PEDIATRIC TRAUMA

Edited by

Robert J. Touloukian, M.D.

Professor of Surgery and Pediatrics
Chief, Pediatric Surgery
Yale University School of Medicine
New Haven, Connecticut

A WILEY MEDICAL PUBLICATION
JOHN WILEY & SONS
New York / Chichester / Brisbane / Toronto

Contributors

William F. Collins, Jr., M.D., Harvey and Kate Cushing Professor of Neurological Surgery, Chief, Neurological Surgery, Yale University School of Medicine, New Haven, Connecticut

John M. Driscoll, Jr., M.D., Associate Professor of Clinical Pediatrics, Columbia University, Associate Attending Pediatrician and Director, Neonatal Intensive Care Unit, Babies Hospital, The Children's Medical and Surgical Center, Columbia-Presbyterian-Medical Center, New York, New York

Frederick Finseth, M.D., Visiting Assistant Professor of Surgery (Plastic), Stanford University Medical Center, Stanford, California

Allen I. Goldberg, M.D., Assistant Pediatrician and Assistant Anesthesiologist, The Children's Hospital of Philadelphia, Assistant Professor of Anesthesia and Pediatrics, The University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania

Richard H. Granger, M.D., Associate Professor of Clinical Pediatrics, Yale University School of Medicine, Child Study Center, New Haven, Connecticut

J. Alex Haller, Jr., M.D., Robert Garrett Professor of Pediatric Surgery, The Johns Hopkins University School of Medicine, Baltimore, Maryland

W. Hardy Hendren, M.D., Professor of Surgery, Harvard Medical School, Chief of Pediatric Surgery, Massachusetts General Hospital, Boston, Massachusetts

Terry W. Hensle, M.D., Assistant Professor of Clinical Urology, Columbia University, Director of Pediatric Urology, Babies Hospital, The Children's Medical and Surgical Center, Columbia-Presbyterian Medical Center, New York, New York

Duane L. Larson, M.D., Chief of Staff, Shriners Burn Institute, Professor of Surgery, Plastic and Maxillofacial Surgery, University of Texas Medical Branch, Galveston, Texas

Thomas S. Morse, M.D., Associate Professor of Surgery (Pediatric Surgery), Ohio State University College of Medicine, Director, Surgical Outpatient Services, Children's Hospital, Columbus, Ohio

John A. Ogden, M.D., Associate Professor of Surgery and Pediatrics, Yale University School of Medicine, New Haven, Connecticut

James A. O'Neill, Jr., M.D., Professor and Chairman, Department of Pediatric Surgery, Vanderbilt University School of Medicine, Surgeon-in-Chief, Children's Hospital of Vanderbilt University, Nashville, Tennessee

H. Biemann Othersen, Jr., M.D., Professor of Surgery and Pediatrics, Chief, Pediatric Surgery, Medical University of South Carolina, Charleston, South Carolina

Donald H. Parks, M.D., Chief, Division of Surgery, Shriners Burn Institute, Assistant Professor of Surgery, Division of Plastic Surgery, University of Texas Medical Branch, Galveston, Texas

Martin P. Sayers, M.D., Clinical Professor of Surgery, Division of Neurosurgery, Ohio State University College of Medicine, Chief, Division of Neurosurgery, Children's Hospital, Columbus, Ohio

Barton D. Schmitt, M.D., Associate Professor of Pediatrics, University of Colorado Medical Center, Director, Child Protection Team, Colorado General Hospital, Denver, Colorado

John N. Schullinger, M.D., Associate Clinical Professor of Surgery, Columbia University, Associate Attending Surgeon, Babies Hospital, The Children's Medical and Surgical Center, Columbia-Presbyterian Medical Center, New York, New York

Marvin L. Sears, M.D., Professor and Chairman, Department of Ophthalmology and Visual Science, Yale University School of Medicine, New Haven, Connecticut

John H. Seashore, M.D., Assistant Professor of Surgery and Pediatrics, Yale University School of Medicine, New Haven, Connecticut

Thomas J. Spackman, M.D., Senior Radiologist, The Children's Hospital of Philadelphia, Associate Professor of Radiology, The University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania

Philip D. Thomson, Ph.D., Chief, Microbiology Division, Shriners Burn Institute, Research Scientist, Faculty, Department of Medicine, University of Texas Medical Branch, Galveston, Texas

