The Rationale of Operative Fracture Care

Third Edition

With Contributions by T.S. Axelrod, R. Hu, and D.J.G. Stephen

With 571 Figures in 1718 Separate Illustrations, 321 in Color and 38 Tables
Dedication

This third edition of our book is dedicated to our families for their patience, devotion, and understanding.

From Joseph Schatzker
To my late mother, Helene Schatzker Schleifer
To my wife, Valerie
To my sons, Erik, Susan and Isabelle and Natalie
        Adam, Elora and Joseph
        Mark and Laura.

From Marvin Tile
To my wife Esther
To my family: Gary, Rosemary, Katy, Sari, and Noah Tile
Stephen, Christine, David, Rachel, and Abby Tile
Steven, Deborah, Ian, and Annie Cass
Andrew Tile and Candy Ramberansingh.
Since its initial publication in 1987, our Rationale of Operative Fracture Care has enjoyed tremendous popularity. Many surgeons have commented repeatedly on how useful they have found the book, particularly when faced with a difficult problem, often in the middle of the night. All have felt that it is a book written by surgeons for surgeons. It explains in clear terms the logical progression of problem-solving while evolving a treatment rationale. Identify the problem first, then logically outline the different possibilities of solving it to decide which is best from a technical perspective, and which will lead to the best outcome for the patient. Then choose from the available armamentarium the most suitable surgical technique and implant.

Since our second revision was published in 1995, little has changed in the process of decision-making, but there has been a further thrust to biologic reduction techniques, and an explosion of new technology.

We delayed our third edition in order to be able to comment on the new technology once it had been in use for some time, which makes an objective appraisal possible. The most dramatic changes have been in the area of minimally invasive techniques and in the introduction of a radically new plate stabilization system, the angularly stable locked plating system.

Minimally invasive surgery has become the driving force of new technology. With the recognition that a fracture is not just a broken bone but a zone of injury which extends to the skin, minimally invasive techniques have come to play a major role not only in surgical exposure, but also in the implants employed. Locked intramedullary nails are the best example of a minimally invasive stabilization system, but nails have their limitations, particularly in metaphyseal and articular areas. This has given rise to the “internal fixators”, the angularly stable LCP which, when combined with minimally invasive techniques of insertion and fixation, have given the surgeon the ability to offer all the advantages of closed minimally invasive stabilization surgery, faster healing, and a lower complication rate in the treatment of fractures in articular and peri-articular areas. They have also improved our ability to achieve stability in osteoporotic bone, now so frequent in our aging population.

All of the chapters of the book have been carefully revised to reflect all the advances in biology, in biomechanics, in understanding of the biology of injuries and surgical wounds, and all the advances in stabilization systems. The book should continue to serve the surgical community well, in the most advanced teaching environments as well as in the forefront of care, the surgeons of the community hospitals.

Toronto, January 2005

Joseph Schatzker
Marvin Tile
Acknowledgements

To the new generation of the Springer-Verlag team, Gabriele Schröder, Irmela Bohn, Neil Solomon, and Kurt Teichmann, for their professionalism, dedication, cooperation, and help in the publication of the third edition.

To our research assistant Shirley Fitzgerald for her continued attention to detail in reading and editing the text.
Foreword to the Second Edition

Eight years have passed since the publication of the first edition of *The Rationale of Operative Fracture Care*. During this time, as I predicted, it has become the standard reference work for all concerned with the treatment of fractures: practicing surgeons, residents, and directors of academic units alike.

The second edition has been greatly expanded in scope. The original chapters have been completely reworked. Once again, Dr. Schatzker and Dr. Tile reveal their consummate understanding and mastery of the problems of trauma. They have included detailed discussions of all the conceptual changes in fracture treatment which have taken place since the publication of the original edition. Thus, indirect reduction, biological plating, indications for absolute and relative stability, as well as information on new implants, such as low contact plates, first and second generation reamed intramedullary nails, and the new unreamed nails and external fixation devices, are critically discussed in appropriate sections of the book.

