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ROCKWOOD AND WILKINS'

FRACTURES IN CHILDREN

SEVENTH EDITION

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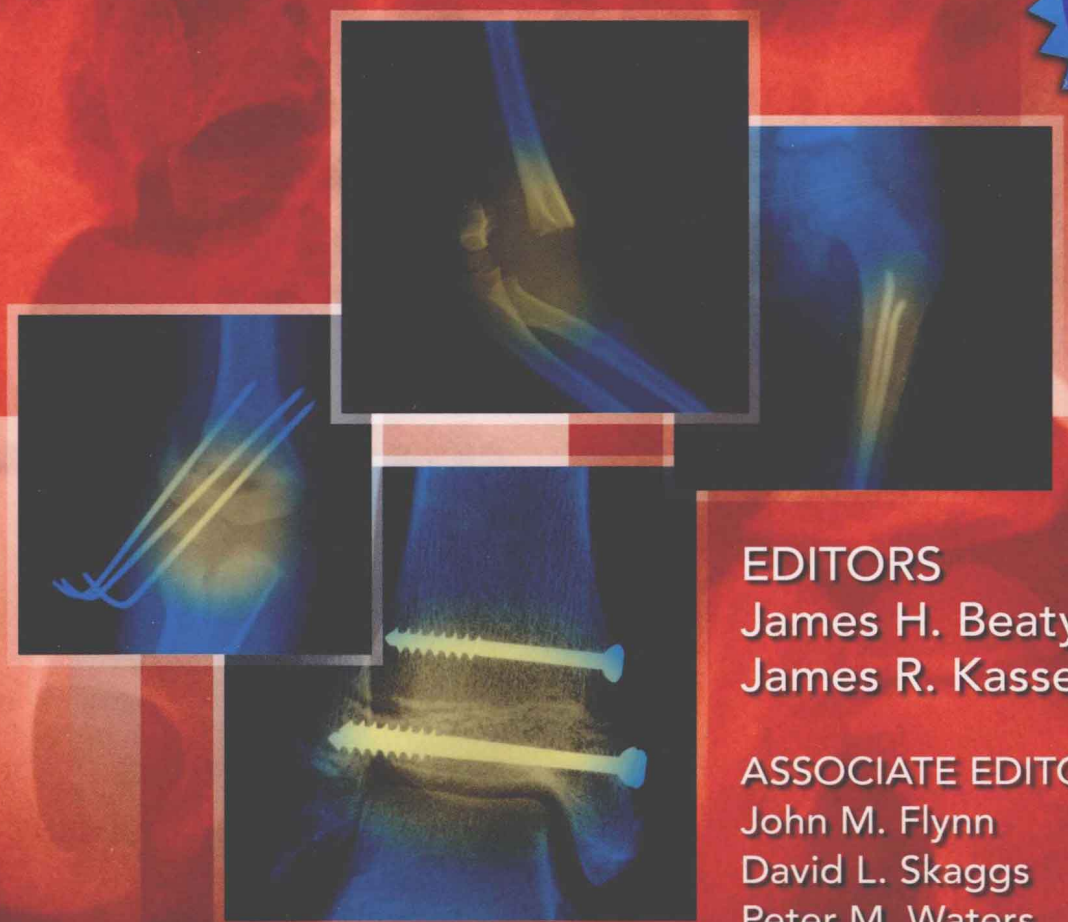

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As we have worked on several editions of this text, we have come to appreciate more fully the extraordinary support and encouragement given to us by our institutions and by our colleagues. Their willingness to allow us time to complete these massive projects, their understanding when we are frantically working to make a deadline, their cooperation with endless requests for just one more x-ray "for the book," and their continued assurances that the result is worth all the effort have made our editorial duties possible. In appreciation for years of unwavering support and belief in our abilities to produce yet another edition, we dedicate this text to our colleagues and our respective institutions:

The Campbell Clinic and Foundation, Memphis, Tennessee
Children's Hospital, Boston, Massachusetts

We also dedicate this text to all of the orthopaedic fellows and residents we have had the privilege of teaching. Their enthusiasm, knowledge, and vision have been impressive and humbling and have reassured us that our specialty of pediatric orthopaedics is in good hands for the future.