Robert J. Touloukian, M.D., Professor of Surgery and Pediatrics, Chief, Pediatric Surgery, Yale University School of Medicine, New Haven, Connecticut

Joan L. Venes, M.D., Associate Professor, Neurosurgery and Pediatrics, Yale University School of Medicine, New Haven, Connecticut

Preface

Although many books are available on all aspects of trauma, management of childhood trauma requires knowledge of the special ways children differ from adults. Each phase of the care of the injured child from the time of transport, resuscitation, clinical and roentgen diagnosis, anesthesia, and operative treatment to postoperative management requires knowledge of such differentiation. This information is the substance of *Pediatric Trauma*.

My aim has been to describe in comprehensive detail all important trauma problems encountered in infants and children, and I take particular pride in the list of outstanding contributors, many of whom are the leading authorities in their field. Part 1 emphasizes certain important general considerations such as the psychological aspects of trauma, anesthesia and intensive care, the battered child syndrome, and birth injuries. Part 2 comprises more detailed discussions of all the important organ system injuries. These chapters deal with the essentials of diagnosis and management, and highlight the mechanism and pathophysiology of injury, infection prevention and the use of antibiotics, and athletic injuries and their prevention.

I hope that *Pediatric Trauma* will appeal to the pediatrician, the family practitioner, and the emergency room physician, who are almost always called upon to initiate resuscitation and diagnostic procedures, as well as to the surgeon who must direct subsequent care of the severely injured child. More and more, the properly trained pediatrician must assume the role of the "team captain," particularly during the most important early phase of management, and be fully aware of how to work up and assess the injured child. Furthermore, many minor injuries, if appropriately treated by a primary physician, never require a surgeon. The importance of this book to both general and pediatric surgeons should be obvious. There are numerous illustrations and figures to help in preoperative decision making and in performing the operation itself. Extensive bibliographies following each chapter supplement those in existing works on the management of trauma.

R. J. T.

Contents

Part 1

General Considerations

1

An Overview of Pediatric Trauma

J. Alex Haller, Jr., M.D.

So much has been written and said in the professional and lay press about the tragic loss of children from congenital heart disease, lung abnormalities, and cancer that it is easy to overlook the fact that half of the children who die in the United States succumb to the immediate or after-effects of major injuries (2)! Almost one half of the deaths in the childhood years (1 through 14 years) in the United States are a result of major trauma, as compared with approximately one death in 10 from injuries in the total general population (9). A similar situation is present in all the industrialized nations of the world. For example, in 1964 Stolowski (8) reported that more than one third of the childhood deaths in Germany were a result of major trauma. Although cardiovascular diseases, cancer, and pulmonary disease lead major injuries as the cause of death in the American population as a whole, trauma is the leading cause of death in children by a wide margin (Fig. 1).

The death of an otherwise normal child is always a great tragedy and is the usual situation in a child dying from trauma. On the other hand, crippling injuries to a child and the resulting need for rehabilitation may have an even greater impact on our health care system than the child's death per se. The expenditure of resources and personnel, as well as the economic loss from termination of work potential when a child is seriously handicapped, are relatively enormous when compared with similar costs resulting from adult injuries. This is true not only because of the long-term nature of such rehabilitation but also because of the difficult problems of growth and development that must take place simultaneously in an immature child. These adjustments to severe disability and a child's image of himself as an incomplete individual may be overwhelming to the young patient unless highly trained professionals participate in the process of rehabilitation. It has been estimated that more than 100,000 children are seriously crippled in the United States each year by accidents, and that another 2,000,000 may be temporarily incapacitated by their injuries. As the number of children increases in our country, along with the general population increase, the problems of emergency treatment, resuscitation, and management, as well as long-term rehabilitation of children with major injuries will inevitably increase and put further strains on our overburdened health care system (4).
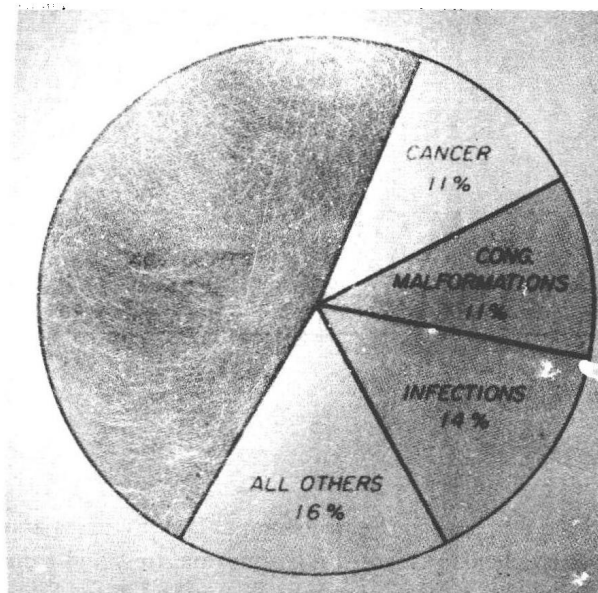
Figure 1. Causes of death in children in the United States, 1975. Trauma is the leading cause.