To fill the gaps in the first publication, Dr. Schatzker and Dr. Tile have turned to their colleagues and close collaborators at Sunnybrook Health Science Centre. Fractures of the wrist and hand, spine, and hip are now included and discussed in great detail in this new edition.

Although three new authors have contributed to this book, the second edition of *The Rationale of Operative Fracture Care* offers a uniformity of approach and method rarely encountered in similar efforts. The close collaboration and collegial scholarship which exists at Sunnybrook’s famous trauma and orthopedic unit has produced this remarkable unity of thought and practice. This second edition will, I believe, be as popular as the first and provide a useful and inspiring reference to trauma surgeons throughout the world.

Berne, December 1995

Maurice E. Müller
Preface to the Second Edition

As Professor Müller predicted in the foreword to the first edition, our book, which dealt with the challenging subject of surgical indications, rapidly filled the void left by the AO Manual which discussed mainly the surgical techniques of internal fixation and the associated instruments and implants. Thus, the *Rationale of Operative Fracture Care*, in dealing critically with the issues of surgical indications in addition to many other important aspects of fracture treatment, quickly became the standard reference for those involved in the treatment of musculoskeletal trauma – resident and practicing surgeon alike.

Eight years have passed since the publication of the first edition. During this time many changes have occurred in surgical philosophy and technique and in implants and instruments. Thus, in the preparation of our second edition, we have found it necessary to completely rework all the original chapters. We have dealt in great detail with the conceptual changes which have occurred in the principles of internal fixation and have made certain that the reader would see the relationship of these changes to the biological and biomechanical properties of the diaphyseal and end segments of bone. The reader will also rapidly become aware of the complexities of stable internal fixation achieved by means of compression and those of relatively stable fixation achieved by splintage and how these two diverse methods of internal fixation must be carefully adapted to the physiological and mechanical requirements of diaphyseal and intraarticular fractures. The new concepts, such as indirect reduction, biological plating, absolutely stable and relatively stable fixation and their respective indications, as well as the new implants such as the low contact plates, the first and second generation reamed intramedullary nails and the new unreamed nails for the tibia and femur as well as the new designs of external fixateurs, are critically discussed in the appropriate segments of the book.

The second edition has also been greatly expanded in its scope. Voids which were left in the first edition have been carefully filled in the second. We have turned to our colleagues and close collaborators at Sunnybrook Health Science Centre to provide us with chapters which were omitted from the first edition. Thus T. Axelrod has written the chapter on the wrist, R. Hu the chapter on the spine, and D. Stephen the chapter on the foot. J. Schatzker has contributed a new chapter on fractures about the hip and M. Tile a chapter on the calcaneus. The close collaboration and unity of thought which exists between the members of the orthopedic unit at Sunnybrook has produced a remarkable unanimity of approach and execution rarely encountered in volumes written by more than one or two authors.

The second edition is thus an expanded and much more comprehensive treatise on the complexities of decision-making and surgical execution of fracture care. We are confident that it will once again enjoy popularity and bring guidance to the surgeons confronted with the difficult problems of their surgical practice.

Toronto, December 1995

Joseph Schatzker

Marvin Tile
Acknowledgements

To the new generation of the Springer-Verlag team, Udo Schiller, Gabriele Schröder, Sherryl Sundell, and Ute Pfaff, for their professionalism, dedication, cooperation, and help in the publication of the second edition.

To our secretaries Shirley McGovern and Carol Young for their continued support and help with this project.

To our research assistant Shirley Fitzgerald for her continued attention to detail in reading and editing the text.

To Maurice Müller for the Foreword and continuing support.
After the publication of the AO book *Technique of Internal Fixation of Fractures* (Müller, Allgöwer and Willenegger, Springer-Verlag, 1965), the authors decided after considerable discussion amongst themselves and other members of the Swiss AO that the next edition would appear in three volumes. In 1969, the first volume was published (the English edition, *Manual of Internal Fixation*, appeared in 1970). This was a manual of surgical technique which discussed implants and instruments and in which the problems of internal fixation were presented schematically without radiological illustrations. The second volume was to be a treatise on the biomechanical basis of internal fixation as elucidated by the work done in the laboratory for experimental surgery in Davos. The third volume was planned as the culminating effort based upon the first two volumes, treating the problems of specific fractures and richly illustrated with clinical and radiological examples. It was also to discuss results of treatment, comparing the results obtained with the AO method with other methods. The second and third volumes were never published.