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PREFACE

With this seventh edition of *Rockwood & Wilkins' Fractures in Children*, we are grateful to have had the assistance of three new section editors: Jack Flynn, David Skaggs, and Peter Waters. In addition to contributing excellent chapters, each has taken on a portion of the editing duties, helping us integrate the vast amounts of new information about children's fractures into the text. All of our contributors, both old and new, have made substantial updates to their chapters to ensure that the most current findings are available about new techniques, clinical outcomes, and basic science research.

As with every edition, we have tried to improve not only the information presented but also the way it is presented, to make access and understanding easier. More color illustrations, new graphics, and new formatting have been used in an effort to make this edition more "user-friendly" for our readers.

We hope that this edition continues the tradition of excellence begun by Drs. Rockwood, Wilkins, and King, and that all those who treat children's fractures will find valuable information to improve their decision-making and treatment skills.

ACKNOWLEDGMENTS

As always, the most important contributors to this text are our chapter authors who so willingly share their knowledge and expertise. Without their conscientious efforts to review the literature, gather illustrations, and compile their chapters in a timely fashion this publication would not have been possible. We are most grateful to all of them for their hard work and dedication. We also thank our associate editors, Drs. Flynn, Skaggs, and Waters, for their skillful assistance in editing and for their commitment to the lengthy process.

The staff at Lippincott Williams & Wilkins again provided their excellent guidance and support, as well as organization and encouragement. Our thanks to Bob Hurley for having confidence in our ability to see this project through, to Dave Murphy for putting all the pieces together to make a coherent whole, and to Eileen Wolfberg for keeping all of us informed and "on task." Personnel at our respective institutions provided invaluable assistance in editing, illustrating, verifying references, and keeping us organized and on track: from the Campbell Foundation in Memphis, Kay Daugherty (Editorial), Barry Burns (Graphics), and Joan Crowson (Library); and from Boston, Kathryn Macdonald (Editorial) and Alison Clapp (Library).

Throughout the four years spent in preparation of this text, our families have provided encouragement and empathy as we struggled to meet deadlines. They were understanding about missed dinners, lengthy phone calls, late nights with manuscripts, and working weekends. We are especially grateful to our wives, Terry Beaty and Candace Kasser, for allowing us to "go do our little thing" with their blessing and support.

James H. Beaty
James R. Kasser

I would like to thank my wife Val for supporting me and enabling me to work on such enjoyable and meaningful projects, while being such a good friend and so fun to be around. To my children Kira, Jamie, and Clay – when you hear Dad upstairs typing before the sun rises on weekends, this is what I am doing. I love you.

David L. Skaggs

I would like to thank my wife, Mary, and children, Erin, Colleen, John, and Kelly, for appreciating the importance of Dad's writing and editing "homework," and for tolerating the early morning noise that results from his reliance on voice-recognition software. That is why Dad required them to master typing in elementary school.

John M. (Jack) Flynn

I do not have enough words to express gratitude to my wife Janet for her support of all my adventures, including academic work; to my children Rebecca and James for always being willing to join me and keep me honest along the way; and to my colleagues for the joy of our lively professional exchanges.

Peter M. Waters, M.D.

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ONE

BASIC PRINCIPLES

1

EPIDEMIOLOGY OF FRACTURES IN CHILDREN

Michael Vitale

INTRODUCTION

Epidemiology is the field of science that examines factors affecting health and disease in populations. As such, epidemiology is the cornerstone of an evidence-based approach to preventing disease and to optimizing treatment strategies. The term "epidemiology" is derived from the Greek roots *epi* = upon, *demos* = people, *logos* = study, meaning "the study of what is upon the people." An understanding of the epidemiology of pediatric trauma is a prerequisite for the timely evolution of optimal care strategies and for the development of effective prevention strategies.