MAIN CAUSATIVE FACTORS IN NONPENETRATING INJURIES TO CHILDREN

In attempting to evaluate children with nonpenetrating injuries, it is helpful to consider the kinds of forces that might be responsible for these injuries. These can be arbitrarily identified as crushing, compressing, and decelerating forces (Fig. 2). Crushing injuries are those in which the child's body is mashed against an unyielding surface, such as a loading platform or wall; a moving missile comes against the body. These are somewhat different from the compressing injury in which there is usually a vector force of motion across the body, such as the passage of an automobile wheel over the child's body. This introduces an additional factor of movement and the tearing stress associated with it.

By far, the most important group of forces are those associated with decelerating or accelerating injuries in which different organ systems are set in motion depending on their masses. This results in differential vector or ripping forces within the body. These may result in a tear, for example, at the stanchion points of the small intestine, at the ligament of Treitz, and at the ileocecal area. Whiplash forces may be brought to bear which result in disruption of the intestine with perforation. Other forms of deceleration injuries may occur in the vascular system and in solid organs.

BLUNT INJURIES IN CHILDREN

By far, the most common group of injuries which we see in the childhood age group are blunt as opposed to penetrating injuries. It has been estimated that at least 80 percent of life-threatening injuries in children occur as a result of blunt trauma (Fig. 3). Blunt trauma introduces a number of significant factors that complicate the management of the

patient. For example, blunt injuries are much more frequently associated with head injuries in children and the evaluation of a semicomatose patient adds an additional problem of lack of contact with the patient and the absence of important feedback from the patient in response to pertinent questions. In addition, blunt trauma is associated with the imponderables of little evidence of external injury, and yet, the possibility of life-threatening internal damage. It is this type of injury, a blunt injury, that emphasizes the need for highly experienced professionals working in emergency facilities for the initial evaluation and resuscitation of children. No injury is more complicated than a major blunt one; and yet, so frequently patients are evaluated initially by the least experienced members of the emergency care team. This fact underlines the importance of re-evaluating our staffing policies in emergency rooms, and considering the addition of full-time emergency medical staff with experience in blunt trauma to supervise the training of younger health professionals and to be available for the important judgment decisions associated with the management of blunt injuries (5). Rarely are such professionals available in our university teaching centers; more frequently, the senior medical student or first year house officer is the individual upon whose shoulders these important decisions rest.
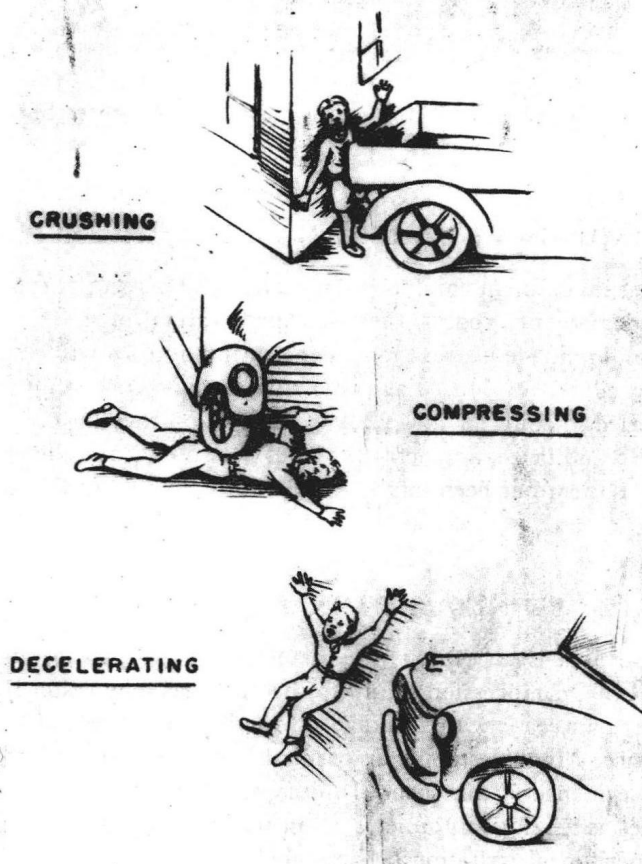