The second edition of the AO *Manual* appeared in 1977. It dealt in greater detail with the problems discussed in the first edition, although it still lacked clinical examples and any discussion of indications for surgery. Like the first edition, it was translated into many languages and was well received.

Finally, after 22 years, the much discussed and much needed third volume has appeared. Two Canadian surgeons have successfully undertaken the challenging task of filling this gap in the AO literature.

Joseph Schatzker and Marvin Tile first came into contact with AO methods of internal fixation in 1965. Impressed by the results of the method, they set themselves to learn it in minute detail and before long became masters of the technique and strong exponents of its effectiveness. They appeared often as lecturers and instructors in AO courses in Switzerland, and North America. Their numerous publications and lectures have greatly contributed to the wide acceptance of the operative method of fracture care.

Joseph Schatzker translated the first and second editions of the *Manual* from German into English, and has, in addition to these excellent translations, achieved distinction as a teacher of the AO method. Both he and Marvin Tile participate annually as instructors in the instructional courses at the American Academy of Orthopedic Surgeons.

With their long association with AO techniques and tremendous clinical experience, these two distinguished surgeons were eminently qualified to undertake the monumental task of defining the specific indications for operative fracture care. In this book they present not only their own views but also a synthesis of the thoughts and writings of other AO members. The book is outstanding and far exceeds the goals originally envisaged for the projected third volume.

The authors have been careful in choosing examples and the appropriate radiological illustrations to delineate the mechanism of injury, the biomechanical problems, the indications for treatment, and the actual execution of surgical procedures. They always guide the reader to the essence of the problem, clearly emphasizing the principles of fracture treatment, a deductive approach through analysis to the clinical decision.

Schatzker and Tile speak of fractures having a “personality.” This “personality” is a key concept requiring careful definition: it includes not only a careful analysis of the fracture...
and all of its soft tissue components, but also a thoughtful assessment of the patient, his or her age, occupation, health, and expectations of treatment, as well as a critical appraisal of the skill of the surgeon and the supporting surgical team and environment. This analysis, combined with the knowledge of what constitutes a reasonable result, allows the authors to formulate a guide to treatment. They also provide useful advice about avoiding technical difficulties and pitfalls, about planning correct postoperative care, and about the treatment of complications which may arise.

The book is superbly illustrated with many drawings skillfully employed to clarify and emphasize essential techniques. The style is easy to understand, clear and unambiguous, giving a lucid presentation of complex and difficult concepts. It will certainly become a standard reference work for everyone involved in the treatment of fractures.

Berne, July 1987

Maurice E. Müller
The purpose of this book is to describe our philosophy of fracture care, which reconciles both the closed and open methods of fracture treatment. We do not regard these two methods as representing opposing points of view, but as complementary to each other. Some surgeons, who tend to treat fractures by closed methods, often imply that the open method is dangerous. By “conservative treatment” they imply a nonoperative method and suggest that it is well thought out, tried, and safe, and will yield results equal to if not superior to those achieved by surgery. “Conservative” as defined by the Oxford dictionary means “characterized by a tendency to persevere or keep intact and unchanged.” The surgeons who continue to view the open method of fracture treatment as the last resort, and who will do anything, no matter how extreme, to avoid opening a fracture, are indeed characterized by a tendency to keep unchanged an attitude whose prevalence was justified when the methods of internal fixation were inadequate and the results of surgical treatment often worse than those of nonoperative care.

However, the founding of the Swiss AO, an association for the study of problems in internal fixation, by Müller, Allgöwer, Willenegger and Schneider in 1958 ushered in a new era in fracture treatment. These pioneer surgeons developed new principles of stable internal fixation along with new implants. Their methods of open reduction and internal fixation, performed by atraumatic techniques, produced sufficient stability to allow early functional rehabilitation without an increase in the rate of malunion or nonunion. The results of treatment changed so dramatically that new standards of care and assessment had to be adopted. Nowadays, an excellent result means the full recovery of function, a painless extremity, a normal mechanical axis, and full joint stability with a normal range of motion. Anything less can no longer be considered excellent, as it has been in reports in the past. Operative fracture care has become safe, scientific, and predictable. It is now based on a firm foundation of biomechanical and clinical data.