As the leading cause of death and disability in children, pediatric trauma presents one of the largest challenges to the health of children, as well as a great opportunity for positive impact. It is estimated that more than 11 million hospitalizations and 15,000 deaths result from childhood injury every year. While children more often survive significant injury than adults, survivors of significant trauma may be left with long-term functional problems.[1]

It has been estimated that up to 25% of children sustain an injury every year, with 10% to 25% of these injuries consisting of a fracture. In fact, on both the outpatient and inpatient sides, musculoskeletal trauma makes up the largest share of pediatric injuries.[106]

The incidence of pediatric trauma in the United States is among the highest in the developing world, reflecting the realities of urban violence, firearms, and the dangers of a highly mechanized society. Given the wide-reaching impact that pediatric musculoskeletal injury has on public health, an understanding of the epidemiology of pediatric fractures provides an opportunity to maximize efforts aimed at prevention and optimal treatment. In the years since the production of the first edition of *Fractures in Children*, there have been many changes in the incidence, etiology, and philosophy of management of children's fractures.

CHANGES IN THE PHILOSOPHY OF MANAGEMENT OF FRACTURES IN CHILDREN

Recent years have witnessed a shift toward a greater role for operative management for many children's fractures. In most instances, operative management produces better results than nonoperative treatment, but this shift in treatment has not been without some controversy.

Changes from Previous Editions

The trend toward surgical intervention can be seen in the changes in the previous editions of this textbook. In the first edition,[100] very little mention was made regarding intramedullary (IM) fixation of either femoral or radial and ulnar shaft fractures. There was an extensive discussion of methods of traction for femoral shaft fractures and supracondylar fractures. In the fifth edition,[10] the reverse was true. There was considerable discussion of IM fixation and very little mention of traction techniques.

This trend toward more operative intervention has been the result of four factors: (i) improvements in technology, (ii) rapid healing that allows minimal and temporary fixation, (iii) financial and social pressures to limit the hospitalization of children, and (iv) an expectation by the public for a "perfect outcome" in every case.

Improvements in Technology

The use of the image intensifier has greatly improved the ease of reducing and internally stabilizing fractures with percutaneous methods. Other technical advances, such as widespread access to computed tomography (CT) and magnetic resonance imaging (MRI), have expanded the ability to better define the fracture patterns. The use of powered instruments and cannulated implants, coupled with the use of radiographic real time images, has greatly facilitated the accuracy of applying fixation devices with percutaneous techniques.

Rapid Healing

Because children's bones heal and remodel rapidly, fixation devices often need to be used for only a short time. Children tolerate all types of casts well for short periods of time, which allows a minimally stabilized fracture to be immobilized with a cast until there is sufficient internal callous to supplement the limited internal fixation.

Minimal Hospitalization

The rising costs of hospitalization have created a trend to mobilize children to an outpatient setting as soon as possible. This is reinforced by the fact that in two thirds of the families in the United States, both parents are wage earners. There are both social and financial pressures to mobilize the child early. The trend now is to surgically stabilize these fractures so that the patient can be discharged early. The shift away from traction and toward IM fixation for femoral fractures in intermediate aged children is but one example of this dynamic at work.

The Perfect Result

Modern parents have become very sophisticated and now often expect a perfect outcome for their child. They inspect the radiographs, question the alignment, and expect the alignment to be perfect. These pressures often direct the treating physician toward operative intervention to obtain a perfect alignment.

Are the Results Better with Operative Intervention?

Yes, Results are Definitely Better for Many Injuries, such as Supracondylar Humeral Fractures. The superiority of operative treatment of supracondylar fractures of the distal humerus was clearly demonstrated in a report published in 1988 from Toronto, Canada, in which treatment in traction, treatment with a cast alone, and treatment with percutaneous pin fixation were compared.[92] The worst results were in patients treated with only a cast. The best results were achieved in those stabilized with percutaneous pin fixation. The universal acceptance of percutaneous pin fixation of these fractures is evidence of the superiority of operative management.