Figure 2. Crushing, compressing, and decelerating forces are responsible for a variety of blunt abdominal injuries. (Haller, JA Jr: Injuries of the gastro-intestinal tract in children. *Clin. Pediatr.* 5: 476, 1966. Used by permission of the publisher.)
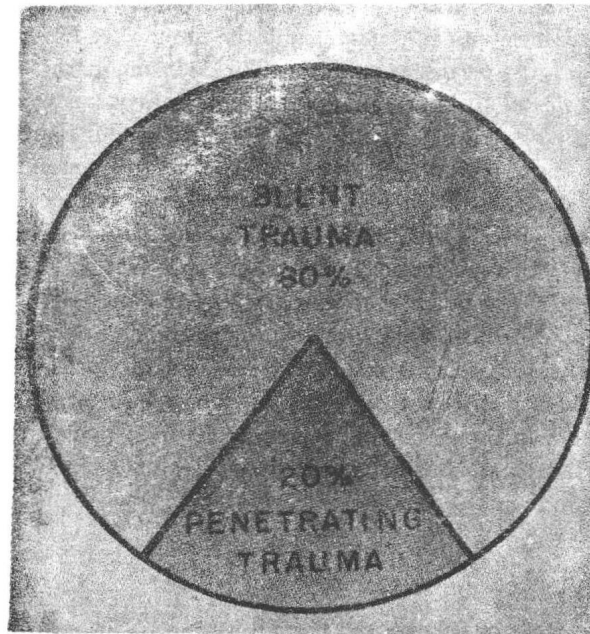
Figure 3. Abdominal injuries in childhood. The majority of life-threatening injuries are the result of blunt trauma.

PENETRATING INJURIES IN CHILDREN

Penetrating injuries do occur in childhood. In perhaps 20 percent of the abdominal injuries seen in major emergency rooms, there is a penetrating force. These are not as difficult to evaluate and manage because most penetrating injuries will require an exploratory operative procedure. Various diagnostic studies that employ injection of contrast media have been used in children as well as in adults, and they have their place in overall management. By and large, a penetrating injury is an indication for surgical exploration as soon as the patient has been totally evaluated and is relatively stable.

SPECIFIC TYPES OF BLUNT ABDOMINAL INJURY

The retroperitoneal area is an especially difficult one to evaluate if blunt injuries have occurred. For example, compression injury to the pancreas may result in a hematoma in the body of the pancreas with leakage of activated pancreatic juices into the retroperitoneal space. Autodigestion may occur if this is not recognized, and yet, there may be very little evidence of this form of injury when the child is first evaluated. The retroperitoneal area is a relatively quiet area in terms of physical signs, and only later will evidences of peritoneal irritation become obvious. The same may be said for more extensive injury to the pancreas, including transection in which major hemorrhage may occur. The evidences for specific cause of hypovolemic shock are not easily ascertained. The adjacent duodenum may be injured from the same compression force resulting in

either retroperitoneal perforation or an intramural hematoma with resulting obstruction to the lumen. These must be considered in the differential diagnosis with any blunt injury to the abdomen.

The solid organs—liver, spleen, and kidney—also may be injured from blunt trauma. Blunt injury to the kidney may result in transection of a portion of the parenchyma and laceration of the blood vessels and drainage system. An expanding hematoma in the retroperitoneal area still represents an indication for exploration, although the use of aortography has greatly improved our ability to diagnose specific injuries and, more and more frequently, partial resections rather than nephrectomy for major injuries to the kidney are possible. Extravasation of urine or IVP contrast medium on the IVP is no longer an absolute indication for exploration because some of these injuries can heal, and if the patient is stable, a more conservative approach is indicated. Blunt injuries to the liver may result in major fractures of the parenchyma with both hemorrhage and bile leakage and may require emergency partial hepatectomy. Techniques of hepatic artery ligation and careful intraoperative cholangiography have improved over-all salvage of these potentially lethal injuries.