Although it has become clear from clinical reviews that open fracture care in certain fractures gives far better results than closed treatment of that same fracture, we emphasize again and again that the indication for surgery for a particular patient must be based on a clear definition of the “personality of the fracture”. The personality of a fracture depends upon many factors, including the age, medical condition, and expectations of the patient, the nature of the injury, and the skill of the health care team and surgical environment in which the fracture is to be treated.

Once the decision has been made that open reduction and stable fixation will afford the patient the best end result, we progress to the execution of the surgical procedure. We describe fully the methods of treatment that are best for each particular fracture based on the principles of stable internal fixation. The details of preoperative investigation and planning so essential to successful surgery are stressed. Technical details are also described, including the surgical approach, the selection of the best implant, the methods of inserting the implant, and the common pitfalls the surgeon may encounter.

Since the operative treatment of fractures demands so-called functional aftertreatment, the details of postoperative care have become as important as the steps of the operative procedure. We therefore describe not only the details of postoperative treatment, but also the danger signals of common complications and their treatment.
We hope that this book will become a guide for all surgeons treating fractures in this era of advanced technology, and that inadequate internal fixation, once so commonly encountered, will become history. Internal fixation should no longer be viewed as a last resort or as a more dangerous form of treatment, but as safe, scientific and predictable, and as the best form of treatment for those cases in which it is indicated.

Toronto, June 1987

Joseph Schatzker
Marvin Tile

Acknowledgements

This book, a labor of love, could not have been completed without the unselfish support and hard work of many individuals. We are especially grateful to:

Our families for their patient understanding during this period
Valerie Schatzker for her help in the English editing
Our orthopedic teachers at the University of Toronto, who roused our interest in orthopedic trauma and have encouraged us to complete the task
Our orthopedic colleagues at Sunnybrook Medical Centre, Stanley Gertzbein, Jim Kellam, and Bob McMurtry, for contributing cases and helpful suggestions, and especially to Gordon Hunter, who read most of the manuscript, for his helpful criticism
The founding members of the AO-ASIF for recognition and support of our efforts
Maurice Müller for reading the manuscript and for his kind remarks in the Foreword
Instructional Media Services at the Wellesley Hospital and Sunnybrook Medical Centre in Toronto for their contribution, especially to Patsy Cunningham who did some of the artwork, and to Jim Atkinson and his staff in Medical Photography
The staff of Springer-Verlag, Heidelberg, for their efficiency and expertise in producing and publishing this volume
Mr. Pupp of Springer-Verlag, Heidelberg, to whom we are indebted for many of the new drawings in this book
Our secretaries, Shirley McGovern and Joan Kennedy, for their constant support
Jan King and Ronda Klapp for typing the manuscript
Carol Young for typing the manuscript and helping with the index
Shirley Fitzgerald for her devotion to detail in both the editing and the completion of the index
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Part I

General Aspects of Internal Fixation
1 Principles of Internal Fixation

J. Schatzker

1.1 Introduction

1.1.1 Mechanical Properties of Bone

The principal mechanical function of bone is to act as a supporting structure and transmit load. The loads which bone has to withstand are those of pure compression, those of bending, which result in one cortex being loaded in tension and the other in compression, and those of torque, or twisting. Bone is strongest in compression and weakest in tension. Fractures as a result of pure compression are therefore rare and occur only in areas of cancellous bone with a thin cortical shell. Thus, we find pure compression fractures in such areas as the metaphyses, vertebral bodies, and the calcaneus. Transverse, oblique, and spiral are the fracture patterns commonly seen in tubular bone.