Cox and Clarke, in evaluating the fracture management in their hospital in Southampton, England, found a high incidence of secondary hospital treatment for fractures initially managed nonoperatively.[28] There was a 12% readmission rate to correct late displacement of fractures of the radius and distal humerus. In addition, 24% of their internal fixation procedures were to salvage unacceptable results of nonoperative management. They concluded that more selective initial operative intervention in radial and distal humeral fractures could decrease the incidence of costly readmissions to the hospital.

Maybe, Depending on What You Call Results. A 7-year-old with a midshaft fracture of the femur may have had the same excellent bony alignment and healing when treated with 6 weeks of skeletal traction as when treated with IM fixation. However, quality of life during treatment, burden of care on the family, and costs are markedly different in these two scenarios.

In some cases, operative fixation has created a new set of iatrogenic problems that result in less favorable outcomes for some children. Some of the specific problems that have occurred over the years are: (i) ulnar nerve injury with medial pin fixation of supracondylar fractures,[67] (ii) high refracture rate with external fixation of femoral shaft fractures,[94] and (iii) osteonecrosis of the femoral head following the use of interlocking IM nails inserted through the piriformis fossa.[9,77]

Phases in the Development of New Operative Techniques

Often, when a new procedure becomes widely used, there is an initial wave of enthusiasm. However, with more widespread use, problems become more apparent and modifications are made to the original technique. Thus, it takes time before the technique becomes relatively complication free.

Nonoperative Techniques Need to Be Maintained

With emphasis on operative management, the fact that most children's fractures can be managed by nonoperative techniques has become obscured. As a result, many recent orthopaedic trainees are less exposed to and less comfortable with nonoperative technical skills.

In fact, several articles have demonstrated excellent results of treating children's fractures by focusing on improvements in nonoperative methods, "pleading for conservatism."[47] Chess et al.[23] showed that when properly applied, a well-molded short-

arm cast provides just as good a result as a long-arm cast in treating displaced fractures of the distal radial metaphysis. These authors believed the key to success in using a short-arm cast is in a careful molding of the cast at the fracture site so there is the proper cast index of 0.7 or less. Walker and Rang challenged traditional thinking by demonstrating that unstable fractures of the radius and ulna could be treated with a lower frequency of remanipulation if immobilized in elbow extension rather than flexion.[127]

It is important to remember that most children's fractures are still treated by nonoperative methods.

EPIDEMIOLOGY OF FRACTURES IN CHILDREN

Despite the importance of understanding the epidemiology of pediatric fractures, there are still significant gaps in our knowledge base, and there is much work to be done. There are several challenges to gathering appropriate data in this area: risk factors for pediatric injury are diverse and heterogenous, practice patterns vary across countries and even within countries, and the available infrastructure to support data collection for pediatric trauma is far from ideal.

Fracture Incidence and Fracture Patterns Are Driven by Many Socioclinical Factors

Cultural Differences

The incidence of pediatric fracture varies in different cultural settings. For instance, Cheng and Shen studied children in Hong Kong who lived in confined high-rise apartments.[22] Their risk of exposure to injury differed from the study by Reed of children living in the rural environment of Winnipeg, Canada.[97] Two separate reviews by Laffoy[55] and Westfelt[86] found that children in a poor social environment (as defined by a lower social class or by dependence on public assistance) had more frequent accidents than more affluent children. In England, children from single-parent families were found to have higher accident and infection rates than children from two parent families.[36]

Two additional studies in the United Kingdom looked at the relationship of affluence to the incidence of fractures in children. Lyons et al.[68] found no difference in the fracture rates of children in affluent population groups compared to those of children in nonaffluent families. On the other hand, Stark et al.[119] in Scotland found that the fracture rates in children from nonaffluent social groups was significantly higher than those in affluent families.

Climatic Differences

The climate may be a strong factor as well. Children in colder climates, with ice and snow, are exposed to risks different from those of children living in warmer climates. The exposure time to outdoor activities may be greater for children who live in warmer climates. For example, the incidence of chronic overuse elbow injuries in young baseball players (Little League elbow) is far greater in the southern United States than in the northern part of the country.