The most common solid organ to be injured is the spleen, and rupture of the spleen remains one of the most frequent indications for exploratory laparotomy. The spleen in children has a very important immunologic function, especially in a child's resistance to certain types of infections. It is the primary source of antibodies against incapsulated gram-positive organisms, such as the pneumococci. Therefore, attempts to preserve the spleen are indicated, and recent suggestions that suturing of the splenic capsule may be possible to preserve the spleen are of great interest. Further experience is necessary before being able to make a final decision on the indications for this conservative approach. Certainly, following splenectomy, all children should be placed on prophylactic penicillin to prevent the occurrence of overwhelming infections which have now been very well documented as a major threat to the splenectomized child (1,7).

Blunt injury to hollow viscera may result in compression perforation or perforation due to tearing of the mesentery and intestine. These may also be difficult injuries to diagnose initially because there may be very little evidence of peritoneal irritation, especially in a child with a head injury who is semicomatose from the concussion effects. Careful observation in the hospital for this type of injury is imperative, so as not to overlook insidiously developing peritonitis. After 24–36 hours of leakage from the intestine, clearcut evidence of peritoneal irritation should be present, and with expeditious exploration and repair, purulent peritonitis, a much more serious complication than chemical peritonitis, usually can be avoided.

THERMAL INJURIES

A major burn is one of the most serious diseases of childhood! The immediate mortality associated with an extensive burn is still quite high and the associated morbidity of a major burn is often overwhelming in terms of commitment of professional personnel as well as financial load on the family. The anguish of debridement followed by multiple skin grafting procedures adds to the severity of the injury to the child. In addition, long-term rehabilitation, cosmetic disfigurement, and emotional adjustments in an immature child add to the tragedy of this preventable injury.

Table 1. Factors in Increased Incidence of Vascular
Injuries in Children

1.   Increased incidence of all accidents
2.   Easy availability of weapons at early ages
3.   Increased use of diagnostic catheterization
a. Cardiovascular malformations
b. Suspected renovascular hypertension
c. Preoperative localization of abdominal tumors
d. Localization of vascular injuries

VASCULAR INJURIES

Vascular injuries in children have become a significant problem, especially in regional referral centers. Penetrating trauma is responsible for most of these vascular injuries, but they may also result from blunt trauma. By far, the most common cause of vascular injuries in major diagnostic centers is the complication of an invasive diagnostic study, such as cardiac catheterization and arteriography (6). This statement of fact does not imply that these tests should not be carried out; but it serves to underline the potential hazard of such tests, particularly in young children, and to emphasize the importance of having skilled personnel and excellent facilities for these highly specialized studies. The factors listed in Table 1 may contribute to an increase in vascular injuries in children. Proper recognition of these factors may help to decrease their incidence.

UNUSUAL RESPONSES OF A CHILD TO MAJOR INJURY

A small child may respond differently from an older patient and adult to major injuries. For example, paralytic ileus following blunt abdominal trauma may be of greater consequence in children because abdominal distention in a young child may elevate the diaphragm and interfere more with limited pulmonary function. In a relative sense, paralytic ileus is, therefore, of greater consequence in an infant or young child. The same may be said for small blood losses in a small patient whose blood volume is limited. A closed fracture of the femur, for example, in a 10 year old may be associated with 300 or 400 cc of blood lost into the soft tissues. The same amount of blood for a similar injury in an adult would be of little consequence; but in the child this may represent 15–25 percent of the total circulating blood volume and contribute to hypovolemic shock. Unless these relative differences are recognized, such blood losses may not be considered significant in the smaller patient. Major heat losses may occur in a young child who is unclothed in an air-conditioned emergency room for proper evaluation and who may remain for several hours in such an environment. A drop in core temperature of several degrees may interfere with normal enzyme function and other metabolic processes. These changes may add a further metabolic insult to a child's response to the stress of trauma.