Transverse fractures are the result of a bending force (Fig. 1.1). They are associated with a small extrusion wedge that is always found on the compression side of the bone. If this extrusion wedge comprises less than 10% of the circumference, the fracture is considered a simple transverse fracture. If the extruded fragment is larger, the fracture is considered a wedge fracture, and the fragment a bending or extrusion wedge. Because it is extruded from bone under load, it retains little of its soft tissue attachment and has therefore, at best, a precarious blood supply. This must be kept in mind when planning an internal fixation. Attempts to secure fixation with lag screws of such extruded fragments may result in their being rendered totally avascular. If the extruded wedge is very small, as in fractures of the radius and ulna, they may be ignored. If larger, as in fractures of larger tubular bones, it is best to leave them alone and use indirect reduction techniques to preserve whatever blood supply remains, and either use a locked intramedullary nail for fixation, or if this is not possible, a bridge plate.

Oblique fractures are also the result of a bending force. The extrusion wedge remains attached to one of the main fragments. The fissure between it and the main fragment is not visible on X-ray. If looked for at the time of an open reduction, it can often be found. During closed intramedullary nailing this undisplaced extrusion wedge is often dislodged and becomes apparent on X-ray.

Spiral fractures are the result of an indirect twisting force (Fig. 1.1). They often occur in combination with spiral wedge fragments of corresponding configuration. These fragments are larger and retain their soft tissue attachment. It is frequently possible to secure them with lag screws without disrupting their blood supply.
supply. These differences in the degree of soft tissue attachment and preserved blood supply are important to consider in the choice of internal fixation. If one is dealing with a spiral wedge or a very large extrusion wedge, then their soft tissue attachment and blood supply will likely be preserved, and an attempt at absolutely stable fixation with lag screws would not render them avascular. If on the other hand the extrusion wedge is small or if the wedge is fragmented or if one is dealing with a complex fracture, it is best not to attempt absolutely stable fixation but resort to splinting and secure the fracture with a bridge plate. These remarks apply, of course, to fractures in metaphyseal areas. Diaphyseal fractures are nailed by preference except in the forearm and humerus.

1.1.2 Types of Load and Fracture Patterns

Bone is a viscoelastic material. Fractures are therefore related not only to the force but also to the rate of force application. Much less force is required to break the bone if the force is applied slowly and over a long period of time than if it is applied rapidly: bone is better able to withstand the rapid application of a much greater force. This force is stored, however, and when the bone can no longer withstand it and finally breaks, it is dissipated in an explosive and implosive fashion, causing considerable damage to the soft tissue envelope. A good example of this is the skier who walks away from a spectacular tumble, only to break his leg in a slow, twisting fall. The amount of energy and the rate of force application are important factors since they determine the degree of associated damage to the soft tissue envelope. We therefore distinguish between low- and high-velocity injuries.

Low-velocity injuries have a better prognosis. They are more commonly the result of an indirect force application such as a twist, and the associated fractures are spiral and the comminution is rarely excessive. In high-velocity injuries the fractures are not only more fragmented but also associated with a much greater damage to the enveloping soft tissues, because of the higher energy dissipation and because of the direct application of force.

1.1.3 Classification of Fractures

The classification of fractures followed in this book is based on the *Comprehensive Classification of Fractures of Long Bones* (Müller et al. 1990). The unique feature of this system of classification is that the principles of the classification and the classification itself are not based on the regional features of a bone and its fracture patterns nor are they bound by convention of usage or the popularity of an eponym. They are generic and apply to the whole skeleton. The philosophy guiding the classification is that a classification is worthwhile only if it helps in evolving the rationale of treatment and if it helps in the evaluation of the outcome of the treatment (Müller et al. 1990). Therefore the classification must indicate the severity of the fracture, which in this classification indicates the morphological complexity of the fracture, the difficulties to be anticipated in treatment, and its prognosis. This has been accomplished by formulating the classification on the basis of repeating triads of fracture types, their groups and subgroups, and by arranging the triads and the fractures in each triad in an ascending order of severity. Thus there are three fracture types A, B, and C in ascending order of severity. Each fracture type has three groups, A1, A2, and A3, B1, B2, and B3, and C1, C2, and C3, and each group three subgroups, A1.1, A1.2, etc. The groups and the subgroups are also organized in an ascending order of severity (please see Fig. 1.2). This organization of fractures in the classification in an ascending order of severity has introduced great clinical significance to the recognition of a fracture type. The identification of the Type indicates immediately the severity.