Pediatric trauma should be viewed as a disease where there are direct and predictable relationships between exposure and incidence.

"Classification Bias": Difficulties Defining Disease

Rigorous epidemiological studies demand consistent information about how we define and classify a given disease state. This is a challenge in pediatric trauma, making it difficult to compare studies. Some studies extend the pediatric age group to only 16 years, for example, while others include patients up to 21 years of age. Moreover, it is particularly difficult to examine injuries that only sometimes result in admission. Many studies[17,66,110] are limited to injuries that require hospital admission, despite the fact that most injuries in children do not. Reports vary in the precision of their defined types of fracture patterns. In the older series, reports were only of the long bone involved, such as the radius. Series that are more recent have emphasized a more specific location, separating the radius, for example, into physeal, distal, shaft, and proximal fracture types.

Thus, in trying to define the exact incidence of pediatric fractures, it is difficult to compare series because of cultural, environmental, and age differences. In the following synopsis, these differences were considered in grouping the results and producing average figures. These data are presented in an attempt to provide a reasonable and accurate reflection of the overall incidence of injuries and fractures in all children.

Modern Day Data Systems May Provide Expanded Opportunities to Examine the Epidemiology of Pediatric Trauma

Several sources of administrative, national, and regional data have recently become available providing significantly improved investigation into various areas within pediatric trauma. The Healthcare Cost and Utilization Project (HCUP) is a family of databases including the State Inpatient Databases (SID), the Nationwide Inpatient Sample (NIS), and the Kids' Inpatient Database (KID). While administrative data may lack clinical detail for certain purposes, these datasets provide a comprehensive overview of healthcare utilization in the United States and are available without purchase (http://www.ahrq.gov/data/hcup/hcupnet.htm).[120] The KID database has been increasingly used to examine the incidence of pediatric trauma as well as practice patterns in pediatric trauma. Data for KIDS are collected and published every 3 years, with data currently available for 1997, 2000, 2003, and 2006. KIDS is "nationally representatative," meaning that the database contains a large but incomplete sample of the hospital discharge records (3.1 million in 2006), which are then statisticaly weighted upward to reflect the complete population of pediatric discharges (7.6 million in 2006). Several other databases including the National Electronic Injury Surveillance System (http://www.cpsc.gov/library/neiss.html) have also been useful in providing information about the epidemiology of pediatric trauma.

Currently available data sources provide scant clinical detail, limiting broader utility as a source of health outcomes data in the field. Constructed in an attempt to fill such a role, the National Pediatric Trauma Registry (NPTR) is a multi-institutional database designed to provide a snapshot of physiological and clinical information. The NPTR was functional for about 15 years and provided a source of important data in the realm of pediatric trauma.[122] The NPTR is currently being redesigned into an even more powerful database that will be called the National Trauma Registry for Children, which should serve as a powerful reference for contributors to future editions of this book.

Incidence of Fractures

Earlier Studies Defined the Remodeling Processes

Early reviews primarily developed a knowledge base of fracture healing in children. In 1941, Beekman and Sullivan published an extensive review of the incidence of children's fractures.[11] Their pioneering work—still quoted today—included a study of 2094 long bone fractures seen over a 10-year period at Bellevue Hospital in New York City. The major purpose of their study was to develop basic principles for treating children's fractures.

In 1954, two reports, one by Hanlon and Estes[41] and the other by Lichtenberg,[62] confirmed the findings of the previous studies with regard to the general incidence of children's long bone fractures and their ability to heal and readily remodel. These initial reviews were mainly statistical analyses and did not delve deeply into the true epidemiology of children's fractures. In 1965, Wong explored the effect of cultural factors on the incidence of fractures by comparing Indian, Malay, and Swedish children.[133] In the 1970s, two other studies, one by Iqbal[44] and another by Reed,[97] added more statistics regarding the incidence of the various long bone fractures.