Congenital abnormalities rarely complicate evaluation and management of adults with major injuries. They can cause serious complications in young children whose congenital anomalies may not have been detected and may not have interfered with reasonably normal function up to the time of injury. For example, a five year old with a

50 percent second- and third-degree burn recently went into profound congestive heart failure during the resuscitative process of fluid and electrolyte replacement. He was then found to have an asymptomatic ventricular septal defect, but under the stresses of rapid fluid replacement, acute myocardial decompensation and heart failure occurred. Possible complications of unrecognized congenital abnormalities must be remembered in the total evaluation of a child under treatment for major trauma.

The rapidity with which metabolic and cardiovascular responses can occur serves to emphasize the importance of good monitoring systems to evaluate the responses of young children to emergency treatment. While monitors are useful in adults, they are mandatory in a small patient because minor changes in response to treatment must be detected early to prevent more serious sequelae.

Head injuries are much more commonly associated with blunt trauma in children than in adults and, as noted previously, complicate the over-all evaluation of the child. It may be that a child's head is relatively larger and therefore more exposed to trauma than that of an adult, or that the child's head is less well supported on the neck and shoulder girdle. Whatever the exact explanation for the high incidence in children, the fact remains that head injuries are very frequently associated with blunt trauma in children. Aside from the errors in diagnosis that may result from evaluating an obtunded child, the lethal effects of subdural hematomas and progressive cerebral edema from blunt trauma are major causes of death in childhood.

The emotional impact of an emergency room experience cannot be overemphasized. A child with a relatively minor injury is often triaged into a corner of a general adult emergency room, while patients with life-threatening injuries are given their proper first priority. The scenes which a young child may see during a 2 hours' stay in such an environment are formidable in terms of emotional impact. Gunshot wounds, stab wounds, drunken adults in various states of disarray, all represent horrible visual experiences to an immature child. Unless these are necessary components of the child's emergency room experience, perhaps better care can be administered to a child in an environment that is designed and staffed for his age group. For many years we have recognized that children have special needs and have designed pediatric departments and children's units within our larger medical centers. The same approach is overdue in our emergency room areas. Whether we design separate but equal facilities for children alongside adult units, or whether we identify committed areas for children within our adult emergency room environments, is an individual decision for each regional medical center. The important principle is that appropriate areas must be designed and staffed especially for children and their special needs and these facilities must contain the best available quality care for the management of both life-threatening injuries and minor injuries to children (Fig. 4).

If a compromise in the organization of these facilities must be made, it would be far better to bring children with life-threatening injuries into an adult environment where the resuscitative efforts are so much more important than the environmental influences and dedicate the special areas for the evaluation of children with minor injuries. A child who is semicomatose or in shock is not likely to remember the environmental aspects of his resuscitative treatment. But, a child with a cut finger, a stubbed toe, or a minor burn may have a longer lasting effect from the emotional trauma than from his physical injury!

The identification of such specialized children's units within the total emergency facility offers a number of other important possibilities for improvement of patient care.
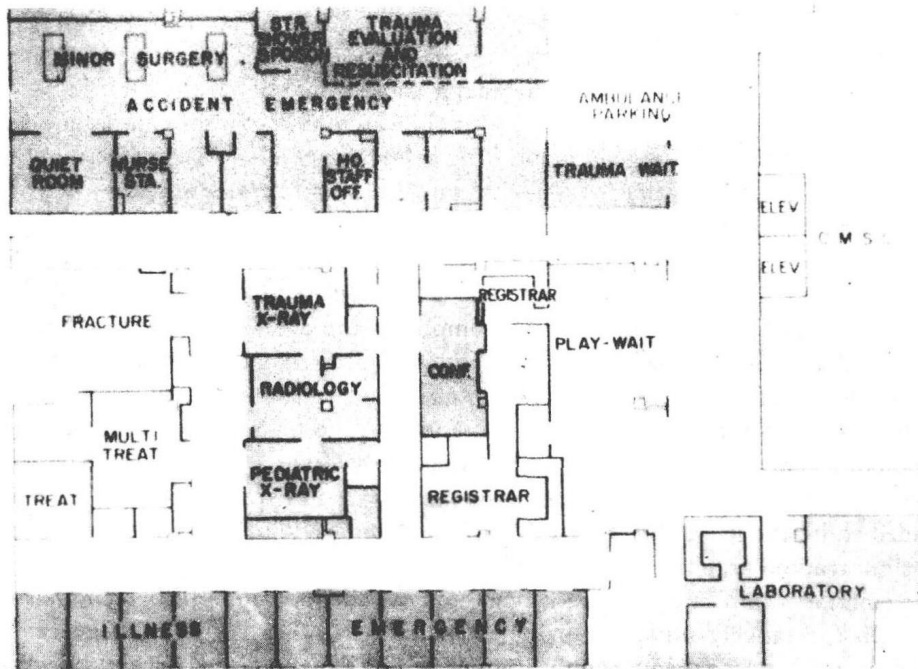
Figure 4. The management of pediatric trauma requires special facilities designed to meet the needs of children.