The classification considers a long bone to have a diaphyseal segment and two end segments (Figs. 1.3, 1.4). Because the distinction between the diaphysis and the metaphysis is rarely well defined anatomically, the classification makes use of the rule of squares to define the end segments with great precision (Fig. 1.4). The location of the fracture has also been simplified by noting the relationship that the center of the fracture bears to the segment.

The authors of the *Comprehensive Classification of Fractures of Long Bones* have also developed a new terminology that is so precise that it is now possible to describe a fracture verbally with such accuracy that its pictorial representation is superfluous. The new precise terminology divides fractures into simple and multifragmentary (Fig. 1.5). The multifragmentary fractures are further subdivided into wedge and complex fractures, not on the basis of the number of fragments, but rather on the key issue of whether after reduction the main fragments have retained contact or not. In treatment this is, indeed, the essence of severity. Thus, a multifragmentary fracture with some contact between the main frag-
ments is considered a wedge fracture. It has a recognizable length and rotational alignment. This is lost in a complex fracture where contact between the main fragments cannot be established after reduction (Fig. 1.6). Articular fractures are defined as those that involve the articular surface regardless of whether the fracture is intracapsular or not. A further distinction exists between partial and complete articular fractures (Fig. 1.7).

The diagnosis of a fracture is given by coupling the location of the fracture with its morphologic complexity. To facilitate computer entry and retrieval of the cases, an alphanumeric code has been created. Computers deal with numbers and letters better than with words. The bones of the skeleton have been assigned numbers (Fig. 1.8). The segments are numbered from one to three proceeding from proximal to distal. Thus it is possible to express the location of a fracture by combining the number of the bone with the number expressing the involved segment: for instance, a fracture of the proximal segment of the humerus would be 11- and a fracture of the distal femur would be 33-. The morphological nature of the fracture is expressed by the combination of the letters

\[ \text{Fig. 1.2.} \text{ The scheme of the classification of fractures for each bone segment or each bone. Types: } A, B, C; \text{ Groups: } A1, A2, A3, B1, B2, B3, C1, C2, C3; \text{ Subgroups: } .1, .2, .3. \text{ The darkening of the arrows indicates the increasing severity of the fracture. Small squares: The first two give the location, the next three the morphological characteristics of the fracture. (From Müller et al. 1990)} \]

\[ \text{Fig. 1.3.} \text{ The long bone. 1, Humerus; 2, radius/ulna; 3, femur; 4, tibia/fibula. The blackened square indicates the portion of the alphanumeric code being illustrated. (From Müller et al. 1990)} \]
1.1 Introduction

A, B, and C, which denote the Type; with the numbers 1, 2, and 3, such as A1, A2, A3, B1, B2, etc., to denote the Groups, and A1.1, A1.2, A1.3, B1.1, B1.2, etc., to denote the Subgroups. The diagnosis can be coded using an alphanumeric code (Fig. 1.9). As stated, this alphanumeric code is intended strictly for computer entry and retrieval and not for use in verbal communication. In verbal communication the clinician should use the terminology which is so precise that it describes the full essence of the fracture, making a pictorial representation of the fracture no longer necessary.

We have validated this fracture classification in two separate clinical studies (J. J. Schatzker and P. Lichtenhahn, unpublished data; J. Schatzker and H. Tornkvist, unpublished data). The inter- and intraobserver concordance has been evaluated for fracture types, groups, and subgroups. Concordance for fracture types was close to 100%, for fracture groups between 80% and 85%, but for fracture subgroups only between 50% and 60%. We feel, therefore, that the clinician should rely principally on the recognition of the fracture types and groups. Classification into fracture subgroups should be reserved only for research studies.

