 299 figures in 462 partially coloured separate illustrations.
XVIII, 314 pages. ISBN 3-540-11716-4
Distribution rights for Japan: Igaku Shoin Ltd., Tokyo

C. J. P. Thijn

Arthrography of the Knee Joint

Foreword by J. R. Blickman
1979. 173 figures in 209 separate illustrations, 11 tables.
IX, 155 pages. ISBN 3-540-09129-7

M. Watanabe, S. Takeda, H. Ikeuchi

Atlas of Arthroscopy

3rd edition. 1979. 226 figures, 11 tables. X, 156 pages
ISBN 3-540-07674-3
Distributions rights for Japan: Igaku Shoin Ltd., Tokyo

Springer-Verlag
Berlin
Heidelberg
New York
Tokyo

P. Beighton, R. Grahame, H. Bird

Hypermobility of Joints

Foreword by E. Bywaters
1983. 101 figures. XIII, 178 pages. ISBN 3-540-12113-7

R. Bombelli

Osteoarthritis of the Hip

Classification and Pathogenesis
The Role of Osteotomy as a Consequent Therapy
With a Foreword by M. E. Müller
2nd revised and enlarged edition. 1983.
374 figures (partly in colour). XVII, 386 pages
ISBN 3-540-11422-X

C. F. Brunner, B. G. Weber

Special Techniques in Internal Fixation

Translated from the German by T. C. Telger
1982. 91 figures. X, 198 pages. ISBN 3-540-11056-9

Current Concepts of External Fixation of Fractures

Editor: **H. K. Uhthoff**
Associate Editor: **E. Stahl**
1982. 227 figures. X, 442 pages. ISBN 3-540-11314-2

Current Concepts of Internal Fixation of Fractures

Editor: **H. K. Uhthoff**
Associate Editor: **E. Stahl**
1980. 287 figures, 51 tables. IX, 452 pages
ISBN 3-540-09846-1

E. Letournel, R. Judet

Fractures of the Acetabulum

Translated and edited from the French by R. A. Elson
1981. 289 figures in 980 separate illustrations.
XXI, 428 pages. ISBN 3-540-09875-5

R. Louis

Surgery of the Spine

Surgical Anatomy and Operative Approaches
Translated from the French by E. Goldstein
Foreword by L. L. Wiltse
Original Illustrations by R. Louis with the Technical Assistance of W. Ghafar
1983. 140 figures in 655 separate illustrations.
XVII, 328 pages. ISBN 3-540-11412-2

A. Sarmiento, L. L. Latta

Closed Functional Treatment of Fractures

1981. 545 figures, 85 tables. XII, 608 pages
ISBN 3-540-10384-8

Progress in Orthopaedic Surgery

Editorial Board: **N. Gschwend, D. Hohmann, J. L. Hughes, D. S. Hungerford. G. D. MacEwen, E. Morscher, J. Schatzker, H. Wagner, U. H. Weil**

Volume 1

Leg Length Discrepancy - The Injured Knee

Editor: **D. S. Hungerford**
With contributions by numerous experts
1977. 100 figures. X, 160 pages
ISBN 3-540-08037-6

Volume 2

Acetabular Dysplasia - Skeletal Dysplasia in Childhood

Editor: **U. H. Weil**
With contributions by numerous experts
1978. 133 figures, 20 tables. IX, 200 pages
ISBN 3-540-08400-2

Volume 3

The Knee: Ligament and Articular Cartilage Injuries

Guesteditor: **D. E. Hastings**
With contributions by numerous experts
1978. 139 figures, 20 tables. X, 191 pages
ISBN 3-540-08679-X

Volume 4

Joint Preserving Procedures of the Lower Extremity

Editor: **U. H. Weil**
With contributions by numerous experts
1980. 87 figures, 9 tables. VIII, 121 pages
ISBN 3-540-09856-9

Volume 5

Segmental Idiopathic Necrosis of the Femoral Head

Editor: **U. H. Weil**
With contributions by numerous experts
1981. 68 figures, 30 tables. VII, 121 pages
ISBN 3-540-10718-5

Springer-Verlag
Berlin
Heidelberg
New York
Tokyo

Contents

Chapter I. Aims and Limitations of the Work

Biomechanics encompasses a study of:

1. the mechanical stresses to which living tissues are subjected under physiological and pathological conditions;

2. the biological response of the tissues to these mechanical stresses and to their modifications;

3. the possibility of surgically changing the stresses in the living tissues to achieve a therapeutic effect.

This monograph will apply the discipline of biomechanics to the knee.

The forces supported by the normal knee will be analysed successively in standing symmetrically on both feet, in standing on one foot and during gait. These forces are transmitted from the femur to the tibia across joint surfaces the size of which will be measured. They provoke compressive stresses in the joint which will be defined.

There normally exists a physiological balance between the mechanical stress and the resistance of the articular tissues. This equilibrium can be disturbed by several factors: either the resistance of the articular tissues can be lowered by metabolic causes with the mechanical stress remaining normal or the mechanical stress can become abnormally great due to a mechanical disturbance while the integrity of the tissue remains normal. Disturbance of the physiological equilibrium produces reactions in the tissues, leading to osteoarthritis (Müller, 1929; Pauwels, 1973).

If the origin of the imbalance is metabolic and diminishes the tissue resistance, osteoarthritis will initially affect the whole knee. If it is mechanical, the osteoarthritis can primarily affect the medial or lateral part of the femorotibial joint. Degeneration can also be localized to the patello-femoral joint.

The causes of mechanically induced degeneration of the knee must be understood. We shall study what can modify the forces exerted on the knee and the mechanical consequences of these changes. The biological phenomena which lower the resistance of the tissues to mechanical stress will not be considered as this is more in the province of metabolic pathology.

After having determined the forces acting on the normal and abnormal knee, as well as the articular joint stresses in both the physiological and pathological states, we shall discuss how to influence the latter by surgery in order to achieve a therapeutic effect. We shall propose several operative procedures which reduce the mechanical stress in the knee. Original techniques will be described. The results of this surgery will be presented to illustrate and substantiate the theoretical analysis and biomechanical principles which are the basis of the treatment.

Methods which replace the whole or parts of the joint by metallic or plastic implants have certain indications but do not use the potential for regeneration possessed by living tissue. By strict definition they are not a biomechanical treatment and will not be considered in this presentation.