Pediatricians in training can work in such units and be given the opportunity to manage children with various injuries and accidents; heretofore, pediatric house officers have been excluded from this environment by traditional training programs which rotate surgical house officers but not pediatric house officers through such facilities.

The importance of identifying a captain of a trauma team does not need to be further emphasized. However, the possibility that a pediatrician with special training in emergency medicine might function in this important role has not been widely suggested. Clearly, such an emergency room pediatrician should not be designated captain of the trauma team by fiat, but rather he must be appointed to this position *after* completing appropriate intensive training in the emergency care of children.

Children, as well as adults, with multiple systems injuries are at great risk from being divided up by organ systems for management by different surgical specialists. For example, the child with a head injury, a fractured femur, and hematuria may have a neurosurgeon, orthopedic surgeon, and urologist each demanding that his particular injury receive priority in management. Under these circumstances, the child trauma victim desperately needs an advocate and one who can intelligently establish priorities in management and organize the team effort in resuscitation and continuing treatment. An emergency physician with pediatric background may represent the best such child advocate. A pediatrician is also more likely to detect other conditions and problems than is a physician with primary surgical orientation. This point is particularly pertinent in the

management of children with minor injuries because in the course of their treatment, significant systemic and social family problems may be discovered and can be appropriately managed.

Another important opportunity available in dedicated units for emergency care of children is the training of physician's assistants with a particular interest and ultimate experience in the management of children. These physician's assistants work under careful supervision of physicians and can carry out management of minor injuries, including suturing and treatment of sprains, strains, and soft tissue injuries. They can be trained more rapidly than physicians and can represent very important components of an emergency care team.

Of course, highly skilled surgical specialists must be immediately available to such emergency facilities for the care of children. Hopefully these surgical specialists would have special expertise in the management of children's surgical problems and would be familiar with some of the unique features of the care of children.

Any consideration of the design of such dedicated outpatient emergency facilities must be combined with the development of inpatient facilities which are dedicated to the continuing care of injured children. These include an operating room always available for life-threatening emergencies requiring immediate surgery and the availability of pediatric anesthesiologists as a part of the treatment team. Intensive care units designed for children and staffed for their care may also parallel intensive care facilities for adults depending on inpatient organization in individual regional centers. A helicopter receiving area is necessary for expeditious transport from the scene of injury as well as for the transfer of newborn infants with life-threatening emergencies (Fig. 5). These combined facilities can be expected to deliver high quality care with special emphasis on the unusual needs of children and would then represent a proper regional trauma center for children.
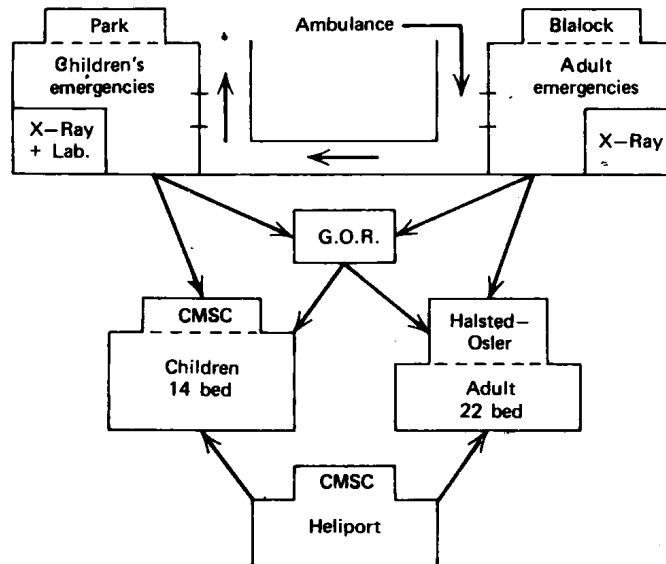

Figure 5. Patient flow pattern for major emergencies. A regional trauma center requires proper transport facilities.