The issue of intra- and interpersonal reliability of classification systems has received a great deal of attention in the recent literature. The authors of these articles fail to discern the essence of the cause of the high discordance. The discordance is either the result of the classifier not knowing the classification system or because the classifier lacked essential data, or relied on pictorial representation of the different fractures, and had no method available to check whether all the essential information was available at the time the fracture was being classified. In order to provide the classifier with a check list of essential data which must be available before a fracture can be classified, the authors of the Comprehensive Classification System have developed a system of binary questions which allow the classifier to determine with precision whether all the essential data necessary to classify a fracture are available. If not, further imaging may be necessary before the classification can be attempted. At times essential information, for instance the damage to the articular cartilage of the femoral head in an acetabular fracture, may not be available until the surgery has been completed.

The Comprehensive Classification System has been adopted by both the Arbeitsgemeinschaft für Osteo-

![Fig. 1.4. The determination of the segments of long bones. The different squares are parallel to the long axis of the body and correspond to the end segments. The malleolar segment (44-) is not represented here as it cannot be compared with the other end segments: 11-, 12-, 13-, 21-, 22-, 23-, 31-, 32-, 33-, 41-, 42-, 43-. (From Müller et al. 1990)
Synthesefragen/Association for the Study of Internal Fixation (AO/ASIF) and Orthopaedic Trauma Association (OTA) as their classification systems. Currently these groups are attempting to complete the classification of fractures and dislocations not included in the published version of the Comprehensive Classification System and to subject their efforts to clinical validation.

The classification of the soft tissue injury associated with open fractures continues to be a problem requiring further elaboration. Many observers have attempted to grade open fractures (Allgöwer 1971; Gustilo and Andersson 1976; Tscherne and Gotzen 1984; Lange et al. 1985). A further classification of the soft tissue component of an injury was presented in the third edition of the Manual of Internal Fixation (Müller et al. 1991). In this most recent attempt a code for the injury is assigned to each of the elements of the soft tissue envelope rather than using an existing classification system. A new classification scheme which would characterize the morphological components of the soft tissue injury, identify its severity, and indicate the potential functional loss in a simple and comprehensive manner, and which could be expressed in a simple code, would be of great value clinically and in research.

**Fig. 1.5.** The diaphyseal fracture types. A, simple fracture; B, wedge fracture; C, complex fracture. (From Müller et al. 1990)

**Fig. 1.6.** The groups of the diaphyseal fractures of the numberus, femur, and tibia/fibula. A1, simple fracture, spiral; A2, simple fracture, oblique (L30°); A3, simple fracture, transverse (<30°); B1, wedge fracture, spiral wedge; B2, wedge fracture, bending wedge; B3, wedge fracture, fragmented wedge; C1, complex fracture, spiral; C2, complex fracture, segmental; C3, complex fracture, irregular. (From Müller et al. 1990)
1.1.4 Effects of Fracture

When a bone is fractured, it loses its structural continuity. The loss of the structural continuity renders it mechanically useless because it is unable to bear any load.

1.1.5 Soft Tissue Component and Classification of Soft Tissue Injuries

We have alluded to the poorer prognosis of high-velocity injuries because of the greater damage to the soft tissue envelope and to the greater devitalization of the involved bone. Long-term disability following a fracture is almost never the result of damage to the bone itself; it is the result of damage to the soft tissues and of stiffness of neighboring joints.

In a closed fracture the injury to the surrounding tissue evokes an acute inflammatory response, which is associated with an outpouring of fibrinous and proteinaceous fluid. If, after the injury, the tendons and muscles are not encouraged to glide upon one another, inflammation may develop and lead to the obliteration of tissue planes and to the matting of the soft tissue envelope into a functionless mass.

In an open fracture, in addition to the possible scarring from immobilization, there is direct injury to the muscles and tendons and in such cases the effects of infection must be reckoned with. Indeed, infection is the most serious complication of trauma because, in addition to the scarring related to the
Principles of Internal Fixation

1.2 Aims of Treatment

The loss of function of the soft tissue envelope due to scarring and secondary joint stiffness can only be prevented by early mobilization. Thus, modern fracture treatment does not focus on bone union at the expense of function but addresses itself principally to the restoration of function of the soft tissues and adjacent joints. A deformity or a pseudarthrosis is relatively easy to correct in the presence of good soft tissue function, while scarring, obliteration of the soft tissue gliding planes, and joint stiffness are often permanent. The modern fracture surgeon will therefore direct treatment to the early return of function and motion, with bone union being considered of secondary importance.