More Recent Studies

Landin's 1983 report on 8682 fractures remains a landmark on this subject.[58] He reviewed the data on all fractures in children that occurred in Malmo, Sweden, over 30 years and examined the factors affecting the incidence of children's fractures. By studying two populations, 30 years apart, he determined that fracture patterns were changing and suggested reasons for such changes. His initial goal was to establish data for preventive programs, so he focused on fractures that produced clean, concise, concrete data.

In 1997, Landin updated his work, re-emphasizing the statistics from his previous publication.[57] He suggested that the two-fold increase in fracture rate during the 30 years from 1950 to 1979 in Malmo was due mainly to an increased participation in sports. In 1999, in cooperation with Tiderius and Duppe, Landin[123] studied the incidence in the same age group again in Malmo and found that the rate had actually declined by 9% in 1993 and 1994. The only exception was an increase of distal forearm fractures in girls, which he attributed to their increased participation in sporting events.

Cheng and Shen,[66] in their 1993 study from Hong Kong, also set out to define children's fractures by separating the incidences into age groups. They tried to gather epidemiologic data on which to build preventive programs. In 1999, this study was expanded to include almost 6500 fractures in children 16 and younger over a 10-year period.[21] The fracture patterns changed little over those 10 years. What did change was the increased frequency of closed reduction and percutaneous pin fixation of fractures, with a corresponding decrease in open reductions. There also was a marked decrease in the hospital stay of their patients.

More recently, using the HCUP's KIDS dataset, Galano et al.[40] examined the face of pediatric inpatient trauma in 1997. They estimated that roughly 84,000 children were admitted for fracture care which resulted in about 1 billion dollars in hospital charges. Of some interest, more than 70% of children were treated at non-children's hospitals.

Frequency of Childhood Fractures

Overall Incidence

In Landin's series from Malmo, Sweden, the chance of a child sustaining a fracture during childhood (birth to age 16) was 42% for boys and 27% for girls.[58] When considered on an annual basis, 2.1% of all the children (2.6% for boys; 1.7% for girls) sustained at least one fracture each year. These figures were for all fracture types and included those treated on an inpatient basis and an outpatient basis. The overall chance of fracture per year was 1.6% for both girls and boys in a study from England of both outpatients and inpatients by Worlock and Stower.[134] The chance of a child sustaining a fracture severe enough to require inpatient treatment during the first 16 years of life is 6.8%.[22] Thus, on an annual basis, 0.43% of the children in an average community will be admitted for a fracture-related problem during the year.

In a series of 23,915 patients seen at four major hospitals for injury-related complaints, 4265 (17.8%) had fractures.[17,41,75,86] Thus, close to 20% of the patients who present to hospitals with injuries have a fracture.

It is interesting to note that, in a follow-up study by Tiderius, Landin, and Duppe[123] in the years 1993 and 1994, 13 years after the termination of the original 30-year study by Landin,[58] there was an almost 10% decrease in the incidence of fractures in the 0- to 16-year age group. They attributed this to less physical activity on the part of modern-day children coupled with better protective sports equipment and increased traffic safety (e.g., stronger cars and use of auto restraint systems). The overall incidence of children's fractures is summarized in Table 1-1.

Age Groups

Fractures Show a Linear Increase with Age. Starting with birth and extending to age 12, all the major series that segregated patients by age have demonstrated a linear increase in the annual incidence of fractures with age (Fig. 1-1).[16,21,22,44,58,134]

Although there is a high incidence of injuries in children ages 1 to 2, the incidence of fractures is low.[55] Most injuries in children of this age are nonorthopaedic entities such as head injuries, lacerations, and abrasions. In fact, the incidence of lacerations in both sexes peaks at this age.[99]

Nonaccidental Trauma

In 1962, Kempe et al.[49] called attention to the frequency of fractures and other injuries in young children that were due to nonaccidental trauma. They termed these injuries part of the

TABLE 1-1 Overall Frequency of Fractures*

Percentage of children sustaining at least one fracture from 0 to 16 years of age: boys, 42%; girls, 27%
Percentage of children sustaining a fracture in 1 year: 1.6% to 2.1%
Percentage of patients with injuries (all types) who have fractures: 17.8%

*8,44,55,57,59,75,86,97,119