Modern functional fracture treatment does not denote only operative fracture care. It makes use of specialized splinting of the bone in special braces that allow an early return of function and motion. There are, however, limitations to the nonoperative system, which we will address as we discuss the different frac-
tures. It can be applied to fractures where angulation, rotation, and shortening can be controlled. Thus, it is limited only to certain long bone fractures. Its application to intra-articular and periarticular fractures is very limited.

Early return of full function following fracture can be achieved only by sufficiently stable internal fixation which will abolish fracture pain and which will allow early resumption of motion with partial loading without the risk of failure of the fixation and resultant malunion or nonunion. With non-functional methods full return of function is rarely achieved, and then only after a prolonged rehabilitation period.

### 1.3 Previous Experience with Internal Fixation

Internal fixation is not a new science. The first half of the twentieth century has provided us with ample documentation of the results of unstable internal fixation. Surgery has frequently proved to be the worst form of treatment. It destroyed the soft tissue hinges, interfered with biological factors such as the blood supply and the periosteum, and was never sufficiently strong or stable to permit active mobilization of the limbs with partial loading. Supplemental external plaster fixation was often necessary. The emphasis was on bone healing and not on soft tissue rehabilitation. Healing became evident when callus appeared. Unfortunately, unstable internal fixation was unpredictable and uncertain, and it frequently resulted in delayed union, nonunion, or deformity. When union did occur, instead of signifying the end of treatment it merely signaled the beginning of a prolonged phase of rehabilitation designed to regain motion in the soft tissue envelope and in the stiff joints. The ravages of this prolonged nonfunctional form of treatment were such that open reduction and internal fixation were looked upon as the last resort in the treatment of a fracture.

### 1.4 Rigidity and Stability

It is important to distinguish between rigidity and stability. Rigidity is the physical property of an implant. It refers to its ability to withstand deformation. Thus, in an internal fixation the fixation devices employed may be rigid but the fixation of the fragments may be unstable.

The introduction of compression introduced stability. Stability was achieved not by rigidity of the implant, but rather by impaction of the fragments. The intimate contact of the fragments brought about by compression restored structural continuity and stability and permitted the direct transfer of forces from fragment to fragment rather than via the implant. Stable fixation restores load-bearing capacity to bone. This greatly diminishes the stresses borne by the implant and protects the implant from mechanical overload or fatigue failure.

Key (1932) and Charnley (1953) were the first to make use of compression in order to achieve stable fixation. Both applied it to broad cancellous surfaces by means of an external compression clamp. Similar attempts to achieve union of the cortex failed. The resorption around the pins of the external fixator employed to stabilize the cortical fragments was thought to be due to pressure necrosis of the cortex. Cancellous surfaces under compression united rapidly, and it was thought initially that compression provided an osteogenic stimulus to bone. The failure of the cortex to unite led to general acceptance of the thesis that cancellous and cortical bone behaved differently and that they probably united by different mechanisms.

Since then it has been demonstrated that, under conditions of absolute stability, both cancellous and cortical fragments heal by what has been referred to as primary direct or vascular bone union (primary bone healing). The simple external fixator of Charnley, applied closely to broad, flat cancellous surfaces of an arthrodesis, was able to achieve absolute stability. The same system applied to diaphyseal bone, where tubular fragments rather than broad, flat surfaces were in contact, resulted in a system of relative instability with micromotion between the fragments. The resorption around the pins and at the fracture was due to motion and not due to pressure necrosis.

Danis in 1949 (Müller et al. 1970) was the first to demonstrate that cortical fragments stabilized by a special plate, which was able to exert axial compression and bring about absolute stability at the fracture, united without any radiologically visible callus. Danis referred to this type of union as “primary bone healing.” Studies on experimental models of healing under conditions of absolute stability by Schenk and Willenegger (1963) revealed a different type of union than that commonly associated with the healing of fractures. Union seemed to occur by direct formation of bone rather than by callus and endochondral ossi-